SECTION 12

CENTRAL FACILITIES

3rd Edition Steering Committee Coordinator

James A. Crum

Special Contributions

Robin Dalton

John Warren

Section 12 Table of Contents

Section 12 List of Figures

Section 12 List of Tables

12 CENTRAL FACILITIES

12.1 Definition

Many cold-climate communities are located where it is difficult to construct and operate water and sewer systems that provide service to individual buildings. Ice-rich permafrost, rock, lack of roads for truck haul, high capital and operating and maintenance (O&M) costs, and low-density housing are among the factors limiting the use of water supply and wastewater systems serving individual homes. In these situations, central facilities (often called "washeterias") have been used to provide several useful services. These include a source for treated water, showers, washing machines, clothes dryers, saunas, and rest rooms.

Over 65 central facilities have been built in rural Alaska. However, very few have been built in the Canadian Arctic because they do not meet the minimum water and sewer service levels, and government O&M subsidies are available to support higher levels of service. Also, favorable environmental conditions are available in the Northwest Territories (i.e., roads) so that the subsidy policies have resulted in truck hauled water and sewer service to individual homes where clothes washing, bathing, and showers are available. Almost all of the Alaskan facilities are located in areas where piped utilities are not presently available; the central facilities are considered interim facilities to be followed later by piped facilities.

This section outlines the design considerations for providing a central facility in a community where piped water and sewer services to individual houses are not presently economically or physically feasible. The following discussion details the level of service to be provided, sizing of utilities and services, energy conservation, fire protection, construction techniques, and costs.

12.2 Planning for a Central Facility

Central facilities can provide many services. Defining the types of service to be provided is one of the important considerations in the planning stages of a project. Decisions made during planning should consider:

- available resources including water supply, land, waste disposal site;
- operation, management, and maintenance capability of the community;
- local desires expressed by the community's willingness to participate in the planning, design, construction and operation of the completed facility;
- social customs, needs, and services that may be addressed by the central facility; and
- assistance available to the community including financial, administrative management, training, etc.

Other useful information to consider when planning a central facility can be found in Section 2.

Realistic consideration of these factors with the meaningful participation and involvement of the community in the decision-making process is essential to a successful project.

Consultation with people in the community, perhaps with the use of a planning questionnaire (Arctic Environmental Engineers, 1978) is essential to providing the best appropriate service. The consultation should provide answers to such questions as:

- How many hours per day and per week should the facility be open?
- How often will people use the services provided per day and per week?
- How many people are willing to pay for the services and how will the payment be made?

Given the community responses to these questions, some design planning estimates can be made.

The minimum level of service is a watering point at which people obtain safe water to drink. A full service facility provides:

- a watering point to obtain drinking water;
- a place to wash and dry clothes;
- bathing and toilet facilities; and
- safe treatment and disposal of wastes from the central facility (including toilets and washing machines, showers, and wash basins).

Saunas have been installed in some facilities to supplement the use of showers. In some parts of the North, especially among native people, saunas are a preferred method of bathing and a requested feature.

Central facilities may be constructed as the first stage of a more complete water and sewer system with service provided to individual buildings. Such central facilities should be designed so that its basic water supply and wastewater treatment systems may be expanded to provide increased service. Typical expanded services might be a truck-haul system or, in some cases, a water and sewer system piped to some individual buildings or to all community buildings.

Whenever possible, arrangements should be made for the central facility to serve buildings such as schools, health clinics, and community centers with piped building service. Since the revenue produced by serving these institutional buildings can be substantial and can offset the income required to operate the central facility, it can therefore reduce the individual user charges. The use of waste heat from local power plants can reduce the heating fuel required and increase system efficiency.

12.3 Design Space Considerations

The amount of floor space required for a central facility depends on the services to be provided and on the needed mechanical equipment area. Also, it will depend on how much water storage is to be provided within the central facility. Central facilities in Alaska have varied from 80 m^2 to 325 m^2 of total floor space. The increased area is often needed when water storage tanks or more sophisticated water treatment equipment are located inside the building. Table 12-1 provides the suggested number of service units for various populations. These numbers should be reviewed taking into consideration local needs and requirements.

Lack of sufficient space was a serious problem in some early central facilities. The early emphasis on saving space resulted in problems for both operators and users. Equipment and piping were so confined that vital repair and maintenance activities could not be undertaken without moving piping and equipment which often resulted in maintenance not being performed. Space considerations must now consider fire codes and access requirements for persons with disabilities.

12.4 Construction Techniques

Central facilities have been built in a modular format and shipped complete for erection on a constructed foundation. Other facilities have been built from components, or have been "stick built" on site. Each of these techniques has costs and benefits in construction times, quality, and local employment opportunities. When modular construction was used, there was a tendency to compact the equipment and service areas in the modules to facilitate shipping and reduce costs. This crowded space discourages use of the facility. See Section 2 for more details on construction techniques.

12.5 Water and Wastewater Service

A central facility must provide water that is chemically and bacteriologically safe, that is more convenient than other sources, and that tastes and appears better than alternative sources. The facility must also provide a sanitary means of wastewater disposal for wastewater generated within the central facility and for wastewater transported to the central facility.

12.5.1 Water Supply and Treatment. Providing a reliable water supply along with necessary treatment is essential to encourage use of the facility. The highest quality of raw water should be selected to be delivered to the central facility for final treatment so treatment costs and complexity are low-

TABLE 12-1 RECOMMENDED NUMBER OF CENTRAL FACILITY SERVICE UNITS

			Bathrooms	
Population	Washers	Dryers	ADA*	Standard
150	4	3	1	1
< 500	6	4	1	2
> 500	8	6	1	3

* American Disabilities Act handicap accessible

ered. Generally, water supply and treatment requirements for central facilities are not particularly unique compared with other water treatment processes needed in cold regions. Details on water supply and treatment systems are discussed in Sections 5, 6 and 7.

12.5.2 Water Storage. Storage capacity for treated water will depend on the availability and reliability of the water source, source flow capacity, and fire flow requirements. Storage may be adequate for a design flow of less than one day to over nine months when it must be drawn from an intermittent supply. The amount of storage should be sufficient to ensure a minimum level of service for the duration of any anticipated power outage or failure (such as a supply pump breakdown). Storage capacity amounting to about one day's total design flow has been used frequently for central facilities where water sources are reasonably available and where water treatment requirements are not unusually complex. Water conservation can ensure several days' reserve to provide minimum services such as drinking water supply and showers. Details for sizing and designing water storage systems can be found in Section 7.

12.5.3 Design Water Flows. Selecting the type of service (showers, laundry, saunas, sewage dump stations, washrooms, etc.) must be done on a case by case basis. Water use data collected on several washeterias indicated that practical treated water demands range between 9 to 31 L/(p•d) with an average demand of 18 L/(p•d) (Warren, 1993).

12.5.4 Wastewater Treatment and Disposal. Detailed wastewater treatment and disposal alternatives are discussed in Section 10. These alternatives, with modification, are appropriate for central facilities. For example, special consideration must be given to treatment of dilute laundry wastes, variations in effluent temperatures, foaming, shock loads from honey bucket wastes, and peak hydraulic flows during specific operating periods.

A major portion of the wastewater flow in the typical central facility comes from the washing machines. Laundry wastewater resembles domestic wastewater in many ways but it does not contain all the essential nutrients to sustain the organisms necessary for effective biological treatment. This is not a problem where domestic wastewater from honey buckets and toilets is added to the waste stream.

Sudsing detergents can cause excessive foaming in wastewater flows, so the use of low-sudsing detergents may be needed to control this problem. The high heat content of central facility wastes due to laundry (hot), and showers (warm) provides ideal flushing and warming to central sewer systems when it is located at the upper ends of arctic sewers. Forms of dosing mechanisms have been built for washer wastes to create surge flows.

Central facilities have been designed with honey bucket waste dump stations, but experience shows that using them is difficult. Many people find it difficult to carry their honey buckets to the central facility for disposal and prefer instead, to dump wastes at a disposal point nearer to their homes. A second problem is that honey buckets often contain material other than human waste (i.e., cans and trash), thereby requiring a separation area prior to the honey bucket sewer discharge or pump station. The disposal of these types of waste has the same considerations as that for a community (Section 10).

12.6 Equipment and Mechanical Aspects

When facilities are constructed in remote arctic areas, factors such as the isolation, an unforgiving climate, the low skills of the operators, and unreliable electrical power service may require that the design have less complex systems and backup systems to provide an acceptable level of reliability. However, some degree of complexity is necessary to address the difficult problems of water supply and waste disposal in arctic climates.

As a practical matter, a minimum of three washers and three dryers (Figure 12-1) should be provided and a minimum of two bathrooms, regardless of community size. This allows service to continue uninterrupted when one or more of these machines are out of service and allows for peak usage periods.

12.6.1 Heating System. An important design consideration for central facilities is choosing a heating system. The basic questions to be answered are:

- What types of heating are required (building heating, clothes drying, sauna, water heating, etc.)?
- What type of system is most appropriate – hot water, hot air, electric, or steam?
- What type of fuel system is most desirable, economical, and available?
- Should there be a single source of heat to meet the heating needs or should there be

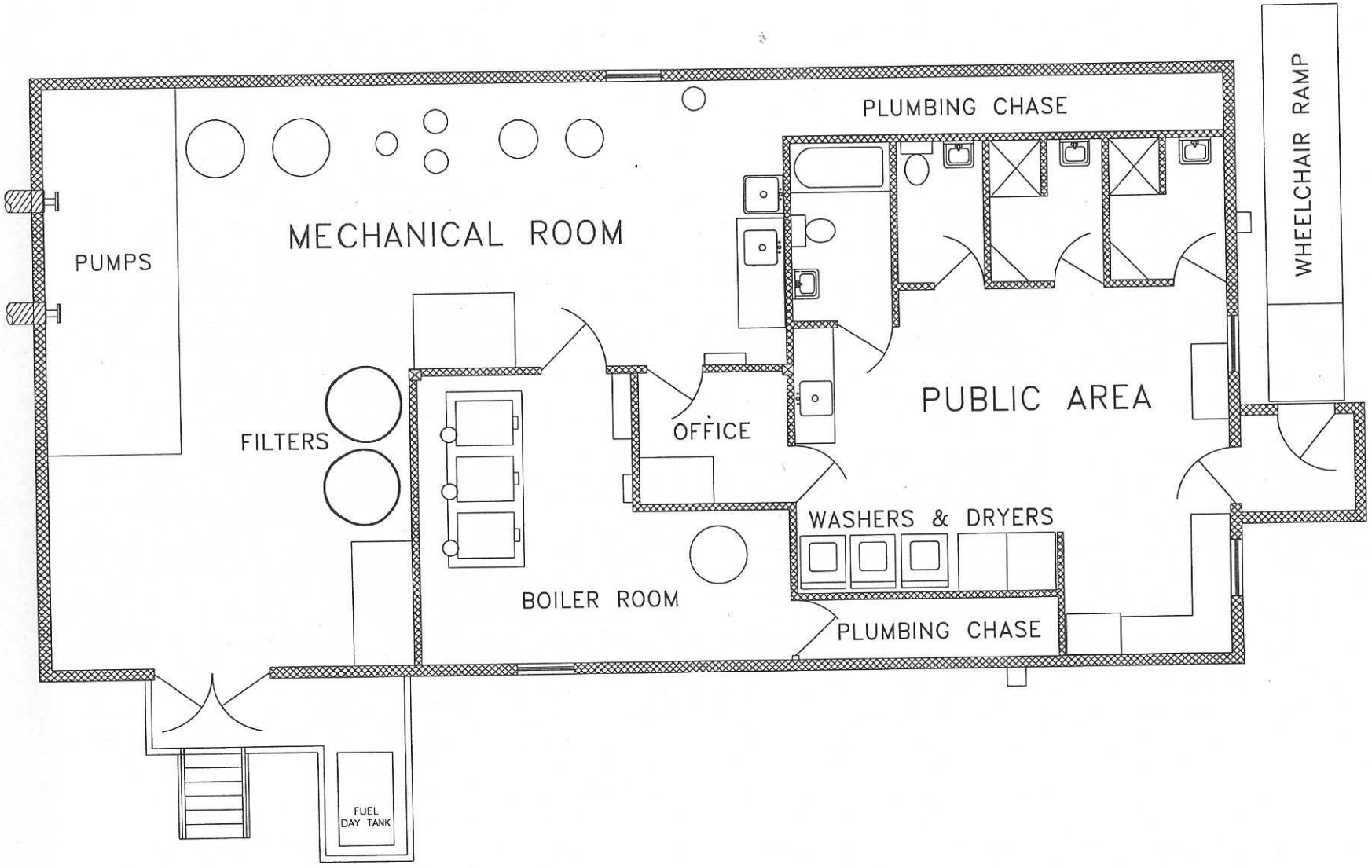


FIGURE 12-1 WASHETERIA FLOOR PLAN

separate sources of heat designed specifically for the point of need?

- How should heat recovery be included in the facility?

Answers to these questions require analysis of both the heating needs and the relative difficulty of maintaining the mechanical plant in a central facility.

Choosing the Type of Heating System. Circulating hot-water heating systems are the most popular in remote areas, probably because they are understood better than other systems. The primary disadvantage of a hot-water heating system is its susceptibility to damage during facility freeze-ups. Propylene glycol can be mixed with water in the system. This fluid can prevent hydronic water system freeze-ups, but requires more attention in handling and maintenance, and is slightly less efficient (10 to 20 percent) in heat exchange properties. Corrosion control inhibitors are often used, but they tend to break down at high temperatures, and maintaining the proper concentration requires testing by the operators.

Hot-water systems cannot provide the higher quality heat needed for saunas and can only marginally meet the higher temperatures required for clothes dryers. One way to achieve the higher quality heat for all services in a central facility and to avoid damage due to freezing is to use special organic fluids instead of water or glycol. These systems operate on the same principle as hot water but at higher temperatures. The fluids can be fairly expensive, and the plumbing system must be more elaborate. A sloppy installation of the plumbing system can make repair difficult, and faulty joints can leak hazardous chemicals into the central facility (Puchtler et al., 1976).

Steam has a relatively high capacity to carry heat; hence, a steam-heating system can readily meet all the needs in a central facility. The main disadvantages of a steam system are that people in remote areas are generally unfamiliar with the higher temperatures and mechanics of steam, and the hot pressurized vapor is more hazardous than hot air or hot water. This makes operation of the steam system more difficult and can result in higher maintenance costs and downtime compared with hot-air or hot-water systems. Pipe damage due to freezing is generally limited to low points or restrictions in the piping systems.

Hot air does not have the heat carrying capacity of water or steam, but it can be used effectively for dryers if separate heat sources are used and the furnace is close to the place where the heat is needed. Hot-air furnaces can also be used for building heat, although preheating make-up air and controlling building pressure becomes a problem. Also, ducting consumes more space than the plumbing for hot-water systems.

Regardless of the type of heating system selected, a nonelectric pot burner stove should be supplied for standby space heating in case an extended power failure or primary heating system failure occurs.

Central Versus Multiple Heat Sources. A central heat source, i.e., one duplex boiler system serving all heating needs for a central facility offers simplified maintenance requirements and reduced fire hazards compared with multiple heat sources, e.g., separate heating units for building heat, hot-water dryers, and other services. However, balancing such a system can be complex. Standby capability for a central heat source can be partially achieved by providing complete spare burners. Control systems for distributing heat from a single source can often be more complex than individual control for each of several heat sources.

Multiple heat sources meeting the specialized heating needs in the central facility is theoretically more efficient than a central source, since they produce different grades of heat, each designed for maximum efficiency. If multiple sources are selected, compatible equipment with interchangeable parts should be used. This reduces the need for a large inventory of spare parts and simplifies maintenance.

12.6.2 Incineration. Incinerators have been installed in central facilities for the primary purpose of disposing of sludges from waste treatment plants, honey-bucket wastes, and other solid wastes in a sanitary manner. Incineration theoretically offers an ideal solution to the problem of organic waste disposal, essentially eliminating the adverse environmental and health effects from these wastes. However, incinerators installed in central facilities are much too complex and costly to operate, rarely last more than a year, and are not recommended.

12.6.3 Washers. Commercial-type washers should be used. They range in capacity (weight of dry clothes that can be placed into them) from 6.8 kg up to about 16 kg. An average washer cycle is about 40 minutes, including loading and unloading time. The smaller units are significantly cheaper, but larger ones have proven particularly useful since

they can handle bulky items such as sleeping bags, blankets, and parkas.

Horizontal axis washers tend to vibrate during use (Puchler et al., 1976). Therefore, they must be properly evaluated and incorporate a vibration dampening support system to prevent vibration damage to the building and foundation. Vertical-axis washers do not vibrate as much, but they are normally available only in the smaller sizes. In addition, top-loading, vertical-axis washers use about 40 percent more water for an average wash load than the front-loading, horizontal-axis machines (Cameron and Armstrong, 1979).

12.6.4 Dryers. Many types of dryers are available: hot water, electric, steam, hot air, and hot liquid. The choice should be based on operational costs and past experience.

Electrically operated dryers are the easiest to maintain but they are also the most expensive to operate. According to the Alaska Department of Environmental Conservation (ADEC) (Dowl Engineers, 1975), heat derived from electricity generated from fuel oil can cost over ten times as much as heat derived from bulk fuel oil. ADEC (Arctic Environmental Engineers, 1978) calculated that for an 8.2 kg capacity dryer requiring 5.9 kW and consuming electric power for 45 minutes/ load at $0.20/kWh (a very low electrical cost in remote areas), the electrical cost for drying alone would be $0.89/load. Comparable heating costs based on the use of oil were calculated to be about $0.11/load.

Hot-water operated dryers are a favored choice in central facilities because they can be connected directly to the hot-water furnace, and operators in remote communities are more familiar with hot-water heating systems. However, to provide sufficient heat to the dryers, the hot-water system must be operated at its upper limit for temperature and pressure and be balanced between the dryer units. This increases the chance of vapor locks in the system because of "flashing" (liquid to vapor).

Steam-operated dryers would appear to be a good choice because of the excellent heat carrying capacity of steam. However, few people in the remote areas are familiar with the principles and operating characteristics of steam systems. In addition, the relatively high operating temperatures and pressures require more maintenance, and the heat exchanger coils tend to require frequent cleaning to maintain efficiency.

Hot organic fluids such as "Dowtherm" or "Therminol" can also supply dryer heat (Reid, 1973; 1977). These systems can be efficient, although they operate at relatively high temperatures (177°C). One advantage, besides efficiency, is that freezing does not damage this type of heating system. But numerous operational, maintenance, and safety problems can occur, particularly if initial construction is substandard (Cameron and Armstrong, 1979).

A hot-air furnace with appropriate duct work can provide dryer heat. Such a system requires one less heat exchanger than steam-operated dryers, but an extra furnace is required (Arctic Environmental Engineers, 1978). It cannot be damaged by freezing, but ducting must be well insulated to reduce heat losses. (A comparison of advantages and disadvantages between separate and multi-purpose furnaces is given in Section 12.6.1). Dryers heated by hot-air furnaces are commercially available, but most systems are converted steam dryers connected to hot-air furnaces.

An extractor, which draws water centrifugally from the laundry, reduces dryer time, and saves energy. They tend to vibrate so it is essential to provide a solid base to which they can be securely anchored.

Dryers should be sized at least 1.5 to 2 times larger than the washers because people tend to put more than one washer load in a dryer. The appropriate dryer size can be determined after the washers have been selected.

Drying cycle times vary with the type of system used. Manufacturers' literature can provide this information. For hot-water systems, the cycle is about 45 minutes. Lower humidity during the winter leads to faster drying times. An additional 10 minutes to load and unload clothes can be used when estimating total cycle times.

Many acceptable brands of washers and dryers are on the market. After the type and size of equipment have been selected, the choice of model should be based on ease of repair and availability of spare parts.

12.6.5 Showers. Shower usage in public central facilities depends greatly on the cultural preference in the community. Some communities prefer steam baths to showers. For example, in the communities of the Lower Kuskokwim River in Alaska where steam baths are a traditional method of keeping clean, the rate of shower use is low. In interior Alaska, which does not have the steam bath tradition, use rates vary from eight to twelve showers/

person/month (rates are in communities without home showers).

Shower water consumption should be efficient to the extent practicable for several reasons:

- cost of heating water, and
- cost of water treatment.

Where the water source is limited, the efficient use of water is critical and extraordinary measures are necessary to minimize the waste of water.

Timers, pressure regulators, mixing valves, and low-flow shower heads are the most useful devices for conserving water (Section 14). Reid (1977) reports adequate and satisfying showers, using only 23 L/shower with these devices. Conventional shower heads use about 25 L/minute, whereas low-flow shower heads use only 5 to 12 L/minute.

12.6.6 Saunas. The sauna is a form of traditional steam bath accepted widely in the culture of the indigenous northern peoples. The operation of a sauna in the community's central facility, where it is a local custom, can provide a desired service and can generate substantial revenues. However, public saunas require a high-quality heat, reliable maintenance to prevent building deterioration, and consistent application of sanitation practices, so they must be managed properly. With a regulated heat source, plenty of insulation, adequate vapor barriers and venting of moisture, and consistent cleaning of the facility, a sauna can provide a desired service and produce sufficient revenue to help support the total central facility operation. Experience has shown that the saunas require adjacent showers for users to cool off as well as to rinse.

12.6.7 Restrooms. Most central facilities that provide more than just a watering point have restrooms for men and women, each with a wash basin and toilet. Some utilize unisex restrooms if space is limited.

Wash basins are required with toilet facilities. They should have automatic closing valves to minimize water wastage.

Where water is readily available at low cost, flush-tank toilets are appropriate. They are simple to operate and require no additional power source. Older flush toilets that use an average of 20 L/flush are wasteful and unnecessary since flush toilets that use only three to six L/flush are readily available (Cameron and Armstrong, 1979). The operation and maintenance costs are the same, but because of the reduced volume, the costs of procuring, treating, and pumping the water, and of disposing of the wastewater are less.

Where water is limited, other types of toilets should be considered. Air pressure discharge types or vacuum toilets use only about 1.5 L/flush (Cameron and Armstrong, 1979). Recirculating chemical toilets use only about 0.07 to 0.2 L of water per flush (Cameron and Armstrong, 1979). Units are available which flush mechanically or electrically. Reid (1973) concluded that recirculating toilets installed in central facilities have been of poor design for the application. Refer to Section 14 for details on available toilet units. Substantial water savings can be realized with these systems, but the cost of maintenance may offset the cost of water savings.

Where water is scarce, greywater recycling has been tried for use in flush toilets. This substantially increases both the cost and the mechanical complexity of the facility. Greywater recycling has also led to foaming and odor problems and has generally proven unsatisfactory.

12.7 Heat Recovery

Central facilities offer a unique opportunity to capitalize on waste heat recovery. Many of the building mechanical components either use or produce significant quantities of heat and the relative closeness of components within each facility facilitates heat recovery. Heat recovery from dryer exhaust air via a heat exchanger provides recoverable waste heat used to supplement heating needs within the facility. Heat recovery often provides substantial low grade (low temperature) heat which is useful either for building heat or preheating purposes.

Several central facilities in Alaska are connected to the community power plant heat recovery system. This allows the facilities to utilize available waste heat to preheat water, preheat dryer air, or heat a large water storage tank. Care should be used in selecting and adjusting multiple heat sources to ensure the high grade heat sources do not add heat to the low grade sources. Heat recovery is discussed in Section 17.

12.8 Fire Protection

Municipal fire departments are often inappropriate for protecting central facilities in remote communities. Unless a fire is controlled within minutes after it has started, little can be done to save the building. Therefore, the design emphasis must be on fire resistent construction, early detection, and rapid au-

tomatic smothering of the fire. Fire protection equipment for central facilities must include smoke detectors, chemical suppression systems for critical fire hazard areas, and hand operated fire extinguishers. Although not required by code for these types of facilities, sprinkler systems connected to the water storage tank or a small pressure system are recommended. It is often difficult to meet design code requirements for pressure and flow on these sprinklers. However, even minimum sprinkler systems could save the facility.

12.9 Requirements Often Overlooked

One of the more frequently overlooked items for central facilities in remote areas is storage space. Transportation of bulky items such as chemicals and general supplies to remote communities is often limited to once a year. Hence, storage areas need to be sized to accommodate this quantity of supplies. Use of fire resistant cabinets should be considered for chemical storage. Another often overlooked requirement is space to work on pumps and motors and to perform other general repair and maintenance functions. Typically, a workbench with shelves is provided so tools can be stored. A utility sink and desk should be considered in the mechanical area for the operators to conduct tests, repair equipment and keep records. Laundromat areas should be provided with benches and adequate table space for folding clothes.

Vital components must be easily accessible. Piping must be arranged so that it does not interfere with basic maintenance and repair functions. Critical piping joints should not be located in walls; where this is unavoidable, removable panels should be provided. Cramped space in the user's portion of the facility discourages use. Easier access to washers, dryers, and other mechanical equipment can be achieved by including utility closets or removable wall panels in the design of a central facility. Chemicals that release corrosive vapors should be stored in areas designed for corrosive environments.

12.10 Costs

In 1991, the base cost for a full-service central facility including a well supply, moderate water treatment, and adjacent sewage lagoon located in a rural Alaskan community with a population of 400 and road access was $800,000 (US). Problems in water supply, wastewater disposal, and unstable soil conditions and remote shipping can easily add 20 to 50 percent to this figure. The most dramatic cost increase, however, is in water storage in those areas where obtaining water throughout the winter is difficult or expensive. A large storage tank (1.0 to 6.0 ML capacity) may be required to provide adequate storage during winter months.

Operating and maintaining central facilities in the North is costly. Operational costs include fuel, electricity, labor, chemicals, spare parts, and janitorial supplies. Operating revenues are generated from user fees assessed by the community for sauna, laundry, showers and other available services. A central facility does have the advantage of being a "cash and carry" business; the service (wash and dry clothes, shower, etc.) can be obtained only after paying first.

Connecting local schools and other institutions to a central facility and charging for piped water and sewer service can take advantage of any economy of scale to help generate the revenue needed to operate a central facility. Contracts between the community and these users of large amounts of water in the community results in a cost-effective method of providing these services.

Table 12-2 is a comparison of operating costs in central facilities in three Alaskan communities. Operational costs range from $25,000 to $70,000/year (US) depending on the size of community and costs of service. Experience has shown that the facilities generally operate slightly below a break-even point with a slight subsidy from municipal government being common.

12.11 References

Arctic Environmental Engineers. 1978. *Conceptual Design for Tanana, Alaska Facility*. Alaska Department of Environmental Conservation, Juneau, Alaska.

Cameron, J.J. and B. Armstrong. 1979. Water and energy: conservation alternatives for the North. In: *Symposium on Utilities Delivery in Northern Regions*. Environmental Protection Service, Rep. No. 3-WP-80-5 Ottawa, Ontario, 41-88.

Dowl Engineers. 1975. *Design Narrative for Pitkas Point Village Safe Water Facility*. Alaska Department of Environmental Conservation, Juneau, Alaska.

Puchtler, B. et al. 1976. *Water-Related Utilities for Small Communities in Rural Alaska*. U.S. Environmental Protection Agency, Rep. No. EPA-600/3-76-104, Corvallis, Oregon.

TABLE 12-2 EXAMPLES OF CENTRAL FACILITY OPERATING COSTS

	Brevig Mission	White Mountain	Koyuk
Population	138	180	277
Average monthly water usage (gallons)	54,000	90,000	50,000
Yearly O&M Costs			
Electricity	$4,261	$8,647	$5 174
	(20 290 KWH x $0.21/KWH)	(39 305 KWH x $0.22/KWH)	(23 518 KWH x $0.22/KWH)
Fuel	$11,609	$6,261	$7,560
	(5 277 gal x $2.20/gal)	(4 930 gal x $1.27/gal)	(5 400 gal x $1.40/gal)
Labor & benefits	$12,110	$21,304	$20,684
	(21 hr/wk x 52 wk x $11.09/hr)	(34 hr/wk x 52 wk x $12.05/hr)	(32 hr/wk x 52 wk x $12.43/hr)
Parts, supplies, chemicals	$3,383	$1,532	$1.994
Miscellaneous	$150	$6,684	$215
Total yearly cost	$31,513	$44,426	$35,627
Yearly Revenues			
Coin-ops (washers, dryers, showers)	$13,212	$14,971	$32,065
School, commercial, other	$4,261	$12,812	$733
Total funds collected	$17,473	$27,783	$32,796
Balance	($14,040) Deficit	($16,645) Deficit	($2,829) Deficit
Water prod. cost/gal	$0.04	$0.015	$0.033

Notes:
1. White Mountain has a circulating water line providing water service to homes from the central facility which results in the higher monthly water use indicated.
2. Cost per KWH in bush Alaskan villages has typically been subsidized by the state. KWH costs for Brevig Mission and White Mountain reflect subsidized costs based on 1992 rates.
3. Typically villages purchase bulk fuel for a break in price. Brevig Mission purchased fuel from the local store resulting in the higher cost per gallon indicated.
4. Equipment amortization is not included in the O&M costs shown. O&M costs are based on actual costs for the most part.
5. Water production cost/gallon reflects costs related to pumping, treating and storing treated water for use.

Reid, B.H. 1973. *Alaska Village Demonstration Projects: First Generation of Integrated Utilities for Remote Communities*. U.S. Environmental Protection Agency. Arctic Environmental Research Laboratory, Working Paper No. 22, College, Alaska.

Reid, B.H. 1977. Some technical aspects of the Alaska village demonstration projects. In: *Utilities Delivery in Arctic Regions*. Environmental Protection Service Rep. No. EPS 3-WP-77-1, Ottawa, Ontario, 391-438.

Warren, J.A. 1993. *Dryer Selection and Design for Alaskan Village Washeterias*. Technical Report, Alaska Area Native Health Service.

12.12 Bibliography

Alaska Area Native Health Service. 1985. *Washeteria Design*. Douglas Marx, Unpublished memoradum, Anchorage, Alaska.

Bailey, J.R. et al. 1969. *A Study of Flow Reduction and Treatment of Waste Water from Households*. Water Pollution Control Research Series 11050 FKE, Deptartment of Health, Education and Welfare, Washington, D.C.

Brown, C.K., et al. 1975. *Conceptual Design of an Environmental Service Module*. Report No.75-01 for Defense and Civil Institute of Environmental Medicine. Ontario Research Foundation, Mississauga, Ontario.

Given P.W. and H.G. Chambers. 1976. Workcamp sewage disposal, washcar - incinerator complex, Fort Simpson, NWT. In: *Some Problems of Solid and Liquid Waste Disposal in the Northern Environment*. Environmental Protection Service Rep. No. EPS-4-NW-76-2, Northwest Region, Edmonton, Alberta.

Mecklinger. 1977. *Servicing of Arctic Work Camps*. Department of Civil Engineering, University of Toronto, Toronto, Canada.

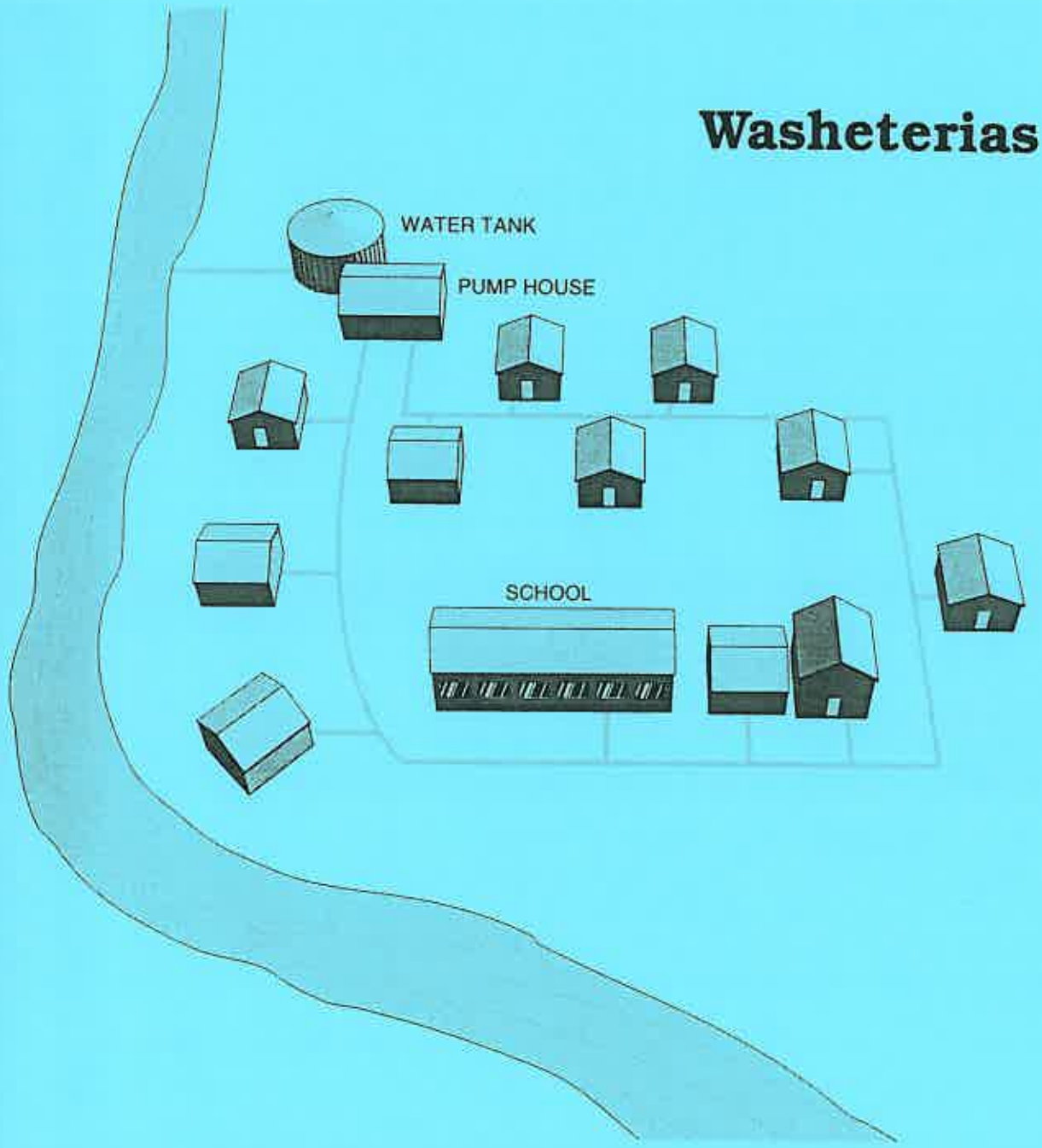
Nehlsen, W.R. 1962. *A Development Program for Polar Camp Sanitation*. Armed Forces Technical Information Agency, U.S. Naval Civil Engineering Laboratory Technical Note 476, Port Hueneme, California.

Sargent, J.W. and J.W. Scribner. 1976. *Village Safe Water Project in Alaska - Case Studies*. Alaska Department of Environmental Conservation, Juneau, Alaska.

U.S. Environmental Protection Agency. 1973. *Alaska Village Demonstration Projects*. Report to the Congress, Washington, D.C.

O & M of Small Water Systems

Washeterias



Alaska Department of Environmental Conservation
Skeet Arasmith

O & M of Small Water Systems

Funding for Development - Alaska Department of Environmental Conservation.

Development - Skeet Arasmith - Arasmith Consulting Resources Inc., Albany, Oregon.

Graphic Art - Kimon Zentz - Arasmith Consulting Resources Inc., Albany, Oregon.

Review team - Greg McPhee-Village Safe Water, Larry Strain-IHS Office of Environmental Health and Engineering, Linda Taylor-ADEC, Bill Fagan & Kerry Lindley-Department of Environmental Conservation, Jim Ginnaty-SEARHC.

Project Managers - Bill Fagan and Kerry Lindley.

ACR Publications, Inc.
1298 Elm Street SW
Albany, Oregon
(503) 928-5211

TABLE OF CONTENTS

Introduction to Washeterias

INTRODUCTION TO WASHETERIAS

WHAT IS IN THIS MODULE?

1. The functions of a washeteria.
2. The basic components of a washeteria.
3. Normal operational routines.

KEY WORDS

- Boiler
- Gray Water
- Heat Recovery
- Watering Point
- Glycol
- Heat Exchanger
- Lint Trap

MATH CONCEPTS DISCUSSED

- None are discussed

SCIENCE CONCEPTS DISCUSSED

- Heat exchange

SAFETY CONSIDERATIONS

- Electrical Measurements
- Confined Space
- Handling Chemicals
- Handling Hot Water

MECHANICAL EQUIPMENT DISCUSSED

- Boilers
- Clothes Dryers
- Toilets
- Heat Exchangers
- Clothes Washers

INTRODUCTION TO WASHETERIAS

INTRODUCTION

General Description

Washeterias are central points that provide one or more environmental services not available to all or a major portion of the population of a village or camp. These facilities are called washeterias, central facilities and environmental service modules. Washeterias are found in logging, mining and drilling camps throughout the US and Canada. There are a significant number of washeterias in villages in Alaska and Canada.

Module Content

There is no such thing as a standard or typical washertia. The services provided range from a single service to multiple services. Therefore, unlike other modules in this series, this module is general rather than specific. To be specific would mean duplicating what was in several other modules and then still not having one that fit the majority of the needs. We suggest that you select other modules to accompany this one, in order to develop a better understanding of the operation and maintenance requirements of a washertia. Other modules of interest may be:

- O & M Hypochlorinators
- O & M Fluoride Saturators
- O & M Boilers & **Heat Exchangers**[1]
- O & M Pressure filters
- O & M Greensand filters
- O & M of Groundwater
- O & M of Surface Water
- Normal Pumping Operations
- O & M of Storage Reservoirs

Functions

Washeterias are used to provide a variety of environmental services to individuals where individual services to homes are not available or in some cases not feasible. These services may include one or more of the following:

- Clothes Washers
- Clothes Dryers
- Drinking Water
- Shower
- Bathtubs
- Sinks

[1] **Heat Exchanger** - A device used to transfer heat from one substance to another without the two substances being in contact with one another. Typical heat exchangers are water to water and glycol to water.

- Toilets
- Saunas
- Heating for adjacent buildings
- Waste collection. While this is not very common, they are occasionally used as honey bucket collection sites. Sewage is then typically pumped from the washeteria to a lagoon or flows to a septic tank.

Facility Size

Washeterias are used to provide services to villages and camps ranging in population from 25 to 600 people. They have been designed and built in a variety of sizes and shapes from 850 square feet to 3400 square feet.

SUCCESS

Other Facilities

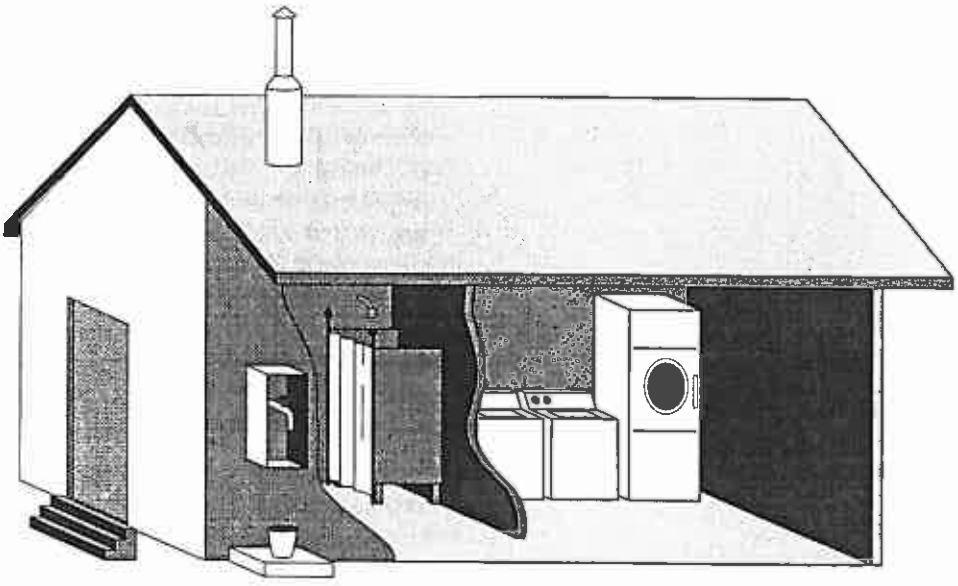
Washeterias have proven to be the most successful, in terms of being able to provide services at a cost level acceptable by members of the village. They are also providing services to other facilities. Typical of these facilities are the school and health clinic. In some cases, the washeteria is provided in conjunction with a standard circulation system that serves a portion of the community.

Heat Recover

Heat needed for clothes dryers is very expensive to produce. The more successful washeterias use heat recovery from the power generating facility for this function.

Revenue

The more successfully run washeterias are those that are operated by the city as a business. If properly operated and maintained, and if a fair price is charged for the services the washeteria can be self-sufficient.



COMPONENTS

Typical System

Because there is no such thing as a typical washeteria, we have made up a typical theoretical unit. This was done to allow us to discuss the various systems found in the wide variety of washeterias that are found in rural Alaska and Canada. The typical theoretical unit we have chosen includes all of the services listed above.

Systems

Our theoretical typical washeteria has the following subsystems.

- Building
- Water system
- Laundry facilities
- Toilet and bathing facilities
- Heating system
- Sewage handling

BUILDING

Wood Frame

The most typical washeteria building is a wood frame building, elevated above ground. The services portion of the washeteria is separated from the treatment portion.

Entrance

The entrance is designed to reduce snow entry into the buildings. Typical of this design is the use of concrete or slotted metal steps and landing. The better facilities have a double entry to prevent the loss of heat and allow those entering the building a place to remove heavy coats and boots.

Floors

The floors in the service portion are commonly concrete or wood covered with commercial grade vinyl. In the treatment portion of the building, the floors are usually plywood sealed and painted with a wear resistant epoxy.

Heating

Heat for the building is commonly provided as part of the diesel fired **boiler**[2] system or waste heat from the electrical generator system. One method of distributing the heat is the use of plate heat exchangers with a fan to move air through the plates. The second common method is a forced air system. This system requires air ducts, an air intake system and a heat exchanger. Commonly the building heat system is designed and built in conjunction with the clothes dryer system. Waste heat from the clothes dryers is used to heat the building.

Counter Space

When washer and dryer facilities are available, there is typically plastic laminated (Formica™) covered counter tops to facilitate sorting and folding clothes.

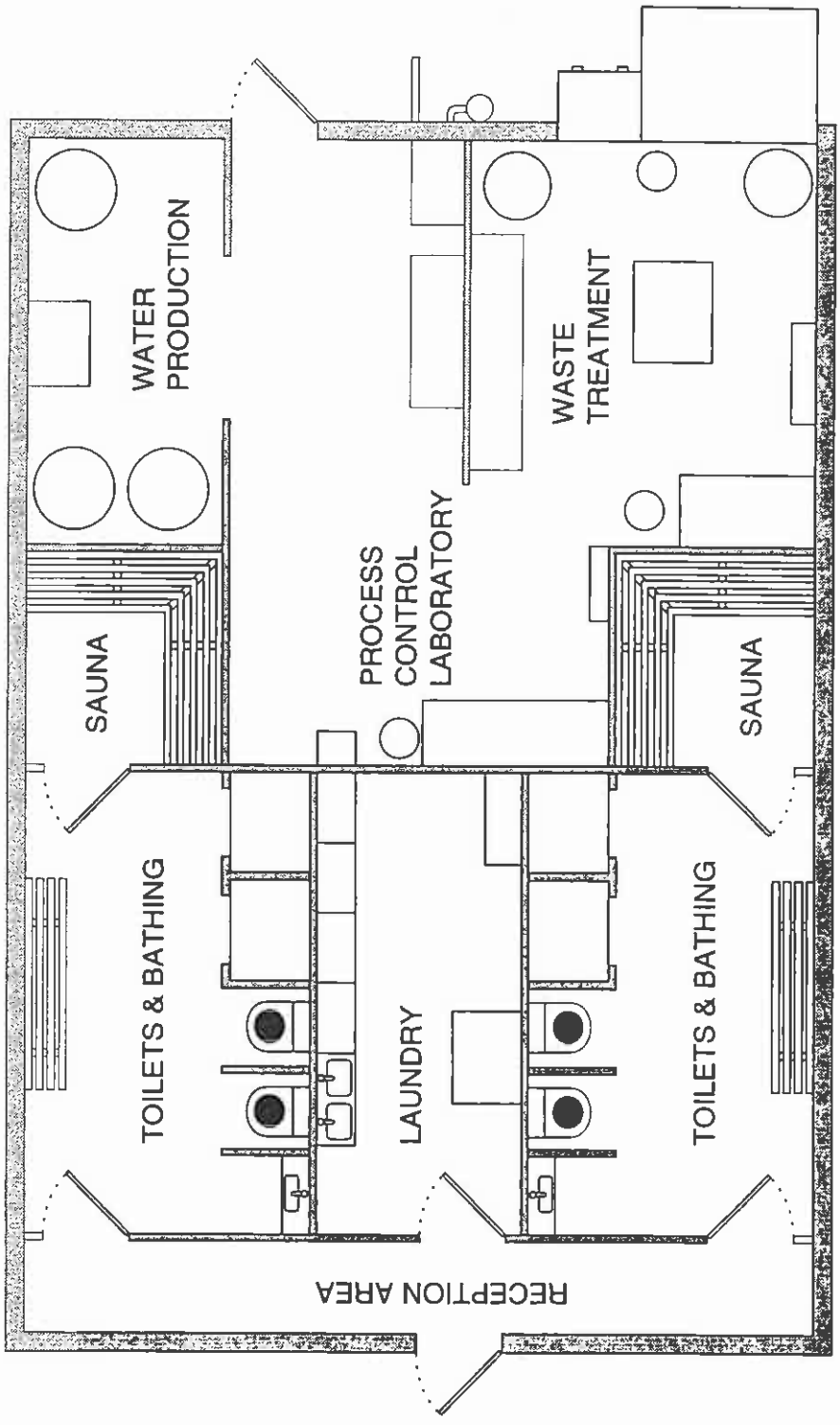
[2] **Boiler** - A device used to heat a fluid. Includes a burner assembly, fire box and water jacket.

Change & Sodas

The more successful facilities provide a coin or token dispensing machine as well as a standard soda pop dispenser.

Generator

It is a common practice to have a diesel powered generator in the facility to provide power, in case of a failure of the local power generator facility.



WATER SYSTEM

Other Material

Information on the operation maintenance, and safety aspects of specific water system components as well as information on chemical handling can be found in the specific O & M modules listed at the start of this text material.

Normal

The water system for a washeteria is typical of most water systems. Our example facility has a surface water source, where water is pumped from a river using a fill and draw process.

Filtration

The raw water is filtered through pressure sand filters. These are standard pressure filters using sand as their primary filter media. In some locations cartridge and bag filters are used instead of the pressure sand filters.

Chemicals & Storage

As water leaves the filter, chlorine and fluoride are added and the water is stored in the fill and draw storage reservoir. Typical reservoirs are 7,000 to 11,000 gallons. This reservoir may be internal or external of the building and is most often made of steel and insulated with polyurethane.

Heating

The temperature of the water in the storage reservoir is maintained from a double walled **glycol**[3] to water heat exchanger. The heat exchanger is part of the heating system described later.

Pressure System

Water is pumped from the storage reservoir into pressure tanks. These pressure tanks are the Well-X-Troll tanks with bladders. Thus they do not require any special air valves or a compressor. The pressure pumps are cycled from a signal from a standard pressure switch placed in the discharge line of the pressure tanks.

Internal Plumbing

Water is supplied directly from the pressure tanks to the water heating system and the other internal plumbing system for the building.

Adjacent Buildings

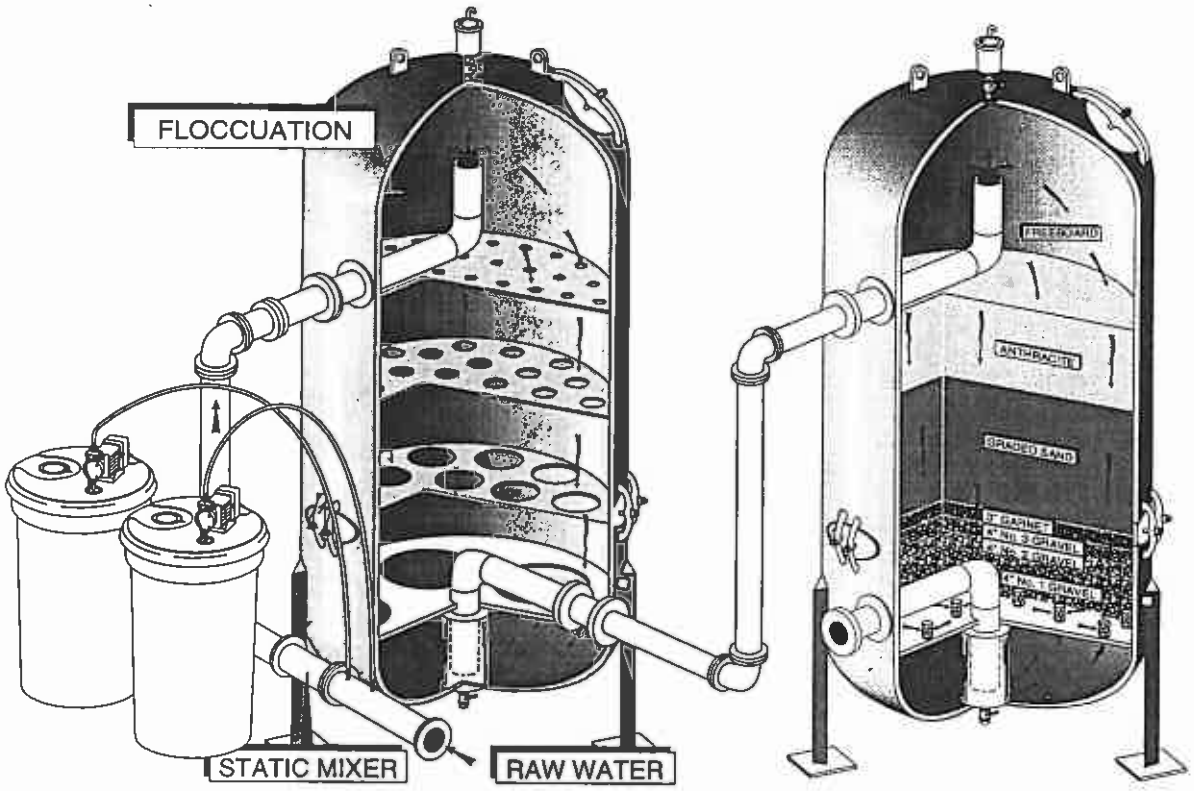
Heated utilidors run from the washeteria to the school, health clinic and city office building. Water is circulated by a pump through these utilidors.

Watering Point

While not always a part of the washeteria, our theoretical facility includes an external **watering point**[4]. The watering point may be composed of hose and real system with the hose penetrating from the wall or a single hose that penetrates the wall. The hose must be long enough to allow access to the water but short enough not to touch the ground. Access to water may be a manually operated push button or a coin operated device that opens and closes a solenoid valve. In most

[3] Glycol - Common name for ethylene or propeleylene glycol, a colorless, thick, sweet liquid used as an antifreeze. Ethylene glycol is highly toxic and should not be used.
[4] Watering Point - A place in a community where members of the community can obtain potable water.

instances, the solenoid valve is on a timer. This prevents excessive loss of water.



Typical - Direct filtration - Pressure Filter System

LAUNDRY FACILITIES

WASHERS

Types

Washers used are standard commercial clothes washers. The most popular are Speed Queen and Wascomat. In most cases these washers are coin or token operated.

Hot Water

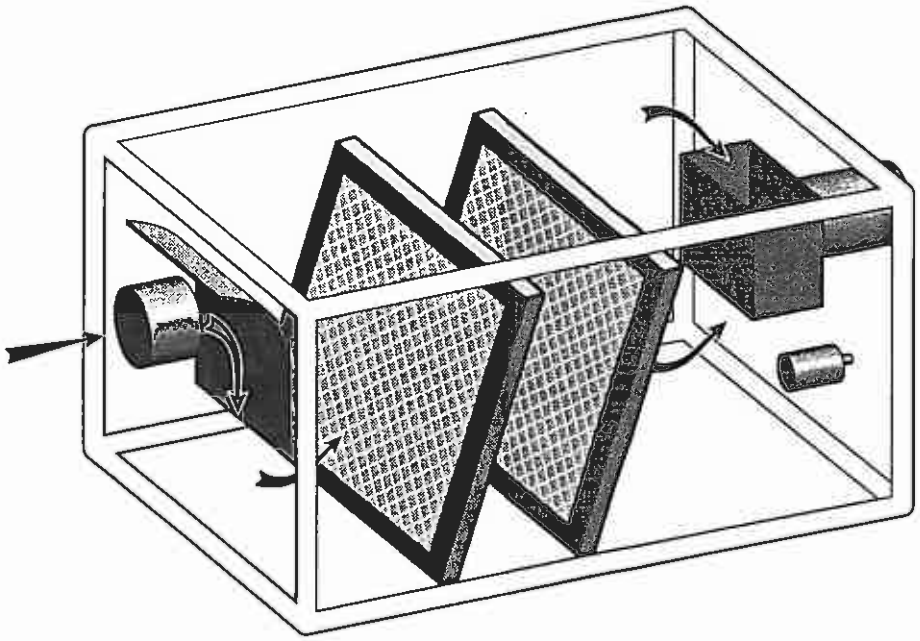
Hot water for the washers is provided by one of two means. A diesel fired water heater or a glycol to water heat exchanger type water heater. These later devices are very efficient and provide hot water quickly. The key to their efficiency and quickness is the size of the heat exchanger. It is very large compared to the overall size of the device. This device is often called the hot water generator rather than water heater.

Gray Water

The water leaving the washers is called **gray water**[5]. It exits the washers into the sewage collection and treatment system. Internally in the building this water is under gravity flow conditions once it leaves the wash-

[5] Gray **Water** - The term used for wastewater that does not contain human waste. Typical gray water sources are washers, showers and sinks.

er. To reduce the load synthetic fibers can have on a septic tank or other treatment system, special **lint traps**[6] are installed in the effluent of the washers. These lint traps are commonly composed of a series of two screens placed at a slight angle. The angle helps prevent plugging and presents a large surface area to the water flow.



DRYERS

Types

Dryers used in washeterias are standard commercial Laundromat dryers. The most popular brands are Hoyt-Huebsch. These are commonly coin or token operated devices.

Heating

The two most common heating systems used for washeteria dryers are hot air and hot water. The hot air is provided by a boiler and heat exchanger system, with air being blown across the heat exchanger coils. The hot water system uses a water loop directly from the hot water boiler. Circulating pumps at each dryer circulate the hot water. A fan is used to force air through the drier.

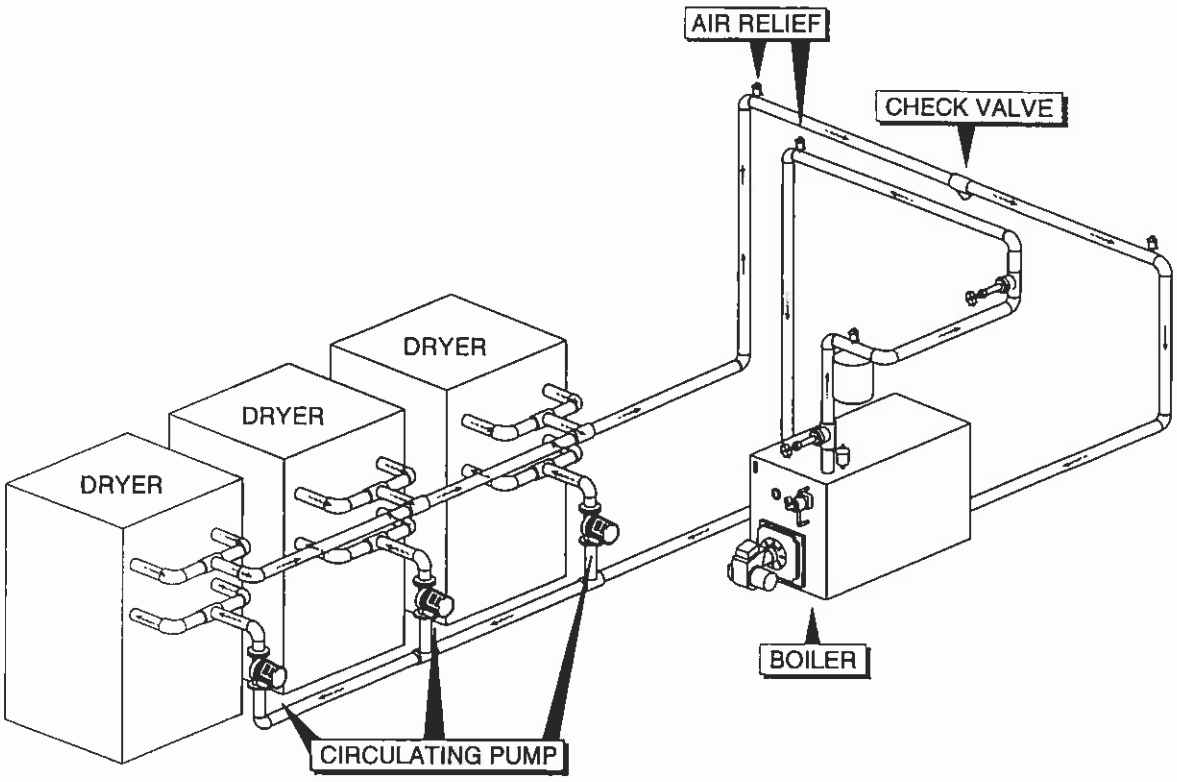
Heat Recovery

When possible a **heat recovery**[7] unit is installed in the nearby power generation facility. These heat recovery units are used for heating the building, utilidor or the dryers.

Exhaust Air

The exhaust air is collected into the air duct system and often used to help heat the building.

[6] **Lint Trap** - A device placed into a water or air flow to trap lint, hair or other material that can cause a problem with the system if the lint goes beyond this point.
[7] Heat Recovery - A process of recovering and using heat that normally would be lost.



TOILET AND BATHING FACILITIES

Separated Facilities

When toilet and bathing facilities are provided, there are separate men's and women's facilities. While toilets normally have no restrictions on use, showers are commonly coin operated. Water is provided through the building plumbing system.

Waste Handling

Gray water from the showers and wastewater from the toilets and urinals is collected by the building wastewater plumbing system and piped to the sewage system.

Saunas

Occasionally electric or oil fired saunas are provided in a washeteria. These are usually separately operated facilities for men and women.

HEATING SYSTEM

Introduction

Depending on the type of dryers used, the heating system may be composed of one or two or more boilers.

