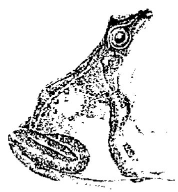
A REVIEW OF THE HEALTH RISKS ASSOCIATED WITH UNDER-SINK POINT-OF-USE DEVICES



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A REVIEW OF THE HEALTH RISKS ASSOCIATED WITH UNDER-SINK POINT-OF-USE DEVICES

Final (Review) Report to the Department of the Environment, Drinking Water Inspectorate

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SUMMARY

The employment of point-of-use devices is well-established on the North American continent as a result of the specialised needs of small and isolated communities. In the USA and Canada, it is often not practical to provide a supply of conventional treated drinking water, and point-of-use treatment is an economically attractive option, particularly if raw water of good quality is available. However, a large body of experimental data from both the USA and Canada has shown that the employment of certain types of point-of-use device leads to raised numbers of heterotrophic bacteria in drinking water, as a result of the multiplication of these organisms within the device itself. Granular activated carbon (GAC) filters are considered to be particularly prone to this problem.

In the UK, where the fitness for consumption of drinking water is protected by statute, and isolated individual water supplies are the exception, the economic and public health arguments for the fitment of point-of-use devices are slender. On the other hand, the presence of raised levels of heterotrophic bacteria in filter effluents must be a cause for concern. Although it has not been possible to demonstrate that the strains found in drinking water are pathogenic to man, at least one epidemiological study claims to show that an increased incidence of gastrointestinal infection is associated with drinking water from point-of-use devices. On microbiological grounds, therefore, it may be justified to discourage the fitment of point-of-use devices.

1. INTRODUCTION

The Drinking Water Inspectorate (DWI) has asked WRc plc to undertake a review of published information relating to the health risks associated with under-sink point-of-use devices in the home. The DWI wanted the review to be confined to microbiological, rather than chemical or toxicological issues.

The term 'point-of-use device' refers principally to units intended for the purification of drinking water, which are placed in the water supply at the point of use, in this context the home of the consumer. In the UK, such devices are often mounted below the sink in the kitchen. Another term, 'point-of-entry', is also current, and refers to the placing of comparable devices at the point at which the water main enters the home. Point-of-entry devices are generally installed for specialised reasons, such as the protection of plumbing systems from hard water, and are beyond the scope of this review.

Although a detailed discussion of the different technologies which are employed in point-of-use devices is not appropriate, it may be useful to give an overview of the different types of device used, and their characteristics. This information is summarised in Table 1.1. Further information may be found in Meheus (1990), and Lykins *et al.* (1992).

Table 1.1 A summary of technologies commonly used in point-of-use devices

Type	Summary of principle
Particulate filters	Foam, membrane or wound filters retain particles of greater than a defined size.
Adsorptive filters	Granular Activated Carbon (GAC) traps particulate material and adsorbs chlorine residuals, organic contaminants, taste and odour compounds, and biological contaminants.
Reverse osmosis	Water is forced under pressure through a cellulose or polyamide semi-permeable membrane, removing dissolved inorganic and organic contaminants, as well as particulates.
Ion exchange	Cation ion exchange reduces the hardness of water by removing divalent cations. Anion ion exchange can be used to remove nitrates.
Distillation	Produces water of high purity by distillation. Unlikely to be employed as an under-sink device.
Dosing devices	Add a corrosion or scale inhibitor to a defined concentration.
Physical anti-scaling devices	Reduce scale formation by an applied magnetic field or low tension electrical current. Mechanism poorly understood.
U.V. lamps	Water is passed over an ultraviolet lamp with a wavelength of 254 nm, thereby killing micro-organisms.

