CHLORINE DIOXIDE WATER TREATMENT
- for hot and cold water services

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PREFACE

Hot and cold water services account for the majority of identified cases of legionnaires’ disease in the UK. During the last five years alternative strategies such as chlorine dioxide and ionisation have increased in popularity as the building services industry has become increasingly aware that a temperature regime is not always achievable and in some cases not effective in controlling the problem.

BSRIA recognised that more information was needed on these alternative strategies. In 1996 we started a research project with industry and government to examine the effectiveness of chlorine dioxide on a full size hot and cold water services test rig. Sponsoring organisations included The Department of the Environment, the Health and Safety Executive, and manufacturers, suppliers and users of chlorine dioxide.

This BSRIA publication is the third in a series on Legionellosis [Ref 1 & 2]. It describes the most comprehensive independent record of chlorine dioxide effectiveness carried out in the UK.

As industry starts to evaluate alternative strategies for legionella control it is hoped that this work will make a valuable contribution to the decision making process.
EXECUTIVE SUMMARY

The aim of the experiment was to directly compare the effectiveness of a temperature regime against chlorine dioxide (ClO₂). This research was conducted at BSRIA Crowthorne, on a hot and cold water services test rig built to compare a temperature regime with hard water against alternative water treatments with hard and soft water. The test rig consisted of three identical systems, each with a total volume of 1790 litres. The plant and manner of operation were selected to represent a typical installation rather than best practice.

All three rigs were infected with higher levels of legionella and other bacteria than would be encountered in normal circumstances. The hot water system operated at 35°C and a typical quantity of water for this size of installation was discharged. After eight weeks the bacteria population had established itself in all three rigs and disinfection could commence. During disinfection the hot water in the temperature regime rig was heated to 60°C whilst in the other two rigs the chlorine dioxide dosing was turned on and the hot water remained at 35°C.

Chlorine dioxide levels were initially kept low in order to keep the total oxidants within the Secretary of State’s legal requirement (for drinking water) of 0.5 ppm at the water outlets. The initial results showed that ClO₂ is effective against legionella within the 0.5 ppm total oxidants limit though the TVCs remained relatively high. Total oxidants did rise beyond 0.5 ppm in Rig 3 (soft water) after day 40, but legionella had been undetectable since day 10 in the cisterns and since day 20 in the remainder of the system including outlets.

After day 60 this control strategy was changed because the low water turnover in the rig was causing a build up of total oxidant, limiting the amount of useful chlorine dioxide which could be injected into the system and preventing rapid elimination of the heterotrophic bacteria.

All the circuits dosed with chlorine dioxide showed an increase in the level of copper found in solution. The increase was most evident in the soft water hot circuit which initially had very low levels of copper. Copper can potentially cause staining at levels above 1000 µg/l but there is no evidence that this has been a problem in actual installations. The trial did not run for long enough to determine whether copper levels would reach an equilibrium level or indeed decrease, nor was it possible to determine the reason for the increase.

The disinfection programme ended after 16 weeks when the chlorine dioxide test rigs were continually producing good results i.e. no planktonic legionella could be detected, heterotrophic bacteria were reduced and controlled in the hot and cold water systems and no legionella were being recovered from the biofilms. Some biofilms were completely killed, whilst others were still viable but seeding reduced quantities of heterotrophic bacteria into the water.
The corresponding results for the temperature regime were mixed. In cold water planktonic and biofilm results were poor because no disinfection measures were applied. For hot water the results were much better but planktonic legionella were detected even with water temperatures maintained to HS(G)70 guidelines.
# Glossary of Terms

**Bacteria**
These are typically single cell micro-organisms. Most are between 0.0005 mm and 0.002 mm long and rarely exceed 0.01mm in length. They can be studied under a high-powered microscope. Bacteria respire aerobically (using oxygen) eg legionella, or anaerobically (without oxygen). Diseases caused by bacteria include pneumonia (eg legionnaires' disease), anthrax, typhoid fever, cholera etc.

**Biofilm**
A community of bacteria and other micro-organisms, embedded in a protective layer with entrained debris, attached to a surface.

**Micro-organisms**
Microscopic life forms that can thrive in water systems. These include algae, fungi and bacteria.

**Drop Test**
In this publication the phrase refers to a test used to determine total oxidant. It uses a potassium iodide tablet and titration using sodium thiosulphate.

**DNA**
Deoxyribonucleic acid. This chemical consists of long molecules coiled in a double helix which along with protein forms chromosomes present in all organisms. DNA is self-replicating. DNA is present in living and dead bacteria.

**RNA**
Ribonucleic acid. This chemical is present in all organisms and plays an important role in the synthesis of proteins. RNA is present in living bacteria only.

**Enzymes**
Group of proteinaceous catalysts produced by living cells.

**Oxidation**
A process involving the gain of oxygen (or similar electronegative non-metals), loss of hydrogen or loss of electrons.

**Redox**
A reaction involving reduction and oxidation.

**Total Oxidant**
Expressed as ppm chlorine dioxide. It represents the total oxidising capability of the chlorine dioxide, chlorite and chlorate.
1 BACKGROUND INFORMATION

1.1 LEGIONELLA BACTERIA

Legionella is the name given to the genus of bacteria which cause the condition commonly known as legionnaires' disease. This is a form of pneumonia which particularly affects those who are susceptible due to age, illness, immunosuppression or smoking. Infection is caused by inhaling airborne droplets or particles containing viable legionella, small enough to travel deep into the lungs and be deposited in the alveoli. Other types of disease associated with legionella bacteria have also been identified. These are Pontiac and Lochgoilhead fever. The generic term used to describe these diseases is Legionellosis.

At least 37 different species of legionella bacteria have been reported to date. The species most commonly associated with disease outbreaks is *L. pneumophila*. Fourteen different serogroups of *L. pneumophila* have been described. *L. pneumophila* Serogroup 1 being most commonly associated with cases of legionnaires' disease in the UK. There are at least a dozen different sub-groups of *L. pneumophila* Serogroup 1, such as OLDA, Bellingham and Pontiac.

Widespread in small quantities within natural water sources, the bacteria present few problems until man-made environments such as cooling towers and hot and cold water services provide the right conditions for multiplication and dissemination.

Although the dose of legionella required to infect man is still not known, the conditions necessary to minimise the risk of disease are well understood.

1.2 LEGISLATION

Guidance aimed at reducing the risk of Legionellosis in the UK was introduced by the Government in the early 1990s in the form of two documents:


- The Health and Safety Executive: The Control of Legionellosis including Legionnaires' Disease: Health and Safety Series Booklet, (HS(G)70). Reprinted in 1995 [Ref 4].

These documents are applicable to work activities and premises where water is used or stored and there is a means of creating or transmitting water droplets which may be inhaled. They provide guidance on statutory regulations and technical advice respectively, for compliance with various sections of the Health and Safety at Work etc Act 1974 and the Control of Substances Hazardous to Health Regulations 1994.

The guidance embodies the concept of a risk assessment to be carried out by or on behalf of employers, self-employed persons and persons in
control of premises. The risk assessment should be carried out on the building services in order to determine the level of risk of Legionellosis and to identify actions to prevent or control the risk.

The risk assessment should:

a) **identify systems** which are susceptible to colonisation by legionella and have a potential means for creating and disseminating water droplets to occupants inside and outside the building

b) **assess risk** for the normal operation of the plant or use of the water system including maintenance, breakdown, commissioning and known occurrences of abnormal operation or unusual circumstances

c) **prepare a scheme** for preventing or controlling the risk which has been identified

d) **implement and maintain that scheme.**

**Hot and cold water services**

For hot and cold water services HS(G)70 advises that the legionella bacteria may colonise plant, pipework, and fittings but in general, proliferation may be avoided by:

- avoiding water temperatures between 20°C and 45°C
- avoiding water stagnation by, for example, good system design such as the elimination of dead legs
- avoiding materials in system construction which could promote microbiological growth
- keeping systems clean
- using a water treatment programme where appropriate and safe and ensuring that the systems operate safely and correctly and are well-maintained by means of routine inspection and maintenance, record keeping and the establishment of management procedures, training and communications.

For hot and cold water services the potential means for creating and disseminating water droplets is normally restricted to water fittings used by occupants inside the building.

In order to assess the risk of exposing the occupants of the building to legionella from the hot and cold water services the risk assessment will involve a site survey of the water services to determine whether the above conditions can be achieved. Since water temperatures are advocated in HS(G)70 as the principal method for controlling legionella in hot and cold water services a large part of the site procedure will involve temperature
checks throughout water systems in a building. Guidance on this subject is contained in BSRIA Application Guide AG4/94, [Ref 1].

These checks will be carried out to determine whether the water systems meet the HS(G)70 operational temperature guidelines for hot and cold water services.

Water services should operate at temperatures that prevent the proliferation of legionella by:

• keeping hot water storage temperatures in calorifiers at 60°C

• keeping the hot water distribution pipework hot. At least 50°C should be attainable at the taps, or entry to temperature control devices, within one minute of discharging water

• keeping cold water storage tanks and distribution pipework at 20°C or below.

In many buildings, particularly older ones, it is difficult to achieve these temperature conditions. Many hot water installations were designed on a gravity rather than pumped recirculation system and contain pipework dead legs. Furthermore, many cold water installations are unable to maintain water temperatures at 20°C or below because of oversized or poorly located cisterns and heat transfer between hot and cold water pipework.

In 1993 HS(G)70 was revised to reflect these problems. It recognised that if these water temperatures could not be achieved, other strategies such as chlorine dioxide could be used if they have been shown to be as effective as a temperature regime.