Water Heating - Boilers

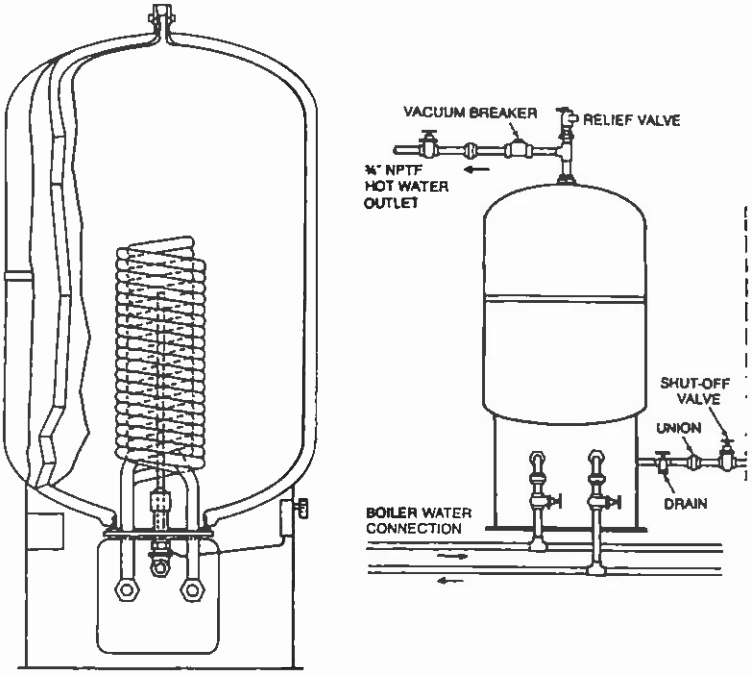
The boiler used to heat water is a typical low-pressure (less than 25 psi) operating at 180°F to 200°F. The boiler is used to heat glycol or a glycol and water mixture. The glycol is pumped through a double wall heat exchanger. Hot water exits the heat exchanger.

Water Heaters

In some locations a diesel fired water heater is used. With this device, cold water enters a storage tank where it is heated by a diesel burner. The burner used is very similar to the burner used on the boiler.

Hot Water Generator

A popular method of providing hot water is the hot water generator described above. This device is composed of a tank with a large heat exchanger installed directly in the tank. The size of the heat exchanger, in relationship to the tank size, provides an efficient method of heating water.



Uses of Hot Water

The heated water can be used, to heat the water in the storage reservoir, provide hot water for the washers and showers and heat the building. In each of these cases a heating loop is installed and a pump is used to circulate water through the loop.

Utilidor Heating - Glycol

When the washeteria provides services to adjacent facilities, the connection of these facilities is commonly through a utilidor. To prevent freezing in the utilidor a glycol loop is commonly installed in the utilidor. This is typically a 3/4 inch or 1 inch copper loop. Heated glycol is pumped through the loop. Heat is transferred from the copper to the air in the utilidor.

Utilidor Heating - Forced Air

When there is sufficient hot air from the heat recovery system or the dryers, the heating of the utilidor may be supplemented with forced hot air.

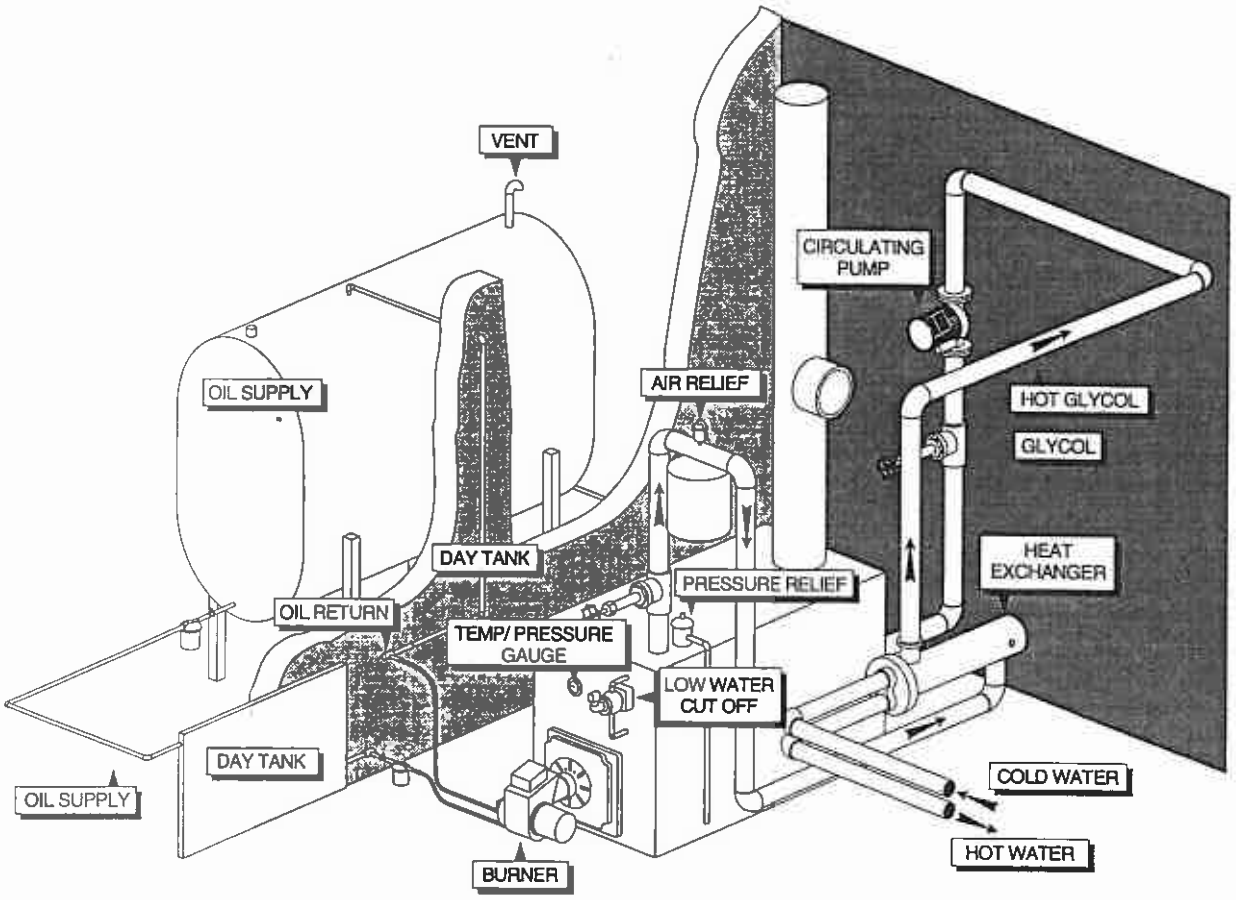
Dryer Boilers

Standard low pressure boilers are used for to provide heat for clothes dryers. The boilers operate at temperatures between 180°F to 200°F and 15 psi and 25 psi.

Air Intake System

A standard boiler system requires large quantities of air in order to efficiently operator. This air is supplied through an air intake system. The air system is connected to the outside. Heat loss is reduced by utilizing louvers at the intake. Failure of or blockage of the lou-

vers will drastically reduce the efficiency of the boiler system.



SEWAGE SYSTEM

Honey Bucket Collection

While each washeteria must have a means of handling its own wastewater, it can serve as a collection point for honey buckets. While this honey bucket collection point is not very common, it is none the less available in some locations.

Type of Treatment

While conventional biological treatment is occasionally available at a washeteria, the most common treatment facilities are septic tanks and sewage lagoons. If a septic tank is not used, the typical process is to install a lift station and holding tank at the washeteria. Wastewater is pumped from this holding tank through a force main to the lagoon.

Caution

Regardless of the treatment system, there is the potential of "sewer gases" entering the washeteria through floor drains and other fixtures attached to the sewer system. To reduce this hazard the "P" traps should be kept full of water.

NORMAL OPERATIONS

Division of Issues

The normal operating task of a washeteria can be divided into two general categories; management issues and operation issues.

MANAGEMENT ISSUES

The Problem With Fees

One of the major problems with washeterias is their potential drain on the financial resources of the community. Establishing equitable rates for showers, use of the sauna, washers, dryers and water is often difficult and plagued with political difficulties. One of the non-scientific methods of determining if the rates are in the proper range is to compare them with rates in Fairbanks and Anchorage. The rates for the same services should be higher in the village than in Fairbanks or Anchorage.

Spare Parts

Keeping adequate critical spare parts on hand can reduce the cost of emergency repairs. Without adequate spare parts, the operator is often required to have parts air freighted into the village, increase cost and causes excessive down time of the facilities.

Fee Base

There are three things that must be considered when developing fees; actual operating cost, maintenance cost and replacement cost. Actual operating cost and maintenance cost can be determined by keeping detailed records of labor, materials, supplies and services purchased on a month by month basis. Determining replacement cost, the rate of depreciation and deterioration of equipment often requires outside help. DCRA or the RMW can provide assistance in determining these costs.

Change Making

A second major management decision is, how to provide change to operate the coin operated devices. One of the common first steps that many villages have taken with this process is to avoid the coin process and instead use token operated equipment. The tokens can be purchased at the city office or from a token machine at the washeteria. Tokens and coins should be carefully counted and recorded each day. This is the best way to track income and cost.

Token Machine

The use of the token machine at the washeteria provides much better control of the income from the facility. Also, using tokens rather than coins, leaves only one coin box that is subject to break-ins that can cause a major financial impact on the community. Because token sizes and weights can be changed easily, the theft of large qualities of tokens can be combated by changing the acceptable token size. Using different tokens for showers, washers and dryers is one way to divide the various cost of different services.

Personnel

The last major management issue is the selecting of the operations and maintenance personnel for the washeteria. This selection should be based on mechanical skills and the ability and desire of the individual to perform routine janitorial tasks. Of major importance to the success of the washeteria is having operating equipment in a clean pleasant building. In order to maintain the washeteria there should be at least one permanent operator and one alternate operator.

Operator Duties

The operator is responsible for cleaning the washeteria, operating the water treatment plant, ordering parts, maintaining an inventory of parts and chemicals, performing preventive maintenance, testing water quality and completing routine reports.

OPERATION ISSUES

Two areas

Unlike other water and wastewater operations the washeteria is composed of two distantly different areas that must be operated and maintained differently. The two areas are the service area and the treatment area.

SERVICE FACILITY

Routine Hours

There are two keys to successfully operating a washeteria; properly operating equipment and clean facilities. Beyond this it is important that the washeteria be open at regular routine hours. These hours should be clearly posted and maintained. When there are expected changes in the hours, the community should be notified, in writing prior to the change.

Clean - Floors

The floor should be swept daily and washed at least 3 times a week. Daily mopping is not an unreasonable expectation. At least once each week the floors should be cleaned with a commercial disinfectant.

Toilet and Bathing

The shower stalls, toilets and urinals should be cleaned and disinfected each and every day they are used. The floor in the bathing facility should be swept and mopped with a commercial disinfectant every day.

Waxing Floor

The vinyl floor covering should be waxed with a high quality commercial wax at least once each quarter. During heavy use times it may need to be more frequently. The wax will speed the daily cleaning and preserve the floor

Clean - Equipment

The washers and dryers should be wiped down with a damp rag each day. The lint should be wiped from inside of the washers and dryers. The lint traps should be removed and cleaned.

Clean - Lint Traps

The gray water lint traps should be removed and cleaned each day.

Remove Trash

To reduce the possibility of fire, the trash containers should be emptied each day and cleaned with a disinfectant once a week.

Coins & Tokens

Tokens and coins should be removed from the washers, dryers, showers and pop dispenser each day (or as described by the management), the amounts recorded and taken to the City Office. The coin change machine should be checked and reloaded daily. Money received should be properly recorded and placed in the safe.

Lights

To reduce electrical cost the interior lights should be shut off each night.

Doors

The interior and exterior of the doors should be cleaned once each quarter.

Windows

The windows should be cleaned once each month. Inside and out (weather permitting).

TREATMENT FACILITY

Introduction

The operation of the equipment in the treatment facility will be found in the modules on each of the various pieces of equipment. Here, we will focus on general observations and data collection.

Building

The building, entrance, walkways, roof, foundation, doors, windows and etc. should be inspected at least once each year and the condition noted. This inspection is best done in the spring after the snow has melted. Maintenance requirements should be noted and action taken to perform the maintenance before freeze up.

Water System

The water system and related components, including building plumbing should be inspected for leakage at least once a month. Washers and bathing facilities, the hoses, faucets and shower heads should be inspected for proper operation at least once a week.

Water temperatures, water consumption, pump pressures should all be properly observed and recorded. The same is true of chemical consumption and filter operations. The following general check list can be used to identify the water system inspection and data collection requirements. Inspect and/or collect:

- ❑ Pump suction and discharge pressures
- ❑ Flow rates on loops
- ❑ Water consumption
- ❑ Differential pressures on the filters
- ❑ Chemical tank levels
- ❑ Quantity of chemicals used
- ❑ Chlorine and fluoride residuals
- ❑ Collect and mail bacteriological sample once a month
- ❑ Clean inside of water storage tank

Heating System

The heating system should be inspected on a regular basis. The inspection should include:

Once each day

- ❑ Check and record temperature in and out of both sides of the heat exchangers
- ❑ Check and record boiler temperatures
- ❑ Check and record boiler pressures
- ❑ Check and record pressures and operation of circulating pumps

Once each month

- ❑ Check the strength of the glycol
- ❑ Check the flow rates in each glycol loop

Twice each year

- ❑ Check for leakage on handhole gaskets on water heaters
- ❑ Replace anodes in the water tank
- ❑ Clean dryer exhaust ducts
- ❑ Check fuel storage tank for water
- ❑ Check condition of the building furnace fan

Once each year

- ❑ Clean the boilers
- ❑ Clean the burner and replace the nozzle
- ❑ Adjust the electrodes
- ❑ Perform smoke and combustion test
- ❑ Oil all motors
- ❑ Clean inside of water heaters

Sewage System

If a sewage system is a lagoon with a lift station at the washeteria then:

- ❑ Three times a week check the operation of the pumps
- ❑ Clean the wet well once each year

If the sewage system is a septic tank with multiple leach fields, then every six months switch leach fields.

ROUTINE MAINTENANCE

Importance

As mentioned in the section on normal operations one of the keys to a successful washeteria is having the equipment in an operating conditions This requires performing the inspections noted above and making repairs as necessary. The repairs may not be possible unless there are adequate tools and spare parts on hand.

Parts Inventory

The spare parts listing below is general in nature. You should consult the O & M manual and the other training modules on specific units to develop a completed list. The RMW in your area will be glad to help you develop a complete spare parts listing. The general list should include:

Washers

- Two sets of belts
- Two timers
- Two coin boxes
- Two door gaskets
- One transmission
- One electric motor
- Two sets of water inlet valves

Dryers

- Two sets of belts
- Replacement heating system
- Two timers
- Two sets of drum rollers
- Two door gaskets
- Two coin boxes

Showers

- Two replacement water control units
- Two shower heads
- Two sets of spare gaskets for water control units

Toilets

- Two complete sets of tank control valves

Urinals

- Two replacement water control valves

INTRODUCTION TO WASHETERIAS WORKSHEET

1. Which of the following services is **not normally** provided with a washeteria?

_____ a. Showers

_____ b. Clothes dryers

_____ c. Solid waste disposal

_____ d. Drinking water

_____ e. Clothes washers

2. The functions of a washeteria can be divided into two (2) general areas they are:

_____ a. Services and Treatment

_____ b. Washing and Drying

_____ c. Showers and Hot Water

_____ d. Water delivery and Services

_____ e. Sewage handling and clothes washing

3. An alternative to using coins to operate the washers and dryers in a washeteria is to use...

_____ a. Coin change machines

_____ b. Bill every member of the community monthly

_____ c. Charge as people enter the door

_____ d. Use tokens

_____ e. Use wooden coins

4. When a hot water dryer is used the boiler maintains the temperature between _____ and _____.

_____ a. 180 & 200

_____ b. 145 & 212

_____ c. 200 & 275

_____ d. 120 & 140

_____ e. 195 & 235

5. There are two lint traps in a washeteria. Where are they located?

_____ a. Gray water from washers

_____ b. Gray water from shower stalls

_____ c. Return line from the utilidor

_____ d. Air intake line

_____ e. Air duct from dryer

6. How often should toilets and shower stalls be cleaned?

_____ a. Hourly

_____ b. Once a week

_____ c. Daily

_____ d. Twice a week

_____ e. Once a month

7. A low pressure boiler used to produce hot water and heat potable water maintains a temperature between _____ and _____ °F

_____ a. 180 & 200

_____ b. 145 & 212

_____ c. 200 & 275

_____ d. 120 & 140

_____ e. 195 & 235

8. The two major keys to a successful washeteria operation are:

_____ a. Short hours

_____ b. Long operating hours

_____ c. Operating equipment

_____ d. Cleanliness

_____ e. Cheap prices

9. The surface and interior of washers and dryers should be cleaned how often?

_____ a. Hourly

_____ b. Weekly

_____ c. Monthly

_____ d. Quarterly

_____ e. Daily

10. The gray water lint traps should be cleaned

_____ a. Hourly

_____ b. Weekly

_____ c. Monthly

_____ d. Quarterly

_____ e. Daily

Staphylococcus aureus including MRSA Cleaning and Disinfection Protocol for Use in Hotels, Motels and Cruise Ships

This document has been developed in accordance with current applicable infection control and regulatory guidelines. It is intended for use as a guideline only. At no time should this document replace existing documents established by the facility unless written permission has been obtained from the responsible facility manager.

PREFACE

Staphylococcus aureus is a common etiologic organism in soft tissue infections and may be found on the skin of nearly 20% of healthy people. Staph bacteria are one of the most common causes of skin infections in North America and are the common cause of pneumonia, surgical wound infections and bloodstream infections.

Over the past several decades, infections with methicillin-resistant *Staphylococcus aureus* (MRSA) among hospitalized patients have become common. Recently, reports of MRSA infections acquired outside of the hospital setting have increased nationally, including fatalities. MRSA is a type of Staph that is resistant to beta-lactam based antibiotics. Resistance to antibiotics happens when the bacteria produce an enzyme that breaks down antibiotics. Staph bacteria have a unique protein that stops the antibiotic from attaching to the bacteria and killing it. This is MRSA, a strain of *S. aureus* that is resistant to a large number of antibiotics making it difficult to treat because of the limited number of antibiotics available.

This protocol has been developed based on current practices for cleaning and disinfection of vegetative bacteria.

INFECTIOUS AGENT[1]

NAME: *Staphylococcus aureus* including MRSA

SYNONYM OR CROSS REFERENCE: MRSA, Staphylococcal diseases,

CHARACTERISTICS: Gram positive cocci, non-spore forming, non-motile

HEALTH HAZARD

PATHOGENICITY: Opportunistic pathogen, normal flora; produces a variety of syndromes with a range of clinical manifestations; may cause surface or deep/system infections in both community and hospital settings; surface infections include impetigo, abscesses, boils;

EPIDEMIOLOGY: Worldwide; particularly in areas where personal hygiene is suboptimal; in hospitals by development of antibiotic-resistant strains.

HOST RANGE: Humans and to a lesser extent, warm-blooded animals.

INFECTIOUS DOSE: Virulence of strains varies greatly

MODE OF TRANSMISSION: Contact with nasal carriers; from draining lesions or purulent discharges, spread person-to-person; contaminated food; from mother to neonate during delivery

INCUBATION PERIOD: Variable, commonly 4 – 10 days; disease may not occur until several months after colonization

[1] PHAC, Material Safety Data Sheet – Infectious Substances: *Staphylococcus aureus*. http://www.phac-aspc.gc.ca/msds-ftss/msds143e.html

Staphylococcus aureus including MRSA Cleaning and Disinfection Protocol for Use in Hotels, Motels and Cruise Ships

Preparation

S. aureus including MRSA is transmitted in a number of ways direct person-to-person contact, direct contact with contaminated body fluids (mucous or wound discharge) and indirect contact from freshly contaminated fomites.

Appropriate personal protection should be taken for those responsible for the decontamination of a room or area.

Protective Barriers

For your own health, use personal protective equipment. Wear disposable (one time use) gloves and mask, for your safety, before entering area. If necessary, you may need to wear plastic apron, face shield and/or boots. When finished, remove gloves carefully, from the inside out, to ensure/avoid contact with outer layer. Wash hands thoroughly with soap and water after this.

Cleaning Supplies

0.5% Accelerated Hydrogen Peroxide Ready-To-Use Tuberculocidal Surface Disinfectant (sold as Oxivir Tb RTU, Carpe Diem Tb RTU and Accel TB RTU)

Product Germicidal Efficacy

All products listed above are based upon Accelerated Hydrogen Peroxide – and have a Sanitizing claim and a Bactericidal claim against Vegetative Bacteria including *Staphylococcus aureus* and MRSA.

Procedures Summary

Seal off affected area, to prevent entry

It is important to seal off the area and restrict access, in order to prevent exposure and keep the visibility low profile. We must also reduce the spread of contaminants, therefore, have people stationed in strategic places, to offer assistance in redirecting the traffic flow.

Consider all surfaces to be potentially affected

It is important to look around and visually inspect the area thoroughly, to ensure all possible contaminants are identified. Think of every surface that may be touched. For example: If a vomit incident were to occur, there may be vomit on the floor but it may have also splattered onto the wall or other nearby surfaces.

Remove Soiled Items (OCCUPIED ROOMS):

Be careful, to avoid further exposure or cross-contamination. Contain as much as possible. Remove all drinking glasses. Remove and dispose trash, rubbish etc. Place the wastebasket and recycle paper holder in shower / tub to be cleaned and sanitized.

Collect and remove all used linens, paying particular attention to bodily fluids, and place in appropriate bag:

a. Use water-soluble bag for items to be laundered
b. Use Bio-Hazard bag, if bodily fluids are present (blood, diarrhea, vomit etc) for items to be discarded or incinerated
c. Remove shower curtain, if applicable
d. Check mattress (including sides), bed skirting and carpet beside bed for bodily fluids.

Note: Linen items include: Terry items (washcloths, hand towels, bath towels and bath mat, Bed items (sheets, pillow case, pillow covers, mattress pad and bed spread and / or pillows, if visibly soiled

Staphylococcus aureus including MRSA Cleaning and Disinfection Protocol for Use in Hotels, Motels and Cruise Ships

Remove and transfer soiled linen or biohazard bags:

Take the water-soluble bag directly to laundry, so they can be washed immediately. The biohazard bag should be taken directly to the infirmary or other designated area and dispose of appropriately.

Clean the Bathroom:

Bathtub / Shower Area:

1. Clean tile wall and soap dish
2. Clean showerhead and faucets
3. Scrub bathtub and clean tub stopper
4. Clean all walls, bathroom door and door handle
5. Rinse all surfaces

Sink / Vanity Area:

1. Wipe light fixture, and exhaust
2. Clean vanity mirror
3. Wipe hair dryer, extend hose and clean hose (if applicable)
4. Clean shelf and/or medicine cabinet
5. Clean ashtray(s)
6. Clean vanity counter / sink and faucets, include sink stopper
7. Wipe towel rack, toilet paper dispenser and any other fittings and fixtures
8. Wipe pipes under sink (if exposed).

Toilet

1. Clean and sanitize toilet lid, toilet seat and outside of toilet bowl using a disposable paper wipe
2. Scrub inside of toilet bowl and around the rime with toilet brush
3. Wipe wall behind toilet, and underside of toilet bowl.

Floor

1. Clean bathroom floor including drain cover (if applicable).

Super-Sanitize Bathroom (OCCUPIED ROOM):

1. Apply ***AHP Solution*** on ALL surfaces of the bathroom with a clean sponge or cloth (excluding the floor).
2. Reminder: Apply on walls from bottom to top.
3. Let dwell for 1 minute.
4. Wet wipe residual after 1 minute.
5. Thoroughly sanitize the wastebasket, recycle paper holder and bathroom wastebasket.

Room Cleaning:

Work from the furthest wall backwards towards the entry door, being sure to cover all surfaces from side to side, and bottom to top.

1. Wipe doors and frames
2. Wipe light fixtures (wall sconces, lamps and lampshades)
3. Wipe mirror
4. Wipe TV, including behind and on top
5. Wipe tables and furniture

6. Wipe upholstered furniture (checking under cushions)
7. Open all closets, and clean all shelves (In vacant cabin: Open and clean all drawers)
8. Wipe/Dust all baseboards
9. Wipe TV Remote Control
10. Wipe telephone
11. Spray carpet spots and blot

Room Sanitizing (OCCUPIED ROOM):

Use the ***AHP Solution*** on applicable surfaces. In general, apply the spray or wipe **ALL** surfaces, with which ever is most appropriate. Work from the furthest wall backwards towards the entry door, being sure to cover all surfaces from side to side, and bottom to top.

1. Spray **AHP Solution** on drapes and glass curtains, both sides (using 32 oz. bottle)
2. Use **AHP Solution** for curtain wands, headboard light-switches and radio controls
3. Spray fancy pillows, bed-skirt, privacy curtain, chair, stool, sofa, etc. without interfering with guest belongs or comfort.
4. Use **AHP Solution** for coffee table top and rim, including telescopic handle control.
5. Use **AHP Solution** on all leather goods. Do not spray with liquid on leather.
6. Wipe remote control and TV (and VCR, if applicable) with **AHP Solution**
7. Wipe Temperature control (thermostat) with **AHP Solution**
8. Wipe drawer handles and under drawer pull opener with **AHP Solution**.
9. Wipe exterior of all books: room directory, literature, and Bible with **AHP Solution**
10. Spray carpet with **AHP Solution**, if visible or known bodily fluids

Room Sanitizing (VACANT ROOMS):

Use **AHP Solution**, on applicable surfaces. In general, apply the spray or wipe **ALL** surfaces, with which ever is most appropriate. Work from the furthest wall backwards towards the entry door, being sure to cover all surfaces from side to side, and bottom to top.

1. Spray **AHP Solution** on drapes & glass curtains, both sides, using hand pump sprayer.
2. Spray/mist **AHP Solution** on all mattresses (top and sides), using hand pump sprayer.
3. Use **AHP Solution** for curtain wand, headboard light-switches and radio controls
4. Spray fancy pillows, bed-skirt, privacy curtain, chair, stool, sofa, etc.
5. Use **AHP Solution** for coffee table top and rim, including telescopic handle control.
6. Use **AHP Solution** on all leather goods. Do not spray with liquid on leather.
7. Wipe with **AHP Solution** remote control and TV (and VCR, if applicable)
8. Wipe with **AHP Solution** Temperature control (thermostat)
9. Using hand pump sprayer, mist closet shelves and hangers and wipe safe, etc.
10. Wipe with **AHP Solution** drawer handles and under drawer pull opener.
11. Wipe with **AHP Solution** exterior of all books: cabin directory, literature and Bible
12. Dispose of all cabin directory inserts, stationary/envelopes/postcards and pen.
13. Wipe Lifejacket with **AHP Solution**, inside and out, including thorough cleaning of straps.
14. Using hand pump sprayer, apply **AHP Solution** on carpet from back of cabin to the front.

Opportunistic pathogens enriched in showerhead biofilms

Leah M. Feazel[a], Laura K. Baumgartner[a], Kristen L. Peterson[a], Daniel N. Frank[a], J. Kirk Harris[b], and Norman R. Pace[a,1]

[a]Department of Molecular, Cellular and Developmental Biology, University of Colorado, Boulder, CO 80309-0347; and [b]Department of Pediatrics, University of Colorado Denver, Aurora, CO 80045

Contributed by Norman R. Pace, July 29, 2009 (sent for review June 25, 2009)

The environments we humans encounter daily are sources of exposure to diverse microbial communities, some of potential concern to human health. In this study, we used culture-independent technology to investigate the microbial composition of biofilms inside showerheads as ecological assemblages in the human indoor environment. Showers are an important interface for human interaction with microbes through inhalation of aerosols, and showerhead waters have been implicated in disease. Although opportunistic pathogens commonly are cultured from shower facilities, there is little knowledge of either their prevalence or the nature of other microorganisms that may be delivered during shower usage. To determine the composition of showerhead biofilms and waters, we analyzed rRNA gene sequences from 45 showerhead sites around the United States. We find that variable and complex, but specific, microbial assemblages occur inside showerheads. Particularly striking was the finding that sequences representative of non-tuberculous mycobacteria (NTM) and other opportunistic human pathogens are enriched to high levels in many showerhead biofilms, >100-fold above background water contents. We conclude that showerheads may present a significant potential exposure to aerosolized microbes, including documented opportunistic pathogens. The health risk associated with showerhead microbiota needs investigation in persons with compromised immune or pulmonary systems.

bioaerosols | Mycobacterium avium complex | Non-tuberculous mycobacteria | public health | rRNA metagenomics

Shower usage provides a source for repeated exposure to microbes through aerosolization and/or direct contact. The inside of a showerhead is a specific niche that is moist, warm, dark, and frequently replenished with low-level nutrient resources and seed organisms. Biofilms form on interior showerhead surfaces and potentially expose the user to a cohort of unknown, aerosolized microorganisms. Shower aerosol particles can be sufficiently small to carry bacteria deep into the airways (1). Pulmonary disease and other health risks such as asthma, bronchitis, and hypersensitivity pneumonitis are associated with inhalation of both viable bacteria and inviable microorganisms or their components (2–4). It has been hypothesized that the rise in pulmonary infections by nontuberculous mycobacteria (NTM) over recent decades is linked to increased use of showers rather than baths (5). Immune-compromised populations are on the rise; thus, identification of anthropogenic reservoirs of potential pathogens is of public health concern (3, 6).

Previous microbiological studies of showerhead biofilms have used culture methodology to detect and identify microbes, and have focused primarily on *Legionella pneumophilia* (7, 8, 9) and *Mycobacterium avium* (10–12). These organisms commonly occur in municipal waters and several studies have traced both *L. pneumophilia* and *M. avium* infections in hospitalized patients to microbes in their home showers (9, 10, 12).

Despite implication as a potential source of disease, the microbial composition of the showerhead environment is poorly known. Characterization of natural microbial communities by use of culture techniques may drastically under-sample the actual numbers and diversity, because most microbes are not readily cultured with standard methods (13, 14). Consequently, we used culture-independent methodology based on ribosomal RNA gene sequences to identify the composition of assemblages of microbes associated with showerhead surfaces over a wide geographical area of the U.S. Many of these microbes are closely related to organisms common in water, but some microbes of potential public health concern are enriched to high levels by the showerhead environment.

Results

Samples and Processing. As described in *Methods and Materials*, biofilms were obtained by swab of interior surfaces of 45 showerheads from nine cities in the United States. Some sites were sampled on multiple occasions to assess the stability of the showerhead microbial assemblages. Water feeding into showerheads was sampled in parallel with the swabs at 12 sites. All swab samples examined by microscopy showed clear evidence of more or less dense microbiology. As illustrated in the micrographs in Fig. 1, microbes generally were clumped and embedded in extracellular material, consistent with biofilm morphology. The DNA yields from the swabs were highly variable, and DNA could not always be extracted.

To identify the microbial constituents of the showerhead biofilms, we amplified rRNA genes from sample DNAs by PCR, using nominally universal primers (515F-1391R), then cloned the amplicons and determined their sequences. Overall, >6,090 unique rRNA gene sequences were determined and used to identify phylogenetically the microbes associated with the sampled sites.

Composition of Showerhead Communities. Ribosomal RNA gene sequences from natural microbial communities seldom are identical to previously encountered sequences. To relate these environmental sequences to named organisms, we binned the sequences into operational taxonomic units (OTUs) of greater than or equal to 97% identity, which corresponds approximately to the rRNA gene sequence variation seen in studied microbial species (15). Most of the sequences fell into species-level (≥97% identity) or genus-level (≥95% identity) bins with one or more named representative.

Fig. 2 summarizes the distribution of genera that comprised at least 0.5% of the total showerhead clones sequenced, grouped by municipality of origin (Dataset S1 shows all observed sequence types). The showerhead communities were comprised of multiple organisms, and the specific organisms varied from site to site. In general, however, compared to high-nutrient microbial communities (e.g., microbial mats, gut contents) the showerhead communi-

Author contributions: L.M.F., L.K.B., and N.R.P. designed research; L.M.F., L.K.B., and K.L.P. performed research; D.N.F. and J.K.H. contributed new reagents/analytic tools; L.M.F., K.L.P., D.N.F., J.K.H., and N.R.P. analyzed data; and L.M.F. and N.R.P. wrote the paper.

The authors declare no conflict of interest.

[1]To whom correspondence should be addressed. E-mail: norman.pace@colorado.edu.

This article contains supporting information online at www.pnas.org/cgi/content/full/0908446106/DCSupplemental.

MICROBIOLOGY

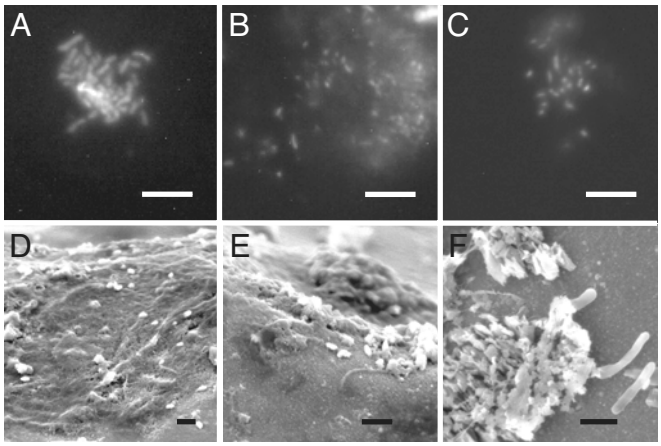


Fig. 1. Fluorescence and SEM images of showerhead biofilm. (*A–C*) Epifluorescence microscopy of biofilm samples stained with DAPI; scale bars, 10 μm. (*D–F*) SEM micrographs of increasing magnification of in situ showerhead biofilm on the inner surface of one water distributor (Scale bars, 2 μm.)

ties were relatively simple (2–29 sequence types per site) and collectively comprised limited phylogenetic diversity. Although representatives of many bacterial phyla were detected (33/≈70 known phyla), most of the sequences were diverse representatives of only three phyla: *Actinobacteria*, *Proteobacteria*, and *Firmicutes* (GreenGenes taxonomy) (16). Less than 1% of sequences analyzed were archaeal or eukaryotic. At the depth of sequence analysis performed, approximately 90 to a few hundred sequences per sample, full survey of the more rare organisms was not anticipated. Nonetheless we sampled the most abundant sequences [>2/3 of species predicted by Chao 1 estimation, (17)] and so collectively these analyses provide an overview of the kinds of microbes expected to occur in showerheads.

Four sites were sampled 2–3 times over intervals of 2–12 months (see Dataset S2 for details) to test the temporal variability of the showerhead assemblages. In general, samples showed persistence of particular sequence types, although distributions varied between dates, perhaps an effect of patchiness in swab sampling (Fig. 2). In one case [showerhead BSK, a Denver Metro 1 showerhead sampled on three occasions (Fig. 2)], attempted cleaning with bleach solution resulted in a 3-fold increase in the load of *M. gordonae*, from approximately 25% of the assemblage sequences initially (BSK1Q) to 72% and 74% subsequently (BSK2Q and BSK3Q). Although anecdotal, this observation is interesting in light of the general resistance of mycobacteria to chlorine, which also may be one reason for the mycobacterial enrichment in municipal systems compared to well-water fed systems (discussed below).

The overall distributions of abundant (>0.5% of total) genus-level OTUs in municipal water and showerhead biofilms are summarized in Fig. 3*A*. The biofilm assemblages were comprised of ubiquitous water and soil microbial groups, some known for biofilm formation. Surprising, however, was the abundance of sequences indicative of *Mycobacterium* spp. in showerhead biofilms compared to feedwaters. As summarized in Fig. 3*B*, the sequences of the dominant mycobacteria corresponded mainly to those of *M. gordonae* and *M. avium*, which comprised respectively 10.5% and 9.1% of the total municipal showerhead sequences, and were the most common sequences observed. Mycobacteria are known to occur at low levels in municipal waters, and were observed in the analyzed showerhead feed waters (Fig. 3*C*). However, libraries from showerhead biofilms were highly enriched in these organisms, >100-fold above background water contents. Moreover, sequences representative of *M. avium*, of

Region	Sample ID	*Mycobacterium* spp.	*Methylobacterium* spp.	*Escherichia* spp.	*Blastomonas* spp.	*Pseudomonas* spp.	*Methylocystis* spp.	*Sphingomonas* spp.	*Staphylococcus* spp.	*Bacillus* spp.	*Rubrobacter* spp.	*Gloeobacter* spp.	*Streptococcus* spp.	*Bradyrhizobium* spp.	*Burkholderia* spp.	*Acinetobacter* spp.	*Neisseria* spp.	*Mastella* spp.	Other Genera*
Genus																			
% of Total†		28.1	21.7	5.2	4.1	3.8	2.9	2.7	2.0	1.8	1.8	1.3	1.0	0.9	0.8	0.6	0.6	0.5	20.2
		Heatmap by % of Library																	
New York City n=1304	NSG3Q	93.8	-	-	-	-	-	-	-	0.4	-	-	1.2	3.5	-	-	-	-	1.2
	¶ NSY2Q	86.0	7.5	-	-	-	-	-	-	1.1	-	-	-	3.2	-	-	-	-	2.2
	§ NSY1Q	79.2	1.6	1.6	3.2	4.8	-	0.8	-	-	-	-	-	-	-	-	-	-	8.8
	NSH3Q	36.1	13.1	13.1	-	1.6	-	4.9	4.9	-	-	-	3.3	-	-	-	4.9	-	18.0
	NSS3Q	35.6	12.3	19.2	-	1.4	-	-	2.7	1.4	-	-	2.7	-	-	-	2.7	-	21.9
	NSO3Q	16.0	16.0	4.0	-	-	-	-	-	4.0	-	-	20.0	-	-	8.0	-	-	32.0
	NSP3Q	15.1	7.0	9.3	-	5.8	-	1.2	4.7	1.2	-	1.2	4.7	-	-	-	10.5	-	39.5
	NSR3Q	10.0	-	34.3	-	1.4	-	2.9	1.4	2.9	-	-	2.9	-	-	2.9	1.4	-	40.0
	NST3Q	7.1	19.6	5.4	-	5.4	-	7.1	-	1.8	-	-	1.8	-	-	1.8	3.6	-	46.4
	NSX3Q	6.4	87.2	-	-	-	-	3.2	-	-	-	-	-	-	-	-	-	-	3.2
	NSN3Q	1.5	7.5	13.4	-	-	-	-	4.5	9.0	-	-	9.0	-	1.5	10.4	3.0	-	40.3
	NSK3Q	1.3	50.0	-	-	-	-	32.5	-	-	-	-	3.8	-	-	-	1.3	-	11.3
	NSW3Q	0.9	37.5	8.0	1.8	-	-	5.4	-	0.9	-	0.9	6.3	0.9	-	0.9	0.9	0.9	34.8
	NSV3Q	-	49.5	16.5	-	1.9	-	1.9	-	1.9	-	-	1.0	-	1.0	-	2.9	-	23.3
Denver Metro #1 n=674	BSE2Q	98.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.4
	‖ BSK3Q	74.3	-	-	17.1	-	-	1.4	-	-	-	-	-	1.4	-	-	-	1.4	4.3
	¶ BSK2Q	72.2	-	-	-	-	-	-	-	16.7	-	-	-	-	-	-	-	-	11.1
	BSF2Q	46.7	38.9	-	3.3	-	-	7.8	-	-	-	-	-	-	-	-	-	-	3.3
	BSC2Q	45.7	2.2	-	-	26.1	-	-	-	-	2.2	-	-	-	-	-	-	-	23.9
	§ BSK1Q	24.7	-	5.9	-	-	2.4	-	-	5.9	-	-	-	-	21.2	-	-	2.4	37.6
	¶ BSB3Q	21.7	21.7	1.4	23.2	-	-	8.7	-	-	-	-	-	-	-	-	-	-	23.2
	§ BSB2Q	11.5	2.6	-	10.3	21.8	2.6	1.3	-	9.0	-	-	1.3	-	2.6	-	-	-	37.2
	§ BSD2Q	4.8	-	4.8	16.1	-	30.6	-	-	9.7	-	-	-	-	-	-	-	1.6	32.3
	¶ BSD3Q	-	36.0	-	48.8	-	-	2.3	-	1.2	-	-	-	11.6	-	-	-	-	-
Denver Metro #2A n=399	BSL4Q	-	82.4	-	5.5	-	-	2.2	-	-	-	-	-	-	-	-	-	-	9.9
	BSN4Q	-	80.0	-	-	-	-	4.4	-	-	-	-	-	-	-	-	-	-	15.6
	URA1Q	-	-	-	-	74.4	-	-	-	2.3	-	-	-	-	-	-	-	-	23.3
	BSP4Q	40.2	10.3	-	-	1.1	-	1.1	-	-	-	-	-	6.9	-	-	-	1.1	39.1
	BSX3Q	4.5	48.9	-	4.5	8.0	3.4	8.0	-	2.3	-	-	-	1.1	2.3	-	-	-	17.0
Southern Colorado #1A n=326	DSW3Q	-	-	6.2	-	-	-	-	-	6.2	-	36.9	-	-	4.6	-	-	-	46.2
	DSV2Q	-	34.9	-	48.8	-	-	-	-	-	-	-	-	-	-	-	-	-	16.3
	DSG3Q	-	-	35.5	-	-	-	-	-	-	-	17.1	-	2.6	1.3	5.3	-	11.8	26.3
	DSJ3Q	-	1.0	35.4	-	3.0	-	3.0	45.5	1.0	-	2.0	-	-	-	-	-	-	9.1
Denver Metro #4 n=323	VSJ5Q	-	91.5	3.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5.3
	VSM5Q	47.1	11.8	5.9	2.4	-	-	2.4	3.5	-	-	-	1.2	-	-	-	-	-	25.9
	VSL5Q	19.7	5.3	5.3	-	-	-	5.3	3.9	23.7	-	9.2	-	2.6	-	2.6	1.3	-	21.1
	VSK5Q	19.1	4.4	20.6	4.4	-	-	1.5	1.5	-	-	1.5	-	-	-	1.5	-	7.4	38.2
Southern Colorado #1B‡ n=262	DSM1Q	-	-	-	-	-	45.5	1.5	-	-	-	-	-	-	-	-	-	-	53.0
	DSR2Q	-	2.9	-	-	-	70.6	-	-	-	-	-	-	-	-	-	-	-	26.5
	DSC2Q	-	81.9	-	-	-	-	-	-	3.2	-	-	-	-	3.2	2.1	-	-	9.6
Denver Metro #2B‡ n=147	BSS3Q	-	0.7	2.0	-	34.0	-	-	0.7	0.7	46.3	-	-	-	-	-	-	-	15.6
North Dakota n=134	NSF1Q	99.2	-	-	-	-	-	-	0.8	-	-	-	-	-	-	-	-	-	-
Illinois n=112	ISH1Q	68.8	0.9	-	-	-	-	-	6.3	-	-	-	0.9	-	-	2.7	-	-	20.5
Denver Metro #3 n=104	LSB3Q	3.6	65.8	-	4.5	5.4	0.9	4.5	0.9	1.8	-	-	0.9	-	-	-	-	-	11.7
Tennessee n=71	TSM1Q	21.1	4.2	-	-	-	-	12.7	2.8	-	-	-	-	-	-	-	-	-	59.2

Shade Key: 0% – 100%

Fig. 2. This heatmap-table summarizes the BLAST results for all showerhead swab libraries, pooled at the genus-level and grouped by municipality of origin. Genera representative by at least 0.5% of the total clones (>20 sequences) were included, for a total of 17 genera. Figure footnotes: *, "Other" is comprised of all genera representing less than 0.5% of total dataset; †, percent of total showerhead clones in study; ‡, showerhead fed by well water; §, signifies the first of multiple samples taken at the site as designated by the first three letters; ¶, signifies the second of multiple samples taken at the site; ‖, signifies the third of multiple samples taken at the site; –, signifies that clones representative of the genera were not detected in the sample.

particular note as an opportunistic pathogen, are enriched over those of *M. gordonae* in showerhead biofilms (Fig. 3*B*) compared to feed waters (Fig. 3*C*). The other minor microbial components that have been implicated in respiratory disease were all common water and soil organisms, including *Pseudomonas* spp. (3.8% of sequences), *Sphingomonas* spp. (2.7%), *Staphylococcus* spp. (2.0%), *Streptococcus* spp. (1%), *Burkholderia* spp. (0.8%), *Neisseria* spp. (0.6%), *Acinetobacter* spp. (0.6%), and *Legionella* spp. (0.1%) (Dataset S1 for details).

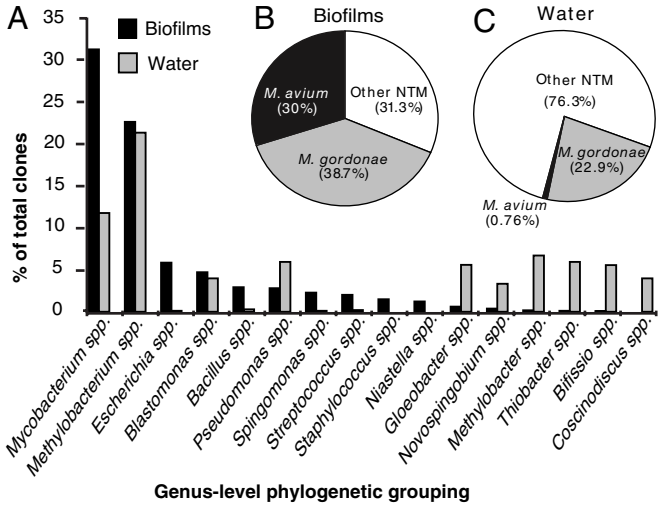


Fig. 3. Comparison of the diversity of abundant sequences from swab biofilm and water samples collected from sites supplied by treated municipal water, private well water supplied sites were excluded from this analysis. (*A*) A comparative histogram of the most abundant swab and water genera identified by BLAST. The total number of sequences for municipal biofilms was $n = 3{,}454$, for municipal water $n = 1{,}146$. (*B*) Pie chart of mycobacterial sequences ($n = 1{,}051$) identified in showerhead biofilm samples. (*C*) Pie chart of mycobacterial sequences ($n = 131$) from water samples.

Sequences indicative of *M. avium*, the most noteworthy potential pathogen detected, were identified in 20% of showerhead swabs overall, with an average density of 32% of the library when observed. Sequenced mycobacterial genomes contain only single copies of rRNA genes, so the frequency of mycobacterial rRNA genes in the assemblages represents a minimal contribution to the observed organismal abundances. The bacterial species *M. avium* is comprised of several extremely closely related subspecies, including *M. avium hominissuis*, *M. avium avium*, *M. avium paratuberculosis* and others, which are not discriminated by rRNA sequences (18). To verify that the sequences belonged to microbes of the *M. avium* complex to the exclusion of other NTMs, we amplified and sequenced several rRNA internal transcribed spacers (ITS), and compared those to known *M. avium* sequences from clinical and environmental isolates. ITS sequences are highly variable and consequently afford better differentiation of organisms represented by the sequences (18, 19). Showerhead *M. avium* sequences clustered phylogenetically with those of known environmental and clinical isolates of *M. avium* (Fig. S1). Twenty-eight of 49 (57%) of the ITS sequences analyzed were identical to those of clinical isolates from NTM disease. Clearly, showerhead biofilms pose an enriched exposure to this recognized opportunistic pathogen.

Although *M. avium* was commonly encountered, many samples were negative for this organism, either because the organism was not present or because it is less abundant than others and not detected because sequence analysis samples only the most abundant microbial species. To test the possibility that *M. avium* was present in samples that were negative by sequence analysis, we used quantitative PCR (Q-PCR) with *M. avium*-specific primers to screen DNAs from 32 biofilm and 14 water sources. Q-PCR identified *M. avium* DNA in 25 of 32 (78%) swab extracts tested, including 20 in which *M. avium* was not encountered in the rRNA gene libraries (Dataset S3). Although *M. avium* was encountered only rarely among 16S rRNA sequences determined from water samples (Fig. 3), Q-PCR detected that organism in 13 of 14 water samples tested from Denver and New York metropolitan systems (Dataset S3).

The opportunistic pathogen *L. pneumophila*, the cause of Legionnaire's Disease, receives much popular attention, but sequences indicative of that organism were encountered only rarely in this survey (only 3/≈6,000 sequences determined). *L. pneumophila* constitutes a broad relatedness group, however, so detection of a representative of the group does not indicate a pathogen. Because of the potential human health implication of this detection, we conducted quantitative PCR (QPCR) assays with a *L. pneumophila*-specific primer pair that targets a pathogenesis gene, the macrophage infectivity potentiator (mip) gene (20–24), to screen a subset of samples. Thirty-six samples (16 water and 20 swabs, representing 10 cities) were tested in duplicate reactions, including samples with positive *L. pneumophila* detection by sequence. The *L. pneumophila* mip gene was not detected in any sample at a sensitivity of 0.5 copies/μL of DNA extract.

Microbial Constituents of Shower Aerosols. Showerhead biofilms and water are potential sources of aerosolized microorganisms. However, different microbes and biofilms have different qualities that can influence partitioning into aerosols. Indeed, we and others have shown that mycobacteria can be selectively aerosolized, possibly a consequence of their waxy, hydrophobic quality (3, 25). To determine the makeup of shower aerosol microbiology, we collected aerosols during 20-min unoccupied shower operations with three showerheads analyzed rRNA gene sequences and compared them with biofilm, water, and ambient bathroom air samples. Microbial constituents were reflective of feedwaters and not biofilm. It seems possible, however, that any initial pulse of biofilm components would have been extensively diluted by water delivered during the aerosol collection period, and so not detected.

Well-Water vs. Municipal-Supplied Showerhead Biofilms. Most of the samples analyzed were supplied by municipal water distribution systems, but we included four homes supplied by private water wells. The microbial compositions of well-water biofilms were distinct from those associated with municipal waters, and no mycobacteria were detected. Three of the systems examined were supplied by individual water wells in Southwestern Colorado overlying the San Juan Basin's Fruitland coal formation. Oil and gas drilling have been implicated in increased methane and chemical release into the aquifers that overlie the coal beds (26). Both water and showerhead biofilm libraries from these homes showed an abundance of sequences closely related to bacterial genera such as *Methylocystis* spp. (10% of biofilm and water clones from these three sites), *Methylobacteria* spp. (8.1%), *Methylomicrobium* spp. (5.2%), and other close relatives of known methane and methanol metabolizing organisms (27). These results indicate that microbial analysis can provide insight into local groundwater geochemistry.

Discussion

In our daily lives, we humans move through a sea of microbial life that is seldom perceived except in the context of potential disease and decay. Indoor air typically has approximately 10^6 bacteria per m^3; municipal tap water usually contains at least 10^7 bacteria per L. Little is known about the nature of these microbial populations, but they are expected to derive from both human traffic and microbial ecosystems that happen to be enriched by the character of the particular setting, in this case the showerhead biofilm ecotope.

The majority of showerhead microbiota encountered in our survey is composed of genus- or species-level relatedness groups that are commonly found in water and soil. The showerhead environment strongly enriches for microbes that are known to form biofilms in water systems, including *Mycobacterium* spp., *Sphingomonas* spp., *Methylobacterium* spp. and others (Fig. 3 and Dataset S1). Particularly, the enrichment and prevalence of

mycobacteria were unexpected. Mycobacteria were detected in clone libraries or by QPCR in most showerheads fed by municipal water systems (Dataset S3).

The detection of significant loads of *M. avium* in many showerhead biofilms identifies a potential personal health concern. The reasons for the enrichment of mycobacteria are not clear. Mycobacteria readily form biofilms and, because of their generally waxy quality, may be particularly resistant to shear forces generated in shower operation (28–36). Furthermore, many species of biofilm-forming mycobacteria are chlorine-resistant, and thus potentially can be enriched by chlorine disinfection protocols used by many municipalities (28, 29, 34, 37, 38). Consistent with this, we only observed mycobacterial rRNA gene sequences in municipal water systems, not in untreated well water systems.

The occurrence of *M. avium* in showerhead biofilms raises the question of exposure. Does shower usage increase risk for NTM disease? At this time there are no epidemiological data with which to assess risk for NTM infections. However, *M. avium* and other NTM can cause pulmonary disease in healthy people, as well as those predisposed to pulmonary infection. In many centers, NTM now outnumber *M. tuberculosis* detections in clinical mycobacteriology labs (39, 40). Risk factors associated with NTM pulmonary infection include smoking, chronic lung disease, alcoholism, and pulmonary or immune genetic defects (5, 40). Diagnoses of disseminated NTM infections of the blood, lymph, bone, skin or other tissues have increased, especially in immune compromised populations such as HIV/AIDS and transplant patients (5, 40–42). Moreover, a few recent studies have shown a link between pulmonary *M. avium* infections and home showerhead water microbiology (10, 12). *M. avium* and other NTM infection rates are on the rise throughout the developed world (5, 39) and have been hypothesized to correlate with increased exposure to aerosolized microbes through increased use of showers rather than bathing (5). Thus, shower usage possibly is contraindicated for individuals with compromised immune or pulmonary systems, an issue that needs evaluation in these populations.

This study is a culture-independent molecular survey of the nature of showerhead microbiology. The finding that NTM are abundant and prevalent in showerhead biofilm assemblages points to one clear source of opportunistic pathogens known for pulmonary disease. Many home and public devices, such as humidifiers and evaporative cooling units, also produce moist aerosols that likely disperse microorganisms associated with the particular system. Little is known about the microbiology of such settings, which we commonly encounter in daily life. We conclude that there is need for further epidemiological investigations of potential sources of NTM infections, including showerheads. The methods we use here provide an experimental approach for such investigations.

Materials and Methods

Sample Collection. Showerhead swab samples were collected between May 2006 and January 2008 from homes, apartment buildings, and public buildings in Colorado (Southwestern Colorado city #1, and four Denver-Metro Cities #1–4), Illinois (IL), Tennessee (TN), North Dakota (ND), and New York City (NYC). Sampling and site data are presented in online Dataset S2. A total of 52 samples from 45 sites were analyzed (see Dataset S2). Following removal and disassembly of the showerhead, sterile swabs were used to wipe biofilm from the inner surface. Swabs were stored in 70% ethanol until DNA extraction. Water samples were collected in new sterile 1-L Nalge bottles and stored at 4 °C until filtration (0–5 h). Water (≈1 L) was filtered through a 0.2-μL polycarbonate filter (Isopore™ Membrane Filters, Millipore) and the filter processed for DNA as described below with the addition of 500 μL chloroform to dissolve the filter.

Aerosol Sample Collection. Before collection of air samples, the shower stall was washed with a 10% bleach solution and a new vinyl shower curtain was hung to minimize aerosols from dislodged biofilms of these surfaces. A specially designed OMNI 3000 air sampler (Evogen Inc.) with UV-sterilized contactor and virgin tubing and cartridges was used to collect shower aerosol samples. The OMNI sampled for 20 min at approximately 270 L/min at the outside periphery of the shower at approximately 2-m high (high enough to place the intake above the shower curtain), impinging into a sterile solution of 1× PBS and 0.005% Tween. Two 20-min air samples were collected: the ambient bathroom air, and then a sample with the shower running at a warm temperature. Aerosol samples were filtered and processed in the same manner as the water samples.

Additional Sample Details. Dataset S4 shows all observed sequence types for water samples, and Dataset S5 shows a comparison of water, biofilm swab, and ambient bathroom air samples.

PCR Amplification of rDNA. DNA was extracted from the cotton tips of the swabs (biofilm samples), or from polycarbonate filters (water and aerosol samples) using a bead beating protocol as previously described (43). DNA extracts were amplified with the universally conserved 16S rRNA primers 515F (5′-GTGCCAGCMGCCGCGGTAA-3′) and 1391R (5′-GACGGGCGGTGWGTRCA-3′) or bacterially conserved 8F (5′-AGAGTTTGATCCTGGCTCAG-3′) (44) and 338R (5′-CTGCTGCCTCCCGTAGGAGT-3′) (45). PCR Reactions were conducted at 94 °C for 2 min, followed by 30 cycles at 94 °C for 20 s, 52 °C for 20 s, and 65 °C for 1:30 min, followed by a 65 °C elongation step for 10 min. Each 25-μL reaction contained 10 μL Eppendorf 2.5× HotMasterMix (Eppendorf), 10 μL water, 0.05% BSA (Sigma-Aldrich), 100 ng of each oligonucleotide primer, and 1–5 ng of DNA template. Triplicate PCR products were pooled before purification and cloning. Individual PCR-amplified rRNA genes were isolated by cloning with Topo-TA as per manufacturer's instructions (Invitrogen) and collected into libraries of 96 randomly chosen clones. DNA preparation and sequencing was performed as previously described (46).

ITS Gene Sequencing. Samples identified to contain *M. avium* were used as template for *Mycobacterium* spp.-specific amplification of the 16S-23S rRNA ITS sequence using Myco1121F primer (5′-CATGTTGCCAGCRGGTA-ATGCCGGG-3′) or Myco 1432F primer (5′-GAAGCCRGTGGCCTAACC-3′) and universal 23S rRNA primer 130R (5′-GGGTTBCCCCATTCGG-3′) (44). Myco1121F and Myco1432F were designed using the ARB software package to identify regions conserved across the non-tuberculosis mycobacterial sequences of interest, and synthesized by IDT (Integrated DNA Technologies). PCR, cloning and sequencing was performed as described above. Phylogenetic analysis was performed by comparison of unknown ITS gene sequences to genes of known *Mycobacteria* in an ARB (http://www.mpibremen.de/ARB.html) database (47).

Phylogenetic Analysis. Sequences initially were compared to other known small subunit rRNA (SSU rRNA) gene sequences in the National Center for Biotechnology Information (NCBI) database through use of the Basic Local Alignment Search Tool (BLAST) (48) using the program XplorSeq (49). A total of 6,090 swab and water 16S, and 52 MAC ITS DNA sequences generated in this study have been deposited in GenBank with accession numbers EU629353–EU635442, and EU697021–EU697072. 16s sequences with low bit scores (<500) or shorter than 300 base pairs were excluded from the analysis; of 6,090 total sequences, 5,745 were used.

Quantitative PCR. Quantitative PCR was conducted using MAC-specific, *Legionellae*-specific and *L. pneumophila* mip (*L.p.*-mip) gene SYBR Green (ABI Biosciences) assays, to determine the prevalence of *M. avium*, *Legionellae*, and *L. pneumophila* throughout the sample set, including those samples in which the species were not represented in the 16S library. Q-PCR was performed on a DNA Engine Opticon System (MJ Research) in 25-μL reaction volumes composed of 12.5 μL SYBR Green, 25 ng each primer, 0.4 μL 10× BSA, 8.6 μL water, and 1.5 μL DNA, the *Legionellae* and *L.p.*-mip reaction mixtures excluded BSA. Sample DNAs were diluted 1:5 before amplification for the MAC assays, and full concentration for the *L.p.*-mip assay.

MAV-specific analysis was conducted with bacteria-specific primer 8F (5′-AGAGTTTGATCCTGGCTCAG-3′) (44) and MAV-specific primer MAV199R (5′-ACCAGAAGACATGCGTCTTG-3′) (Degroote MA, and NRP). For the MAV-assay, a deletion plasmid (MAP- 8FΔ) was constructed with a 40 base pair deletion in positions 28–68 at the 5′ end of the *M. avium* subsp. *paratuberculosis* 16S rRNA gene (Degroote, MA, and NRP). The plasmid was amplified, and cloned into TOPO-4 vector, then screened by agarose gel electrophoresis to verify the deletion. Sequencing of the insert was performed to verify that the correct region was amplified. *E. coli* cells containing the cloned deletion plasmid grew overnight in 2× yeast-tryptone

broth containing 0.1 mM ampicillin, and were purified with a QiaFilter Plasmid Maxi Kit (QIAGEN). Plasmid concentration was quantified with spectrofluorometry and serially diluted from 10^7 to 1 copies. The MAV-specific QPCR assay included an initial denaturation step of 94 °C for 10 min was followed by 45 cycles of 94 °C for 15 s, 60 °C for 45 s, a fluorescence read, then 1 s at 80 °C, and a second plate read.