In North America, point-of-use devices are often employed to solve specialised problems associated with the provision of a wholesome water supply. In particular, there are many small communities, and isolated homesteads, which could not economically be supplied with mains water from a normal water treatment works. The total number of such independent rural water supplies in the USA is about ten million. Because raw waters of comparatively high quality are often available, for the removal of biological contaminants such as *Giardia* and *Cryptosporidium*, a simple filtration step is often enough to make the water fit for human consumption. Point-of-use devices are one of a number of means of carrying out this filtration.

In the UK, the fitness of all drinking water for human consumption is protected by statute, and only a small minority of homes are supplied by individual rural water systems. There is therefore far less need or justification for the fitment of point-of-use filtration devices. Although there may be a tiny group of consumers with a specialised medical need for purified water, such as those receiving immunosuppressive therapy, no benefit to general public health can be claimed for the widespread adoption of point-of-use devices. Point-of-use water softeners may be employed in hard water areas, but this will be done for economic or engineering reasons (to lengthen the lifespan of domestic water heaters), rather than for health reasons. Indeed, it has been suggested that softened water should not be used as drinking water (Meheus, 1990).

In the UK, point-of-use devices are often sold and installed on the basis of a *perceived* risk to health on the part of the consumer, or for aesthetic reasons such as a dislike of the taste of chlorine. This situation is partly the result of biased and misleading information in the media, and has led to a generalised and uninformed anxiety about the presence of contaminants in drinking water. Manufacturers of point-of-use devices have been able to capitalise on the fear and concern of the consumer to promote the sale of devices which are of value only in strictly limited circumstances (Meheus, 1990). Currently, there is no scientific evidence to show that the fitment of point-of-use devices is desirable or necessary for the protection of public health.

On the contrary, many authors report that, compared to the mains water supply, the output water from point-of-use devices can contain increased numbers of certain types of bacteria. Although there is little doubt that the vast majority of these bacteria are harmless to man, there is nevertheless a legitimate cause for concern on the part of the DWI. It is therefore important to establish whether point-of-use devices, installed by the consumer as the answer to a *perceived* (but negligible) risk to health, do in fact pose an *actual*, microbiological, threat to health. It is therefore the principal aim of this review to evaluate the published information in this area, with a view to determining the likelihood of microbiological health risks arising from the employment of point-of-use devices in the home.

2. PUBLISHED INFORMATION ON THE MICROBIOLOGY OF POINT-OF-USE DEVICES

2.1 Published information from the USA and Canada

2.1.1 Introduction

Because of the widespread and legitimate employment of point-of-use water treatment in North America, as a means of removing specific pollutants from otherwise pure water supplies in isolated communities, by far the greatest portion of the published information comes from the USA and Canada.

It has been known for many years that certain types of point-of-use device can act as sources of bacteria in drinking water. In particular, devices which contain a finely-divided matrix, such as ion-exchange resins or granular activated carbon (GAC), provide a very high surface area on which bacteria can grow, and in consequence are widely recognised to require careful maintenance. Some types of device, such as UV systems and distillation units, are unlikely to become colonised by bacteria, and should not therefore create a risk.

2.1.2 Microbiology of GAC filters

From a microbiological point of view, GAC has been the focus of the greatest concern. It has been known for many years that GAC is an excellent support for the growth of bacteria, and indeed the efficiency of GAC filtration in water treatment works can be improved by the growth of films of micro-organisms (biofilms) on the surface of GAC particles (Denny and Pitchers, 1994).

By the early 1970s it was already clear that home GAC filters were also excellent sites for bacterial growth (Wallis *et al.*, 1974). Lykins *et al.* (1992) provide a number of reasons why the growth of bacteria on home GAC filters is especially favoured. Firstly, there is a constant input of bacteria to the filter, where they are trapped and retained. These bacteria, which are normally 'heterotrophic', arise from incomplete disinfection of drinking water, from biofilms on the inner surfaces of water mains, or indeed from untreated water. Secondly, the dissolved organic compounds and particulate material which are also trapped by the filter act as an source of nutrients for bacterial growth. Thirdly, disinfectant residuals are adsorbed by GAC, or neutralised by the organic material trapped on the filter. Lastly, point-of-use GAC filters are often kept at room temperature, which promotes the strong growth of heterotrophic bacteria (see also Meheus, 1990).

