NiDI

Nickel
Development
Institute

Cleanability in relation to bacterial retention on unused and abraded domestic sink materials

by J. T. Holah & R. H. Thorpe

NiDI Technical Series № 10 046

Reprinted from
The Journal of Applied Bacteriology
August 1990

Journal of Applied Bacteriology 1990, **69**, 599–608 3219/10/89

Cleanability in relation to bacterial retention on unused and abraded domestic sink materials

J.T. HOLAH & R.H. THORPE *Campden Food and Drink Research Association, Chipping Campden, Gloucestershire GL55 6LD, UK*

Accepted 30 March 1990

HOLAH, J.T. & THORPE, R.H. 1990. Cleanability in relation to bacterial retention on unused and abraded domestic sink materials. *Journal of Applied Bacteriology* **69**, 599–608.

The relative cleanability of stainless steel, enamelled steel, mineral resin and polycarbonate domestic sink materials was assessed by comparing the number of organisms remaining on surfaces after cleaning. In unused condition all materials, other than one enamelled steel, were equally cleanable. Stainless steel, abraded artificially or impact damaged to a similar degree as stainless steel subjected to domestic wear, retained approximately one log order less bacteria after cleaning than the other materials subjected to the same treatments. Little difference in cleanability was recorded between the abraded surfaces of the other materials although enamelled steel surfaces were less cleanable than mineral resin or polycarbonate after impact damage, because of the greater susceptibility of enamelled steel to damage by this treatment. When cleaning time was extended beyond 10 s for the abraded and impact damaged materials, their cleanability was not enhanced as compared with stainless steel. Changes in surface finish after abrasion were assessed by surface roughness measurement and scanning electron microscopy. Surfaces with poor cleanability before and after abrasion were characterized by pitting, crevices or jags. These surfaces are likely to retain more bacteria because of increased numbers of attachment sites, a larger bacterial/material surface contact area and topographical areas in which applied cleaning shear forces are reduced. Materials that resist surface changes, e.g. stainless steel, will remain more hygienic when subjected to natural wear than materials which become more readily damaged.

The importance of bacteria that remain on surfaces after cleaning, in relation to potential contamination of food, is becoming increasingly apparent whether in food processing, catering or the domestic environment. The domestic sink is a focal point in the kitchen for the preparation and disposal of food. Sink surfaces may harbour food spoilage and/or pathogenic bacteria, either attached to the sink surface or within adherent food particles. Although with good hygienic practices food particles are usually cleaned from the sink, bacteria attached to sink surfaces are not visible to the eye and may therefore not be removed.

Bacteria remaining on sink surfaces may contaminate food either by direct contact or by indirect means, such as hands, utensils, crockery or cloths. Sink materials that retain the smallest number of bacteria after cleaning are therefore the most hygienic in terms of food contamination potential.

Stainless steel has been the material of choice for both domestic and catering sink construction for many years because of its mechanical strength, corrosion resistance, longevity and ease of fabrication. Advances in material technology, however, have made a number of alternative materials available. The cleanability of stainless steel as a food contact surface has been reviewed by Milledge & Jowitt (1980) in terms of the cleanability of the various available surface finishes rather than in comparison with other materials. Ridenour & Armbruster (1953) investigated the bacterial cleanability of various types of eating surfaces and concluded that stainless steel, although not as cleanable as glass or china, was more cleanable than aluminium or the plastics tested. Similar results were obtained by Davis (1963) who showed that stainless steel was less cleanable than glass, about equal to vitreous enamelled steel and more cleanable than aluminium, polythene and a laminated plastic. Masurovsky & Jordan (1960), however, showed that aluminium and plastic were more cleanable than stainless steel. There appears to be no information in the literature as to the cleanability of other sink materials presently in use, including polycarbonate and mineral resin.

In the above studies few trial replicates were undertaken and statistical analysis of results was not carried out. Swabbing, the method of enumerating bacteria remaining on surfaces after cleaning, has also been shown to be highly variable (Holah *et al.* 1988). Plastics technology has also advanced, so that present-day materials may not be similar to those previously tested. The results of these reports should therefore be treated with caution. Recent work (Holah *et al.* 1989) has shown that there was little difference in cleanability between materials commonly used in food production equipment, including stainless steel, high density nylon, PVC and polypropylene, when in new condition.

In this work the relative cleanability of stainless steel was compared with that of enamelled steel, mineral resin and polycarbonate sink materials. The cleanability of the material types was assessed when in unused condition, artificially abraded and after simulated impact damage.

Materials and Methods

PREPARATION OF SINK SURFACES

Two examples, from different manufacturers, of the following sink material types were purchased: stainless steel (sinks 1 and 2), enamelled steel (sinks 3 and 4), mineral resin (sinks 5 and 6) and polycarbonate (sinks 7 and 8). Samples, 40 × 20 mm, were cut from the bowl bases with a hand-held jigsaw with the cutting angle of the teeth entering the sample on the inside of the base to minimize damage. All samples were washed with a mild detergent before testing to remove surface grime.

