THE EFFECT OF MATERIAL AND PROCESS DEVELOPMENTS ON THE LEACHING OF SPECIFIC ORGANICS FROM EPOXY RESIN LINED WATER MAINS

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October 1986

RESTRICTION: This report to be issued to the Committee on Chemicals and Materials of Construction for use in Potable Water and Swimming Pools only

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A series of laboratory and field experiments have been carried out on two epoxy resin systems for relining potable water mains to determine the effect on organic leachate levels of increasing the air-cure time from 4 to a minimum of 16 hours. Laboratory experiments were conducted to assess the effect of duration of the air-cure, temperature during cure and some minor formulation changes. The best process for each resin system, as indicated from laboratory work, was then tested in a series of field trials.

The results showed that significant improvements in leachate levels could be obtained by increasing cure time from 4 to 16 hours. As a result of this work, specific recommendations are made regarding the epoxy resin relining process.
1. INTRODUCTION

The condition of cast iron water mains in the UK justifies a programme of rehabilitation. At present this can be achieved either by replacing the main or relining it with cement mortar or epoxy resin. Relining is favoured by many water utilities since it is cheap, durable and causes minimal disruption to the consumer. At present epoxy resin takes only a small part of this market, primarily because full approval from the Committee on Chemicals and Materials of Construction for Use in Potable Water and Swimming Pools (CCM) has not been obtained. This report describes laboratory experiments and field trials associated with the development of an extended air-cure relining process and epoxy resin formulation changes.

1.1 Development of the extended air-cure process

The development of the in situ epoxy resin relining process in the late 1970s was based on achieving same day return to service thus making it a direct competitor to the bitumen relining process which had the disadvantage of limited durability. Same day return to service was achieved by the use of resin systems which would cure rapidly at temperatures as low as 5 °C with good build and water tolerance. Typically, the main would be scraped and relined in the morning followed by a minimum 4 hr air-cure, chlorination for 30 mins with a 1 hr flush at 0.5 m.s⁻¹ velocity before return to service. The consumer would be without water for some 10 hrs.

A series of laboratory and field studies conducted during 1983/84, determined the concentration of specific organic compounds leaching into water following in situ epoxy resin relining with the 4 hr cure process. Two epoxy resins were studied in these trials, from Geopaints and Sika, and a
report of these findings submitted to the CCM in 1984 (Elvidge et al. 1984). The results showed that consumers in a typical area being relined with epoxy resin will experience a wide range of concentrations of the specified organic compounds. This range is a function of time, sample location, the layout of the system and flow pattern. Concentrations were generally at their highest after a period of low overnight flow. In the field trials carried out, levels as high as 6 mg.l⁻¹ were found after the first night in service. Additional overnight flushing at 0.5 m.s⁻¹ velocity reduced the concentration of the specified organics by dilution, but did not reduce the rate of leaching.

The CCM considered these high levels of organics to be unacceptable on health grounds and also considered that additional flushing to reduce the levels was not a viable alternative. This view was also shared by the water utilities, due mainly to the operational problems of handling large volumes of wastewater.

An alternative method of reducing organic leachate levels by extending the period of air-cure from the minimum of 4 hrs to a period of at least 16 hrs was suggested. This was considered acceptable operationally since a period of cure of this order is normal for cement mortar relining. When this proposal was first made no information on the effect of extended air curing on organic leachate levels was available. However, extrapolation of the results from the 4 hr cure process suggested that extended curing for 16-24 hrs would give at least an order of magnitude reduction in leachate levels. In addition, if a low flow of water was induced above normal consumer demand on dead-end mains for the first 24 hrs following return to service, the levels might be reduced by a further order of magnitude. These estimates were
sufficiently encouraging for laboratory and field studies to be conducted.

A summary of the extended air-cure process is provided in Appendix A.

