Advice on Monitoring the Effectiveness of Treatment to Reduce Plumbosolvency (WTA 9516)

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ADVICE ON MONITORING THE EFFECTIVENESS OF TREATMENT TO REDUCE PLUMBOSOLVENCY

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SUMMARY

The Water Quality Regulations place a responsibility on water undertakers to treat water to reduce lead concentrations in water at consumers' taps. Guidance has been issued to water undertakers on the interpretation of the Regulations. That guidance advises water undertakers to use on-site lead pipe test rigs, or sampling from consumers' taps during field trials, to monitor the effectiveness of treatment to achieve a significant reduction in lead concentrations.

This document provides advice on the construction and operation of lead pipe rigs and on the sampling from consumers' taps for monitoring the effectiveness of treatment to reduce plumbosolvency. This advice draws upon extensive experience by the authors. In particular the document includes:

- the rationale for the use of half-hour stagnation samples in monitoring plumbosolvency;
- the rationale for the use of lead pipe rigs;
- discussion of the merits of using "old" or "new" lead pipe;
- general details for construction of a "basic" lead pipe rig;
- general details for construction of an "automatic" lead pipe rig;
- the basic principles for monitoring at consumers' taps.

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This report can be obtained from the WRc Publications Unit, telephone (0491) 571531, priced at £25.
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1. INTRODUCTION

1.1 BACKGROUND

The Water Supply (Water Quality) Regulations 1989\(^{(1)}\) set a standard for lead of 50\(\mu\)g/l. Regulation 24 places a new responsibility on water undertakers to treat water whenever there is a risk that the standard may be exceeded in a water supply zone except, \textit{inter alia}, where treatment is unlikely to achieve a significant reduction in the concentration of lead. The Department of the Environment and Welsh Office have published a guidance document\(^{(2)}\) entitled "Guidance on Safeguarding the Quality of Public Water Supplies" which provides advice on the interpretation of the regulations, including Regulation 24.

The guidance document provides advice on the methods for determining the effectiveness of treatment in achieving a significant reduction in lead concentrations. It recommends the use of an on-site lead pipe test rig or sampling from consumers' taps during a field trial in a small part of the water supply zone. This report provides detailed advice on the construction and operation of lead pipe test rigs and the sampling of consumers' taps for monitoring the effectiveness of treatment to reduce plumbosolvency.

1.2 HALF-HOUR STAGNATION SAMPLES

The guidance document recommends the use of random daytime samples from consumers' taps for monitoring compliance with the standard for lead and determining whether there is a risk of failure to meet the standard in a water supply zone. However, for most other investigations involving lead, stagnation samples taken after a standard period of the water standing in the plumbing following flushing (see Section 4.1) are an effective and reliable basis for monitoring lead concentrations. The period of stagnation generally is standardised as 30 minutes (half-hour). Half-hour stagnation samples have been found very effective\(^{(3,4,5)}\) and they provide an estimate of the mean lead concentration in water used for drinking and cooking\(^{(6)}\).

1.3 LEAD PIPE RIGS

Lead pipe rigs were used effectively in 1979 - 1981 at several sites to monitor seasonal changes in plumbosolvency and for comparing the effects of different treatments to reduce plumbosolvency\(^{(3,4)}\). These pipe rigs were of a basic design and required manual interruption to take appropriate stagnation samples. Details are given in Section 2. If such lead pipe rigs are going to be used on a widespread basis, then the stagnation and sampling of water from them can be "automated" so that a suitable sample is ready for the sampler to collect (so that the sampler is not delayed by having to stagnate the water himself).

An "automatic" stagnation lead pipe rig has been devised (by Anglian Water in consultation with WRc) and a number of them are in regular use in Anglian Water with more planned. The principal feature of the "automatic" stagnation lead pipe rig is the sample vessel which receives water that has been stagnated within the lead pipe with the
aid of a timer unit. The sampler simply draws his sample from the sample vessel when he visits the pipe rig. An "automatic" stagnation lead pipe rig is adequate when long term monitoring of plumbosolvency is intended. Details are given in Section 3. When tests are planned to select the most appropriate treatment, then a basic lead pipe rig is advised. However, preliminary comparison and selection of treatments may be made more easily in a laboratory using short lengths of lead pipe in water baths\(^{(5,7,8)}\).

The investigations in 1979 - 1981 with lead pipe rigs were made in conjunction with sampling from consumers' taps. Lead pipe rigs were conceived originally to determine as accurately as possible the effects of treatment changes on lead concentrations in order to predict the effects of treatment in practice. Experience showed that rigs using "old" lead pipe could demonstrate the effects of treatment in practice. ("Old" lead pipe is lead pipe which has been removed from service on the water under investigation.) It was found that lead concentrations in half-hour stagnation samples from lengths of old lead pipe in the pipe rigs followed the concentrations in half-hour stagnation samples from consumers’ taps. This applied when seasonal and operational variations in water quality occurred and when dosing orthophosphoric acid. Therefore lead pipe rigs fitted with "old" lead pipe can be used to monitor the effectiveness of treatment to reduce plumbosolvency.

