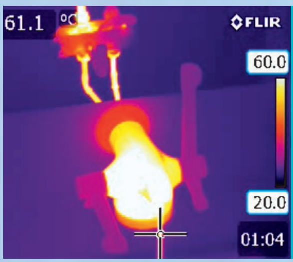

Pathogen Control in Hospital Domestic Water Systems - a New Approach

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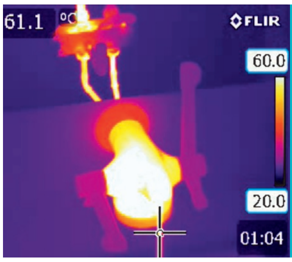

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Background

In late 2011/early 2012, 4 babies died in neonatal care in Northern Ireland. The babies were infected by *Pseudomonas Aeruginosa*, an ubiquitous, opportunistic pathogen (having intrinsically advanced antibiotic-resistance mechanisms) of environmental origin but favouring moist surfaces. A subsequent investigation into the fatalities identified hospital water systems and taps as potential reservoirs for the bacteria. Attention has since focussed on tap fittings and the last few metres of the water system for its potential to host pathogenic micro-organisms.

Retrograde contamination

The interface between the water system and the outside world is inherently vulnerable to colonisation by such pathogens. The entry point for pathogenic bacteria into the water system is also the exit point of water from the water system. Thus, if pathogenic bacteria (or viral and fungal spores) are present in the surroundings, then the water outlets risk becoming colonised.

The origin of the pathogenic bacteria is a topic of much discussion. HTM 04-01[1] speculates that they may be of patient origin, but that basin drains are "almost always contaminated"[2]. Antibiotic-resistant bacterial strains, are almost *certain* to be of patient origin rather than be naturally occurring strains in the environment. The bacteria from the drain trap can be transmitted to the tap by splashing during hand washing. This has long been recognised, and is also why basin taps must not discharge directly into the drain hole below the tap outlet - disturbing the drain contents - and taps themselves should not cause splashing[3,4].

Poor cleaning practices, for example sharing cleaning cloths or materials, can quickly spread a localised colonisation to multiple locations[2].

Self-draining showers were identified a number of years ago as supporting the proliferation of Legionella bacteria, and are now not recommended[1]. When a shower drains down, the water is replaced by warm, moist air drawn in through the shower head and this creates an ideal haven for bacteria. Similarly, when a tap spout drains down, it draws air in (possibly contaminated air from the vicinity of the basin and its drain trap) creating an oxygen-rich, warm and moist environment within the spout.

One or more of the above mechanisms could result in contamination of an outlet. The requirement for human interaction with the water system, in a non-sterile environment such as a hospital ward, results in a significant risk factor. Any outlet is likely to become contaminated at some point during its operational lifetime. Only fastidious attitudes to local hygiene and cleanliness can prevent this.

A number of potential solutions for reducing the incidence and risk of pathogenic colonisation of water systems have been tried, yet each method has its own associated disadvantages, and does not provide a sustainable control mechanism. In fact, some approaches will actually exacerbate the problem.

Potential, but flawed solutions

1. Replacing the affected tap or shower

Replacing a colonised tap or shower should instinctively remove the colonisation and thus eliminate the problem. However, this simplistic analysis ignores the fact that pseudomonas colonisations are known to predominantly inhabit the last two metres of the pipework from the point of discharge[5] and so, unfortunately, the colonisation very likely extends upstream of the tap or shower, into the cold supply pipework feed (it does not colonise the hot water pipework because the heat of the passing water kills it). This colonised length of cold water pipework has been known to re-seed a new tap or shower that is fitted, and the original colonisation problem rapidly recurs.

2. Chemical treatment of the water

Oxidising chemicals have been used to treat the water to kill pathogenic bacteria. It would seem reasonable that treating a colonisation with a strong oxidising chemical ought to eliminate it. However, there is an inherent problem with oxidising chemicals in that they do not actually permeate the biofilm and so leave underlying bacteria unaffected, and potentially developing resistance. An additional problem is that the resulting dead micro-organisms at the surface can then become a nutrient source for the remaining living ones. Since it has been estimated that 95% of DWS bacteria live within biofilms on the pipe walls and the remaining 5% are planktonic, i.e. carried in the flow of water[6], chemical treatment of the water will affect only a small proportion of the total system bioload whilst also, potentially, allowing a tolerance for that chemical to develop. There is another aspect of chemical treatment that HTM 04-01 acknowledges; water treatment chemicals can have detrimental effects on metals, plastics, and elastomers used in fittings and fixtures thus may shorten the lifespan of components[3].