1.2 Modifications to the resin formulations

1.2.1 Geopaints Ltd

The suggested change from a 4 hr cure to a 16 hr cure required changes to the resin formulation. In the 4 hr cure process, the resin is only partially cured when returned to service and exposed to water. Therefore, the resin must withstand some leaching of unreacted ingredients. Such tolerance was achieved by formulating with an excess of hardener (i.e., diamine) so that after leaching sufficient remains to provide satisfactory cure. Since the degree of cure after 16 hrs is much greater, there is no need for an excess of diamine and the level of diamine in the Geopox formulation was reduced accordingly. In addition, Geopaints incorporated a 'protective-agent' into the resin which is intended to form a layer over the surface of the resin during the curing process to inhibit the leaching of organic compounds. This modified resin (GX-014) satisfied the requirements of the Water Byelaws Advisory Service (WBAS) and is listed as a material approved for in situ use. Formulations with and without the protective agent were tested in the laboratory leaching experiments described below.

1.2.2 Sika Ltd

Sika Ltd were of the opinion that the level of diamine in their formulation was not sufficiently in excess to warrant a change. However, an experimental batch of material, with a reduced
hardener content, was prepared and tested in a laboratory leaching experiment.

1.3 Experimental work

A programme of laboratory and field experiments was designed to measure the concentration of organic leachates arising from changes in formulation and extended air-curing. The most effective combination of material and cure time was identified in a series of laboratory tests and the most promising process evaluated in field trials.

The field trials were conducted in two series. The first involved relining two abandoned lengths of main, one with Geopox and the other with Sikagard. Abandoned lengths were used to eliminate the possibility of exposing consumers to high levels of organics whilst 'worst case' situations were being monitored.

A second series of trials was then carried out using six live mains (three for each material). These experiments were designed to assess the variability in organic leachate levels that might be expected from routine application of the epoxy resin relining process.

During the course of the field trials, faults with the relining equipment/technique became apparent. Investigation of these faults led to the introduction of certain quality control procedures to the process. These procedures are outlined in Appendix B.

1.4 Analytical methods and treatment of results

The analytical methods used for monitoring concentration of organic leachate have been summarised in the previous report to CCM (Elvidge et al 1984) and have also been published (Crathorne et al 1984a, 1984b, 1984c, 1986). Methods were
developed for all of the principal organic components in the epoxy resin formulation ie trimethylhexamethylene diamine (TMHD), bisphenol A diglycidyl ether (BisA), bisphenol F diglycidyl ether (BisF) and p-toluenesulphonic acid (PTSA). Although these methods are not fully characterised, a series of spiking experiments was carried out for each determinant so some idea of the performance of each method is known. The results from these experiments, given in the previous report, showed that good recoveries (80–95%) were obtained for TMHD, BisA and BisF, with recoveries averaging 60% for PTSA. However, more recent work with TMHD has shown that reduced recovery of this compound is now being obtained due to incomplete reaction in the derivatisation procedure. The reason for the poor derivatisation efficiency is not known, but it means that recovery of TMHD is effectively reduced to between 60–70%.

In this report the following recoveries are assumed and results adjusted accordingly; TMHD 70%, PTSA 60%, BisA and BisF 100% (ie these results are unadjusted).

As explained in the previous report (Elvidge et al 1984), it is estimated that all results are subject to a maximum error of ±30%.

2. LABORATORY EXPERIMENTS

2.1 Objectives

The objective of these laboratory experiments was to determine whether the length of air-cure, the temperature under which curing takes place and the relative proportions of hardener and resin in the epoxy resin formulation have a significant effect on the level of organic leachate. To maximise the number of variables tested, a simplified testing protocol was followed.
2.2 Experimental design

The laboratory experiments were carried out as described in the previous report (Section 4.2 and Appendix A; Elvidge et al 1984), except experiments were streamlined by taking only four samples (at 1, 4, 7 and 22 hours) after the plates had been placed in the test cell. In initial experiments only TMHD and PTSA were monitored, with bisphenol diglycidyl ethers being included in later experiments. The sequence of experiments (Table 1), were designed to test the effect of the duration of air-cure (16 hrs or 24 hrs), cure temperature (5 °C or 10 °C) and altering the relative ratio of resin to hardener.