New, virgin, lead pipe can be used instead of "old" lead pipe but with certain limitations. After an initial period of stabilisation, lead concentrations from new lead pipe follow the same trends as concentrations from "old" lead pipe and consumers’ taps. However, experience has shown that lead concentrations in stagnation samples from new lead pipe are greater than from "old" lead pipe; the more plumbosolvent the water then the greater is the relative difference between concentrations from new and "old" lead pipe. Thus, new lead pipe can be used for monitoring changes in plumbosolvency but not to reflect the magnitude of concentrations likely to be found in water sampled from consumers’ taps. An exception to this occurs when dosing orthophosphate because concentrations of lead in water sampled from both new and "old" lead pipe are relatively low and very similar. When lead pipe rigs are used for comparing different treatments then the relative order of effects of treatments are the same for new and "old" lead pipe, only the magnitude of the effects is different. Laboratory pipe tests can be conveniently carried out using new lead pipe\(^{(5,7,8)}\).

Lead pipe rigs are suggested for monitoring plumbosolvency and effectiveness of treatment to reduce plumbosolvency because their use should be more economical than sampling from consumers’ taps and will enable more standardised test conditions to be applied. However, when setting up a lead pipe rig for the first time, on a different kind of water or with new pipe only, the parallel monitoring of consumers’ taps for a period is recommended to validate the results from the pipe rig.

\subsection{1.4 Monitoring Consumers’ Taps}

Although the protocol for monitoring lead concentrations in water from consumers’ taps supplied through lead pipes to assess the effectiveness of treatment has been described elsewhere\(^{(9)}\), the principles are reiterated in Section 4. The protocol is based on the use of half-hour stagnation samples. This is to be compatible with use of such stagnation
samples taken from lead pipe rigs, to have a standard procedure, and because the mean inter-use time in domestic consumption of water from dietetic taps is approximately half an hour. This means such samples produce concentrations of lead representative of average exposure to water lead\(^6\). When enhanced lead concentrations in water from consumer’s taps might be due to "particulate" lead (identified when lead concentrations are greater than accounted for by solubility) then it may not be appropriate to replace monitoring at consumers’ taps with use of lead pipe rigs, at least not until it has been shown that lead concentrations in samples from pipe rigs do reflect the concentrations in samples from consumers’ taps.
2. THE BASIC LEAD PIPE RIG AND ITS USE

2.1 SOURCE OF "OLD" LEAD PIPE

The source of "old" lead pipe for a pipe rig should be a pipe which has been in service for many years on the water to be monitored with the pipe rig. Once a house with a suitable length of lead pipe has been selected, sampling will be necessary to verify that lead concentrations from this pipe are not atypical, compared to other lead-plumbed houses in the same supply area. The easiest way to identify possible houses in the first instance is to take a number of half-hour stagnation samples from potential donor houses. The house which appears to have the most accessible service pipe of sufficient length should be selected as the donor house.

The lead pipe should be exhumed carefully. It should be cut into the required number of 2m or 3m long sections, as appropriate, before removal. The method of cutting should minimise the chance of lead particles entering the pipe or disruption of the deposits within the pipe. A method of cutting the pipe is to cut round but not completely through the pipe with a hacksaw and then break off that section of pipe. Any water within the pipe should be allowed to drain slowly. Both ends of each section of pipe should be plugged gently to prevent drying out and intrusion of contaminants. The pipe sections should be removed, taken to the pipe rig and installed in the rig with care to avoid flexing and disruption of internal deposits. Flow of water through the sections of pipe installed in the rig should be established as soon as possible. If there is a risk of delay in establishing use of the pipe sections, then they should be refilled with water immediately following removal and tightly plugged to ensure no leakage; it must not be possible for an air-water interface to move about within the pipe and disturb the deposits.

2.2 RIG DESCRIPTION

A pipe rig (Figure 1) consists essentially of a number of pipe sections mounted on a supporting framework. Water is pumped through the sections of lead pipe by a peristaltic pump and facilities are provided for dosing chemicals into the water entering some of the pipe sections. Samples of water are collected from the outlets of the pipe sections as required.

The supporting framework of the rig consists simply of two lengths of inverted Dexion open steel plank, 2m long by 0.22m wide bolted side by side, or similar. This forms a trough into which up to 10 lengths of either 13mm of 19mm (1/2" or 3/4") nominal bore lead pipe can be placed. This trough is supported on Dexion legs to provide a height of 0.85m at the inlet end of the pipe sections and 1m at the outlet end. The resulting slope helps to avoid air entrapment in the sections of pipe.