1.3 WATER QUALITY STANDARDS

In England and Wales all public water supplies are required to comply with the quality standards laid down in the Water Supply (Water Quality) Regulations 1989 [Ref 5]. These regulations list a total of 57 parameters. It is the duty of the water supplier to ensure that the supply of water to the boundary of the property (communication pipe) meets the standards specified in the regulations.

The most important indicator organisms for water quality are bacteria. In the public water supply these organisms are reduced and controlled by various methods of chemical and physical water treatment in order to achieve microbial test limits set out in the water regulations. Of these tests the coliforms, especially Escherichia coli, are particularly important because they suggest the presence of faecal contamination which denotes that intestinal pathogens could be present and therefore the supply of water is potentially dangerous to health. The presence of other bacteria such as those associated with soil and vegetation are measured using colony counts at 22°C and 37°C incubation temperatures. Although the counts themselves have little direct health significance they provide a general indication of the bacteria l content and can provide advance warning of more serious pollution. Colony counts from the mains water
will vary according to seasonal factors. The water supply regulations therefore prescribe that there should be no significant increase in the value of counts over that normally observed in the water supply.

The regulations do not list legionella as a control parameter for water quality. This is because they are not normally infectious when swallowed. In practice low numbers of the bacteria have been found in the mains water but it is widely accepted that conditions for colonisation are more favourable in hot and cold water services within the building.

**Quality of water in hot and cold water services**

The potable water supplied to a building by a water undertaker must meet the quality requirements laid down in the Water Supply (Water Quality) Regulations (1989). Table 1.1 summarises the main requirements in relation to bacterial content.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit of Measurement</th>
<th>Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colony Counts @ 22°C</td>
<td>number/ ml</td>
<td>No significant increase over that normally observed</td>
</tr>
<tr>
<td>Colony Counts @ 37°C</td>
<td>number/ ml</td>
<td>No significant increase over that normally observed</td>
</tr>
<tr>
<td>Total Coliforms</td>
<td>number/ 100 ml</td>
<td>0</td>
</tr>
<tr>
<td>Faecal Coliforms</td>
<td>number/ 100 ml</td>
<td>0</td>
</tr>
<tr>
<td>Faecal streptococi</td>
<td>number/ 100 ml</td>
<td>0</td>
</tr>
<tr>
<td>Sulphite reducing clostridia</td>
<td>number/ 20 ml</td>
<td>≤ 1</td>
</tr>
</tbody>
</table>

The building operator has a responsibility under the Health and Safety at Work etc. Act, 1974 (where it applies), to ensure that the quality of the water supplied does not significantly deteriorate whilst stored and distributed in the building for domestic purposes, which include drinking, washing and cooking. To achieve this, a number of guidance documents have been issued for the design, installation, testing and maintenance of hot and cold water domestic services [Refs 6 & 7]. These do not prescribe sampling for legionella in hot and cold water systems but concentrate instead on avoiding contamination and maintaining temperatures within prescribed limits.

It should be emphasised that sampling for legionella is separate and quite different from sampling to assess water quality. It is normally carried out to monitor the efficiency of a water treatment regime or to trace the source of an infection. HS(G)70 does not require the sampling of hot and cold water systems for legionella.

Colony counts are often referred to as TVCs (total viable counts). This is simply a measure of the heterotrophic bacteria population. The bacteria are incubated at 22°C and 37°C because the difference in temperature
provides an indication of the preferred habitat of the bacteria. 22°C represents the natural water environment and 37°C the body temperature. In general, bacteria results for cold water systems would tend to be higher at 22°C and results for hot water systems would tend to be higher at 37°C. The preferred habitat of legionella bacteria is body temperature so these bacteria are incubated at 37°C.
2 CHLORINE DIOXIDE WATER TREATMENT

2.1 Theory

Chlorine dioxide (ClO₂) is a yellow green gas and in its raw state it is highly volatile and explosive at concentrations above 10% in air. It is a molecule with an unpaired electron that will readily react with other compounds to gain an electron. The reaction process of chlorine dioxide with bacteria or other substances involves two stages of oxidation which leaves reduction by-products in the water. The first stage involves gaining one electron to form chlorite and the second stage involves gaining four electrons to form chloride (as in common salt). In practice, the first stage of oxidation predominates and therefore chlorite will be the major by-product in the water. Another by-product in the water will be chlorate because this is present in proprietary solutions of chlorine dioxide. Both chlorite and chlorate have further oxidising capacity.

Chlorine dioxide, chlorate and chlorite ions are toxic. The WHO recommended guideline for chlorite in drinking water is 0.2 mg/l. In order to minimise the risk from ingestion of chlorine dioxide as well as the precursors and by-products involved in the use of chlorine dioxide as a disinfection agent for drinking water, the Secretary of State’s legal requirement is that the combined concentration of chlorine dioxide, chlorite and chlorate should not exceed 0.5 ppm chlorine dioxide equivalent (see section 2.3). The measurement of the combined concentration chlorine dioxide, chlorite and chlorate is described in this report as “total oxidants”

For hot and cold water services chlorine dioxide is usually generated using one of two methods. The first method is to generate the chlorine dioxide on site by mixing sodium chlorite with acid or chlorine. The second method involves the use of proprietary solutions containing a blend of precursors which release chlorine dioxide on acidification.

2.2 Biocidal properties

Chlorine dioxide is an oxidising biocide capable of reacting with a wide range of organic substances including many of the constituents of bacterial cells. The low levels of chlorine dioxide used in drinking water inactivate bacteria due to oxidation disrupting a number of different cell processes.

Several studies show that chlorine dioxide reacts readily with amino acids [Ref 8] and RNA [Ref 9]. Whether chlorine dioxide attacks the peripheral structure of the cell or the acids within is still not clear but it is suggested that oxidation reactions at both of these sites contribute to cell inactivation.

Other studies have looked at the effect of chlorine dioxide on the physiological function of cells. These have shown that inactivation is due to disruption of protein production [Ref 10] whilst other studies [Ref 11 &12] have shown that the chlorine dioxide weakens the membrane of the cell and inhibits respiration. In general it has been shown that levels of chlorine dioxide at 0.5 ppm produce an effective disinfection.
2.3 **CHLORINE DIOXIDE IN HOT AND COLD WATER SYSTEMS**

**Background**

As early as the 1940s published papers reported the efficacy of chlorine dioxide as a bactericide. Since 1949 it has occasionally been used for the treatment of public water supplies and more often in large scale processes like paper pulp mills where the gas is generated on site and can be closely monitored. More recently, it has been used in the building services industry as a method of water treatment.

The principles of the technology for building services were developed in the 1970s with small scale chlorine dioxide generators and in the 1980s with a method of generating chlorine dioxide from a buffered solution. Chlorine dioxide is currently approved by the Secretary of State for the Environment, for use in the treatment of public water supplies, on condition that the combined concentrations of chlorine dioxide, chlorite and chlorate, as chlorine dioxide, do not exceed 0.5 ppm. Such approval is given upon the advice of the Committee on Chemicals and Materials of Construction for use in Public Water Supplies and Swimming Pools.

**The construction of the chlorine dioxide plant**

For chlorine dioxide generators the process typically relies on one of two reactions with sodium chlorite to produce chlorine dioxide. The first involves chlorine and the second is an acidification reaction using acid. In general the plant consists of two source chemicals, metering pumps, reaction chamber and monitoring system. The metering pumps are designed to transfer the source chemicals according to demand using proportional dosing based on a water meter placed in the water system or a pulse controller. The dosing pumps feed the source chemicals into the reaction chamber where these react to form chlorine dioxide in solution. This chlorine dioxide solution is then injected into the water via an injection valve.

For chlorine dioxide generated from a proprietary solution the plant is very similar apart from the source chemicals. These are a solution containing a blend of precursors and an acid. When mixed together in the reaction chamber the acid releases chlorine dioxide from the proprietary solution.

The reaction chamber is normally a vortex chamber. This promotes the efficiency of generating chlorine dioxide by ensuring that the two chemicals completely mix at all water velocities.

The plant may contain a number of reaction chambers and injection points dependent upon the size and complexity of the system being served. The size and number of dosing pumps and chemical stores will vary according to the application. This will depend upon a number of factors including the water volume in the system, flow rate, and the anticipated level of bacterial loading.
In general, the most common injection point is the cold water cistern feeding the hot and cold water services. This injection point would normally dose the chlorine dioxide on a proportional basis according to a signal received from a water meter registering the amount of water being used from the tank.

Other injection points in a hot and cold water services system are:

- The cold water main serving the entire water services in the building.
- The hot water service return pipework to the water heater.

**Operation and control**

The dosing system is designed to inject chlorine dioxide at a controlled rate in order to maintain a desired concentration of chlorine dioxide throughout the system.

The level of chlorine dioxide in the water is normally monitored and the ratio of dosing relative to water usage adjusted accordingly. The method of monitoring may be manual analysis or automatic via an electrochemical (chlorine dioxide or redox) sensor.

The manual method involves measuring the level of chlorine dioxide in solution using portable test kits. The most commonly used method is the diethyl-p-phenylene diamine (DPD) method. This is based on the fact that chlorine dioxide reacts with DPD in buffered solution to produce a pink colouration. Chlorine acts in a similar manner. Glycine is therefore added to prevent the reaction with chlorine in order to give specific determination of chlorine dioxide. A portable photometer is required to provide the necessary precision of measurement. It is important to note that the measured concentration of chlorine dioxide will not reflect the concentration of by-products in the water.