2.3 Results

2.3.1 Sikagard resin

Results from investigations on the duration of air-cure showed that a significant reduction in the level of organic leachate can be obtained by increasing cure time from 4 hrs to 16 hrs. However, no significant improvement was observed when the cure time was increased to 24 hrs. These results are compared with results from laboratory tests on the 4 hr cured resin in Table 2. It should be emphasised that the results are from static laboratory tests, and no account of water flow has been made. The leaching rates in Table 2 provide an indication of the rate at which organic compounds are leached from the resin and are calculated by dividing the measured concentration by the residence time in the test cell.

Results from varying the cure temperature (Table 2) showed that in the limited experiments carried out, no significant difference was obtained in the level of organic compounds leached from the resin when curing takes place at 5 °C compared to 10 °C.
The reduction in organic leachate obtained when cure time is increased from 4 hrs to 16 or 24 hrs is illustrated in Figure 1. This shows a log-linear plot of leaching rate against time for THMD from the results obtained in experiments on 4, 16 and 24 hr cured resin. Thus the peak leaching rate from the resin cured for 4 hr is 2148 μg.l⁻¹.hr⁻¹ and this is reduced to 159 μg.l⁻¹.hr⁻¹ for the 16 hr cured resin and 147 μg.l⁻¹.hr⁻¹ for the 24 hr cured resin. The data in Figure 2 also shows that the greatest reduction in leaching occurs during the first few hours of the experiment and after 22 hrs the leaching rates are approximately the same ie at about 35-40 μg.l⁻¹.hr⁻¹.

The results obtained from changing the resin formulation are given in Table 3. Results from the unmodified resin are included for comparison. Thus, in this experiment, the expected reduction in the level of organic leachate was not observed from the modified resin.

2.3.2 Geopox resin

Tables 4 and 5 give the results obtained from laboratory experiments on Geopox resin. Table 4 shows the results using Geopox GX-012 with a 16 hr cure time and, for comparison, the results when the resin was cured for 4 hr. It should be noted that the original GX-012 formulation (used for the 4 hr cure experimental work) was not available when the 16 hr cure work was carried out, so a direct comparison is not possible. Table 5 shows the results obtained when the Geopox resin formulation was further modified by incorporating a 'protective agent'. This was intended to form a layer over the surface of the resin during the curing process, thus inhibiting the leaching of organic compounds. There was a further experimental variable with Geopox. It was suggested by the formulator that
curing in a CO$_2$-free atmosphere might reduce the leaching of TMHD. In these experiments this was investigated by introducing ammonia into the curing chamber such that all of the atmospheric CO$_2$ had been removed.

The results show that of the modified resins examined, GX-014 (ie reduced diamine content plus protective agent) gave the lowest organic leachate. Comparison of the results from this resin with those obtained from the 4 hr cured resin also shows an improvement.

The differences observed in the leaching of TMHD from each of the modified resins (16 hr cure) is illustrated in Figure 2 as a linear plot, of leaching rate against time. Thus a peak leaching rate of 260 μg.l$^{-1}$.hr$^{-1}$ observed for GX-014, compares with peak leaching rates of 1156 μg.l$^{-1}$.hr$^{-1}$ for GX-012 and 351 μg.l$^{-1}$.hr$^{-1}$ for and GX-014 cured in a CO$_2$ free atmosphere.

2.4 Discussion of results

The conclusions drawn from the laboratory work were that an extended air-cure (a minimum of 16 hrs) could considerably reduce the level of organic compounds leaching into water. Little improvement was observed by increasing the cure-time to 24 hrs. The most promising processes which emerged were as follows: Sikagard DW2 with a minimum 16 hr air-cure and Geopox GX-014 also with a minimum 16 hr air-cure. Data from the laboratory work indicates that peak leachate concentrations using these processes would be in the region of 10-100 μg.l$^{-1}$.