3. *Point of use microbial filters*

POU microbial filters are addressed in HTM 04-01 as an acceptable interim method of protecting vulnerable patients. The downside of the POU filter is that while it treats the symptom (i.e. it removes the bacteria coming out of the tap) it does not treat the cause (i.e. the colonisation of the pipework causing the bacteria to discharge from the tap). The filters represent an ongoing expense and do not pretend to address the core problem, and thus the colonisation will remain, perhaps becoming progressively worse if other methods are not taken to eradicate it. As such, POU filters are a useful "sticking plaster", and can provide a temporary assurance of patient safety, but they certainly do not offer a solution to the problem. For this reason, HTM 04-01 states that *"Continuous long-term use of POU filters is not recommended, except where there is no effective alternative"* [1]. In addition, as observed by Garvey et al[7], the POU filter is as susceptible to retrograde contamination as the original tap outlet.

4. Copper-lined 'simple' outlet fitting

Some Tap manufacturers have been selling Tap Outlet Fittings that claim to be anti-pseudomonas. These are predominantly open fittings that lack the flow straightening and flow control functionality of more sophisticated Tap Outlet Fittings. There have been no studies on the efficacy of this kind of outlet fitting, but anecdotal evidence suggests that they have no effect on the bacterial load present. There are also several reasons why they may actually do more harm than good.

Being of an open construction without internal componentry, these fittings do not offer the laminar flow stream and controlled flow rate of their more sophisticated equivalents, and thus, it could be argued, they may be prone to promoting splashing around the basin area from an unregulated, turbulent flow stream. This may lead to concern as to the potential unintended consequences of fitting them. HTM 04-01 Part A[3] addresses this very point and states that the '*Water flow profile should be compatible with the shape of the wash-hand basin to avoid splashing*'. It goes further and states that components should be '*selected for their ability to minimise the accumulation of debris and splashing (including devices that deliver a smooth non-splashing/spraying flow)*'.

Some of these fittings purport to be copper-lined, with the anti-bacterial properties of copper alluding to some potential efficacy. However, the entire pipework system is very often plumbed in copper, and that should therefore have a greater effect on pathogenic bacteria levels present than a small end fitting could have. In any case, a protective layer of oxides and carbonates forms on the copper and that shields the bacteria from any anti-microbial effects it may have[8], both in the pipework and the outlet fitting.

Draining down of the tap spout upon flow cessation may also prove to be a problem, as previously discussed. The more sophisticated tap Outlet Fittings harness the surface tension of the water to prevent the spout from draining down, and thus prevent the spout from drawing in potentially contaminated air from the area of the basin and drain. These fittings also generally regulate the outlet flow rate and ensure that an unbroken, laminar column of water flows from the tap, which minimises localised splashing.

An earlier version (2012) of HTM 04-01 expressed concern regarding flow straightener's materials of construction; speculating that they provided nutrients that could support microbial growth. Quality products, however, only feature WRAS Approved Outlet Fittings, which have been specifically tested to ensure that they do not provide nutrients for pathogenic micro-organisms. This concern is not expressed in the latest (2016) version of HTM 04-01.

5. UV Treatment

UV treatment relies upon the water supply passing through a chamber that is illuminated by a UV lamp. The UV light damages the bacteria's DNA[9]. When the outlet is not it use, the captive water in the chamber is illuminated with UV and the idea is that retrograde contamination is retarded. Water quality and flow rate, however, play a part in the effectiveness of this approach. Colloidal particulate matter, planktonic biofilm and dissolved organic compounds suspended within the flow can shield bacteria from the UV light and allow it to pass untreated to the outlet.

Bio-fouling of the UV window by a sacrificial biofilm layer can also reduce the exposure of the water to the UV source. Several trials of UV light treatment have actually resulted in increased biofilm growth, one trial showing a ten-fold increase in biofilm numbers following UV treatment[10]. Informed speculation by experts is that this growth is a result of the UV increasing the bioavailability of natural organic matter.