Legionella-specific primers were Leg448F (5′-GAGGGTTGATAGGTTAA-GAGC-3′) (50) and Leg880R (5′-GGTCAACTTATCGCGTTTGCT-3′) (51). *L. pneumophila* primers were Lp-mip-PT69 (5′- GCA TTG GTG CCG ATT TGG- 3′) and Lp-mip-PT70 (5′- GYT TTG CCA TCA AAT CTT TCT (52). Standards for the *Legionella* and *L.p.*−mip assay were generated with DNA extracted from a plate scrape of *L. pneumophila* subsp. *pneumophila* strain Philadelphia-1, ATCC 33152. The genes were amplified, cloned into TOPO-4 vector, purified, and quantified as described above. The *Legionella*-specific QPCR cycling was as follows 94 °C for 10 min, 45 cycles of 94 °C for 15 s, 52 °C for 15 s, and 65 °C for 30 s, a fluorescence read, then 1 s at 80 °C, and a second plate read. *L.p.*-mip-specific QPCR cycling was as above except the annealing temperature was 58 °C and the second plate read was at 75 °C.

Duplicate Q-PCR reactions were performed on each sample and for each primer set tested. Copy numbers were adjusted to account for the 1:5 dilution (when applicable) and baseline and blank subtracted. Samples with >0.5 copies/μL of DNA extract were considered ''positive.'' A melting curve was used in all assays to ensure specificity of amplification. Data from the second plate reads were used for quantitation.

Microscopy. Fluorescence and SEM microscopy were used to visualize showerhead biofilm microbes. Fluorescence microscopy entailed wiping the inner surface of a showerhead with a sterile swab, then rolling the swab into 100 μL of 1$\times$ TE on a glass slide. Slides were then heat fixed and stained with 10 μg 4,6-diamidino-2-phenylindole (DAPI; Sigma). Epiflourescence microscopy was performed on a Nikon Eclipse E600 microscope (Nikon Instruments Inc.). SEM was carried out on several biofilms in situ on the showerhead surface. Preparation for SEM entailed disassembly and fragmentation of the plastic showerhead distributor, fixation in a 2% glutaraldehyde solution in sodium cacodylate buffer for 1 h, then soaking in a 1% osmium tetroxide, 20% acetone solution for 30 min. Samples were desiccated by ethanol series dehydration (15 min in each 30% and 70%, and 45 min in 100% ethanol), affixed to microscope stubs with double-sided carbon conductive tape and colloidial silver liquid, then sputter coated with approximately 5 nm of gold/palladium using a Cressington 108Auto Sputter Coater (Cressington Scientific Instruments). Microscopy was performed on a JEOL JSM-6480 LV-SEM (JEOL).

ACKNOWLEDGMENTS. We thank Dr. Marcel Behr for advice on *M. avium* taxonomy, Thomas Giddings for his invaluable assistance with the SEM, the students of Spring 2006 MCDB 4110 at the University of Colorado at Boulder for their initial efforts on this research, Ray Grunzinger for the collection of many showerhead swab samples, and the multiple people and institutions that allowed us access to their showerheads. This work was supported by grants from the Alfred P. Sloan Foundation and the National Institute of Occupational Safety and Health to N.R.P.

1. Zhou Y, Benson JM, Irvin C, Irshad H, Cheng YS (2007) Particle size distribution and inhalation dose of shower water under selected operating conditions. *Inhal Toxicol* 19:333–342.
2. Thorn J (2001) The inflammatory response in humans after inhalation of bacterial endotoxin: A review. *Inflamm Res* 50:254–261.
3. Falkinham JO, 3rd (2003) Mycobacterial aerosols and respiratory disease. *Emerg Infect Dis* 9:763–767.
4. Marras TK, et al. (2005) Hypersensitivity pneumonitis reaction to *Mycobacterium avium* in household water. *Chest* 127:664–671.
5. O'Brien DP, Currie BJ, Krause VL (2000) Nontuberculous mycobacterial disease in northern Australia: A case series and review of the literature. *Clin Infect Dis* 31:958–967.
6. Exner M, et al. (2005) Prevention and control of health care-associated waterborne infections in health care facilities. *Am J Infect Control* 33:S26–40.
7. Bollin GE, Plouffe JF, Para MF, Hackman B (1985) Aerosols containing *Legionella pneumophila* generated by shower heads and hot-water faucets. *Appl Environ Microbiol* 50:1128–1131.
8. Alary M, Joly JR (1991) Risk factors for contamination of domestic hot water systems by legionellae. *Appl Environ Microbiol* 57:2360–2367.
9. Pedro-Botet ML, Stout JE, Yu VL (2002) Legionnaires' disease contracted from patient homes: the coming of the third plague? *Eur J Clin Microbiol Infect Dis* 21:699–705.
10. Falkinham JO, Iseman MD, Haas P, Soolingen D (2008) *Mycobacterium avium* in a shower linked to pulmonary disease. *J Water Health* 6:209–213.
11. Shin JH, et al. (2007) Prevalence of non-tuberculous mycobacteria in a hospital environment. *J Hosp Infect* 65:143–148.
12. Nishiuchi Y, et al. (2007) The recovery of *Mycobacterium avium*-intracellulare complex (MAC) from the residential bathrooms of patients with pulmonary MAC. *Clin Infect Dis* 45:347–351.
13. Jannasch HW Jones GE (1959) Bacterial populations in sea water as determined by different methods of enumeration. *Limnol Oceanogr* 4:128–139.
14. Pace NR (1997) A molecular view of microbial diversity and the biosphere. *Science* 276:734–740.
15. Stackebrandt E, Goebel BM (1994) Taxonomic note: A place for DNA-DNA reassociation and 16S rRNA sequence analysis in the present species definition in bacteriology. *Int J Syst Bacteriol* 44:846–849.
16. DeSantis TZ, et al. (2006) NAST: A multiple sequence alignment server for comparative analysis of 16S rRNA genes. *Nucleic Acids Res* 34:W394–399.
17. Chao A, Lee SM (1992) Estimating the number of classes via sample coverage. *J Am Stat Assoc* 87:210–217.
18. Turenne CY, Wallace R, Jr, Behr MA, (2007) *Mycobacterium avium* in the postgenomic era. *Clin Microbiol Rev* 20:205–229.
19. Roth A, et al. (1998) Differentiation of phylogenetically related slowly growing mycobacteria based on 16S–23S rRNA gene internal transcribed spacer sequences. *J Clin Microbiol* 36:139–147.
20. Cianciotto NP, Eisenstein BI, Mody CH, Toews GB, Engleberg NC (1989) A *Legionella pneumophila* gene encoding a species-specific surface protein potentiates initiation of intracellular infection. *Infect Immun* 57:1255–1262.
21. Cianciotto NP, Fields BS (1992) *Legionella pneumophila* mip gene potentiates intracellular infection of protozoa and human macrophages. *Proc Natl Acad Sci USA* 89:5188–5191.
22. Cianciotto NP, Stamos JK, Kamp DW (1995) Infectivity of *Legionella pneumophila* mip mutant for alveolar epithelial cells. *Curr Microbiol* 30:247–250.
23. Helbig JH, et al. (2003) The PPIase active site of *Legionella pneumophila* Mip protein is involved in the infection of eukaryotic host cells. *Biol Chem* 384:125–137.
24. Swanson MS, Hammer BK (2000) *Legionella pneumophila* pathogenesis: A fateful journey from amoebae to macrophages. *Annu Rev Microbiol* 54:567–613.
25. Angenent LT, Kelley ST, St Amand A, Pace NR, Hernandez MT (2005) Molecular identification of potential pathogens in water and air of a hospital therapy pool. *Proc Natl Acad Sci USA* 102:4860–4865.
26. Beckstrom JA, Boyer DG (1993) Aquifer-protection considerations of coalbed methane development in the San Juan basin. *SPE Form Eval* 8:71–79.
27. Hanson RS, Hanson TE (1996) Methanotrophic bacteria. *Microbiol Rev* 60:439–471.
28. Steed KA, Falkinham JO, 3rd (2006) Effect of growth in biofilms on chlorine susceptibility of *Mycobacterium avium* and *Mycobacterium intracellulare*. *Appl Environ Microbiol* 72:4007–4011.
29. Norton CD, LeChevallier MW, Falkinham JO, 3rd (2004) Survival of *Mycobacterium avium* in a model distribution system. *Water Res* 38:1457–1466.
30. Lehtola MJ, et al. (2007) Survival of *Mycobacterium avium*, *Legionella pneumophila*, *Escherichia coli*, and caliciviruses in drinking water-associated biofilms grown under high-shear turbulent flow. *Appl Environ Microbiol* 73:2854–2859.
31. Williams MM, et al. (2009) Structural analysis of biofilm formation by rapidly and slowly growing nontuberculosis mycobacteria. *Appl Environ Microbiol* 75:2091–2098.
32. Vaerewijck MJ, Huys G, Palomino JC, Swings J, Portaels F (2005) Mycobacteria in drinking water distribution systems: Ecology and significance for human health. *FEMS Microbiol Rev* 29:911–934.
33. Le Dantec C, et al. (2002) Occurrence of mycobacteria in water treatment lines and in water distribution systems. *Appl Environ Microbiol* 68:5318–5325.
34. Hilborn ED, et al. (2006) Persistence of nontuberculous mycobacteria in a drinking water system after addition of filtration treatment. *Appl Environ Microbiol* 72:5864–5869.
35. Falkinham JO (2003) The changing pattern of nontuberculous mycobacterial disease. *Can J* Infect Dis 14:281–286.
36. Szewzyk U, Szewzyk R, Manz W, Schleifer KH (2000) Microbiological safety of drinking water. *Annu Rev Microbiol* 54:81–127.
37. Hilborn ED, et al. (2008) Molecular comparison of *Mycobacterium avium* isolates from clinical and environmental sources. *Appl Environ Microbiol* 74:4966–4968.
38. Falkinham JO, 3rd, Norton CD, LeChevallier MW (2001) Factors influencing numbers of *Mycobacterium avium*, *Mycobacterium intracellulare*, and other Mycobacteria in drinking water distribution systems. *Appl Environ Microbiol* 67:1225–1231.
39. Field SK, Fisher D, Cowie RL (2004) *Mycobacterium avium* complex pulmonary disease in patients without HIV infection. *Chest* 126:566–581.
40. Heifets L (2004) Mycobacterial infections caused by nontuberculosis mycobacteria. *Semin Respir Crit Care Med* 25:283–295.
41. Suffys P, et al. (2006) Detection of mixed infections with *Mycobacterium lentiflavum* and *Mycobacterium avium* by molecular genotyping methods. *J Med Microbiol* 55:127–131.
42. Khan K, Wang J, Marras TK (2007) Nontuberculous mycobacterial sensitization in the United States: National trends over three decades. *Am J Respir Crit Care Med* 176:306–313.
43. Dalby AB, Frank DN, St Amand AL, Bendele AM, Pace NR (2006) Culture-independent analysis of indomethacin-induced alterations in the rat gastrointestinal microbiota. *Appl Environ Microbiol* 72:6707–6715.
44. Lane DJ (1991) 16S/23S rRNA sequencing. In *Nucleic Acid Techniques in Bacterial Systematics*, eds Stackenbrandt E, Goodfellow M (John Wiley & Sons, Chichester, England), pp 115–176.
45. Suzuki MT, Giovannoni SJ (1996) Bias caused by template annealing in the amplification of mixtures of 16S rRNA genes by PCR. *Appl Environ Microbiol* 62:625–630.

46. Frank DN, St Amand AL, Feldman RA, Boedeker EC, Harpaz N, Pace NR (2007) Molecular-phylogenetic characterization of microbial community imbalances in human inflammatory bowel diseases. *Proc Natl Acad Sci USA* 104:13780–13785.
47. Ludwig W, et al. (2004) ARB: A software environment for sequence data. *Nucleic Acids Res* 32:1363–1371.
48. Altschul SF, Gish W, Miller W, Myers EW, Lipman DJ (1990) Basic local alignment search tool. *J Mol Biol* 215:403–410.
49. Frank DN (2008) XplorSeq: A software environment for integrated management and phylogenetic analysis of metagenomic sequence data. *BMC Bioinformatics* 9:420.
50. Miyamoto H, et al. (1997) Development of a new seminested PCR method for detection of *Legionella* species and its application to surveillance of legionellae in hospital cooling tower water. *Appl Environ Microbiol* 63:2489–2494.
51. Chang B, et al. (2008) Specific detection of viable Legionella cells by combined use of photoactivated ethidium monoazide and PCR/real-time PCR. *Appl Environ Microbiol* 75:147–153.
52. Wellinghausen N, Frost C, Marre R (2001) Detection of legionellae in hospital water samples by quantitative real-time LightCycler PCR. *Appl Environ Microbiol* 67:3985–3993.

Sample showerhead disinfection procedure

Showers deliver water at approximately 45°C which is an ideal temperature for pathogens to proliferate. Showerheads act as filters trapping debris and scale which can be used by bacteria both as a nutrient and a safe habitat. When water stagnates bacteria are allowed to multiply. Cleaning and disinfecting showerheads on a regular basis removes both the nutrients and habitat required by bacteria, thus minimising the risk of any legionella bacteria which may be present in the water from multiplying.

Procedures

Following the guidance in HSE (L8) Approved Code of Practice and Guidance (Legionnaires' disease - The Control of Legionella Bacteria in Water Systems), quarterly cleaning of showerheads should take place as part of any effective management system. Cleaning and disinfection is a fundamental component of controlling Legionella bacteria and should be a central part of a suitable and sufficient management system. In order to effectively cleanse and disinfect showerheads and hoses, a three stage procedure should be adopted, as detailed below.

Employers are required to carry out a suitable and sufficient Risk Assessment and Control of Substances Hazardous to Health (COSHH) Assessment for this work activity, prior to exposing anyone to the associated risks.

Method

Stage 1 - Clean/De-scale

Remove and disassemble the shower heads and hoses from one another.

1. De-scale the shower heads and hoses using a proprietary de-scaling agent for 1 hour (or to manufacturer's instruction).
2. Dispose of the waste water safely and in accordance with environmental protection guidance.
3. Flush the showerheads and hoses through with clean water.

Stage 2 - Disinfect

1. Immerse the shower heads and hoses in an approved biocide solution (50mg/l hypochlorite solution, (e.g. "Titan Sanitiser" (Johnson Diversey), "Shower Head Plus" (Water Treatment Products), or other approved disinfectant that has an equivalent proven biocidal effect), at the appropriate concentration and for the appropriate amount of time - following the manufacturers instructions.
2. Dispose of the waste water safely and in accordance with environmental protection guidance.

Stage 3 - Flush

1. Flush and wash the shower heads and hoses through with clean water and replace.

2. Dispose of the waste water safely and in accordance with environmental protection guidance.
3. Replace soft rubber or plastic washers or gaskets with neoprene or other approved rubber substitutes.

Under no circumstances should any acidic cleaning fluids or other acid products be added to any solution. Such action will release toxic chlorine gas from the solution, with the potential to cause a risk of explosion, respiratory failure and potential death. A COSHH assessment must be carried out before any hazardous substances are used and a Safe Operating Procedure (SOP) devised.

Contact details

Food, Health and Safety

Perth & Kinross Council

Pullar House

35 Kinnoull Street

Perth

PH1 5GD

01738 476476

foodhealthandsafety@pkc.gov.uk

online enquiry form

See full contact details

How to Clean a Sauna

Traditional Scandinavian saunas are usually small rooms made with wooden benches onto which one can sit and have posts where one can place their feet. Steam within the sauna rises to the top and is so hot that it virtually sterilizes all bacteria that it comes in contact with. But just because the environment of the sauna is sterile does not mean that it is clean! Dead skin cells and sweat can be found around every square inch, so it is very important that one maintains the sauna on a regular basis. Proper maintenance of your sauna can be attained by following the steps listed below.

Steps

1 **All Saunas have a drain underneath the seating.** Usually a hose can literally be dragged into the sauna and it can be hosed down and washed with mild soap that will not irritate the skin. When washing the Sauna one should concentrate their focus on areas where peoples skin comes into direct contact with the sauna, such as on the sides of the walls where people lean or where they may post their feet.

2 **When washing the sauna hose down first, then wash with soap and a gentle abrasive to cleave all the dirt and dead cells off of the wood.** It is probably a good idea to dilute the detergent in a bucket of water, the idea here again is not to sterilize but rather just to wash away debris.

3 **After a good scrub, rinse well with water and the sauna should be as good as new.**

4 **For a single family home, the sauna should be maintained according to this wash protocol only a few times a year depending on usage.** It is common practice to hose down the sauna after every use by throwing buckets of water here and there.

Tips

- In Scandinavian countries it is not usual practice to wash the sauna, but rather accompany oneself with the proper equipment to prevent contamination of the sauna. After enjoying a hot sauna, Europeans prefer to rather wash themselves well instead of their sauna.
- Many saunas have a hose or keep buckets of water with which to rinse the seats after use.
- To ensure that your sauna remains clean, it is a good idea to have guests accompany themselves into the sauna with seating towels on which they can sit. It may also be a good idea to place a towel on the top of any post where the feet can be rested. It is much less work to wash a few towels than it is to have to wash your sauna.

Warnings

- Be sure to do a bit of research as to which soap agent is the best for your particular type of sauna. You want to avoid harsh volatile chemicals such as bleach or ammonium which may seep into wood and vaporize at high temperatures when the sauna is in use. Be sure to avoid chemicals which may irritate your skin as well. It is not common practice to wash the sauna. Wash your body and feet well after the sauna instead.

LIVESTRONG.COM

Sauna Cleaning Requirements

Last Updated: Jun 05, 2010 | By Chris Sherwood

Photo Caption Keeping your sauna clean Photo Credit sauna image by Andrejs Pidjass from Fotolia.com (http://www.fotolia.com)

Saunas employ dry or steam heat to provide relaxing and therapeutic effects on the body. Over time a sauna can build up dirt and grime and may even foster the growth of mold or mildew. To prevent your sauna from becoming unusable, clean it every few weeks or more, depending on how often you use it.

Floor

The warm, moist environment of many saunas can foster the growth of bacteria on the floor and other surfaces of the sauna. These bacteria include tinea pedis, more commonly known as athlete's foot, states the Mayo Clinic. Public saunas can also spread the bacteria Staphylococcus aureus, which can cause serious skin staph infections, including the deadly methicillin-resistant Staphylococcus aureus--MRSA--according to the Centers for Disease Control and Prevention.

To prevent these infections from spreading, regularly sweep and mop the sauna floor using a household floor cleaner or a water and bleach solution. Let the floor dry and the sauna air out before continuing use.

Benches

Benches in a sauna should also be routinely cleaned, especially if you regularly use your sauna without clothing. Because the benches of a sauna are made of soft wood, do not use regular household cleaning products; clean your benches using a solution of water and mild detergent. Commercial sauna-cleaning products, made specifically to be safe for sauna surfaces, are available online and through sauna dealers.

Sitting or lying on towels can help reduce the amount of cleaning needed, as towels create a barrier against body sweat, which can stain the wood of your sauna. If sweat marks become a serious problem, the

Finlandia Sauna Products Corp. recommends using a sandpaper with 120 grit to lightly sand the sweat stains from the wood.

Stones

When using a sauna with heating stones, clean them if they begin to emit any unusual or unpleasant smells. Wash the rocks using a mild cleanser and soap and allow them to dry completely before placing them back in the sauna. Replace any cracked stones or stones that continue to smell after cleaning. You can use any stones in a sauna; rough-edged peridotite and olivine stones are popular choices available at most sauna dealers.

Other Surfaces

Clean other surfaces of your sauna periodically with a solution of water and mild detergent. These surfaces include the sauna walls, door handles, operational switches and the heater. When cleaning the heater be sure that the unit has completely cooled to prevent burns. Wood-burning heaters require additional maintenance including the regular removal of ashes. Hire a professional chimney cleaner to clean creosote in the exhaust pipe of a wood sauna to reduce fire dangers.

Cleaning and Sanitizing your Home Sauna Keeps it Fresh and Healthy

Written by Mike Nekahi

Sauna Cleaning

If you haven't tried sauna, it is likely that you don't appreciate what a delightful and refreshing activity it can be. This can be a little hard for the uninitiated to accept; after all, aren't you just sitting in a very hot box and sweating?

Well, yes, that really is about all there is to sauna, at the same time there is so much more! Many cultures that live in the higher latitudes indulge in some sort of sweat bathing. The North American Indians enjoy the sweat lodge. The Japanese have a long tradition of bathing in very hot natural hot springs. Many Russians enjoy time in the banya, a type of public steam bath.

Traditional Finnish sauna shares elements of these other traditions, but adds some of its own twists. There are certainly public saunas throughout Finland, but sauna is also enjoyed privately, in the comfort of the home. The sauna is such an important part of Finnish culture that many women prefer to deliver their babies in the comfort of the family sauna.

Part of this is because the sauna is an almost holy place, but it is also usually the cleanest part of the home. The sauna is a place where sweaty, naked people congregate, so obviously there are some hygiene issues that must be addressed.

Keeping the sauna sanitary is a much simpler commitment than is required for other recreational bathing systems. Hot tubs, swimming pools, and steam baths are all not only warm, but also moist, which can be an ideal environment for all sorts of nasty bacteria to grow. Because sauna is much drier, it is harder for the bacteria to take hold.

But it is not completely dry, so there can be some danger. For the most part, keeping your sauna sanitary is simple house keeping. This is obviously much easier to accomplish with a home sauna than the one found at the gym or the health club.

Between uses, take a couple minutes to dust and sweep the inside of the sauna. Once in a while it is a good idea to gently wash the floor with a mild bleach solution or a commercial sauna cleaning agent from the pool supply store.

Occasionally it will be necessary to wash the boards of the benches and walls with a mild detergent. Afterwards, wipe the wood down with clean water, dry with a towel, and allow to air dry. One way to make this necessary less often is to insist that sauna users sit on a towel, which provides a barrier between the wood and the oils from sweaty bodies.

If you find the wood becomes discolored, it can be treated with a light grade of sand paper.

If your heater uses stones, they will occasionally need to be washed as well. Be sure to allow the stones to completely air dry before turning on the heater.

That is really about all there is to keeping a sauna sanitary. Because they use mostly dry heat, saunas are largely self cleaning. As simple as they are to keep clean, there is no end to the amount of enjoyment you can derive from your home sauna!

Leave a Comment

Name *

E-mail *

How To Maintain A Sauna

Written by Mike Nekahi

Sauna Enthusiasts often talk about the spirit of the sauna. Some would have you believe that the sauna spirit is a sort of ephemeral version of the Scandinavian garden gnome, only this one lives in the home sauna. Many sauna traditionalists would have us believe that the sauna spirit stays away from the modern Far-Infrared saunas, but this is far from the truth.

For many, the sauna spirit exists in the presence of löyly. Traditional Finnish sauna takes place with dry heat of course, in a small wooden room where hot rocks are heated. The primary heat of the sauna comes from the rocks, but at some point in the sauna ceremony water is splashed on the rocks. The water immediately flashes into steam which carries the intensity of the heat to the users of the sauna. Infrared saunas cannot produce this steam, or löyly, because there are no hot rocks, only the elements producing the gentle infrared heat waves.

Although there is no true löyly in the infrared sauna, a friendly spirit can still take up residence in your sauna. One way to invite a friendly spirit into your home sauna, even in an infrared sauna, is to make ceremony and maintenance an important part of your sauna experience.

Part of the appeal of infrared saunas is their efficiency. The infrared elements bring the sauna to temperature much faster than hot rock saunas. Even an infrared sauna is not an instantaneous experience. The first time you take sauna in your new infrared sauna, take a couple minutes to remove any construction or packing materials, and give the room a quick sweep. It is a good idea to allow a few extra minutes the first time you energize the infrared elements for the "new" to burn off.

Part of the sauna ceremony should be for users to take a cleansing shower before entering the sauna. Yes, you are going to be sweating, intensely, in the sauna, but by bathing before you begin, you minimize the dirt and toxins taken into the sauna. In authentic Finnish sauna, good manners call for nudity in the sauna, and this is encouraged in a home sauna as well. Wrapping in a soft cotton towel should be sufficient for comfort and modesty, but allowing clothes in the sauna will bring in extra dirt and chemicals.

Whether or not you wrap in a towel, it is a good idea to have a towel to sit or lay on in the sauna. This is partly to make the bare wooden benches more comfortable, but it also helps to protect the wood from the occupant's sweat.

At the end of the session, take a minute to wipe down the wood and surfaces of the sauna with a clean wet cloth or brush. Lift the duck board from the floor and lean it to dry. Leave the element on and the door closed for a few minutes after everyone has left the sauna. This will allow the heat to dry everything, then leave the door open for ventilation.

If the wood begins to discolor despite the regular wipe down, feel free to use some mild detergent, or even light sand paper to remove the stains, but do not be tempted to paint, oil, or otherwise finish the boards.

The dry heat of the sauna makes it far simpler to maintain than a hot tub with its complicated water chemistry. The more you enjoy and take care of your sauna, the sooner you will notice that a friendly spirit will take up residence.

To learn more about portable Infrared Saunas, Hot Tubs, or billiard tables, come see Black Pine Spas today!

FREQUENTLY ASKED QUESTIONS

Sauna Steam

01) What is a sauna?
A sauna is a room lined with softwood heated by an electric or wood-heated sauna heater designed for sweat bathing. It can be enjoyed at any temperature depending on the preference of the bather.

02) How is the sauna heated?
Most saunas are heated by electricity. There are also wood-heated saunas.

03) What is the correct bathing temperature in a sauna?
The recommended temperature is from 60-90 degrees celcius but the bather can enjoy the sauna according to his preference.

04) How long does it take for a sauna to reach operating temperature?
If the walls and ceiling are properly insulated, the room will reach operating temperature in an hour. It is recommended that vents and doors be closed during the warm up period.

05) What effect will a sauna have on surrounding areas?
There will be a very slight increase in temperature in surrounding areas but no change in moisture or humidity.

06) Why are sauna heater rocks important?
Sauna rocks store heat from the sauna heater. When the bather throws water onto the hot rocks, a moistened air will blend with the dry air in the room, giving the bather an enjoyable and relaxing atmosphere. Never use the heater withour stones, it may cause a fire. Use only stones that are

recommended by the sauna heater manufacturer.

07) Can I throw any kind of water onto the sauna heater rocks?
No. You can only use water that is suitable for household use. Do not use water that contains chlorine like that from a swimming pool or hot tub because it will cause corrosion of your heater.

08) Why must sauna benches be built of softwood?
They are also cool to the touch. Hardwoods absorb heat and easily become too hot.

09) Why are there upper and lower benches in a sauna room?
The temperature of the sauna room is warmer at ceiling level and cooler near the floor. Benches are installed at different heights to give the bather a choice of different bathing temperatures.

10) How can the wood panels in the sauna be protected from moisture? Is it advisable to paint the sauna?
The best protection against moisture is proper ventilation and drying after using the sauna. Do not apply paint, sealants or any preservative on the wood panels. Wood swells and shrinks and tears off paint and sealants, which are only on the surface of the wood. It is best to leave the wood bare.

11) What kind of floor is appropriate for a sauna?
A sauna must have a waterproof floor so that it can be easily washed and kept clean. Tile, cement, or heavy duty vinyl are recommended because they are washable and do not absorb water.

12) Is it necessary to provide a floor drain in a sauna?
It is not necessary. Water should be thrown on the sauna heater rocks with the use of a ladle so that the right amount of water is applied. Once the water hits the rocks, it turns to steam. You should not pour too much water onto the heater. But if you can provide a drain, it may be more convenient for cleaning purposes.

13) What is the best way to clean the sauna?
You can brush the sauna floors and walls with detergent and water or apply disinfecting agents like alkalescent or alkaline detergent. If you apply a disinfecting agent, use cold water and rinse the wood panels thoroughly. It is advisable to clean the sauna before heating it so that it is dried easily.

14) How frequently should I take a sauna?
As often as you like. But most people go to the sauna twice or thrice a week usually in the evenings to relax after a hard day's work.

15) How long should I stay in the sauna?
As long as you feel comfortable. You must leave the sauna and cool yourself off if you begin to feel uncomfortable.

16) Who should not take a sauna?
One should not take a sauna when very full or intoxicated by liquor. People with heart problems or acute illnesses should consult the doctor before taking a sauna.

17) Is it safe for small children to be in the sauna?
Yes with adult supervision but only for a few minutes and in a moderate temperature. Small children should not stay long in the sauna, as they do not perspire as much as the adults do.

How to Sauna: A Guide to Public Sauna Etiquette

Posted on November 17th, 2011 by Chris in Guides, How to, news, tags: body prints, etiquette, guide, How to, locker room, sauna, saunas, steam bath, Steam room, sweat, top ten list

Photo of the Kotiharju Public Sauna in Helsinki. Image by Sami Oinonen via Flickr

A reader wrote us this question:

Dear SaunaScape:
I'm going to a resort with some friends this weekend. In the spa area, they have a sauna. I've never used one before. There is one in my gym locker room and I don't use it because it intimidates me. I don't want to make a sauna faux-pas.
What is the etiquette for using a public sauna or a steam room like this?
Thank you,
Jordan

Jordan:

You shouldn't get anxious about the sauna. It is a place to relax and do what is comfortable. Yes, it is a new experience for a lot of people, but as long as you remember the golden rule – *Do unto others as you would have them do unto you* – you'll be just fine.

If you are looking for some more specific rules, here is our top ten list of the most important etiquette rules consider when using a public sauna or steam bath:

10. Close the door.

Nothing upsets me more than when I am getting a good sweat on and someone else gets up to leave and does not close the door behind them. Nearly as bad is when someone is on their way in, and stops to chat with someone else while holding the door open.

When the sauna door is open, it does not take long for the heat to spill out of the sauna. It's even worse in a steam room. If your gym or resort was stingy while sizing their sauna heater, it may take ten minutes or more for the sauna to recover from the door being open for just a minute.

If you are going in or out, please do it quickly, and make sure the door closes firmly behind you.

9. Sit on a towel.

Nothing is worse than walking into a sauna and having to find a spot to sit among the sweaty body prints others have left on the sauna bench. Saunas are not hot enough to kill germs, and in a high-use area like a public sauna, there may be a sealant or a protective barrier of gunk that neutralizes the disinfecting properties of wood.

Bring a towel in the sauna or steam room that is large enough to make a barrier between your body and the benches. If you're sitting upright, a hand towel is big enough. If you're going to lay down, you probably need a beach towel. It will protect you from what others have left behind, and keep you from leaving things behind.
Source: http://saunascape.com/2011/11/public-sauna-etiquette-guide/

Make sure you have a second towel that you leave outside the sauna to dry off with afterwards. You won't want to use a sauna towel, and you can't use a steam room towel to dry off after you're done.

8. The sauna is not a clothes dryer.

There is a person at my gym who believes that the sauna is his personal clothes dryer. He does cardio, then goes for a swim. He brings in his sweaty clothes, wet bathing suit and towel and hangs them on the railing around the sauna stove to dry while he showers. Please, whatever you do, don't do this.

7. Silence is golden.

I use the sauna as my place for relaxation and introspection. If you are going to talk, please do it quietly. Of course, if it is your own sauna, or you have the sauna to yourself, you can yak it up if you want. Just respect that in a public place, other people may want quiet.

6. If it's in a locker room, it's OK to got naked.

It seems like Tobias Fünke wrote most sauna etiquette guides. Most begin with a rant against seeing other people's naked bodies in locker rooms. I'm going to rant the other way: It's a locker room. You're supposed to change clothes in there, which means you need to get naked in there. Until the early 1970′s, many high school and YMCA swimming pools throughout the US and Canada *expected* men to swim naked. Now, proper decorum says we aren't supposed to show our bodies to anyone. This ad is indecent (but not this one).

They call it a *sauna bath* for a reason. You wouldn't complain about people being naked in the shower, would you? So if the sauna is in an area where you can be naked, then go naked in the sauna! It's more hygienic and better for you too.

By the way, a sweat suit or a sauna suit is never appropriate attire for the sauna. If you don't want to get naked, see our post on what to wear in the sauna.

5. Keep your hands and eyes to yourself.

I may sauna naked, or with very little clothing. That does not mean that I amshowing off for anyone else. The Finns have a saying, "behave in a sauna like you would in church." I've been in a number of saunas and seen some things that definitely aren't church-like.

My attitude is, that if someone is coming on to someone else in the sauna, it isn't hot enough. I go looking for the thermostat to turn up the heat. In a proper sauna, you can't think about anything except "can I stay in here another minute?"

4. Leave your electronics outside.

The sauna isn't good for your electronics, but electronics also aren't good for the sauna. The heat and humidity (yes, even if it's a dry sauna) in the sauna will damage your phone, iPod or other gizmo. The etiquette problem is nearly every device has a camera these days. I don't know if you are just browsing through your music collection or if you're taking photos of me. I'd rather not have to ask. The other problem is your music. Yes, you're listening to it on earphones, but if it is quiet in the sauna, I'm probably going to hear most of it. And really, if that phone call is so important, why are you taking it in the sauna?

Use your gizmo while you're working out, but leave it in your locker when you take a sauna.

3. No spitting on the rocks.

I've seen this happen before. I shouldn't have to write it. Just don't do it.

2. Shower before you sauna.

Source: http://saunascape.com/2011/11/public-sauna-etiquette-guide/

Reading through other sauna etiquette posts on the internet, it is amazing how many people see nudity as dirty, but don't see dirt as dirty. I've seen it at my gym too: people remove their sweaty workout clothes to reveal a sweaty swimsuit underneath and head straight for the sauna. Or someone comes right out of the pool and heads straight into the sauna.

If you've been swimming, there is chlorine on your body that will volatilize in the sauna and can irritate everyone's eyes and lungs who shares the sauna with you. If you have been out in public, your perfume or some other smell you picked up throughout your day will become stronger and more pungent in the sauna.

Be considerate to the others who use the sauna with you: Take a shower first. If you're wearing a swimsuit or some other clothing in the sauna, take it off while you shower.

Don't forget to take at least a quick rinse off after you sauna before you get into the pool.

1. Remember to ask first before you do anything that affects me.

This is a public sauna, and I'm going to share it with you. I may like what you want to do, like splashing water on the rocks, or using that secret trick that sends the heater into overdrive. I may not care about others, like if you prepare some secret skin rub that you're going to use or if you're going to exercise in the sauna. Or, I may not want to stay, and may ask you to wait until I leave before you start.

This is a public place. I have as much right to enjoy the sauna the way I want to as you do. If they conflict, let's talk about it and find a way we both can live with. Everyone will be better off that way.

Keep in mind, these are the general rules for a public sauna. If you are lucky enough to have your own, you can make your own rules. If you are a guest in someone else's sauna, then you should ask them what their rules are before making assumptions.

Good Luck!

Source: http://saunascape.com/2011/11/public-sauna-etiquette-guide/

Proper Management of Saunas and Steam Rooms by Emily Attwood August 2011

In Europe, saunas and steam rooms are commonplace. In Finland especially, where the traditional sauna has its roots, saunas are simply a part of life.

Ample glass and a high-visibility location on the pool deck help discourage inappropriate uses of saunas and steam rooms. (Photo by Sam Fentress/Fentress Photography, courtesy of Hastings + Chivetta Architects Inc.)

In Europe, saunas and steam rooms are commonplace. In Finland especially, where the traditional sauna has its roots, saunas are simply a part of life. Most Finns grow up with a sauna in their home, and using it becomes a weekly (if not more frequent) ritual from childhood on.

Though not as ingrained into the American culture, saunas and steam rooms are a major draw in the United States for people looking to soothe muscles after a workout, lose weight, heal the body, remove toxins or simply relax after a long day. As the cost and time needed to maintain saunas and steam rooms decreases and energy efficiency increases, more health club owners are looking to add these amenities to their facilities.

Despite the benefits, the addition of a sauna or steam room should not be undertaken without a fair amount of consideration. Unlike in Finland, where users know how to work a sauna as though it were any other household appliance, the typical U.S. club member is often unfamiliar with how to use a sauna properly - and the typical club owner may not know how to best take care of either a sauna or steam room. For the uninitiated, the nature of the steam room and sauna - a harsh environment set off from supervision - lends itself to risks.

As with any product, there are discrepancies between the way these amenities are intended to be used and how they are actually used. As Tom Frisbie, manager of Teton Sports Club in Jackson Hole, Wyo., says, "Whatever people can do, they will do. You have to expect anything."

Vandalism is one of the more common types of misuse, especially in recreational clubs and resorts, where the user demographic includes not only people interested in these spaces' health benefits but those attracted by the social draw or entertainment value. Club owners have experienced users defiling signs, tampering with seating or other infrastructure and leaving behind garbage or other messes. The Teton Sports Club has a membership of about 750, but Frisbie believes that most of the problems are caused by vacationers passing through.

To curb vandalism or misuse perpetrated by teens, Frisbie, like many other facility owners, has created rules restricting sauna and steam room usage based on age. For example, YMCA regulations vary by facility, with some prohibiting users under the age of 18 and others allowing visitors as young as 13. Still others require adult supervision.

One of the worst and potentially most dangerous problems involves users interfering with a sauna's heating element. There is no shortage of club owners or managers who can share their experience of a user urinating on the heating element or pouring something other than water onto it. At best, the substances do no harm, but they necessitate a thorough cleaning of the heating element. Sometimes the heating element will sustain damage and require replacement. In the worst-case scenario, substances such as oils can start a fire and endanger users.

Source: http://www.athleticbusiness.com/featured-ab-writers/emily-attwood.html

The rocks in a sauna are meant to have some water added, so giving users access to the proper tools to do so reduces the likelihood of users seeking out their own methods of increasing the room's humidity. This can still lead to problems, though, when users disregard guidelines, so many club owners prefer to discourage water usage altogether.

"We supply bucket and dipper," says Reino Tarkiainen, president of Portland, Ore.-based Finlandia Sauna, "but the club owners usually don't put them in. It's okay to use clean water if you know how to do it."

The design of sauna heating elements has remained the same since 1962, according to Jon Vanderpool, commercial sales manager at Am-Finn Sauna and Steam in Eagle, Idaho, though added safety features have reduced many of the risks associated with them. Am-Finn offers a special heating-element model that separates the heating element from the rocks using a stainless steel tray. Thus, water (or other substances) added to the rocks does not come into contact with the heating element, lowering the risk of harm. Sauna and steam manufacturers have also added other features to combat users' attempts to tamper with the controls.

"No matter how hot you run the room," says Vanderpool, "You're always going to have someone who wants it hotter. If they have a way to manipulate the sauna heater, they'll do it; they'll figure it out."

Users of steam rooms often try to increase the steam output by manipulating the temperature gauge or steam element. Increased steam can make the environment uncomfortable as well as dangerous, raising temperatures to unsafe levels or causing skin to feel like it is burning. To circumvent this problem, rooms can be designed with the temperature sensor inside the shell of the heater, where users can't access it.

"Another thing facility operators like to do is go with a 24-hour timer," says Vanderpool. "They can preprogram the hours of operation for the room so that it turns on automatically in the morning and turns off at night. Members don't have access; it's all run off controls in a self-contained unit."

In the event that a user is able to manipulate the controls or some other problem occurs, sauna heaters come with high-limit switches, which shut down the heating element when a preset temperature is reached or surpassed. Also available are alarms that clubs can install in the rooms - either audible alarms or mechanisms that disconnect the power to the heating element.

Such safety features reduce a lot of the risk associated with users tampering with the environment, but not with some of the inappropriate behaviors endemic to saunas and steam rooms. For example, users who want to take advantage of the benefits of steam to their skin sometimes do their shaving in the steam room. Shaving cream and razors can leave behind messes or lead to damage, and the hair and potential for cuts and blood create hygiene issues.

More problematic than shaving is the possibility of sexual activity (consensual or otherwise). The behind-closed-doors nature of these building spaces creates a temptation and opportunity for steamy (or dry-heat) encounters. This is one of the reasons that more facility operators and architects are moving steam rooms or saunas out of locker rooms and onto pool decks or into other more visible areas.

"The more private or gender-specific rooms are usually at the private clubs or hospital-based wellness centers," says Robert McDonald, senior principal at Denver-based Ohlson Lavoie Collaborative. "Public recreation centers and YMCAs are increasingly leaning toward the other model. We try to address all of the issues upfront in the pre-design phase, talk about the type of clientele they want to attract and what kind of amenities they want to see in the locker room versus out on the pool deck."

The most obvious advantage of having one larger unisex sauna or steam room instead of two smaller spaces is the reduction in maintenance costs. The major complaint among owners of steam rooms has always been the upkeep - the environment of a steam room makes it a prime breeding ground for mold and bacteria, necessitating thorough daily cleanings.

Source: http://www.athleticbusiness.com/featured-ab-writers/emily-attwood.html

Fiberglass construction is associated with lower maintenance, but still requires daily attention. (Photo courtesy of Am-Finn Sauna and Steam)

The advent of fiberglass steam rooms has done away with many of these complaints. "Fiberglass steam rooms have been on the market for about 10 years," says Vanderpool, "They are becoming very popular now because they have lower maintenance requirements. Typically, they're 30 to 50 percent more efficient than tile, and the units we have are self-cleaning, using ozone."

Even with lower-maintenance models, saunas and steam rooms still require some daily cleaning and staff to ensure that everything is in proper condition. Not only does having one unisex steam room or sauna instead of separate amenities cut maintenance costs and reduce the amount of staff time required to supervise the areas, having the facilities on the pool deck gets them out in the open. In addition to watching over the pool, lifeguards are now finding care of the steam room or sauna added to their rotation schedule.

Despite the reduced element of privacy, some may argue that the potential for sexual behavior increases with a shared room. In reality, shared usage of a sauna or steam room usually means more traffic, facility operators say, leaving fewer opportunities for total privacy.

"We supply a glass door so you always have visibility. Management doesn't have to go through the door but can look in," says Finlandia's Tarkiainen. Simply having windows decreases the privacy factor and thus potential for vandalism or inappropriate behavior. Fiberglass steam rooms provide a similar benefit, as they can be built with a front wall made completely of glass, Vanderpool says.

These steps are not always enough to prevent uneducated users from behaving in ways they don't realize is harmful or inappropriate. "There are health risks to people staying in them too long, and you might actually see people exercising in them, as well," says McDonald. Prolonged exposure can lead to dehydration or heat exhaustion, especially after a hard workout (or combined with consumption of alcohol - a problem often seen in resort facilities). People with heart or respiratory conditions should take heed before entering a sauna or steam room, and despite studies indicating that the heat of these facilities can increase resistance to illness, it can be detrimental to those who are already ill or running a fever.

"Each sauna has a warning not to stay in for more than 30 minutes. We supply that with every heater," says Tarkiainen. Signage is the easiest way to educate readers on the dos and don'ts. Comprehensive rules should include not just how to use the room properly, but identify health risks and dictate proper dress, hygiene, behavior, and time and age restrictions.

But signs are easily ignored or overlooked, and should not be relied upon to enforce sauna or steam room rules. For membership facilities, education of proper practices and health risks should be addressed before initial use, and clauses addressing misuse included in the membership agreement.

In clubs like Frisbie's, however, where a large number of users are visitors, it's harder to ensure everyone is provided with that information. "We do give everybody a little speech every time they come in," he says. "But even still, we have to keep our eyes on them."

The best way to minimize the risks associated with saunas and steam rooms is not to rely on users to know and follow the rules of operation: Staff walk-throughs are the most common and effective means of preventing inappropriate behavior or misuse.

Source: http://www.athleticbusiness.com/featured-ab-writers/emily-attwood.html

"Most clubs should have somebody who will check into the sauna at least every 15 to 30 minutes," says Tarkiainen. Scheduling walk-throughs at regular intervals during the day allows staff members to ensure that users are following posted rules, not exceeding time limits or suffering from any health issues. This also gives staff a chance to make sure all equipment is working properly and to catch and remedy any vandalism or other potential problems. Walk-throughs should be accompanied by a checklist documenting conditions.

When a club's staffing schedule makes it impractical to do regular walk-throughs, surveillance and monitoring equipment is recommended. A combination of visual and electronic surveillance is better still. Cameras placed outside of the rooms can be used to actively monitor usage or create a record that can be reviewed later.

Saunas and steam rooms don't have to be a headache for owners and managers. With proper planning, maintenance and staffing, as well as education on the part of the management team and users alike, the risks associated with these rooms can be minimized. Facility owners should not hesitate to take on the challenge associated with saunas and steam rooms in exchange for the many benefits they can bring to their business.

"There are a lot of people who will buy a membership simply because of the amenities a facility has," says Vanderpool. "If the rooms are down, we hear from those people; they're always the ones who complain the loudest."

Emily Attwood is Associate Editor of *Athletic Business*.

Source: http://www.athleticbusiness.com/featured-ab-writers/emily-attwood.html

Journal of Hospital Infection 81 (2012) 217–223

Available online at www.sciencedirect.com

Journal of Hospital Infection

journal homepage: www.elsevierhealth.com/journals/jhin

Review

Application of copper to prevent and control infection. Where are we now?

J. O'Gorman [a,b,*], H. Humphreys [a,b]

[a] Department of Microbiology, Beaumont Hospital, Dublin, Ireland
[b] Department of Clinical Microbiology, Royal College of Surgeons in Ireland, Dublin, Ireland

ARTICLE INFO

Article history:
Received 18 February 2012
Accepted 21 May 2012
Available online 26 June 2012

Keywords:
Copper
Environmental contamination
Healthcare-associated infection
Hygiene
Infection prevention and control

SUMMARY

Background: The antimicrobial effect of copper has long been recognized and has a potential application in the healthcare setting as a mechanism to reduce environmental contamination and thus prevent healthcare-associated infection (HCAI).
Aim: To review the rationale for copper use, the mechanism of its antimicrobial effect, and the evidence for its efficacy.
Methods: A PubMed search of the published literature was performed.
Findings: Extensive laboratory investigations have been carried out to investigate the biocidal activity of copper incorporated into contact surfaces and when impregnated into textiles and liquids. A limited number of clinical trials have been performed, which, although promising, leave significant questions unanswered. In particular there is a lack of consensus on minimum percentage copper alloys required for effectiveness, the impact of organic soiling on the biocidal effect of copper, and the best approach to routine cleaning of such surfaces. Limited information is available on the ability of copper surfaces to eradicate spores of *Clostridium difficile*.
Conclusion: Additional studies to demonstrate that installing copper surfaces reduces the incidence of HCAI are required and the cost-effectiveness of such intervention needs to be assessed. Further research in a number of key areas is required before the potential benefits of using copper routinely in the clinical setting to prevent and control infection can be confirmed and recommended.

Introduction

Copper, a metal utilized by human civilization for more than 10,000 years, has become the focus of renewed scientific interest for its antimicrobial properties and potential application in the healthcare setting. Although the exact mechanisms by which this metal exerts its biocidal effect are not fully understood, its benefits have long been recognized. An Egyptian papyrus written between 2600 and 2200 BC describes the application of copper to sterilize chest wounds and to purify drinking water. Later, Hippocrates recommended the topical application of copper to treat leg ulcers, and, in the pre-antibiotic era of the nineteenth and twentieth centuries, copper preparations were widely used in the treatment of skin conditions, syphilis and tuberculosis.[1]

In the modern healthcare setting one of the most widespread and successful applications of the antimicrobial effect of copper is in the control of legionella and other bacteria in hospital water distribution systems using the method of copper and silver ionization.[2] However, recent research into the antimicrobial effects of copper has focused on the mechanism by

* Corresponding author. Address: Department of Clinical Microbiology, Beaumont Hospital, Dublin 9, Ireland. Tel.: +353 1 8093320; fax: +353 1 8092871.
E-mail address: joanneogorman@gmail.com (J. O'Gorman).

0195-6701/$ – see front matter
http://dx.doi.org/10.1016/j.jhin.2012.05.009

which there is 'contact killing' of microbes on exposure to copper surfaces and the impact this may have on reducing environmental contamination. In 2008 commercial interest in this potential application of copper increased due to the decision of the US Environmental Protection Agency (EPA) to grant recognition to copper surfaces as having antimicrobial efficacy. Copper is the first metal to be awarded such a status and to date almost 300 copper and copper alloy surfaces have demonstrated their biocidal effect against five strains of bacteria when tested according to US EPA protocols.[3] In addition to its use as a material for contact surfaces, the biocidal effects of a wide variety of copper-impregnated textiles and liquids have been reported, with particular speculation about their potential to reduce healthcare-associated infection (HCAI).[4]

This article reviews the rationale, mechanism of antimicrobial effect, efficacy and clinical studies on copper to reduce the microbial load on contact surfaces. The addition of copper in water systems to prevent legionella is well established and represents its use to prevent a specific waterborne pathogen; this aspect is not addressed here. A PubMed search of the available literature was conducted using such terms as 'copper', 'antimicrobial copper', 'copper-based biocide', 'copper resistance', 'hospital acquired infection', 'infection prevention and control', 'hygiene', 'cleaning' and 'environmental contamination'. The search was limited to articles published in English. References from bibliographies of articles included in the search were also assessed.

Rationale for using copper surfaces in the healthcare setting

Environmental surfaces are a likely reservoir for potential pathogens and play a role in the acquisition of healthcare infection.[5] Studies have demonstrated that hard surfaces can be contaminated with isolates such as meticillin-resistant *Staphylococcus aureus* (MRSA), vancomycin-resistant enterococci (VRE) and spores of *Clostridium difficile* which can remain viable for several weeks to months.[6] These micro-organisms from contaminated surfaces may then be transmitted via hands to other inanimate objects or to patients. To standardize the assessment for monitoring hospital cleanliness, benchmarks for assessing hygiene have recently been updated. The original quantitative standard stated that aerobic colony counts (ACC) on hand-touch sites should not exceed 5 cfu/cm^2 but this has since been reduced to 2.5 cfu/cm^2.[5,7] Achieving such a target may be challenging, especially as there is considerable variation in standards and methods of cleaning.[8] In one US study a fluorescent marker solution was employed to determine cleaning efficacy of more than 13,000 surfaces in 23 hospitals. Terminal room cleaning after patient discharge decontaminated a mean of only 49% of the standardized surfaces including $<$30% of toilet handholds, bedpan cleaners, room doorknobs and bathroom light switches.[9] It is clear that in addition to routine cleaning, additional strategies to reduce microbial contamination should be considered.

Mechanism by which copper exerts its antimicrobial effect

Copper is an essential trace element involved in numerous physiological and metabolic processes.[10] Although toxicity in humans can occur at high concentrations, in general exposure to copper is considered safe, as is evidenced by the widespread use of copper intrauterine devices and the documented low risk of adverse reactions due to dermal contact with copper.[11,12] The low sensitivity of human tissue to copper can be contrasted with micro-organisms which are extremely sensitive to its toxic effects.

The exact mechanisms by which copper exerts its biocidal effect is a source of ongoing investigation. It is thought that the cause of cell death is multifactorial rather than the result of a single universal mechanism.[13] A key property of copper which significantly contributes to its toxic effect is its ability to accept and donate single electrons as it changes oxidation state between Cu^+ and Cu^{2+} [Cu(I) and Cu(II)]. This allows copper to act as a catalyst for the generation of reactive oxygen species (ROS) such as hydroxyl radicals and superoxide anions. These ROS have the potential to cause oxidative damage to vital cell constituents such as proteins, nucleic acids and lipids (including those in the cell membrane).[14–16] Free copper ions may compete with zinc or other metal ions for important binding sites on proteins, leading to conformational change and the loss of protein function.[17] Copper ions can also inactivate proteins by damaging Fe–S clusters in cytoplasmic enzymes needed to make branched-chain amino acids.[18]

Recent research into the biocidal properties of copper surfaces has focused on establishing the primary mechanisms which result in cell death, and on the effect of copper on bacterial DNA. One set of studies, involving enterococci (including VRE) exposed to copper alloys, reported that cell death results from the action of released copper ionic species and the generation of superoxide, leading to arrested respiration with the substantial disintegration of both plasmid and genomic DNA as a primary effect.[15,16] Research from this group also suggests that different mechanisms of toxicity are observed in Gram-negative bacteria such as *Escherichia coli* and *Salmonella* spp. with depolarization of the cytoplasmic membrane playing a key role and DNA degradation occurring at a slower rate.[13] By contrast, other studies have proposed that depolarization of the cytoplasmic membrane is the main target for the antimicrobial effect of copper and that degradation of genomic material only occurs subsequent to cell death.[14,19] Although investigations into the exact biocidal effects of copper toxicity are ongoing, the consensus that degradation of DNA occurs at some point is noteworthy. Compromising DNA in this way has a role to play in preventing resistance mutations and inhibiting the potential transmission of toxin, virulence and antibiotic resistance genes.[16]

In vitro evidence for biocidal efficacy of copper surfaces

The use of copper materials in contact surfaces to reduce environmental contamination was first postulated almost 30 years ago. During a training session to promote hygiene awareness, cleaning staff in a US hospital were asked to take environmental swabs from a variety of locations and it was noted that brass doorknobs (an alloy of typically 67% copper and 33% zinc) had very sparse bacterial growth in comparison with swabs from doorknobs of stainless steel.[20] Initial laboratory protocols to investigate this phenomenon in a standardized way were derived from a testing method developed in

Japan: JIS Z 2801 (Japanese Industrial Standards Association, 2000). However, this method is not representative of actual surface contamination events in a hospital setting, since it involves applying a dilute liquid inoculum to the surface area, which is maintained at a relative humidity of >90% for a period of 24 h, and incubated at a higher than ambient temperature of 35 °C.[21]

In an attempt to replicate *in vivo* situations, two main experimental techniques have since been described, a moist inoculation technique and a dry inoculation technique. Incubation temperatures and relative humidity in both methods are also modified to more accurately reflect indoor settings. In studies using a moist inoculation technique, small volumes of liquid suspensions of bacteria are applied to metal plates (coupons) and can take >30 min to dry.[22] It has been suggested that the aqueous nature of the contaminating inoculum may have an impact on the toxicity of the copper surface, and this technique, which mimics a wet contamination incident such as a sneeze or a wipe, does not reflect the contamination of dry surfaces encountered in healthcare settings.[15] In an attempt to address this issue, a second method has been developed which involves the application of liquid cell suspensions to metal plates using a cotton swab. This provides a higher concentration of inoculum in the form of a thin film of liquid which evaporates within seconds and may more accurately reflect the clinical scenario.[22]

Studies have been published demonstrating the ability of copper to inactivate a multitude of bacteria, fungi and viruses in the laboratory setting. These include MRSA, enterococci, *Pseudomonas* spp., *Acinetobacter* spp., *Klebsiella* spp., *Escherichia coli*, *Listeria* spp., *Campylobacter* spp., *Salmonella* spp., *Staphylococcus warnerii*, influenza A, *Mycobacterium tuberculosis* and *Candida* spp.[13,15,21–26] The majority of these laboratory studies have been carried out using a 'wet inoculation' technique and there is wide variation in incubation temperatures, relative humidity and copper content of the alloys tested. Nonetheless a number of consistent findings are reported. In general, micro-organisms are inactivated within hours although the greatest efficiency is seen in alloys with higher copper content. The percentage copper required for significant biocidal effect has been reported to range between 55% and 100%.[16,22–26] Temperature and humidity both have an important impact on the kill rate for bacteria with a slower, though still significant, impact evident at 4 °C and evidence that higher relative humidity increases the efficacy of contact killing.[21,23,25] It appears also that dry surfaces bring about bacterial killing more rapidly than moist ones, though the mechanism for this is as yet unclear.[14,27]

In vivo evidence for biocidal efficacy of copper surfaces

The efficacy of copper in the contact killing of microbes has been the subject of extensive laboratory investigation. However, *in vivo* studies are limited and to date there have been only five reports published in the literature.

The first study was a 10-week trial in a busy acute medical ward of a UK hospital.[28] A plastic toilet seat, a chrome set of tap handles and an aluminium ward entrance door push plate were replaced by equivalent items containing a minimum of 60% copper. The items were installed six months prior to the study to facilitate ageing and for staff to become accustomed to them. To further reduce bias the study was designed as a cross-over trial with the copper- and non-copper-containing controls interchanged after five weeks. Items were sampled on a weekly basis for the presence of micro-organisms. A benchmark value for all bacteria of <5 colony-forming units per cm^2 (cfu/cm^2) was used in line with standards which had been proposed at the time.[5] The results of the study showed that, based on median total aerobic cfu counts, 5/10 controls and 0/10 copper sample points failed the proposed benchmark value of <5 cfu/cm^2. Although this benchmark value has subsequently been lowered to 2.5 cfu/cm^2 the overall findings that median numbers of micro-organisms harboured by the copper-containing items were between 90% and 100% lower than their control equivalents remain significant. An additional finding of the 10-week study was that although no isolates of MRSA and *C. difficile* were isolated from either type of surface, meticillin-susceptible *Staphylococcus aureus* (MSSA), VRE and *E. coli* were found only on the control surfaces.

A second extended phase of this hospital trial was carried out over a six-month period.[29] Fourteen types of frequently touched items made of copper alloy were installed in an acute medical care ward three months prior to the study. These included door handles, push plates, toilet seats and flush handles, grab rails, light switches, pull-cord toggles, sockets, overbed tables, dressing trolleys, commodes, taps, and sink fittings. The percentage copper content of the alloys used ranged from 58% to 99.95%. After 12 weeks the copper and standard items were switched over. Weekly sampling was carried out for 24 weeks. The study found that 8/14 item types demonstrated significantly lower cfu counts on the copper surfaces than on the standard materials with the other six types showing reduced microbial numbers on the copper surfaces but the difference did not reach statistical significance. The study also assessed the presence of five indicator organisms MRSA, MSSA, VRE, *C. difficile* and coliforms. All five bacteria were recovered from both control and copper-containing surfaces. However, significantly fewer copper surfaces were contaminated with VRE, MSSA and coliforms than were the controls.[29]

A third trial was conducted in the consulting rooms of a walk-in primary care clinic in South Africa. Contact surfaces such as a desk, trolleys, the top of a cupboard and windowsills were covered with copper sheets (99.9% copper alloy). Over six months the surfaces were sampled every six weeks for a 4.5-day period with multiple samplings per day. An overall 71% reduction in the bacterial load on the copper surfaces was observed compared with that of the control surfaces. Comparable numbers of bacteria were counted when surfaces remained untouched for 71 h over the weekends but this was not investigated further.[30]

A fourth study was carried out on medical wards of a German hospital.[31] Touch surfaces such as push plates, doorknobs and light switches were replaced with new copper-containing alloys (percentage of copper alloy not stated). The trial was carried out over 32 weeks equally divided between summer and winter. The number of aerobic heterotrophic cfu on the surfaces was determined once or twice per week and the presence of ciprofloxacin-resistant *S. aureus* (CRSA) was chosen as an indicator organism for the presence of resistant nosocomial bacteria. The study found that the total number of cfu on metallic copper surfaces was 63% of that on control surfaces with statistically significant differences noted between door

knobs. No significant difference in survival of CRSA on copper surfaces versus controls was noted. Following initial sampling each morning all surfaces were cleaned with disinfectant. It was noted that surfaces repopulated at different rates, 12.4 cfu/h for copper surfaces and 22.5 cfu/h on other surfaces.

