

A Comparison of Hand and Machine Dishwashing from a Hygienic Standpoint

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SUMMARY

In Europe, the majority of dishwashing is done manually, whereas dishwashing machines are used in approximately one-fourth of washing procedures. In this work, we investigated the survival of *Enterococcus faecium* with machine dishwashing and hand dishwashing. Bacterial counts in the wash tank of the dishwasher were reduced by more than 3 log units within 5 minutes. Bacterial reduction was much slower during hand dishwashing, in which a reduction of 0.7 log units was observed after 43 minutes. It was also observed that the type of soil has little influence on the survival of *E. faecium* in dishwater during hand dishwashing.

The mean numbers of *E. faecium* on cleaned dishware was 13–26 times higher for items cleaned by hand dishwashing than for those cleaned by machine dishwashing. Plates that were not visually clean after hand dishwashing had higher numbers of surviving *E. faecium* than plates that were visually clean.

From a hygienic point of view, machine dishwashing is superior to hand dishwashing. In the machine, a higher temperature and pH are combined with lower COD (chemical oxygen demand) and faster drying, creating a harsh environment for microorganisms. Machine dishwashing is also more easily replicated than hand dishwashing, since it is controlled by the specifications of the machine.

INTRODUCTION

Dishwashing is one of the oldest activities in kitchens all over the world. The most common way to perform dishwashing is to soak the items in water with detergent, clean them in dishwater together with detergent, and finally put them through a rinsing process. It is tedious work, often performed in odd locations where ergonomics and ventilation are not optimum. Still, this way of cleaning is the most common method in both domestic and professional kitchens.

Hygiene is essential for dishwashing in both domestic and professional kitchens (1, 4, 23). In domestic kitchens, a small number of meals are served to a restricted number of persons, so that if cross-contamination occurs, only a relatively small number of individuals are affected. In professional kitchens, there is a chance for numerous people to be infected by foodborne illness caused by, for example, contaminated dishes (7). Foodborne illness can cause a large cost and a burden for society (16, 22). Increased use of dishwashers can improve hygiene through dishwashing at higher temperatures and the use of more effective and aggressive detergents (30). Dishwashers that utilize a combination of chemical and mechanical treatment of dishes are offered on the market in Europe (27).

A peer-reviewed article

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An estimate of the distribution of various dishwashing methods for professional kitchens in Europe shows that about 70% utilize hand dishwashing, 20–25% dishwashers that use water as a means to remove soil mechanically, and 5–10% dishwashers that use additional means of removing soil mechanically, through the use of granules. This study reveals some aspects of the differences between hand dishwashing and machine dishwashing. An experimental method was designed for hand dishwashing, and similar experiments were performed in a one-tank dishwasher. The test organism used, *Enterococcus faecium*, is a heat-resistant bacterium utilized in microbiological testing of dishwashers (2, 6). Water consumption and capacities are discussed.

MATERIALS AND METHODS

Preparation of *E. faecium*

Cells of *E. faecium* were prepared from freeze-dried cultures (ATCC 6057, purchased from CCUG (5)). The freeze-dried cells were dissolved in 1 ml physiological saline solution and then cultivated for 24 h at 30°C in 100-ml Tryptic Soy Broth (Merck 1.05459.0500, Darmstadt, Germany) in a 1000-ml flask shaken at 200 rpm (Rotamax 120, Heidolph-Instruments GmbH & Co.Kg, Schwabach, Germany). One ml was then transferred from the overnight culture to 100 ml fresh Tryptic Soy Broth and cultivated as just described. The procedure was repeated once more. The third culture was transferred to centrifuge tubes and centrifuged at 2500 g for 5 min in a table centrifuge (Jouan, Saint-Herblain, France). The pellets were washed 3 times with cold 0.9% NaCl solution and the cells were then stored in 0.9% NaCl at 4°C for two weeks.

The cell suspension was serially diluted, and 100 µl of each dilution were spread on agar plates using a bent glass rod. The concentration of *E. faecium* was determined by the spread plate technique, in duplicate, on Kanamycin esculin azide agar (Merck 1.05222.0500); the plates were incubated for 4 days at 30°C. The concentration of the *E. faecium* cell suspension was found to be 9.48 log CFU/ml. The absence of contamination in the cell suspension was assured by micro-

scopy, using a Sagitta microscope XSP-136A (Sagitta Pedagog AB, Mariestad, Sweden) and by colony morphology as determined with Tryptic Soy Agar (Merck 1.05458.0500).