Wallis *et al.* (1974) were one of the first to report the potential problems associated with the use of GAC filters in the home. They tested proprietary charcoal filters under conditions which were designed to mimic home use. It was shown that, after only six days of use, more than 1 000 000 cfu ml^{-1} of bacteria could be present in the first 100 ml of water collected in the morning from a charcoal filter. The authors considered this to be of importance from the point of view of public health.

Tobin *et al.* (1981) tested three types of point-of-use device containing activated carbon, both in the laboratory and in the field, over an eight week period. It was found that numbers of heterotrophic bacteria in the outflow of the filters increased over the first three weeks in service, and did not decline thereafter. Typically, counts of 1000 to 100 000 cfu ml^{-1} were obtained. The filters were also challenged with tap water containing settled sewage, and it was shown that coliform bacteria could survive and multiply on the filters for several days. Furthermore, high coliform counts were collected from the filters on the first morning after the challenge, when the filters had been allowed to stagnate overnight. The authors concluded that the employment of point-of-use carbon filters in the home, without post-treatment disinfection, was a potential health hazard.

Geldreich *et al.* (1985) investigated the bacterial colonisation of a range of designs of point-of-use GAC filters. They concluded that all types of filter provided favourable conditions for colonisation by bacteria, but that the large number of factors controlling growth, such as temperature, chlorine residual, and time in service, made consistent results difficult to obtain. They challenged the filters with bacteria of faecal origin such as *Escherichia coli* and *Salmonella typhimurium*, but these were found to pass straight through the filters. Other challenge species (*Enterobacter aerogenes, Serratia marcescens*, and *Pseudomonas aeruginosa*) were found to colonise the filters for up to 156 days, and shed low numbers into the product water during this time.

Rozelle (1987) summarises microbiological information relating to four field studies of GAC point-of-use filters carried out in the USA. In one study (Silverdale, Pa.) a 100 times increase in the count of heterotrophic bacteria was found after overnight stagnation. However, bacterial counts could be reduced to that of the distribution system by a 2 min flush of the filter. Similar findings were obtained in a second study (Rockaway). A third study (Emington, Ill.) also showed increases in counts for the outflow from the filter compared to the distribution water. The fourth study was conducted on a large scale (180 homes) and was partly funded by the US Environmental Protection Agency. High counts (> 800 cfu ml^{-1}) were found in the outflow from GAC filters, but no significant adverse effects on health were seen when the filter users were compared with a control group.

Reasoner *et al.* (1987) report the results of further long-term (one year) monitoring of GAC point-of-use devices. Maintenance of the filters was deliberately neglected, to simulate a 'worst-case' situation in which a home user failed to follow the manufacturer's recommendations. In almost all cases, heterotrophic plate counts for the outflows from the GAC filters were higher than that of the mains water supply. In general, higher counts were obtained in the morning than the afternoon, though this effect could be reduced by a thorough flushing of the filter. Higher counts were also seen in the summer months, almost certainly the result of higher ambient temperatures. Challenges of the units with specific bacterial pathogens (*Klebsiella pneumoniae, Aeromonas hydrophila*, and *Yersinia enterocolitica*) showed that only the first species was capable of colonising the filters for any length of time. This species is thought of as an 'opportunist' pathogen, and is probably not a serious threat to human health.

DePhillipi and Baier (1987) report the results of a field study on Long Island (N.Y.) involving 18 homes, and 15 point-of-use or point-of-entry devices containing carbon. Although these units performed satisfactorily in terms of the removal of specific chemical contaminants present in the source water, some microbiological problems were encountered. For example, coliform bacteria were found in the outflow from the filters, and counts of heterotrophic bacteria were higher than in the source water, sometimes by over 1000 times. In only one instance was a lower count obtained after passage of the source water through a carbon filter. The authors report, however, that none of the bacteria isolated were pathogenic.