The final *in vivo* study of the contact killing effect of copper surfaces was carried out in a critical care unit.[32] This small trial compared the contamination of copper versus stainless steel pens after use over a 12 h clinical shift. In total 25 pens of each type were examined. A lower total number of cfu was found on copper pens sampled immediately after collection but this did not reach statistical significance. When pens were left in storage for 11 h (reflecting the time lapse between shifts) significantly fewer copper-containing pens were contaminated compared with stainless steel pens. A summary of each *in vivo* assessment and its findings is outlined in Table I.

Copper-impregnated textiles and liquids

In addition to its use as a contact surface, the antimicrobial effect of copper is being exploited in a number of other settings. This has been facilitated by the development of a technique for the mass production of copper oxide-impregnated textiles, latex and other polymer products.[4] In the area of personal protective equipment, for example, the addition of copper oxide into respiratory protective face masks has been shown to have anti-influenza biocidal effects without altering the physical barrier properties of the material.[33] A role for copper oxide-impregnated wound dressings has also been investigated with preliminary results from animal models demonstrating a strong biocidal effect with no adverse reactions in closed skin wounds.[34] Furthermore a novel clinical study assessing the impact of copper-impregnated socks demonstrated improvement in the symptoms of fungal foot infections.[35]

Although it has been postulated that there may be a role for making hospital soft surfaces such as sheets and clothing from copper-impregnated biocidal textiles, there are no clinical data to support the efficacy of such an intervention in reducing HCAI and questions remain unanswered about issues such as cleaning and the decontamination of such materials.[36] The biocidal effects of liquid formulations containing copper have also been assessed; a number of laboratory studies have postulated a role for copper-based hand rubs and cleaning products as effective infection prevention and control interventions.[37,38] Furthermore, a clinical study assessing the performance of ultramicrofibre cleaning technology with the addition of a copper-based biocide (CuWB50) demonstrated a significant reduction in total viable count in the hospital environment when compared with ultramicrofibre mops and cloths moistened with water alone.[39]

Resistance to copper

As copper is an essential micronutrient but toxic at elevated concentrations, micro-organisms have developed complex systems to maintain precise intracellular levels. In addition to specific uptake and efflux pumps, other mechanisms of tolerance include exclusion by a permeability barrier, intra- and extracellular sequestration, enzymatic detoxification and reduction in the sensitivity of cellular targets to copper ions.[40] Although the genes responsible for such processes can be encoded by transmissible plasmids, the potential emergence of widespread bacterial strains resistant to copper surfaces appears unlikely given the rapid rate of contact killing and the complete degradation of DNA known to occur.[22]

Studies to investigate this issue have focused on known plasmid-borne copper resistance mechanisms. One such target is the *tcrB* gene identified in certain strains of *E. faecium* and *E. faecalis*. This gene encodes for a membrane-bound protein involved in copper homeostasis and is thought to originate from pigs fed with copper sulphate-supplemented food.[41] Although isolates containing the *tcrB* gene exhibit growth on brain–heart infusion agar plates containing high concentration of copper sulphate, it is thought that their resistance mechanism is not sufficient to prevent cell death when exposed to copper surfaces.[41,42] Other studies of *E. coli* strains containing a resistance plasmid *PCo* demonstrated a decreased killing rate when exposed to copper surfaces but did not prevent cell death.[27]

Efforts to assess the potential for resistance to develop in bacteria in continual contact with copper led to a novel investigation of isolates colonizing European 50 cent coins. Although coins have not been confirmed to have antimicrobial efficacy as defined by EPA standards, the authors of this study postulated that 50 cent pieces (89% copper alloy) may be ideal surfaces to give rise to natural selection of metallic copper-resistant bacteria.[42] In total, 294 strains of bacteria (the majority being Gram-positive cocci) were recovered from an international sample of coins and tested for survival on a pure copper surface (99% Cu). The survival of the isolates was compared to matched type-specific control strains. Although some isolates demonstrated prolonged survival on dry surfaces compared with their controls, no significant copper-resistant bacteria were identified. *Staphylococcus* spp. isolated from coins did not have antibiotic resistance profiles more extensive than their matching control strains, arguing against the co-selection of copper surface resistance traits.[42]

Areas for further study

Much work has been done to investigate the bactericidal efficacy of copper as part of a contact surface, but a number of questions remain unanswered about the benefit of the widespread implementation of copper-based products in the healthcare setting. Although there is increasing evidence of the importance of hand-touch sites in the transmission of pathogens, the clinical trials of copper contact surfaces published to date have not been designed to show a reduction in HCAI rates. Instead a surrogate marker of aerobic cfu compared with control surfaces has been used. The clinical impact of such a reduction is unclear. To address this issue a large-scale, multicentre US trial using HCAI rates as an outcome has recently been completed. Preliminary assessment of these unpublished data suggests that significant reductions in HCAI were observed when copper alloys were used in an ICU setting.[43] Hospital trials in Japan, South Africa, Greece and Chile are underway and it is possible that results from these trials may provide further evidence in this regard.[22,43]

Concerns also arise with regard to the lack of clinical trials assessing the role of copper contact surfaces in eradicating anaerobic spores, especially *C. difficile*. As the

decontamination of surfaces exposed to *C. difficile* spores is challenging for conventional cleaning methods, the beneficial effects of copper contact surfaces may have a significant impact. One laboratory-based study postulated that the efficacy of contact killing may be improved by the addition of a spore germinant to cleaning solutions used on the copper surfaces.[44] Further research, both into the effect of copper and the potential role for spore germinants, is required.

Table I
The setting, methods used and findings from five studies in clinical areas of copper-impregnated surfaces

Study no. (reference)	Setting	Methods and criteria used	Results	Comment
1 (Casey *et al.*[28])	Acute care medical ward, UK. 10-week study.	Cross-over study. Three existing surfaces replaced with copper alloys (toilet seat, tap handles, door push plate). Total aerobic microbial counts per cm^2 monitored weekly and compared with benchmark value of <5 cfu/cm^2. Also evaluated for indicator organisms.	Based on median total aerobic cfu, 5/10 controls and 0/10 copper sample points failed the benchmark value. Median numbers of micro-organisms on copper-containing items were 90–100% lower than their control equivalents.	60–70% copper alloys. Items installed 6 months prior to start of study to allow staff to become accustomed to fixtures and so fixtures 'aged'.
2 (Karpanen *et al.*[29])	Extension of study 1. Acute medical ward, UK. 24-week study.	Cross-over study. Fourteen frequent-touch items replaced with copper alloys.	8/14 items noted significantly reduced bacterial load. 6/14 trend towards reduction but not statistically significant.	>58% copper alloys.
		Total aerobic microbial counts per cm^2 monitored weekly and compared with benchmark value of <5 cfu/cm^2. Also evaluated for indicator organisms.	Significantly fewer copper surfaces contaminated with VRE, MSSA and coliforms compared with controls.	No significant difference between copper and control items colonized with MRSA.
3 (Marais *et al.*[30])	Primary healthcare clinic, Western Cape, South Africa. 24-week study.	Consulting room refitted with copper sheets on touch surfaces (desk and trolleys, top of cupboard, windowsill). Sampled every 6 weeks for 4.5 days. Total aerobic colony count.	Overall 71% reduction in bacterial load of copper surfaces compared with that of control surfaces.	99.9% copper alloys used. Comparable numbers of bacteria counted when surfaces remained untouched over the weekends (71 h).
4 (Mikolay *et al.*[31])	Oncology, respiratory and geriatric ward, Germany. 32-week study (summer and winter).	In total 147 push plates, doorknobs, light switches replaced with brass (copper/zinc alloy). Sampled once or twice per week for total aerobic colony count. CRSA as an indicator organism.	Average 63% reduction in bacterial load of copper surfaces compared with controls. Results significant for door handles. No significant difference in survival of CRSA although lower numbers on copper surfaces.	Also demonstrated average rate of repopulation of copper surfaces less than half that of controls.
5 (Casey *et al.*[32])	Intensive care unit, UK. Copper pens used during a 12-h clinical shift.	Comparison of surface microbial contamination associated with pens of copper alloy vs stainless steel (50 pens in total).	Statistical significance only reached when pens left in storage for 11 h. Lower total cfu found on copper pens immediately after shift completed but not significant.	

Cfu, colony-forming units; VRE, vancomycin-resistant enterococci; MRSA, meticillin-resistant *Staphylococcus aureus*; MSSA, meticillin-susceptible *Staphylococcus aureus*; CRSA, ciprofloxacin-resistant *Staphylococcus aureus*.

Assuming that a reduction in healthcare infection rates could be attributed to the use of copper contact surfaces and impregnated materials, issues arise in relation to cost-effectiveness. In international markets the price of copper continues to rise.[45] The cost-benefit analysis of replacing existing surfaces and materials would need to be established and it would be important to ascertain which surface areas should be targeted for maximum impact, if, for cost or other reasons, all surfaces could not be replaced. Establishing the minimum percentage of copper required in alloys for efficacy is also an area of uncertainty with wide variation in surfaces tested in laboratory experiments. Studies suggest that anything from 55% to 100% copper composition are required for biocidal impact.[16,22—26] In choosing which alloy to employ there needs to be a balance between efficacy and other considerations such as durability of surfaces and their aesthetic appeal.

Concerns regarding the impact of soiling and cleaning on the effectiveness of contact killing surfaces also need to be addressed. The effect of soil residue on antimicrobial surfaces has most notably been studied in the area of food handling and preparation. One such laboratory investigation assessed the benefit of using copper alloys to reduce *E. coli* 0157 cross-contamination and established that the addition of a liquid beef extract mimicking soiling provided a protective matrix for the bacterial cells to 'hide in' but significant reductions in viability were still achieved.[25]

Only one laboratory-based study has exclusively addressed the problems associated with cumulative soiling and cleaning on the antimicrobial properties of copper.[46] Test surfaces of copper and copper alloys were soiled with *S. aureus* suspended in a protein-based organic soil (bovine serum albumin: BSA), dried rapidly and incubated for 24 h. Surfaces were then wiped clean using a standardized wiping procedure with two cleaning agents commonly used in the UK National Health Service (1% sodium hypochlorite and 70% industrial methylated spirit). The soiling/cleaning procedure was carried out daily over five days and after each cycle the amounts of residual soil and live cells were assessed using epifluorescence microscopy. After the second soiling/cleaning cycle it appeared that the application of the cleaning agent caused subsequent layers of the BSA—bacteria soil to bond more strongly to the copper surface, increasing its resistance to cleaning. The stainless steel surfaces by comparison remained highly cleanable. This surface conditioning has also been raised as an issue of concern in one of the clinical trials which noted that the cleaning solution containing glucoprotamin as an active substance may have generated a thin layer between metallic copper surface and the bacteria, reducing the biocidal effect of copper on bacteria.[31]

Conclusion

The biocidal effect of copper as a contact surface has been extensively investigated in a wide variety of laboratory studies and appears to have a potential application in healthcare infection prevention and control efforts. However, it must be acknowledged that further research is required in a number of areas before the widespread implementation of copper contact surfaces could be recommended, including any significant additional costs. In particular, further clinical trials demonstrating a sustained reduction in HCAI rates need to be reported. Minimum percentage copper content and effective cleaning protocols for copper surfaces should be established. It is fitting that the US EPA requires those making public health claims related to the antimicrobial benefit of copper to clearly state that the use of such surfaces is a supplement to, not a substitute for, standard infection prevention and control practices. Effective hand hygiene and the routine cleaning of environmental surfaces remain integral components in reducing HCAI, and the additional routine contribution of copper surfaces, while potentially beneficial, remains to be clearly established.

Conflict of interest statement

H.H. has had recent research collaborations with Steris Corporation, Inov8 Science, Pfizer & Cepheid. He has also recently received lecture and other fees from Novartis, AstraZeneca & Astellas.

Funding sources

None declared.

References

1. Dollwet H, Sorenson J. Historic uses of copper compounds in medicine. *Trace Elements Med* 1985;**2**:80—87.
2. Stout JE, Yu VL. Experiences of the first 16 hospitals using copper—silver ionization for Legionella control: implications for the evaluation of other disinfection modalities. *Infect Control Hosp Epidemiol* 2003;**24**:563—568.
3. Michels HT, Anderson DG. Antimicrobial regulatory efficacy testing of solid copper alloy surfaces in the USA. *Metal Ions Biol Med* 2008;**10**:185—190.
4. Borkow G, Gabbay J. Putting copper into action: copper-impregnated products with potent biocidal activities. *FASEB J* 2004;**18**:1728—1730.
5. Dancer SJ. How do we assess hospital cleaning? A proposal for microbiological standards for surface hygiene in hospitals. *J Hosp Infect* 2004;**56**:10—15.
6. Curtis LT. Prevention of hospital-acquired infections: review of non-pharmacological interventions. *J Hosp Infect* 2008;**69**:204—219.
7. Mulvey D, Redding P, Robertson C, *et al*. Finding a benchmark for monitoring hospital cleanliness. *J Hosp Infect* 2011;**77**:25—30.
8. Dancer SJ. The role of environmental cleaning in the control of hospital-acquired infection. *J Hosp Infect* 2009;**73**:378—385.
9. Carling PC, Parry MF, Von Beheren SM. Identifying opportunities to enhance environmental cleaning in 23 acute care hospitals. *Infect Control Hosp Epidemiol* 2008;**29**:1—7.
10. Olivares M, Uauy R. Copper as an essential nutrient. *Am J Clin Nutr* 1996;**63**:791S—796S.
11. Hostynek JJ, Maibach HI. Copper hypersensitivity: dermatologic aspects — an overview. *Rev Environ Health* 2003;**18**:153—183.
12. Sivin I. Utility and drawbacks of continuous use of a copper T IUD for 20 years. *Contraception* 2007;**75**(6 Suppl.):S70—S75.
13. Warnes SL, Caves V, Keevil CW. Mechanism of copper surface toxicity in *Escherichia coli 0157:H7* and *Salmonella* involves immediate membrane depolarization followed by slower rate of DNA destruction which differs from that observed for Gram-positive bacteria. *Environ Microbiol* 2011 Dec 19. http://dx.doi.org/10.1111/j.1462-2920.2011.02677.x [Epub ahead of print].
14. Espirito Santo C, Lam EW, Elowsky CG, *et al*. Bacterial killing by dry metallic copper surfaces. *Appl Environ Microbiol* 2011;**77**:794—802.
15. Warnes SL, Keevil CW. Mechanism of copper surface toxicity in vancomycin-resistant enterococci following wet or dry surface contact. *Appl Environ Microbiol* 2011;**77**:6049—6059.

16. Warnes SL, Green SM, Michels HT, Keevil CW. Biocidal efficacy of copper alloys against pathogenic enterococci involves degradation of genomic and plasmid DNAs. *Appl Environ Microbiol* 2010;**76**:5390–5401.
17. Borkow G, Gabbay J, Copper. An ancient remedy returning to fight microbial, fungal and viral infections. *Curr Chem Biol* 2009;**3**:272–278.
18. Macomber L, Imlay JA. The iron–sulfur clusters of dehydratases are primary intracellular targets of copper toxicity. *Proc Natl Acad Sci USA* 2009;**106**:8344–8349.
19. Quaranta D, Krans T, Espirito Santo C, *et al*. Mechanisms of contact-mediated killing of yeast cells on dry metallic copper surfaces. *Appl Environ Microbiol* 2011;**77**:416–426.
20. Kuhn PJ. Doorknobs: a source of nosocomial infection. *Diagnost Med* 1983:62–63.
21. Michels HT, Noyce JO, Keevil CW. Effects of temperature and humidity on the efficacy of methicillin-resistant *Staphylococcus aureus* challenged antimicrobial materials containing silver and copper. *Lett Appl Microbiol* 2009;**49**:191–195.
22. Grass G, Rensing C, Solioz M. Metallic copper as an antimicrobial surface. *Appl Environ Microbiol* 2011;**77**:1541–1547.
23. Mehtar S, Wiid I, Todorov SD. The antimicrobial activity of copper and copper alloys against nosocomial pathogens and *Mycobacterium tuberculosis* isolated from healthcare facilities in the Western Cape: an in-vitro study. *J Hosp Infect* 2008;**68**:45–51.
24. Noyce JO, Michels H, Keevil CW. Inactivation of influenza A virus on copper versus stainless steel surfaces. *Appl Environ Microbiol* 2007;**73**:2748–2750.
25. Noyce JO, Michels H, Keevil CW. Use of copper cast alloys to control *Escherichia coli* O157 cross-contamination during food processing. *Appl Environ Microbiol* 2006;**72**:4239–4244.
26. Noyce JO, Michels H, Keevil CW. Potential use of copper surfaces to reduce survival of epidemic meticillin-resistant *Staphylococcus aureus* in the healthcare environment. *J Hosp Infect* 2006;**63**:289–297.
27. Espirito Santo C, Taudte N, Nies DH, Grass G. Contribution of copper ion resistance to survival of *Escherichia coli* on metallic copper surfaces. *Appl Environ Microbiol* 2008;**74**:977–986.
28. Casey AL, Adams D, Karpanen TJ, *et al*. Role of copper in reducing hospital environment contamination. *J Hosp Infect* 2010;**74**:72–77.
29. Karpanen TJ, Casey AL, Lambert PA, *et al*. The antimicrobial efficacy of copper alloy furnishing in the clinical environment: a crossover study. *Infect Control Hosp Epidemiol* 2012;**33**:3–9.
30. Marais F, Mehtar S, Chalkley L. Antimicrobial efficacy of copper touch surfaces in reducing environmental bioburden in a South African community healthcare facility. *J Hosp Infect* 2010;**74**:80–82.
31. Mikolay A, Huggett S, Tikana L, Grass G, Braun J, Nies DH. Survival of bacteria on metallic copper surfaces in a hospital trial. *Appl Microbiol Biotechnol* 2010;**87**:1875–1879.
32. Casey AL, Karpanen TJ, Adams D, *et al*. A comparative study to evaluate surface microbial contamination associated with copper-containing and stainless steel pens used by nurses in the critical care unit. *Am J Infect Control* 2011;**39**:e52–e54.
33. Borkow G, Zhou SS, Page T, Gabbay J. A novel anti-influenza copper oxide containing respiratory face mask. *PloS One* 2010;**5**:e11295.
34. Borkow G, Gabbay J, Dardik R, *et al*. Molecular mechanisms of enhanced wound healing by copper oxide-impregnated dressings. *Wound Repair Regen* 2010;**18**:266–275.
35. Zatcoff RC, Smith MS, Borkow G. Treatment of tinea pedis with socks containing copper-oxide impregnated fibers. *Foot (Edinb)* 2008;**18**:136–141.
36. Borkow G, Gabbay J. Biocidal textiles can help fight nosocomial infections. *Med Hypotheses* 2008;**70**:990–994.
37. Hall TJ, Wren MW, Jeanes A, Gant VA. A comparison of the anti-bacterial efficacy and cytotoxicity to cultured human skin cells of 7 commercial hand rubs and Xgel, a new copper-based biocidal hand rub. *Am J Infect Control* 2009;**37**:322–326.
38. Gant VA, Wren MW, Rollins MS, Jeanes A, Hickok SS, Hall TJ. Three novel highly charged copper-based biocides: safety and efficacy against healthcare-associated organisms. *J Antimicrobiol Chemother* 2007;**60**:294–299.
39. Hamilton D, Foster A, Ballantyne L, *et al*. Performance of ultra-microfibre cleaning technology with or without addition of a novel copper-based biocide. *J Hosp Infect* 2010;**74**:62–71.
40. Borkow G, Gabbay J. Copper as a biocidal tool. *Curr Med Chem* 2005;**12**:2163–2175.
41. Hasman H, Aarestrup FM. *tcrB*, a gene conferring transferable copper resistance in *Enterococcus faecium*: occurrence, transferability, and linkage to macrolide and glycopeptide resistance. *Antimicrob Agents Chemother* 2002;**46**:1410–1416.
42. Espirito Santo C, Morais PV, Grass G. Isolation and characterization of bacteria resistant to metallic copper surfaces. *Appl Environ Microbiol* 2010;**76**:1341–1348.
43. Efstathiou PA. The role of antimicrobial copper surfaces in reducing healthcare-associated infections. *Eur Infect Dis* 2011;**5**:125–128.
44. Wheeldon LJ, Worthington T, Lambert PA, Hilton AC, Lowden CJ, Elliott TS. Antimicrobial efficacy of copper surfaces against spores and vegetative cells of *Clostridium difficile*: the germination theory. *J Antimicrob Chemother* 2008;**62**:522–525.
45. Elguindi J, Hao X, Lin Y, Alwathnani HA, Wei G, Rensing C. Advantages and challenges of increased antimicrobial copper use and copper mining. *Appl Microbiol Biotechnol* 2011;**91**:237–249.
46. Airey P, Verran J. Potential use of copper as a hygienic surface; problems associated with cumulative soiling and cleaning. *J Hosp Infect* 2007;**67**:271–277.

http://www.epa.gov/pesticides/factsheets/copper-alloy-products.htm
Last updated on 05/09/2012

Pesticides: Topical & Chemical Fact Sheets

EPA registers copper-containing alloy products

Current as of May 2008

On February 29, 2008, EPA registered five copper-containing alloy products. The registration allows the registrant, the Copper Development Association (CDA) to market these products with a claim that copper, when used in accordance with the label, "kills 99.9% of bacteria within two hours." This Web page explains the conditions of the registration and provides information on the pesticidal claims.

Use of the products

These products will be marketed in sheets that can be fabricated into various articles such as door knobs, counter tops, hand rails, I.V. (intravenous) poles, and other objects found in commercial, residential, and healthcare settings.

The registered copper alloy may be used as a supplement to – not a substitute for – standard infection control practices. Users must continue to follow all current infection control practices, including those practices related to cleaning and disinfection of environmental surfaces.

Two conditions for registration were:

- The Copper Development Association (CDA) will prepare and implement an Antimicrobial Copper Alloy Stewardship Plan designed to support the responsible use of antimicrobial copper products; and
- For at least the first 24 months after registration and until the Agency terminates this condition, CDA will submit to EPA sample advertising materials representative of advertisements intended for use in the marketplace.

Risk findings

These products are registered under the Federal Insecticide, Fungicide, and Rodenticide Act's no "unreasonable adverse effects" standard. These products pose no risks to public health; copper products have been in use for centuries, and we know of no harm from such use.

The products have been rigorously tested and have demonstrated antimicrobial activity. After consulting with independent organizations – the Association for Professionals in Infection Control and Epidemiology and the American Society for Healthcare Environmental Services – as well as a leading expert in the field (Dr. William A. Rutala, Ph.D., M.P.H., University of North Carolina (UNC) Health Care System and UNC School of Medicine), the Agency has concluded that the use of these products could provide a benefit as a supplement to existing infection control measures.

In addition, EPA has required the registrant to take specific steps in its marketing of copper products to ensure that prospective purchasers understand the nature of the antimicrobial protection these products can provide and the importance of continuing to practice appropriate infection control measures diligently.

For further explanation of our "no risk concerns" position, see the copper Reregistration Eligibility Decision (RED) document.

Registrations by other manufacturers

To make the same type of pesticide claims as CDA, other manufacturers have two options:

1. file for EPA registration
2. seek to obtain a "Supplemental Distributor Registration," becoming a distributor of CDA's registrations to market products that make the same registration claims.

Related information

- What Are Antimicrobial Pesticides?
- Regulating Antimicrobial Pesticides

JOURNAL OF BIOLOGICAL ENGINEERING

RESEARCH Open Access

A demonstration of the antimicrobial effectiveness of various copper surfaces

Victor K Champagne[1] and Dennis J Helfritch[2*]

Abstract

Background: Bacterial contamination on touch surfaces results in increased risk of infection. In the last few decades, work has been done on the antimicrobial properties of copper and its alloys against a range of micro-organisms threatening public health in food processing, healthcare and air conditioning applications; however, an optimum copper method of surface deposition and mass structure has not been identified.

Results: A proof-of-concept study of the disinfection effectiveness of three copper surfaces was performed. The surfaces were produced by the deposition of copper using three methods of thermal spray, namely, plasma spray, wire arc spray and cold spray The surfaces were then inoculated with meticillin-resistant *Staphylococcus aureus* (MRSA). After a two hour exposure to the surfaces, the surviving MRSA were assayed and the results compared.
The differences in the copper depositions produced by the three thermal spray methods were examined in order to explain the mechanism that causes the observed differences in MRSA killing efficiencies. The cold spray deposition method was significantly more effective than the other methods. It was determined that work hardening caused by the high velocity particle impacts created by the cold spray technique results in a copper microstructure that enhances ionic diffusion, and copper ions are principally responsible for antimicrobial activity.

Conclusions: This test showed significant microbiologic differences between coatings produced by different spray techniques and demonstrates the importance of the copper application technique. The cold spray technique shows superior anti-microbial effectiveness caused by the high impact velocity imparted to the sprayed particles which results in high dislocation density and high ionic diffusivity.

Background

Bacterial growth on surfaces is a cause of concern in many hospitals and food processing industries due to the possibility of increased risk of bacterial infection [1]. The bacterial contamination of hospital surfaces, including patient rooms, nurse stations and kitchens has been extensively documented [2-5]. Contamination of meat and vegetable preparation surfaces, including refrigerators, and conveyors have also been the subject of investigation [6-10]. In addition to topically applied disinfectants, the use of surfaces that can self-disinfect would enhance overall infection prevention.

In the last few decades, work has been done on the antimicrobial properties of copper and its alloys against a range of micro-organisms threatening public health in food processing and healthcare applications [11]. The use of copper and copper alloys for frequently touched surfaces such as door and furniture hardware, bed rails, light switches and food preparation surfaces can help limit microbial infections in hospitals and food dispensing organizations. Michels, et al. [12] show that increasing the copper content of alloys increases antimicrobial effectiveness. The contact killing is so rapid that the production of protective biofilms is not possible [13].

The specific mechanism by which copper affects cellular structures is not yet proven, but the active agent of cell destruction is generally considered to be the copper ion [11,14,15].

Recent studies showed that large amounts of copper ions were taken up by E. coli over 90 min, when cells were applied to copper coupons via an aqueous suspension (a standing drop). When cells were plated on copper using minimum liquid and a drying time of 5 seconds, the accumulation of copper ions by cells was even more dramatic, reaching a high concentration in a fraction of the time.

* Correspondence: dennis.j.helfritch.ctr@mail.mil
[2]Dynamic Science, Aberdeen, MD, USA
Full list of author information is available at the end of the article

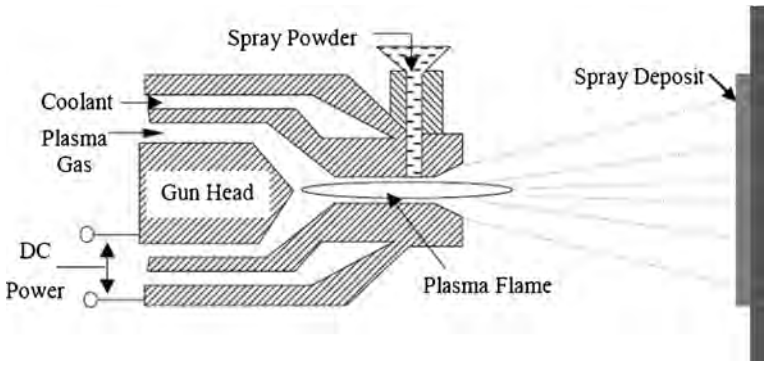


Figure 1 The plasma spray deposition system.

The copper ion level of cells remained high throughout the killing phase, suggesting that cells become overwhelmed by their intracellular copper [15]. The grain structure of the copper material affects ion diffusion and hence affects bacterial destruction by copper ions.

The US Environmental Protection Agency (EPA) registers five copper alloys with public health claims [16]. All of the alloys have minimum nominal copper concentrations of 60%. Registration of copper and certain copper alloys such as brass and bronze means that the EPA recognizes these solid materials' antimicrobial properties. Products made from any of the registered alloys are legally permitted to make public health claims relating to the control of organisms that pose a threat to human health. Laboratory studies conducted under EPA-approved protocols have proven copper's ability to kill, within 2 hours of contact time, more than 99.9% of the following disease-causing bacteria: *Staphylococcus aureus, Enterobacter aerogenes, Escherichia coli* O157:H7, *Pseudomonas aeruginosa,* Vancomycin-resistant *Enterococcus faecalis* (VRE) and MRSA.

Copper surface generation

In order to make use of the antimicrobial ability of copper, surfaces that contact skin and foods should be composed of copper or copper alloy. This can be accomplished with solid copper equipment or by means of copper surface coating. In general, cost considerations favour copper coatings over solid structural copper. Various metal spray techniques are available for the purpose of depositing a copper surface onto implements that can transmit microorganisms, and it is desired to identify an optimal deposition method. Accordingly, three metal spray techniques are evaluated with respect to the anti-microbial activity of the copper surfaces produced by each.

Plasma spray

The plasma spray process shown in Figure 1 uses a DC electric arc to generate a stream of high temperature ionized plasma gas, which acts as the spraying heat source. The coating material, in powder form and carried by an inert gas, is injected into the plasma jet where it is melted and propelled towards the substrate.

The plasma spray gun includes a copper anode and tungsten cathode, which are both water cooled. Plasma gas (argon, nitrogen, hydrogen, helium) flows around the cathode and through the anode, which is shaped as a constricting nozzle. The plasma, containing suspended

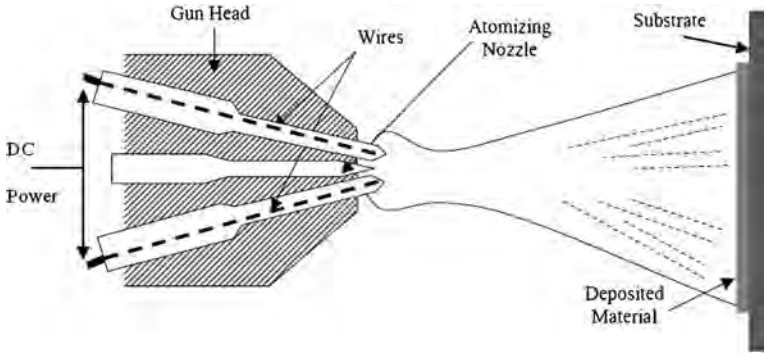


Figure 2 The wire Arc spray deposition system.

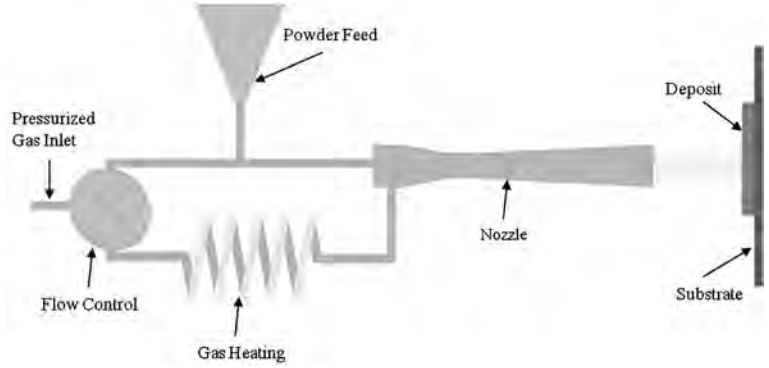


Figure 3 The cold spray deposition system.

metal droplets, exits in the anode nozzle and is directed toward a surface, where the particles deposit.

Arc spray

The arc spray process shown in Figure 2 creates an arc between two metallic wires acting as consumable electrodes. A DC voltage is applied between the wires, and an arc discharge is created at the contact of the wires. The wire electrodes are melted by the electric arc and a compressed air jet disperses the molten droplets and propels them onto a surface.

Cold spray

The cold spray process shown in Figure 3 imparts supersonic velocities to metal particles by placing them in a heated nitrogen or helium gas stream that is expanded through a converging–diverging nozzle. The powder feed is inserted at high pressure at the nozzle entrance. The particles, entrained within the gas, are directed towards a surface, where they are embedded on impact, forming a strong bond with the surface. The term "cold spray" has been used to describe this process due to the relatively low temperatures (100-500°C) of the expanded gas stream that exits the nozzle. Subsequent spray passes increase the structure thickness. The adhesion of the metal powder to the substrate, as well as the cohesion of the deposited material, is accomplished in the solid state.

The relatively low porosity of the cold spray coating results from particle packing caused by high velocity impact. Another characteristic of high velocity impacts is the creation of grain dislocations and work hardening. The low oxide content of cold sprayed deposits occurs because the particle temperature remains low and thus inhibits oxidation.

The spray techniques described each produce impacting metal particles in distinct temperature and velocity ranges. These temperatures and velocities create metal coatings with different characteristics with respect to the presence of oxides, porosity, grain dislocations, and hardness. Because of these metallurgic differences, it is reasonable to assume that the coatings will exhibit differences in antimicrobial efficiency. Table 1 gives the particle temperatures and impact velocities, as well as the porosity and oxide ranges of the resulting deposits.

Test procedure

These three surface coating techniques were used to produce copper-coated metal coupons. Approximately 1 mm thick coatings were applied to aluminum substrates. The coatings completely covered the metal substrates with an impervious seal. The copper powder feedstock used for the plasma and cold sprays is shown in Figure 4. Cross sections of the coupons produced by the three spray techniques are shown in Figures 5, 6 and 7. Differences in microstructure are clearly evident, suggesting that differences in biological activity may also occur. Evidence of particle melting is clear for the high-temperature plasma and wire arc processes. The incidence of large voids is seen in the wire arc process cross section.

The coated coupons were inoculated with MRSA. The plated samples were then held at room temperature for two hours, after which survivors were resuspended and cultured. This procedure followed the EPA Protocol [17] "Test Method for Efficacy of Copper Alloy Surfaces as a Sanitizer". The details of this procedure are given below [17-20].

Carrier surfaces and preparation

The copper coupon surfaces were utilized as the test carriers and stainless steel squares were used as control

Table 1 Typical spray gun operating parameters

Spray/ Property	Temperature °C	Velocity, m/s	Porosity, %	Oxides, %
Plasma	2500 - 3500	100 - 300	1 - 10	1 - 3
Wire Arc	2500 - 3500	50 - 100	5 - 20	10 - 20
Cold Spray	100 - 500	600 - 1000	<1	<1

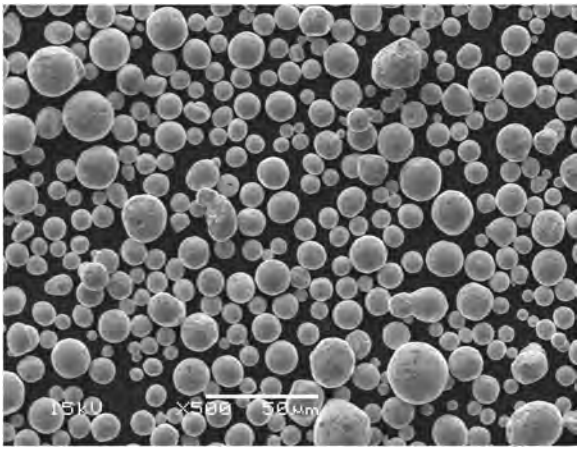


Figure 4 Feedstock copper powder for plasma and cold spray.

carriers. The carriers were dipped into ethanol, rinsed with deionized water, and allowed to air dry. The carriers were autoclaved prior to use in test. After sterilization, each carrier was placed into a Petri dish matted with two pieces of filter paper.

Preparation of test organisms

Ten (10) mL tubes of Synthetic Broth were inoculated from stock cultures and incubated for 24 hours at 36°C. Using a 4-mm inside diameter disposable sterile plastic transfer loop, at least three consecutive daily transfers of cultures were made in Synthetic Broth prior to use as test inoculum. Two loopfuls of culture were transferred to 10 ml broth medium and incubated for 48 hours.

The culture was thoroughly mixed on a "vortex" mixer and allowed to settle. The upper two thirds of this suspension was used as the inoculum for testing.

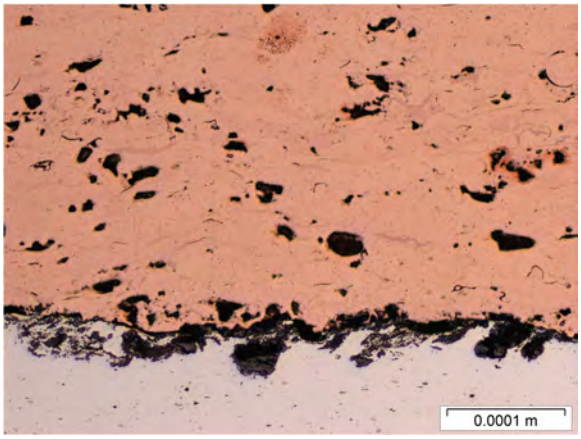


Figure 6 Cross sectional view of the wire arc sprayed copper deposit.

Addition of organic soil load

An organic soil load containing Triton X-100 (to aid in spreading of the inoculums) was added to the test culture. A 0.25 ml aliquot of fetal bovine serum and 0.05 mL aliquot of 1% Triton X-100 was added to 4.70 ml of culture to yield a 5% fetal bovine serum and 0.01% Triton X-100 soil load.

Inoculation of carriers

Each test and control carrier was inoculated at staggered intervals with 0.02 ml of 48 hour culture using a calibrated pipettor. The inoculum was spread to within 3 mm of the edges of the carrier. The lids of the Petri dishes were replaced and the carriers were held at room temperature (20°C) for 2 hours. The exposure period began immediately after inoculation.

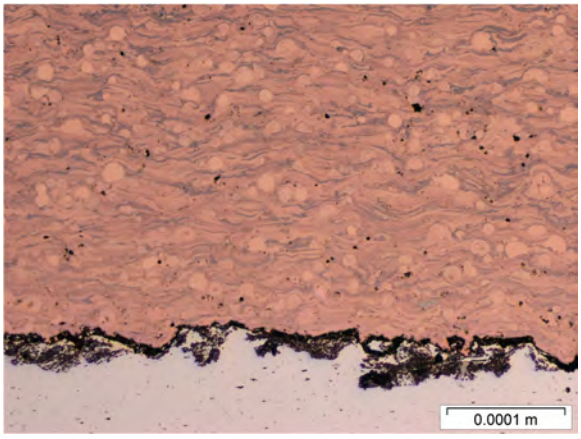


Figure 5 Cross sectional view of the plasma sprayed copper deposit.

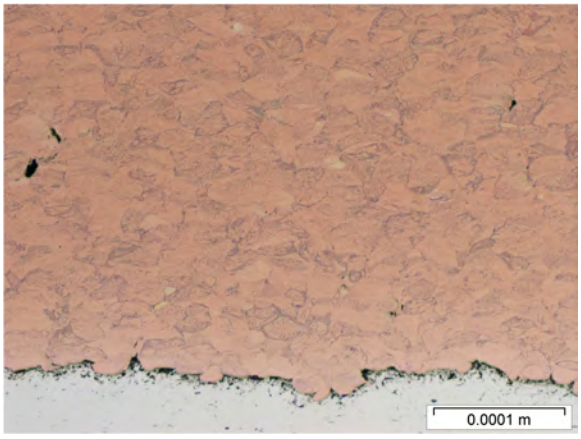


Figure 7 Cross sectional view of the cold sprayed copper deposit.

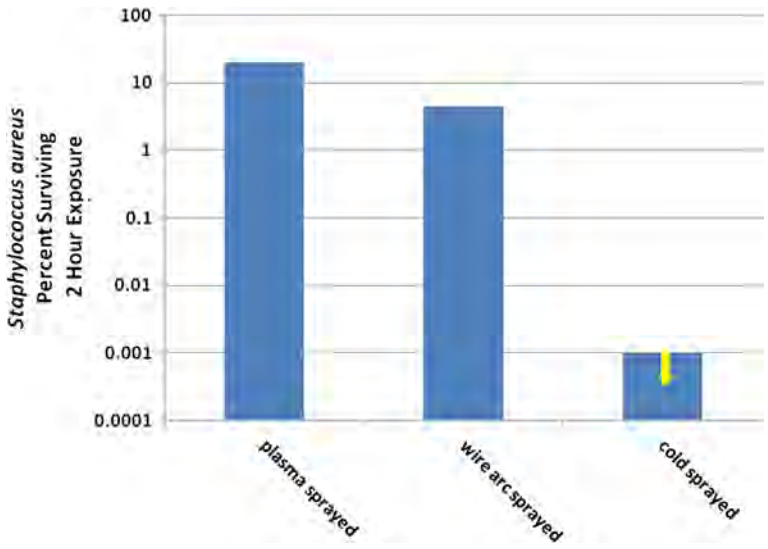


Figure 8 Percent MRSA surviving after exposure to various copper deposits.

Neutralization and subculture

Following the 2 hour exposure, the carriers were transferred to jars containing 20 mL of Letheen Broth + 0.07% Lecithin + 0.5% Tween 80 at staggered intervals. Each neutralizer jar was sonicated for five minutes to suspend any survivors and rotated to mix. Serial dilutions (10^{0} – 10^{-4}) of the neutralized solution from each of the jars were prepared. One (1.0) mL aliquots of those dilutions were plated in duplicate using standard spread plate technique onto sheep blood agar plates (BAP).

Incubation and observation

The plates were incubated at 36°C for 44 hours prior to observation and enumeration. Following incubation, the plates were visually enumerated. Subcultures containing 30–300 colonies were used for calculations.

Results and discussion

The reduction of inoculated *S. aureus* was normalized by the results of the control exposure to a stainless steel surface. The results of these tests in terms of the percent of surviving *S. aureus* after two hours are shown in Figure 8. The result for cold spray was below minimal measurement thresholds and is thus reported as "less than".

The results show a greater than three order of magnitude difference in kill efficiency between the plasma and wire arc methods and the cold spray method of copper deposition. This large difference in anti-microbial effectiveness between copper spray deposition methods requires an examination of how the deposition mechanism affects the nature of the copper. The plasma and wire arc methods deposit molten particles at relatively low velocity (<200 m/s). The cold spray method deposits solid particles at high velocity (>600 m/s). Champagne, et al. [21] have shown that the high velocity impacts of cold sprayed particles lead to extreme work hardening and correspondingly high dislocation density within the deposit. For example, the Vickers Hardness values for plasma, wire arc, and cold spray deposited copper were 94, 105, and 141, respectively. Ion diffusion in metals is augmented by the presence of grain dislocations, known as "pipe diffusion", and ionic diffusion occurs principally through these dislocations. The relationship between

Figure 9 Hospital table coated with cold-sprayed copper.

dislocation density and Vickers Hardness is [22] $\rho \propto H^2$, and the relationship between diffusivity and displacement density is given by [23] $D_p \propto \rho$. Diffusivity in metals thus varies as the square of hardness and is therefore very sensitive to impact hardening by cold spray deposition. The diffusion of copper ions can therefore be significantly increased through the hardness increase produced by the cold spray process, which serves to enhance the flow of Cu^{2+} ions needed for microbial destruction.

Conclusions

The effectiveness of copper and copper alloys as anti-microbial coatings on touch-surfaces has been well documented by many researchers [5-7,10,12-15]. Except for the copper content of alloys, the effects of the metallurgical properties of the copper coatings have not been investigated by these efforts. The significant anti-microbiologic differences between coatings produced by different spray techniques, as shown here, demonstrate the importance of the copper application technique and of the resulting deposition structure. The cold spray technique showed superior anti-microbial effectiveness caused by the high impact velocity imparted to the sprayed particles which results in high dislocation density and high ionic copper diffusivity.

The cold spray process is a mature technology which is currently in use for a variety of applications requiring various metal coatings. The cold spray process can readily apply copper coatings onto touch surfaces. Figure 9 is an example of copper coating by cold spray. The hospital tray and the entire metal support structure of the hospital table have been coated with cold-sprayed pure copper. In addition to providing highly efficient antimicrobial surfaces, the cold spray technique is less likely to damage heat sensitive substrates than are high temperature thermal sprays. This work is a proof-of-concept effort, and additional, more statistically significant, work should be performed in order to justify commercialization.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

VKC conceived and directed the test program. DJH interpreted the test results and justified the mechanism. Both authors read and approved the final manuscript.

Acknowledgements

The sanitizer efficacy testing conducted against *Staphylococcus aureus* and reported in this paper was carried out under contract by ATS Labs at Eagan MN. The experiments were performed by Amy Jeske and Becky Lien.

Author details

[1]U.S. Army Research Laboratory, Aberdeen Proving Ground, MD, USA.
[2]Dynamic Science, Aberdeen, MD, USA.

Received: 24 January 2013 Accepted: 15 March 2013
Published: 27 March 2013

References

1. Page K, Wilson M, Parkin I: **Antimicrobial surfaces and their potential in reducing the role of the inanimate environment in the incidence of hospital-acquired infections.** *J Mater Chem* 2009, **19:**3819–3831.
2. Aycicek H, Oguz U, Karci K: **Comparison of results of ATP bioluminescence and traditional hygiene swabbing methods for the determination of surface cleanliness at a hospital kitchen.** *Int J Hyg Environ Health* 2006, **209:**203–206.
3. Bernard L, Kereveur A, Durand D, Gonot J, Goldstein F, Mainardi J, Acar J, Carlet J: **Bacterial contamination of hospital physicians' stethoscopes.** *Infect Control Hosp Epidemiol* 1999, **20:**626–628.
4. Rutala WA, Katz EB, Sherertz RJ, Sarubbi FA: **Environmental-study of a methicillin-resistant staphylococcus -aureus epidemic in a burn unit.** *J Clin Microbiol* 1983, **18:**683–688.
5. White LF, Dancer SJ, Robertson C: **A microbiological evaluation of hospital cleaning methods.** *Int J Environ Health Res* 2007, **17:**285–295.
6. Faúndez G, Troncoso M, Navarrete P, Figueroa G: **Antimicrobial activity of copper surfaces against suspensions of *Salmonella enterica* and *Campylobacter jejuni*.** *BMC Microbiol* 2004, **4:**19.
7. Gounadaki S, Skandamis PN, Drosinos EH, Nychas GJ: **Microbial ecology of food contact surfaces and products of small-scale facilities producing traditional sausages.** *Food Microbiol* 2008, **25:**313–323.
8. Jackson V, Blair IS, McDowell DA, Kennedy J, Bolton DJ: **The incidence of significant foodborne pathogens in domestic refrigerators.** *Food Control* 2007, **18:**346–351.
9. Kaneko K, Hayashidani H, Takahashi K, Shiraki Y, Limawongpranee S, Ogawa M: **Bacterial contamination in the environment of food factories processing ready-to-eat fresh vegetables.** *J Food Prot* 1999, **62:**800–804.
10. Noyce J, Michels H, Keevil C: **Use of copper cast alloys to control *Escherichia coli* O157 cross-contamination during food processing.** *Appl Environ Microbiol* 2006, **72:**4239–4244.
11. Grass G, Rensing C, Solioz M: **Metallic copper as an antimicrobial surface.** *Appl Environ Microbiol* 2011, **76:**1541–1547.
12. Michels H, Wilks S, Noyce J, Keevil C: *Copper Alloys for Human Infectious Disease Control.* Pittsburgh, PA: Proceedings of the Materials Science and Technology Conference; 2005.
13. Nie Y, Kalapos C, Nie X, Murphy M, Hussein R, Zhang J: **Superhydrophilicity and antibacterial property of a Cu-dotted oxide coating surface.** *Ann Clin Microbiol Antimicrob* 2010, **9:**25.
14. Raffi M, Mehrwan S, Bhatti T, Akhter J, Hameed A, Yawar W, Masood Ul Hasan M: **Investigations into the antibacterial behavior of copper nanoparticles against Escherichia coli.** *Ann Microbiol* 2010, **60:**75–80.
15. Santo CE, Lam EW, Elowsky CG, Quaranta D, Domaille DW, Chang CJ, Grass G: **Bacterial killing by dry metallic copper surfaces.** *Appl Environ Microbiol* 2011, **77:**794–802.
16. EPA registers copper-containing alloy products. www.epa.gov/pesticides/factsheets/copper-alloy-products.htm.
17. Test method for efficacy of copper alloy surfaces as a sanitizer. www.epa.gov/oppad001/pdf_files/test_method_copper_alloy_surfaces.pdf.
18. Lien B: *Test Method for Determining the Efficacy of Antimicrobial Surfaces as Sanitizers.* Eagan: ATS Labs Report A09966; 2010.
19. Jeske A: *Custom Microbiology – Evaluation of Coated Copper Surfaces.* Eagan: ATS Labs; 2009 Report.
20. Jeske A: *Custom Microbiology – Evaluation of Cold Spray Copper Surfaces*, ATS Labs Report. Eagan: ATS Labs; 2008. Report A06255.
21. Champagne V, Helfritch D, Trexler M: **Some Material Characteristics of Cold-Sprayed Structures.** *Res Lett Mater Sci* 2007, **2007:**ID 27347.
22. Al-Rub R, Faruk NM: **Dislocation-based model for predicting size-scale effects on the micro and nano indentation hardness of metallic materials.** *Int J Mater Struct Integrity* 2010, **4:**251–277.
23. Hart EW: **On the role of dislocations in bulk diffusion.** *Acta Metall* 1957, **5:**597.

doi:10.1186/1754-1611-7-8
Cite this article as: Champagne and Helfritch: **A demonstration of the antimicrobial effectiveness of various copper surfaces.** *Journal of Biological Engineering* 2013 **7**:8.

Journal of Hospital Infection (2007) **67**, 271–277

Available online at www.sciencedirect.com

ScienceDirect

www.elsevierhealth.com/journals/jhin

Potential use of copper as a hygienic surface; problems associated with cumulative soiling and cleaning

P. Airey, J. Verran*

Manchester Metropolitan University, Manchester, UK

Received 15 August 2007; accepted 5 September 2007
Available online 24 October 2007

KEYWORDS
Disinfection; Hospital-acquired infection; Hygiene; Infection control; *Staphylococcus aureus*

Summary It has been suggested that antibacterial copper could be used in place of stainless steel to help reduce the occurrence of hospital-acquired infections. The antibacterial activity of copper has been clearly demonstrated when using cell suspensions held in prolonged contact with copper or copper alloys. The aim of this study was to evaluate the antimicrobial properties of copper in comparison with stainless steel in a generally dry environment. Three stainless steels of varying surface finish and polished copper were soiled with *Staphylococcus aureus* suspended in a protein-based organic soil (bovine serum album), dried rapidly, and then incubated for 24 h. Surfaces were then wiped clean using a standardised wiping procedure with two cleaning agents recommended by UK National Health Service guidelines. This soiling/cleaning procedure was carried out daily over five days. After each cleaning cycle the amount of residual soil and live cells was assessed using direct epifluorescence microscopy. All materials were easily cleaned after the first soiling episode but a build-up of cells and soil was observed on the copper surfaces after several cleaning/wiping cycles. Stainless steel remained highly cleanable. Accumulation of material on copper is presumably due to the high reactivity of copper, resulting in surface conditioning. This phenomenon will affect subsequent cleaning, aesthetic properties and possibly antibacterial performance. It is important to select the appropriate cleaning/disinfecting protocols for selected surfaces.

* Corresponding author. Address: Manchester Metropolitan University, Manchester, UK. Tel.:+44 0161 247 1206.
E-mail address: j.verran@mmu.ac.uk

0195-6701/$ - see front matter
doi:10.1016/j.jhin.2007.09.002

Introduction

It has long been recognised that contamination of surfaces by pathogenic micro-organisms can compromise overall environmental hygiene.[1] In the hospital, contamination of open, metal surfaces, such as door plates and handles, bed rails and operating trolleys, will occur either by contact with the hand, spillage/splashing with non-sterile solutions or via aerosols.

To prevent subsequent further cross-contamination these surfaces should be cleaned and disinfected regularly.[2,3] Selection of an appropriate cleaning regimen is therefore critical.

Stainless steel is commonly found in the healthcare environment because it can be manufactured to produce a smooth aesthetically pleasing finish that looks clean. Stainless steel surfaces are also, under most circumstances, stable and inert.[4–7] It has been suggested that metals such as copper and silver, with antibacterial behaviour based on the release of biotoxic ions, may be better suited for certain hospital and healthcare environmental applications, especially in the context of the problem of hospital-acquired infections (HAIs).[8,9] Copper in particular is known to possess strong antibacterial activity and it has been reported that 100% of a large population (10^7 cfu/ml) of meticillin-resistant *Staphylococcus aureus* (MRSA) were killed in 45 min when exposed to pure copper.[8] Similar results have been reported for *Escherichia coli* and *Listeria monocytogenes*.[10,11] Copper alloys, such as brass, also exhibit antibacterial activity dependent on copper content.[8,10] A likely mechanism is thought to be the inhibition of the respiratory cycle of microorganisms by copper ions. Although there have been extensive laboratory tests there appear to have been few observations made under simulated conditions of sustained exposure. For example, in the hospital environment the majority of surfaces undergo wet–dry cycles during both service and cleaning conditions.[12] In addition, there are few data for the effects of cleansing and disinfecting agents on surface activity. In terms of surface hygiene assessment and ease of cleaning, there is a need for a test procedure that more closely resembles the situation in situ. Survival is rarely monitored on antibacterial surfaces under dry conditions although the need for such a test has been recognised.[12,13]

The aim of this study was to extend the knowledge in this area, by comparing inert and active surfaces. *S. aureus* in a protein-based organic soil (bovine serum album) was used as a model contaminated soil. Selected stainless steel and copper surfaces were used to assess levels of bacterial survival and ease of cleaning after repeated fouling episodes.

Methods

Four test surfaces were used in this study; one nominally pure copper (99.97%: to compositional requirements of ASTM B380) and three stainless steels of the widely used BSEN 1.4301 (ASTM 304) type, each of varying finish. The copper was stockholder-supplied with a polished finish. The three finishes for the selected stainless steels were bright annealed (BA) (Outokumpu Stainless Ltd, Sheffield UK), bright annealed and electropolished, and a fine mechanical (mirror) polish (Rimex Metals Ltd, Enfield, UK).

All materials were approximately 1 mm thick and were cut, on a guillotine, into 6 cm × 3 cm coupons. Prior to use, the protective plastic coatings on the as-delivered surfaces were removed. All coupons were cleaned and disinfected by wiping with acetone and were rinsed with copious amounts of filter-sterilised deionised water. Each coupon was air-dried and stored at room temperature in a separate Petri dish until required. All experimental work was carried out in a class II air flow cabinet.

In order to compare the topography of the test substrata studied in the present work, white light interferometry (WLI) (Omniscan, Wrexham, UK) was used and roughness measurements were taken: ten random three-dimensional images were obtained for all four surfaces each of 80 μm × 80 μm. The Ra (a widely used indicator of surface roughness) was derived using the software [scanning probe imagine processor (Hørsholm, Denmark)] along one randomly selected two-dimensional plane for each image. When the surfaces showed evidence of unidirectional polishing features, measurements were taken out perpendicular to the linear features.

Microorganisms

Stocks of *Staphylococcus aureus* (NCIMB 9518) were prepared by adding 0.5 ml aliquots of 18 h culture in nutrient broth (Oxoid, Hampshire, UK) to 1.0 ml glycerol (BDH, Hampshire, UK) and stored at −20°C. Aliquots of these were inoculated onto nutrient agar (Oxoid) monthly. Plates were incubated for 24 h at 37°C, and maintained at 4°C until required.

Test suspension

One colony of *S. aureus* was inoculated from a stock plate into 25 mL nutrient broth (Oxoid, Hampshire, UK) and incubated for 24 h at 37°C with shaking. To minimise nutrient carry-over, cells were washed three times in 10 ml phosphate-buffered saline (PBS) (Oxoid) and finally resuspended in 25 ml 1% bovine serum album (BSA) (Sigma, filter-sterilised). Serial dilutions into sterile 9 ml PBS were performed to determine the initial viable cell concentration ($9.2 \pm 1.3 \times 10^7$ cfu/mL) by the spread plate method.

Contamination of surfaces

It has been suggested that the number of viable cells present on open, dry surfaces in hospitals can vary between 0 and 100 cfu/cm^2.[2] The test suspension was diluted by transferring 1 mL into 9 mL 1% BSA (filter-sterilised) in order to obtain a contaminated surface relating to the upper limit of this range. Ten microlitres of this diluted test suspension was then deposited and spread on the test coupons over an area of 10 cm^2 (5 cm $\times$ 2 cm) using a glass spreader with three wipes back and forth. The glass spreader was cleaned between wipes by submerging it in ethanol, passing it through a flame, wiping with moist paper tissue then dipping in ethanol and flame-sterilising again before the re-soiling cycle. Contaminated test pieces were then left in the class II air flow cabinet, with the Petri dish lid displaced until dry (approximately 5 min). All soiled coupons were incubated for 24 h at 25°C ($\pm$ 2°C) and 50% ($\pm$ 3%) humidity prior to being cleaned.

Simulated cleaning

After 24 h at 25°C incubation the coupons were wiped clean using a crockmeter (Atlas Electric Devices Co., Chicago, IL, USA). This is a device commonly used in the textile industry to assess fabric colourfastness when subjected to a repeated, consistent, wiping procedure. A cloth is applied to the nib of the crockmeter (Figure 1) and the instrument applies a constant pressure to the surface enabling different surfaces to be cleaned under comparable conditions. Using this standardised wiping mechanism, the surfaces were cleaned with two liquid cleaning agents commonly used in the National Health Service (NHS).[14] Solutions of 1% sodium hypochlorite (BDH, Poole, UK) and 70% industrial methylated spirit (BDH) were prepared for use with deionised water, and were then filter-sterilised.

An 8 cm $\times$ 2 cm rectangle of household blue cleaning cloth (Tesco own brand, Tesco Stores, UK) was folded twice to produce a square (2 cm $\times$ 2 cm) and was loaded with 0.5 ml liquid cleaning agent. The cloth was then mounted onto the tip of the crockmeter and the coupons wiped five times back and forth (giving 10 wipes in total under a pressure/load of 900 g). Care was taken to ensure the cloth area was placed on to, and removed from, the surface at a location where

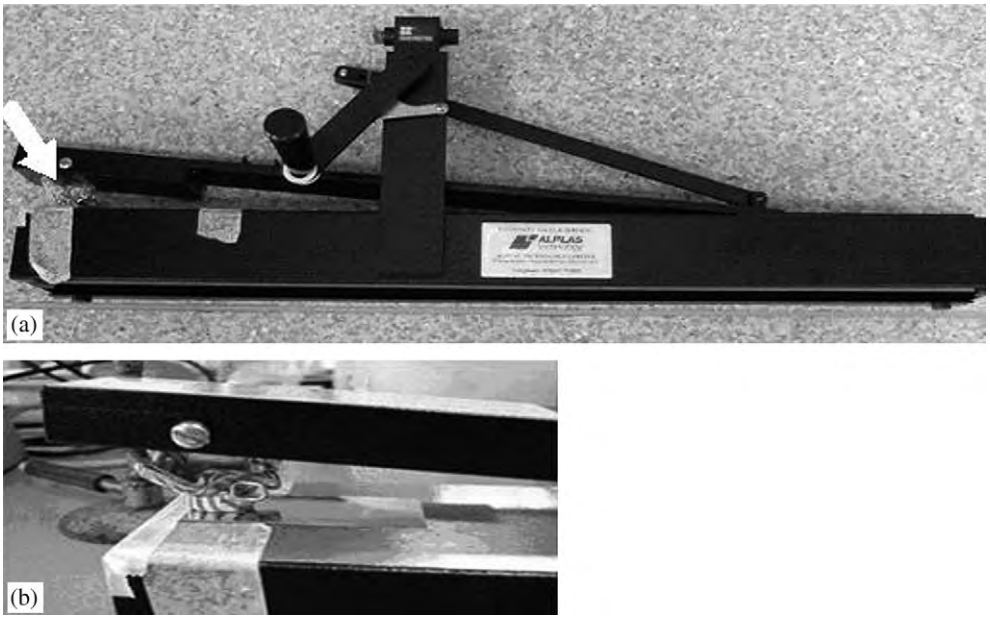


Figure 1 (a) The crockmeter, showing the area where the surfaces are 'cleaned' (arrowed) and (b) the nib of the crockmeter with the cleaning cloth is attached.

soiling was absent. When the surface possessed a directional finish (visible to the naked eye) the 'wiping' motion was carried out perpendicular to the surface features.