Preparation of soiled dishware

Soil 1 was made of 10 g egg powder mixed with 50 ml tap water. Then 20 g castor sugar was dissolved in 150 ml water; the solution was heated to boiling, then removed from the heat; 50 g potato powder (Felix®) and the dissolved egg powder was added and the mixture was stirred until homogenous. The dishware was baked for 17–20 h at 55°C. Soil 2 was prepared from a pie filling recipe, according to NSF/ANSI 3–2005 (18); the dishes were baked for 1 h at 93°C. Soil 3 consisted of boiled rice; the dishes were baked for 18 h at 55°C. Soil 1 is a heavy soil that adheres firmly to dishware and that has a more complex composition than soil 2 and 3 (26).

Dishware was autoclaved before use. The bottom of three Gastro-Norm trays (GN (24)), was covered with soil 1: one GN 1/1 65 mm tray, one GN 1/2 200 mm tray and one GN 1/3 200 mm tray. Half the bottom of a GN 1/1 65 mm tray was covered with soil 1, whereas one 1/1 20 mm tray was not soiled. Plates were treated with soil 1, 2 and 3, which was streaked out on the inner circle (~14 cm in diameter) of the plates. Approximately one tablespoon of soil 1, 2 and 3 was used for each plate. One tablespoon of soil 1 corresponds to 5 g baked soil.

Cross-contamination test in dishwasher

The dishwasher used in this study can be utilized for washing of both pots and items such as plates, cutlery, cups, etc. (13). Dirty trays and plates are placed in the dishwasher as shown in Fig. 1. In the granule washing mode, the machine uses plastic granules in the water flow to remove soil mechanically from the dishware. The granules are made of poly oxy methylene (POM), which is approved for use with foodstuffs. The times for washing and rinsing are summarized in Table 1 for the normal program with granules (one of the programs used for washing of pots) and the program used for plates, cutlery, cups, etc. The wash water temperature

is regulated at 65°C and the rinse water temperature at 85°C. Dishwashing agent (2 ml/liter Tornado, Diskteknik; Vallentuna, Sweden (20)) and Tryptic Soy Broth (3%) were added to the wash tank. Rinse agent was added to the rinse tank before the programs began (0.5 ml/liter Tyfon, Diskteknik (21)).

The wash tank was inoculated to a starting concentration of 4 log CFU/ml. A total of 18 plates were washed in a square basket. Every second plate was soiled with soil 1. In the next sequence with the same water, ordinary dishwasher-utensils, Gastro-Norm trays, treated with soil 1 were washed. The combi mode program was used for the plates, and the normal program with granules was used for the trays. The dishwater was mixed about 30 s before withdrawal of the first sample.

Cross-contamination tests in hand dishwashing

The same test setup was used for the two hand dishwashing tests, A and B. Hand dishwashing agent (0.5 ml/liter Dizzy, Diskteknik (19)) and 3% Tryptic Soy Broth (Merck 1.05459.0500) were added to the washing bowl containing hot tap water (final volume 15 liters). *E. faecium* was added to the dishwater (4 log CFU/ml) and mixed in. The starting concentration was determined by dilution and spread plating of the solution used for inoculation. The rinse water bowl was filled with 12 liters of hot tap water. The temperature of dishwater and rinse water was measured during the experiment by use of a calibrated PT100 (ETI Precision s/n D9811393, Pentronic, Gunnebo, Sweden) and a calibrated Logger 175-T3 (Testo, Lenzkirch, Germany). The COD in dishwater and rinse water was measured with the COD Cell test (Merck 1.14691.0001). The pH of the dishwater before inoculation was measured with a calibrated pH meter PHM210 and a pHC2015-8 electrode (Radiometer Copenhagen, Copenhagen, Denmark).

In test A, twelve plates with soil 1 were soaked for five min in the dishwashing bowl. A manual washing was then started; as a result, the plates were soaked for 5–20 min. Each plate was washed for 30 s, dipped into the water in the rinse bowl, and placed in a basket. One person washed and rinsed the first 6 plates; another person washed and rinsed the remaining 6.