A piece of waterproof plywood is mounted at the outlet end. This forms a support for a set of polyethylene filter funnels (90mm diameter) which act both as collectors for the outflows from the pipe sections and as supports for polyethylene sample bottles during sample collection. The funnels are connected by flexible tubing to a common 25mm uPVC drain.
The sections of pipe are mounted carefully on the supporting framework. Each section is sealed at both ends with a silicone rubber bung each fitted through with a length of glass tube (3mm internal diameter). The bungs are wired to the pipe sections to prevent them falling out. Each inlet is connected to a channel on the peristaltic pump with flexible PVC tubing, with a polyethylene stopcock between this tubing and the glass inlet tube. Each glass outlet tube is connected to about 40cm of small bore (3mm) flexible PVC tubing; these outlet tubes are all the same length so that the "dead" volume is the same.

The water supply to each pipe section is provided by a multi-channel peristaltic pump with variable speed drive set to deliver 55ml/minute to each section. The pump draws from a small constant head tank. Other pumps are used to apply various treatments to the water before flow through the pipe sections, using Y-piece connectors on the suction side of the peristaltic pump for mixing, see Figure 1. All pumps are controlled by a timer which provides an operating cycle such as 8 hours on and 16 hours off to simulate domestic water consumption.

Treatment with orthophosphate or a "corrosion inhibitor" can be achieved easily by direct dosing of solution as described above. Some other treatments, such as pH adjustment, need to be applied so that fluctuations in water quality entering the pipe sections are minimised. pH adjustment can be achieved by using a small pH controlled dosing pump to dose alkali, then passing the treated water to a small header tank from which it is pumped to the pipe sections (shown as "water with other treatments" on Figure 1). Some treatments, such as acid de-alkalisation, may be too difficult for successful operation at such a small scale.

2.3 SAMPLING AND MAINTENANCE

Although the pipe rigs are designed to operate without intervention for one or even two weeks at a time, it is advisable to inspect the rig daily and attend to any malfunctions. At each weekly visit the following should be carried out:

(i) replace peristaltic pump tubing as necessary;
(ii) check flowrates and functioning of pumps and timers; and
(iii) prepare enough fresh solutions for dosing to last until the next visit.

Sampling is carried out during each weekly visit although this frequency can be reduced once consistent and reproducible results are established and no rapid changes in quality of test water are expected. Samples are taken simultaneously from all pipe sections to form a set of samples. The sampling procedure is:

(i) Check that all operating conditions are satisfactory;
(ii) Prior to taking any samples, the pipe sections must be flushed at the test flowrate for at least 30 minutes; at the end of this period a set of samples is taken (i.e. fully flushed). These are analysed only if the subsequent stagnation sample results appear to be inconsistent.
(iii) A set of stagnation samples should be taken after 30 minutes of stagnation.

Whenever a set of samples is taken from the lead pipe sections, a sample of the water from the main constant head tank should be taken and analysed for pH value, alkalinity, temperature and lead and a flushed sample from each of any orthophosphate-dosed pipe sections should be taken and analysed for orthophosphate.

In some cases other parameters which may change substantially from week to week in the test water supply, such as aluminium, iron and manganese, should be analysed in the water from the main constant head tank. It also may be appropriate to keep a log of major alterations to source of water, changes in treatment at the treatment works and any other operational factors which may affect the quality of the test water.
3. THE "AUTOMATIC" STAGNATION LEAD PIPE RIG

3.1 DESCRIPTION

An "automatic" stagnation lead pipe rig consists of a single lead pipe arranged to automatically produce stagnation samples ready for collection by a sampler at any time. The rig is illustrated schematically in Figure 2. All the components are mounted on a vertical board, 0.91m high and 1.22m wide.

The rig is connected to the water supply to be monitored. The water flows through a non-return valve and strainer to a constant flowrate valve and gap meter. The flowrate is set at 0.5 litres/minute, when either of the outlet solenoid valves is open. The water then flows through 3m of lead pipe. For compactness the lead pipe is coiled in a gentle S-shape. Finally the water can either flow to waste directly through a solenoid valve or alternatively through another solenoid valve to waste via the sample vessel.

The storage capacity of the sample vessel to its overflow does not have to be limited by the volume of the lead pipe. Only the time the solenoid valve to the sample vessel is open is limited by this volume. For example, 3m of 13mm (½") diameter lead pipe has a volume of approximately 400ml; thus for a flowrate setting of 500ml/minute, the solenoid valve should not be open for more than 45 seconds before the next flush and stagnation sample is started. It then follows that a sample vessel of one litre is viable even though it will take at least 3 flush and stagnation cycles to fill or displace it. The vessel has a conical base which the inlet protrudes down into. Thus, incoming freshly stagnated water displaces previously sampled water. The sampler draws his sample from the tap connected to the base of the sample vessel.