3. FIELD TRIALS

To confirm the results from the laboratory experiments, field trials have been carried out using both resin systems. Two series of field
trials were undertaken. In the first, two abandoned lengths of main were relined (one for each resin) and a water-flow induced to represent that typical of a dead-end main supplying a small number of consumers. Abandoned mains were used in order to eliminate the risk of exposure of consumers to organic leachates. In addition, the flow rate/residence time of water in the pipe could be controlled so it was ensured that a likely 'worst-case' was being monitored.

The second series of field trials were carried out to assess the likely variability in organic leachate levels arising from routine application of the relining process. 'Live' mains were therefore used for these trials and organic leachate concentrations were monitored from six lengths of main relined with epoxy resin (three lengths for each resin system). Again, dead-end mains supplying a small number of consumers were selected so that a likely 'worst-case' was monitored.

The relining process studied in all field trials entailed a minimum 16 hr air-cure (ie overnight) followed by chlorination and flushing to waste for 1 hr. The relined pipe was then returned to supply. To ensure that water was not stagnant in the main during the 24 hr period immediately following return to service, a low flow (about 13 l.min⁻¹ additional to consumer demand) was induced. With this additional flow the retention time of the water in the main was always less than 1 hr.

The concentrations of BisA, BisF, TMHD and PTSA were determined in all samples. In addition, gas chromatography-mass spectrometry (GCMS) analysis was carried out on dichloromethane extracts of selected water samples to detect the presence of volatile compounds arising from the reactive
diluent used in formulating the resins. In water samples from pipes relined with Sikagard DW2 the concentration of two compounds, chlorohydroxybutyl ether and a compound of molecular weight 222 (Compound A) was monitored. In samples from pipes relined with Geopox GX-014, the concentration of butyldiglycidyl ether was monitored. The structures of these compounds are:

\[ \text{CH}_3\text{CH}_2\text{CH}_2\text{OCH}_2\text{CH} (\text{OH})\text{CH}_2\text{Cl} \]

chlorohydroxybutyl ether

\[ \text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{OCH}_2\text{CH} (\text{CH}_2\text{Cl})\text{OCH}_2\text{CH} - \text{CH}_2 \]

Possible structure for Compound A (mw 222)

\[ \text{CH}_2 - \text{CHCH}_2\text{O} (\text{CH}_2)_4\text{OCH}_2\text{CH} - \text{CH}_2 \]

butyldiglycidyl ether

3.1 Field trials on abandoned mains

These trials were carried out on lengths of main on which a simulated flow pattern, typical of a dead-end main supplying a small number (about ten) of consumers, was induced. Seven samples were taken during the first 72 hrs after the pipe was 'put back into supply' in order to monitor the relatively high leachate concentrations expected during this time. Sampling was continued at less frequent intervals for up to five months after relining, to determine long-term leachate concentrations. After the initial 72 hr period, three replicate samples (taken at about 5 min intervals) were analysed in order to be able to check on the accuracy of results.
3.1.1
Sikagard DW2

Results obtained for the concentrations of TMHD, BisA and PTSA are shown in Table 6 and for the concentrations of chlorohydroxybutyl ether and Compound A in Table 7.

The residence time in the main is a measure of how long the water is in contact with the resin. Thus, during the period of extra, induced flow (ie 24 hrs), the residence time is approximately constant. After this, residence time depends on consumer flow and is very long during overnight periods but shorter during daytime. In the field trials these times were 10.35 and 4.4 hr respectively.

Results from this system were broadly in line with those predicted from the laboratory work (Section 2.4). The peak concentration measured was 150 μg.l⁻¹ for TMHD in the sample taken 42.5 hrs after the main is 'put back into supply'. It should be noted that this sample was taken after a period of overnight stagnation. The leaching rate in Table 6 provides an indication of the rate at which organic compounds are leached from the resin and is calculated by dividing the measured concentration by the residence time in the main. The rate starts relatively high (>150 μg.l⁻¹.hr⁻¹) but drops considerably during the first 24-48 hrs. After 66.5 hrs in supply the leaching rate had dropped to about 8 μg.l⁻¹.hr⁻¹. The concentrations measured after 22 days indicate that the leaching rate remained at this low level during this period.