Samples were abraded with 40-grit abrasive paper mounted on a rubber sanding block (640 × 120 mm) to which a 4·8 kg weight was attached. This weight simulated the force measured when volunteers produced a light rubbing action on a balance pan. All strokes were in the same direction, traversing the long axis of the sample. This degree of abrasion produced a surface finish on stainless steel similar to that observed on seven second-hand stainless steel sinks, 4–10 years old, purchased locally from domestic sources. This degree of abrasion was achieved for the stainless steel samples with 10 strokes of the sanding block and this treatment was applied to the three other sink type materials. The change in surface roughness between unused and abraded sink surfaces was assessed with a surface roughness measuring instrument (Rank Taylor Hobson Surtronic 3P) in accordance with British Standard B.S. 1134 (Anon. 1972).

Impact damage was simulated by producing grooves in the sink samples. Grooving was undertaken as an alternative to estimating bacterial retention in repeated impact damage 'pits', because initial work had shown that for some materials, 'pits' were particularly difficult to locate microscopically. With grooves, however, once located, many estimates of bacterial retention could be undertaken. Grooves were cut by mechanically drawing samples, clamped in a vice, under a ground point of high speed steel mounted in the jaws of a Bridgeport Universal Milling machine. A pressure of 0·7 kg was applied to the steel point to produce grooves in stainless steel of a similar depth as caused by dropping stainless steel cutlery onto pieces of stainless steel from a height of 300 mm. Areas of impact damage of this depth were not uncommon on the stainless steel sink samples that had been abraded in domestic environments. Grooving was undertaken with a force of 0·7 kg on the other three sink types.

CLEANING STUDIES

Biofilms of *Acinetobacter calcoaceticus* (CFDRA Culture Collection—CRA 296) were attached to sink samples using techniques described by Holah *et al.* (1988). By this method, growth of culture in contact with the test pieces resulted in a biofilm density of *ca* 10^7 colony forming units (cfu)/cm^2. Sink samples were cleaned in a purpose-built spray cleaning test rig. This comprised two 50 l stainless steel heated tanks, a 10·8 l/min pump and a height adjustable sprinkler type spray head. The temperature in the tanks could be thermostatically controlled over the range 40°–80°C. The spray head was set at a height of 250 mm above the sample under test, as this resulted in complete spray coverage. The cleaning solution was a 0·33% v/v aqueous solution of 'Velvet', a domestic washing-up liquid supplied by Maigret Chemicals Ltd (Daventry, UK) and sprayed at a temperature of 40°C. Detergent residues were rinsed off with distilled water from a wash bottle before enumeration.

Bacteria attached to sink sample surfaces, both before and after spraying, were enumerated by direct epifluorescent microscopy using the bio-Foss Automated Microbiology System (Foss Electric (UK) Ltd) as described by Holah *et al.* (1988) with a minimum of 20 fields-of-view being enumerated per sample. Differences in the number of bacteria remaining on sink samples were assessed statistically by analysis of variance (ANOVA) with 'significance' expressed throughout this work at the 95% confidence level or greater ($P < 0{\cdot}05$).

Results

To assess the cleanability of new materials, biofilms were attached to unused samples of each of the eight sinks. Counts of the biofilms established on each of the sink surfaces, taken as a control of biofilm growth, indicated little difference between sink types, with counts *ca* 10^7 cfu/cm^2. Spray cleaning was undertaken for 10 s and the results of 13 trials are shown in Table 1. No significant difference in cleanability between the sink types ($P = 0{\cdot}124$) was indicated with the exception of sink 3 (enamelled steel), which was significantly less cleanable ($P = 0{\cdot}040$).

The cleanability of unused sink samples was compared with that of artificially abraded samples. Biofilms were developed on abraded samples of each of the eight sinks and control biofilm growth counts were *ca* 10^7 cfu/cm^2. Spray cleaning results from 15 trials are shown in Table 1. When compared by ANOVA, both mineral resin and polycarbonate sinks, and enamelled steel sink 4 were not significantly different ($P = 0{\cdot}366$), with enamelled steel sink 3 being slightly more cleanable ($P = 0{\cdot}041$). The stainless steel sinks, however, were significantly more cleanable than the other materials ($P = 0{\cdot}000$) and not significantly different from each other ($P = 0{\cdot}995$).

The results in Table 1 for the abraded surfaces were a point estimate of surface bacterial retention within a cleaning time curve. To determine whether relative cleanabilities between surface types would differ with cleaning time, biofilms were developed on sink surfaces which were cleaned for 5, 10, 20 or 40 s. The mean log counts for 15 trials, at each spray time, are shown in Fig. 1. When compared by ANOVA, the combined values of the stainless steel sinks [not significantly different at all spray times ($P = 0{\cdot}431$)] were significantly more cleanable than the other sink materials at each cleaning time ($P = 0{\cdot}000$). No significant difference was observed between both enamelled steel, polycarbonate and mineral resin sinks after 5 s ($P = 0{\cdot}464$) and 10 s ($P = 0{\cdot}399$) though after 20 s ($P = 0{\cdot}011$) and 40 s ($P = 0{\cdot}006$) enamelled steel sink 4 was significantly less cleanable.