TABLE 1. Times and temperatures during dishwashing

Program	Dishware	Granules	Wash		Rinse	
			Time (s)	Temp. (°C)	Time (s)	Temp. (°C)
Combi mode	Plates, cutlery, etc.	No	120	65	20	8
Normal	Pot wash	Yes	210*	65	40	85

* 210 s wash cycle: 180 s with granules and 30 s without granules

TABLE 2. Type of dishware and soil in the different experiments

Experiment	Dishware	Soil
Dishwasher	9 plates	1
	9 plates	-
	Two 1/1 65 mm trays	1
	One 1/2 200 mm tray	1
	One 1/3 200 mm tray	1
	One 1/1 20 mm tray	-
Hand dishwashing (A)	12 plates	1
Hand dishwashing (B)	10 plates	2
	10 plates	3

In test B, ten plates with soil 2 (pie filling base) were soaked for five min in the dishwashing bowl and then a manual washing was started, so that the plates were soaked for 5–12 min. Each plate was washed for 30 s, dipped in the water rinse in the bowl, and placed in a basket. Another ten plates with soil 3 (boiled rice) were soaked for five minutes in the dishwashing bowl, and the same washing procedure was used. One person washed the plates with soil 2, and another person washed the plates with soil 3.

Two hand dishwashing experiments were performed to evaluate the experimental procedure used; these experiments were performed on two non consecutive days, and the machine dishwashing experiments were performed on a separate day. The types of dishware and soil in the dishwasher and the hand dishwashing experiments are summarized in Table 2.

Analyses of wash and rinse water

Samples of 20 ml were aseptically withdrawn from the wash tank of the dishwasher at different time points. The

samples were immediately neutralized by addition of 1 ml 0.1 M HCl and cooled in an ice bath. Samples of 20 ml were aseptically withdrawn from the washing bowl and from the rinse water bowl at different time-points during the hand dishwashing tests, and the samples were cooled. The dishwater and rinse water samples were streaked out on Tryptic Soy Agar (Merck 1.05458.0500) and kanamycin esculin azide agar (Merck 1.05222.0500). A volume of 100 µl sample was streaked out in duplicate on each type of medium. The rinse water samples were not diluted before spreading. For dishwater, both undiluted samples and samples diluted 1:10 were spread. The agar plates were incubated for 3–4 days at 36°C.

Analyses of dishware

Kanamycin esculin azide agar (~50°C) was poured onto the bottom inner areas of the washed trays and on the washed plates. Only the inner circle (~14 cm in diameter) of the plates was covered with agar. All washed dishware was included, as well as non-soiled dishware. The trays and plates were incubated for 3 days at 36°C.

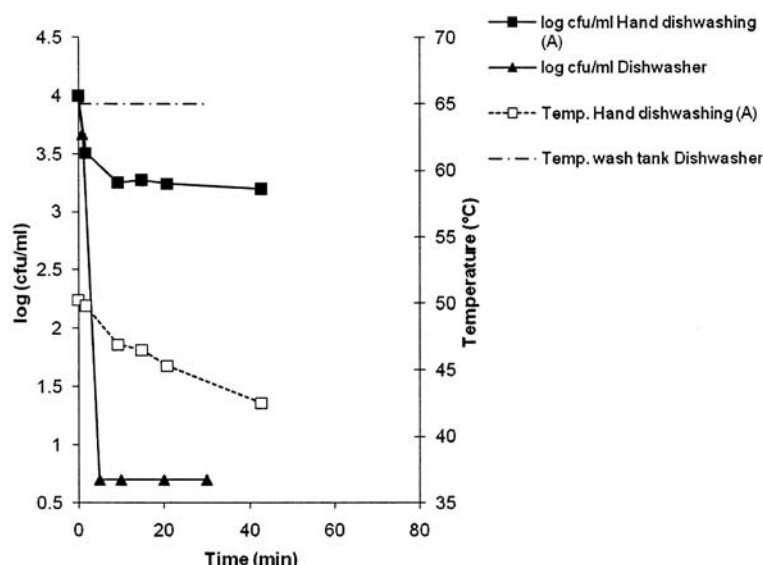
RESULTS

Bacterial counts and temperatures of the dishwater during machine dishwashing and hand dishwashing are summarized in Fig. 2. The dishware was soiled with the more complex and adhering soil 1 in both experiments. The bacterial counts in the dishwasher were reduced by more than 3 log units within 5 min. The water in the wash tank in the dishwasher had a temperature of 65°C. Bacterial reduction was much slower during hand dishwashing, in which a reduction of 0.7 log units was observed after 43 min. The temperature, approximately 50°C at the start of the hand dishwashing experiment, decreased over time (43°C after 43 minutes). Figure 3 displays the bacterial counts and temperatures in the two hand dishwashing experiments. Plates with soil 1 were cleaned in Experiment A, whereas plates with soils 2 and 3 were cleaned in experiment B. Bacterial reductions and temperatures were similar in the two hand dishwashing experiments. After 14–15 minutes, a bacterial reduction of 0.7 log units and a temperature decrease of 4°C

FIGURE 1. The dishwasher with plates.