The two solenoid valves are controlled by a timer unit mounted at the top of the board. The timer unit controls the duration of stagnation prior to flushing to waste, the duration of flushing directly to waste, the period of stagnation and the subsequent release of stagnated water through the sample vessel. The timers can be set to provide a simple model of domestic water consumption with a long period of overnight stagnation. The timers also can be set to minimise the consumption of water so that it is no greater than necessary for flushing and sampling stagnated water.

3.2 USE OF "AUTOMATIC" RIGS

The "automatic" rig was conceived primarily to minimise or avoid the need for monitoring consumers' taps to assess the effectiveness of treatment. The use of solely one rig per water supply would be an inadequate and insecure strategy. At least two rigs are needed, one to monitor water before corrective or additional treatment and the other after such treatment. Comparison of results from the two then will show the extent to which treatment has been effective. When blending with other sources takes place within supply then an additional rig will be needed to monitor the effect in the affected part of the supply. Samples for analysis should be collected from each rig weekly until lead concentrations stabilise.
4. MONITORING AT CONSUMERS' TAPS

4.1 STAGNATION SAMPLING

The effectiveness of treatment may be determined by a field trial carried out in a small part of a zone by measuring lead concentrations at selected consumers' taps before and after the introduction of treatment. Half-hour stagnation samples from consumers' taps supplied through lead pipes are recommended as the type of sample for assessing the effectiveness of treatment.

The following procedure is used to take a stagnation sample:

(a) ensure other taps or cisterns will not draw water from that service or any shared service for at least 30 minutes;

(b) flush water through the tap until its temperature is constant (to displace all the water in the service pipe), record the temperature and collect a flushed sample for analysis for pH value and any other parameters likely to affect lead concentrations such as alkalinity, iron and orthophosphate;

(c) allow water to stagnate in the pipe for 30 minutes; and

(d) collect a one litre sample and analyse it for lead.

If samples are to be taken from private properties, it is important to be considerate to the householders about the frequency of visiting. Therefore, if weekly visiting to sample properties was envisaged it might be more considerate to collect samples as clusters by collecting one sample on each of 3 consecutive days every 3 weeks or so. This cluster approach also provides a better assessment of sample reproducibility thereby strengthening the confidence in the information generated. Large within-cluster variability, greater than about 20% relative standard deviation, can indicate poor sampling technique, very changeable water quality or presence of particulate lead. A variability of less than about 10% is good. At certain stages of a monitoring programme it can be useful to increase the frequency of sampling, particularly at the beginning in order to build up a picture of the situation quickly.

Sampling should be carried out by the same small group of samplers to increase reproducibility and householders' cooperation. Whilst it may not be reliable in all circumstances, the householder may be willing and able to take samples following appropriate instruction; sample bottles can be delivered and collected on a "milk round" basis.

4.2 SELECTION OF CONSUMERS' PROPERTIES

At least 2 suitable lead-plumbed properties should be monitored in each trial zone; one property should be located near the beginning of the zone and the other near the end. It may be necessary to monitor 4 - 6 properties initially and give up those producing the lowest lead concentrations or proving the least reliable for regular and prolonged access.
The properties selected should have individual service pipes consisting of at least 10m of lead pipe connected to the tap to be sampled. Properties with lead service pipes which have a length of copper pipe (or other material) between the lead pipe and the sample tap may also be used. Where the length of copper pipe is less than 2m, it is acceptable to collect a one litre sample immediately after 30 minutes stagnation. However, where the length is greater than 2m, a volume of stagnated water (standardised for that tap) equal to the capacity of the pipe (1m of 13mm (½") internal diameter pipe contains approximately 130ml) should be drawn off before collecting a one litre sample.

Outside taps may be selected only if they are used regularly by the consumer. New taps should be avoided because exposure of fresh solder, a new brass surface or bare lead pipe to water gives rise to uncharacteristically high lead concentrations which take several months to stabilise. Taps in places such as in cemeteries, public toilets and garage forecourts are attractive because of their accessibility. However, they should only be monitored provided they are regularly used and are shown to produce lead concentrations representative of those obtained from private houses.
REFERENCES


(2) Guidance on safeguarding the quality of public water supplies. HMSO. 1989.


TECHNICAL CONTACTS

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FIGURE 1  TYPICAL LAYOUT FOR A MULTI-CHANNEL BASIC LEAD PIPE RIG
FIGURE 2  LAYOUT OF THE "AUTOMATIC" STAGNATION LEAD PIPE RIG