Table 1. Surface roughness values and comparative cleanability of unused and abraded sink materials after 10 s of standard spray treatment

			Bacteria retained (cfu/cm^2)			
	Mean surface roughness (μmR$_a$)		Unused		Abraded	
Sink type	Unused[a]	Abraded[b]	Mean[c] (×10^4)	S.D. (×10^4)	Mean[d] (×10^4)	S.D. (×10^4)
1 Stainless steel	0·602	0·706	2·69	2·50	4·20	6·54
2 Stainless steel	0·484	0·698	1·53	1·86	4·18	7·80
3 Enamelled steel	0·866	1·976	27·04	58·99	12·4	5·78
4 Enamelled steel	0·284	2·72	3·59	3·69	37·9	25·2
5 Mineral resin	4·790	3·854	3·50	3·05	72·2	89·7
6 Mineral resin	7·392	6·586	1·79	1·73	74·8	95·7
7 Polycarbonate	15·54	14·90	2·67	2·71	39·1	32·3
8 Polycarbonate	6·618	7·918	2·69	3·79	64·3	56·4

a, $n = 5$; b, $n = 5$; c, $n = 15$; d, $n = 13$.

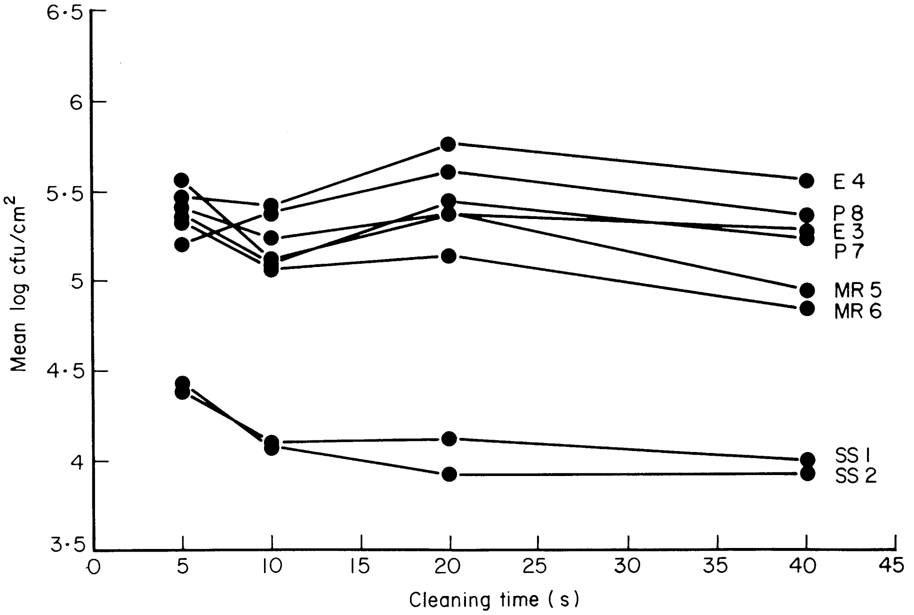

Fig. 1. Mean ($n = 15$) log cfu/cm^2 *vs* cleaning time for a range of abraded domestic sink materials. SS, Stainless steel; E, enamelled steel; P, polycarbonate; MR, mineral resin. The number refers to the sink number.

The surface roughness values in μmR$_a$ of both unused and abraded sink surfaces are shown in Table 1. Stainless steel and enamelled steel sink surfaces had low μmR$_a$ values and were hence very smooth. Mineral resin and polycarbonate sink surfaces had high μmR$_a$ values which would suggest that these surfaces were not as smooth. On examination with a low power microscope, it was apparent that the high μmR$_a$ values recorded on the mineral resin and polycarbonate surfaces were due to the close spacing of waviness caused by a type of stippled surface finish, designed to reduce the visible effect of surface scratching. A more accurate picture of the surface profiles of each of the unused material types, as observed using scanning electron microscopy (SEM), together with how these materials' surfaces changed with abrasion, is shown in Fig. 2. Typical results, obtained by SEM, of biofilms attached to abraded surfaces, both before and after detergent cleaning, are shown in Fig. 3.

The surface roughness measurements of artificially abraded stainless steel compared with the naturally abraded stainless steel surfaces of seven second-hand sinks (labelled A–G) are shown in Table 2. With ANOVA, stainless steel sinks 1 and 2 were not significantly different

Table 2. Surface roughness values and comparative cleanability of naturally and artificially abraded stainless steel sink materials after 10 s of standard spray treatment

	Surface roughness (μmR$_a$)		Bacteria retained (cfu/cm^2) (× 10^3)	
Sink type	Mean^a	S.D.	Mean^b	S.D.
Stainless steel sink 1	0·706	0·102	11·95	19·70
Stainless steel sink 2	0·698	0·101	10·25	14·58
Naturally abraded sink A	0·918	0·174	8·03	8·92
Naturally abraded sink B	0·304	0·043	6·60	9·31
Naturally abraded sink C	0·614	0·081	11·61	18·00
Naturally abraded sink D	0·770	0·230	12·15	23·06
Naturally abraded sink E	0·420	0·187	17·62	27·44
Naturally abraded sink F	0·538	0·070	3·57	4·07
Naturally abraded sink G	0·654	0·131	7·91	10·19

a, $n = 5$; b, $n = 15$.