Results after 86 days (3 months) show that the leaching rate for TMHD and BisA had fallen to about 0.3-0.6 μg.l⁻¹.hr⁻¹, so that concentrations after overnight stagnation were in the region of 3-6 μg.l⁻¹. PTSA was not observed (ie is less than the detection limit of 5 μg.l⁻¹).
However the three replicate samples taken five months after relining showed a marked increase in concentration compared to previous samples. Thus a concentration of 114 µg.l⁻¹ was found for TMHD compared to 6 µg.l⁻¹ in the 3 month sample, 21 µg.l⁻¹ was found for PTSA compared to <5 µg.l⁻¹ and 208 µg.l⁻¹ was found for Bis A compared to 6 µg.l⁻¹. These results were very much higher than anticipated, being the first samples to show any departure from a gradual decline in the concentration of organic leachate. The water from the main was sampled 1 week later, and low concentrations, consistent with the concentrations observed in other samples from this experiment, were found.

In order to investigate the reasons for these unexpectedly high concentrations, the entire length of lined pipe was examined using Closed Circuit Television (CCTV). This showed that the lining was complete with no obvious defects in application. However, on removal of the TV camera a small amount of unmixed resin was found on the centralising brushes. Although the exact location of the unmixed resin was not found, it is likely that the high leachate concentrations observed in the five month sample was caused by contamination from this source.

Since contamination from the unmixed resin would have been spread along the entire length of the pipe by the CCTV, no further samples from this pipe were taken.

The results given in Table 7 show that volatile compounds arising from the reactive diluent were found in some samples. A peak concentration of about 20 µg.l⁻¹ was found for chlorohydroxybutyl ether in the sample taken 1 hour after the main was 'returned to supply', while the peak concentration
for Compound A was 30 µg.l⁻¹. It must be emphasised that these results are only semi-quantitative since no authentic standards are available for these compounds.

3.1.2
Geopox GX-014

Results obtained for the concentrations of TMHD, PTSA and Bis A plus Bis F are shown in Table 8. Analysis for butyldiglycidyl ether was carried out on samples taken 1, 4, 7 and 17.75 hrs after the reclined section was 'returned to supply'. However this compound was not found (ie at concentrations >5 µg.l⁻¹) in any of these samples. In general, the results from this system follow the same pattern as that described for Sikagard. Peak levels were lower (ie a peak concentration of 30 µg.l⁻¹ for TMHD) but the same trends (ie a reduction of the rate of leaching with time) were observed.

Results after 30 days showed that TMHD was being leached from the resin at a low level during this time. Thus 4 µg.l⁻¹ of TMHD was measured after a residence time of 10 hrs. PTSA and the bisphenol diglycidyl ethers however were below detection limit in these samples (ie <5 µg.l⁻¹ and <1 µg.l⁻¹ respectively).

Results after 64 days showed that low levels (ie about 3 µg.l⁻¹) of TMHD were still present. As in the previous sample (30 days) both PTSA and the bisphenol diglycidyl ethers are below detection limit. However, after 4 months none of the determinands were found and sampling was discontinued.

3.1.3
Discussion of results

Results from both field trials were broadly in line with those predicted from the laboratory work. In both systems leaching rate falls rapidly during the
first 24-48 hrs to reach a low level (ie in the region of 0.1-5 μg.l⁻¹.hr⁻¹) which is maintained for a considerable time. The cause of the unexpectedly high concentrations found in the five month sample taken from the main relined with Sikagard DW2 was not definitely established. However, it is likely that a small amount of unmixed resin was present in the main and contaminated this particular sample.

It should be noted that the field results refer only to one 'experiment' on each resin system. It is probable that day-to-day variability in the relining process exists, and therefore the level of leachate could vary considerably from relining one length of water main to another. The precise magnitude of this variability is impossible to assess without carrying out a series of monitoring exercises. However, this variability appears to apply only to the amount of material leached from the resin during the first 24-48 hrs. After this time, the results indicate that a level of leaching is reached which is much less dependent on any day-to-day changes in relining practice. In order to assess the variability in organic leachate levels arising from routine application of the relining process further field trials were carried out for each resin system.