As noted earlier, chlorine dioxide is authorised for use in public water supplies on condition that the combined concentration of chlorine dioxide, chlorite and chlorate does not exceed 0.5 ppm. Whilst the condition of approval has no legal effect within buildings, where water is used for drinking, washing, cooking or food production purposes it would be irresponsible to wilfully expose consumers to higher concentrations, given that the approval has been set to protect public health.

This means that the combined total of chlorine dioxide, chlorite and chlorate anywhere in the hot and cold water system may exceed 0.5 ppm provided that this value is not contravened at the consumer’s taps. To achieve this it is important to measure and take account of chlorites and chlorates already present in the incoming water supply and the water system. This should be done whether a manual or automatic system of control is used for the determination of the concentration of chlorine dioxide in the water. It is generally agreed that the combined total of chlorine dioxide, chlorite and chlorate, commonly known as total oxidant
and can be measured using the DPD test, drop test or the oxidising capacity indicated by a redox sensor.

During the operation of the chlorine dioxide system it is important to recognise that variations in chlorine dioxide concentration and total oxidant can occur according to the level of water usage. Periods of low water usage will generally produce low chlorine dioxide concentrations and high total oxidant levels whilst those taken during periods of high water usage will show high concentrations of chlorine dioxide and low total oxidant levels. This is because chlorine dioxide is a comparatively transient chemical.

Plate 2.1 and Plate 2.2 illustrate chlorine dioxide units from UK manufacturers.
Plate 2.1
Chlorine dioxide generation for potable water

Photo courtesy of Water Technology Ltd

Plate 2.2
A typical chlorine dioxide generation unit

Photo courtesy of Feedwater Ltd
Measuring the effectiveness of chlorine dioxide

Water sampling and enumeration of micro-organisms is the most commonly employed technique for determining the biocidal effectiveness of chlorine dioxide.

**Plate counts (planktonic)**

One of the simplest forms of detection is the total viable counts of bacteria. Commonly known as TVCs or plate counts, this sampling and enumeration technique is widely used to indicate the number of living bacteria present in the water system in suspensions (planktonic). It is important to recognise that plate counts only measure the general bacteria (heterotrophic) and not legionella.

Samples of water are taken from outlets by discharging water directly into a sterile container after the outlet has been suitably sterilised using heat or alcohol. A measured quantity of water, normally 1 ml, is added to agar growth media and then cultured at a given temperature of 22°C or 37°C. The results are then expressed as colony-forming units per millilitre (cfu/ml) at the respective temperatures.

The effectiveness of the chlorine dioxide water treatment may be determined by comparing samples before and during chlorine dioxide dosing. The aim should be to maintain plate counts at a level where there are no significant increases over that normally observed in “clean” systems.

**Legionella (planktonic)**

Sampling for legionella is very similar to plate counts. Samples of water are taken from outlets by discharging water directly into a sterile container after the outlet has been suitably sterilised using heat or alcohol. A measured quantity of water, 500ml, is filtered. Aliquots are then either treated with acid or heated to 50°C for 30 minutes and then added to buffered charcoal yeast extract medium (BCYE) and cultured for up to 10 days. Presumptive legionella colonies are subcultured onto other plates for isolation. The bacterial cells are then treated with specific antibodies to identify the type of legionella by examining for fluorescence under UV light using a microscope. The results are then expressed as colony forming units per litre (cfu/l) at respective days of culture, normally 7 and 10 days.

The effectiveness of the chlorine dioxide water treatment may be determined by comparing successive samples before and during chlorine dioxide dosing. The aim should be to produce results where legionella are ‘not detectable’.

It is widely recognised that planktonic plate counts and legionella sampling provide limited information because they only indicate the number of living organisms currently active in the water sample. This sample of water may not necessarily provide a true indication of the microflora present in the pipework system. It is commonly agreed that the analysis of biofilms present on the surfaces of the pipework and plant can provide an additional indicator because this is where heterotrophic
bacteria and legionella survive even when planktonic measurements indicate that the system is clean.

**Biofilms**

Work has shown that biofilm which occur on the internal surfaces of pipework and plant are not homogenous layers [Ref 13]. In fact, they have a basal biofilm layer approximately 5-10 µm thick with microcolonies projecting 100 µm into the water. This feature is thought to allow water to circulate within the biofilm providing nutrients and oxygen to the bacteria present. The topology of the biofilm also provides a mosaic of micro-environments which are thought to provide a haven against biocide treatments.

For analysing biofilms a range of techniques is available, but the two methods employed on this project were:

1. **Fluorescent Microscopy**

   This technique is concerned with visualising the biofilm through a microscope. On opaque materials such as copper pipework the technique uses a method called episcopic DIC (Differential Interference Contrast) microscopy. This involves staining a coupon specimen with a fluorescent dye which enables the biofilm on the surface to be visualised and photographed. The images are then transferred to a computer and analysed for percentage biofilm coverage using appropriate software.

2. **Culture techniques**

   This technique is concerned with determining whether the biofilm contains viable bacteria. The biofilm is scraped off the surface of the material and then cultured on a plate for heterotrophic or legionella bacteria using methods described in “*Measuring the effectiveness of chlorine dioxide*”. Note that these results are expressed as colony-forming units per square centimetre of biofilm (cfu/cm²).
3  BSRIA TEST FACILITY

The BSRIA test facility as shown in Plate 3.1 consists of a commercial-size hot and cold water services system built in triplicate at BSRIA laboratories in Crowthorne, Berkshire. The facility was designed to replicate the size of system commonly found in an office building containing 50 persons, or a small home for the elderly. Three rigs were built in order to compare one rig using a temperature regime with hard water (control rig) against two rigs using chlorine dioxide at reduced hot water temperatures with hard and soft water.

Plate 3.1
BSRIA hot and cold water services test facility
3.1 PLANT SPECIFICATION

Hot and cold water system
The cold water system in each rig consisted of a glass reinforced plastic cistern having a capacity of 1350 litres and manufactured to bylaw 30 standards. This served a cold water copper pipework circuit 30 metres in length.

The hot water system consisted of a vertical hot water storage calorifier of copper construction having a capacity of 440 litres. This had a concave base and was not fitted with a shunt pump. This served a hot water copper pipework circuit of 40 metres length. Each hot and cold water pipework circuit was designed to replicate the normal length of pipework which would be present in this size of system.

To discharge water from each circuit a number of water outlets were installed on each rig:

- a hot water tap with a pipework dead leg exceeding the recommendations of BS 6700
- a thermostatic mixer shower with hose attachment
- a low-temperature mixing valve
- two cold water taps located nearest to and furthest from the cistern.

Each water outlet was fitted with a solenoid-operated valve controlled via a building energy management system.

Water supplies
The success of a water treatment regime varies with different supply waters. To give the chlorine dioxide results a national perspective a ‘hard’ and ‘soft’ water were chosen as being representative of the extremes of water found in this country. The hard water was sourced direct from the mains water supply in the building. This was used in Rig 1 with the temperature regime, and Rig 2 with chlorine dioxide. The soft water was sourced from Glasgow. This was transported to BSRIA and stored in a tanker parked adjacent to the building housing the test rig. This was used in Rig 3 with chlorine dioxide.

Chlorine dioxide system
The BSRIA chlorine dioxide dosing system consists of one unit serving the cold water cistern and one unit serving the hot water circuit independently on each rig. Each unit consists of a dosing pump, chlorine dioxide sensor, controller and source chemicals. Each unit is designed to sense the chlorine dioxide in the water and dose a solution of chlorine dioxide into the system to achieve a set point on the controller. Figure 3.1 illustrates the basic layout of the chlorine dioxide system.
To avoid using proprietary chemicals directly, a solution of chlorine dioxide was produced by BSRIA. This was achieved by stripping out pure chlorine dioxide from source chemicals provided by manufacturers, and then re-absorbing the chlorine dioxide into de-ionised water to produce a pure stock solution of chlorine dioxide at a concentration of 1000 ppm. For each rig a stock solution of chlorine dioxide was stored in small refrigeration units located below the dosing pumps. To monitor chlorine dioxide levels in the water the chlorine dioxide sensors were linked to the BEMS. Periodic water samples were also taken to measure chlorine dioxide and total oxidant using the Palintest DPD method. A further check on the total oxidant was carried out using a drop test provided by Feedwater Ltd. This uses a potassium iodide tablet and titration with sodium thiosulphate.
General operating conditions

To replicate typical conditions in buildings the following conditions were applied to all three rigs:

- the water outlets were only discharged for 15 seconds every two hours

- chlorine was removed from the incoming water supplies to the test rigs. This was achieved by installing granulated activated carbon (GAC) filters. This action was taken for two reasons:

  a) The mains water supply typically has free chlorine concentrations below 1 ppm (mg/l). These concentrations are not sufficient to inactivate and suppress legionella or remove biofilm where the legionella proliferate but they can have a disinfecting effect on the planktonic heterotrophic bacteria. Therefore, if the chlorine was introduced it would have been difficult to determine whether the decay of planktonic heterotrophic bacteria was due to the chlorine in the water or the method of disinfection being applied.

  b) The amount of residual chlorine contained within the two incoming supply waters would not be the same because the soft water is stored whilst the hard water is direct from the main. This could lead to different results if the residual chlorine was allowed to enter the test rigs.

Building energy management system

A Trend BMS outstation was installed for controlling and monitoring all three test rigs.