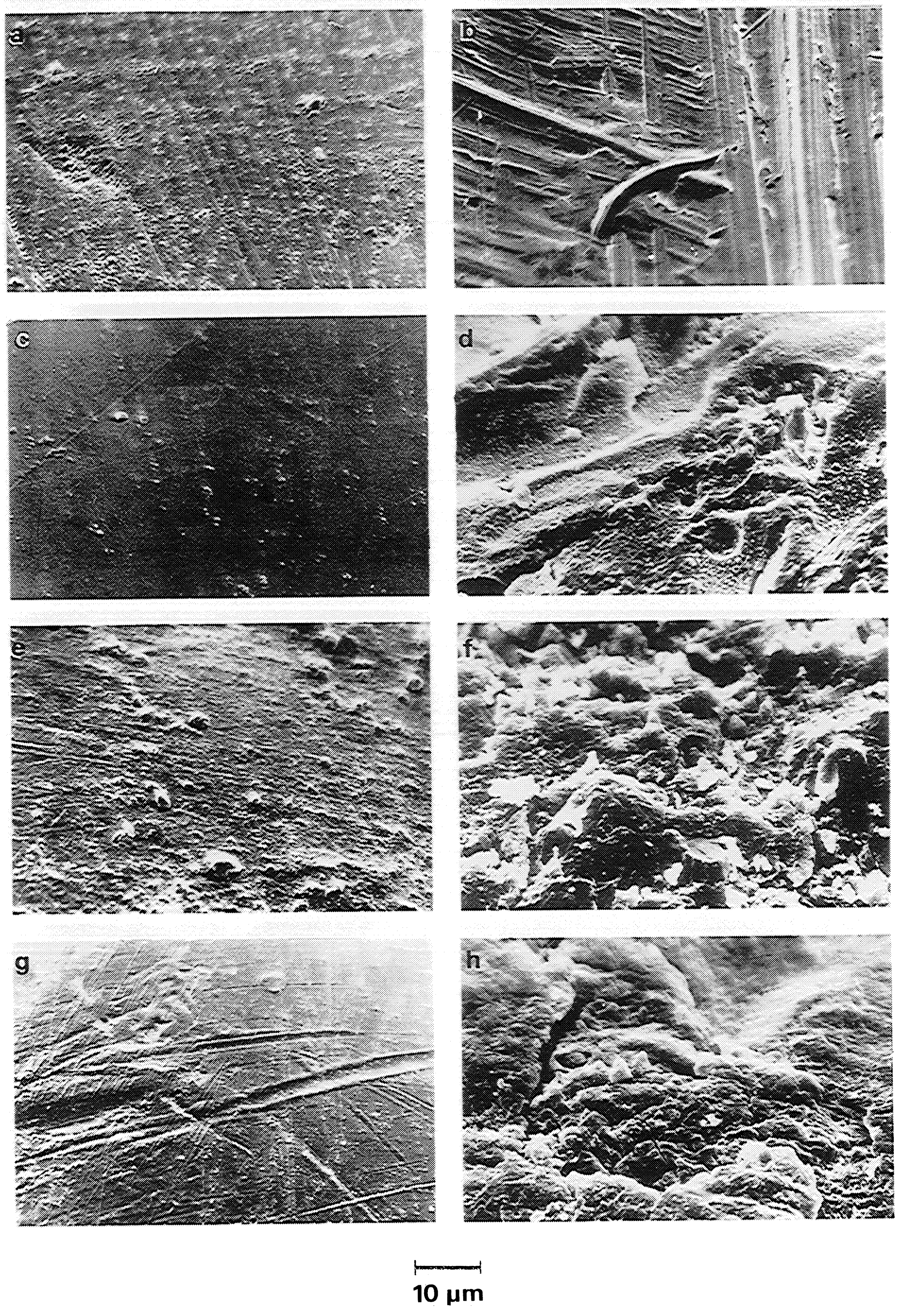

Fig. 2. Electron micrographs of a range of domestic sink materials to illustrate changes in surface roughness when artificially abraded. (a) Stainless steel unused (Sink 1); (b) stainless steel abraded (Sink 1); (c) enamelled steel unused (Sink 3); (d) enamelled steel abraded (Sink 3); (e) mineral resin unused (Sink 6); (f) mineral resin abraded (Sink 6); (g) polycarbonate unused (Sink 7); (h) polycarbonate abraded (Sink 7).