One set of eight coupons (one of each of the four finishes; cleaned with the two detergents) was retained and rinsed with approximately 50 ml filter sterilised deionised water run from a wash bottle, while holding the coupons at an angle. The remaining 32 samples were recontaminated using the soiling technique, described previously. The coupons were stored and cleaned on the crockmeter the following day. The soiling and cleaning procedure was repeated at further 24 hour intervals for up to five days and a set of surfaces was retained for hygienic assessment at each of these 24 h intervals.

Monitoring hygiene

The number of viable cells and the amount of remaining organic soil was assessed. Survival was assessed using live/dead differential staining. The Live Dead Baclight® bacterial viability kit is supplied with two dyes. When examined under an epifluorescence microscope (Nikon, Kingston, Surrey, UK), equipped with the correct filters, SYTO 9 labels all bacteria green and emits at 500 nm, whereas propidium iodide, which is the dominant dye, labels red only cells with damaged membranes and emits at 635 nm. The ratio that produced the clearest images was found to be one part SYTO 9 to two parts propidium iodide in four parts filter-sterilised deionised water. Test surfaces were mounted on to a glass side using double-sided adhesive tape. The dye was added to one half of the area that had been soiled and cleaned and then examined under an epifluorescence microscope (Nikon). Ten random fields of view were examined using the highest objective on the microscope that did not require oil immersion ($\times$40). The number of live cells within each field of view was counted. When it was not possible to count all of the cells on heavily contaminated coupons when more than 100 live cells per field of view were present, the result was recorded as 100.

The amount of residual soil was assessed for the other half of the coupons. Coupons were stained with 0.03% acridine orange (Sigma; filter-sterilised) for 1 min. This stained both BSA and cells. The test pieces were then rinsed with filter sterilised deionised water and examined using epifluorescence microscopy ($\times$ 40 magnification). The percentage of a microscopic field covered by stained material was calculated using Cell^F image analysis software for 10 randomly selected fields of view for each test piece.

The baseline was established by examining an unsoiled, uncleaned but stained area, and fluorescence was set to 0% coverage. An area that had been soiled and stained but not cleaned was examined and fluorescence was set at 100% coverage.

Results

Surface roughness

All surfaces had Ra values lower than that considered to be appropriate for a material to be used in a hygienic environment (0.8 μm).[15] Ra values for the bright annealed and electropolished stainless steels and the polished copper were very similar in terms of surface roughness ($P < 0.05$). The Ra value for the Rimex mirror finish was 10-fold lower than the other surfaces.

Bacterial survival

After the initial cleaning operations with either 1% sodium hypochlorite or 70% industrial methylated spirit, no cells were observed on the Rimex mirror finish stainless steel. On the cleaned areas for the bright annealed and electropolished finishes it was rare to observe more than 10 cells per field. This trend did not alter after repeated soiling/cleaning over five days. For copper surfaces cleaned with 1% sodium hypochlorite no cells were observed after the first soiling/cleaning procedure. After repeated soiling, over two, three, four and five days, however, there was a significant residual cell mass, with $>$100 viable cells observed on every field of view (Figure 2a). More variability was observed for the copper surfaces cleaned with 70% industrial methylated spirit (Figure 3) but the overall trend was repeated in that there was a build-up of cells, although these were in isolated areas (Figure 2b and c).

Residual organic soil

For all repeated soiling and cleaning procedures, Rimex mirror-finished stainless steel consistently retained the lowest levels of soil (Figure 4), and the percentage coverage values actually decreased as the number of soiling/cleaning cycles increased. Similar trends were noted for the other two stainless steel finishes. Following one soiling/cleaning cycle, the copper [3.88% ($\pm$ 0.33) remaining fluorescent material] was cleaned more efficiently than the electropolished [5.23%

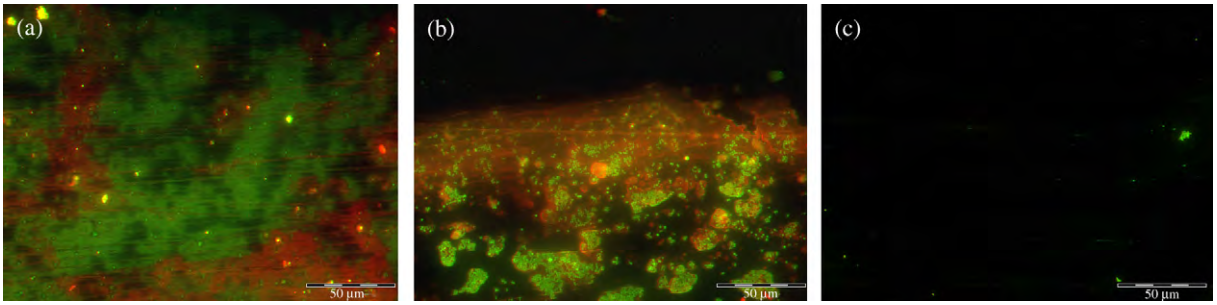


Figure 2 *S. aureus* and bovine serum album (BSA) on copper surfaces imaged using live/dead differential staining and direct epifluorescence microscopy. Live cells were labelled green and dead cells red. When copper had been subjected to five soiling and cleaning cycles, using 1% hypochlorite as the detergent, a build-up of live cells (≥100 per field of view) and soil was observed (a). Copper surfaces that had been subjected to five soiling and cleaning cycles, using 70% industrial methylated spirit as the detergent, displayed areas where there was a build-up of cells and soil (b) and relatively clean areas where there were few cells and residual soil (c).

(± 1.23)] and bright annealed [5.74% (± 0.98)] finished stainless steels. Following the second soiling cycle the amount of stained organic material increased substantially, and was not removed for any of the subsequent soiling/cleaning cycles.

Discussion

Open surfaces in clinical environments, such as the hospital ward, should be cleaned regularly.[2,3] One key objective of this study was to develop laboratory techniques to simulate the effectiveness of daily cleaning of open surfaces where a low level of bacterial contamination is present. It involves deliberately contaminating surfaces with a protein soil (BSA) inoculated with a known concentration of bacteria, and cleaning daily using a standardised wiping procedure. An important component of the test procedure is the cyclic recontamination and reassessment of soils and cells.

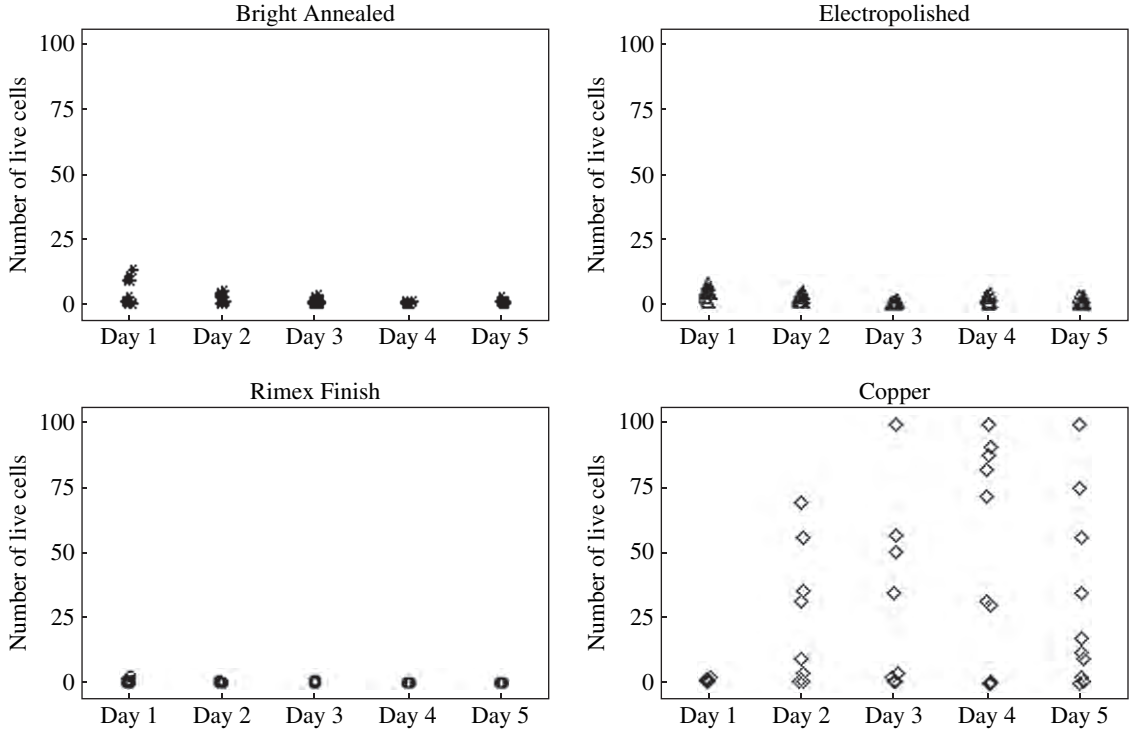


Figure 3 The number of live cells detected per field of view after deliberate daily soiling and cleaning with 70% industrial methylated spirit. For each day, 10 fields of view were examined per substratum.

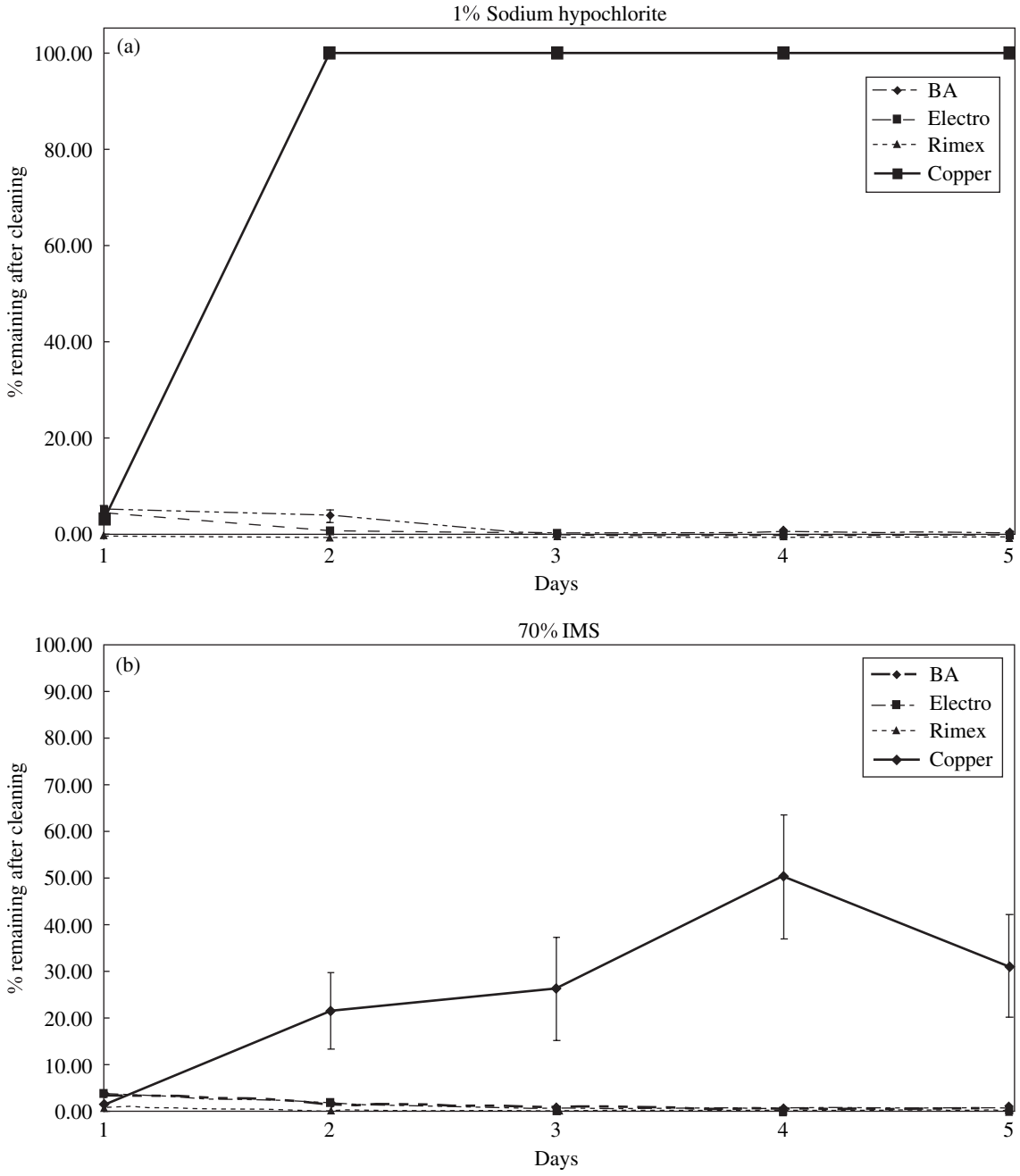


Figure 4 Bright annealed (BA), electropolished (Electro), Rimex mirror finish (Rimex) stainless steel finishes and polished copper were soiled with *S. aureus* suspended in 1% bovine serum albumin and cleaned using a standardised wiping device at daily intervals for up to five days. Two detergents were used: 1% sodium hypochlorite (a) and 70% industrial methylated spirit (IMS) (b). Following staining with acridine orange the percentage of a field covered by stained material was assessed at 10 random locations in the 'clean' area.

All test surfaces were smooth with Ra values lower than that recommended for a hygienic surface ($Ra < 0.8\ \mu m$).[15]

After the first soiling/cleaning cycle, a large decrease in the number of microorganisms and BSA was observed for all four test surfaces. After the second soiling/cleaning cycle it appeared that, for copper, the application of cleaning agent caused subsequent layers of the BSA-bacteria soil to bond more strongly to the surface, increasing its resistance to cleaning. The performance of stainless steel surfaces was unchanged. There was an increase in the number of viable cells on the surface of the soil indicating some inhibition of the active

copper species to the bacteria newly deposited on the soil.

The relatively low-cost cleaning agents used in this study are commonly used in hospitals.[14] 1% hypochlorite is recommended to disinfect surfaces soiled with body solutions (e.g. proteins or blood), whereas 70% industrial methylated spirit is recommended to clean open hard surfaces such as contaminated trolleys. It appears that both of these common agents react with copper. If copper is to be used in the hospital environment as an antibacterial surface, then cleaning and disinfection practices need to be re-examined to ensure that surfaces are cleaned with a formulation that ensures effective cleaning.

Clearly, there is considerable scope for further studies to evaluate surfaces.

Conflict of interest statement
None declared.

Funding sources
Experimental work carried out as part of a PhD project (PA) funded by a EPSRC CASE award with the OutoKumpu UK Stainless UK Research Foundation.

References

1. Sanborn WR. The relation of surface contamination to the transmission of disease. *Am J Publ Hlth Nations Hlth* 1963;**53**:1278—1283.
2. Griffith CJ, Cooper RA, Gilmore J, Davies C, Lewis M. An evaluation of hospital cleaning regimes and standards. *J Hosp Infect* 2000;**45**:19—28.
3. French GL, Otter JA, Shannon KP, Adams NMT, Watling D, Parks MJ. Tackling contamination of the hospital environment by methicillin-resistant *Staphylococcus aureus* (MRSA): a comparison between conventional terminal cleaning and hydrogen peroxide vapour decontamination. *J Hosp Infect* 2004;**57**:31—37.
4. Boyd RD, Verran J, Hall KE, Underhill C, Hibbert S, West R. The cleanability of stainless steel as determined by X-ray photoelectron spectroscopy. *Appl Surf Sci* 2001;**172**(1—2):135—143.
5. Holah JT, Thorpe RH. Cleanability in relation to bacterial retention on unused and abraded domestic sink materials. *J Appl Bacteriol* 1990;**69**:599—608.
6. Whitehead KA, Verran J. The effect of surface properties and application method on the retention of *Pseudomonas aeruginosa* on uncoated and titanium-coated stainless steel. *Int Biodeterior Biodegradation*, in press.
7. Verran J, Rowe DL, Cole D, Boyd RD. The use of the atomic force microscope to visualise and measure wear of food contact surfaces. *Int Biodeterior Biodegradation* 2000;**46**:99—105.
8. Noyce JO, Michels HT, Keevil CW. Potential use of copper surfaces to reduce survival of epidemic meticillin-resistant *Staphylococcus aureus* in the healthcare environment. *J Hosp Infect* 2006;**63**:289—297.
9. Bragg PD, Rainnie DJ. Effect of silver ions on respiratory-chain of *Escherichia coli*. *Can J Microbiol* 1974;**20**:883—889.
10. Wilks SA, Michels HT, Keevil CW. The survival of *Escherichia coli* O157 on a range of metal surfaces. *Int J Food Microbiol* 2005;**105**:445—454.
11. Wilks SA, Michels HT, Keevil CW. Survival of Listeria monocytogenes Scott a on metal surfaces: implications for cross-contamination. *Int J Food Microbiol* 2006;**111**:93—98.
12. Obee P, Griffith CJ, Cooper RA, Bennion NE. An evaluation of different methods for the recovery of meticillin-resistant *Staphylococcus aureus* from environmental surfaces. *J Hosp Infect* 2007;**65**:35—41.
13. Neely AN, Maley MP. Survival of *enterococci* and *staphylococci* on hospital fabrics and plastic. *J Clin Microbiol* 2000;**38**:724—726.
14. Anon. Hygienic equipment design criteria. *Trends Food Sci Technol* 1993;**4**:225—229.
15. Anon. Infection Control Policy No. 5. 2005: Shropshire County and Telford and Wrekin Primary Care Trusts.

Applied and Environmental Microbiology, Mar. 2011, p. 1541–1547 Vol. 77, No. 5
0099-2240/11/$12.00 doi:10.1128/AEM.02766-10

MINIREVIEWS

Metallic Copper as an Antimicrobial Surface[▽]

Gregor Grass,[1] Christopher Rensing,[2] and Marc Solioz[3]*

School of Biological Sciences, University of Nebraska—Lincoln, Lincoln, Nebraska[1]; Department of Soil, Water, and Environmental Science, University of Arizona, Tucson, Arizona[2]; and Dept. of Clinical Pharmacology, University of Bern, Bern, Switzerland[3]

Bacteria, yeasts, and viruses are rapidly killed on metallic copper surfaces, and the term "contact killing" has been coined for this process. While the phenomenon was already known in ancient times, it is currently receiving renewed attention. This is due to the potential use of copper as an antibacterial material in health care settings. Contact killing was observed to take place at a rate of at least 7 to 8 logs per hour, and no live microorganisms were generally recovered from copper surfaces after prolonged incubation. The antimicrobial activity of copper and copper alloys is now well established, and copper has recently been registered at the U.S. Environmental Protection Agency as the first solid antimicrobial material. In several clinical studies, copper has been evaluated for use on touch surfaces, such as door handles, bathroom fixtures, or bed rails, in attempts to curb nosocomial infections. In connection to these new applications of copper, it is important to understand the mechanism of contact killing since it may bear on central issues, such as the possibility of the emergence and spread of resistant organisms, cleaning procedures, and questions of material and object engineering. Recent work has shed light on mechanistic aspects of contact killing. These findings will be reviewed here and juxtaposed with the toxicity mechanisms of ionic copper. The merit of copper as a hygienic material in hospitals and related settings will also be discussed.

The use of copper by human civilizations dates back to between the 5th and 6th millennia B.C. It was the first metal used, presumably because it could be found in a native, metallic form which did not require smelting. Its use remained scattered throughout Europe and the Middle East, and the archeological evidence remains scarce. With the invention of smelting, the metallurgic age began and the advantage of combining copper with tin to form bronze was discovered. The earliest bronze artifacts originated from the Middle East and China and date to before 3000 B.C., but it was not until the second millennium B.C. that bronze was used throughout Europe. The ability to smelt and forge iron from about 1000 B.C. marks the end of the Bronze Age and the beginning of the Iron Age.

The oldest recorded medical use of copper is mentioned in the Smith Papyrus, one of the oldest books known (8). This Egyptian medical text, written between 2600 and 2200 B.C., describes the application of copper to sterilize chest wounds and drinking water (8). Greeks, Romans, Aztecs, and others also used copper or copper compounds for the treatment of such ailments as headaches, burns, intestinal worms, and ear infections and for hygiene in general. In the 19th century, a new awareness of copper's medical potency was spawned by the observation that copper workers appeared to be immune to cholera in the 1832 and subsequent outbreaks in Paris, France (8). The use of copper in medicine became widespread in the 19th and early 20th centuries, and a variety of inorganic copper preparations were used to treat chronic adenitis, eczema, impetigo, scrofulosis, tubercular infections, lupus, syphilis, anemia, chorea, and facial neuralgia (8). The use of copper as an antimicrobial agent continued until the advent of commercially available antibiotics in 1932. The spread of antibiotic resistance through selective pressure began and today has made antibiotic-resistant bacteria ubiquitous in hospitals, nursing homes, food processing plants, and animal breeding facilities. This has raised the need for different approaches to keep pathogenic microorganisms at bay. One such alternative is the use of copper surfaces in hygiene-sensitive areas. While this approach is not novel (7), it had lost importance and acceptance in the last few decades. A 1983 report documenting the beneficial effects of using brass and bronze on doorknobs to prevent the spread of microbes in a hospitals remained largely unnoticed (18). Similarly, the idea of using copper vessels to render water drinkable has been revived only very recently as a low-cost alternative for developing countries (37). Currently, there is an intense interest in the use of copper as a self-sanitizing material, and many recent publications deal with mechanistic aspects of "contact killing" (contact-mediated killing) by copper.

COPPER AS A TOXIC BUT ESSENTIAL TRACE ELEMENT

Copper is an essential trace element in most living organisms, and more than 30 types of copper-containing proteins are known today. Prominent examples are lysyl oxidase, which is involved in the cross-linking of collagen, tyrosinase, required for melanin synthesis, dopamine β-hydroxylase, which functions in the catecholamine pathway, cytochrome *c* oxidase, the terminal electron acceptor of the respiratory chain, and super-

* Corresponding author. Mailing address: Dept. of Clinical Pharmacology, University of Bern, Murtenstrasse 35, 3010 Bern, Switzerland. Phone: 41 31 632 3268. Fax: 41 31 632 4997. E-mail: marc.solioz@ikp.unibe.ch.

▽ Published ahead of print on 30 December 2010.

oxide dismutase, required for defense against oxidative damage. In these enzymes, copper serves as an electron donor/acceptor by alternating between the redox states Cu(I) and Cu(II) (15). Other copper proteins, such as plastocyanins or azurins, act as electron carriers. Depending on the type of coordination of the copper to the protein, the redox potential of copper can vary over the range +200 mV to +800 mV. On the other hand, the redox properties of copper can also cause cellular damage. A number or mechanisms have been suggested. Reactive hydroxyl radicals can be generated in a Fenton-type reaction:

$$Cu^{+} + H_2O_2 \rightarrow Cu^{2+} + OH^{-} + OH^{\cdot} \quad (1)$$

The extremely reactive hydroxyl radical can participate in a number of reactions detrimental to cellular molecules, such as the oxidation of proteins and lipids (45). Copper ions can also lead to depletion of sulfhydryls, such as in cysteines or glutathione, in a cycle between reactions 2 and 3:

$$2\,Cu^{2+} + 2\,RSH \rightarrow 2\,Cu^{+} + RSSR + 2H^{+} \quad (2)$$

$$2\,Cu^{+} + 2\,H^{+} + O_2 \rightarrow 2\,Cu^{2+} + H_2O_2 \quad (3)$$

The hydrogen peroxide thus generated can in turn participate in reaction 1 and lead to further generation of toxic hydroxyl radicals. It is still not clear to what extent reactions 1 to 3 cause copper toxicity. Cells try to keep H_2O_2 at very low levels, and reaction 1 may not be the chief toxic mechanism, although this has been frequently claimed. An alternative route of copper ion toxicity has been shown to be the displacement of iron from iron-sulfur clusters (20). Similarly, copper ions may compete with zinc or other metal ions for important binding sites on proteins. The toxic effect of copper on microbes is utilized in agriculture for the control of bacterial and fungal diseases (4), which in fact led to the first thorough investigation of bacterial resistance to copper ions (5).

Bacteria evolved a range of mechanisms to protect themselves from the toxic effects of copper ions: extracellular sequestration of copper ions, relative impermeability of the outer and inner bacterial membranes to copper ions, metallothionein-like copper-scavenging proteins in the cytoplasm and periplasm, and active extrusion of copper from the cell. The latter appears to be the chief mechanism of copper tolerance in bacteria and has been extensively studied in Gram-positive and Gram-negative bacteria. In *Escherichia coli*, the CopA copper-transporting ATPase resides in the cytoplasmic membrane and pumps excess Cu(I) from the cytoplasm to the periplasm (32). In the periplasmic space, the multicomponent copper efflux system CusCFBA and the multicopper oxidase CueO control the copper level and redox state, respectively. In addition to these chromosomally encoded systems, *E. coli* strains can harbor related, plasmid-encoded systems which further increase copper tolerance (33). All the components of this copper detoxification machinery are transcriptionally upregulated by copper via two regulatory circuits. In Gram-positive bacteria, which are devoid of a periplasmic space and an outer membrane, only CopA-type copper exporters are present and a single regulatory circuit usually controls their expression (34, 36). A number of other components, like copper-binding proteins, copper reductases, etc., support these basic defense systems against copper and have been described elsewhere (2, 16, 22, 35).

In contrast to copper defense, copper utilization by bacteria is much less well understood. In *Synechocystis*, it appears that a special copper uptake ATPase serves in supplying copper to the photosynthetic components in the thylakoid membranes (38). On the other hand, methanotrophic bacteria that require copper for particulate methane monooxygenase secrete siderophore-like substances, the methanobactins, to scavenge extracellular copper (2). In Gram-negative bacteria, like *E. coli*, it is believed that the metalation of cuproenzymes takes place in the periplasmic space and does not require special copper uptake systems across the cytoplasmic membrane. Finally, many novel proteins of unknown function which are regulated by copper have been identified in the Gram-positive organism *Lactococcus lactis* (21), and further efforts will be required for an in-depth understanding of copper handling by bacteria.

CONTACT KILLING IN THE LABORATORY

The study of the antimicrobial properties of metallic copper surfaces is a relatively recent development and gained momentum when the Environmental Protection Agency (EPA) registered almost 300 different copper surfaces as antimicrobial in 2008 (http://www.epa.gov/pesticides/factsheets/copper-alloy-products.htm). Prior to that, a number of studies have already dealt with the kinetics of contact killing upon exposure of bacteria to copper and copper alloy surfaces (14, 28, 29, 43, 44). Table 1 summarizes the species tested, test procedures, and killing kinetics. In general, microbes were inactivated on copper within hours, but such parameters as the inoculation technique, incubation temperature, and copper content of the alloy used were not usually investigated in a systematic way and are difficult to compare between studies. Nevertheless, a few general principles appear clear: higher copper content of alloys (43), higher temperature (10), and higher relative humidity (25) increased the efficacy of contact killing. Treatments that lowered corrosion rates, e.g., application of corrosion inhibitors or a thick copper oxide layer, lowered the antimicrobial effectiveness of copper surfaces (9).

In most studies on contact killing, a "wet" inoculation technique was used by applying typically 20 μl of cell suspensions to coupons. While this is a valid approach for laboratory testing, it might not mimic well the dry copper surfaces encountered in health care environments. In an alternative "dry" method, a small volume of liquid is applied to coupons with a cotton swab. The thin film of liquid evaporates within seconds and allows direct contact of all cells with the metal surface. Under these conditions, *E. coli* and other bacteria were inactivated within a few minutes of exposure (11–13). This suggests that dry metallic copper surfaces are even more antimicrobial than moist ones, which raises interesting questions about the mechanism of contact killing.

Certain Gram-positive bacteria, such as members of the *Bacilli* and *Clostridia*, form endospores which can resist heat, radiation, desiccation, denaturing chemicals, etc. Thus, endospores pose a real challenge to aseptic procedures. *Clostridium difficile* is an important pathogen of the group of spore-forming bacteria and leads to diseases like diarrhea and colitis. Excretion of endospores by infected persons might contaminate sur-

TABLE 1. Contact killing of microbes by copper surfaces

Species	Application method	Killing time, RT[a]	Reference
Salmonella enterica	Wet, 4.5×10^6 CFU[b]	4 h	14
Campylobacter jejuni	Wet, 4.5×10^6 CFU[b]	8 h	14
Escherichia coli O157	Wet, $(3–4) \times 10^7$ CFU[c]	65 min	43
Escherichia coli O157	Wet, 2.7×10^7 CFU[c]	75 min	29
MRSA[d] (NCTC10442)	Wet, $(1–1.9) \times 10^7$ CFU[c]	45 min	28
EMRSA-1[e] (NCTC11939)	Wet, $(1–1.9) \times 10^7$ CFU[c]	60 min	28
EMRSA-16[e] (NCTC13143)	Wet, $(1–1.9) \times 10^5$ CFU[c]	90 min	28
Listeria monocytogenes Scott A	Wet, 10^7 CFU[c]	60 min	44
Mycobacterium tuberculosis	Wet, 2.5×10^7 CFU[f]	5 to 15 days[g]	24
Candida albicans	Wet, $>10^5$ CFU[f]	60 min	24
Klebsiella pneumoniae	Wet, $>10^7$ CFU[f]	60 min	24
Pseudomonas aeruginosa	Wet, $>10^7$ CFU[f]	180 min	24
Acinetobacter baumannii	Wet, $>10^7$ CFU[f]	180 min	24
MRSA	Wet, $>10^7$ CFU[f]	180 min	24
Influenza A virus (H1N1)	Wet, 5×10^5 viruses[h]	6 h, 4-log decrease	30
C. difficile (ATCC 9689) vegetative cells and spores	Wet, 2.2×10^5 CFU[c]	24–48 h	40
C. difficile NCTC11204/R20291 vegetative cells	Wet, $(1-5) \times 10^6$ CFU[i]	30 min	42
C. difficile dormant spores	Wet, 8×10^6 CFU[i]	Unaffected in 3 h	42
C. difficile germinating spores	Wet, 8×10^6 CFU[i]	3 h, 3-log decrease	42
Pseudomonas aeruginosa PAO1	Wet, 2.2×10^7 CFU[j]	120 min	10
MRSA NCTC 10442	Wet, 2×10^7 CFU	75 min, 7 log decrease	25
Escherichia coli W3110	Dry, 10^9 CFU[i]	1 min	12
Acinetobacter johnsonii DSM6963	Dry, 10^9 CFU[k]	A few minutes	12
Pantoea stewartii DSM30176	Dry, 10^9 CFU[i]	1 min	12
Pseudomonas oleovorans DSM 1045	Dry, 10^9 CFU[k]	1 min	12
Staphylococcus warnerii DSM20316	Dry, 10^9 CFU[k]	A few minutes	12
Brachybacterium conglomeratum DSM 10241	Dry, 10^9 CFU[k]	A few minutes	12
Aspergillus flavus	Wet, $(2–300) \times 10^5$ spores[c]	120 h	41
Aspergillus fumigatus	Wet, $(2–300) \times 10^5$ spores[c]	>120 h	41
Aspergillus niger	Wet, $(2–300) \times 10^5$ spores[c]	> 576 h	41
Fusarium culmonium	Wet, $(2–300) \times 10^5$ spores[c]	24 h	41
Fusarium oxysporum	Wet, $(2–300) \times 10^5$ spores[c]	24 h	41
Fusarium solani	Wet, $(2–300) \times 10^5$ spores[c]	24 h	41
Penicillium crysogenum	Wet, $(2–300) \times 10^5$ spores[c]	24 h	41
Candida albicans	Wet, $(2–300) \times 10^5$ spores[c]	24 h	41
Enterococcus hirae ATCC 9790	Wet, 10^7 CFU[c]	90 min	27
Different *Enterococcus* spp.	Wet, 10^6 CFU[f]	60 min	39
Candida albicans	Dry, 10^6 CFU[k]	5 min	31
Saccharomyces cerevisiae	Dry, 10^6 CFU[k]	30 s	31

[a] RT, room temperature; only the values for the most efficient alloy are reported.
[b] Inoculation with 1.5 ml of culture (4.5×10^6 CFU), kept under humid conditions.
[c] Inoculation with a 20-μl drop of culture.
[d] Methicillin-resistant *Staphylococcus aureus.*
[e] Epidemic methicillin-resistant *Staphylococcus aureus.*
[f] Twenty microliters of culture spread on coupons.
[g] Time before strain became culture positive in Bactec 12B growth medium after exposure to copper.
[h] Inoculation with 20 μl of virion suspension.
[i] One hundred microliters of dilute culture.
[j] Twenty-five microliters of culture spread on coupons with a glass spreader.
[k] Thin film applied with a cotton swab.

faces and generate a long-term reservoir for transmission. In spite of the robustness of these spores, killing by metallic copper has been reported in some cases. In one study, viable spores were found to be diminished by 99.8% in 3 h on solid copper (42), while complete inactivation of spores in 24 to 48 h was reported in a second study (40). Clearly, endospores are more resilient to contact killing by copper than vegetative cells, but killing may still occur and thus warrant the strategic use of copper to curb spreading of *C. difficile*.

What is the mechanism of contact killing? This question cannot yet be answered clearly, but a number of factors contributing to contact killing have been identified. In wet inoculation of copper surfaces with bacteria, the copper homeostatic systems of the cell appear to play a role. *Pseudomonas aeruginosa* PAO1 deleted in the *cinR* gene, encoding a copper-responsive regulator, or the *cinA* gene, encoding an azurin-like protein involved in copper resistance, was more rapidly killed on copper surfaces than the wild type (10). Similarly, an *Enterococcus hirae* mutant deleted in the gene for the copper export pump, *copB*, was killed after 75 min, while complete inactivation of the wild type took 90 min. In *E. coli*, finally, deletion of three systems, *cueO* (encoding periplasmic copper oxidase), *cus* (encoding a periplasmic copper efflux system), and *copA* (encoding a cytoplasmic copper extrusion pump), led to faster killing kinetics than for the wild type, preincubated with copper to express the copper-homeostatic genes (10, 13). Preincubation with copper also increased the killing time of *E. coli* carrying the plasmid-borne *pco* copper resistance system

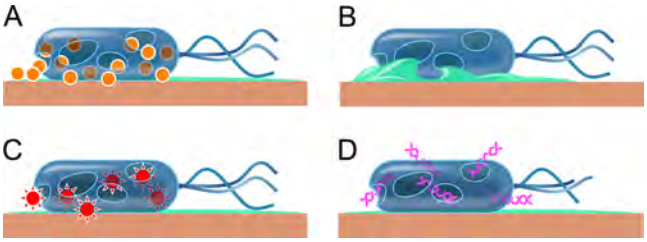


FIG. 1. Cartoon of the tentative events in contact killing. (A) Copper dissolves from the copper surface and causes cell damage. (B) The cell membrane ruptures because of copper and other stress phenomena, leading to loss of membrane potential and cytoplasmic content. (C) Copper ions induce the generation of reactive oxygen species, which cause further cell damage. (D) Genomic and plasmid DNA becomes degraded.

(13). Clearly, bacterial copper resistance systems do not offer protection from contact killing, but they do prolong survival. This suggests the involvement of dissolved copper ions in the killing process (Fig. 1). This is further supported by the effect of medium composition on contact killing. Application of the cells to copper surfaces in Tris buffer dramatically enhanced contact killing, and much more copper was dissolved by Tris buffer than by water or phosphate buffer (27). Although spent medium dissolved as much copper as Tris buffer, this copper was probably tightly bound to media components and not bioavailable and thus did not accelerate contact killing. For *E. coli*, it was shown that copper chelators protected cells from contact killing (13). All these observations support a role of surface-released free copper ions in contact killing, but they are clearly not the sole determinant of the process.

Recent studies showed that large amounts of copper ions were taken up by *E. coli* over 90 min, when cells were applied to copper coupons in a standing drop. When cells were plated on copper by the dry method, the accumulation of copper ions by cells was even more dramatic, reaching a low molar concentration, or 27-fold the level observed by wet plating, in a fraction of the time. The copper ion level of cells remained high throughout the killing phase, suggesting that cells become overwhelmed by their intracellular copper (11). Another factor that influences cell survival on metallic copper is oxidative stress. Generation of reactive oxygen species (ROS) is probably mediated by redox cycling between the different copper species, Cu(0), Cu(I), and Cu(II). The absence of oxygen did not inhibit contact killing of *E. coli* but doubled the time required for complete killing of 10^9 cells from 1 to 2 min in the dry plating method (13). This indicates that stress caused by reactive oxygen species is another factor contributing to contact killing.

The fate of DNA during contact killing by copper has also been investigated. According to one study, DNA is a major target of copper toxicity, leading to rapid DNA fragmentation and cell death (39). This contrasts with recent findings by Espirito Santo et al., which suggest that the primary damage to cells in contact killing is membrane damage (11). It is likely that DNA damage ensues only as a secondary event following cell death. It could be shown that membrane damage by copper was not accompanied by an increase in the mutation rate or DNA fragmentation. *Deinococcus radiodurans* is a bacterium that is exceptionally resistant to ionizing radiation because of its ability to repair even highly fragmented DNA. Remarkably, *D. radiodurans* was as sensitive as *E. coli* to contact killing by copper (11). At the current state of knowledge, it appears that contact killing proceeds by successive membrane damage, copper influx into the cells, oxidative damage, cell death, and DNA degradation (cf. Fig. 1). Clearly, this sequence of events is still tentative, and further work on contact killing is required to offer more-detailed molecular insight into the process.

How soiling, cleaning, exposure to chemicals, and tarnishing affect the antimicrobial properties of copper has not yet been studied in detail. In a study where copper surfaces were inoculated with bacteria in 1% solutions of albumin, dried, and subsequently cleaned with 70% ethanol or 1% sodium hypochlorite, there was a build-up of residues and a concomitant decrease in killing efficiency (1). On the other hand, it was reported that copper surfaces remained active when soiled (42). Also, it was found that there was no reduction in killing efficiency over 30 cycles of bacterial inoculation, followed by cleaning with a 1% nonionic detergent solution (M. Solioz and C. Molteni, unpublished observations). From what is known about the mechanism of contact killing, it appears clear that a clean copper surface, free of oxide, wax, or other coating agents, will always be active in contact killing. A future task will be to establish reproducible protocols for cleaning copper surfaces such that they maintain maximal efficacy in contact killing.

CONTACT KILLING IN HEALTH CARE SETTINGS

Touch surfaces commonly found in hospitals, such as door handles, touch plates, bed rails, call buttons, toilet seats, etc., can be highly contaminated with microbes. It was shown that germs such as *Staphylococcus aureus* and *Acinetobacter* spp. can persist on such surfaces for months (17). Frequent and efficient cleaning, combined with proper hand hygiene, diminishes transmission of infections, but complete elimination appears impossible (6). With the worldwide spread of such antibiotic-resistant organisms as methicillin-resistant *S. aureus* (MRSA) or more recently New Delhi metallo-beta-lactamase (NDM)-harboring strains, dangerous nosocomial infections have become a primary concern for hospitals. It can be approximated that in 2006 there were about 720,000 hospital-acquired infections in the United States, causing $125 billion in extra hospital charges and more than 74,000 fatalities (database on hospital-acquired infections in Pennsylvania [http://www.phc4.org/]). These numbers emphasize the need for new approaches to hospital hygiene, and antimicrobial copper promises to provide one such approach to supplement the current hygiene measures.

Stainless steel is the metal predominantly used in health care environments because of its "clean" appearance and corrosion resistance. However, there is no inherent antimicrobial advantage to using this metal (19). Copper surfaces, with their self-sanitizing properties, could be envisioned as making an important contribution to infection control. Thus, the use of antimicrobial metallic copper surfaces is likely to provide protection from infectious microbes by reducing surface contamination, as was recently shown in successful hospital trials.

Hospital trials are now ongoing worldwide, and the first results have been reported (3, 23, 26).

The 10-week Selly Oak Hospital trial in Birmingham, United Kingdom, was carried out with both copper and control surfaces in the same ward. This approach was chosen to decrease potential bias in the microbial challenge to copper and control surfaces (3). In addition, after 5 weeks, the copper-containing and non-copper-containing surfaces and items were interchanged to further diminish bias. Bacterial contamination of a copper-coated (70% Cu) composite toilet seat, brass tap handles (60% Cu), and a brass door push plate (70% Cu) was compared against that of equivalent items with plastic, chrome-plated, or aluminum surfaces. Median numbers of bacteria recovered from surfaces of copper-containing items were between 90% and 100% lower than those from control surfaces. While MRSA and *C. difficile* were not isolated in this study, methicillin-sensitive *S. aureus* (MSSA), vancomycin-resistant *Enterococcus* (VRE), and *E. coli* were found only on control surfaces but not on copper surfaces.

It is noteworthy that in contrast to laboratory studies, in which unused copper surfaces are usually tested, this hospital trial employed "aged" surfaces. The items to be tested were installed at least 6 months prior to commencement of the study. This also allowed domestic staff and health care workers to become accustomed to the copper-containing fixtures. In addition, it provides support for the notion that copper surfaces will not lose their antimicrobial activity over time. Nevertheless, long-term studies are still required to evaluate the sustainability of the antimicrobial properties of copper surfaces over the course of several years.

A second hospital trial was contracted at a walk-in primary health care clinic in Grabouw, a rural region of the Western Cape, South Africa (23). Here, a consulting room rather than a medical ward was refitted with copper surfaces. In this room, items in frequent contact with patients and staff, such as desks, trolleys, the top of a cupboard, and windowsills, were covered with copper sheets. During 6 months, surfaces were sampled every 6 weeks for a 4.5-day period, with multiple samplings per day. An overall 71% reduction in the bacterial load of the copper surfaces was observed compared to that of the control surfaces, with significantly lower mean total colony counts during working days and overnight (23). Interestingly, comparable numbers of bacteria were counted when surfaces remained untouched over the weekends (71 h), but this phenomenon was not investigated further.

Finally, in the German trial at the Asklepios Hospital, Hamburg, touch surfaces in patient bed rooms, rest rooms, and staff rooms in an oncological/pneumological and a geriatric ward were refitted with brass (a copper/zinc alloy). Control rooms retained aluminum door handles and push plates and plastic light switches (26). The total duration of this trial was 32 weeks, equally divided into summer and winter months. The number of aerobic, heterotrophic bacteria on these surfaces was determined once or twice per week. The presence of ciprofloxacin-resistant *Staphylococcus* (CRS) as an indicator organism for multiple-drug-resistant nosocomial pathogens was determined. Following sampling each morning, all surfaces were cleaned with a disinfectant. Additional samples were taken immediately after cleaning and 3, 6, and 9 h later. Over both halves of the trial, there was an average 63% reduction in the bacterial load on copper surfaces compared to controls. Results were significant for door handles, which had the highest overall microbial load. Bacterial numbers recovered from copper and plastic light switches were similar. No significant differences in the survival of CRS on copper and noncopper surfaces were observed, but on average cell numbers from copper were lower. Interestingly, the repopulation of surfaces by microbes occurred at different rates. For copper surfaces, the average rate of repopulation was less than half of that for the control surfaces, documenting the antibacterial properties of copper surfaces.

Results are still awaited from trials at the Memorial Sloan-Kettering Cancer Center in New York City, NY, the Medical University of South Carolina in Charleston, SC, the Ralph H. Johnson VA Medical Center in Charleston, the Hospital del Cobre de Calama in Chile, and the Kitasato University Hospital in Japan. In the hospitals trials described so far, only heterotrophic, aerobic bacteria were assessed. It would be interesting to conduct similar trials in which anaerobic bacteria, including endospore formers and eukaryotic microbes, are also evaluated, since these microbes pose their own unique challenges.

CONCLUSIONS AND FUTURE DIRECTIONS

The antimicrobial properties of copper surfaces have now been firmly established. Hospital trials have shown a reduction in bacterial counts, indicating that copper surfaces are a promising additional tool alongside other hygienic measures to curb the number and severity of hospital-acquired infections. At this point, additional studies would be helpful in determining the most cost-effective way to give maximal protection in hospitals. For example, should only highly frequented sites be made of copper, e.g., doorknobs, faucets, and bed rails, or should the majority of accessible surfaces be made of copper? In addition, different copper alloys should be tested not only for their effectiveness but also for their esthetic appeal. Finally, the antimicrobial properties of copper surfaces must be integrated with other methods of disinfection and the overall hygiene concept of a health care facility. Additional measures, such as the addition of spore germinants to cleaning solutions to improve killing of spores, also deserve further investigation.

Bacterial resistance is a major concern in infection control. Are there bacteria which are naturally refractory to contact killing by copper? It is known that live bacteria can be isolated from copper-containing surfaces, and in a recent study, 294 isolates from European 50-cent coins were investigated in regard to copper resistance. Some of the isolates indeed exhibited prolonged (1 to 3 days) survival on dry but not on moist copper surfaces, but none of the strains was exceptionally copper resistant in culture (12). Survival on copper-containing coins appeared to be the consequence of either endospore formation, survival on patches of dirt, or a special ability to endure a dry metallic copper surface. While the latter, rare property is not yet understood, widespread appearance of bacterial resistant to contact killing appears unlikely for the following reasons: (i) plasmid DNA is completely degraded after cell death by contact killing, preventing the transfer of resistance determinants between organisms (39), (ii) contact killing is very rapid, and cells are not dividing on copper surfaces,

precluding the acquisition of resistance, and (iii) copper and copper alloys have been used by humans for thousands of years, yet no bacteria fully resistant to contact killing have been discovered.

ACKNOWLEDGMENTS

Financial support from the Swiss National Foundation (grant 3100A0_122551 to M.S.), pilot NIH grant P20 RR-017675 from the National Center for Research Resources (to G.G.), National Institutes of Health grant GM079192 (to C.R.), grants from the International Copper Association to G.G., C.R., and M.S., and a grant from the Swiss State Secretary for Education & Research (to M.S.) are greatly appreciated. Equipment in the lab of G.G. was purchased with Nebraska Tobacco Settlement Biomedical Research Development Funds.

The contents of this work are solely the responsibility of the authors and do not necessarily represent the official views of the NIH.

REFERENCES

1. **Airey, P., and J. Verran.** 2007. Potential use of copper as a hygienic surface; problems associated with cumulative soiling and cleaning. J. Hosp. Infect. **67:**272–278.
2. **Balasubramanian, R., and A. C. Rosenzweig.** 2008. Copper methanobactin: a molecule whose time has come. Curr. Opin. Chem. Biol. **12:**245–249.
3. **Casey, A. L., et al.** 2010. Role of copper in reducing hospital environment contamination. J. Hosp. Infect. **74:**72–77.
4. **Cha, J. S., and D. A. Cooksey.** 1991. Copper resistance in *Pseudomonas syringae* mediated by periplasmic and outer membrane proteins. Proc. Natl. Acad. Sci. U. S. A. **88:**8915–8919.
5. **Cooksey, D. A.** 1994. Molecular mechanisms of copper resistance and accumulation in bacteria. FEMS Microbiol. Rev. **14:**381–386.
6. **Dancer, S. J.** 2008. Importance of the environment in meticillin-resistant *Staphylococcus aureus* acquisition: the case for hospital cleaning. Lancet Infect. Dis. **8:**101–113.
7. **Dick, R. J., J. A. Wray, and H. N. Johnston.** 1973. A literature and technology search on the bacteriostatic and sanitizing properties of copper and copper alloy surfaces. Battelle Columbus Laboratories, Columbus, OH.
8. **Dollwet, H. H. A., and J. R. J. Sorenson.** 1985. Historic uses of copper compounds in medicine. Trace Elem. Med. **2:**80–87.
9. **Elguindi, J., et al.** Metallic copper corrosion rates, moisture content, and growth medium influence survival of copper-resistant bacteria. Appl. Microbiol. Biotechnol., in press.
10. **Elguindi, J., J. Wagner, and C. Rensing.** 2009. Genes involved in copper resistance influence survival of *Pseudomonas aeruginosa* on copper surfaces. J. Appl. Microbiol. **106:**1448–1455.
11. **Espirito Santo, C., et al.** 2011. Bacterial killing by dry metallic copper surfaces. Appl. Environ. Microbiol. **77:**794–802.
12. **Espirito Santo, C., P. V. Morais, and G. Grass.** 2010. Isolation and characterization of bacteria resistant to metallic copper surfaces. Appl. Environ. Microbiol. **76:**1341–1348.
13. **Espirito Santo, C., N. Taudte, D. H. Nies, and G. Grass.** 2008. Contribution of copper ion resistance to survival of *Escherichia coli* on metallic copper surfaces. Appl. Environ. Microbiol. **74:**977–986.
14. **Faundez, G., M. Troncoso, P. Navarrete, and G. Figueroa.** 2004. Antimicrobial activity of copper surfaces against suspensions of *Salmonella enterica* and *Campylobacter jejuni*. BMC Microbiol. **4:**19.
15. **Karlin, K. D.** 1993. Metalloenzymes, structural motifs, and inorganic models. Science **261:**701–708.
16. **Kim, E. H., C. Rensing, and M. M. McEvoy.** 2010. Chaperone-mediated copper handling in the periplasm. Nat. Prod. Rep. **27:**711–719.
17. **Kramer, A., I. Schwebke, and G. Kampf.** 2006. How long do nosocomial pathogens persist on inanimate surfaces? A systematic review. BMC Infect. Dis. **6:**130–138.
18. **Kuhn, P. J.** 1983. Doorknobs: a source of nosocomial infection? Copper Development Association, New York, NY. http://www.copperinfo.co.uk/antimicrobial/downloads/kuhn-doorknob.pdf.
19. **Kusumaningrum, H. D., G. Riboldi, W. C. Hazeleger, and R. R. Beumer.** 2003. Survival of foodborne pathogens on stainless steel surfaces and cross-contamination to foods. Int. J. Food Microbiol. **85:**227–236.
20. **Macomber, L., and J. A. Imlay.** 2009. The iron-sulfur clusters of dehydratases are primary intracellular targets of copper toxicity. Proc. Natl. Acad. Sci. U. S. A. **106:**8344–8349.
21. **Magnani, D., O. Barré, S. D. Gerber, and M. Solioz.** 2008. Characterization of the CopR regulon of *Lactococcus lactis* IL1403. J. Bacteriol. **190:**536–545.
22. **Magnani, D., and M. Solioz.** 2007. How bacteria handle copper, p. 259–285. *In* D. H. Nies and S. Silver (ed.), Molecular microbiology of heavy metals. Springer, Heidelberg, Germany.
23. **Marais, F., S. Mehtar, and L. Chalkley.** 2010. Antimicrobial efficacy of copper touch surfaces in reducing environmental bioburden in a South African community healthcare facility. J. Hosp. Infect. **74:**80–82.
24. **Mehtar, S., I. Wiid, and S. D. Todorov.** 2008. The antimicrobial activity of copper and copper alloys against nosocomial pathogens and *Mycobacterium tuberculosis* isolated from healthcare facilities in the Western Cape: an *in-vitro* study. J. Hosp. Infect. **68:**45–51.
25. **Michels, H. T., J. O. Noyce, and C. W. Keevil.** 2009. Effects of temperature and humidity on the efficacy of methicillin-resistant *Staphylococcus aureus* challenged antimicrobial materials containing silver and copper. Lett. Appl. Microbiol. **49:**191–195.
26. **Mikolay, A., et al.** 2010. Survival of bacteria on metallic copper surfaces in a hospital trial. Appl. Microbiol. Biotechnol. **87:**1875–1879.
27. **Molteni, C., H. K. Abicht, and M. Solioz.** 2010. Killing of bacteria by copper surfaces involves dissolved copper. Appl. Environ. Microbiol. **76:**4099–4101.
28. **Noyce, J. O., H. Michels, and C. W. Keevil.** 2006. Potential use of copper surfaces to reduce survival of epidemic meticillin-resistant *Staphylococcus aureus* in the healthcare environment. J. Hosp. Infect. **63:**289–297.
29. **Noyce, J. O., H. Michels, and C. W. Keevil.** 2006. Use of copper cast alloys to control *Escherichia coli* O157 cross-contamination during food processing. Appl. Environ. Microbiol. **72:**4239–4244.
30. **Noyce, J. O., H. Michels, and C. W. Keevil.** 2007. Inactivation of influenza A virus on copper versus stainless steel surfaces. Appl. Environ. Microbiol. **73:**2748–2750.
31. **Quaranta, D., et al.** 2011. Mechanisms of contact-mediated killing of yeast cells on dry metallic copper surfaces. Appl. Environ. Microbiol. **77**:416–426.
32. **Rensing, C., and G. Grass.** 2003. *Escherichia coli* mechanisms of copper homeostasis in a changing environment. FEMS Microbiol. Rev. **27:**197–213.
33. **Rouch, D., J. Camakaris, B. T. Lee, and R. K. Luke.** 1985. Inducible plasmid-mediated copper resistance in *Escherichia coli*. J. Gen. Microbiol. **131:**939–943.
34. **Solioz, M., H. K. Abicht, M. Mermod, and S. Mancini.** 2010. Response of Gram-positive bacteria to copper stress. J. Biol. Inorg. Chem. **15:**3–14.
35. **Solioz, M., S. Mancini, H. K. Abicht, and M. Mermod.** The lactic acid bacteria response to metal stress. *In* K. Papadimitriou and E. Tsakalidou (ed.), Stress response of lactic acid bacteria, in press. Springer, Heidelberg, Germany.
36. **Solioz, M., and J. V. Stoyanov.** 2003. Copper homeostasis in *Enterococcus hirae*. FEMS Microbiol. Rev. **27:**183–195.
37. **Sudha, V. B. P., K. O. Singh, S. R. Prasad, and P. Venkatasubramanian.** 2009. Killing of enteric bacteria in drinking water by a copper device for use in the home: laboratory evidence. Transact. R. Soc. Trop. Med. Hyg. **103:**819–822.
38. **Tottey, S., P. R. Rich, S. A. Rondet, and N. J. Robinson.** 2001. Two Menkes-type ATPases supply copper for photosynthesis in Synechocystis PCC 6803. J. Biol. Chem. **276:**19999–20004.
39. **Warnes, S. L., S. M. Green, H. T. Michels, and C. W. Keevil.** 2010. Biocidal efficacy of copper alloys against pathogenic enterococci involves degradation of genomic and plasmid DNA. Appl. Environ. Microbiol. **76:**5390–5401.
40. **Weaver, L., H. T. Michels, and C. W. Keevil.** 2008. Survival of *Clostridium difficile* on copper and steel: futuristic options for hospital hygiene. J. Hosp. Infect. **68:**145–151.
41. **Weaver, L., H. T. Michels, and C. W. Keevil.** 2010. Potential for preventing spread of fungi in air-conditioning systems constructed using copper instead of aluminium. Lett. Appl. Microbiol. **50:**18–23.
42. **Wheeldon, L. J., et al.** 2008. Antimicrobial efficacy of copper surfaces against spores and vegetative cells of *Clostridium difficile*: the germination theory. J. Antimicrob. Chemother. **62:**522–525.
43. **Wilks, S. A., H. Michels, and C. W. Keevil.** 2005. The survival of *Escherichia coli* O157 on a range of metal surfaces. Int. J. Food Microbiol. **105:**445–454.
44. **Wilks, S. A., H. T. Michels, and C. W. Keevil.** 2006. Survival of *Listeria monocytogenes* Scott A on metal surfaces: implications for cross-contamination. Int. J. Food Microbiol. **111:**93–98.
45. **Yoshida, Y., S. Furuta, and E. Niki.** 1993. Effects of metal chelating agents on the oxidation of lipids induced by copper and iron. Biochim. Biophys. Acta **1210:**81–88.

Ozone: Science & Engineering, 31: 339–347

ISSN: 0191-9512 print / 1547-6545 online
DOI: 10.1080/01919510903091318

Taylor & Francis
Taylor & Francis Group

The Ozone Laundry Handbook: A Comprehensive Guide for the Proper Application of Ozone in the Commercial Laundry Industry

Rip G. Rice,[1] Marc DeBrum,[2] Dick Cardis,[3] and Cameron Tapp[2]

[1]RICE International Consulting Enterprises, Sandy Spring, Maryland, USA
[2]ClearWater Tech, LLC., San Luis Obispo, California, USA
[3]JLA Limited, Meadowcroft Lane, Ripponden, West Yorkshire, United Kingdom

Applications of ozone in commercial laundry systems began in the late 1980s–early 1990s. Early installations showed promise for ozone to save considerable energy over conventional (thermal) systems. However, inconsistent performances of ozone equipment of that period coupled with a lack of in-depth understanding of how ozone was performing hindered commercial acceptance of ozone. With continued study and testing, these early misunderstandings about ozone have been overcome, and today many thousands of commercial laundry systems are using ozone successfully in many parts of the world. For example, more than 2,000 ozone laundry systems are operating in commercial laundry systems in the USA and another 2,000 commercial ozone laundry systems in the United Kingdom alone! Based on proven performance data obtained from many of these successful applications of ozone in commercial laundry systems, the authors have developed an Ozone Laundry Handbook, intended to be a summation of current knowledge and a guide to the laundry owner/operator considering the use of ozone. The Handbook contains 10 chapters, including discussions of the economic, environmental and microbiological benefits of ozone in commercial laundries, a discussion of ozone technologies as they apply to laundry systems, a comparison of traditional vs ozone laundry formulations, methods of applying ozone for laundering, operator training and ozone safety, a discussion on facts and fallacies about ozone for laundering, and finally a chapter on the future of ozone for laundering. The Handbook also contains a Glossary of Ozone Terms, Indices, and an Index.

Keywords Ozone, Laundering, Ozone Laundering, Benefits of Ozone Laundering, Economic Benefits, Environmental Benefits, Microbiological Benefits of Ozone Laundering, Ozone Laundry Formulas, Ozone Laundry Methods, Operator Training, Ozone Safety, Ozone Facts and Fallacies in Laundering

Received 4/23/2009; Accepted 6/4/2009
Address correspondence to Rip G. Rice, RICE International Consulting Enterprises, 1710 Hickory Knoll Road, Sandy Spring, MD 20860 USA. E-mail: RGRice4ozone@aol.com

INTRODUCTION

Handbook Chapter 1

There are upwards of 200,000 commercial laundry facilities in the United States today. These can be free-standing laundry plants, located in hotels, hospitals, nursing homes, health clubs, resorts, as well as in penal institutions, athletic facilities, in coin-operated laundromats, and in dry-cleaning establishments. These locations are using, *in toto*, tens of billions of gallons of water and massive amounts of energy each year.