FIGURE 2. Bacterial counts and temperatures in dishwater during hand dishwashing (Experiment A) and in dishwasher. Dishware was soiled with soil 1 and 3% tryptic soy was added to the dishwater. Detergent was added to the dishwasher (2 ml/liter Tornado) and to the washing-up bowl (0.5 ml/liter Dizzy). The dotted line at 0.7 CFU/ml indicates the detection level.



were observed in both hand dishwashing experiments. The deviation in bacterial reduction between the two hand dishwashing experiments was at most 0.1 log units for comparable sampling time points. For the temperature, the maximum deviation was 2°C for comparable sampling time points. For each set of duplicate plates during the two hand dishwashing experiments and the sample withdrawn from the wash tank of the dishwasher after 1 min,

the deviations of CFU/plate were at most 12 to 15%.

E. faecium was detected at a level of 0.7 CFU/ml in the rinse water during the two hand dishwashing experiments (Fig. 4). The temperature decrease of the rinse water was similar in the two hand dishwashing experiments, 3–4°C during the first 15 min. Figure 5 shows the COD concentrations of the dishwater during the hand dishwashing experiments. COD lev-

els of 6000–10000 mg/liter were found at the end of the experiments. The COD of the rinse water was below detection level in both hand dishwashing experiments.

Figure 6 displays the mean CFU of *E. faecium* per washed item in the different experiments. The mean numbers of *E. faecium* were 13–26 times higher for the items washed by hand than for those washed by machine. *E. faecium* was detected on all 32 plates after hand dishwashing, but on only 2 out of 18 plates and 2 out of 5 trays after machine dishwashing.

For hand dishwashing, the plates with soils 1 and 3 were not visually clean, with several spots of soil remaining on the surface. The plates with the soil that adhered least, soil 2, were visually clean. In the dishwasher, the plates with soil 1 did not get clean, whereas the trays with soil 1 got almost perfectly clean. For the adherent soil, the COD in the dishwater for hand dishwashing increased to about 12000 mg/l, and for the less complex soils (2 and 3) 8000 COD mg/liter was achieved. From Fig. 5, it is seen that it takes some time to dissolve the soil in the dishwater. The concentration of nutrients in the dishwater is not homogeneous which results in variation for different samples.

DISCUSSION

The reduction of bacteria and the temperature changes in the dishwater show good correspondence between the hand dishwashing experiments. The temperatures varied from 50°C at the beginning to 37°C at the end of the experiments, which are the most common temperatures for washing dishes (12, 15). The reduction of *E. faecium* was small for hand dishwashing, only 0.7 to 1.0 log units, which is in accordance with previous results (10). The different types of soil did not influence the reduction of *E. faecium*.

When hand dishwashing is compared to machine dishwashing with regards to hygienic aspects, the reduction of *E. faecium* in the dishwater was much more efficient for this type of machine than for hand dishwashing of soiled plates. One difference between hand dishwashing and machine dishwashing is the detergents used. Detergents for hand dishwashing normally have a pH

FIGURE 3. Bacterial counts and temperatures in dishwater during hand dishwashing. Dishware was soiled with soil 1 (Experiment A) or soils 2 and 3 (Experiment B). An amount of 3% tryptic soy and 0.5 ml/liter detergent (Dizzy) was added to the dishwater. The dotted line at 0.7 CFU/ml indicates the detection level.