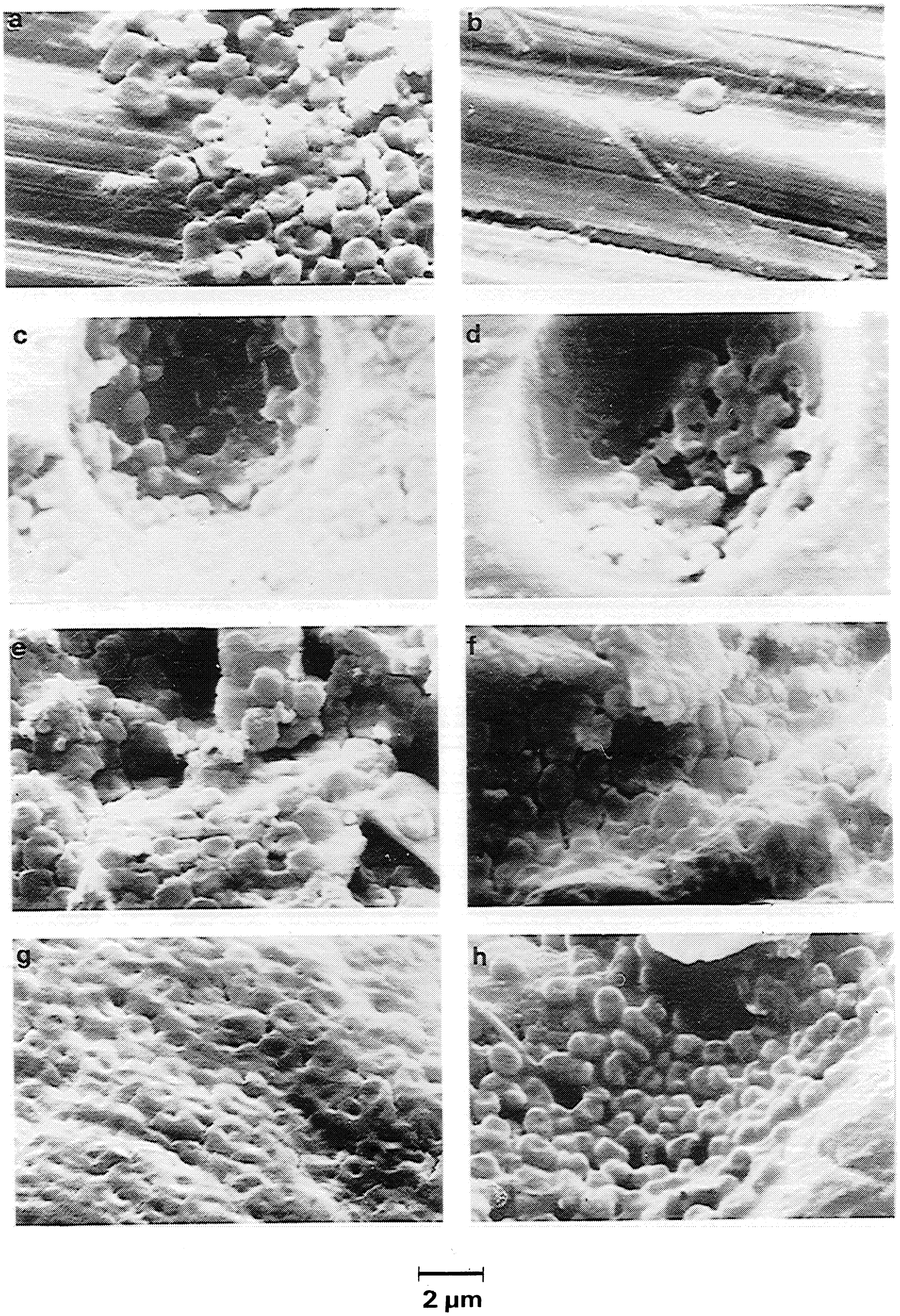

Fig. 3. Electron micrographs to illustrate the degree of surface bacterial contamination before and after cleaning for a range of domestic sink materials. (a) Stainless steel (Sink 1) before and (b) after cleaning; (c) enamelled steel (Sink 3) before and (d) after cleaning; (e) mineral resin (Sink 6) before and (f) after cleaning; (g) polycarbonate (Sink 7) before and (h) after cleaning.

from naturally abraded sinks C, D, F and G ($P = 0{\cdot}129$); were smoother than sink A ($P = 0{\cdot}033$) and were rougher than sinks B and E ($P = 0{\cdot}000$). The cleanability of artificially abraded sinks 1 and 2, and naturally abraded sinks A–G, after a 10 s clean for 15 trials, are shown in Table 2. When compared by ANOVA, no significant difference in cleanability between the artificially abraded sinks 1 and 2 and the seven naturally abraded sinks was apparent ($P = 0{\cdot}535$).

The effect of impact damage on cleanability was investigated on stainless steel, mineral resin and polycarbonate sinks. Enamelled steel surfaces were not included in the grooving trials as they were found to be impossible to groove, the nature of the surface causing them to splinter. In practice the effect of impact on an enamelled surface was characteristically much greater than on the other types since, due to splintering and chipping, the area of impact damage was larger. A relatively few enumerations were undertaken on impact damaged enamelled steel which indicated a bacterial retention of about 5×10^5 cfu/cm^2. Biofilms were spray cleaned for 5, 10, 15, and 30 s. Bacterial retention at the bottom of each groove was estimated and the mean log counts from eight trials at each spray time are shown in Fig. 4.