6.Thermal Disinfection

Thermal disinfection is a long-established method of reliably killing bacteria. It is successful because heat is penetrating and travels by conduction through materials. Heating a biofilm to 60°C kills all the pathogenic micro-organisms present within the biofilm. '*The use of heat is probably the most effective method to control bacterial numbers*'[11]. Heat is a "first principles" method of killing bacteria, even within a biofilm, and is one method that the bacteria have no defence against. However, thermal disinfection does have some associated practical problems. For example, when using thermal disinfection in pipework fitted with a TMV near to the point of use, a problem has traditionally been the inability to raise the temperature of the pipework downstream of the TMV, as observed by Kelsey (2015)[11]. That leaves this downstream pipe work liable to colonisation. Some modern TMVs now incorporate methods for internal thermal flushing, and that overcomes the downstream problem. However, there is another, equally important, but less appreciated problem associated with self-disinfecting (manually or by automatic flush) TMVs: no thermal disinfection facility located at or within the TMV is able treat the upstream cold pipework that very often also harbours the bacteria. As discussed earlier, *Pseudomonas Aeruginosa* is known to inhabit the last 1 – 2 m of pipework. The Pseudomonas Working Group, established in 2011, included representatives from Centre Hospitalier Universitaire - Amiens, in France, who reported that in 9 out of 10 colonised outlets, the colonisation was within 1m upstream of the tap outlet[5]. Without treating this upstream colonisation, re-seeding of the downstream fittings and outlet will rapidly occur and the colonisation will soon return. Anecdotal evidence supports the view that thermal flushing of the TMV alone cannot rid a persistent colonisation, however the weakness is with the implementation of the thermal disinfection, not a fundamental or philosophical problem with the process itself.

7. A new thermal approach

With the benefits of thermal disinfection using the local hot water supply established, but considering the need to perform disinfection from a point upstream, Horne's design engineers set about designing a radical, but very simple and logical, departure from the established state of the art. The idea being a stand-alone passive unit that would sit upstream of the TMV/shower/tap/mixer, and, when operated periodically, could pass system temperature hot water down both the hot and cold inlet pipes. This disinfection approach has been effective in the past, however, operated centrally (system-wide) rather than locally, had intrinsic complications, safety implications and additional costs[12]. Horne's approach allows for treatment locally, at the most relevant location (upstream of the TMV), and without excessive demand upon the hot water system.

Routing 60+°C hot water to drain via the cold water drop means that the CW pipework and *all the downstream fittings* - strainers, check valves, thermostatic mixing valve and all its internal components, plus the terminal outlet fitting are raised to system temperature.

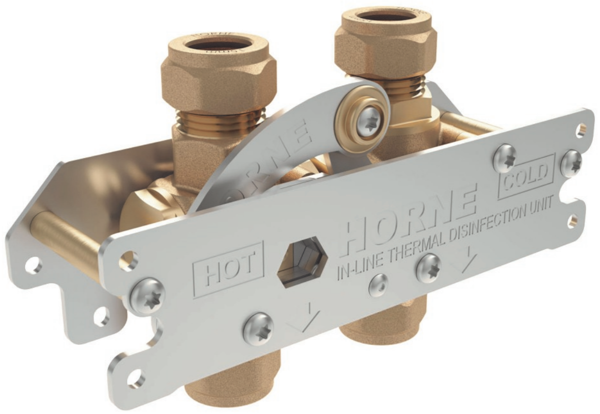

Figure 1. Horne's patented In-Line Thermal Disinfection Unit (ILTDU)

Naturally, a disinfecting method that allows for system temperature hot water to discharge from the tap fitting will introduce the risk of burns and scalds for the operator and, more importantly, local patients. A critical aspect, therefore, of the new product's design brief was to incorporate safety measures to mitigate this risk.

The resulting product design, the **Horne In-Line Thermal Disinfection Unit ILTDU** (Figure 1), now has patents granted and applied for around the world.

The design is very clever, but simple, and utilises two 3-way ball valves, connected by a bridging piece, that rotate by a single gear mechanism or 4-way link. Shifting the mechanism rotates the hot water ball valve through 180° and, simultaneously, rotates the cold water ball valve through 90°. This repositioning of the ball valves opens a temporary pathway from the hot water supply to the cold water drop as shown in Figure 2 below.

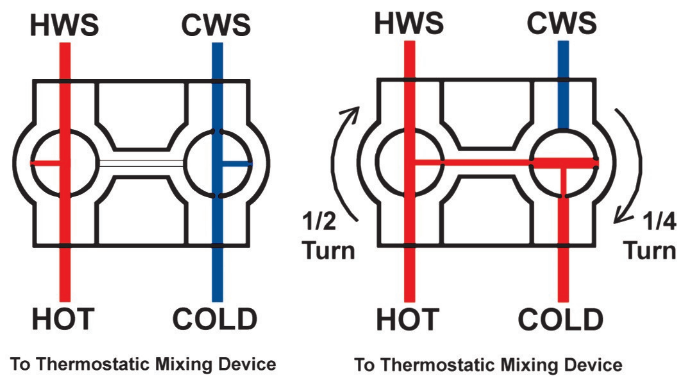

Figure 2. Hot and cold water pathways in Passive (LH) & Disinfecting (RH)

A special key is used to operate the mechanism. A large red warning triangle attached to the key alerts users and nearby personnel and patients to the risk of scalding. When in *Disinfection Mode*, the key is locked in position and cannot be removed - therefore the Very Hot Water warning sign is permanently present (Figure 3). Only when the device is returned to *Passive Mode* can the key be removed.