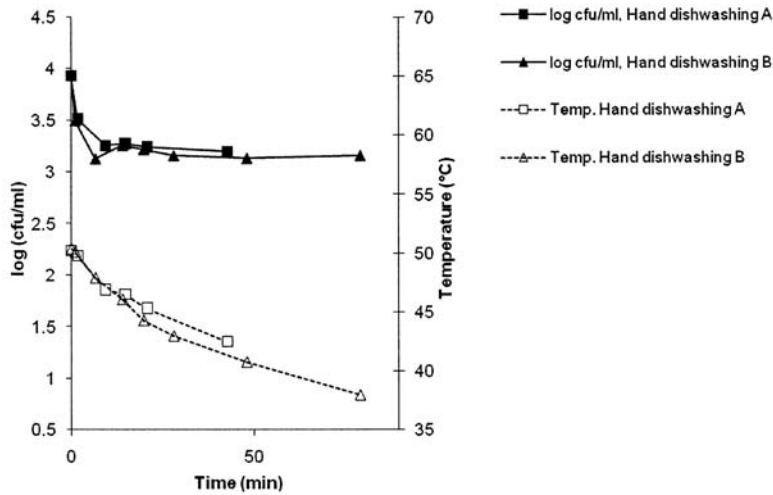
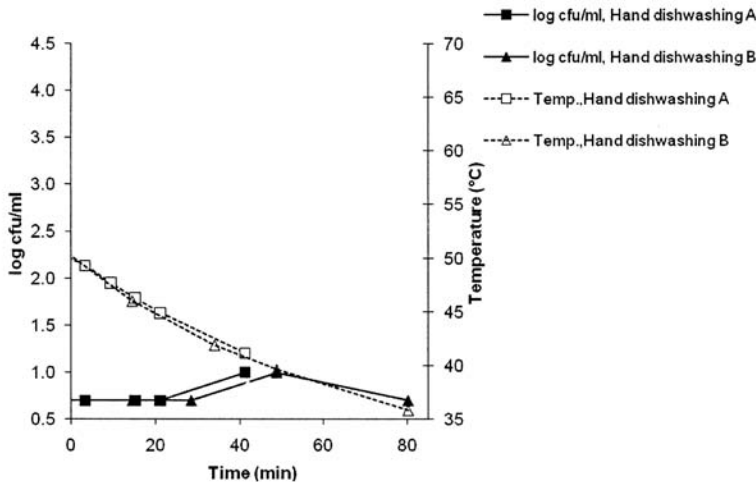


FIGURE 4. Bacterial counts and temperatures in rinse water during the two hand dishwashing experiments. The dotted line at 0.7 CFU/ml indicates the detection level.



around 7, with or without antibacterial substances (3, 9). For machine dishwashing, the normal pH is about 10–12. The combination of high temperature (55–65°C) and high pH in machine dishwashing reduces the bacterial number more effectively than hand dishwashing (10, 14, 29). Machines with granules to assist in cleaning do not show any increased levels of bacteria in the dishwater or among granules (25).

From the start of the hand dishwashing experiments, the numbers of bacteria were below the detection limit in the rinse water. When the hand dishwashing was finished after 40 minutes, a slight increase of the bacterial content of the rinse water was seen. After another 40 minutes, the content of bacteria was below the detection limit. The reason for this behavior is the lack of nutrients remained in the rinse water.

After completion of dishwashing, a small amount of nutrients remained in the water and the temperature had decreased; both of these are favorable factors for growth of microorganisms. The amount of nutrition measured as COD was less than 300 mg/liter in the rinse water, in contrast to the amount in the dishwater, in which all the soil from the dishware was collected. In dishwashers, values from 2000 up to 6000 COD mg/liter have been reported (8, 28). Furthermore, the procedure in a dishwasher is different from the rinse procedure in hand dishwashing. In a machine, rinse water is sprayed over the dishware after the washing cycle, and the rinse water is reused as dishwater. Contaminating the rinse water from the dishware is therefore not possible.

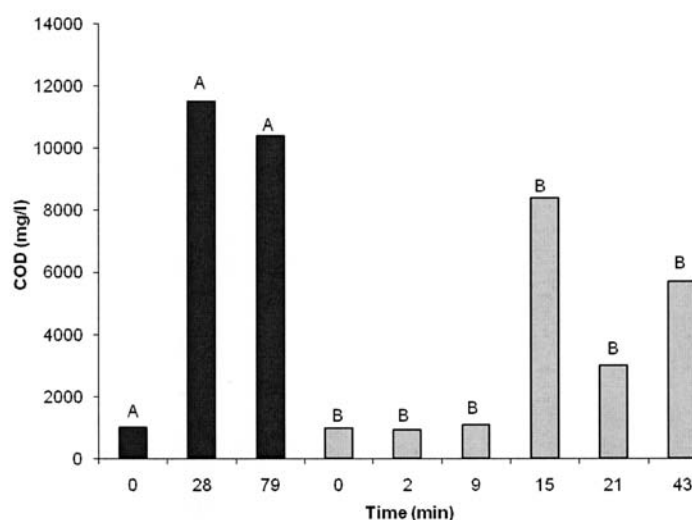
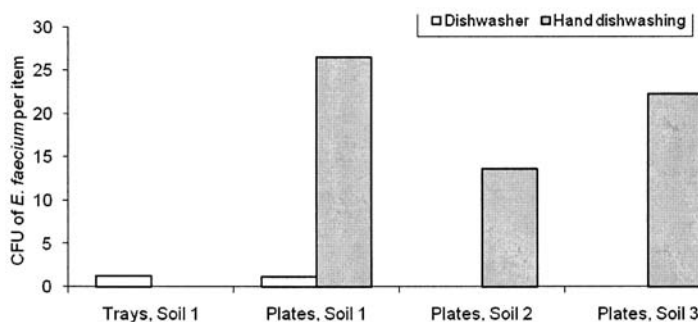
The number of CFU/item is considerable higher for hand dishwashing than for machine dishwashing, because the concentration of bacteria in the dishwater was considerably higher for hand dishwashing than for machine dishwashing, and the plates were not properly cleaned. To compare hand dishwashing to machine dishwashing, plates were used as dishware. However, a dishwasher can be used for both trays and plates; for this reason, experiments were conducted for trays also. The results (CFU/item) were the same for plates and for trays in the dishwasher. Cross-contamination from dishwater to plates has been found in a traditional dishwasher and in hand dishwashing, but only on those plates or bowls that contained visible soil after dishwashing (26). There are, of course, other processes and items in the kitchen in which different surfaces act as vectors for microbial transfer, i.e., plastic gloves, plastic aprons, plastic salad crates, stainless steel surfaces and conveyor belts (11, 17).