3.2 Field trials on live mains

These trials were carried out to assess the variability in organic leachate levels arising from routine use of the epoxy resin relining process. Three trials were conducted for each resin and each trial was carried out on a dead-end main supplying a small number of consumers (approx 10-15) so that a likely worst-case was monitored. Results from field trials on abandoned mains (Section 3.1) and earlier laboratory and field trials (Elvidge et al 1984) have indicated that any significant variation
in organic leachate levels occur during the first few days after relining. Sampling for the field trials on live mains was therefore designed to assess the variability in leachate concentrations encountered during this period.

Four samples and one blank were analysed in each field trial. These were taken at the following times after the relined pipe was put back into public supply.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 hour</td>
<td>Taken to determine initial leachate concentrations (NB this sample was taken during the period of an imposed flow above normal demand).</td>
</tr>
<tr>
<td>Approx 29 hour</td>
<td>Taken after the period of imposed extra flow and before the first overnight stagnant period.</td>
</tr>
<tr>
<td>Approx 42 hour</td>
<td>Taken during the first overnight stagnant period after relining.</td>
</tr>
<tr>
<td>Approx 68 hour</td>
<td>Taken during the second overnight stagnant period after relining.</td>
</tr>
</tbody>
</table>

The resin and hardener components of epoxy resin linings are formulated to be mixed, just before application, at a specific ratio. It became apparent during both laboratory and field work that it is critical to mix these components at the correct ratio in order to maintain a minimum amount of organic leachate. The amount of each component delivered in a given time was therefore measured (during the field trials with Geopox GX-014) to
assess the variability in this mix ratio during application. Further work on the dependence of organic leachate concentrations on variation of the mix ratio is now underway.

Field trials using this material were carried out in the Haywards Heath area with the co-operation of Mid-Sussex Water Company. Results are presented in Tables 9-11 and the results obtained for chlorohydroxybutyl ether, which comes from the reactive diluent in the resin are given in Table 12. Compound A (Figure 3) was not found (ie at concentrations >5 µg.l⁻¹) in any of the samples.

Results from the second field trial (length B, Table 10) were higher than was expected from previous work and it was suspected that a malfunction had occurred during application. For this reason a further sample was taken from an adjacent water main which had been relined the following day. This result was lower than that found for the trial main and was in the range expected, indicating there was no fault on the resin application rig. This was subsequently confirmed by a detailed examination of the rig. A sample from a consumers tap on the test main was also analysed to ascertain whether the high concentrations may have been due to contamination near the sampling tap. The results from this sample were consistent with those observed in samples taken from the sampling tap and therefore, it was concluded that such contamination was not causing the high concentrations.

As a precaution against the possibility that high concentrations of organic compounds could be leached from this epoxy resin lining for a prolonged period, the length of main for the second field trial was overlined with epoxy resin. Two
samples were analysed from the overlined length of main and the results showed the presence of reduced concentrations of organic leachate compared to the initial samples.

Since no faults could be found with any aspect of the relining process, the sampling and the analysis for the second field trial, it must be concluded that the results represent a true spread of concentrations likely to be encountered from routine operation of the Sikagard DW2 epoxy resin relining process.

Summarising the three field trials, the concentrations found for each of the determinands were in range of 19-589 μg.l⁻¹ for TMHD, 8-390 μg.l⁻¹ for PTSA and 1-22 μg.l⁻¹ for Bis A. In addition a peak concentration of about 100 μg.l⁻¹ was obtained for chlorohydroxybutyl ether. As explained previously (Section 3.1.1) results for this compound are only semi-quantitative.

Field trials with this material were carried out in the Bradford area with the cooperation of Yorkshire Water. Results are presented in Tables 13-15.

Analysis for the compound arising from the reactive diluent in this material (butyldiglycidyl ether) showed that it was not present in any of the samples analysed (ie at concentrations >5 μg.l⁻¹).