In recent years ozone laundry technology has proven itself to be an effective tool in helping to reduce water usage and energy consumption while also reducing wash and dry times, ensuring the absence of microorganisms, and improving the quality and useful life of laundered products. There are economic advantages to an ozone system as well as microbiological and environmental benefits. Currently in the United States there are over 2,000 ozone laundry systems in place and as many as 2,000 more in the United Kingdom alone.

No organized, reliable reference material exists today that provides unbiased, scientific information for the prospective user of ozone laundry systems. The authors of this document have brought together leaders of the ozone and commercial laundering communities to describe not only the benefits and effectiveness of ozone technology as applied to commercial laundries, but also to provide a comprehensive guide for the application of ozone in the commercial laundry industry.

EARLY EVOLUTION OF OZONE LAUNDRIES

The concept of using ozone to assist commercial laundering was first introduced in the United States in the late 1970s-early 1980s, primarily in penal institutions. Many of those early ozone installations showed very poor performances. A second generation of ozone laundry facilities began to be installed in the 1990s that provided better performances. Early systems touted many of the same cost savings and energy efficiencies that are being promoted today. However, as is the case with many new technologies, not all aspects of ozone technology were understood or had been fully explored by the early vendors, and many promises that were made oftentimes were not fulfilled.

The primary shortcomings of early ozone laundry systems can be attributed to lack of ozone chemistry knowledge and poor business models (lack of adequate service and support) by the early ozone equipment vendors to this market. Ozone chemistries are different from those of traditional laundering, and must be taken into consideration in order to achieve all of ozone's benefits during laundering. The uniqueness of ozone as a wash additive had not yet been properly researched or developed so as to be able to deliver a high quality wash. Facilities were seeing savings from reducing water temperatures, but other results were poor, and end users had no resource to consult as an education aid. Nowadays however, many companies understand the most effective ways to maximize the potentials of ozone and today are able to deliver the cleaned, disinfected, bright and soft linens that ozone can provide, along with its many cost-savings, microbiological, and environmental benefits.

Some of today's modern ozone laundering systems offer controlled and even variable levels of ozone instead of using a single level for all washes. Also, a variety of systems include sensors to monitor and also, in some cases, control ambient ozone levels. These newer systems are overcoming the blemishes that some of the original systems marked the industry. Not only have ozone laundering systems and support been updated, but the marketplace also has evolved. The extensive demand for cost saving, disinfection, and "green" technologies has sent decision-makers in search of technologies such as ozone.

BENEFITS OF OZONE

There are three primary advantages to employing ozone in commercial laundries—economic, microbiological, and environmental. Each of these advantages is discussed in a separate chapter of the Ozone Laundry Handbook.

Economic Benefits of Ozone Laundry Systems – Handbook Chapter 2

A comparative evaluation of traditional vs. ozone laundering was conducted at a California hotel having 104 rooms. The study was conducted over a consecutive 2-month period (one month traditional laundering and the second month ozone laundering. Many parameters were monitored so as to quantify the savings that can be attributed to the use of ozone laundering (Ozone Laundry Case Study, 2005).

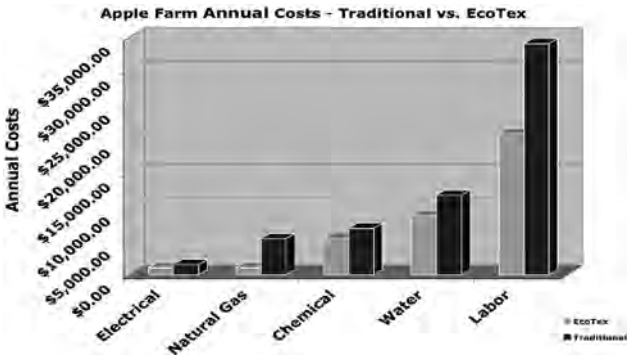


FIGURE 1. Annual Costs of Traditional vs Ozone Laundering at Apple Farm Inn, CA.

Figure 1 is a bar graph comparing the annual costs of the two laundering procedures; these savings lead to returns-on-investment of 7.7 months, when labor savings are included. Figure 2 is another bar chart showing the percent of annual savings found as a result of ozone laundering in the following categories: electrical energy, natural gas, water, chemicals, and labor.

In the United Kingdom, weekly savings in costs at three different establishments operating ozone laundering were quantified (Cardis et al., 2006). The establishments surveyed were a 50-bed care home (70% incontinence), a 90-bed care home (85% incontinence) and an 800-bed hotel (zero or little incontinence). Items quantified included electricity, gas, hot and total water, chemicals,

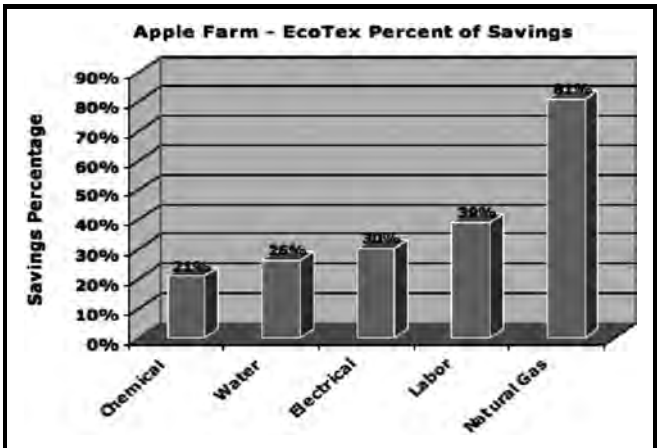


FIGURE 2. Percent of Annual Savings by Ozone :aundering at Apple Farm Inn, CA (Ozone Laundry Case Study, 2005).

linen and labor costs. Annual savings were found to be as follows:

50-bed care home (70% incontinence)	£ 11,311 annual savings
90-bed care home (85% incontinence)	£ 15,967 annual savings
800-bed hotel (no incontinence)	£ 21,276 annual savings

To summarize the economic benefits of ozone in laundering:

1. Ozone laundering brings reduced energy costs by using cold water (ambient temperature, from the municipal tap), which lowers the energy necessary to heat water. In the USA, these energy savings alone are in the range of 86–90%.
2. Ozone laundering eliminates the need for the amounts of many chemicals currently used in conventional laundering systems. These chemical savings amount to about 21%.
3. Because ozone laundering systems result in lower chemical usage, the number of rinses required is lowered, with resulting savings in water and labor. Labor savings alone amount to about 39%.
4. Fabric life is extended by ozone laundering, due to the lower temperatures required and lowered amounts of chemicals employed.
5. Confirmation of these cost savings in the UK shows total annual cost savings of ozone laundry systems ranging from £11,310 to £16,000 in two health care homes (with incontinent patients). In an 800 bed commercial hotel, these cost savings are as high as £21,275 per year.
6. Annual cost savings found for ozone laundering in the USA allow a return-on-investment between 7.7 and 17.4 months for ozone systems, depending on the size of equipment required.

Environmental Benefits of Ozone Laundering – Chapter 3 (Cardis et al., 2006)

There are many environmental benefits of ozone laundering when compared to conventional laundering procedures. These include significantly decreased use of chemicals – which benefit the user of ozone laundering by lowering costs, but benefit the environment by decreasing discharges of chemicals in laundry wastewaters, and benefit the safety of the ozone laundry user by decreasing the storage requirements for laundering chemicals and the handling necessary.

When chemicals are discharged into the environment, they often can react with components of the receiving lakes, rivers and streams to produce byproducts which are not well degraded by natural microorganisms, and sometimes find their way into the food chain. On the other hand, when ozone does its work in a properly designed laundry system, its strongly oxidizing power actually initiates the oxidative conversion of most organic components of the soiling materials on the laundry to be cleaned into more readily biodegradable byproducts. This "preoxidation" of soiling components in an ozone laundry system then continues their biodegradation to harmless carbon dioxide and water as they continue to diffuse into the environment.

Additionally, when ozone is added to aqueous systems (in this case to laundry machines), the dissolved oxygen levels of the laundering waters rises. This is a significant advantage particularly when ozone is generated from oxygen-enriched air. The solubility of oxygen in water from a gas that contains mostly oxygen is several times higher than when that gas contains mostly nitrogen (as when air is used to feed the ozone generator). Higher levels of dissolved oxygen in laundry wastewater discharges benefit receiving streams, lakes, and rivers by providing oxygen for the natural microorganisms to do a better job of breaking down discharged pollutants into carbon dioxide and water.

Laundry wash effluent samples of a typical nursing home were analyzed for COD levels comparing the effects of conventional (thermal) laundering to ozone laundering on this parameter (Scientifics Ltd., 2006). The results showed lower COD levels in the ozone wash and final rinse waters:

Thermal Cycle – Main Wash 3890 mg/L COD
Thermal Cycle – Final Rinse 171 mg/L COD
OTEX Cycle – Main Wash 2000 mg/L COD
OTEX Final Rinse 154 mg/L COD

Ozone also is an effective deodorizer that works by breaking molecular bonds of many organic and inorganic compounds typically responsible for odors that are found in and on soiled laundry – particularly those received from hospitals and health care facilities which often house incontinent patients.

The UK's WRc-NSF Ltd. conducted an Independent Risk Assessment (WRc-NSF, 2005) of the impact of discharging spent laundry wash water that had been treated with ozone. It was concluded that wash water treated with ozone is safe to discharge to the sewer system; indeed any such aeration of sewage can be seen as beneficial since it encourages the breakdown of the organic matter and aids the sewage treatment process.

In late 1997, the Hong Kong Environmental Protection Department (1997) confirmed compliance of effluents of the laundry system at the Chi Lin Monastery (operating an ozone laundry system) with the required discharge limits for foul sewers under the (Hong Kong) Water Pollution Control Ordinance.

To summarize the environmental benefits of ozone laundering:

1. Reducing the amounts of chemicals and rinse water used in conventional laundering decreases the

volume of wastewater discharged from the laundry as well as decreasing the amount of laundering chemicals discharged to the environment.
2. Ozone itself can be considered to be a "green" chemical, in that if any dissolved ozone remains in laundry discharge water, it will quickly convert to dissolved oxygen upon contact with dissolved organic materials present in surface waters. In turn, dissolved oxygen benefits microorganisms present in receiving natural waters or in sewage treatment plants.
3. As ozone oxidizes organic soils on laundry, the oxidized materials become more easily biodegradable by microorganisms in sewage treatment plants and/or receiving waters.
4. Lowering the amounts of laundering chemicals also increases the safety of laundry personnel, since smaller volumes of chemicals need to be stored and handled.

Microbiological Benefits of Ozone Laundering – Chapter 4

A major benefit of ozone in commercial laundry systems is the control, disinfection, and/or total eradication of microorganisms normally found in/on soiled laundry. In hospitals, health care, retirement facilities, as well as in locker rooms of academic and professional athletes, certain microorganism strains exist and proliferate that are particularly resistant to modern medications. Numerous infections from the two currently prevalent "superbugs" – Methycillin-Resistant *Staphylococcus aureus* (MRSA) and *Clostridium difficile* (*C. difficile*, or C. diff) have created panics in recent years in various countries around the Earth.

Detailed studies conducted in the United Kingdom (Cardis et al., 2006) on both the "routine" microorganisms found in hospital and health care facilities (*E. coli*, *Pseudomonas aeruginosa*, etc.) as well as many types of viruses, showed that these and the two superbugs (MRSA and *C. difficile*) are rapidly eradicated by ozone cold water laundering within 3–6 minutes. These studies also have shown that *C. difficile* spores are not consistently eliminated from microfiber mops and wiping cloths by conventional (thermal) laundering processes. This means that this superbug can be spread around the facility when reused after conventional laundering, thus increasing the potential for possible re-infection of patients, staff, and visitors.

Nurses' Uniforms Contaminated with MRSA (Cardis et al., 2006)

Care labels of nurses' uniforms commonly carry the recommendation that they be laundered at 40 °C (104 °F). Therefore a comparison of thermal washing (40 °C) with ambient temperature ozone washing was conducted on soiled nurse uniforms into which were implanted membranes impregnated with MRSA. After 40 °C laundering, MRSA was clearly present on the membrane samples, but totally absent after ozone laundering. Data obtained indicated a $>$ 8-log reduction ($>$ 99.999999%) in MRSA on garments washed with ozone, but only a 3.3-log reduction (99.93%) after thermal washing at 40 °C (104 °F).

Six-Month Hospital Evaluation of Ozone Laundering

The Queen Elizabeth II Hospital (Welwyn Garden City, Herts., UK) first conducted testing of microfibre mops and wiping cloths contaminated with various microorganisms found in hospitals by conventional laundering (thermal disinfection at 71 °C = 160 °F over 60 minutes) and with detergent. Microbiological analyses showed the mops and cloths to be still contaminated. *C. difficile* counts were over 150,000 TVC (total viable counts). This means that even after the recommended thermal laundering, microfibre mops and wiping cloths were simply distributing *C. difficile* spores throughout the hospital.

An ozone laundering system was installed in the QE II Hospital and a 6-month trial of this system began on May 17, 2005. Microbiological analyses of microfibre mops and cloths sampled during April 2005 (before ozone laundering testing began) established a "control base line". Many problematic bacterial species were present, including MRSA and *C. difficile*.

Microfibre mops and wiping cloths taken randomly from the existing "live laundry" bins were processed every week of the 6-month trial period in the ozone-ambient temperature washing system. One sample of mop or cloth from a bag washed was analyzed before and after ozone laundering.

Throughout the 6-month ozone laundering trial, no residual target organisms, as set by the East and North Hertfordshire NHS Trust Infection Control, were detected, including MRSA and *Clostridium difficile,* after laundering with the ozone system. In addition the ozone system provided a simple laundering process with one cycle, which also can accommodate traditional cotton mops while using less detergent and being energy efficient.

Performance data comprised a total of 53 individual samples of microfibre mops and wiping cloths taken weekly from in-use laundry bins of the QE II Hospital. Most samples (but not all) were contaminated with MRSA, *C. difficile*, *A. niger*, yeasts and molds. After ozone laundering, every single one of these 53 samples showed zero cfu in each of the microorganism categories analyzed.

Based on this 6-month evaluation, the Queen Elizabeth II hospital adopted the ozone laundering system as their method of laundry decontamination in December, 2005.

Follow-Up Testing of Ozone-Laundered Microfibre Mops and Wiping Cloths

Another study was conducted at the QE-II Hospital to determine the effects of repeated ozone laundering on the physical properties of new and ozone-laundered microfibre mops and wiping cloths (Hook, 2007a, 2007b). Results obtained in this study indicated the following:

- Color loss is experienced irrespective of either washing under current HSG (Health Safety Guidelines) guidelines utilizing thermal disinfection or ozone disinfection wash cycles.
- No association between color loss and fibre damage resulting in a reduced performance was found. This finding is supported by information on color loss supplied by one of the microfibre manufacturers.
- No chemical damage/erosion was found in any of the samples evaluated.
- There is evidence that physical damage to the microfibres occurred during laundering. However, the data also shows that the cloths processed with ozone exhibited ***less*** damage than those processed by thermal laundering. The damage is localized on the tips of the fibers and is indicative of exposure to high temperatures during the drying process.
- The effect of physical damage was shown by the loss of the original surface area together with a corresponding reduction in the original absorbency. The physical damage is likely to be a result of drying at high temperatures for prolonged periods, since the cloths are polymers or "plastic" and are therefore susceptible to heat. Processing mops and cloths together also will have a detrimental effect on the cloths by increasing the physical action or abrasion of the materials.

The results obtained showed clearly that the use of ozone laundering does not result in any detrimental effect to the microfibre effectiveness or integrity and is a viable alternative to thermal disinfection. In contrast, there is evidence to show that the use of ozone maintains the microfibre integrity, with the added benefit of an improved disinfection process and additional utility savings.

Microfibre laundering via the ozone process subsequently has been carried out at several sites including nursing homes and hospitals with no adverse reports on their performance. One installation which currently has 12 ozone trial sites has been laundering microfibre items for over three years with ozone, with no apparent detrimental effects (Hook, 2007b).

Comparative Testing of Ozone vs. Standard Laundering (Reid et al., 2007)

Based on an August 2006 evaluation of an ozone laundering system, Reid et al. (2007) conducted a phase 1, single blind, randomized, controlled series group study of standard laundry disinfection techniques using the current standard VIKING machine versus a validated ozone laundering system (OTEX, from JLA Ltd.), set up at the laundry at Woodend Hospital, Aberdeen, Scotland.

The objectives of this study were to assess the safety, tolerability and efficacy of an ozone laundering system *versus* standard laundry cleaning procedures (VIKING machine). In addition, it was deemed important to assess the reproducibility of the OTEX ozone disinfection system on a standardized series of heavily fouled laundry loads contaminated with hospital-acquired bacteria, fungi and/or viruses in comparison to a matched series of heavily fouled laundry loads using the Standard VIKING laundry machine.

Forty (40) loads of very contaminated hospital laundry were processed comparatively as follows:

a) One washing cycle with conventional chemical products (detergent, alkalis and 150 ppm chlorine), humidification and pre-wash),
b) One washing cycle with ozone (up to 4 g per hour)

The mean reductions in log levels achieved post-wash by the two different methods were compared by *t*-tests, since the reductions were normally distributed. No statistically significant differences in reduction levels by ozone and conventional processes were evidenced in any of the five categories compared. Mean reductions fluctuated for the two methods over the five categories, but not in a significant manner.

Ozone laundering gave significantly lower mean levels for *C. difficile*, eliminating this microorganism completely. Additionally, ozone laundering provided a zero mean for *C. difficile* and much lower standard deviations than by the conventional laundering process. MRSA had a zero mean for both methods. The *C. difficile* difference and the differences in variations are visually clear in the box plot (Figure 3).

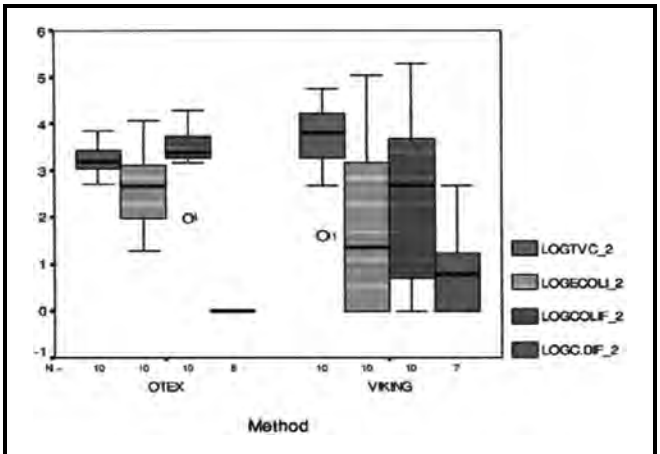


FIGURE 3. Box Plot of Post-Wash *C. difficile* Levels by Method of Wash (Personal Laundry) (Hook, 2007a).

OZONE TECHNOLOGY

Chapter 5

The properties, chemistries of ozone in water and in air, methods of generating ozone (corona discharge and ultraviolet radiation), methods of contacting ozone with water, and methods of analyzing for ozone in water and air are discussed in this chapter as these topics relate to laundering with ozone.

TRADITIONAL VS OZONE LAUNDRY FORMULAS

Chapter 6

In this chapter the relationships between laundering formulations of traditional chemicals are compared to laundering formulations when employing ozone. The use of ozone sometimes has effects on the amounts of traditional chemicals and laundering formulations now required. Equally important are the effects of washer agitation, selection of water levels and durations of these steps.

The simultaneous use of ozone and high water temperatures for laundering is mutually exclusive, because temperature not only aids in the decomposition of ozone, but also aids in driving dissolved ozone from aqueous solution into the surrounding air. Consequently, ozone is considerably more effective at lower temperatures (cold water = ambient temperature water) because of its increased stability and higher solubility the lower the water temperature.

It is a fallacy that ozone can be used as the sole laundering chemical, replacing all traditional chemicals. However, by incorporating ozone into the laundering process, some traditional chemicals can be eliminated, and at times the amounts of other chemicals can be reduced.

For example, alkali chemicals are added traditionally to elevate the pH of the wash water to as high as pH 11–13. On the other hand, ozone decomposes quite rapidly in water at pH levels above 9. Consequently, the overuse of alkali chemicals defeats the benefits of ozone.

Detergents work well to remove soils from cloths being laundered, and this includes soils that have been oxidized by ozone. Because ozone destroys many of the organic soil constituents, less detergent normally is required for ozone laundering.

Chlorine is used in traditional laundering for two purposes – bleaching stains and for disinfection. If stains are the primary problem with soiled laundry, then chlorine still will be required when ozone is employed, although perhaps in lower quantities. If chlorine is used solely for disinfection, then that role can be assumed by ozone.

When chlorine is used for bleaching, attention must be paid to proper pH adjustment so as to optimize the bleaching properties of chlorine. The pH should be below ~ 8 so as to guarantee the presence of hypochlorous acid, HOCl, which is the bleaching agent of aqueous chlorine. Normally this is accomplished by addition of a souring agent (an acidic formulation) to lower the pH. Softening agents then are added to counter the harsh effects on linens caused by souring chemicals.

Whenever hydrogen peroxide is employed for bleaching laundry in place of chlorine, it is important that the pH be maintained at 9 or higher. At lower pH, H_2O_2 is not as effective.

By using ozone for laundering, the amounts of several of the chemicals used traditionally can be lowered, thus reducing or even eliminating the need for softeners. In turn, less softener results in shorter drying times.

METHODS OF APPLYING OZONE FOR LAUNDERING

Chapter 7

This chapter includes a discussion of the equipment and methods for producing and applying ozone to commercial laundry machines. Ozone normally is generated by corona discharge for commercial laundries, rather than by UV-radiation, for several reasons. With corona discharge ozone generation:

- Oxygen-enriched air will allow higher ozone production rates and higher gas phase concentrations of ozone to be produced than when feeding ambient air,
- Higher gas phase ozone concentrations will result in higher aqueous phase ozone concentrations in the washer,
- Higher ozone production rates means that a single corona discharge ozonation unit can be sized to provide sufficient ozone to service multiple washers in the laundering facility.

If UV radiation is used to generate ozone, the ozone output rates and gas phase ozone concentrations are much lower than those attainable by corona discharge. Consequently, a single UV-ozone generating unit can service only a single commercial laundering machine, at best.

Experiences with ozone laundering to date have resulted in the development of four methods for applying corona discharge generated ozone to commercial laundry machines:

1. *Recirculation Injection* – whereby ozone is added to the wash water drawn from the commercial washer which then is sent to the washer;
2. *Direct Injection* – involving less peripheral equipment than Recirculation Injection, this method involves adding ozone directly to the water during fill to the washer;
3. *Ozone Charge* – similar to Direct Injection, but involving either a water storage tank operated at atmospheric pressure, or with the system operating at a positive pressure and without the water storage tank;

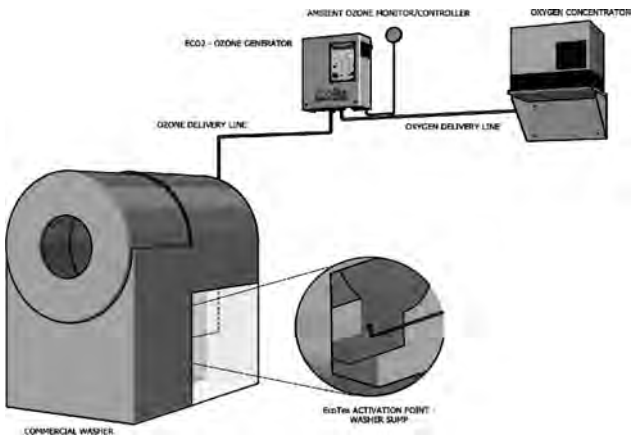


FIGURE 4. Schematic Diagram of Ozone Diffusion Method of Ozone Laundering.

4. *Ozone Diffusion* – in which gaseous ozone is added directly to the water inside the washer through a special diffuser.

This last procedure, Ozone Diffusion (diffusing ozone directly into the washer itself), enables constancy of the desired dissolved ozone levels inside the washer at all times during all laundering cycles. In addition, the rate of ozone production and addition is controlled and automated by monitoring the gas phase ozone concentrations within the washer itself.

The Ozone Diffusion system is considered to be the current state-of-the-art method of ozone laundering. Figure 4 shows a schematic diagram of the Ozone Diffusion system. Figure 5 shows plots of residual ozone in washer waters over 15 minutes of laundering as provided by an Ozone Charge system compared with an Ozone Diffusion system (Hook, 2005). Clearly, the Ozone Diffusion system provides a higher and more constant level of dissolved ozone for the totality of the laundering cycle time (~15 minutes).

Adding ozone directly to the washer drum not only ensures the appropriate dissolved ozone level, but as the laundry is being agitated with ozone-containing water, there is considerable gaseous ozone that is repeatedly folded into and throughout the linens or other materials being laundered. Thus the targeted microorganisms and laundry soils are constantly in contact with ozone at all times, thus making the functions of ozone even more efficient than by other methods of ozone addition.

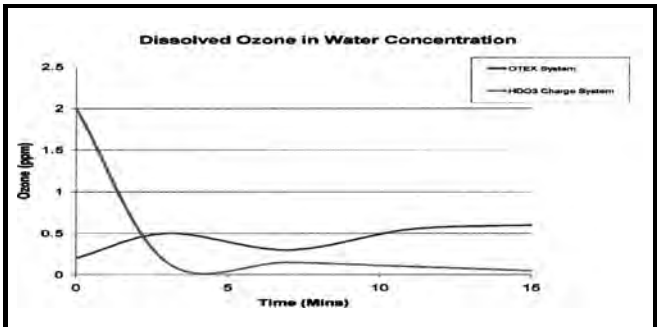


FIGURE 5. Dissolved Ozone Levels by Ozone Charge vs Ozone Diffusion Techniques (Hook, 2007b).

OPERATOR TRAINING AND OZONE SAFETY

Chapter 8

Whenever equipment that is new to the owner and staff is installed for any application, a period of time is necessary for staff to develop a comfort level with that equipment. Ozone and its equipment are new to the laundry industry and the new user of ozone must understand what this material is, how it is made and applied, and how to know when the equipment is not performing as it should, and then what to do to rectify the situation.

The lay public is bombarded many times during the year with media announcements such as "the ozone level in the ambient air is high, therefore certain classes of citizens should be careful about venturing outdoors." Another common negative announcement is "the hole in the ozone layer is widening, thus allowing harmful high energy UV radiation to reach the Earth's surface."

All of this plus EPA, FDA and OSHA regulations for ozone in the air makes it clear that humans should not breathe ozone, because above regulated ambient air concentrations, that air can cause detrimental health effects to humans breathing it. This chapter addresses these topics.

Operator Training for Ozone Laundering

There are three approaches to the operation and maintenance of equipment that is new to the user:

1. Do it yourself – select one or more staff members and have them trained by the equipment supplier,
2. Set in place an operation and maintenance service contract with the equipment supplier that requires the equipment supplier to operate and maintain, or
3. Effect some combination of approaches #1 and #2.

Doing it yourself (approach #1) usually is cost-effective for the larger laundry systems that already have access to at-hand maintenance staff and laundry operators. Approach #2 is effective for smaller laundry systems that do not have ready access to full-time maintenance staff and laundry operators.

Approach #3 normally is the most cost-effective of the three. Usually, suppliers of ozonation equipment offer a break-in period following installation and startup during which one or more operatives of the equipment supplier are on-site to be sure that all items have been installed correctly and are operating properly. During and preceding this startup period (on the order of 14–30 days)

laundry operators and their maintenance staffs are taught the ins and outs of their new ozone equipment operation. These ins and outs include developing the "feel" of the ozonation system – when it is operating properly, what problems may arise and how to address them, and when to recognize that an item of equipment is not operating properly, in which case the supplier should be contacted.

Equipment for commercial ozone laundering usually is sold and installed by firms that also sell and install traditional types of laundering equipment. These are the people that usually service traditional equipment, and also can service the ozonation equipment when it is part of their product line.

For example, the firm JLA Ltd. (United Kingdom) has a fleet of service trucks operating in all regions of the UK. Staff of their customers are trained to operate their ozone laundry systems on a day-to-day basis. If any problem arises, a call to JLA Ltd. fetches a service truck within a few hours to solve the problem.

Safety of Ozone Laundering

An important and common inquiry for any prospective ozone laundry system user is the question of safety. Ozone systems can be operating in small rooms with laundry personnel in close proximity to the ozone generator(s). Since it is well-known that ozone is a powerful oxidizer and causes disagreeable responses to persons breathing it (coughing, wheezing, nausea, shortness of breath, etc.) above certain concentration and exposure levels, the safety of the use of ozone in a laundry operation is a valid and important concern.

People come in contact with ozone every day in the air we breathe (produced via ultraviolet radiation from the Sun reacting with air pollutants) and with equipment such as photocopiers and electrical motors which can produce ambient air ozone concentrations as high as 0.5 ppm. Naturally - occurring ozone levels can reach as high as 3.0 ppm in heavily urbanized areas (Water Quality Association, 1997).

On the other hand, during more than 100 years of varied commercial applications (i.e., drinking water, wastewater, swimming pools, etc.), the safety record of ozone is unsurpassed. No fatalities ever have been linked to exposure to ozone anywhere in the world as a result of its generation and application.

This incredible safety record of ozone is attributed largely to the fact that those who manufacture ozone generators and ozonation equipment recognized early on that the strong oxidizing and disinfection properties of this unique gas must be controlled. Users of ozone and ozonation equipment must not be exposed to ozone that might leak or escape from the enclosed environments of its production and application.

To this end, responsible suppliers of ozone generating and application equipment also supply ozone sensors and monitors to control the processes occurring inside both the ozonation system as well as inside the laundry washing equipment. These analytical devices sense and quantify the levels of ozone in gas and aqueous phases of any application of ozone. Some of these devices control the operation of ozone equipment in a laundry, calling for the ozone generator to produce ozone and dissolve it up to a predetermined concentration in the washer water. These same devices also automatically turn down the output of an ozone generator so that excesses of ozone are not produced.

Because ozone is only partially soluble in water, there will always be ozone escaping from the water during gas/liquid contacting and washer drum agitation. This "off-gas" containing ozone is passed through an ozone off-gas destruction device, which converts ozone into oxygen (from which ozone is produced), and this harmless gas is discharged to exhaust. These ozone monitoring and control approaches ensure that operating personnel in laundry facilities are not exposed to ozone at any time.

As a final check, another type of gas-phase monitor/controller is installed in the laundry room to sense and control the accidental discharge of ozone from (possibly) leaking piping or connections. If the ambient ozone level inside an ozone laundry were ever to rise to the OSHA Permissible Exposure Limit of 0.10 ppm (time-weighted average over an 8-hour working day), the ozone monitor/controller can be programmed to sound an alarm, start up room exhaust fans, and also to turn off the power to the ozone generator(s), thus ceasing any subsequent generation of ozone until the cause of the ozone leakage has been determined and corrected.

These precautionary safety procedures for ozone were developed decades ago and have been operating successfully in industrial applications all around our world.

OZONE FACTS AND FALLACIES IN LAUNDERING

Chapter 9

This chapter deals primarily with the misunderstandings about ozone as applied to laundries. As happens many times, when ozone began to show promise in laundering, those who knew something about ozone but little about laundering, made many overclaims for ozone in their zeal to make a sale. Oftentimes that situation was exacerbated by zealots new to the ozone field as well as to laundering. As a result, many fallacious statements and claims about ozone were circulated initially that were not supported by later performances. The authors list many of these fallacies and then counter them with known scientific facts.

THE FUTURE FOR OZONE IN LAUNDERING

Chapter 10

There is little question that ozone laundering has a very bright future. Not only does the use of ozone in

ambient temperature water ensure the killing/inactivation of microorganisms, including MRSA, *C. difficile*, and viruses within six minutes of the initiation of laundering, but this remarkable result is attained at approximately half the cost of traditional methods of laundering that do not utilize ozone. Additionally, discharging laundry wash waters to publicly operated wastewater treatment plants or to rivers, lakes or streams actually provides environmental benefits to these receiving waters (because of increased oxygen contents).

Several different approaches to the addition of ozone to laundry systems have been developed. The most recent, the Ozone Diffusion method in which ozone is diffused directly into the washer itself, is the most effective since the concentration of ozone in the wash water can be better monitored, controlled and stabilized by this approach. This technique of adding ozone to the washer drum also provides the benefits of exposure of the laundry to gaseous ozone as well.

Modern methods of generating ozone by corona discharge from high oxygen concentrations in dried air now allow a single ozone generating system to service multiple laundry washers at the same or at differing times.

For home laundering, an application so far unapproached (as far as the authors are aware), small-scale corona discharge ozone systems are available. However, UV-ozone generators also are available which might prove to be appropriate for this application at lower cost because UV-ozone generators do not require air treatment. For UV-ozone systems to be successful in the home laundry market, however, performance and design data need to be developed, so that interested users can have confidence in this potential approach to home laundering.

A current barrier to mass acceptance of ozone for laundering is the reticence of regulatory authorities to modify the current mandatory use of high temperatures which (unknowingly) exclude the use of ozone. At elevated temperatures ozone decomposes rapidly, providing no disinfection or oxidation benefit. Regulators should stand ready to accept credible scientific studies that prove the performance of ozone for laundering under the conditions determined in such studies.

REFERENCES

Cardis, D., Tapp, C., DeBrum, M., and Rice, R.G., "Ozone in the Laundry Industry – Practical Experiences in the United Kingdom", *Ozone Sci. Eng.*, 29(2):85–99 (2006), DOI: 10.1080/01919510601186048.

DeBrum, M., "Ozone Laundry Case Study – Apple Farm Inn, San Luis Obispo, CA", on ClearWater Tech web site, 2007, http://www.cwtozone.com/uploads/SalesDocs/Markets/Laundry/EcoTex/EcoTex%20PPT:PPS/EcoTex%20Apple%20Farm%20Inn%20CS%20050608.pps

Hong Kong Environmental Protection Department, Ltr. dated Nov. 11, 1997, from the Hong Kong Environmental Protection Dept., to Technologies Ltd. (Hong Kong), www.ETechnologies.com.

Hook, J., "Bacteriological Investigation: OTEX Laundry System Solution Test", OTEX Report No. LD01, Sept. 2005, JLA Ltd., Meadowcroft Lane, Ripponden, West Yorkshire, HX6 4AJ, United Kingdom, 2005.

Hook, J., 2007a, "Degradation Analysis of Microfibre Cloths Within the Healthcare Environment", JLA Report OTEX LD17, February 2007, JLA Ltd., Meadowcroft Lane, Ripponden, West Yorkshire, HX6 4AJ, United Kingdom.

Hook, J., 2007b, "Microfibre Condition Investigation Following Healthcare Laundry Process", JLA Ltd. Report LD28, May 2007, JLA Ltd., Meadowcroft Lane, Ripponden, West Yorkshire, HX6 4AJ, United Kingdom.

Reid, T., A.W. Wilson, and D.B. Galloway, "A Comparative Study on the Disinfection of Hospital Laundry Using Ozone: A 2-Part Single Blind Study Using Standard Hospital Laundry Cleaning Techniques versus the OTEX Validated Ozone Disinfection System, Final Study Report", Protocol No. Ozone/01–2007/120207/Hospital Laundry Study, Version 6, 22 June 2007.

Scientifics Ltd., 4 Hexthorpe Road, Doncaster DN4 0AE, UK, letter report to JLA Ltd., SD/DOW07090-01, 21 August 2006.

Water Quality Association, 1997, *Ozone for Point-of-Use, Point-of-Enrty, and Small Water Treatment Applications – A Reference Manual*, J.F. Harrison and P. Blazek, Editors (Lisle, IL, USA).

WRc-NSF Ltd., Medmenham, Marlow, Bucks, UK, May 22, 2005, "The OTEX Validated Ozone Disinfection Washing System".

Does Ozone Laundry *Really* Work? A User's Report

Employed as early as 1906 to treat the water supply in Paris, France, and used today in some processes for producing bottled water, ozone is known for its bleaching action and ability to kill bacteria and viruses. This "cousin" of oxygen also has a practical, money-saving application: treating water used in laundry operations.

Ozone—which, simply put, is oxygen plus an extra atom (O_3 as opposed to O_2)—is formed when oxygen comes into contact with highly charged electrical energy. Systems that generate ozone and inject it into laundry water can dramatically reduce hot water use in large laundry operations, as well as reducing the amount of cleaning chemicals used and producing cleaner, brighter linens and clothing.

Penacook Place Nursing and Rehabilitation Center, a 160-bed facility in Haverhill, Mass., had two ozone generators installed in its laundry room in January of 2002. *Nursing Homes/Long Term Care Management* spoke with Julian Rich, Penacook's president and CEO, and Bob Rawding, its director of building services, about how this addition has affected their facility's laundry operation.

What prompted you to consider using ozone generators in your laundry room?

Rich: I was initially interested because of the potential for cost savings from reduced hot water use. Based on the calculations of a vendor I spoke to at a conference, it appeared that the ozone generators would pay for themselves within approximately two years of their installation. With a savings potential like that, the decision was a "no-brainer" for me. Now we're tracking the actual savings, and after one year we're right on track with the projected savings.

Are there other benefits of using an ozone system besides saving hot water?

Rich: Yes, there are some benefits we weren't even aware of when we purchased the system. For example, the laundry turns out much whiter. You can set towels washed with ozonated water next to towels washed traditionally, and the superior whitening effect of ozone is immediately and dramatically obvious.

Another benefit is that the laundry room is much cooler in the summer. The decreased need for hot water reduces room temperature by a great deal, and anything we can do to make our staff more comfortable at work is a plus.

Rawding: Specifically, using ozonated water has eliminated approximately 75 to 80% of our hot water use, and our gas bill has declined by 25 to 30% since the ozone generators were installed.

Not only is the laundry whiter and brighter, but it's also fluffier. This means we are sending out a product that residents enjoy more. You can also stack towels and washcloths washed in ozonated water next to a stack of the same number washed in nonozonated water, and the ozone-treated pile will be twice as high. This is because using ozone in the water opens the fabrics' pores. For this reason, in addition to using less hot water, laundry washed with ozonated water dries faster, so there is less energy used for drying and there are fewer dryer cycles to raise the room temperature in warm weather.

Did you have to obtain regulators' approval for installing the ozone generators?

Rich: We checked with the state, because we didn't want to discover we had any inappropriate sanitation issues with the ozone system. The state was very comfortable with our plans and approved the system.

How long did installation take?

Rawding: It took one day for installation, followed by a few hours the next day after start-up for adjustments.

How many washing machines do you have connected to each ozone generator?

Rawding: We have two washers per generator, which works well.

Can you use ozonated water on colored fabrics, or just on whites?

Rawding: We can use it on everything we wash.

Are there any disadvantages to be aware of when considering the installation of this sort of equipment?

Rawding: One thing you have to be aware of is that the laundry area needs to be well ventilated; ozone does have a slight odor. But if the laundry is properly vented, the presence of the ozone doesn't affect anyone.

Rich: Initially we had some leakage that had to be repaired, which caused one employee some discomfort, but it was remedied immediately, and she suffered no harm.

Rawding: It's also important to know that ozone deteriorates rubber. As a result, we had to replace some rubber hoses on our washers.

How much maintenance do the ozone generators require?

Rawding: Very little. There are some small filters we have to keep clean, but overall they perform well without much routine maintenance.

Do you feel you made the right decision when you purchased the ozone generators?

Rawding: It was a good investment. I have to admit that I was a little leery going in, but it has definitely worked well for our facility.

Rich: We're extremely happy with our decision. **NH**

For more information, call Julian Rich at (978) 374-0707. *To comment on this article, send e-mail to rich0203@nursinghomesmagazine.com.*

PRODUCT FOCUS

LAUNDRY

High-Speed Extractors

Maytag Commercial Laundry's easy-to-operate Rigid-mount 50-, 80-, and 100-lb high-speed extractors offer large load capacity and save time by washing more laundry per load.

Multilingual microprocessor controls allow users to set up to 20 preprogrammed cycles for all select cleaning requirements. The high-speed extraction force of 250 Gs reduces drying time and energy costs.

An oversized door makes loading and unloading laundry quick and efficient. Additional features include simple-to-operate controls, liquid chemical supply system, dual drain system, heavy-duty steel foundation and frame, and easy-access servicing.

CIRCLE 75 ON READER SERVICE CARD

Energy-Saving Washer-Extractors

The UniMac UWPV line of washer-extractors now offers a faster cleaning process that reduces cycle time to increase labor and energy savings for on-premises laundries. UWPV washer-extractors now have higher extraction speeds of up to 300 G-force. The higher spin speeds reduce drying times to more exactly match UWPV wash cycle times. With the increase in extraction speed, along with other product features, the amount of time it takes to both wash and dry laundry has been equalized.

UniMac washer-extractors are backed by a five-year warranty on the frame, basket, shaft, bearings, and seals. A full three-year warranty is issued on all other parts.

CIRCLE 76 ON READER SERVICE CARD

Laundry Systems

Speed Queen offers its MicroMaster™ washer-extractor line in sizes from 18 through 125 lbs, and partners them with tumblers in capacities up to 170 lbs. MicroMaster tumblers and washer-extractors offer programming for a range of fabric care options. The washer-extractor features 30 cycles with 11 steps per cycle.

MicroMaster tumblers are equipped with an automatic drying time or a time-dry option.

CIRCLE 77 ON READER SERVICE CARD

Fire-Sensitive Dryers

Laundries can virtually eliminate the risk of dryer fires caused by spontaneous combustion with S.A.F.E. (sensor-activated fire-extinguishing) technology developed by American Dryer Corporation (ADC).

S.A.F.E. will extinguish fires that start in the dryer tumbler, whether the dryer is idle or in operation. Sensors are positioned throughout the tumbler and interface with the microprocessor; if the sensors detect a sharp increase in temperature, S.A.F.E. automatically activates a water-vapor mechanism to douse the flames. The tumbler will continue to rotate every 15 seconds to ensure that all articles have been extinguished. Water jets will remain on for two minutes and will automatically reactivate should the fire reignite.

Unlike a typical sprinkler system, which continues to spray until a stop valve is closed, the water-vapor mechanism in S.A.F.E. will stop once the sensors no longer detect a fire. S.A.F.E. is now standard on ADC on-premise dryers ranging in capacity from 15 to 75 lbs.

CIRCLE 78 ON READER SERVICE CARD

Whiter whites. . .brighter brights: The ozone difference

Not only is laundry cleaner, this technology can also brighten a facility's bottom line, reports **Sandra Hoban,** Managing Editor

Based on educational materials from ClearWater Tech, LLC

Laundry rooms in long-term care facilities have *never* been profit centers, yet they hold one of the keys to customer satisfaction and facility reputation. Residents and families notice whether linens are fresh and if clothes are clean without showing signs of industrial abuse. But what if you could *lower* operating costs and still provide quality laundry services? Adding ozone to the wash could be the answer.

The general public is acutely aware of the ozone layer—the gaseous umbrella that protects Earth from solar ultraviolet (UV) radiation. However, there are other important benefits provided by ozone, or O_3. It is used to purify bottled water, municipal water, and well water. Ozone is also an effective, natural cleaning and disinfecting agent, which makes it an excellent choice for long-term care laundries.

The Ozone Difference

A form of oxygen with an extra molecule, ozone is injected into the wash water, where it breaks down rapidly, oxidizing the fatty oils that allow dirt to adhere to fabric. As it does this, it also disinfects the linen and helps to whiten the laundry load.

A natural oxidizer, ozone is stronger than chlorine and other oxidizers used to kill microorganisms and remove organic and inorganic chemicals from fabrics. And because ozone "decays" rapidly, there is no residue buildup, resulting in whiter whites and brighter colors. Linen and clothing life is also extended because ozonated laundry uses much cooler water temperatures.

Ozone systems generate the gas on-site for immediate use only, which contributes to its roster of benefits for facility laundries. Cost savings are realized through energy and water conservation and reduced chemical

(i.e., detergents and bleaches) use. A typical long-term care facility laundry operation runs wash water at about 180°F, but an ozone system operates at a temperature range of approximately 50 to 60°F.

In addition, ozone breaks down the molecular bonds of soil quickly, so fewer rinses are needed than in conventional laundry processes. Consequently, soils are effectively removed from the wash and do not redeposit on fabrics, preventing laundry "graying" and reducing the need for bleaching. Items washed with ozone dry faster and come out softer and fluffier, a benefit that residents and their families quickly notice.

Fabric life is extended because shorter cycle times, cooler wash temperatures, fewer rinses, and less exposure to chemicals reduce the wear and tear on laundry items. Above all, ozone purifies and disinfects. Its efficacy against bacteria, viruses, and other microorganism makes using ozone a smart addition to infection control procedures.

Converting to Ozone

It's not necessary to revamp the entire laundry system to install an ozone system to meet a facility's specific needs. Steve Gerace, commercial water and laundry manager at ClearWater Tech, LLC, (**www.cwtozone.com**) in San Luis Obispo, California, says that almost any laundry can be converted to an ozonated system, even those designed as households. "Ozone laundry systems are sized to be compatible with the existing washers. These systems are compact, wall-mounted, and take up very little space." He adds that ClearWater Tech and other manufacturers offer systems that operate on washers ranging from 35 lb. to 400 lb. each. "It is not the size of the facility, it is the amount of laundry processed that determines the time frame in which the system will pay for itself," he adds. Ozone generators can be installed as add-ons to existing laundry equipment, eliminating the costly financial outlay for new machines.

Ozone systems are designed as *recirculation injection (RI), direct water-injection,* and *air-injection* systems. With recirculation systems, water is continually cycled back to the ozone system for reoxidation at a predetermined level, and returned to the washer for laundry sanitation. Piping is put in place to facilitate this continuous recirculation. This design can handle the heaviest demands and save water, energy, and time, although it can also be the most expensive of the three alternatives in terms of initial cost. RI systems permit most traditional chemical cycles to be replaced with cold water and minimal chemical injection.

The direct water-injection system also provides a good return on investment through chemical and energy savings. This method injects ozone directly into the cold water

supply line. A variation on this approach includes a contact tank in which ozone is mixed with cold water and stored until needed by the wash cycle. The contact tank approach is used to make it possible to achieve higher concentrations of ozone, which allows for effective disinfection and odor control in any of the cold water cycles. The ozonated water is not recharged once it enters the washer. This method offers effectiveness with a solid return on investment primarily from savings in energy and chemicals.

In air-injection systems, ozone gas is injected directly into the catch basin of the washer. Because it is injected into the washer, as opposed to the water supply, ozone is treating linen throughout the entire wash time. A properly designed air-injection system will activate traditional laundry detergents, allowing them to do their job with less water and at a lower temperature. In this approach, ozone provides disinfection and overall laundry quality with reduced costs. Disinfection is achieved with the application of ozone gas in solution, as well as directly into the linen as it folds into the ambient [illegible]e within the wash drum. These systems typically have an ambient air ozone monitor, within the facility and/or within the wash drum, to control off-gassing and eliminate any concern about high ozone levels in the laundry room. Of the three system alternatives, the air-injection method will yield the highest return on investment, according to Gerace.

Ozone laundry systems save energy, water, and time, and increase fabric life. These benefits quickly make up for the cost of converting laundry operations to an ozone system. With ozone laundry, facilities can improve their bottom line, satisfaction rates, and the environment. ■

For more information, call (800) 262-0203 or visit www.cwtozone.com. *To send your comments to the author and editors, please e-mail hoban0207@nursinghomesmagazine.com.*

focus on LAUNDRY

◂ Large-Capacity Tumbler

The Huebsch® Super Twinstar 45-lb. stack unit provides 90 lb. of drying capacity. Although the Super Twinstar has 40 lb. more rated capacity than Huebsch's 50-lb. single-pocket tumbler, it occupies less floor space. A large door opening aids loading and unloading, while user-friendly dual-digital controls make the stack easy to operate. The Super Twinstar's axial airflow system sends all the heat through the cylinder for energy efficiency. The tumblers are easy to install, with single gas, electrical, and vent connections.

CIRCLE 60 ON READER SERVICE CARD

Laundry Pretreatment ▲

The new Bio-Pro Urine Odor and Stain Laundry Pre-Treat, available from Direct Supply, contains bioenzymes that destroy uric acid on linens, blankets, towels, napkins, clothing, and all other machine-washable textiles. With this pretreatment, alkaline boosters or higher temperatures are not needed to leave linens less acidic, which helps to reduce bedsores.

CIRCLE 61 ON READER SERVICE CARD

Cabinet-Style Washer-Extractors ▲

As part of its new MWR line, Milnor offers two cabinet-style washer-extractors with 20- and 40-lb. capacities for any size laundry rooms. Both models have rugged structures and single-motor inverter drive systems. They are user-friendly and feature the E-P OneTouch control with four preprogrammed formulas.

The units have three speeds (wash, distribution, and extract) and use water and fuel efficiently to minimize expenses. The washer-extractors fit through standard 36" door frames for easy installation.

CIRCLE 62 ON READER SERVICE CARD

Ozone: Science and Engineering, 29: 85–99

ISSN: 0191-9512 print / 1547-6545 online
DOI: 10.1080/01919510601186048

Ozone in the Laundry Industry—Practical Experiences in the United Kingdom

Dick Cardis,[1] Cameron Tapp,[2] Marc DeBrum,[2] and Rip G. Rice[3]

[1]JLA Limited, Meadowcroft Lane, Ripponden, West Yorkshire, United Kingdom
[2]ClearWater Tech, Inc., San Luis Obispo, California, USA
[3]RICE International Consulting Enterprises, Sandy Spring, Maryland, USA

Since the early 1990s, the use of ozone in many commercial and industrial laundering applications has been evolving rapidly. Ozone allows washing to be conducted using cold water, thereby saving considerable heat energy and water consumption. Additionally, ozone enhances the wash process, resulting in a significant reduction in detergent dosage and number of rinses, thus saving water. Ozone/cold water cycles are gentler to fabrics, thus extending linen life. Finally, ozone/cold water laundering is beneficial for effluents, resulting in reductions in COD (chemical oxygen demand). Microorganisms are destroyed effectively in ozone-wash waters, and washing and drying cycles are shorter, thus saving labor. In this paper, the authors describe some specific case studies at commercial laundering installations in the UK, whereby the users of ozone have reaped major benefits, including enhanced microorganism kills/inactivation and significant cost savings.

Keywords Ozone, Laundries, Bacteria Kills, Virus Inactivation, Economic Benefits, *Clostridium difficile*, MRSA

INTRODUCTION

(ClearWater Tech, 2003, 2006)

Over the years, commercial laundry operations have improved by achieving higher per-load capacities and automated cycle and chemical management to ensure consistent quality over many loads. These improvements are notable, yet many financial and regulatory pressures continue to face commercial laundering, including:

- Water consumption and conservation
- Energy conservation
- Waste products management
- Efficiency per laundry load
- Fabric lifetime cost

These issues apply in all commercial laundry settings, ranging from hospitals and institutional care to hospitality installations and for-profit commercial laundries. The number of commercial laundering facilities in the United States alone was estimated in 2003 at 140,400, categorized in Table 1 (ClearWater Tech, 2003).

Starting in the mid-to-late 1980s, work began to determine if ozone, O_3, a known powerful oxidant and disinfectant, would allow laundering to be performed using ambient temperature water. The strong oxidizing and bleaching properties of ozone might allow reduction or even elimination of laundering detergents, thus lowering the chemical loads in discharge wastewaters. Simultaneously, ozone's strong disinfecting capabilities might also kill or inactivate problematic microorganisms found in many soiled textiles, e.g., from hospitals, medical facilities, nursing homes, etc.

Two remarkable properties of ozone stand out in its application to laundry systems:

1. Because it leaves no chemical residue and because the amount of detergent needed with ozone treatment is much lower, ozone-sanitized wash needs far less rinsing, saving water; and,
2. Because ozone works so efficiently in cold water, sanitizing as well as cleaning can be done in cold water, saving energy.

With less rinsing, wash loads can be completed faster, thus utilizing the laundry equipment more efficiently and reducing the total staff hours per load.

Ozone's arrival for commercial laundries has proceeded on a normal innovation-adoption path.

Received 09/19/2006; Accepted 12/20/2006
Address correspondence to Rip G. Rice, 1710 Hickory Knoll Road, Sandy Spring, MD 20860, USA. E-mail: RGRice4 ozone@aol.com

TABLE 1. U.S. Commercial Laundering Facilities (ClearWater Tech, 2003)

Category	Laundry Facilities
Hospitals	7,400
Nursing Homes	39,700
Hotels and Motels	47,000
Prisons	4,200
Commercial Laundries	7,100
Coin Operated Laundries	35,000

Ozone-based commercial laundries currently are operating in all segments of the commercial laundry market, in many places round the globe, with some in continuous operation since the early 1990s.

OBJECTIVES

In the United Kingdom, rapid and significant advances in developing the application of ozone in commercial laundries have been made in recent years. A leader in this effort has been JLA, Limited, of Ripponden, West Yorkshire, that has been marketing ozone systems to the institutional laundry business since mid-2004. The primary purpose of this publication is to document results from studies conducted by independent microbiological laboratories and other organizations to document the various aspects of ozone's application in commercial laundering equipment. Another objective is to document and quantify the cost savings obtainable by utilizing this revolutionary technology in commercial laundries.

OZONE (COLD WATER) WASHING

(ClearWater Tech, 2003, 2006)

When designing a commercial laundering system incorporating ozone and/or when retrofitting ozone systems into existing commercial laundering systems, there are three fundamentally different design approaches in use.

- Recirculation Injection—This design can handle the heaviest demands and saves the most water, energy and time. The break cycle uses conventional laundry methods with hot-warm water and chemicals. However, that's where conventional processes end. All other chemical cycles are replaced with cold water and low and at times no chemical injection. The rinse water is continually cycled back to the ozone system for extreme oxidation of the rinse water and a predetermined amount of dissolved ozone is sent back to the washer for sanitizing of the laundry.
- Direct Water Injection—Ozone is introduced directly by injection to the cold water supply line. This approach allows for effective concentrations of ozone for disinfection and odor control in any cold water cycle. This method offers good effectiveness with good return on investment through savings in chemicals and energy. A variation on this approach includes a contact tank in which ozone is mixed with cold water and stored until needed by the wash cycle. The contact tank approach makes it possible to achieve higher effective concentrations of ozone.
- Air Injection—Ozone gas is injected directly into the catch basin of the washer. A properly designed air injection system will activate traditional laundry detergents, allowing them to do their job with less water and at lower temperature. In this approach, ozone is relied on for disinfection and overall laundry quality with reduced costs. Disinfection is achieved with the ozone gas in solution as well as linen folding into the ambient ozone in the wash drum. An ambient air ozone monitor within the facility and/or within the wash drum will control ozone off-gas and eliminate any concerns of high ozone levels in the laundry facility. However, if applied correctly the air injection method of ozonating a commercial or institutional laundry will yield the highest return on investment of the three basic designs.

Figure 1 (California Urban Water Conservation Council, 2006) shows a schematic diagram of a direct injection laundry system with holding tank, (three washing machines) using ozone. This figure shows the optional installation of a Granular Activated Carbon filter to treat incoming municipal water.

Figure 2 (ClearWaterTech, 2006) shows more details of the air injection ozone equipment for a single washing machine (Figure 2a) and Figure 2b shows the same details for two washing machines fitted with a single ozone air injection system. The oxygen concentrator removes some of the nitrogen from ambient air, thereby concentrating the oxygen to levels above 90% by weight. Higher oxygen concentrations in the feed gas to ozone generators result in higher ozone concentrations being produced. The ambient ozone controller monitors ozone in the ambient air. Should the level of ambient ozone ever exceed local regulations, this controller automatically shuts off the ozone generator until the source of the ambient ozone can be found and repaired. The gaseous ozone produced by the generator is fed via a diffuser into water entering the washer. The ozone system turns on during any "step" within the wash formula via a "dry contact" (no voltage) signal or 120-240V AC signal to the main control board of the ozone generator.

Other LED units on the display panel indicate other functions of the equipment. Thus the operational status of this equipment can be checked and monitored visually

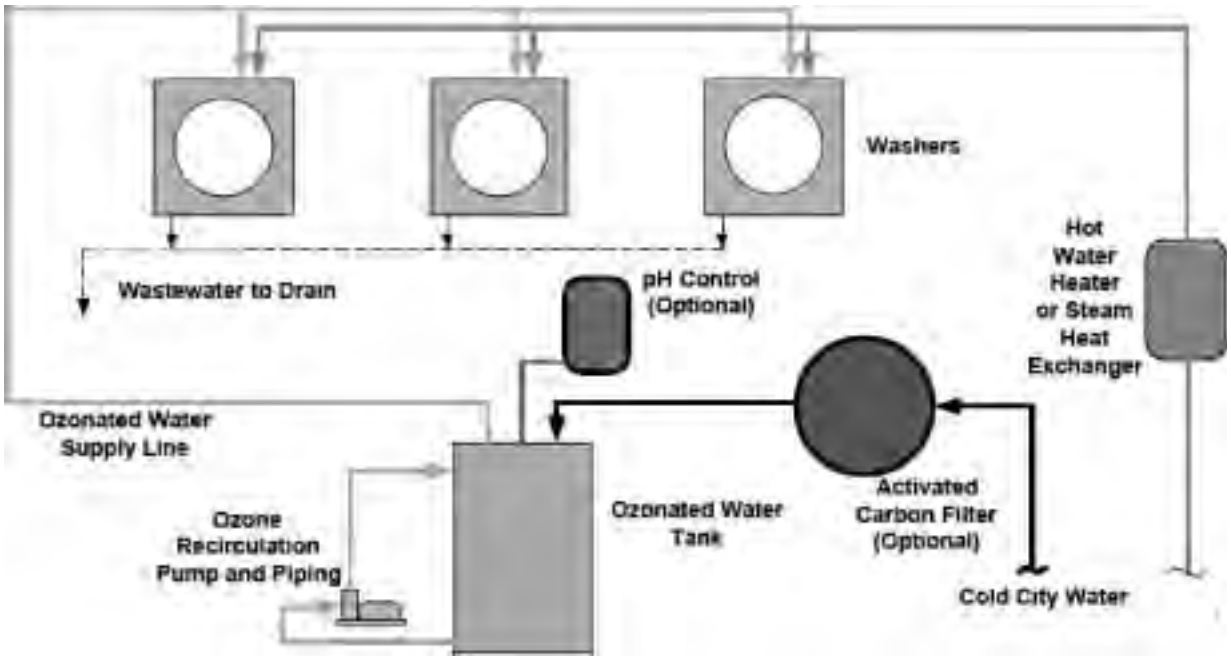


FIGURE 1. Ozone laundry systems (California Urban Water Conservation Council, 2006).