Figure 3. In Disinfection Mode, the key and its warning sign cannot be removed

Pipework Cleaning

Hans-Curt Flemming[6] stresses that disinfection is not cleaning and therefore dead biofilm left after disinfection should be removed, as far as possible, from the internal pipe walls. A practical means to remove this is by flushing the water system at an elevated velocity, which abruptly increases shear stresses at the pipe walls, eroding and detaching the biofilm[13]. The water flow then carries the suspended bacteria concentration away to drain. Although this shearing will never entirely remove the biofilm, it will diminish it to a pre-dispersion state, reduce planktonic motility and thus have a positive effect on overall water quality. An example is given below, Figure 4, showing how to flush at elevated velocity via a Horne TSV1 shower panel.

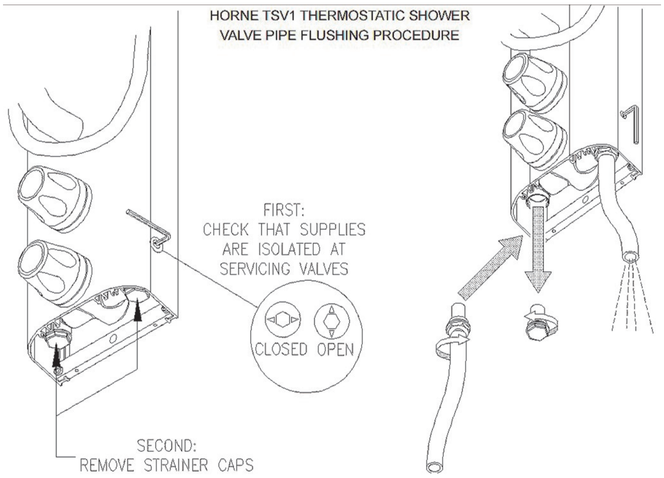

Figure 4. Flushing at elevated velocity through a Horne TSV1 shower panel

Hospital Trials

Since its launch, the uptake of the Horne ILTDU has been strong. After realising the limitations of other treatment methods, Hospital Engineers have been keen to try this new approach, the concept of which is easily grasped. Anecdotally, problem outlets (showers and taps) treated using the ILTDU have, time and again, reversed high *P. Aeruginosa* counts to zero, as described in our case-study from St Richards Hospital in Chichester.

The graph below, from Spinks *et al*[14], shows inactivation temperatures versus time for Pseudomonas Aeruginosa. To achieve an effective 6 log reduction in pathogen numbers, the disinfection temperature should achieve at least 60°C. Temperatures a mere 1-2° lower will require a significantly longer disinfection duration: the graph shows how 55°C requires at least 35 minutes to achieve the same degree of disinfection. Early hospital trials confirm that temperatures are crucial and Horne now recommend a minimum of 60°C for a duration of 10 minutes for optimum efficacy.

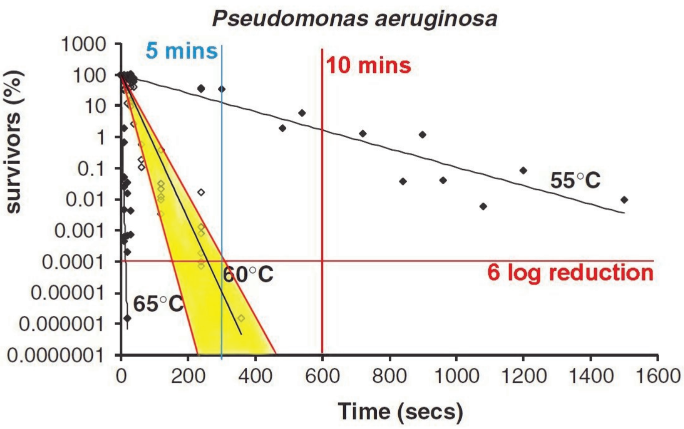

Figure 5. Annotated thermal inactivation curve for Pseudomonas Aeruginosa from Spinks *et al*, 2006[14].

A major benefit of the ILDTU is that it can be installed up-stream of any make of TMV, tap or shower – i.e. wherever there is a risk of colonisation of *P. Aeruginosa*, *L. Pneumophila*, *S. Maltophilia* or any other pathogen that survives in the water system, it can be thermally disinfected with the available hot water supply.

The ILTDU is available from Horne Engineering Ltd as a stand alone unit, for fitting in new or retrofit installations. It is also integrated into Horne's range of TSV1 surface mounted shower panels. Periodic ILTDU disinfection is easily achieved and continued pa-tient safety ensured.

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