This carried out the following functions:

a) Control of hot water storage temperatures

b) Control of water discharges via solenoid valves

c) Monitoring water temperatures in the hot and cold water systems

d) Monitoring volume of water discharged from the entire test facility

e) Monitoring chlorine dioxide levels in the cisterns and hot water circuit

f) Control of safety circuits

The BMS system was linked to a personal computer running Trend ‘921’ supervisory software. This offered the facility to alter control functions and review data and produce graphs from current and historical data.
3.2 MICROBIOLOGY

To compare the effectiveness of the temperature regime against chlorine dioxide the quality of water in the test rigs was frequently monitored. The locations chosen on the rigs for water sampling and biofilm analysis are shown in Figure 3.2.

**Figure 3.2**
BSRIA chlorine dioxide test rig - location for water sampling and biofilm analysis

**Water sampling**

To measure the bacterial population in suspension (planktonic) water samples were taken and analysed for legionella and general (heterotrophic). All water samples were collected in polyethylene containers which comply with BS 6920: Part 1. All water outlets were sterilised by swabbing with ethanol and allowed to dry before a water sample was taken. All samples were taken as post-flush. This means that the outlet was run to waste before a water sample was taken and therefore the water sample was representative of held in the pipework supplying the fitting.

All water samples were analysed by the Centre for Applied Microbiology and Research (CAMR).

**Biofilm analysis**
This included analysing the coverage of biofilms and determining the existence and number of viable legionella and heterotrophic bacteria within them. Biofilms were analysed in the copper pipework circuits, base of the calorifiers and the GRP cisterns by removing small material coupons and visually recording the percentage biofilm coverage using the episcopic DIC (Differential Interference Contrast) microscopy technique. Total culturable counts of bacteria were obtained by scraping the biofilm and incubating on BCYE and selective buffered charcoal yeast extract medium with antibiotic supplements (GVPC) for legionella, and nutrient agar for heterotrophic bacteria. All biofilm samples were analysed by the Centre for Applied Microbiology and Research (CAMR).

**Copper pipework coupons**

To remove copper coupons from the pipework circuits a “trombone” arrangement was designed by BSRIA. This consisted of a pipework trombone with two valves having compression fittings, a drain cock and a vent. The trombone was removed by isolating the valves, opening the vent and draining down. Using a pipe cutter, a copper coupon (section of pipe) was removed from the top and bottom of the trombone. One of these coupons was then filled with source water, capped at both ends to keep the biofilm hydrated, and boxed for transport to CAMR. The remainder of the trombone was then installed back into the pipework circuit using new olives on the compression fittings.

Biofilms are not homogenous throughout a pipework system. For this reason, coupon samples were taken on a rotational basis at two locations on the cold and hot water circuits. These were at the beginning and end of the hot water pipework circuit and middle and end of the cold water pipework circuits.

**Base of calorifier coupons**

On each rig a copper pipework coupon was placed in the base of the calorifier before infection took place. These coupons were removed at the end of the project.

**Cistern coupons**

Glass reinforced plastic (GRP) coupons 2 cm² in area were provided by the manufacturer of the cisterns. These coupons had a smooth face reflecting the inside surface of the cisterns. The coupons were suspended on monofilament lines in the cisterns. Sampling involved removing a coupon and placing it in a container with source water for transport to CAMR for analysis.
4 TEST PROGRAMME

4.1 OBJECTIVE

The objective of the test programme was to assess the effectiveness of chlorine dioxide at reduced water temperatures against a temperature regime for the disinfection and control of microbiological contaminants including legionella bacteria in a hot and cold water system.

To achieve this objective the test programme was divided into two distinct stages:

- Infection
- Disinfection

4.2 INFECTION

The infection stage of the project was designed to allow a mixture of waterborne micro-organisms, including a non-pathogenic strain of legionella *L. pneumophila*, Serogroup 1, sub type ‘Pontiac’ to infect the rig.

The inoculum for infection consisted of:


This inoculum was prepared by CAMR (The Centre for Applied Microbiology and Research) at Salisbury. Each rig was inoculated via the cold water cistern and the cold and hot water systems were operated. To promote bacterial growth during this period the hot water storage temperatures were held at 35°C.

Before disinfection could commence two conditions had to be achieved. Firstly, the bacterial population needed to have reached steady state conditions so that any further population variations in bacteria could not be then be attributed to any influences other than disinfection. Secondly, the resulting bacterial population had to be large enough to show, without question, the comparable effects of temperature and chlorine dioxide disinfection.

4.3 DISINFECTION

Table 4.1 summarises the operating parameters for the hot water system during disinfection.

<table>
<thead>
<tr>
<th>Table 4.1</th>
<th>Disinfection programme for the hot water system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rig</td>
<td>No. 1</td>
</tr>
<tr>
<td>Storage °C</td>
<td>60</td>
</tr>
<tr>
<td>ClO₂</td>
<td>None</td>
</tr>
<tr>
<td>Water</td>
<td>Hard</td>
</tr>
</tbody>
</table>
To evaluate chlorine dioxide at reduced hot water temperatures the decision was taken to leave the stored hot water at the incubation temperature of 35°C. This avoided any temperature induced changes in the bacterial population during disinfection.

For the temperature regime the temperature of the stored hot water was increased to 60°C in the calorifier and the return water temperature to the calorifier was maintained at 50°C or above throughout the disinfection period.

For the cold water system the test programme was a direct comparison between a rig with a temperature regime where the stored water is kept within HS(G)70 temperature recommendations and the other two rigs where chlorine dioxide water treatment is additionally applied via the cisterns.
5 RESULTS

5.1 CHLORINE DIOXIDE CONTROL STRATEGY

During the first sixty days of disinfection the chlorine dioxide levels were kept low in order to keep the total oxidant within the approved limit of 0.5ppm at the water outlets. To achieve this the set points on the hot water circuit and cold water cistern were set at 0.01 and 0.04 ppm ClO₂ respectively. The set point for the hot water circuit was set lower because the calorifier was fed with water from the cistern.

After day 60 this control strategy was changed because the low turnover of water in the rig was causing the total oxidant levels to stay high which limited the amount of useful chlorine dioxide which could be injected into the system. The bacteria results showed that whilst the planktonic legionella were removed the heterotrophic bacteria remained and the biofilm results were inconclusive. The set points for the hot and cold water were therefore increased to 0.05 and 0.1 ppm ClO₂ respectively and the level of total oxidant at the outlets was measured but not used as a control parameter.

At day 72 the control strategy was further changed because the planktonic TVCs suggested that biofilm was still present and seeding the system. The set points were increased to 0.2ppm ClO₂ on both the hot and cold water.

At day 96 the set points were further increased to 0.4 ppm ClO₂ on both the hot and cold water till the end of the project. This was carried out because the planktonic TVC results were still questionable and the last two weeks of testing provided the opportunity to see how effective chlorine dioxide would be at these levels.

5.2 MEASURING THE SUCCESS OF BACTERIA DISINFECTION

To measure the success of bacteria disinfection, the following guidelines were used:

Legionella and plate counts

A successful disinfection regime was considered to be one in which the legionella were ‘not detectable’ and the plate counts at 22°C and 37°C showed no significant increase over background levels.

Biofilms

A successful disinfection regime for biofilms was considered to be one in which the capability of the biofilm to seed the water with legionella bacteria was removed, and heterotrophic bacteria were removed or reduced to low levels. To assess this two parameters were considered.

The first parameter was biofilm coverage. This would ideally reduce but because the analysis of biofilm coverage used a dye which reacts with DNA, present in both dead and live bacteria, the results would not be conclusive because dead bacteria can remain as deposits, particularly in hard water.
The second parameter was recovery of bacteria from the biofilm which would indicate whether the biofilm was viable. If the recovery of bacteria produced negative results for legionella and negative or low results for heterotrophic bacteria then disinfection was successful.

### 5.3 CISTERNS

**Chlorine dioxide**

Figure 5.1 illustrates the chlorine dioxide concentrations measured in the cold water cisterns during disinfection.

The graph serves to illustrate how chlorine dioxide concentrations rose as a result of control strategies being changed to improve bacteria results through the disinfection period. The peak concentrations on day 86 of Rig 3 occurred because of low flow rate through the chlorine dioxide sensor housing.

**Total oxidant**

Figure 5.2 illustrates total oxidant levels measured in the cisterns during disinfection using the DPD test method.
The results were generally below the limit of 0.5 ppm total oxidant when the control strategy was 0.04 ppm ClO₂. After the strategy was changed to 0.1 ppm after day 60 the levels rapidly rose. The difficulty in controlling the total oxidant levels resulted from the low turnover of water in the cistern (turnover period = 4.5 days).

**Legionella (planktonic)**

Figure 5.3 illustrates planktonic legionella results for the cisterns.

**Figure 5.3**
Legionella (planktonic) results for cisterns during disinfection

The graph illustrates that prior to disinfection all three rigs started with legionella at 10⁶ cfu/l but this gradually decayed to 10⁵ cfu/l log before disinfection due to natural decay. During the first two days of disinfection the legionella in Rigs 2 and 3 dramatically reduced to ‘not detectable’ with chlorine dioxide concentrations maintained at 0.05ppm. During days 3 to 8 when the chlorine dioxide was still maintained at 0.05 ppm Rig 2 continued to have no legionella detected whilst Rig 3 had two peak counts of 10⁴ and 10⁵ cfu/l on days 3 and day 8 respectively. The most likely cause for these peaks was dispersion of bacteria from the biofilm. During the remainder of the disinfection period both Rigs 2 and 3 had no legionella detected with chlorine dioxide concentrations as low as 0.05 ppm.

For Rig 1 the results showed that planktonic legionella continued to survive in the cistern even though the water temperature was 20°C or below. At day 92 no legionella were detected, possibly as a result of the natural decay predicted by the chain line shown on the graph.