Because of higher temperatures of the plates after the machine dishwashing cycle and the addition of drying agent in the rinse water, drying of the dishware is much faster for machine dishwashing than for hand dishwashing. Trays, utensils and plates should be as dry as possible after the dishwashing cycle to minimize the risk of bacterial growth on the surfaces.

Machine dishwashing is a more reproducible process than hand dishwashing, since it is controlled by the specifications of the machine. The temperature of the dishwater is kept constant at 65°C, in contrast to the dishwater temperature for

TABLE 3. Comparison of capacities for dishwashing of plates by machine and manually

Procedure	Pre soaking	Dishwashing and rinsing	Loading and unloading	Capacity	Capacity of plates per hour
Hand dishwashing soils (2, 3)	5–15 min	15 min	-	20 plates per 20 min	60
Hand dishwashing soil (1)	5–15 min	15 min	-	12 plates per 20 min	36
Machine dishwashing soil (1)	-	3 min	3 min	18 plates per 6 min	180

FIGURE 5. COD in dishwater samples withdrawn at different time points during hand dishwashing Experiments A (soil 1) and B (soils 2 and 3).**FIGURE 6.** Mean CFU of *E. faecium* per washed item in the different experiments.

hand dishwashing, which decreases during the process. Because of the risk of injury, the dishwater temperature is seldom above 55°C for hand dishwashing.

The total consumption of tap water for hand dishwashing was 27 liters in the experiments. Assuming that the water is used for two batches of dishware, 20 plates each batch, then the ratio is 0.7 liters fresh water per plate. For the dishwasher, 5 liters of rinse water are used each time a program is run. Before the first program, the wash water tank is filled with 83 liters of tap water. The dishwater is reused, except for the exchange using the 5 liters of rinse water at each program. Generally, 20 programs are performed before depletion of water in the dishwater tank occurs. This corresponds to 360 plates, resulting in a consumption of 0.5 liters of fresh water per plate. With regard to overall fresh water consumption, the dishwasher is more efficient. The capacity is higher for machine dishwashing than for hand dishwashing, even though only a short pre-soaking time (5 min) is accounted for in hand dishwashing (Table 3).

CONCLUSIONS

The bacterial content of dishwater is not reduced significantly in hand dishwashing over time. However, in machine dishwater, the reduction of *E. faecium* is more than 3 log units, compared to 1 log unit for hand dishwashing. Furthermore, the results show that for machine dishwashing, there is less cross-contamination from dishwater to dishes and other wares because of the lower bacterial level in the dishwasher process. The consumption of water is less for machine dishwashing. Taking soaking into account, the time needed for wash-

ing is longer for the hand dishwashing process. Because the rinse water dilutes the dishwater in the dishwashing machine, the concentration of soil, measured by determining the COD, becomes lower than for hand dishwashing. The risk of personnel becoming contaminated by the dishwater is less for the closed process in a machine dishwasher than for the open process used in hand dishwashing. Even aerosols can cause irritations in the hand dishwashing process.

ACKNOWLEDGMENTS

Granuldisk AB is gratefully acknowledged for supplying the dishwasher for tests and for communication.

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