Regunathan and Beauman (1987) investigated the microbiological characteristics of PAC (powdered activated carbon) filters in conjunction with silver or copper as potential bacteriostatic agents. The behaviour of micro-organisms in standard, commercial, carbon filter units was studied in the presence of proprietary silver releasing compounds and powdered copper metal. The filters were challenged with coliform bacteria (*Enterobacter aerogenes*), with human enteroviruses, and protozoan (*Giardia*) cysts. Counts of heterotrophic bacteria were also carried out. The authors found that the outflow from the PAC devices had lower counts of heterotrophic bacteria than the source water, and suggested that this was due to the higher efficiency of this type of filter in removing small suspended particles (including micro-organisms). The filters also removed up to 99.9% of the challenge organisms. It was found that silver had a pronounced antimicrobial effect on the coliform challenge bacteria, though little effect on the levels of heterotrophic bacteria. Copper had a similar, but slighter, antimicrobial effect.

Dufour (1988) summarises an epidemiological study carried out by the University of Yale, and supported by the US Environmental Protection Agency, which investigated the health implications of the heterotrophic bacteria colonising point-of-use GAC filters. The population of armed-service families in this study was divided into two groups: those using GAC filters, and a control group which did not, and their health was monitored for an extended period of time. It was found that although much higher (>1000 times) counts of heterotrophic bacteria could be recovered from the outflow of GAC filters, compared with the mains water, there was no significant difference in the rate of symptomatic illness between filter users and the control group. The author concludes that point-of-use filters cannot be linked to excess illness, but that conversely there is no evidence that they lower the incidence of illness.

Reasoner (1988) presents a summary of extensive investigations into the microbiology of point-of-use GAC and PAC filters from 1977 onwards. The first phase of these studies established that counts of heterotrophic bacteria in the outflow of a GAC filter are always higher than that of the source water. The second phase was reported by Geldreich *et al.* (1985), and has already been referred to. The third phase was partially reported by Reasoner *et al.* (1987), though it was not then complete. Further and more recent challenge tests with the bacterial pathogen, *Legionella pneumophila* have failed to show any colonisation of filters by this species, which may grow poorly at ambient temperatures and in the presence of chlorine residuals. From this extensive experience, the author concludes that all GAC point-of-use devices act as sites for the proliferation of heterotrophic bacteria, but that the potential risk to human health from taking in large numbers of these bacteria in drinking water seems to be low.

2.1.2 Microbiology of other point-of-use devices

Lykins *et al.* (1992) have reviewed microbiological concerns which have been expressed about the major types of point-of-use devices. Their views may be summarised as follows:

Membrane filtration (including reverse osmosis)

The inlet side of filter membranes are excellent environments for bacterial growth, for the same reasons as GAC filters: room temperatures, high surface areas, and a constant input of organic nutrients. Although the pores of the membranes are in principle too small to allow the passage of micro-organisms, bacteria are nevertheless found on the outlet side of the filter. This is said to be due to a phenomenon known as 'grow-through'. A study carried out by Payment (1989), involving 300 reverse osmosis units is summarised, which showed that the outflows from such units typically contained 1000 to 100 000 cfu ml^{-1} heterotrophic bacteria, an increase of >1000 times over the level in the mains water. It was considered that each membrane was normally colonised by only one species of bacteria at a time, but that none of the species identified were pathogenic.

Payment has also carried out an epidemiological study of the health effects associated with reverse osmosis units (Payment *et al.* 1991). The study took place over a period of ten months, and involved 115 families, who had reverse osmosis units installed in their homes. Bacteriological analyses and surveillance of gastrointestinal illness were carried out during this period. It was concluded that there was an association between the numbers of heterotrophic bacteria culturable at 35 °C in drinking water and a (low) incidence of gastrointestinal illness. They consider that this evidence raises concerns about the use of such devices in the home.