**Heterotrophic bacteria (planktonic)**

Figure 5.4 illustrates planktonic heterotrophic bacteria results for the cisterns.
During the first two days of disinfection the bacteria in Rigs 2 and 3 reduced dramatically relative to Rig 1 but thereafter were subject to considerable fluctuations. These fluctuations in bacteria numbers were due to the biofilm on the surfaces of the cistern breaking down and releasing bacteria into the water.

Up to day 60 the chlorine dioxide concentrations in the cisterns were maintained at around 0.05 ppm. The results therefore suggest that this concentration of chlorine dioxide was not sufficient to control the heterotrophic bacteria released from the biofilm during disinfection. By day 64 when the chlorine dioxide concentration had increased to 0.1 ppm the heterotrophic bacteria were under control.

For Rig 1 the heterotrophic bacteria gradually declined with very little correlation to the legionella results apart from day 92.

**Biofilms**

Figure 5.5 illustrates biofilm coverage results for the cisterns.
During the first 7 days of disinfection the biofilm coverage in all three rigs changed little apart from Rig 1 which dropped from 29% down to 5%. This result was very surprising because the cistern had no disinfection measures applied to it. Nine weeks into disinfection (at day 64), both of the chlorine dioxide rigs showed biofilm coverages down to insignificant levels when chlorine dioxide concentrations were at 0.1 ppm.

Figure 5.6 illustrates results of legionella recovered from the biofilm. Note that these results are expressed as cfu/cm² of biofilm.

Prior to disinfection the results show that legionella within the biofilm was reducing for all three rigs due to natural decay. During disinfection, the first results (on day 8) indicated that no legionella could be recovered from any of the rigs. These results may have been inaccurate given that Rig 1 had no disinfection measures applied. The graph therefore shows chain lines indicating a trend line which ignores these results. After day 8 the results show that legionella was recovered from all three rigs and at day 21 and day 64 onwards no legionella were recovered from the rigs with chlorine dioxide concentrations around 0.1 ppm. These results were good compared to Rig 1 where legionella continued to be recovered up to the end of the disinfection period.

Figure 5.7 illustrates results of heterotrophic bacteria recovered from the biofilm. Note that these results are expressed as cfu/cm² of biofilm.
Prior to disinfection the results show a slight decay in bacteria levels. During disinfection the results are mixed. For Rig 1 the recovery of bacteria actually increased which suggests that these were the dominant species in the biofilm. For Rigs 2 and 3 the recovery of bacteria showed a decreasing trend. By day 64 with chlorine dioxide concentrations around 0.1 ppm they have reduced by a factor of $10^1$ or $10^2$ down to bacteria levels of 500 to 5000 cfu/cm$^2$ of biofilm. These levels of recovery were maintained throughout the disinfection period with chlorine dioxide concentrations rising to 0.4 ppm. In light of the low biofilm coverage these levels of recovery were not significant.

Overall, the results suggest that a chlorine dioxide concentration of 0.1 ppm had produced successful control of the biofilms in the cisterns.

### 5.4 Cold Water Pipework Circuits

**Legionella (planktonic)**

Figure 5.8 illustrates planktonic legionella results for the cold water pipework circuits.
Prior to disinfection the results show that all three rigs started with legionella at $10^7$ cfu/l but this gradually decayed to $10^5$ cfu/l before disinfection. During disinfection Rigs 2 and 3 produced rapid rates of disinfection with chlorine dioxide concentrations of 0.1 ppm.

**Heterotrophic bacteria (planktonic)**

Figure 5.9 illustrates planktonic heterotrophic bacteria results for the cold water pipework circuits.

![Figure 5.9](image)

Heterotrophic bacteria (planktonic) results @ 22°C for cold water pipework circuit during disinfection

Prior to disinfection bacteria levels in all three rigs were approximately $10^2$ cfu/ml. When disinfection took place the bacteria rapidly diminished but then recovered in all three rigs. The reasons for this were not fully understood, particularly in Rig 1 where no disinfection measures were being applied.

For the chlorine dioxide rigs the results indicate that control of heterotrophic bacteria levels was not achieved until a chlorine dioxide concentration of 0.1 ppm to 0.2 ppm was established in the pipework circuits around day 70.

**Biofilms**

Figure 5.10 illustrates biofilm coverage in the cold water circuits.
Prior to disinfection all three cold water circuits showed a low level of biofilm colonisation of the copper pipework surfaces.

This appears to suggest that the copper pipework continued to be naturally biocidal against the biofilm in all three rigs.

Figure 5.11 illustrates the number of legionella recovered from the biofilm.

Prior to disinfection legionella were recovered from the biofilm of all three test rigs.

During disinfection no legionella were recovered from the chlorine dioxide test rigs whilst some legionella continued to be recovered from the control rig. This would suggest that chlorine dioxide had killed the legionella within the biofilm but the control rig legionella also reduced. The results were therefore not conclusive.

Figure 5.12 illustrates the number of heterotrophic bacteria recovered from the biofilm.
Prior to disinfection numbers of heterotrophic bacteria were generally around $10^2$ cfu/cm$^2$ in all three rigs.

During disinfection numbers reduced in all three rigs, initially because the biofilm coverage was so low. As disinfection continued, heterotrophic bacteria were recovered at levels equivalent to infection. From day 92 onwards however, no bacteria were recovered from the biofilm of the rigs with chlorine dioxide concentrations around 0.2 ppm to 0.3 ppm. This would suggest that this concentration of chlorine dioxide had killed the heterotrophic bacteria in the biofilm and no further seeding of the water in the pipework circuit was taking place. The planktonic results correlate well with this finding. For Rig 1 bacteria continued to be recovered.

**Chlorine dioxide**

Chlorine dioxide sampling on the cold water circuit was undertaken at the end of the pipework circuit. This point was chosen because the cold water circuit is effectively a dead leg when there is no draw off of water. These results would provide a good indication as to whether the chlorine dioxide had been distributed throughout the pipework circuit. Figure 5.13 illustrates chlorine dioxide and total oxidant concentrations measured at the end of the cold water pipework.

**Figure 5.12**

Heterotrophic bacteria recovered @ 22°C from biofilm in cold water pipework circuit during disinfection

**Figure 5.13**

Chlorine dioxide and total oxidant concentrations in cold water circuits (DPD method)
approximately half those established in the cisterns because of intervening reactions. In terms of total oxidant levels the graph illustrates that 0.5 ppm was exceeded in both rigs after day 60 when the control strategy was changed.

### Copper levels

Copper levels were recorded in the cold water pipework circuits during infection and disinfection in order to monitor the influence of chlorine dioxide copper leaching. Figure 5.14 illustrates copper results for the cold water pipework circuits.

![Figure 5.14](image)

**Figure 5.14**

Copper levels measured in the cold water pipework circuits during infection and disinfection

The graph illustrates that as chlorine dioxide concentrations in Rigs 2 and 3 were increased during disinfection (day 61 onwards) the copper levels in solution also increased. For Rig 2 with hard water the trend line indicates an increase of approximately 0.4 ppm of copper over the entire disinfection period compared to Rig 1 where the increase is only 0.1 ppm. For Rig 3 with soft water the trend line indicates a copper increase of 0.5 ppm. Further discussion of this point is contained in Section 6.1.

### 5.5 Cold Water Outlets

**Legionella (planktonic)**

Figure 5.15 illustrates planktonic legionella results for the cold outlet located nearest to the cistern.
5. Legionella (planktonic) results for cold water during disinfection

Prior to disinfection all three rigs started with legionella at 10 cfu/l but this gradually decayed to 10 cfu/l before disinfection. During disinfection Rigs 2 and 3 produced rapid rates of disinfection with concentrations below 0.5 ppm respectively. For Rig 2, no legionella were detected on day 7 but on day 17 there was a 10 cfu/l peak. The reason for this peak is not clearly understood but it is possibly connected either with the fact biofilm harbouring bacteria had detached itself.

Figure illustrates planktonic legionella results for the cold outlet located furthest away from the cistern.

During disinfection Rigs 2 and 3 also produced rapid rates of disinfection concentrations below 0.5 ppm.
Heterotrophic bacteria (planktonic)

Figure 5.17 illustrates planktonic heterotrophic bacteria results for the cold water outlet located nearest to the cistern.

Prior to disinfection bacteria levels in all three rigs were approximately $10^2$ cfu/ml. When disinfection took place the bacteria rapidly decayed in the chlorine dioxide rigs on day 2 but then recovered on day 7 back to levels of bacteria which were slightly higher than infection. The reasons for this are not fully understood, but the results do correlate well with the breakdown of biofilm in the cisterns. Control of bacteria was not achieved until day 60 with chlorine dioxide concentrations around 0.1 ppm and total oxidants exceeding 0.5 ppm in both rigs. Figure 5.18 illustrates results for the water outlet located furthest from the cistern.

These results were very similar to the outlet located nearest to the cistern. As disinfection commenced the bacteria numbers in the chlorine dioxide rigs dropped.
In terms of controlling bacteria this was not achieved until day 92 with chlorine dioxide concentrations around 0.2 ppm and total oxidant concentrations greater than 0.5 ppm (Figure 5.16).

**Biofilms**

At the end of the experiment rubber washers were removed from the cold taps located nearest and furthest from the cisterns in all three test rigs. A biofilm often forms on tap washers and serves to provide a source of bacteria seeding the water being discharged from the outlet. Table 5.1 illustrates results for biofilm coverage and recovery of heterotrophic and legionella bacteria from the biofilm.