No significant difference in cleanability was observed after 5 s between stainless steel sinks 1 and 2 and the most cleanable of the other materials, polycarbonate sink 8 ($P = 0{\cdot}118$). At 10, 15 and 30 s, however, the stainless steel sinks were significantly more cleanable ($P = 0{\cdot}003$). In terms of the relative cleanability of the other materials, polycarbonate sinks 7 and 8, and mineral resin sink 5 at all cleaning times and mineral resin sink 6 (at 10 and 15 s) were not significantly different ($P = 0{\cdot}082$). Mineral resin sink 6 was only significantly less cleanable than sinks 5, 7 and 8 at 5 and 30 s ($P = 0{\cdot}000$).

Discussion

The biofilm control counts for each unused material indicated similar levels of initial bacterial attachment. The results in Table 1 suggested that apart from one enamelled steel surface, there was little difference in cleanability between the four unused material types. Also, the results in Fig. 2 suggested there was little difference between the unused materials in terms of surface roughness at the microscopic level.

Bacterial attachment to surfaces is thought to take the form of a two-stage process: reversible adhesion followed by irreversible adhesion (Marshall *et al.* 1971). Reversible adhesion is an instantaneous attraction holding bacteria near the surface by hydrophobic, electrostatic or other forces. Irreversible adhesion involves the bacteria physically attaching to the surface by

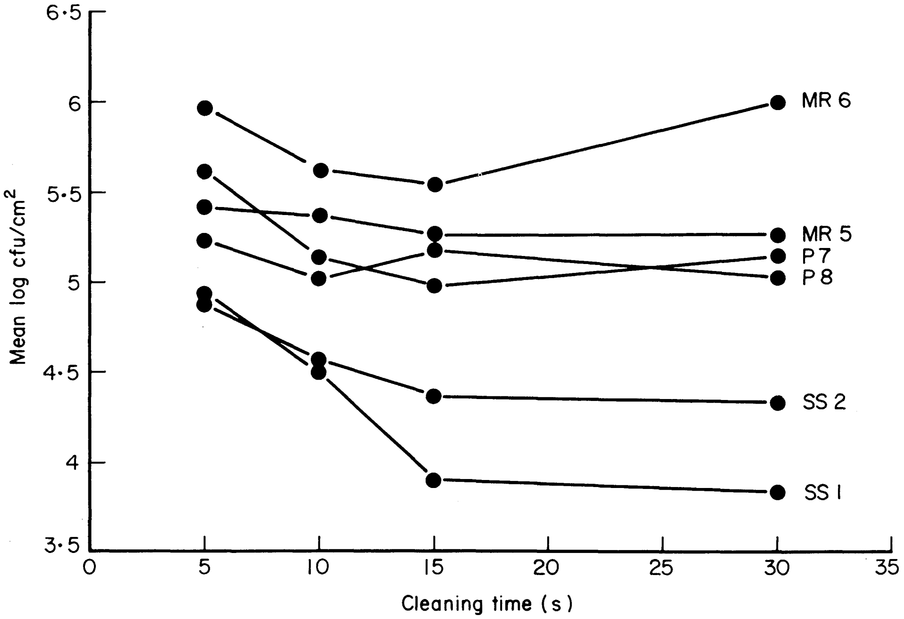

Fig. 4. Mean ($n = 8$) log cfu/cm^2 retained *vs* cleaning time for a range of impact damaged domestic sink materials. SS, Stainless steel; P, polycarbonate; MR, mineral resin. The number refers to the sink number.

means of extracellular polymer fibrils, pili or flagella. In terms of the nature of the surface, bacterial attachment will depend on the number of attachment sites available (related to surface area and topography) and bacterial/surface chemical interactions (Gibbons & Denton 1981). Material texture and topography are also likely to influence surface cleanability in that bacteria attached in pits or crevices would not receive the same cleaning shear forces as bacteria attached to the surface. Those that are more pitted or creviced, on a microscopic scale, would therefore be less cleanable.

As bacterial attachment was similar on all four surfaces, and all the surfaces were reasonably smooth at the microscopic level (Fig. 2), it could be suggested, therefore, that it is unlikely that there would have been significant differences in cleanability between these surfaces (in terms of bacterial retention). The reason why one enamelled steel surface was less cleanable was probably related to small pits present in this surface, as shown by the unused enamelled steel surface in Fig. 2 (plate c slightly right of and below centre). These pits, probably caused by gas bubbles produced when the enamelled steel was fired, tended to retain bacteria after cleaning. Where no pits were present on the surface, enamelled steel tended to be no less cleanable than the other materials. An example of how bacteria were retained in enamelled steel pits (in this case a pit made apparent due to abrasion), but not the surface, is shown in Fig. 3. Enamelled steel sink 3 may have been less cleanable than enamelled steel sink 4 due to the former's higher surface roughness measurement (Table 1), which was reflected by the presence of more pits (the mean pit count for sink 3 was 25 times that for sink 4 per given area).