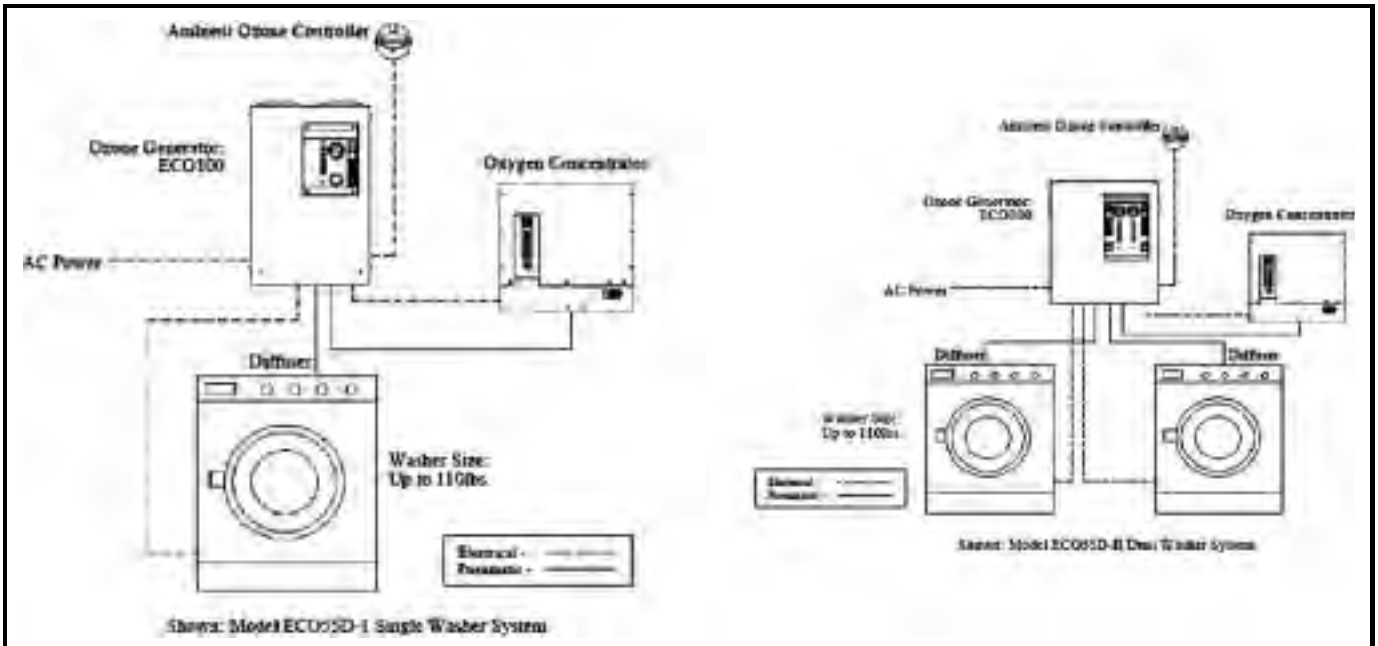


FIGURE 2. (a and b): Schematic drawings of two CWT ECOTEX ozone laundry systems (ClearWater Tech, 2006).

by personnel responsible for laundering without requiring detailed technical training.

The ozone output for any given wash load can be increased or decreased by turning a potentiometer or manual ozone output control knob located on the control panel of the ozone generator. As this potentiometer is turned clockwise, the LED bars illuminate one at a time. In this manner, the proper amount of ozone is applied to cope with the kind/type of soils on articles placed in the washer. The ozone output also can be varied by changing the flow rate of air entering the ozone generator.

The OTEX Ozone Washing System and Process

This process and complete laundering system is offered on a fixed-price rental basis, including full maintenance, in the United Kingdom by JLA, Ltd. The firm has been monitoring

ozone technology since 1995, and developing and perfecting an ozone laundering system since 2002. Commercial ozone-laundering systems were introduced in 2004.

OTEX washing equipment ranges in size to allow laundering of from 16 lbs to 126 lbs, and each equipment component complies fully with all relevant UK water and health regulations. Materials of construction are resistant to ozone-containing gases and waters. Dryers handle capacities of from 20 lbs to 179 lbs, and include the S.A.F.E. (Sensor Activated Fire Extinguishing) system for dryers. Typically, the equipment installer sets the ozone output control knob for the desired ozone output for the degree(s) of soil likely to be encountered on linens at the facility. Personnel doing the laundering then only need choose the program number 1 through 4 (1 being for the heaviest soil and 4 for the lightest), then push "start."

Liquid detergent and other chemicals are injected according to measured doses into the wash cycle using peristaltic pumps supplied by detergent companies. Detergent control is important in ozone laundering because indiscriminate addition of more detergent than is needed will use up the ozone and will require more-than-necessary rinsing.

A proprietary ozone/water contacting system (the interfusor) is employed that creates a vortex effect, enabling more ozone to be dissolved in a given volume of water than by standard ozone contacting methods. In turn, this allows a higher degree of microorganism kills without producing excessive amounts of ozone off-gas.

An additional feature of the OTEX ozone laundry systems is the inclusion of a means to vary the amount of ozone fed to any wash water. As with household clothing and linens, some soils are heavy (oils, greases, mud, etc.) while other soils are light (personal garments). Heavier soils require more ozone than do light soils. Consequently, the OTEX display board contains a sequence of 10 LED bars, which indicate 0 to 100% of the ozone output available from the ozonation equipment installed. Each LED bar indicates an additional 10% of the ozone output available above that of the preceding LED bar.

The OTEX single reaction chamber ozone generator produces 4 g of ozone per hour at 3% ozone concentration in the gas phase at a gas flow rate of 4 scfh at 100% output (LED bar #10 illuminated). At a gas flow rate of 3 scfh, this same unit produces 3.1 g/h of ozone at 3.2% ozone concentration in the gas phase at 100% output. At 60% output (6th LED bar illuminated), this unit produces 1.86 g/h of ozone at 1.92% concentration in the gas phase at 3 scfh.

ADVANTAGES OF OZONE IN COMMERCIAL LAUNDERING SYSTEMS

(ClearWater Tech, 2006)

- Reduces Energy Use—Ozone enhances the effectiveness of the actions of chemicals, reducing the need for high temperature washing. Estimates of savings potential are as high as 90% in washing and 20% in drying. The Magnolia Manor, an assisted-living facility in Americus, GA (USA) using ozone laundering since 1993 has documented energy savings of 51.3%.
- Reduces Water Use—Ozone wash systems normally require fewer rinse steps, thus reducing water usage by an estimated 30–45%. Closed loop systems are more expensive but recover most of the water, so that reductions in water use can reach 70–75%.
- Reduces Chemical Use—Ozone makes existing chemicals work better, and reduces overall chemical demand in several ways.

    1. Ozone helps supply oxygen to the wash water, which increases chemical effectiveness and reduces chemical demand.
    2. Ozone oxidizes linen soils, making them easier to remove from the wash water.
    3. Ozone can reduce the need for harsh, high-pH chemicals traditionally used to remove Fats, Oils and Grease (FOG) by breaking some of the molecular bonds in FOG and reducing them to simpler carbon compounds. While virtually all ozone laundry systems use at least some chemicals, savings claims range from 25% to 70%. Actual savings will depend on the type of laundry being washed, the temperature and hardness of supply water and the design of the ozone-laundering system.
    4. Ozone in water solution performs the function of chlorine bleach, without producing by-products. Ozone works quite well and safely in conjunction with hydrogen peroxide if a separate bleach cycle is desired. Also, because ozone improves the removal of soils from wash water, it helps prevent redeposition of soil onto the wash (one of the major causes of fabric graying), which in turn reduces the need for bleaching.

- Purifies and Disinfects—Ozone is very effective against bacteria, viruses and other microorganisms. The key is achieving a "Ct" value (contact time in minutes multiplied by ozone concentration in mg/L) of 1 mg/L-min or more.
- Improves Textile Life and Quality—Shorter cycle times and cooler temperature water (because fewer rinse steps are required) means less wear and tear on textiles. Also, reduced exposure to chemicals can improve fabric life. Additionally, ozone assists in water softening by removing hardeners such as calcium and

magnesium from the water. This occurs by the complex mechanism of ozone adding oxygen moieties to some of the partially oxidized organic materials present in laundry soils. The oxygenated organic laundry soils can form insoluble complexes with polyvalent cations (Ca, Mg, Fe, etc.), thereby partially softening the ozone-treated laundry waters. Softer water produces a better feel in washed fabrics due to better sudsing and more complete rinsing action. Finally, ozone is an effective deodorizer that works by breaking molecular bonds of many organic and inorganic compounds typically responsible for odors.

- Improves Effluent Quality—Effluent surcharges can be reduced because ozone oxidizes bacteria, other microorganisms, and some dissolved organic compounds that make up biochemical oxygen demand (BOD). Also, because fewer chemicals are used in ozone laundry systems, chemical oxygen demand (COD) may be reduced as well.

These benefits will be quantified later in this paper.

SPECIAL TESTING CONDUCTED FOR THIS PAPER

Many test studies were conducted during 2004–2005 in the United Kingdom to determine particular effects and efficacy of ozone in commercial laundering systems. Several representative studies will be described next.

Microbiological Testing

Test #1. Comparison of hot water (75–80°C) to OTEX laundering process vs. C. difficile spores (Microsearch Labs., May 15, 2004). A laboratory test was conducted by Microsearch Laboratories Ltd., West Yorkshire, UK using the European Suspension Test (E.N., 1997) comparing the effects of hot water (75°C and 80°C) over 15 minutes to 2.5-minutes laundering using cold water in the OTEX ozone-laundering process on *Clostridium difficile* spores. *C. difficile* is an intestinal bacterium that causes hospital-acquired diarrhea. In elderly patients, this can result in serious illness, and even death. The bacterium produces toxins that damage the cells lining the bowel. *C. difficile* survives well outside the body because it is a spore-forming microorganism.

Data are presented in Figures 3 (hot water results) and 4 (OTEX results). Hot water testing was conducted at 75°C over 15 minutes, and at 80°C over 15 minutes. The reduction in levels of *C. difficile* spores was insignificant (Figure 3). Figure 4 shows data obtained from OTEX ozone laundry water at ambient temperature (cold water). Even after only 2.5 minutes, no viable trace of spores could be found.

Test #2. Testing of four OTEX laundering cycles–Microsearch Labs–Nov. 8, 2004. Four ozone laundering cycle studies (Test Codes) of various garments were conducted and the challenge organisms (*S. aureus MRSA strain* and *C. difficile*) recovered and analyzed post-washing. Cycle 1 (Test Code 1) is a heavy washing for foul and infected, heavily soiled clothing. This cycle also has a sluice cycle (high wastewater level flush). The machine fills up with cold water, does a wash action, and continuously drains through an overflow. This sluice cycle is followed by a normal wash cycle. Cycle 2 (Test Code 2) is for lightly soiled sheets and towels. Cycle 3 (Test Code 3) is for delicate items, such as personal clothing and woolens. Cycle 4 (Test Code 4) is a rewash cycle used for oil/grease stained articles. With this cycle, 50°C (122EF) water is used to emulsify the oils and aid washability.

The amount of ozone is constant for each washing program. The difference between cycles is that the more

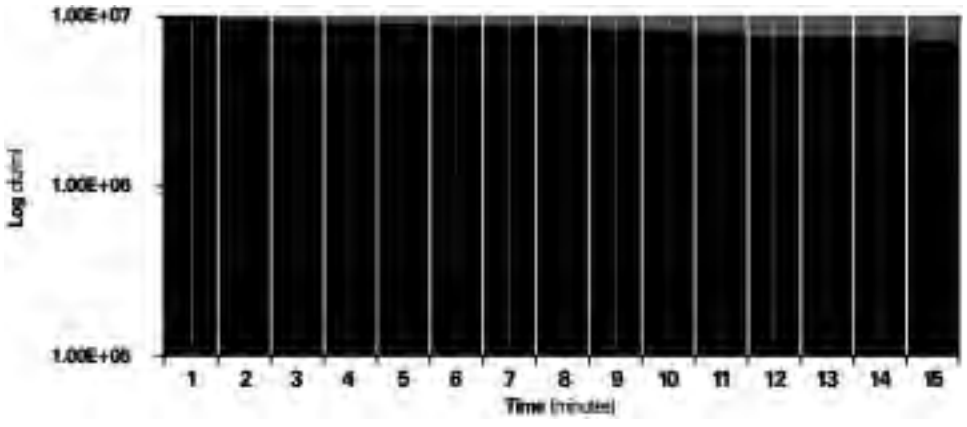


FIGURE 3. Data obtained during 16-min test on water that contained *C. difficile* spores at 75°C (Microsearch Laboratories Ltd., May 15, 2004).

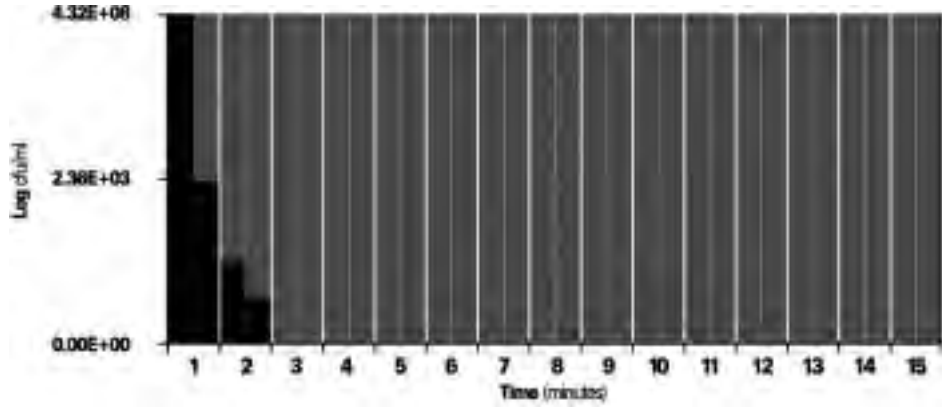


FIGURE 4. EU Suspension Test conducted on OTEX ozone laundry water with *C. difficile* spores (Microsearch Laboratories Ltd., May 15, 2004).

heavily soiled items require more detergent, which destroys some of the ozone. It is important to know that satisfactory microorganism kills can be attained by the four washing cycles, regardless of the degree of soil. A control untreated batch also was tested for these microorganisms in duplicate. Results are listed in Table 2. All ozone launderings resulted in >5-logs kill (>99.999%), whereas washing without ozone (Controls) gave <99.999 % kill.

Test #3. – Microsearch labs – MRSA contamination of nurses uniforms test – 2004. Microsearch Laboratories carried out comparative tests on nurses' uniforms impregnated with a strain of the superbug MRSA (methicillin-resistant *Staphylococcus aureus*). This microorganism is being detected with increasing frequency in USA hospitals and care homes (TIME Archive, 2006).

The care labels of nurses' uniforms commonly carry the recommendation that they should be washed at 40°C (104EF). Therefore, one test was carried out using a conventional 40°C wash cycle (without ozone). A second test was carried out with an OTEX (cold water) cycle.

Figure 5 is a photograph showing the MRSA microorganism which had been impregnated onto a membrane. The membranes were implanted into the garments prior to the uniforms undergoing any laundry process. Figure 6 shows the residual MRSA culture on the recovered membrane after having been washed at 40°C (104EF). Figure 7 shows the absence of residual MRSA culture on the recovered membrane after an OTEX ozone-laundering cycle.

Results

These results indicate that a greater than log-8.0 reduction (99.999999%) in MRSA was obtained on populations of garments washed by the OTEX process. The average log reduction achieved by the 40°C (104EF) wash was only 3.3 (99.93%). To clarify, the reduction of MRSA achieved by the OTEX procedure was greater than log-8.0. Microsearch personnel were unable to

TABLE 2. Recovery of Challenge Organisms from Garments Process by a Variety of OTEX Processes

Trial	Clothing Item	Test Code	*S. aureus* MR Cfu/25 cm^2	*S aureus* MR % kill	*C. difficile* Cfu/25 cm^2	*C. difficile* % kill
OTEX1	ITEM 1	TEST 1	<1	>99.999	<1	>99.999
OTEX1	ITEM 2	TEST 1	<1	>99.999	<1	>99.999
OTEX2	ITEM 1	TEST 2	<1	>99.999	<1	>99.999
OTEX3	ITEM 2	TEST 2	<1	>99.999	<1	>99.999
OTEX3	ITEM 1	TEST 3	<1	>99.999	<1	>99.999
OTEX3	ITEM 2	TEST 3	<1	>99.999	<1	>99.999
OTEX4	ITEM 1	TEST 4	<1	>99.999	<1	>99.999
OTEX5	ITEM 1	TEST 4	<1	>99.999	<1	>99.999
Lab Control	Untreated	TEST 5	7.10E + 07		2.10E + 07	

FIGURE 5. MRSA impregnated onto membrane (Microsearch Labs, 2004).

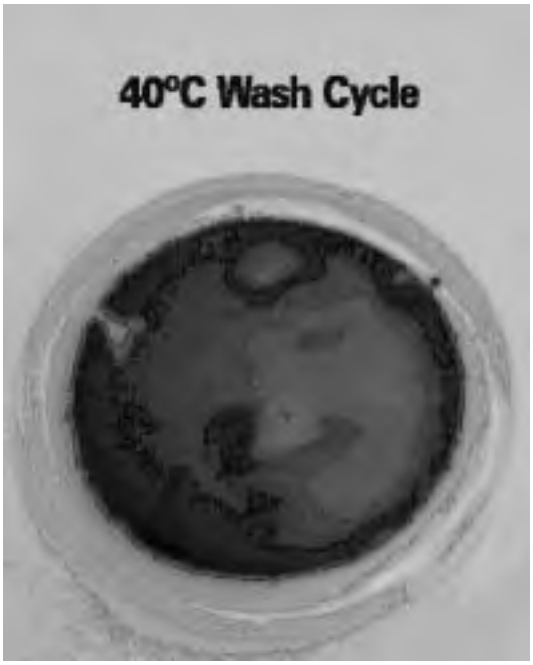


FIGURE 6. MRSA on membrane after 40EC wash.

isolate any survivors from the OTEX treated garments (Microsearch Laboratories, 2004).

Test #4. Antimicrobial efficacy of the OTEX process at 60% ozone output against Escherichia coli *- Microsearch labs, April 29, 2005.* A validation trial was conducted to determine the antimicrobial activity of an OTEX treatment at 60% of the maximum ozone output

FIGURE 7. Absence of MRSA after OTEX.

of the OTEX system against *Escherichia coli*. In this trial, *E. coli* was added as liquid culture directly to the input flow of a JLA washing machine. This culture was added in sufficient volume to produce a contamination level of the order of log-7 cells/mL.

This work and the reconsideration of the optimum operating ozone level was prompted by confounding adverse evidence produced during a third-party evaluation during which poor log kill data was obtained for *E. coli*. The initial aim in this trial was to produce evidence of a baseline log kill potential with *E. coli* as a direct contaminant of wash waters with no additives running at ambient temperature, then to demonstrate the effect of ozone under identical conditions.

An ambient temperature wash trial was conducted which contained no additives and which was of 20 minutes duration. Estimates of the *E. coli* levels in the wash water were obtained by the analysis of samples collected at 3, 10 and 20-minute intervals. In an identical wash program after the first sample was recovered (i.e., 3 minutes) the OTEX device was activated and thereafter produced a continuous charge of ozone at 60% of the maximum available ozone output. Subsequent sampling occurred as described previously. Each trial was preceded by a hot sanitizing wash and rinse cycle. Data obtained are reported in Table 3 and Figure 8.

In the control experiment with no additives or ozone treatment, these data show an *E. coli* log-reduction of approximately 1 log cycle during the 20-minute wash period. During the treatment with ozone, *E. coli* could not be recovered after the initial dosing period. In fact

TABLE 3. OTEX Revalidation Trial 60% Ozone Output Treatment

Treatment	T = 3 min *E. coli* Cfu/mL	T = 10 min *E. coli* Cfu/mL	T = 20 min *E. coli* Cfu/mL
Ambient Wash No Ozone No Additives	9.30E + 07	8.40E + 07	6.20E + 06
Ambient OTEX Only 60% Ozone Output Wash	7.80E + 07	< 1	< 1

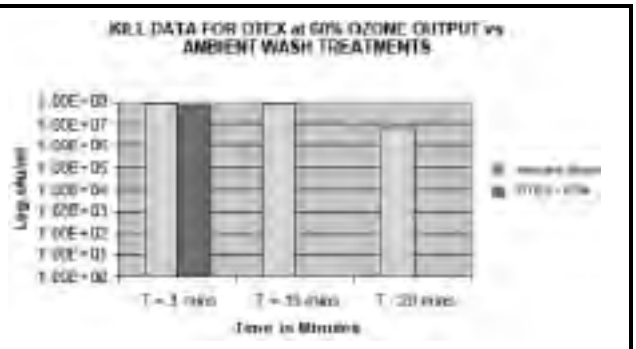


FIGURE 8. *E. coli* kill data for OTEX at 60% of the available ozone output vs. ambient wash treatments. Microsearch Labs, April 29, 2005.

by the 10-minute mark, these data indicate that a 7-log reduction was obtained corresponding to 7 minutes of ozone dosing at 60% of the maximum available output.

Test #5. OTEX bacteriological and viral investigation: OTEX laundry system solution test (OTEX report Sept. 2005). A laboratory investigation was carried out with the objective of providing documentary evidence of the bactericidal and virucidal activity of the OTEX system at ambient temperature against thermal disinfection (75EC = 167EF)) wash processes. The work was carried out on 1 July 2005 at JLA's R & D Technical Laboratory, Ripponden, West Yorkshire, UK. The microorganisms and viruses employed (Table 4) were independently prepared by Microsearch Laboratories Ltd. for testing. The four virus particles selected for testing represent both single- and double-strand RNA and DNA, which is the structure of the vast majority of all virus types.

Program Details and Test Conditions

Tests were carried out using an extended sluice program in a JLA model HW164 (16 k dry weight) washing machine. No detergent was employed during this series of tests. Details are tabulated below. Tests were conducted with water temperatures at both ambient, i.e., as supplied, and at 75EC (167EF), which is above the recommended thermal disinfection temperature of 71EC (160EF). Domestic supply water was employed with a water hardness of 60 ppm $CaCO_3$ for all tests.

Program Details:	Cycle Time (mins)	Temp (°C)	Wash Action
Program 1: Cold Sluice	30	Ambient	12 sec wash 3 sec stop time
Program 2: Thermal Sluice	30	75°C	
Detergent Volumes		No Detergent in use.	

A single unit OTEX system was employed and was maintained at the following settings throughout the trial with the exception of the control test with no ozone:

Ozone Concentration Setting	8 (highest)
Pressure	5 psi
Flow Rate	3.5 cfh

TABLE 4. Solution Challenge Test Organisms

Microorganism	Cfu/mL
Staphylococcus aureus	1.3E+08
Pseudomonas aeruginosa	3.1E+09
Candida Albicans	3.1E+08
Escherichia coli	5.2E+08
Streptococcus faecalis	5.0E+08
Aspergillus niger	3.1E+08
Clostridium difficile	4.2E+08
Clostridium perfringens	9.2E+08
Campylobacter jejuni	6.0E+08
Aeromonas mixed species	8.2E+08
Actinobacter sps	4.3E+08
Lactobacilli sps	3.9E+08
Virus particle	Particles/mL
Lambda phage	3.8E+24
FCoVA	2.6E+24
Saccharomyces virus ScV-L-BC	3.1E+23
Vibrio phage fs1	2.6E+28

Test samples were taken from the wash drum throughout the wash cycle to determine the concentration of dissolved ozone in the water. This was measured by using the Chemets method, which employs DPD chemistry. Dissolved ozone levels increased from 0.2 ppm at the start to 0.6 ppm after 15 minutes, with samples being taken at 3, 7, 11, and 15 minutes of washing.

Data obtained are presented in Figures 9–14. Figures 9, 10 and 11 show results of bacterial sampling at ambient temperature-no ozone (control), 75EC (167EF = thermal washing), and ambient temperature with ozone (OTEX), respectively. Note that without ozone and at ambient temperature (Figure 9), only small amounts of bacterial kills were obtained. With thermal washing (Figure 10), three strains of bacteria remained at significant levels even after 15 minutes. But with ozone at ambient temperature (Figure 11), no bacteria were present after 3 minutes of washing.

Figures 12, 13 and 14 show similar results of virus and phage sampling at ambient temperature-no ozone (control), 75EC (167EF = thermal washing), and ambient temperature with ozone (OTEX), respectively. Note that without ozone and at ambient temperature (Figure 12), only small amounts of viral inactivation were obtained. With thermal washing (Figure 13), viral inactivation was obtained after 5 minutes, and the same results were obtained with ozone at ambient temperature (Figure 14) after 5 minutes (but at lower costs).

NOTE: United Kingdom guidelines for thermal disinfection of laundry require a temperature of 71°C (160EF) to be held for only 3 minutes, which is below the time found to be required for inactivation of the four viruses tested. In the United States, each state has developed its own regulations or guidance, which may differ from state to state. For example, the Illinois General Assembly, Joint Committee on Administrative Rules, Administrative Code (undated) offers the following:

> "All linens shall be mechanically washed using soap or detergent and warm or hot water. Linens shall be disinfected by using one of the following procedures:
>
> 1. *Thermal Disinfection*: Linen must be exposed to hot water of at least 160EF (71EC) for a cumulative time of at least 25 minutes.

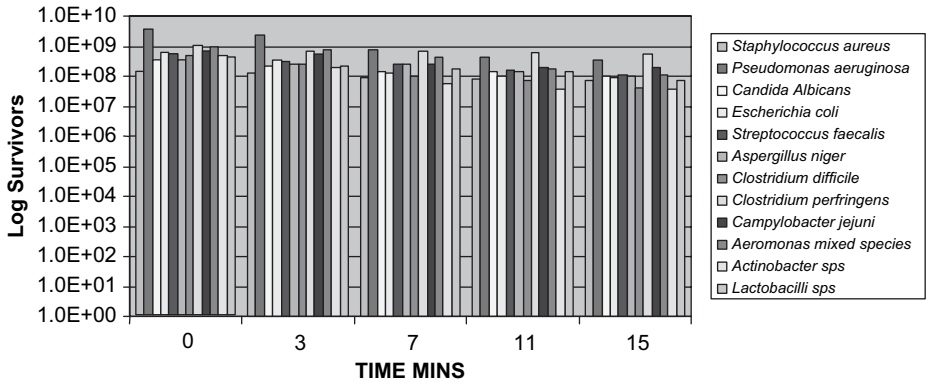


FIGURE 9. Test results—control @ ambient temperature–no ozone–bacteria.

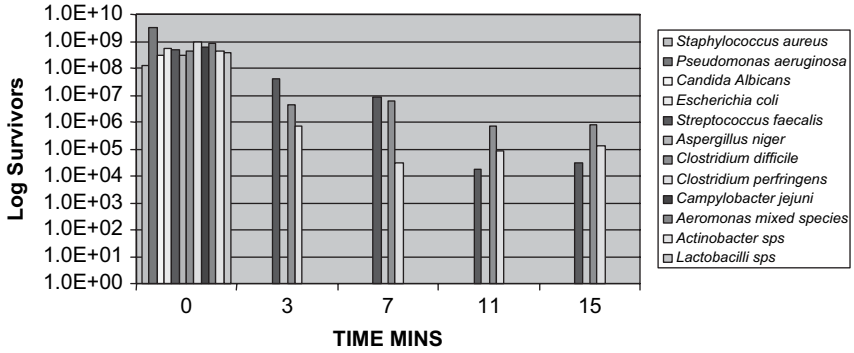


FIGURE 10. Test results - Thermal @ 75EC - no ozone – bacteria.

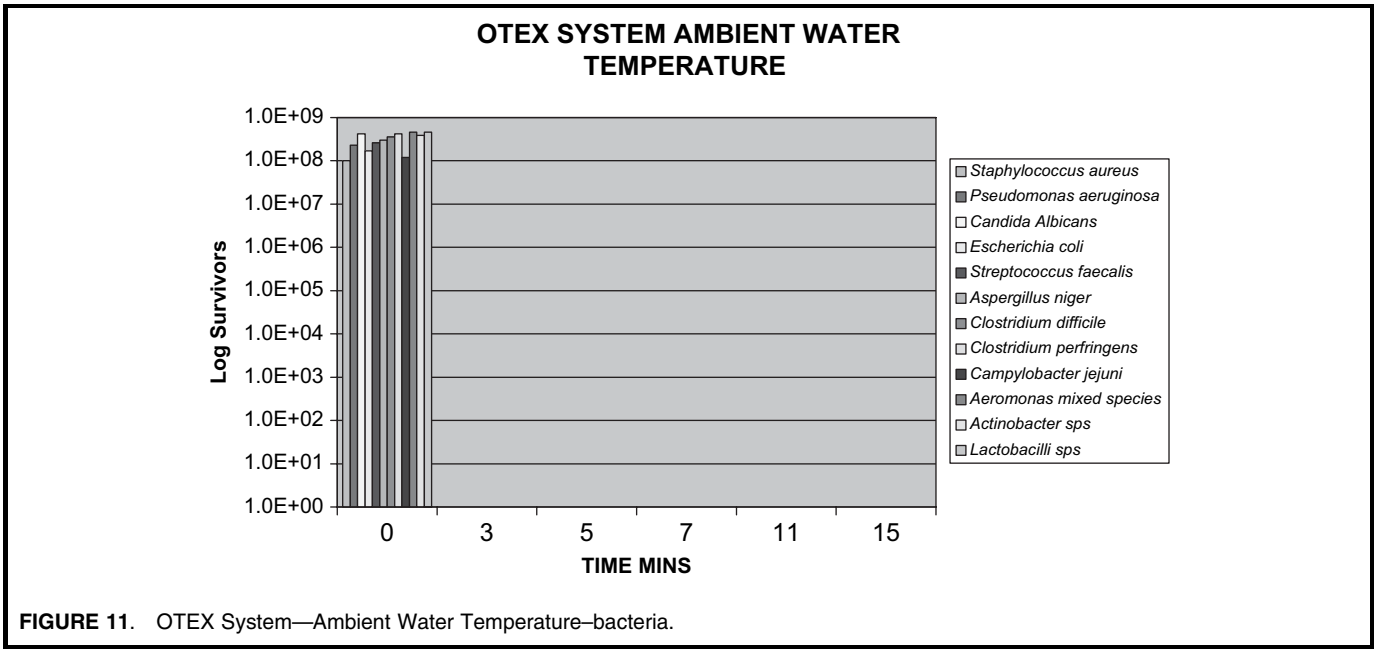


FIGURE 11. OTEX System—Ambient Water Temperature–bacteria.

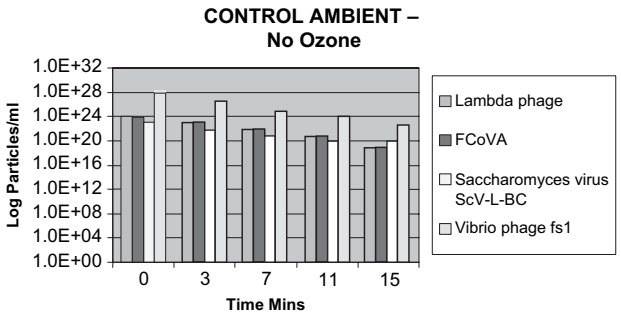


FIGURE 12. Test results—control @ambient temperature–no ozone–viruses and phages.

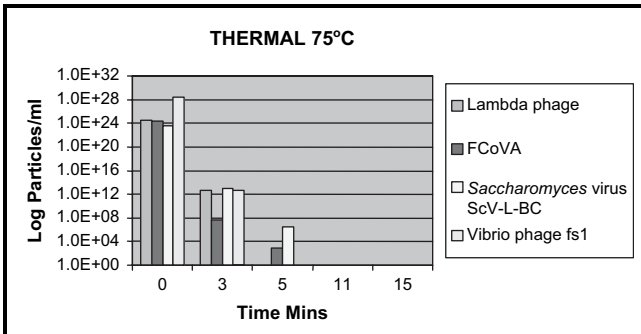


FIGURE 13. Test results—Thermal @ 75EC (167EF)–viruses and phages.

2. *Chemical and Thermal Disinfection*: Linen must be exposed to wash and bleach bath water at least 140EF (60EC). The bleach bath must be at least 10 minutes long and have a starting bleach concentration of 100 ppm. This bleach concentration should be measured by titration on a periodic basis.

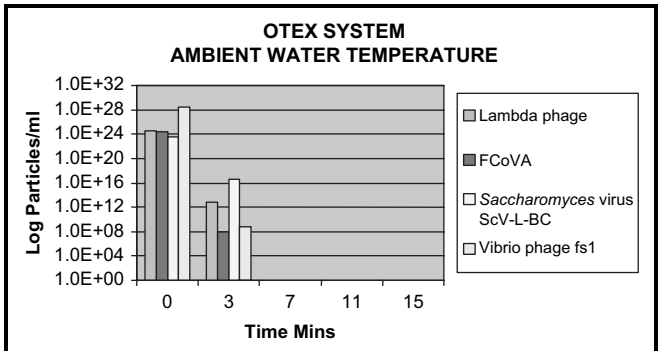


FIGURE 14. Test Results—OTEX System–Ambient Water Temperature–viruses and phages.

3. *Other*: A stepwise wash process that has been previously documented by microbiological study published in a scientific journal. The results must indicate no surviving pathogenic microorganisms and a low level of other organisms. Low level is defined as 9 out of 10 samples with less than 2 colonies per 10 square centimeters of test surface."

Test #6. Microsearch Labs–6-Month QE II hospital bacterial test–completed November 2005. Preliminary testing of microfibre mops and cloths contaminated with various microorganisms found in hospitals by conventional laundering (thermal disinfection at 71EC = 160EF) showed the mops and cloths to be still contaminated. *C. difficile* counts were over 150,000 TVC (total viable counts). An OTEX system was installed in the QE II Hospital, Welwyn Garden City, Herts., UK, and a 6-month trial of the OTEX ozone laundering system began on May 17, 2005, and was concluded successfully.

Throughout the 6-month OTEX trial, no residual target organisms, as set by the East and North Hertfordshire NHS Trust Infection Control, were detected, including

Clostridium difficile, after processing with the OTEX system. In addition the OTEX system provided a simple laundering process with one cycle, which can also accommodate traditional cotton mops while using less detergent and being energy efficient. The hospital adopted the OTEX ozone laundering system as their method of decontamination on Dec. 12, 2005.

Test #7 – Laundering tests on marquee linings (JLA Ltd., July 2005). A mildew-soiled marquee lining was submitted for cleaning, the condition being so bad that the lining was considered only fit for disposal. The current practice is to treat the linings with chemicals individually to remove the mildew. Stains which are not normally removed by conventional washing processes are likely to need treatment in a cold solution containing 700 ppm of hypochlorite bleach acidified with acetic acid. This technique has its own inherent safety implications, i.e., reaction between an acid and an oxidizing agent liberating chlorine gas. Commercially available alternative products are based on hypochlorite or citric acid.

Methodology

The lining was cut into samples for cleaning by various wash programs. A control sample was retained. Tests were carried out in a 16 kilo JLA Model HW164 washing machine. Tests were carried out as follows:

Traditional Wash at 40EC (104EF) – no ozone
Traditional Wash at 60EC (140EF) – no ozone
OTEX wash – detergent only
OTEX wash – detergent and destainer

Reflectance readings were taken on the control and test samples to provide numerical data on the effectiveness of the wash cycles. Reflectance measurements allow a numerical value to be assigned, 0 being black and 100 white. Since mildew tends to discolor surfaces black, the higher the reflectance reading (or closer to 100), the better the cleaning process. It should be noted that the presence of mildew was more pronounced at bottom of the lining. Reflectance readings are plotted in Figure 15.

CONCLUSIONS

The results indicate that the OTEX system was successful in removing a high buildup of mildew, which was not removed as effectively with conventional wash programs. In addition, the brightness and odor of the lining was improved with the process, as shown by the higher reflectance readings of the three OTEX-washed test samples.

ECONOMIC BENEFITS OF OZONE LAUNDERING

Estimated Cost Benefits in the USA

National averages (USA) as of December 2005 for consumables and labor costs were used to project cost savings (in U.S. dollars) obtainable with four production models of the ClearWater Tech ECOTEX ozone-laundering system. Actual savings may vary based on geographical locations and actual washing programs used at specific facilities.

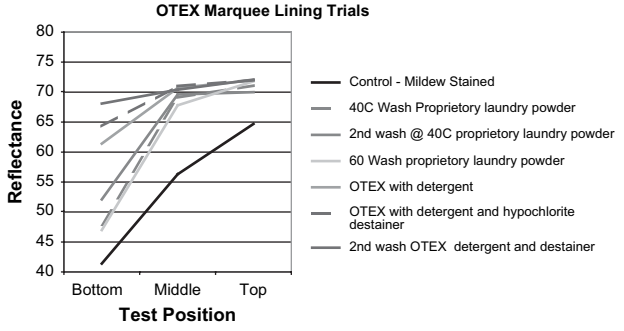


FIGURE 15. Reflectance data on laundered marquee linings (JLA, July 2005).

Facility Costs

Water/Sewer:	$0.006/gallon
Natural Gas, 2005:	$1.24/therm
Chemical Costs:	$0.25/oz
Av. Facility Labor Cost:	$10.00/hr

Table 5 shows the total estimated cost savings for ozone washing projected on the basis of detailed calculations for each cost item. Tables 6 and 7 show the Return-on-Investment calculation results for the ClearWater Tech ECOTEX ozone laundering system based on these cost savings at 10 loads per day per washing machine.

ESTIMATED COST BENEFITS IN THE UK

In contrast to the United States, where ClearWater Tech sells ECOTEX ozone laundering equipment outright, JLA Ltd. rents OTEX ozone laundering equipment to their several thousand clients. The rental fee includes a service contract. Consequently, some specifics

TABLE 5. Total Estimated Cost Savings for Ozone Washing

	Savings		
Item Saved	per load	per day	percent
Water/Sewer	$0.54	$5.40	47%
Water Gas	$1.14	$11.44	90%
Hot Water	165 gal/load		86%
Dryer Gas	$0.34	$3.40	20%
Chemicals	$0.25	$2.50	42%
Labor	$4.93	$49.30	31%

TABLE 6. Laundering Savings With ECOTEX Ozone Systems

ECOTEX Return on Investment (ROI)				
	Potential ROI			Costs
System - Model ECO55D	per Load	per Month	per Year	Sug. Retail Price
- I	$2.27	$635.60	$7,627.20	$11,066
- II	$4.54	$1,271.20	$15,254.40	$13,634
- III	$6.81	$1,906.80	$22,881.60	$20,110
- IV	$9.08	$2,542.40	$30,508.80	$23,110

TABLE 7. ECOTEX Time to Return-On-Investment—Consumables Only

System	Estd Time to ROI (months)	Estd Time to ROI (years)
Model ECO55D-I	17.41	1.45
Model ECO55D-II	10.72	0.89
Model ECO55D-III	10.54	0.87
Model ECO55D-IV	9.08	0.75

Note: Labor and Linen Savings NOT Included.

in estimated ozone benefits will vary as a result. Additionally, the amounts of estimated savings in the United Kingdom are expressed below in pounds Sterling. Nevertheless, the estimated savings as a result of ozone laundering are strikingly similar on either side of the Atlantic Ocean.

Tables 8–10 show weekly savings in three different establishments having OTEX ozone laundering equipment installed, a 50-bed care home (70% incontinence) (Table 8), a 90-bed care home (85% incontinence) (Table 9), and an 800-bed hotel (Table 10).

THIRD-PARTY TESTING/EVALUATION

The Laundry Technology Centre

The Laundry Technology Centre, Ilkley, West Yorkshire, UK tested an OTEX laundering system installed in the laundry of a 90-bed care home, just to the north of Manchester in early 2004 (Laundry Technology Centre, 2004). Measurements were taken by the Laundry Technology Centre to assess the disinfection and washing performance of the new system against recognized national standards for healthcare work.

Objectives

Wash quality was assessed using Swiss EMPA (Swiss Federal Laboratories for Material Testing and Research) calibrated test fabric for (a) protein removal (blood, urine, feces, perspiration, skin sebum), and (b) vegetable dye removal (red wine, tea, coffee, beer, beetroot, black currant). Disinfection was assessed for (a) total viable count (TVC) of all surviving microorganisms, (b) an indication of mold and fungal growth (including athletes foot and prickly itch), and (c) an indication of coliforms, including *E. coli*.

Methodology

Every load processed through each of the three 16-kg washer extractors in the laundry was monitored. Microorganism counts were taken on the line before washing and immediately after the end of the final spin after washing. The EMPA test pieces were used in 10 cm squares, securely pinned to a carrier towel and placed in the center of each load. Each load contained one protein piece and one vegetable dye piece. Replication was achieved by having a test piece in every load rather than by having multiple pieces in a single load. The wash quality was measured by assessing the "whiteness" of the EMPA test pieces using a standard laundry reflectometer. Each measurement was performed four times at right angles to eliminate weave effects. During testing, it was found that the ozone generator had been inadvertently switched out of circuit for one machine thereby affecting two of the test runs. This was corrected for the rest of the trial.

RESULTS

The measurement results both before and after for microorganism counts were remarkably consistent, so the contact techniques and the replication were both considered adequate. The wash quality results obtained by measuring the reflectance of the EMPA test pieces were consistent, taking into account the different wash programs used.

Conclusions

The trial wash processes effectively disinfect the linen, even at temperatures well below 71EC, using relatively gentle cycles designed to protect garments from damage. The ozone generation plays a significant part in the disinfection process, as demonstrated by the poor results obtained with no ozone supply to machine number 2 for two of the trial runs.

Discharge of Ozone-Treated Laundering Wastewaters—WRc-NSF Ltd. Assessment

WRc-NSF Ltd. (Water Research Council - National Science Foundation) were commissioned by JLA, Ltd. to assess independently the impact of discharging spent wash water that had been treated with ozone. The following statements form the basis of the WRc-NSF report (WRc-NSF, May 22, 2005):

TABLE 8. Weekly Savings with OTEX—50-Bed Care Home—70% Incontinence

Period	Pre-OTEX	1-week	Post-OTEX	1-week	% Saving	Weekly Saving	Notes
Electric kw	360	£21.60	119	£7.14	67%	£14.46	
Gas kw	1150	£13.80	691	£8.29	40%	£5.50	Incl. 369 kw hr to heat water
Hot Water L	8026		992		88%		
Total Water L	44015	£66.02	26633	£39.95	39%	£26.07	
Chemicals mL	36280	£90.70	11682	£29.21	68%	£61.50	
Subtotal		£192.12		£84.59		£107.53	
Linen Saving						£10.00	Based on 20% extra linen life
Labor	72	£360.00	52	£260.00		£100.00	
Weekly Cost		£552.12		£344.59			
Total Weekly Saving						£217.53	
Total Annual Saving						£11,311.46	
Costs							
Electric kw	0.06						
Gas kw	0.012						
Water/effluent L	0.0015						
Chemicals mL	0.0025						
Labor £/hr	5						

TABLE 9. Weekly Savings with OTEX—90-Bed Care Home—85% Incontinence

Period	Pre-OTEX		OTEX		% Saving	Weekly Saving	Notes
Electric kw	529	£28.57	319	£17.23	40%	£11.34	
Gas kw	1764	£19.04	1166	£12.59	34%	£6.45	Incl. 436 kw hr to heat water
Hot Water L	13580		1670		88%		
Cold Water L	63980		34250		46%		
Total Water L	77560	£116.34	35920	£53.88	54%	£62.46	
Chemicals mL	58215	£145.54	27488	£68.72	53%	£76.82	
Sub Total		£309.48		£152.42		£157.07	
Linen Costs		£50.00		£40.00		£10	Based on 20% extra linen life
Labor Saving	112	£560.00	84	£420.00	25%	£140.00	
Weekly Cost		£919.48		£612.42			
Total Weekly Saving						£307.07	
Total Annual Saving						£15,967.51	
Costs							
Electric kw	0.054						
Gas kw	0.0108						
Water/effluent L	0.0015						
Detergent mL	0.0025						

Ozone rapidly decomposes to oxygen. The rate of decay depends on several factors including temperature, pH and quality of water. In natural freshwater, ozone has a half-life of around 10 minutes at 20°C (68EF). Lower temperatures will encourage greater stability of ozone, but the time scales are not significantly greater. Predictions based on published sources indicate that in clean water, the half-life of ozone increases from 20 minutes at 20°C (68EF) to around 60 minutes at 5°C (41EF).

TABLE 10. Weekly Savings with OTEX—at an 800-Bed Hotel

	Before OTEX		After OTEX				
Period	W/C 30 March 2004		W/C 18 May 2004		% Saving	Saving (£)	Notes
Electric kw	1127	£67.62	585	£35.10	48%	£32.52	
Gas kw	3337	£40.04	1739	£20.87	48%	£21.26	Includes 173 kw hrs to heat water
Hot Water L	22700		3322		85%		
Total Water L	65100	£97.65	31465	£78.66	52%	£18.99	
Chemicals mL	180810	£452.03	54256	£135.64	70%	£316.39	
Total		£657.34		£270.27	59%	£389.15	
Avg cost/cycle		£2.96		£1.40		£1.56	
Estd Linen Saving						£20.00	
Total Weekly Saving						£409.15	
Total Annual Saving						£21,275.72	
Machine Operating Hours		136	114		16%		
Type of Laundry Equipment			Industry-Based Costs				
Washers		2x HF304	IPSO65 & 50		Electric kW	0.06	
Dryers		4x ADC			Gas kW	0.012	
		75 Gas					
					Water/effluent L	0.0015	
					Chemicals mL	0.0025	
					Labor £/hr	5	

When the spent (OTEX) wash water is discharged to the sewer system, the residual ozone will also rapidly react with any organic matter in raw sewage. At the point of discharge from a washing machine, the residual ozone concentration varies between 0.5 to 3.0 parts per million, (milligrams per liter), and in volumes of between 140 and 240 liters per cycle dependent on the wash cycle selected and capacity of machine.

These concentrations of ozone are similar to those applied to drinking water and, with the considerable dilution encountered in the sewer system, will become insignificant. Also, any residual ozone will rapidly disappear immediately on contact with sewage.

Conclusion

On the basis of information in the literature and data supplied by JLA, the conclusion from this risk assessment is that spent wash water treated with ozone is safe to discharge to the sewer system; indeed, any such aeration of sewage can be seen as beneficial since it encourages the breakdown of the organic matter and aids the sewage treatment process.

Hong Kong Environmental Protection Department

On November 11, 1997, the Hong Kong Government, Environmental Protection Department, sent a letter to E Technologies Ltd. (Hong Kong) confirming compliance of effluents of the laundry system at the Chi Lin Monastery (with an E-Technologies ozone laundry system installed) with the required discharge limits for foul sewers under the (Hong Kong) Water Pollution Control Ordinance (<www.ETechnologies.com>).

WORKPLACE HEALTH AND SAFETY ASPECTS OF OZONE

The OTEX and ECOTEX™ systems are fully automatic and require very little operator input. Ozone is automatically generated and injected into the wash water at a stable concentration throughout the wash programs within the washing machine. It is generated *only* when the washers are activated and *only* during washing and rinsing cycles of the program.

Ozone sensors and detectors continually monitor the exposure levels of ozone within the laundry room. These monitors are located within the laundry to measure exposure levels within the breathing zone of the operator, i.e., by inhalation. These will automatically shut down the ozone generating system, not the washing machines, if the level of ozone reaches a specified level of 0.2 ppm ozone (UK standard) or 0.1 ppm (U.S. OSHA standard). The system will restart automatically once the levels have fallen below the particular standard level. The sensors are calibrated and regular visits by trained specialist engineers (OTEX System

Technicians) are programmed to check all aspects of the OTEX system. In the event of a fault on the OTEX system, back-up programs for thermal disinfection are provided.

SUMMARY AND CONCLUSIONS

The use of ozone for laundering is a cost-effective boon to commercial, particularly Nursing Care Homes, hotels, and other facilities that must rely on laundering for the health and safety of their guests. Incorporation of ozone into laundering cycles allows washing to be conducted using cold water, thereby saving considerable heat energy and water consumption. Additionally, ozone enhances the wash process, resulting in a significant reduction in detergent dosage and number of rinses, thus saving water. Ozone/cold water cycles are gentler to fabrics, thus extending linen life. Ozone/cold water laundering is beneficial for effluents, resulting in reductions in COD (chemical oxygen demand).

Microorganisms are destroyed effectively in ozone-wash waters, and washing and drying cycles are shorter, thus saving labor. The use of ozone and cold water allows three traditional washing steps to be eliminated (the initial flush, one rinse, and the softener steps). Depending upon the size of ozone-laundering units installed, a customer can obtain a full Return on Investment in 8 to 16 months from cost savings.

Of particular significance is the ability of ozone/cold water to destroy/inactivate a wide variety of microorganisms within several minutes. The "usual suspects" (*S. aureus, Ps. aeruginosa, Candida albicans, E. coli, Streptococcus faecalis, A. niger, C. perfringens, Campylobacter jejuni*, and *Aeromonas, Actinobacter* and *Lactobacilli* species) are destroyed, and four virus strains (representative of single- and double-strand RNA and DNA) are quickly inactivated.

The recent "superbug" (described by Time Archive as the "new killer bug," MRSA (methicillin-resistant *Staphylococcus aureus*), that is prevalent in hospitals and nursing homes, is quickly eradicated during ozone/cold water washing. This infectious microorganism is not affected by standard techniques of thermal washing with bleaching.

An organism particularly resistant to conventional laundering is *Clostridium difficile*, a cause of diarrhea, which is usually acquired in – hospital. It is sometimes referred to as C.D.A.D. (*Clostridium difficile*-acquired diarrhea). Although in most cases it causes a relatively mild illness, occasionally and particularly in elderly patients, especially those who have recently taken or are on a course of antibiotics, it may result in serious illness and even death. The bacterium produces toxins that are responsible for the diarrhea and that damage the cells lining the bowel. Because it is a spore-former, *C. difficile* can survive outside the human body. It is totally eradicated from soiled linens within minutes during ozone/cold water laundering.

ACKNOWLEDGMENT

The authors are grateful to Daniels Equipment Company, Inc., 45 Priscilla Lane, Auburn, NH (USA) for making available to us certain ozone/laundry application information.

REFERENCES

California Urban Water Conservation Council, "Commercial Laundry Facilities", draft report dated 'Revised 3-30-05', 2006, p. 4.

Clearwater Tech, LLC, "Ozone: A Fresh Innovation for Commercial and Institutional Laundry", White Paper, February, 2006, downloadable from <www.cwtozone.com>.

Clearwater Tech, LLC, "Ecotex Advanced Laundry Systems", CWT brochure, revised April 17, 2006.

E.N. (European Standard), 1997, "Chemical Disinfectants and Antiseptics—Quantitative Suspension Test for the Evaluation of Basic Bactericidal Activity of Chemical Disinfectants and Antiseptics – Test Method and Requirements (Phase 1)", superseded in 2005.

Gorman, C., "Surviving the New Killer Bug", TIME Archive, June 26, 2006, http://www.time.com/time/archive/preview/0,10987,1205364,00.htm

Illinois General Assembly, (undated), Joint Committee on Administrative Rules, Administrative Code, Title 77: Public Health, Chapter 1: Dept. of Public Health, Subchapter f: Emergency Services and Highway Safety, Part 518: Freestanding Emergency Center Demonstration Program Code, Section 518.2100: Laundry Service.

JLA LTD., "Investigation Into the Wash Performance of JLA's OTEX system On Marquee Linings", Report No. JH/OTEX/072005, July 2005.

JLA LTD., "OTEX Validated Ozone Disinfection Report No. OTEX LD01", Sept. 2005.

Laundry Technology Centre, "Assessment of Disinfection and Wash Performance in Care Home Laundry", report by Richard Neale (LTC), Ilkley, West Yorkshire, UK, May 7, 2004.

Microsearch Laboratories Ltd., Mytholmroyd, Halifax, UK, "Ozone as a Functional Wash Cycle Additive", Executive Summary, letter dated Feb. 18, 2004 to D. Cardis at JLA Ltd.

Microsearch Laboratories Ltd., Mytholmroyd, Halifax, UK, "Blind OTEX Evaluation, letter dated August 11, 2004 to D. Cardis at JLA Ltd."

Microsearch Laboratories Ltd., Mytholmroyd, Halifax, UK, "The Antimicrobial Efficacy of the OTEX Process at 60% Ozone Output with *Escherichia Coli*", April 29, 2005.

Microsearch Laboratories Ltd., Mytholmroyd, Halifax, UK. "Bacteriological Test Results Following Disinfection of Microfibre Mops & Cloths Using JLA's OTEX System at the QE II Hospital, Welwyn Garden City. 6 Month Final Report, November 2005".

WRc-NSF Ltd., "The OTEX Validated Ozone Disinfection Washing System", Medmenham, Marlow, Bucks, UK, May 22, 2005.

Ozone: Science & Engineering, 31: 348–356

ISSN: 0191-9512 print / 1547-6545 online
DOI: 10.1080/01919510903091839

Taylor & Francis
Taylor & Francis Group

Economic and Environmental Benefits of Ozone in Ozone Laundering Systems

Rip G. Rice,[1] Marc DeBrum,[2] Jacqueline Hook,[3] Dick Cardis,[3] and Cameron Tapp[2]

[1]RICE International Consulting Enterprises, Sandy Spring, Maryland, USA
[2]ClearWater Tech, LLC., San Luis Obispo, California, USA
[3]JLA Limited., Meadowcroft Lane, Ripponden, West Yorkshire, United Kingdom

Three primary benefits (advantages) of properly designed and operated ozone laundering systems have been proven in successful commercial installations – microbiological kills/inactivation of all microorganisms found in linens to be laundered; economic cost savings and significant environmental benefits. Each of these benefits of ozone laundering is described and quantified in the Ozone Laundry Handbook by Rice et al. (2009). In this paper, two of these benefits, Cost Savings and Significant Environmental Benefits are discussed.

Keywords Ozone, Ozone Laundry Systems, Economic Benefits of Ozone Laundering, Environmental Benefits of Ozone Laundering, Laundry Systems

ECONOMIC (COST) SAVINGS RESULTING FROM OZONE LAUNDERING

Two remarkable properties of ozone stand out in its application to laundry systems:

a) because it leaves no chemical residue and because the amounts of detergent and other chemicals needed with ozone treatment are much lower than for conventional laundering systems, ozone-sanitized wash requires far less rinsing, thus saving water, and
b) because ozone works so efficiently in cold water, sanitizing as well as cleaning can be performed in cold water, saving considerable energy.

Received 4/23/2009; Accepted 6/4/2009
Address correspondence to Dr. Rip G. Rice, RICE International Consulting Enterprises, 1710 Hickory Knoll Road, Sandy Spring, MD 20860 USA. E-mail: RGRice4ozone@aol.com

Additional cost savings accruing to the ozone user will become apparent from the following discussions of specific items.

SPECIFIC ITEMS THAT RESULT IN COST SAVINGS FROM OZONE LAUNDERING

1. *Reduces Energy Use* – Ozone enhances the effectiveness of the actions of chemicals, reducing the need for high temperature washing. Estimates of savings potential made by ClearWater Tech personnel based on commercially operating ozone laundry systems are as high as 90% in washing and 20% in drying.
2. *Reduces Water Use* – Ozone wash systems normally require fewer rinse steps, thus reducing water usage by an estimated 30–45%. Closed loop laundering systems are more expensive from a capital cost point of view. On the other hand, these systems recover most of the water, so that reductions in water use can reach 70–75%.
3. *Reduces Chemical Use* – Ozone makes existing chemicals work better, and reduces overall chemical demand in several ways:

   a) *Ozone helps supply oxygen to the wash water*, which increases chemical effectiveness and reduces chemical demand.
   b) *Ozone oxidizes linen soils*, making them easier to remove from the wash water.
   c) ***Ozone can reduce the need for harsh, high-pH traditional chemicals.*** While all ozone laundry systems use some chemicals, savings claims range from 5% to 30%. Actual savings will depend on the type of laundry being washed,

the temperature and hardness of supply water and the design of the system.

d) *Ozone in water solution performs some (but not all) of the functions of chlorine bleach.* Because ozone improves the removal of soils from wash water, it helps prevent redeposition of soil onto the linen (one of the major causes of fabric graying), which in turn, reduces the need for bleaching. Control of ozone output, concentrations, dilutions, etc., allows ozone to do its soil-removing work without actually bleaching the laundry. Additionally, ozone works quite well and safely in conjunction with hydrogen peroxide if a separate bleach cycle is desired (see Chapter 6 of [1]).

e) *Ozone assists in water softening* by helping to remove water hardness cations (calcium and magnesium ions) from the water. This occurs by the complex mechanism of ozone adding oxygen moieties to some of the partially oxidized organic materials present in laundry soils. The oxygenated organic laundry soils then can form insoluble complexes with polyvalent cations (Ca, Mg, Fe, Al, etc.), thereby *partially* softening the ozone-treated laundry waters (this does *not* mean that an ozone system will replace the need for or use of a water softening system). Softer water produces a better feel in washed fabrics due to better sudsing and more complete rinsing action.

4. *Improves Textile Life and Quality* – Shorter cycle times and cooler temperature water means less wear and tear on textiles. Also, reduced exposure to chemicals can improve fabric life. A study performed in the United Kingdom on ozone laundering of nurses' uniforms showed that ozone laundering removed significant moisture from laundry in comparison to a conventional wash cycle (both cycles had the same final spin speed and time). Thus, ozone laundering results in less drying time and increased linen life (Hook, 2007).
5. *Improves Effluent Quality* – In addition to reducing the volume of wastewater to be discharged, effluent surcharges can be reduced because the effluent contains lower levels of biochemical and chemical oxygen demand (BOD and COD). This is because ozone oxidizes bacteria, other microorganisms, and some dissolved organic compounds that make up biochemical and chemical oxygen demands. Also, because fewer chemicals are used in ozone laundry systems, chemical oxygen demand (COD) levels in effluents will be reduced as well.
6. *Lowers staff labor costs* – With less rinsing, wash loads can be completed faster, thus utilizing the laundry equipment more efficiently and reducing the total staff hours per load.

ESTIMATED COST BENEFITS OF OZONE LAUNDERING OBTAINED IN THE USA

Comparative Evaluation of Traditional vs Ozone Laundering

At the Apple Farm Inn laundry facility (San Luis Obispo, CA), a several-month evaluation was conducted during late 2006 to early 2007 to compare the costs of laundering by traditional and by ozone laundering. The Apple Farm Inn is a hospitality hotel with 104 rooms. Laundry processed includes bedding (sheets, blankets, pillow cases) and towels (from rooms and swimming pool area), bath mats and robes. There was no unusual contamination (such as would be found in hospitals or nursing home/health care institutions) at any time during this testing program.

Facilities and Equipment Employed

In the Apple Farm Inn laundry room are two 80 lb Unimac Commercial Washers and two 120 lb Unimac Commercial Dryers (Alliance Laundry Systems, Ripon, WI). Twenty (20) loads per day were laundered on the average, equating to 1,600 lbs per day of laundry. Traditional laundering was conducted for one month, followed by ozone laundering for a second month.