<table>
<thead>
<tr>
<th>Rig 1</th>
<th>% Biofilm coverage</th>
<th>TVC Results cfu/cm² 22 °C</th>
<th>TVC Results cfu/cm² 37 °C</th>
<th>Legionella cfu/cm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cold tap (nearest)</td>
<td>56.08</td>
<td>57000</td>
<td>2140</td>
<td>0</td>
</tr>
<tr>
<td>Cold tap (furthest)</td>
<td>6.17</td>
<td>3100</td>
<td>40</td>
<td>10</td>
</tr>
<tr>
<td>Rig 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cold tap (nearest)</td>
<td>39.06</td>
<td>4400</td>
<td>840</td>
<td>0</td>
</tr>
<tr>
<td>Cold tap (furthest)</td>
<td>64.84</td>
<td>380</td>
<td>130</td>
<td>0</td>
</tr>
<tr>
<td>Rig 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cold tap (nearest)</td>
<td>29.614</td>
<td>10</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Cold tap (furthest)</td>
<td>14.92</td>
<td>40</td>
<td>10</td>
<td>0</td>
</tr>
</tbody>
</table>

Biofilm coverage varied between the rigs. In general, none of the rigs had low biofilm coverage on both of the water outlets located nearest and furthest from the cisterns. The more important indication that disinfection had taken place however was the recovery of bacteria from the biofilm.

The recovery of legionella from the biofilms of the rubber washers produced only one positive result. This was from Rig 1 on the outlet located furthest away from the cistern. Removal of the heterotrophic bacteria was most effective in Rig 3, while the slightly higher levels of bacteria recovery from Rig 2 suggest that scale deposits may have partially shielded the bacteria from the effects of chlorine dioxide. Overall, the results suggest that disinfection has been effective in the chlorine dioxide rigs with chlorine dioxide concentrations up to 0.2 ppm.
5.6 HOT WATER CALCIFIERS

Figure 5.19 illustrates planktonic legionella results for the base of the calorifiers.

Prior to disinfection all three rigs started with legionella at $10^7$ cfu/l but this gradually decayed to $10^5$ cfu/l before disinfection. During this period the supply water temperatures in each of the calorifiers was maintained at 35 °C with base temperatures of 30°C. During disinfection the supply water temperature in Rig 1 was elevated to 60°C whilst the two chlorine dioxide rigs remained at 35°C. With no change in water temperatures Rigs 2 and 3 produced rapid rates of disinfection with chlorine dioxide concentrations ranging between 0.1 ppm and 0.4 ppm. These chlorine dioxide concentrations were relatively high. This was because the calorifier was receiving chlorine dioxide in the water from the cistern in addition to receiving chlorine dioxide from the pumped hot water circuit.

For Rig 1 the results show that legionella continued to survive in the base of the calorifier up to day 113 because the calorifier was not fitted with a shunt pump which would have enabled the base water temperature to be elevated above 45°C.

Heterotrophic bacteria (planktonic)

Figure 5.20 illustrates planktonic heterotrophic bacteria results for the base of the calorifiers.
Prior to disinfection heterotrophic bacteria levels in all three rigs were approximately $10^2$ cfu/l. When disinfection took place the bacteria decayed in all three rigs but then recovered. For the chlorine dioxide rigs, control of bacteria was not achieved until day 60 when chlorine dioxide concentrations were between 0.2 and 0.35 ppm. This also suggests that the system was overloaded with bacteria as a result of biofilm decay in the cisterns. For Rig 1 the results show that with a base water temperature of 45°C the bacteria were not controlled.

**Biofilm**

At the end of the disinfection period a copper pipework coupon was removed from the base of each calorifier and analysed. Table 5.2 illustrates results for biofilm coverage and recovery of heterotrophic and legionella bacteria from the biofilm.

<table>
<thead>
<tr>
<th>Rig</th>
<th>% Biofilm coverage</th>
<th>TVC results cfu/cm²</th>
<th>Legionella cfu/cm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rig 1</td>
<td>1.744</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Rig 2</td>
<td>3.54</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Rig 3</td>
<td>6.07</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

The results show low biofilm coverage for all three rigs. This was quite surprising because Rig 1 had a low base water temperature of 45°C for most of the time during disinfection.

No legionella bacteria were recovered from any of the samples and only one sample produced a small recovery of heterotrophic bacteria. Overall, the results are inconclusive with respect to chlorine dioxide since disinfection has taken place in Rig 1. Although Rig 1 is not technically a control rig in this instance disinfection would not be expected at a water temperature of 45°C. Like the cold water pipework circuits, the results suggest that the copper coupons are naturally biocidal.

**5.7 HOT WATER PIPEWORK CIRCUITS**

**Chlorine dioxide**

Figure 5.21 illustrates the chlorine dioxide concentrations measured in the hot water pipework circuits during disinfection.
Figure 5.21
Chlorine dioxide concentrations in hot water pipework circuits during disinfection

The graph serves to illustrate how chlorine dioxide concentrations rose as control strategies were changed to improve bacteria results through the disinfection period.

Legionella (planktonic)

Figure 5.22 illustrates planktonic legionella results for the hot water circuits.

Prior to disinfection all three rigs started with legionella at $10^7$ cfu/l but this gradually decayed to $10^5$ cfu/l before disinfection. During disinfection all three rigs produced rapid rates of disinfection. For the chlorine dioxide rigs effective disinfection and control of legionella was achieved by day 17 in both rigs with chlorine dioxide concentrations around 0.05 ppm. For Rig 1 effective disinfection was achieved on day 2 but at the end of the disinfection period a $10^4$ cfu/l increase occurred. This legionella was found to be L-pneumophila serogroup 6. It was not found in the results from the incoming water and base of the calorifier and therefore it is possible that it had entered the rig from an extraneous
source, possibly via the open vent pipe which discharges in the cold water cistern.

**Heterotrophic bacteria (planktonic)**

Figure 5.23 illustrates planktonic heterotrophic bacteria results for the hot water circuits.

Prior to disinfection, bacteria levels in all three rigs were approximately $10^2$ cfu/ml. When disinfection took place the bacteria decayed in all three rigs but then recovered. For the chlorine dioxide rigs, control of heterotrophic bacteria was not achieved until around day 64 when chlorine dioxide concentrations were 0.05 ppm or above. For Rig 1 the results show that with a flow temperature of 60°C and a return temperature of 50°C the bacteria were under control as early as day 15.

**Biofilms**

Figure 5.24 illustrates biofilm coverage results for the hot water circuits.

---

**Figure 5.23**  
Heterotrophic bacteria (planktonic) results @ 37°C for hot water circuits during disinfection

**Figure 5.24**  
Biofilm coverage in hot water pipework circuits during disinfection
Before disinfection the biofilm coverage on the chlorine dioxide rigs rarely exceeded 10% whilst Rig 1 had double the coverage at 20%. The reason for these differences, if significant, is not clear. Tests on pipe samples ruled out the possibility of residual silver from the previous use of the rig.

During disinfection all three rigs experienced a drop in biofilm coverage down to less than 5%. For Rigs 2 and 3 this was achieved with chlorine dioxide concentrations of around 0.1 ppm and water temperatures of 30°C to 35°C. For Rig 1 this was achieved with flow and return circuit temperatures of 60°C and 50°C respectively.

Figure 5.25 and Figure 5.26 illustrate numbers of legionella and heterotrophic bacteria recovered from the biofilm. These illustrate that no legionella were recovered but numbers of heterotrophic bacteria were recovered from the biofilms in Rigs 1 and 2 which suggests that the biofilm was viable in these rigs and scale may be responsible for protecting these bacteria from the effects of chlorine dioxide and temperature.

Overall, the results for biofilms are good but the effects of scale harbouring heterotrophic bacteria need to be considered.
water pipework circuits during disinfection

**Figure 5.26**
Heterotrophic bacteria recovered @ 37°C from biofilm in hot water circuits during disinfection

**Copper levels**
Figure 5.27 illustrates copper levels measured in the hot water pipework circuits.

**Figure 5.27**
Copper levels measured in the hot water pipework circuits during infection and disinfection.

was increased to 0.4 ppm on day 96. During the period after day 96 the copper level increased by 0.3 ppm in Rig 2 and over 3 ppm in Rig 3 ie exceeding the water supply regulation limit of 3 ppm. Further discussion of this point is contained in Section 61.
5.8 Hot Water Outlets

Prior to disinfection all three rigs started with legionella at $10^7$ cfu/l but this gradually decayed to $10^5$ cfu/l before disinfection. During disinfection the two chlorine dioxide rigs recorded no detection of legionella with chlorine dioxide concentrations around 0.1 ppm and total oxidant concentrations below 0.5 ppm. For Rig 1 the legionella continued to produce spikes throughout the disinfection period. This was not surprising because the hot water deadlegs were only discharged for 15 seconds every two hours. The discharge temperature on Rig 1 only achieved 31°C at the end of the 15 second discharge. This explained why the outlet persistently had a legionella problem.

As a separate exercise to see whether the outlet would meet the current HS(G)70 criterion of 50°C within one minute the outlet was discharged and the water temperature logged. The results surprisingly showed that 50°C was achieved after 30 seconds discharge. This was despite having a deadleg which exceeded the recommended length in BS6700 and having a flow rate discharge which is normal in use. The result therefore highlighted the fact that outlets connected to deadlegs exceeding BS6700 could pass the HS(G)70 criteria but still cause problems in use if only discharged for 15 seconds every two hours.

The last result from the hot water deadleg on Rig 1 showed that the legionella was L-pneumophila serogroup 6. This result correlates with the finding of the same organism in the hot water circuit (see Section 5.8).