The effect of artificial abrasion on the sink surfaces is shown in Fig. 2. The stainless steel surfaces were characterized by grooves in the surface where they had been scratched by the abrasive grit. The surfaces, however, remained smooth and, other than the grooves themselves, were free from pits and crevices. The enamelled steel surfaces became pitted after abrasion, whilst the mineral resin surfaces became extremely rough and consisted of jagged spikes and deep pits and crevices. The polycarbonate surfaces were also extremely rough after abrasion, although the pits and crevices were deeper with more rounded edges. In general, enamelled steel, mineral resin and polycarbonate materials were much more marked around the abrasive grit lines than stainless steel.

The extent of surface damage due to abrasion is also reflected in the surface roughness measurements in Table 1. The surface roughness values for stainless steel increased slightly due to the scratches left after abrasion, whilst those for the enamelled steel surfaces were a lot higher after abrasion and clearly show how much more easily this material became damaged. The surface roughness values for the mineral resin and plastic surfaces showed little change after abrasion. This was probably due to the fact that although these materials developed a much more jagged profile at the microscopic level (Fig. 2), the high surface waviness caused by the anti-scratch finish was 'polished' down with abrasion. The increase in roughness and reduction in waviness resulted in a net surface roughness value that was little changed. Care is therefore required in interpreting changes in surface roughness values when the material has a high $\mu m R_a$ value in unused condition.

The results in Figs 1 and 4 showed that when the sink materials were abraded or impact damaged, the stainless steel sinks were one log order of magnitude more cleanable than the other materials. When cleaning time was extended to 30 s (Fig. 4) and 40 s (Fig. 1), the cleanability of the other sink materials did not approach that of the stainless steels after 5 s. No significant difference in cleanability was found between abraded polycarbonate, mineral resin and enamelled steel sink 3 after extended cleaning. For impact damaged surfaces (Fig. 4) the cleanability of the polycarbonate sinks and mineral resin sink 5 was not significantly different. With bacterial retention levels of about 5×10^5 cfu/cm^2, the cleanability of impact damaged enamelled steel was similar to that of polycarbonate and mineral resin materials. Because of the increased area of damage to enamelled steel by impact damage together with the reduced cleanability of abraded enamelled steel sink 4, this material was the least cleanable.

It could be argued that the cleanability in terms of percentage bacterial removal was quite good for both stainless steel (99·9%) and the other materials (99%). This is not relevant, however, as the degree of percentage removal will depend on the cleaning method employed and what is of more significance is the final number of organisms remaining after cleaning (in this case 10^4–10^6 cfu/cm^2!). This is illustrated in Fig. 3 which gives an indication of typical levels of bacteria present in abraded surfaces before and after cleaning. The number of bacteria retained on stainless steel was low and was on average around one bacterium per field of view. On enamelled steel surfaces, bacteria were usually retained in pits, whilst the jagged nature of the abraded mineral resin surface allowed individual bacteria to attach to the mineral resin over a larger contact area than would be possible with a smooth, flat surface. Such bacteria were therefore not only protected from cleaning shear forces by surface topography, they were also able to attach to the surface more firmly due to the increased bacterial/material surface area interface. On the polycarbonate materials, bacteria were retained in the deep crevices and, as with bacteria retained on mineral resin, had high bacterial/material surface area interfaces.

Demonstrated differential cleanability between materials after abrasion and impact damage, together with surface roughness determinations and photographic evidence, would suggest that the greater the degree of surface irregularities (roughness, pits, crevices, etc), the greater the chance of bacterial retention after cleaning programmes. This could be due to an increase in attachment sites (for a given surface area), stronger adhesion due to increased bacterial/material surface area interfaces and enhanced protection from cleaning shear forces. Bacteria retained after the cleaning regimes applied would, due to the nature of their attachment, be unlikely to be removed if the cleaning times were extended beyond those tested.

Both Ridenour & Armbruster (1953) and Davis (1963) investigated the effects of abrasion on the cleanability of various surfaces and found little difference in cleanability between unused and abraded surfaces. However, the techniques used to enumerate attached organisms retained after cleaning were unlikely to count bacteria retained in pits and crevices. More recent work undertaken to ascertain the development of biofilms in pipes (Characklis 1973; Gibbons & Denton 1981) has shown that the rougher the pipe surface, the quicker the development of biofilms. This was because with increased roughness bacteria were more able to colonize the surface in areas of reduced shear force from circulating fluids. Work undertaken using non-microbial methods for the assessment of cleanability (Masurovsky & Jordan 1958; Von Bockelmann 1974) has indicated that aluminium and polycarbonate surfaces abraded with wire wool were more difficult to clean than their respective unused surfaces.