Ion exchangers

Lykins *et al.* (1992) consider that bacterial growth in ion exchange units is common, leading to numbers in the outflow greater than that of the raw water. The growth will arise for the reasons already outlined for GAC and membrane filters. No figures are presented to support these statements, however, and they are probably based on empirical observations.

Other point-of-use devices

Lykins *et al.* (1992) also mention briefly the microbiological concerns relating to other types of point-of-use device, such as distillation units and disinfection units. They consider that microbiological problems with these devices are only likely to arise from serious misuse or lack of maintenance.

2.2 Information from Europe

In contrast to the relative wealth of microbiological data available from the USA and Canada, information relating to the situation in Europe is sparse. From a Swiss standpoint, Theiler (1988) evaluated five types of point-of-use devices, which were intended to reduce calcium precipitation from hard water. None were found to give measurable reduction in the extent of precipitation, but more importantly the article was followed by an express statement from the Swiss Society for the Gas and Water Industry, insisting that such devices should not normally be necessary for drinking water, and that they should in any case be tested for conformity to the relevant microbiological standards.

Wagner (1989) reviewed the point-of-use devices available in the then West German Republic. He considered water softening devices (ion exchangers) to be potential sources of bacterial contamination if wrongly installed and used. Various physical treatments were also reviewed, but the fact that such devices only seemed to work, if at all, under a narrow range of conditions meant that there was little justification for their installation.

Meheus (1990) reviewed point-of-use devices available in the low countries. Microbiological problems with GAC filters and ion-exchange devices are summarised, using the data from the USA described above. The article ends with statements of the viewpoints of different countries round the world. From the Netherlands, there is a categorical statement from the Dutch Association of Water Undertakers declaring that the Association does not feel that it is any part of its duty to evaluate devices for home use, and that in any case the quality of drinking water is guaranteed by statute. In view of this, the use of 'tap filters' is stated to be unnecessary, and not without risk. A summary of the situation in Italy states that tap-mounted point-of-use devices are forbidden, and that GAC filters and physical treatments for calcium precipitation are not allowed to be used for water treatment in the home. The author concludes by saying that additional treatment of drinking water is quite unnecessary, and that the dissemination of publicity relating to devices which purport to improve the quality of drinking water should be suppressed by the authorities.

In a report commissioned by WRc plc, the Warren Springs Laboratory of the Department of Trade and Industry tested three types of commercial cartridge filter for their ability to remove a surrogate for the protozoan parasite, *Cryptosporidium* (Anon., 1993). It was found that the filters were highly efficient (99.97%) at removing the challenge organisms. However, it was found that hydraulic shocks (water hammer) occasionally released cells into the effluent stream, at concentrations of up to 100 cells l^{-1}. The authors recommended that installations should be constructed to minimise the chances of hydraulic shock.

3. DISCUSSION

As has already been described, the problems of drinking water supply and treatment on the North American continent differ from those in Europe. The very large number of small community and individual supplies allows the employment of point-of-use treatment to be justified, particularly where a source of relatively pure raw water is available. For surface waters, a straightforward filtration to remove biological contaminants, such as *Giardia* cysts, is often all that is needed. In some areas, groundwater which would otherwise be fit to drink is contaminated with agricultural fertilisers, pesticides, or radon. Again, a simple point-of-use treatment may be sufficient. In these situations, where there are definite public health and economic grounds for the employment of point-of-use devices, it is possible to draw up a balance between microbiological, and chemical, toxicological, and radiological health risks.