Figure 5.29 illustrates planktonic heterotrophic bacteria results.
Prior to disinfection heterotrophic bacteria levels in all three rigs were approximately $10^3$ cfu/ml. When disinfection took place the bacteria decayed in Rigs 1 and 3 only but then recovered. From day 60 onwards the chlorine dioxide rigs started to show control of bacteria when chlorine dioxide concentrations rose to around 0.2 ppm and total oxidant concentrations exceeded 0.5 ppm.

Table 5.3 illustrates biofilm results for washers removed from the hot water taps.

<table>
<thead>
<tr>
<th>Rig</th>
<th>% Biofilm coverage</th>
<th>TVC results cfu/cm²</th>
<th>Legionella cfu/cm²</th>
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</thead>
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<tr>
<td>1</td>
<td>78.1</td>
<td>4600</td>
<td>12800</td>
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<tr>
<td>2</td>
<td>44.6</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>3</td>
<td>0.25</td>
<td>10</td>
<td>0</td>
</tr>
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These results illustrate that disinfection was successful in both of the chlorine dioxide rigs with chlorine dioxide concentrations up to 0.4 ppm. Whilst the biofilm coverage in Rig 2 would appear to be high the recovery of heterotrophic bacteria suggests that this biofilm is actually dead.

For Rig 1, the results were poor. The results serve to illustrate the problem of a temperature regime and the discrepancy between the HS(G)70 criterion of one minute’s discharge to achieve 50°C and normal usage where 15 seconds discharge is not uncommon.

In general the biofilm coverages were higher in the hard water than the soft because scale on the surface of the pipework has provided an ideal environment for the biofilm to grow.

**Showers**

Figure 5.30 illustrates planktonic legionella results from the showers.
Prior to disinfection all three rigs started with legionella at $10^7$ cfu/l but this gradually decayed to $10^5$ cfu/l before disinfection. During disinfection the two chlorine dioxide rigs recorded no legionella with chlorine dioxide concentrations around 0.1 ppm and total oxidant concentrations below 0.5 ppm. For Rig 1 legionella were detected throughout the disinfection period because of the infected cistern supplying cold water to the mixing valve with no disinfection measures being applied. The last sample from the shower which contained L-pneumophila serogroup 6 legionella indicated another possible route for infection. This particular organism was not detected in the cistern but was detected in the hot water circuit. It is possible that the shower was infected by the hot water circuit on this occasion. The result correlates well with the finding in Section 5.8.

Figure 5.31 illustrates planktonic heterotrophic bacteria results for the showers.
Prior to disinfection heterotrophic bacteria levels in all three rigs were approximately $10^3$ cfu/l. Initially during disinfection the number of bacteria in all three rigs remained fairly stable. From day 60 onwards the chlorine dioxide rigs started to control bacteria with chlorine dioxide concentrations around 0.1 ppm to 0.2 ppm and total oxidant concentrations greater than 0.5 ppm. For Rig 1 bacteria levels from the shower outlet were high because no disinfection measures were being applied to the cold water feeding one side of the mixing valve.

Table 5.4 illustrates results for washers removed from the shower mixing valves.

<table>
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<tr>
<th>Rig</th>
<th>Sample location</th>
<th>% Biofilm coverage</th>
<th>TVC results cfu/cm²</th>
<th>Legionella cfu/cm²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Shower - Hot Inlet</td>
<td>83.2</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Shower - Cold Inlet</td>
<td>21.9</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Shower - Outlet</td>
<td>-</td>
<td>2400 2760</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>Shower - Hot Inlet</td>
<td>59.4</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Shower - Cold Inlet</td>
<td>39.8</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Shower - Outlet</td>
<td>-</td>
<td>0 20</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>Shower - Hot Inlet</td>
<td>92.7</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Shower - Cold Inlet</td>
<td>9.8</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Shower - Outlet</td>
<td>-</td>
<td>10 0</td>
<td>0</td>
</tr>
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</table>

The results were generally good for the chlorine dioxide rigs. Whilst the % biofilm coverage on the inlets to the valves appears quite high the very low recovery of bacteria from the outlets suggests that these biofilms were dead. These results were achieved with chlorine dioxide concentrations up to 0.2 ppm.

For Rig 1 the biofilm coverages were high and the recovery of heterotrophic bacteria suggests that the biofilm was viable.
Low temperature mixing valves

Figure 5.32 illustrates planktonic legionella results for the low temperature mixing valves.

All three rigs had legionella levels around $10^7$ cfu/l at some stage during infection but this gradually decayed to $10^5$ cfu/l before disinfection. During disinfection the two chlorine dioxide rigs recorded no detection of legionella with chlorine dioxide concentrations of around 0.1 ppm and total oxidant concentrations below 0.5 ppm. For Rig 1 legionella were detected throughout the disinfection period for the same reasons as the shower.

Figure 5.33 illustrates planktonic heterotrophic bacteria results for the low temperature mixing valves.

Prior to disinfection bacteria levels in all three rigs were approximately $10^3$ cfu/l. When disinfection took place the bacteria in all three rigs remained fairly stable. From day 60 onwards the chlorine dioxide rigs started to control bacteria as chlorine dioxide concentrations rose to
between 0.1 ppm and 0.2 ppm and total oxidant concentrations exceeded 0.5 ppm.

Table 5.5 illustrates biofilm results for washers removed from taps served by the low temperature mixing valves

<table>
<thead>
<tr>
<th>Rig</th>
<th>% Biofilm coverage</th>
<th>TVC results cfu/cm²</th>
<th>Legionella cfu/cm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>34.7</td>
<td>3400</td>
<td>2720</td>
</tr>
<tr>
<td>2</td>
<td>29.9</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>4.4</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
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The results show that effective disinfection took place in the low temperature mixing valves of Rigs 2 and 3 compared to Rig 1 with chlorine dioxide concentrations up to 0.4 ppm. The % biofilm coverage for Rig 2 is high but the fact that no bacteria are recovered shows that this biofilm is dead.
6 SUMMARY OF FINDINGS

The infection results indicated that the bacterial population had established itself in the planktonic phase and biofilm in all three rigs after 8 weeks. This was a very important point to establish before disinfection took place so that further changes in bacteria population could not be attributed to any influences other than the disinfection process.

The disinfection programme was brought to an end after a period of 16 weeks when the chlorine dioxide test rigs were continually producing good results ie no planktonic legionella could be detected and heterotrophic bacteria were reduced and controlled in the hot and cold water systems. In terms of biofilms, the results in both hot and cold water showed that no legionella could be recovered. Some biofilms were completely killed, whilst others were still viable but seeding reduced, and in some cases insignificant, quantities of heterotrophic bacteria into the water.

The corresponding results for the temperature regime were mixed. In cold water planktonic and biofilm results were poor because no disinfection measures were applied. For hot water the results were much better but planktonic legionella were detected even with water temperatures maintained to HS(G)70 guidelines.

Table 6.1 provides a summary of the findings. Using a scale ranging from Poor to Excellent the overall evaluation covers planktonic and biofilm results.

<table>
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<tr>
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<th>Chlorine dioxide with hard water</th>
<th>Chlorine dioxide with soft water</th>
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<tr>
<td><strong>Cisterns</strong></td>
<td>No disinfection</td>
<td>Good</td>
<td>Good</td>
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<tr>
<td><strong>Cold water pipework circuits</strong></td>
<td>No disinfection</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td><strong>Cold water outlets</strong></td>
<td>No disinfection</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td><strong>Hot water calorifiers</strong></td>
<td>Poor</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td><strong>Hot water circuits</strong></td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td><strong>Hot water outlets</strong></td>
<td>Poor</td>
<td>Good</td>
<td>Excellent</td>
</tr>
</tbody>
</table>

**Notes:**

1. Gradual decay due to lack of nutrients. In the absence of residual chlorine the biofilms established themselves and survived despite gradual reduction.
2. No planktonic legionella detected at day 2 onwards. 0.1 ppm ClO₂ was needed to control heterotrophic bacteria dispersion from breakdown of biofilm.
3. Similar performance to hard water but a few peaks of planktonic legionella possibly due to bacteria dispersion from biofilm.
4. No apparent reductions in planktonic bacteria apart from natural decay but reduction in biofilm coverage and legionella within the biofilm due to biocidal effect of copper pipework.
5. No planktonic legionella detected from day 7 onwards. 0.1 ppm ClO₂ was needed to control heterotrophic bacteria. Results from biofilm coverage and legionella...
within were not conclusive because of biocidal effect of copper pipework. For heterotrophic bacteria within biofilm, no bacteria were detected from day 92 onwards.

6. Similar performance to hard water but one peak of planktonic legionella on day 10 possibly due to bacteria dispersion from biofilm. Results from biofilm coverage and legionella within were not conclusive because of biocidal effect of copper pipework. For heterotrophic bacteria within biofilm, no bacteria were detected from day 92 onwards.

7. Gradual reduction of planktonic legionella due to natural decay only.

8. Rapid rate of disinfection for planktonic legionella with ClO₂ concentrations around 0.1 ppm. For planktonic heterotrophic bacteria disinfection with 0.1 ppm ClO₂ was slow. Biofilm results were generally good but the scale in hard water may have partially shielded the heterotrophic bacteria from the chlorine dioxide.

9. Rapid rate of disinfection for planktonic legionella with ClO₂ concentrations around 0.1 ppm. For planktonic heterotrophic bacteria disinfection with 0.1 ppm ClO₂ was slow. Biofilm results were excellent.

10. No disinfection took place apart from natural decay because base water temperature was 45°C.

11. Good disinfection of planktonic legionella but scale in hard water appears to have partially shielded bacteria from the effects of the chlorine dioxide. Control of planktonic heterotrophic bacteria was difficult even with ClO₂ between 0.1 and 0.45 ppm.