The results in Table 2 showed that the level of abrasion applied to the sink surfaces produced a surface profile on stainless steel sinks 1 and 2 similar to that found on naturally abraded domestic stainless steel sinks. There was also no significant difference in cleanability between the artificially abraded sinks 1 and 2 and the naturally abraded domestic sinks. It can be postulated therefore that the degree of artificial abrasion undertaken was not dissimilar to that which could occur in the domestic environment and hence the differential material cleanabilities established in the laboratory are likely to occur in the domestic environment. Modern sink materials such as polycarbonate, mineral resin and some enamelled steels would be as cleanable as stainless steel when new, but stainless steel, due to its resistance to abrasion/impact damage, is more likely to retain its hygienic properties throughout a domestic working life.

Camden Food and Drink Research Association wishes to thank the Nickel Development Institute, Toronto, Canada for their financial support and permission to publish this work.

References

ANON. 1972 B.S. 1134 Method for the assessment of surface texture. Part 1, Method and Instrumentation. Part 2, General Information and Guidance. London: British Standards Institution.

CHARACKLIS, W.G. 1973 Attached microbial growths; 1. Attachment and growth. *Water Research* **7**, 1113.

DAVIS, J.G. 1963 The cleansability of various materials. *The Medical Officer*, 8th November, 301–304.

GIBBONS, D.B. & DENTON, P.H. 1981 Surface roughness and biofouling. *Proceedings 2nd World Congress of Chemical Engineering*, Vol. 1, pp. 430–441. Montreal, Canada: Canadian Society for Chemical Engineering.

HOLAH, J.T., BETTS, R.P. & THORPE, R.H. 1988 The use of direct epifluorescent microscopy (DEM) and the direct epifluorescent filter technique (DEFT) to assess microbial populations on food contact surfaces. *Journal of Applied Bacteriology* **65**, 215–221.

HOLAH, J.T., BETTS, R.P. & THORPE, R.H. 1989 The use of epifluorescence microscopy to determine surface hygiene. *International Biodeterioration* **25**, 147–153.

Marshall, K.C., Stout, R. & Mitchell, R. 1971 Mechanism of the initial events in the sorption of marine bacteria to surfaces. *Journal of General Microbiology* **68**, 337–348.

Masurovsky, E.B. & Jordan, W.K. 1958 Studies on the relative bacterial cleanability of milk contact surfaces. *Journal of Dairy Science* **41**, 1342.

Masurovsky, E.B. & Jordan, W.K. 1960 Studies on the removal of *Staphylococcus aureus* from milk contact surfaces. *Journal of Dairy Science* **43**, 1545.

Milledge, J.J. & Jowitt, R. 1980 The cleanability of stainless steel used as a food contact surface. *Institute of Food Science and Technology Proceedings* **13**, 57–62.

Ridenour, G.M. & Armbruster, E.H. 1953 Bacterial cleanability of various types of eating surface. *American Journal of Public Health* **43**, 138–149.

von Bockelmann, I. 1974 The importance of material and design for the cleanability of dairy equipment. *XIX International Dairy Congress*, Vol 1E, p. 9. New Delhi, India.

The Nickel Development Institute is an international nonprofit organization to serve the needs of people interested in nickel.

NiDI

North America
Nickel Development Institute
15 Toronto Street - Suite 402
Toronto, Ontario, Canada M5C 2E3
Telephone 416 362 8850
Telex 06 218 565
Fax 416 362 6346

Europe
Nickel Development Institute
42 Weymouth Street
London, England W1N 3LQ
Telephone 071 493 7999
Telex 51 261 286
Fax 071 493 1555

Nickel Development Institute
European Technical Information Centre
The Holloway, Alvechurch
Birmingham, England B48 7QB
Telephone 0527 584 777
Telex 51 337 125
Fax 0527 585 562

Japan
Nickel Development Institute
11-3, 5-chome, Shimbashi
Minato-ku, Tokyo, Japan
Telephone 03 436 7953
Telex 72 242 2386
Fax 03 436 7734

Central & South America
Nickel Development Institute
c/o Instituto de Metais Não Ferrosos
Av. Nove de Julho, 4015, Caixa Postal 6691
São Paulo-SP, Brasil
Telephone 011 887 2033
Telex 38 112 5479
Fax 011 885 8124

India
Indian Nickel Development Institute
c/o Indian Lead Zinc Information Centre
Nº 7 Shopping Centre, Block B-6, Safdarjung Enclave
New Delhi 110 029, India
Telephones 600 973, 604 230
Telex 81 317 2050

Australasia
Nickel Development Institute
P.O. Box 28
Blackburn, South Vic 3130, Australia
Telephone 61 3 878 7558
Fax 61 3 894 3403

Members of NiDI

Companhia Níquel Tocantins
Empresa de Desenvolvimento
de Recursos Minerais "CODEMIN" S.A.
Falconbridge Limited
Impala Platinum Limited
Inco Limited
MEQ Nickel Pty. Ltd.
Morro do Níquel S.A.
Nippon Yakin Kogyo Co., Ltd.
NRNQ (a limited partnership)
Outokumpu Oy
Pacific Metals Co., Ltd.
Sherritt Gordon Mines Limited
Shimura Kako Company, Ltd.
Sumitomo Metal Mining Co., Ltd.
Tokyo Nickel Company Ltd.
Western Mining Corporation Limited

Printed in United Kingdom Aug 90/3.0