The ozone system installed for this study was the EcoTex system (ClearWater Tech, LLC, San Luis Obispo, CA), consisting of an ECO2 ozone generator (maximum ozone output rating of 8 g/h at 3% concentration by weight), a SeQual Technologies Workhorse 8c Oxygen Concentrator (San Diego, CA), an Aeroqual 100 Ambient Air Ozone Monitor (Aeroqual Ltd., Auckland, NZ), and an EcoTex Diffuser installed in the sump of the clothes washer.

Figure 1 shows a schematic diagram of this system.

A key step in the application of ozone to be used in a commercial laundry facility is to determine the

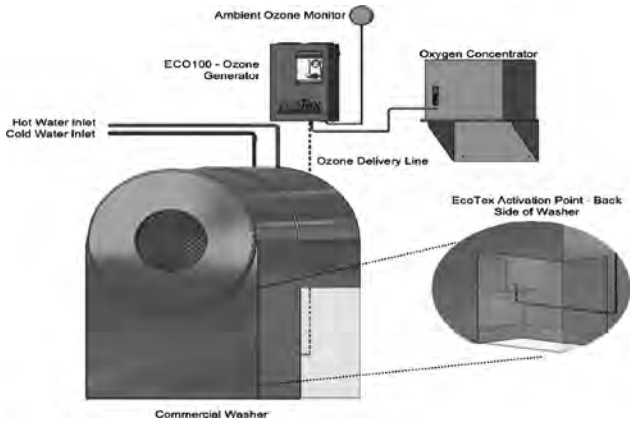


FIGURE 1. Schematic diagram of ozone system installation at Apple Farm Inn. Traditional vs Ozone Laundering Cycles Used.

Traditional Cycles

PROGRAM: Sheets/Towels

STEP	TEMP	LEVEL	TIME	S1	S2	S3	S4	S9
1 SUDS	H	M	8	20	3			
2 BLEACH	H	M	7			13		
3 RINSE	H	H	2					
4 EXTRACT		E	2					
5 RINSE	W	H	2					
6 FINAL RINSE	W	M	3				3	
7 EXTRACT		E	5					
Total Cold Water:	0							
Total Warm Water:	52							
Total Hot Water Gallons:	74							
Total Gallons:		126						
Total Time (min):			29					0
Total Time (sec):				20	3	13	3	
Total Chemical Used/Signal (OZ):				4	0.6	2.6	0.6	
Total Chemical Used/Wash (OZ):								7.8

FIGURE 2. Laundering cycles used for the traditional procedure.

appropriate cycle configurations. Among other factors, these wash cycles are designed based on the type of linen being laundered, the soil content of the linen, and the capacity of the washer. Figures 2 and 3 provide a visual indication of the differences between the traditional wash cycle and ozone wash cycle, respectively, used at the Apple Farm Inn. Chemical signals are as follows; S1 = Break, S2 = Detergent, S3 = Bleach, S4 = Sour/Soft, S9 = Ozone.

To highlight, the ozone cycle uses two fewer steps with the removal of an extract and combining detergent (suds) and bleaching into one step. Removing these two steps plus reducing the amount of water and time in each of the steps, allows for 22 fewer gallons of water to be used (18% savings) and 11 minutes less in over-all time of laundering – time which not only saves labor but also electrical consumption.

These figures also break down the amount of hot, warm and cold water used in the laundering cycles. The ozone cycle is clearly shown to reduce the volume of elevated temperature water by 37 gallons (27%) per wash load. Additional savings in natural gas also result from the use of less hot water. Finally, a portion of the savings shown in the test case cycles comes from

Ozone Cycles

PROGRAM: Sheets/Towels

STEP	TEMP	LEVEL	TIME	S1	S2	S3	S4	S9
1 SUDS	H	M	5	14	3	10		5
2 RINSE	C	H	2					2
3 RINSE	C	H	2					2
4 FINAL RINSE	C	M	2				3	2
5 EXTRACT		E	6					
Total Cold Water:	82							
Total Warm Water:	0							
Total Hot Water Gallons:	22							
Total Gallons:		104						
Total Time (min):			18					11
Total Time (sec):				14	3	10	3	
Total Chemical Used/Signal (OZ):				2.8	0.6	2	0.6	
Total Chemical Used/Wash (OZ):								6.0

FIGURE 3. Laundering cycles used for ozone laundering.

Traditional Cycle	
Water	
Total Avg Per Load - Gallons	141.00
Avg Cost Per Load	$1.69
Cost Per Month	$974.59
Cost Per Year	$11,695.10
Chemical	
Total Avg Per Load - Ounces	7.60
Avg Cost Per Load	$0.99
Cost Per Month	$569.09
Cost Per Year	$6,829.06
Electrical	
Total Avg Per Load - kWH	1.53
Avg Cost Per Load	$0.21
Cost Per Month	$123.70
Cost Per Year	$1,484.42
Natural Gas	
Total Avg Per Load - Therms	0.62
Avg Cost Per Load	$0.77
Cost Per Month	$444.02
Cost Per Year	$5,328.26
Labor	
Total Avg Per Load - Minutes	29.50
Avg Cost Per Load	$4.92
Cost Per Month	$2,712.00
Cost Per Year	$33,984.00

FIGURE 4. Cost analysis of traditional laundry process.

chemicals, which has been reduced in the ozone cycle by 1.6 ounces (21% savings).

Commodity/Consumables Used

Figures 4 and 5 show the Traditional and Ozone formula totals used in each of the one month test times for each process. The bottom two lines show the costs per month and projected costs per year, respectively. It is clear that the ozone system resulted in annual cost savings in all categories [water, chemicals, electrical (with ozone considered as electrical), natural gas and labor] of $13,248 (38%).

Figure 6 is a graph showing the annual costs of the traditional vs ozone laundering systems at Apple Farm Inn. Figure 7 is a graph showing the annual percent savings resulting from use of the ozone laundering system. Total Annual Savings by ozone laundering were 38%.

One of the most interesting benefits found in this (Apple Farm Inn) case study is that of labor and/or production savings, which also can be quantified as facility efficiency. This efficiency was equated to the overall reduction of cycle time saved by the ozone laundry system. This does not necessarily mean that the facility paid

Ozone Cycle	
Water	
Total Avg Per Load - Gallons	104.00
Avg Cost Per Load	$1.25
Cost Per Month	$718.85
Cost Per Year	$8,626.16
Chemical	
Total Avg Per Load - Ounces	6.00
Avg Cost Per Load	$0.78
Cost Per Month	$449.28
Cost Per Year	$5,391.36
Electrical	
Total Avg Per Load - kWH	1.07
Avg Cost Per Load	$0.15
Cost Per Month	$86.12
Cost Per Year	$1,033.48
Natural Gas	
Total Avg Per Load - Therms	0.12
Avg Cost Per Load	$0.15
Cost Per Month	$84.77
Cost Per Year	$1,017.28
Labor	
Total Avg Per Load - Minutes	18.00
Avg Cost Per Load	$3.00
Cost Per Month	$1,728.00
Cost Per Year	$20,736.00

FIGURE 5. Cost analysis of ozone laundry process.

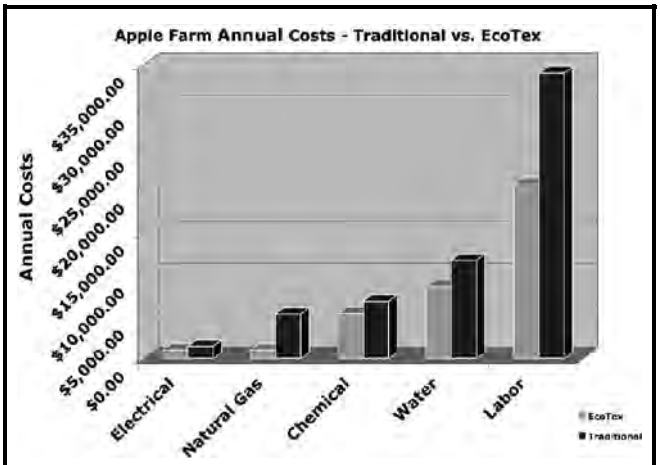


FIGURE 6. Annual costs of traditional vs ozone laundering at Apple Farm Inn.

less in staff labor, but rather that the staff was available to perform other housekeeping duties.

The efficiencies of less water and fewer rinsing cycles resulting from ozone laundering allowed the Apple Farm Inn to launder nearly sixty (60) more loads per month more than with their traditional wash cycles.

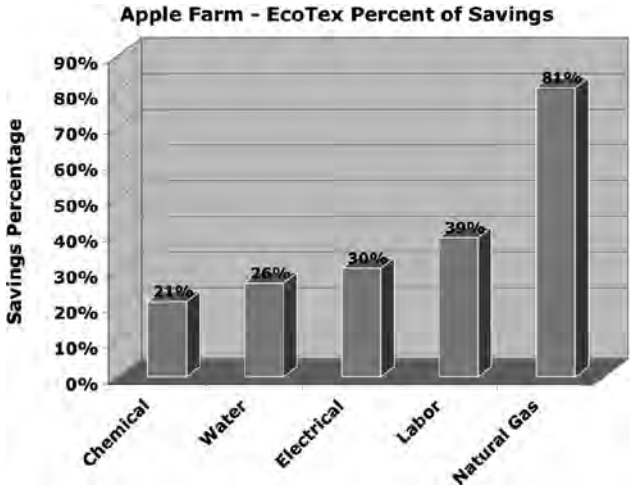


FIGURE 7. Percent of annual savings by ozone laundering at Apple Farm Inn. Labor and Production Savings.

Return on Investment

Ozone laundry systems not only provide microbiological benefits, but through reduced cycles times, water, energy, and chemicals, they can also pay for themselves and typically within short time periods. As shown in Figures 4, 5 and 7, the ozone laundry system has saved the Apple Farm Inn nearly 40% of the annual overall costs related to the washing of linens in their laundry facility. This savings paid for the ozone laundering system in less than eight months.

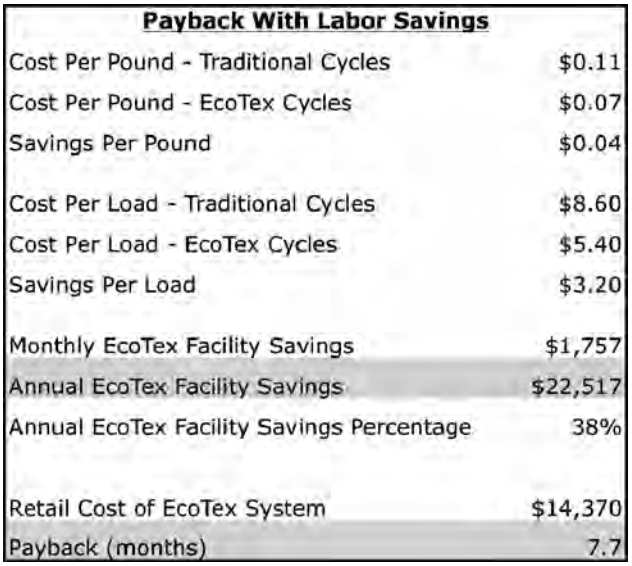
The rate of return on a system such as this may increase dramatically through state and local energy providers and water companies, who provide grants, rebates and other incentives to facilities that install energy and water saving technologies and equipment.

Figure 8 shows an estimated payback time of 7.7 months resulting from the ozone laundering system, including the labor savings, of $1,756 per month or $22,517 (annually).

Figure 9 shows a payback time, without considering labor savings, of 18.6 months.

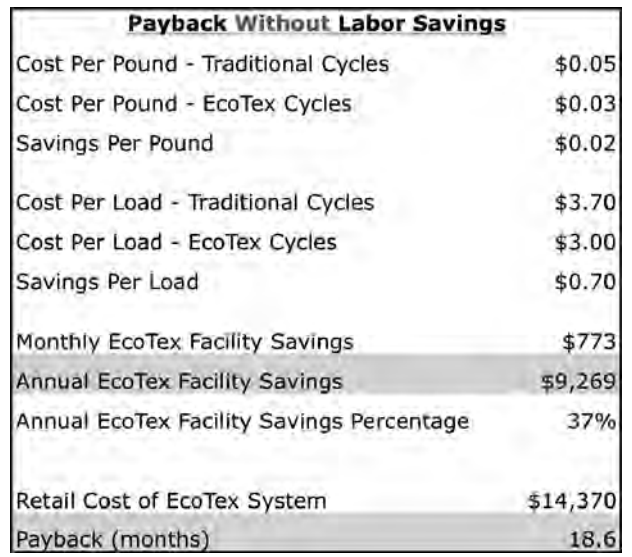
Corroborating Ozone Performance Data

Information provided by the Daniels Equipment Company, Inc., Auburn NH (a laundry firm with many ozone laundry facilities operating throughout the United States) confirm results from the Apple Farm Inn case study. Table 1 is a metered savings analysis of the Arapahoe County Detention Facility laundry system (Lakewood, CO) showing total annual utility savings (water, hot water, and dryer) of $35,559 (Daniels Equipment Company, 2009). Table 2 is a metered savings



Payback With Labor Savings	
Cost Per Pound - Traditional Cycles	$0.11
Cost Per Pound - EcoTex Cycles	$0.07
Savings Per Pound	$0.04
Cost Per Load - Traditional Cycles	$8.60
Cost Per Load - EcoTex Cycles	$5.40
Savings Per Load	$3.20
Monthly EcoTex Facility Savings	$1,757
Annual EcoTex Facility Savings	$22,517
Annual EcoTex Facility Savings Percentage	38%
Retail Cost of EcoTex System	$14,370
Payback (months)	7.7

FIGURE 8. Estimated payback time, considering labor savings.



Payback Without Labor Savings	
Cost Per Pound - Traditional Cycles	$0.05
Cost Per Pound - EcoTex Cycles	$0.03
Savings Per Pound	$0.02
Cost Per Load - Traditional Cycles	$3.70
Cost Per Load - EcoTex Cycles	$3.00
Savings Per Load	$0.70
Monthly EcoTex Facility Savings	$773
Annual EcoTex Facility Savings	$9,269
Annual EcoTex Facility Savings Percentage	37%
Retail Cost of EcoTex System	$14,370
Payback (months)	18.6

FIGURE 9. Estimated payback time without considering labor savings.

analysis of a hotel at which annual utility savings total $80,639 (Daniels Equpiment Company, 2009).

Cost Savings at Installed United Kingdom Ozone Laundering Systems

In contrast to the USA, where ClearWater Tech, LLC markets ozone laundering equipment outright, JLA Ltd. leases ozone laundering equipment in the UK, then provides service contracts to their many clients (as of the last quarter of 2008, JLA had installed close to 2000 ozone systems in 980 establishments including 38 hospitals). Consequently, some specifics in estimated ozone benefits will vary as a result. Additionally, the amounts of estimated savings in the United Kingdom are expressed in pounds Sterling.

TABLE 1. Metered Savings Analysis at Arapahoe County (CO, USA) Detention (Daniels Equipment Company, 2009)

	Before ozone	After ozone
Daily Total Water - gal	6,565	4,989
Daily Total Hot Water - gal	4,267	640
Temperature Rise (°F)	120	
Cost per Therm, $	$1.10	
Hot Water Heater Efficiency	65%	
Water Cost per 1,000 gal	$4.32	
Sewer Cost per 1,000 gal	$3.45	
Total BTUs	11,811,581	1,771,599
Hot Water Therms	65.62	9.84
Dryer Therms	52.50	42.00
Water Cost – Annual	$18,618.67	$14,149.05
Hot Water Cost, Annual	$36,346.39	$3,951.65
Dryer Cost, Annual	$21,077.11	$16,861.69
ANNUAL UTILITY SAVINGS		
Water		$4,469.61
Hot Water		$26,873.69
Dryer		$4,215.42
TOTAL ANNUAL UTILITY SAVINGS		$35,558.72

TABLE 2. Metered Savings Analysis at Equinox Hotel (Daniels Equipment Company, 2009)

	Before ozone	After ozone
Daily Total Water - gal	13,409	6,831
Daily Total Hot Water - gal	9,329	1,505
Temperature Rise (°F)	110	
Cost per Therm, $	$1.35	
Hot Water Heater Efficiency	65%	
Water Cost per 1,000 gal	$3.00	
Sewer Cost per 1,000 gal	$3.00	
Total BTUs	23,671,835	3,818,856
Hot Water Therms	131.51	21.22
Dryer Therms	105.21	84.17
Water Cost – Monthly	$2,494.07	$1,270.57
Hot Water Cost, Monthly	$5,503.70	$887.88
Dryer Cost, Monthly	$4,402.96	$3,522.37
ANNUAL UTILITY SAVINGS		
Water		$14,682.10
Hot Water		$55,389.81
Dryer		$10.567.11
TOTAL ANNUAL UTILITY SAVINGS		$80,639.01

Nevertheless, the estimated percentage savings as a result of ozone laundering are strikingly similar on either side of the Atlantic Ocean. Tables 3, 4 and 5 show weekly savings in three different establishments having OTEX ozone laundering equipment installed, a 50-bed care home (70% incontinence) (Table 3), a 90-bed Care home (85% incontinence) (Table 4), and an 800-bed hotel (Table 5) (Cardis et al., 2006).

At the North Hertsfordshire Hospital (U.K.), JLA Ltd. was able to prove electricity savings of 85% with an ozone-microfibre mop laundering program (Hook, 2007).

SIGNIFICANT ENVIRONMENTAL BENEFITS OF OZONE LAUNDERING (DANIELS EQUIPMENT COMPANY, 2009)

In addition to the numerous cost savings and microbiological benefits of ozone laundering, there are many environmental benefits from ozone laundering when compared with conventional laundering procedures. These include significantly decreased use of chemicals – which benefit the user of ozone laundering by lowering costs, but benefit the environment by decreasing discharges of chemicals in laundry wastewaters, and benefit the safety of the ozone laundry user by decreasing the amount of storage of laundering chemicals and the handling/disposal necessary.

When chemicals are discharged into the environment, they can often react with components of the receiving lakes, rivers and streams to form byproducts, which are not well degraded by natural microorganisms, and sometimes these byproducts find their way into the human food chain. On the other hand, when ozone does its work in a properly designed laundry system, its strong oxidizing power actually initiates the oxidative conversion of most organic components of the soiling materials on the laundry to be cleaned into more readily biodegradable byproducts. This "preoxidation" of soiling components in an ozone laundry system then continues to degrade to harmless carbon dioxide and water as they continue to diffuse into the environment.

In this respect, discharging effluents from ozone laundering processing can be considered to be the reverse of eutrophication, whereby dissolved oxygen in the water is consumed by the prolific growth of algae. The level of growth of algae and subsequent depletion of oxygen and production of toxins can have serious consequences for all forms of aquatic life.

Additionally, when ozone is added to aqueous systems (in this case to laundry machines), the dissolved oxygen levels of the laundry waters rise. This is a significant advantage particularly when ozone is generated from oxygen-enriched air. The solubility of oxygen in water from a gas that contains mostly oxygen is up to 10 times higher than when that gas contains mostly nitrogen (as when air is used to feed the ozone generator). Higher levels of dissolved oxygen in laundry wastewater discharges benefit receiving streams, lakes, and rivers by providing oxygen for the natural microorganisms to do a better job of breaking down discharged pollutants into carbon dioxide and water.

Laundry wash effluent samples of a typical nursing home were analyzed for COD levels comparing the effects

TABLE 3. Weekly Savings with OTEX - 50-Bed Care Home - 70% Incontinence

Period	Pre-OTEX	1-week	Post-OTEX	1-week	% Saving	Weekly Saving	Notes
Electric kw	360	£21.60	119	£7.14	67%	£14.46	
		£13.80	691	£8.29	40%	£5.50	Incl. 369 kWh
Gas kw	1150						to heat water
Hot Water L	8026		992		88%		
Total Water L	44015	£66.02	26633	£39.95	39%	£26.07	
Chemicals, mL	36280	£90.70	11682	£29.21	68%	£61.50	
SubTotal		£192.12		£84.59	28%	£107.53	
						£10	Based on 20%
Linen Saving	72						extra linen life
Labor £		£360.00	52	£260		£100	
Weekly Cost		£552.12		£344.59			
Ttl Weekly Saving						£217.53	
Ttl Annual Saving						£11,311.46	
COSTS							
electric kw	0.06						
gas kw	0.012						
water/effl'nt L	0.0015						
chemicals mL	0.0025						
labor £/hr	5						

TABLE 4. Weekly Savings with OTEX - 90-Bed Care Home - 85% Incontinence

Period	Pre-OTEX		Post-OTEX		% Saving	Weekly saving	Notes
Electric kw	529	£28.57	319	£17.23	40%	£11.34	
		£19.04	1166	£12.59	34%	£6.45	Incl. 436 kWh to heat water
Gas kw	1764						
Hot Water L	13,580		1,670		88%		
Cold Water L	63980		34,250		46%		
Total Water L	77560	£116.34	35920	£53.88	54%	£62.46	
Chemicals, mL	58215	£145.54	27488	£68.72	53%	£76.82	
SubTotal		£309.48		£152.42		£157.07	
		£50.00		£40.00		£10	Based on 20% extra linen life
Linen Costs							
Labor Saving	112	£560.00	84	£420.00	25%	£140	
Weekly Cost		£919.48		£612.42			
Ttl Weekly Saving						£307.07	
Ttl Annual Saving						£15,967.51	
COSTS							
electric kw	0.054						
gas kw	0.0108						
water/effl'nt L	0.0015						
detergent mL	0.0025						
labor £/hr	5						

TABLE 5. Weekly Savings with OTEX - at an 800-Bed Hotel

	Before OTEX		After OTEX				
Period	W/C 30 March 2004		W/C 18 May 2004		% Saving	Saving (£)	Notes
Electric kw	1127	£67.62	585	£35.10	48%	£32.52	
Gas kw	3337	£40.04	1739	£20.87	48%	£21.26	Incl. 173 kWh
Hot Water L	22700		3322		85%		to heat water
Total Water L	65100	£97.65	31465	£78.66	52%	£18.99	
Chemicals, mL	180810	£452.03	54256	£135.64	70%	£316.39	
Total		£657.34		£270.27	59%	£389.15	
Avg cost/cycle		£2.96		£1.40		£1.56	
Estd Linen Saving						£20.00	
Total Weekly Saving						£409.15	
Total Annual Saving						£21,275.72	
Machine Operating Hours		136	114		16%		

Type of laundry	Equipment	Industry based costs	
Washers 2x HF304	IPSO65 & 50	Electric kW	0.6
Dryers (Gas) 4x ADC 75		Gas kW	0.012
		Water/Effluent	0.0015
		Chemicals, mL	0.0025
		Labor, £/hr	5

of conventional (thermal) laundering to ozone laundering on this parameter (Scientifics Ltd., 2006). The results showed lower COD levels in the ozone wash and final rinse waters:

Thermal Cycle – Main Wash 3890 mg/L COD
Thermal Cycle – Final Rinse 171 mg/L COD
OTEX Cycle – Main Wash 2000 mg/L COD
OTEX Cycle — Final Rinse 145 mg/L COD

Ozone also is an effective deodorizer that works by breaking molecular bonds of many organic and inorganic compounds typically responsible for odors that are found in and on soiled laundry – particularly as received from hospitals and health care facilities which usually house incontinent patients.

INDEPENDENT RISK ASSESSMENT – DISCHARGE OF OZONE-TREATED LAUNDERING WASTEWATERS – WRC-NSF LTD. ASSESSMENT

The WRc-NSF Ltd. (Water Research Center of the UK; National Sanitation Foundation) was commissioned by JLA, Ltd. to assess independently the impact of discharging spent laundry wash waters that had been treated with ozone. The following statements form the basis of the WRc-NSF report (2005):

Ozone rapidly decomposes to oxygen. The rate of decay depends on several factors including temperature, pH and quality of water. In natural freshwater, ozone has a half-life of around 10 minutes at 20 °C (68 °F). Lower temperatures will encourage greater stability of ozone but the time scales are not significantly greater. Predictions based on published sources indicate that in clean water the half-life of ozone increases from 20 minutes at 20 °C (68 °F) to around 60 minutes at 5 °C (41°F).

When the spent (OTEX) wash water is discharged to the sewer system, the residual ozone will also rapidly react with any organic matter in raw sewage. At the point of discharge from a washing machine, the residual ozone concentration varies between 0.5 to 3.0 parts per million (milligrams per liter), and in volumes of between 140 to 240 liters per cycle dependent on the wash cycle selected and capacity of machine.

These concentrations of ozone are similar to those applied to drinking water and, with the considerable dilution encountered in the sewer system, will become insignificant. Also, any residual ozone will rapidly disappear immediately on contact with sewage.

Conclusion

On the basis of information in the literature and data supplied by JLA Ltd., the conclusion drawn from this risk assessment by WRc-NSF Ltd. is that spent wash water treated with ozone is safe to discharge to the sewer system; indeed any such aeration of sewage can be seen as beneficial since it encourages the breakdown of the organic matter and aids the sewage treatment process.

Hong Kong Environmental Protection Department

On November 11, 1997, the Hong Kong Government, Environmental Protection Department, sent a letter (Hong Kong EPD, 1997) to E Technologies Ltd. (Hong Kong) confirming compliance of effluents of the laundry system at the Chi Lin Monastery (with an E-Technologies ozone laundry system installed) with the required discharge limits for foul sewers under the (Hong Kong) Water Pollution Control Ordinance. (www.ETechnologies.com)

SUMMARY AND CONCLUSIONS

Economic (Cost) Savings Resulting From Ozone Laundering

1. Ozone laundering brings cost savings in reduced energy use by using cold water (ambient temperature, from the municipal tap), which lowers the energy necessary to heat water. In the USA, these reduced energy savings alone are in the range of 70–90%.
2. Ozone laundering reduces or eliminates the need for the amounts of many chemicals currently used in conventional laundering systems. These chemical savings amount to about 30%, but can be lower or higher depending on the specific factors involved at each specific installation.
3. Because ozone laundering systems lower chemical usage, the number of rinses required is lowered, with resulting savings in water and labor. Labor savings alone amount to about 30%.
4. Fabric life is extended by ozone laundering, due to the lower temperatures required, less agitation time, and lowered amounts of chemicals employed.
5. Confirmation of these cost savings in the UK shows total weekly cost savings of ozone laundry systems ranging from £11,310 to £16,000 in two health care homes. In an 800-bed hotel, these cost savings are as high as £21,275 per week.
6. Annual cost savings found for ozone laundering in the USA allow a return-on-investment between 8 and 18 months for ozone systems, depending on the size of equipment required.

Environmental Benefits of Ozone Laundering

1. Reducing the amounts of chemicals and rinse water used in conventional laundering benefits the environment by decreasing the volume of wastewater discharged from the laundry as well as decreasing the amount of laundering chemicals discharged to the environment.
2. Ozone itself can be considered to be a “green” chemical, in that if any dissolved ozone remains in any laundry discharge water, it will quickly convert to dissolved oxygen upon contact with dissolved organic materials present in surface waters. In turn, dissolved oxygen benefits microorganisms present in receiving natural waters or in sewage treatment plants.
3. As ozone oxidizes organic soils on laundry, these oxidized materials become more easily biodegradable by microorganisms in sewage treatment plants and/or receiving waters.

4. Lowering the amounts of laundering chemicals also increases the safety of laundry personnel, since smaller volumes of chemicals need to be stored and handled.

REFERENCES

Cardis, D., C. Tapp, M. DeBrum, and R.G. Rice, "Ozone in the Laundry Industry – Practical Experiences in the United Kingdom", *Ozone: Sci. Eng*., 29(2):85–99 (2006); DOI: 10.1080/01919510601186048, 2009.

Daniels Equipment Company, Inc., Auburn, NH, USA, Metered Savings Analysis for Arapahoe County (Colorado, USA) Detention Facility Laundry, 2009.

Daniels Equipment Company, Inc., Auburn, NH, USA, Metered Savings Analysis for Equinox Hotel.

Hong Kong Environmental Protection Department, Ltr. dated Nov. 11, 1997, from the Hong Kong Environmental Protection Dept., to E Technologies Ltd. (Hong Kong), www.ETechnologies.com.

Hook, J., "Microbiological Analysis of Microfibre Cloths Employed Within a Hospital Environment", JLA Report, JLA Ltd., Meadowcroft Lane, Ripponden, West Yorkshire, HX6 4AJ, UK, May 2007.

Rice, R.G., D. Cardis, R. Daniels, C. Tapp, M. DeBrum, and J. Watt, "The Ozone Laundry Handbook, A Comprehensive Guide for the Proper Application of Ozone in the Commercial Laundry Industry", Published by ClearWater Tech, LLC, San Luis Obispo, CA, USA, 2009.

Scientifics Ltd., 4 Hexthorpe Road, Doncaster DN4 0AE, UK, letter report to JLA Ltd., SD/DOW07090-01, 21 August 2006.

WRc-NSF Ltd., "The OTEX Validated Ozone Disinfection Washing System", Medmenham, Marlow, Bucks, UK, May 22, 2005.

hundred and ninety eight inner-city households (96.4% Hispanic) were surveyed and the only hygienic practices in a home setting that were associated with transmission of infectious disease symptoms among household members were use of communal laundries or a failure to use bleach when washing laundry. Other home hygiene practices that were not identified as being significant ($p<0.05$) to the prevalence of infection included personal hygiene habits such as bathing, frequency of general cleaning, duration of kitchen sponge use, wearing gloves when cleaning the toilet, and use of an automatic dishwasher.

Literature review

Changes in home-laundering practices

The primary objectives of the laundering process are removal of soil, stains, creases, and pathogens, and haven't changed over time; however, the equipment available to consumers has. In a household washing process the main hygienic effect is probably due to removal of dirt itself. Microorganisms, affixed to soil or fibers of fabric, are dislodged by mechanical and chemical action, suspended in the suds, and then removed along with the dirt during one of the rinse cycles (Terpstra 1998). Incomplete soil removal can allow microorganisms to attach to soil remaining on the fabric, making them less sensitive to the influence of thermal and chemical disinfection and thereby leading to insufficient pathogen removal as well. Microorganisms do not reproduce well on clean fabrics (Terpstra 1998).

Laundering practices have changed dramatically over the past several decades. There are several reasons behind these alterations. Environmental concerns and cost

impact how both home and industrial laundering processes are evolving and have resulted in procedural changes that include a general trend toward lower wash temperatures, the utilization of less water, and the reduction in bleach use (Scott 1999).

Eighty-five to 90 percent of the energy used by a washing machine goes to heating water (Bluejay 2007). Besides rising energy costs, consumers have switched to cold water wash cycles because it extends the life and minimizes shrinkage of fabrics. Only five percent of households currently use hot water wash cycles (Gerba 2001). Currently, the majority of domestic laundering is done at 40˚C or 60˚C which is followed by tumble drying or ironing and does not use many of the chemicals routinely added in industrial machines (Patel *et al.* 2006). At washing temperatures below 60˚C, soil removal becomes more difficult and the effectiveness of bleach systems decrease, so not only are clothes less clean, they are also less hygienic. Washing clothes at reduced temperatures is encouraged by The Department of Energy (DOE), who has developed lower energy usage goals for new washing machines to support Federal sustainability initiatives (U.S. Department of Energy 2008).

DOE's Energy Star target values also include reductions in water usage per cycle for all newly constructed washing machines. To meet DOE Energy Star rating goals, washing machines must have a maximum ratio of 8 gallons of water used per cubic foot of washer capacity. Lower water use in new washing machines is being achieved through design modifications that reduce the initial water fill level and eliminate one or two rinse cycles per wash load. Subsequently, rinsing efficiency has decreased, resulting in greater amounts of soil and microorganisms left behind in washed laundry (Terpstra

1998). Rinsing programs are again being modified somewhat to reverse this trend, but it is unknown whether these changes will be sufficient to reduce transmission of microorganisms (Terpstra 1998).

Steps to minimize the environmental impacts associated with the laundering process have also influenced detergent composition and availability. Household detergent alkalinity has been lowered by 1 to 2 pH units making them less effective as disinfectants in the wash process, particularly when no bleach products are used (Terpstra 1998). In addition, low phosphate, biodegradable detergents containing less effective builders are mandated to comply with environmental regulations, and concentrated soap products have been introduced to not only lessen the amount of product in effluent, but also reduce the amount of product packaging needed. Similarly, by 1993 at least 35 states had issued guidebooks recommending the use of alternative products to sodium hypochlorite bleach additives (Parnes 1997), citing among other reasons, it's potential to produce an adverse environmental impact. Worry about the effect detergents and bleaching agents have on the environment has been driven in part by the fact that washing machine effluent is increasingly used as "gray" water by homeowners to eliminate water waste.

New types of fabrics and dyes also have affected both the type of laundry products used and wash cycle temperatures. New fabrics have significantly reduced the amount of time consumers spend doing laundry. The introduction of wrinkle-resistant fabrics has made hanging clothing and linens outside where sunlight can aid in denaturing many of the microbes, and ironing which allows steam to penetrate and reduce

the microbial load in the fabric, much less common (Kagan *et al*. 2002). The current generation of fabrics has new fibers, construction, quality of dyes, and special finishes that cannot withstand traditional bleach, and therefore laundering of these items requires use of non-chlorine products (Belkin 1998). The germicidal effectiveness of these nonchlorine type bleach substitutes has not been well documented. The changing composition of fabrics ultimately may impact the retention and release of viable microorganisms (Sattar *et al*. 1999).

Over the years, laundry "soap" has been replaced with laundry "detergent". Soap is made of materials found in nature, while detergents are composed of synthetic cleaners. Detergents remove soil better over a wider range of water hardness levels and do not require hot water to catalyze their action (Galt Technologies Incorporated 2008). Laundry detergents are composed of several primary ingredients, each designed to perform a different role in the cleaning process. There exists a great diversity among laundry detergent formulas, but nearly all detergents contain a mixture of surfactants, builders, whitening agents, colorants, and fragrance.

The type of home washing machine used is also changing. Approximately 30% of new washers purchased in the United States are the front-load variety (Consumer Reports 2001). Currently, this type of machine accounts for 90% of the European market (Wikipedia 2008). In the U.S., front-load washing machines are gaining in popularity because they have several unique benefits over top-load models. They are significantly more energy efficient, using 30-50% less energy or approximately 400-560 kwh/year versus 800 kwh/year for top-load models (Bluejay 2007). Front-loaders also use 40-60%

less water than their top-load counterparts. In addition, they help extend the life of clothing washed in them, are quieter, and have larger capacities than conventional washing machines (Morrissette 2008). Front-load washing machines also have faster spin cycles resulting in shorter time periods needed for drying. Finally, front-load washers use less detergent which saves the consumer money and is less stressful on the environment.

Front-load washing machines use entirely different mechanisms for washing clothes than top-load models. Conventional washing machines wash clothes by using a large agitator to force clothes back and forth through soapy water, and then again through clean water to rinse out the detergent. Top-load machines are also known as vertical-axis washers, because the tub spins vertically. Front-load washers spin horizontally and are often referred to as horizontal-axis washers. There is not an agitator to move the clothes through the water, rather the tub itself moves, causing the clothes to be repeatedly lifted out of the water and dunked back in (Morrissette 2008). While top-load washers fill their tub up with a standard volume of water at the beginning of the wash cycle, front-loaders control water usage through the surface tension of water and capillary wicking action of the fabric weave. Front-load washers always fill to a same low water level, but the pile of dry clothes soaks up the moisture, causing the water level to drop. The washer then refills to maintain the original water level. Because it takes time for water absorption to occur in a motionless pile of laundry, nearly all front-load machines begin the wash process by slowly tumbling the clothing under the stream of water entering and filling the drum. This facilitates a more rapid saturation of the dry laundry with water.

Hospital- versus home-laundering practices

The steps in an industrial laundry are essentially the same as those performed in a home setting, only the magnitude is different. The process begins with collecting and sorting, and then proceeds to washing, drying and whatever subsequent actions may be required for the particular type of item being washed. Ironing and folding, either by hand or machine, are performed for most items. Packaging and distribution are the final steps in a commercial setting.

The two main differences between industrial and home-laundering are 1) the water to fabric ratio in an industrial laundering operation is about 5:1 (w/w), whereas in a home or coin-operated washing machine, the ratio is about 10:1 (U.S. EPA 2007), and 2) most commercial hospital laundries follow CDC guidelines (2003) to provide thermal disinfection in the wash cycle by washing for ≥ 25 minutes, holding the temperature for 3 minutes at 71˚C, and by using chemicals suitable for low-temperature washing if ≤ 70˚C laundry cycles are used (Smith *et al.* 1987).

Previous laundry research

In 1938, Lloyd Arnold performed the first laundry studies, enumerating bacteria counts in wash water and on textiles. Arnold's work showed that exposure to water temperature above 71.1˚C for 25 minutes was sufficient to kill nearly all bacteria forms except spores. Laundering at lower temperatures allowed bacteria contamination to accumulate inside the commercial washing machines of the era, a condition attributed to the tallow-based soaps used which required hot water for proper emulsification. He also identified seasonal variation in bacteria counts on clothes coming into the laundry that ranged from

325,000 bacteria counts/cm^3 of wash water during the coldest months to well over 18 million/cm^3 in the warm weather months of the year. His results formed the basis of hospital laundry policies (Blaser *et al*. 1984).

Since that initial study, a variety of other wash conditions have been evaluated to determine microbial survival during and after the laundering process. Besides varying temperature as Arnold (1938) did, the effectiveness of chlorine bleach use, detergent type, duration of wash cycle, and drying have all been assessed with sometimes disparate results.

By far the most frequently studied parameter is that of wash water temperature. Wiksell *et al*. (1973) tested *S. aureus* survival on polyester cotton blend fabric. He found that when wash temperatures were increased from 35˚C to 46˚C and from 46˚C to 57˚C, a significant reduction in the number of viable *S. aureus* cells recovered occurred. However, survival was substantial even at 68˚C, with 3.5 organisms per square centimeter of fabric. His data also demonstrated that Gram positive bacteria could be transferred to uncontaminated fabrics at all tested wash water temperatures which ranged from 24˚C to 68˚C, and that they were much more resistant to the laundering process than Gram negative bacteria and viruses. His findings were similar to those published earlier by McNeil (1964) and Sidwell *et al*. (1971). Christian *et al*. (1983) testing bacteria concentrations in hospital laundered fabrics, concluded that low temperature washing (47.8˚C to 60˚C) eliminated bacteria groups, including *S. aureus* at least as effectively as did wash temperatures above 70˚C. Although, they qualified their findings by admitting that the effectiveness may have resulted in part from increased concentrations of bleach

used at lower temperatures. Battles and Vesley (1981) reviewed nearly a dozen laundry studies published after 1937. They concluded that most vegetative organisms are killed by laundering at 60˚C, 66˚C is effective for more resistant species such as *Streptococcus*, and chlorine bleach greatly enhances the effectiveness of heat.

Numerous investigators have established the importance of longer wash cycles or the need for chemical disinfection when water temperatures were reduced below 60˚C: Walter and Schillinger (1975) in hospital and hotel linen, Lemaire *et al*. (1996) in an industrial laundering process, and Terpstra (1991) and Ainsworth *et al*. (1993) in household laundry. Wiksell *et al*. (1973) found that the longer "regular" wash cycle was significantly more effective in removing microorganisms than a shorter, gentler "permanent press" cycle. Ainsworth and Fletcher (1993) showed that a liquid detergent and a laundry powder containing activated bleach (nonanoyloxybenzene sulfonate added) each vastly improved the antimicrobial action of a wash cycle, both at 30˚C and 50˚C. Bacteria transferred from the interior of a washer to wash water of a subsequent cycle was also reduced when bleach was used (Wiksell *et al*. 1973).

Blaser *et al.*'s 1984 research was one of the few studies to evaluate the importance of each individual stage of disinfection during the laundry process. He found that a standard low temperature (22.2˚C) wash cycle without laundry additives removed 3 $\log_{10}$ of bacteria in hospital sheets and towels by agitation, dilution and drainage alone. Addition of soap and bleach further reduced post-wash colony counts by one to two logs, and drying removed yet another one to two logs. They concluded that bacteria counts were comparable whether low temperature or high temperature washing was employed,

and that the addition of a bleaching agent was the most important bacteria reduction step when washing at low temperatures. Later studies by Smith *et al*. (1987) mirrored these results. Contrarily, work by Jaska and Fredell (1980) determined that water temperature was more significant in determining bacteria survival than other wash system parameters such as detergent amount or type, soil load, water hardness or wash time.

While some studies have shown that wash-water temperatures and the addition of laundry disinfectants affect the initial success of viable microbial elimination (Blaser *et al*. 1984, Wiksell *et al*. 1973), there is virtually no difference seen in resulting microbial levels once fabrics are tumble dried or ironed (Patel 2006). Gerba (2001) found that washing and drying together reduced bacteria levels in inoculated laundry loads by at least 99.99 percent.

Wiksell *et al*. (1973) reported that in most studies, the type of laundry detergent used made little difference on microbial reduction. Several subsequent reports have refuted these findings. Jaska *et al*. (1980) found that the detergent action of a variety of nonphosphate detergent products and soaps were consistently less efficient than that of typical phosphate formulations even though the pH was similar in all products. Kagan *et al*. (2002) quantified the effectiveness of both liquid and powdered detergents containing either oxygen bleach or non-sanitizing bleach alternatives and concluded that products containing sanitizing components demonstrated superior performance. New powder and liquid sanitizing laundry detergents were shown to reduce *S. aureus* and *Klebsiella pneumoniae* (a Gram negative bacteria) in laundry fabric more effectively than other laundry detergents (Bloomfield 2002). Gerba *et al*. (1999) found that *S. aureus* survival

was greatly reduced when laundered with a Tide (Proctor and Gamble, Cincinnati, OH) detergent formula that contained enzymes. The Gram positive bacteria were resistant when washed with Clout (Pharmacal, Naugatuck, CT), a detergent without enzymes.

Some studies have shown that Gram positive bacteria appear to survive the laundry process better than Gram negative bacteria. This increase in survival is thought to be because of differences in susceptibility of the two types of bacteria to drugs and other chemicals (Belkin 2001). The outer membrane of Gram positive bacteria may protect them from antibiotics, dyes, detergents, influencing survival. Bauer *et al*. (1994) discovered that high pH levels caused by bleaching altered hydrogen ion concentrations around bacteria cells which may have inactivated surface elements of Gram negative *E. coli* more readily than Gram positive *S. aureus*. Neely *et al*. (2000) surmised that the antibiotic sensitivity of Gram positive bacteria had no consistent effect on survival, Takashima (2004) showed similar results.

Numerous studies have shown that regular washing at or below 40˚C without the use of a bleach product does not completely destroy the microflora in fabric, and the result may be a buildup of biofilms where cells have become embedded within the clothing matrix. The resistance of resident and transient biofilms to detergents and bleach will most likely be much different than where fabric surfaces have been prepared using laboratory grown inocula (Bloomfield *et al*. 2002), so this must be taken into account when evaluating bacteria survival rates. Washing machines may also provide sites for adhesion and development of biofilms over time if microorganisms are not completely eradicated, then allowed to re-grow (Sheane 2000).

Studies over the past four decades have demonstrated that cloth may become contaminated with high levels of microorganisms which can survive for long periods of time in the fabric (Larson 2001). Distribution of bacteria on soiled fabrics is not uniform and four to six orders of magnitude variations in density have been recorded (Christian *et al.* 1983). Wilkoff *et al*. (1969) found that cloth type and construction, mode of bacteria exposure, exposure to light, and relative humidity can affect the survivability of *S. aureus* on fabric prior to washing. These investigators theorized that the physical characteristics of the cloth fibers themselves such as the scales of wool fibers, twisted cylindrical cotton fibers, and tightness of the textile weave, as well as the charge on the surfaces of both the fiber and the bacteria may influence attachment capability of *S. aureus*. *S. aureus* survived for one week on cotton and two weeks on terry cloth. This may have occurred because the bacteria became imbedded within deep woven terry cloth used in towels. While most initial studies examined survival of *S. aureus* using cotton as the test fabric, as cotton-polyester blends became more common, so did testing of them. Neely *et al*. (2000) found that all bacteria survived for at least a day on cotton-polyester blend fabrics, and concluded that *S. aureus* survived longer on polyester than on cotton, indicating that fabric type may also influence survival. These results were similar to those of Wilkoff *et al*. (1969). Takashimi *et al*. (2004) measured binding of bacteria to fibers. They similarly determined that polyester or acrylic fibers bound *S. aureus* at higher levels (>80%) than wool (63.2%), cotton (10%), or nylon (0.9%). Takashima was not able however, to demonstrate this same result when using entire cloth materials instead of cloth fibers. They theorized that fibers had more binding sites available to

microorganisms and that cloth interiors might not be as accessible to bacteria. They noted that the amount of moisture absorbed by the various types of fiber bundles was not uniform and therefore it was hard to get reproducible results. A study performed by Bloomfield and Scott (1997) showed opposing results and concluded that *S. aureus* survived longer on 100% cotton fabrics. Neely *et al*. (2000) theorized that the difference in persistence between the two studies was due to a much lower initial inoculum level (10^2 CFU versus 10^8 CFU) used by Bloomfield and Scott (1997).

Besides looking at bacteria attachment, Wilkoff *et al*. (1969) also investigated the effects of humidity and mode of contamination as they pertain to *S. aureus* survival on fabric. They found that in general, fabrics contaminated by aerosolized *S. aureus* cultures and dust containing bacteria survived longer than those exposed by direct contact. Relative humidity also affected bacteria persistence in their studies. They determined that at a higher relative humidity (78%), bacteria populations on fabrics survived a substantially shorter period of time than at a lower humidity level (35%).

Lidwell and Lowbury (1950) noted that bacteria death rate in dust was approximately five times higher when it was exposed to daylight, low intensity ultra-violet light and fluorescent lights than when in the dark. This phenomenon may also apply to bacteria dusts attached to fabrics, however no studies have been conducted to date verifying this.

There are equally as many factors that can influence the level of transfer of bacteria, or cross-contamination, among fabrics (Montville *et al*. 2003). Type of bacteria, initial inoculum level, type of source and destination fabric, as well as moisture level may

all affect a fabric's ability to transfer bacteria. The degree to which a garment is hydrophobic or hydrophilic has also been shown to impact bacteria transfer. Sattar *et al*. (2001) found that bacteria transfer from cotton blends was consistently higher than that seen from all-cotton materials, implying that bacteria were less able to penetrate deeper into the fabric because of the hydrophobic nature of the polyester component. As in previous studies, he also noted that bacteria transfer levels were always greater when coming from moist donor fabric. However, Rusin *et al*. (2002) reported lower transfer rates from 50:50 cotton/polyester swatches than 100% cotton swatches. The discrepancy in these results may be due to Sattar's significantly shorter contact time and much smaller contact surface area as compared to the Rusin study.

Residual quaternary ammonium compounds on laundry fabrics is another factor which has been hypothesized as affecting both bacteria attachment and transfer ability. Cody *et al*. (1983) concluded that Gram positive organisms are more susceptible than Gram negative ones to the bacteriostatic properties of this class of compounds, which are present in nearly all new as well as previously washed fabrics as an antimicrobial finish. As the use of synthetic fibers and blends continue to increase in manufacture of shirts, hosiery, blouses, and underwear, so does the use of bacteriostatic finishes. These types of fabrics display drastically different moisture-transport characteristics than those of natural fibers, resulting in a greater degree of perspiration wetness for wearers (Aegisasia 2005). The antimicrobial finishes are added to clothing made from synthetic fabrics and blends to combat increased odors and bacteria counts seen. Durability of these finishes varies among articles of clothing, but is purported to last through at least 10 laundering

cycles. While still active, a bacteriostatic finish has the side benefit of reducing transfer of microorganisms from other fabrics to the clothing where it has been applied.

Microbial contamination of uniforms

Speers *et al*. (1969) found that approximately one third of microorganisms recovered from a nurse's uniform originate from the flora of the wearer with uniforms most frequently becoming contaminated below the waist during procedures such as dressing wounds. Sixty-two percent of the microorganisms recovered were attributed to patients.

Loh *et al*. (2000) tested the cuffs, side pockets and backs of white coats of one hundred medical students using contact plates. Every coat was contaminated on all three sites to some degree. As with similar studies (Babb *et al*. 1983, Wong *et al*. 1991), *Staphylococcus* spp. was most frequently seen (all 100 students), and *Acinetobacter* spp. (7 students) and dystheroids (12 students) were also isolated from the white coats. No MRSA was found and only three instances of a Gram negative organism were detected. None of the Gram negative organisms identified were considered normally pathogenic. A study by Wong *et al*. (1991) found that the maximum level of *S. aureus* contamination on doctor's white coats is reached within a week of use and doesn't change significantly until the coat is laundered.

Callaghan (1998) examined the effect of laundering frequency on bacteria levels for nurses' uniforms, with or without use of an additional cover apron. Wide variations in bacteria contamination levels were seen. Unwashed uniforms were found to be equally and heavily contaminated at all sites sampled. End of shift samples produced no statistically higher contamination levels than beginning or middle of a shift samples.

Nurse participants who did not additionally use an apron (59.4%, 116/196) reported that they wore a clean uniform each day. Fewer nurses who wore aprons (7.3%, 14/196) felt it necessary to wear a clean uniform each day and 30.6% (60/196) of the survey participants did not always wear clean uniforms at the start of a shift. More than half of the nurses used the hospital's laundry, so further research was conducted to determine initial bacteria counts on clean uniforms. From the dozen hospital-laundered uniforms tested, no bacteria were recovered.

Perry *et al*. (2001) used a vacuum method to analyze 57 nurse's home-laundered uniforms at the beginning and end of a shift for MRSA, VRE, and *C. difficile*. Thirty-nine percent (22/57) of uniforms tested were positive for one or more of the organisms prior to the start of the shift. VRE was detected on 21% (12/57) of uniforms, while MRSA and *C. difficile* were each found on 12% (7/57). Contamination levels varied from one to greater than 100 colonies. Scrubs at the end of a shift showed that 54% (31/57) of uniforms were positive for at least one of the test organisms. VRE was found on 31% (22/57) of uniforms, *C. difficile* on 19% (11/57) of uniforms and MRSA on 15% (8/57) of uniforms. Perry *et al*. (2001) noted that some uniforms had fewer organisms after being worn for a shift, and that the levels of post-duty contamination varied based on the type of ward.

Conversely, Babb *et al*. (1983) did not detect an increase in *S. aureus* or Gram negative bacilli when gowns and plastic cover aprons were used for periods up to 11 days in a main isolation unit. This study employed contact plates and detected *S. aureus* in 12.6% (26/207) of the fronts/shoulders of cotton gowns and 9.2% (22/239) of the plastic

aprons tested. Gram negative bacilli were only recovered from one gown (1/207). While 47% (42/89) of strains identified could not be associated with either the patients or staff, 35% (31/89) were linked to patients and 18% (16/89) were matched to the nurse's own nasal strain. Two percent (11/707) of garments evaluated produced *S. aureus* counts greater than one per square centimeter, however little difference was seen in the numbers of bacteria recovered between the two different areas tested.

Pilonetto *et al*. (2004) analyzed specific types of microbiota from uniforms using RODAC contact plates at both the beginning and end of a work shift. Samples were analyzed from the cuffs of long-sleeved gowns and the abdominal region from short-sleeved gowns for total viable and Gram negative bacteria counts. Researchers found a significant ($p=0.027$) increase in total bacteria from the beginning to the end of a work shift, with average total viable counts increasing from 2.2 to 4.9 CFU/cm^2. Converse to findings in Loh *et al*. (2000), bacteria levels were higher in the abdomen region than at the cuff. Pilonetto speculated this was because the earlier work by Loh only evaluated contamination in physicians clothing, while his work involved gowns from staff that generally had a much closer patient contact. Pathogens were isolated from 48% (15/31) of the gowns. Of the isolated pathogens, 61% (11/18) were *S. aureus* none of which were MRSA. Gram negative isolates found included *Acinetobacter baumanni* (2/18), *Klebsiella pneumonia* (2/18), *Stenotrophomonas maltophilia* (2/18), and *Serratia rubidate* (1/18). No *E. coli* or *Pseudomonas* spp. were detected, however, it was felt that the fewer number of Gram negative organisms was due in part to their poor ability to attach to fabrics

Fijan *et al*. (2005) also attempted to identify specific organisms on fabrics from a hospital setting. RODAC plates were used to evaluate the number and types of microorganisms on surfaces from a hospital laundry's clean area as well as ironed and folded textiles processed at the laundry. The most common microorganisms found were normal skin bacteria from the *Micrococcus* and *Staphylococcus* genera. Specimens from the genus *Bacillus* and the genus *Corynebacterium* were also frequently detected, even after surface disinfection measures had been implemented by the hospital laundry.

Hospital- versus home-laundered scrubs

Few studies compare the microbial flora of hospital- versus home-laundered attire. Previous research focused mainly on enumeration rather than identification of specific biota.

After recovering no bacteria from 12 randomly selected hospital-laundered uniforms, Callaghan (1998) inoculated uniforms previously laundered by the hospital with *Serratia marcescens* and washed them using a home washing machine. A variety of temperature settings, wash cycles, and laundry load contents were employed. All loads were tumble dried. She concluded that uniforms could be laundered at home provided they were washed with no other items of clothing, at no less than 50˚C, and ironed dry with a hot iron.

Jurkovich (2004) swabbed the left front shoulder of 50 operating room personnel, 60% (30/50) of whom had laundered their scrubs at home. No pathogenic microorganisms were found on either the home- or hospital-laundered scrubs. Also, no significant differences were found when comparing the normal skin flora on the two

different types of scrubs. Most staff who had home-laundered their scrubs (70%, 35/50) used warm water cycles, 73% (37/50) had washed their scrubs separate from other clothing, and all had dried their scrubs completely in the drier.

Outbreaks attributed to contaminated laundry

Only a few isolated studies have explored the possible transfer of organisms from nursing scrubs and uniforms to patients during identification of an outbreak, and those have taken place mainly in specialized wards such as burn or cardiothoracic units.

After two patients developed *Bacillus cereus* meningitis following neurosurgery at a London hospital, extensive environmental testing was performed by Barrie *et al*. (1992) to determine the source of the organism. Operating room linen was found to be the most probable origin of the infections. Hospital administrators made alternate laundering arrangements until the outbreak investigation, including analysis of the laundry facility, was complete. No further cases were reported after these changes were implemented. It was eventually determined that a contaminated continuous batch tunnel washer harbored large numbers of the organism and was not effectively disinfecting the linen (Wilcox *et al*. 1995).

Laundry contaminated with *Streptococcus pyrogenes* was identified as the cause of infection in a maternity ward outbreak involving several babies. The organism was traced to a heavily contaminated dryer used during laundering of the babies' clothes. The outbreak ended once the clothes were autoclaved (Fijan *et al.* 2005)

Microbes on laundry-associated surfaces

Studies show that pathogenic microorganisms survive on environmental surfaces for extended periods of time providing an opportunity for the transmission of infectious diseases. (Kramer *et al.* 2006, Manangan *et al.* 2001, Reynolds *et al.* 2005, Rusin *et al.* 1998, Scott *et al.* 1982, Weber *et al.* 2001). Little is known about bacteria levels in public laundries, as few studies have been performed. Buford *et al.* (1977) found bacteria ranging from geometric mean counts of 5 to 73,960 CFU/cm^2 in the interior tub surfaces of automatic washers in self-service laundry facilities, with a count of 490,000 CFU/cm^2 obtained on one occasion. The researchers hypothesized that even greater numbers would be found if samples had been taken from less accessible areas that receive little abrasion, or wet surfaces. Legnani and Leoni (1997) also tested interior washing machine surfaces and wash water in commercial launderettes. They concluded that bacteria contamination was highest in the most heavily used machines and those where customers, trying to reduce costs, overloaded them or used lower temperature programs to wash various kinds of clothing together (underwear, pants, shirts, shoes, etc.). Higher wash water temperature or using an oxygen-based bleach with a low temperature cycle provided a significant bacteria reduction ($p<0.001$) both in terms of percentages of positive samples and mean concentrations. However, both bleach and hot water were necessary to ensure a nearly complete elimination of bacteria from fabric, wash water and washer interiors, including the less accessible parts of the washing machine, such as the drum. No published data were found for bacteria numbers on home washing machine interiors.

Viable bacteria have also been found on the interior tub surfaces of automatic washers in self-service laundry facilities. Buford *et al*. (1977) found the $\log_{10}$ of the geometric mean counts ranged from 1.260 to 2.489 in 160 swab samples taken at each of four locations. Microorganisms can be disseminated within loads, between loads, and between families who use communal laundries (Wiksell 1973). As would be expected, bacteria contamination of communal washing machines was higher in the most heavily used units and levels found were relatable to bleach use as well as wash cycle temperatures. Washing at 55˚C or adding an oxygen-based bleach to a lower temperature cycle did provide a significant reduction in bacteria recovery, but did not prevent all bacteria from surviving inside the washer. Adding bleach to a hot water cycle ensured almost complete elimination of bacteria from protected parts of the washing machine drum (Legnani *et al*. 1998). Along similar lines, Larson and Duarte (2001) also identified lack of bleach use in a communal laundry as a significant predictor of increased disease transmission among family members. This was the first study in a home setting to demonstrate a potential link between laundry practices and disease transmission in the household.

Risk assessment for handling laundry

A quantitative risk assessment is the process of estimating and describing the probability that an event will occur. Originally developed for chemical hazards, it is now being applied to disease-causing microorganisms. In 1990, the Environmental Protection Agency first used a quantitative risk assessment to establish regulations for drinking water treatment. They set a goal to reduce the risk of waterborne diseases like Giardia

and Cryptosporidium to 1 per 10,000 people per year (Gerba 2001). There are several reasons to use a risk assessment instead of a typical epidemiological study when attempting to quantify hazards. Quantifying the probability that an infection will occur from handling contaminated laundry cannot be done using typical epidemiological studies because of the low rate expected (Gerba 2001, Gibson *et al*. 1999). Risks less than 1 per 10,000 require a very large study population and epidemiological studies are not able to evaluate risks over time. Also, risks associated with unwashed laundry are difficult to document by using standard disease surveillance and epidemiologic tools since most cases of disease in the home would not be immediately reported and the route of exposure would not be clear. Alternatively, a four step risk assessment involving hazard identification, exposure assessment, dose-response, and risk characterization can be employed to increase sensitivity of the endpoint analysis.

The two instances where laundry may be most likely to act to disseminate infection are during handling before laundering, and after laundering in the event the laundry process fails to fully remove microorganisms, the laundry remains damp for a period of time before being handled, and residual bacteria are allowed the opportunity to re-grow. Gibson *et al.* (1999) developed a quantitative risk assessment for the fecal-oral transfer of *Shigella* from handling contaminated laundry. No risk estimate has been done for handling laundry contaminated with *S. aureus*.

Information needed to estimate the likelihood of *S. aureus* infection transmission includes: 1) concentration of pathogens in soiled laundry; 2) the effectiveness of laundering practices used, taking into account wash water temperature, additives, type of

washing machine, and drying technique; 3) potential for cross-contamination of other laundry items in the same load or to the inside of the washing machine for transference to subsequent loads (communal laundries have been found to be particularly problematic, Larson *et al*. 2001); 4) potential for contamination of nose or abraded skin surface; and 5) immune status of laundry handler. The ultimate purpose of the risk assessment analysis is to determine the number of cases of *S. aureus* disease that can be prevented by implementing certain control strategies. By evaluating microbial counts in laundry and on laundry-associated surfaces, a more accurate risk assessment can be developed for persons handling laundry.