Point-of-use devices have been subjected to considerable investigation and evaluation, both in the laboratory and in the field, in the USA and Canada, and the microbiological problems associated with their use are therefore well documented. The information that has been gathered may be summarised as follows:

(i) Certain types of point-of-use device, when installed in the home, provide a good breeding ground for heterotrophic bacteria. The types of device implicated are principally activated carbon filters, ion exchangers, and membrane devices, including reverse osmosis devices. Bacterial growth is favoured by the large surface area available for growth, a constant supply of fresh organic nutrients, and a suitable ambient temperature. As a result, the numbers of heterotrophic bacteria downstream of such devices may be over 1000 times that in the raw water.

(ii) Point-of-use filters are capable of removing many bacterial and protozoan contaminants from drinking water. However, there may be some risk of a subsequent release of micro-organisms from activated carbon filters into the filter effluent. Hydraulic shock may lead to the passage of cells through other types of filter into the product water.

(iii) The health risks associated with the intake of raised numbers of heterotrophic bacteria seem negligible, and most epidemiological investigations have not shown any differences in the incidence of gastrointestinal infections between populations consuming water treated at the point of use, and control groups. The main exception to this pattern is the study reported by Payment *et al.* (1991).

The microbiological risks associated with point-of-use devices, therefore depend largely on the risks associated with the ingestion of increased numbers of heterotrophic bacteria. It has recently been suggested by Payment *et al.* (1994) that many of the heterotrophic bacteria present in drinking water do in fact have virulence factors which could be related to pathogenicity in man. The authors tested tap water samples for cytotoxicity, haemolysis, cell adherence, and cell invasiveness. Up to 24% of samples were found to contain bacteria possessing three or more virulence factors, and it was concluded that the microbiological analyses currently employed (the enumeration of coliform and heterotrophic bacteria) were inadequate. Tests which gave an indication of the true pathogenicity of bacteria were required, and the authors suggest culture on blood agar at 35 °C as one possible screening method. However, these views should perhaps be set against the findings of Havelaar *et al.* (1992) who compared strains of the heterotrophic bacterium *Aeromonas* isolated from drinking water with those isolated from human diarrhoeal stools. These workers concluded that strains from the two different sources were generally different, and that it was unlikely that *Aeromonas* from drinking water was a significant source of gastrointestinal disease.

The current situation, therefore, is as follows. Several types of commonly-employed point-of-use device give rise to increased concentrations of heterotrophic bacteria in drinking water. The true significance of these bacteria for human health is not fully understood at the time of writing. Some species are opportunist pathogens in specialised clinical circumstances, but whether the strains present in drinking water are genuinely significant causes of illness remains to be proved. However, the fitness for consumption of drinking water in the UK, where the vast majority of households are supplied by conventional treatment works, is protected by statute, so that in principle there will very rarely be any need for the employment of point-of-use devices.

In view of this, and given that the impact of raised levels of heterotrophic bacteria on human health is still a legitimate subject for debate, the conclusion must be drawn that the fitment of point-of-use devices, other than for defined and specialised reasons, cannot be recommended. This conclusion is supported by the views and practices current in other European countries, where similar protection of the quality of drinking water applies. Of course, some consumers in the UK are not satisfied with the taste and odour of their drinking water. Point-of-use devices can provide an improved product from this point of view, and in these (strictly aesthetic) terms there might be some justification for their use.

4. CONCLUSIONS

The use of under-sink point-of-use devices in the home has the following implications for the microbiological quality of drinking water:

- Many common types have consistently been shown to give rise to increased numbers of heterotrophic bacteria in drinking water.
- Some heterotrophic bacteria are opportunist pathogens of man, though the public health significance of those found in drinking water is still uncertain.
- At least one epidemiological study has linked point-of-use devices to an increased incidence of gastrointestinal illness.

Since the fitness of drinking water for human consumption is protected by statute, additional treatments are in principle superfluous. The main justification for the use of such devices lies in specialised circumstances, which do not often arise in the UK. Outside these circumstances, discouraging the use of point-of-use treatment would seem to be warranted on the basis of a heightened risk of microbiological contamination of the treated water. Adopting such a position would be in line with the general opinion of public bodies and water undertakings in the rest of Europe.

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