12. No legionella detected from day 7 onwards. Control of planktonic heterotrophic bacteria was difficult even with ClO₂ between 0.1 and 0.45 ppm.

13. Excellent rate of disinfection apart from last water sample which detected serogroup 6 legionella that had possibly entered rig via the open vent.

14. Disinfection of planktonic legionella good but scale does appear to harbour bacteria from the effects of the chlorine dioxide.

15. Results better than hard water in terms of rate of disinfection and control of planktonic bacteria.

16. Despite meeting HS(G)70 temperature criteria the results for the hot water deadleg were poor because the outlet was only discharged 15 seconds every two hours. For the other outlets results were poor because of the cold feed having no disinfection measures applied.

17. Excellent results from planktonic and biofilm results. The only concerns were the control of heterotrophic bacteria and biofilm coverage.

18. Control of planktonic heterotrophic bacteria and biofilm coverage better than results in hard water.

### 6.1 Copper Levels

All the circuits dosed with chlorine dioxide showed some increase in the level of copper found in solution.

Any increase in copper levels was of interest for three reasons. Firstly copper concentrations above 1000 µg/l (WHO aesthetic guideline) can potentially cause staining of baths and showers, though there is no evidence that this has been a problem in actual installations. Secondly, copper concentrations above 3000 µg/l would contravene the Water Supply (Water Quality) Regulations 1989. Thirdly, raised copper levels may be a sign of pipework corrosion.

There are thought to be four possible mechanisms for the increased concentrations of copper:

- The biofilm contained small quantities of copper and copper compounds that were released into solution as the chlorine dioxide disrupted the biofilm.
- Copper compounds in the surface deposits/scale coating the pipe were mobilised by the application of chlorine dioxide.
- The chlorine dioxide stripped off the protective deposits on the copper pipe leading to increased rates of conventional corrosion.
• The chlorine dioxide attacked the copper pipework directly, releasing corrosion products into solution.

The trial did not run for long enough to conclusively determine which of these mechanisms was most significant or whether the copper levels would reach an equilibrium or indeed decrease. The major cause of corrosion failure of copper pipe in buildings is usually pitting corrosion. The duration of this trial was insufficient to determine whether this problem would be aggravated by chlorine dioxide. However, any oxidising biocide (such as bromine or chlorine, as well as chlorine dioxide) has the potential to react with copper pipework, and may increase corrosion rates.
7 CONCLUSIONS

7.1 Chlorine Dioxide Regime

Low concentrations of chlorine dioxide were effective in controlling planktonic legionella bacteria. Where chlorine dioxide concentrations were maintained at 0.1 ppm or above chlorine dioxide was shown to provide effective disinfection and control of planktonic legionella in both cold water systems and hot water systems with reduced water temperatures as low as 30°C to 35°C.

For heterotrophic bacteria higher concentrations of chlorine dioxide were needed to produce effective disinfection and control in both cold and hot water systems. For cold water systems chlorine dioxide concentrations of 0.1 ppm to 0.2 ppm were shown to be effective whilst higher concentrations up to 0.35 ppm were needed for the hot water system.

For biofilms chlorine dioxide concentrations around 0.1 ppm produced effective disinfection of the biofilm in the GRP cisterns and the hot water pipework circuit running at a reduced water temperature of 30°C to 35°C. For hot and cold water outlets the final results from the washers showed that chlorine dioxide concentrations of 0.4 ppm were effective in killing biofilm. For cold water pipework and the base of hot water calorifiers the biofilm results were inconclusive with respect to chlorine dioxide because copper is naturally biocidal.

Maintaining effective chlorine dioxide concentrations whilst keeping total oxidant concentrations below 0.5 ppm was not a straightforward task even with a test rig which had identical water discharges each day. One of the main problems was the low turnover of water in the rig which caused the total oxidant levels to rise. Another problem was the method of dosing chlorine dioxide according to a sensor in the system. In industry, these problems are less significant because typical water systems have higher turnover rates and the chlorine dioxide would normally be proportionally dosed according to the amount of water entering the system.

In terms of chlorine dioxide usage, the results showed that more chlorine dioxide was used in the soft water than hard water systems to achieve the same concentration. Furthermore, the results suggested that chlorine dioxide may be gassing off up the open vent of the hot water calorifiers because more chlorine dioxide was used in the hot water than cold in both rigs. This suggests that excessively high calorifier temperatures should be avoided.

To obtain effective control of bacteria it is important to distribute the chlorine dioxide throughout the system. In systems with low throughputs of water as experienced in the test rig this can be a problem if total oxidant levels at outlets are to be controlled below 0.5 ppm.

In terms of measuring chlorine dioxide, the results suggest that low chlorine dioxide concentrations experienced at water outlets were difficult to measure with the DPD test method. An easier and more appropriate control measure (providing reasonable water throughput is achieved) might be total oxidant measured with the DPD or drop test.
Scale and bacteria play an important part in any water treatment regime. The results in hard water showed that consideration must be given to controlling scale if chlorine dioxide is to be fully effective against heterotrophic bacteria in biofilms in a low level disinfection programme.

All the circuits dosed with chlorine dioxide showed some increase in the level of copper found in solution.

The trial did not run for long enough to conclusively determine whether the copper levels would reach an equilibrium or indeed decrease. The major cause of corrosion failure of copper pipe in buildings is usually pitting corrosion and the trial duration was insufficient to determine whether this problem would be aggravated by chlorine dioxide. Any oxidising biocide (such as bromine or chlorine, as well as chlorine dioxide) has the potential to react with copper pipework, and may increase corrosion rates. However no problems of direct copper corrosion have been reported in industry associated with the use of up to 0.5 mg/λ of chlorine dioxide for water disinfection.

### 7.2 Temperature regime

In cold water storage the results showed that in the absence of residual chlorine in the mains water, biofilms can establish themselves in glass reinforced plastic (GRP) cisterns built to bylaw 30 standards even when the temperature of the water is kept at or below 20°C.

Furthermore, the results showed that cold water cisterns can be a source of infection to the systems they serve, namely the hot water storage calorifier, cold water pipework circuit and water outlets such as showers and low temperature mixing valves which receive water supplies from both of these sources.

For hot water circuits the results suggest that the maintenance of hot water at 60°C flow and 50°C return does not provide complete protection from legionella surviving. The hot water circuit has an open vent to atmosphere which stores cooler water. The results suggest that this was the potential source of contamination to the hot water circuit.

For hot water outlets the results were generally poor because the cold water supply to the shower and low temperature mixing valve did not have any disinfection measures applied and therefore served as a source of contamination. The results for the hot water deadleg highlighted the problem of a temperature regime where normal usage of 15 seconds water discharge every two hours did not produce effective disinfection. The deadleg meets HS(G)70’s suggested test criteria of achieving 50°C at the outlet within one minute of running. However, HS(G)70 also demands that a thorough risk assessment is carried out, which should reveal that the expected usage would not protect the outlet, preventing compliance with HS(G)70.
## 8 SPONSORS AND OTHER PROJECT CONTRIBUTORS

### Microbiological Services

<table>
<thead>
<tr>
<th>Name</th>
<th>Address</th>
<th>Phone</th>
<th>Fax</th>
</tr>
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<tbody>
<tr>
<td>Dr J Walker</td>
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<td>01980 612643</td>
<td>01980 612731</td>
</tr>
<tr>
<td>The Water Quality Centre</td>
<td>Thames Water, Spencer House, Manor Farm Road, READING, Berkshire, RG2 0JN</td>
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### Suppliers of Chlorine Dioxide Units

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<tr>
<td>Mr J Wilson</td>
<td>Chloroxy-Tech Ltd, Powke Lane Industrial Estate, Blackheath, BIRMINGHAM</td>
<td>0121 561 3144</td>
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</tr>
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<td>Mr T Parkinson</td>
<td>Feedwater Ltd, Tarran Estate, Moreton, WIRRAL, L46 4TP</td>
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<td>0151 678 5459</td>
</tr>
<tr>
<td>Mr D W Lee</td>
<td>Houseman Ltd, Chapel House, Alma Road, Windsor, BERKSHIRE, SL4 3HD</td>
<td>01753 712000</td>
<td>01753 712140</td>
</tr>
<tr>
<td>Mr S Hartley</td>
<td>Hertel Services, Poolspringe, LLANWERNE, NR HEREFORD, HR2 8JJ</td>
<td>01981 540020</td>
<td>01981 540853</td>
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### Prominent Fluid Controls (UK) Ltd

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<th>Name</th>
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<th>Phone</th>
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<tr>
<td></td>
<td>Resolution Road, Ashby de la Zouch, Leicestershire, LE65 1DW</td>
<td>01530 560 555</td>
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### DPD and Copper Test Kits

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<tr>
<td>DPD Test</td>
<td>Palintest Ltd, Palintest House, Kingsway, Team Valley, Gateshead, Tyne &amp; Wear</td>
<td>0191 491 0808</td>
<td>0191 482 5372</td>
</tr>
<tr>
<td>Copper 1 DCR™ Instrument Test Kit</td>
<td>Galco (UK) Ltd, Holywell Lodge, 41 Holywell Hill, St Albans, Herts, AL1 1HD</td>
<td>01727 850267/837872</td>
<td>01727 837141</td>
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### Publications

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<td>01344 426511</td>
<td>01344 714846</td>
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<tr>
<td>HSE Books</td>
<td>PO Box 1999, Sudbury, Suffolk, CO10 6FS</td>
<td>01787 881165</td>
<td>01787 313995</td>
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