Concentrations measured for the other compounds were in the range of 4-123 μg.l⁻¹ for TMHD, 5-137 μg.l⁻¹ for PTSA and 3-20 μg.l⁻¹ for Bis A plus Bis F.

In addition to monitoring the concentration of specific organic compounds, in this series of field
trials tests were carried out to determine the amount of resin and hardener delivered to the spinner application head, ie 'the mix ratio'. Three repeat determinations of this ratio were made during each field trial. The GX-014 formulation specifies a mix ratio of 100 parts resin to 42 parts hardener. Results obtained from each field trial are given below:

Field Trial 1
a) 100:43
b) 100:42
c) 100:42

Field Trial 2
a) 100:41
b) 100:40
c) 100:40

Field Trial 3
a) 100:41
b) 100:42
c) 100:41

3.2.3 Discussion of results

Three field trials have been carried out for each resin system to assess the variability in leachate concentrations arising from routine application of the relining process.

Results from mains relined with Sikagard DW2 showed that it is possible to obtain a wide range of concentrations of TMHD and PTSA and, in some cases, higher than predicted from laboratory experiments. In contrast, concentrations of Bis A were invariably low.

Results from the three trials using Geopox GX-014 indicated that leachate concentrations from this material were more consistent and generally in agreement with those predicted from laboratory work.
A small amount of work has been carried out on the variability of the ratio at which resin and hardener are mixed during routine application. Results indicated that a consistent ratio was maintained.

4. CONCLUSIONS AND RECOMMENDATIONS

Laboratory experiments were carried out on the two resins, Sikagard DW2 and Geopox GX-014, to determine the effect on the magnitude of the organic leachate of duration of air-cure, temperature under which cure takes place and various resin formulation modifications. The results showed that, for both resin formulations, extending the cure-time from 4 to a minimum of 16 hours significantly reduced the level of organic compounds leaching from the resin. Changes in temperature and formulation produced smaller changes but, for Geopox resin, reduction of the hardener content plus incorporation of a protective agent did show some improvement. Data from the laboratory work indicated that peak leachate concentrations in the field (for dead-end mains with a small number of consumers) would be in the region of 100 µg.l⁻¹.

Four field trials have been carried out on each resin. Results from mains relined with Sikagard DW2 showed that it is possible to obtain concentrations of organic leachate of widely different magnitude and generally higher than predicted from laboratory work. Thus, for the determinands TMHD and PTSA, peak concentrations were in the region of 400–600 µg.l⁻¹. However, concentrations of Bis A were consistently much lower, with a peak concentration of about 20 µg.l⁻¹. Volatile compounds, present in the reactive diluent, were also observed in some samples taken from mains relined with Sikagard DW2.
In particular, chlorohydroxybutyl ether was detected in all four field trials with a peak concentration of about 100 µg.l⁻¹, while Compound A was seen in only one field trial.

Results from mains relined with Geopox GX-014 indicated that leachate concentrations from this material were more consistent and generally in agreement with those predicted from laboratory work. Thus peak concentrations for TMHD were about 120 µg.l⁻¹, for PTSA about 140 µg.l⁻¹ and for Bis A plus Bis F about 20 µg.l⁻¹. Volatile compounds from the reactive diluent were not detected in any of the samples analysed.

A constant mix ratio was found to be important. Limited work (Section 3.2.2) carried out on the variability of the mix-ratio during application showed that, for one spray applicator system, a consistent ratio was maintained.

From the results of these investigations, we would make the following recommendations regarding the epoxy resin relining process:

1. At present, only Sikagard DW2 and Geopox GX-014 should be considered for relining water mains.

2. A minimum 16 hr cure is required before the main is put back into public supply.

3. On dead-end mains, an additional flow should be induced for the first 24 hr after return to service sufficient to ensure a maximum residence time of 1 hr during this period.

4. A constant mix ratio must be maintained.

5. Monitoring organic leachate levels from selected lengths of pipe in any relining work would be
prudent to serve as a check on lining quality. This could be done relatively quickly and cheaply by analysing only for THHD using a UV method recently developed at WRC (Crathorne et al 1986).

ACKNOWLEDGEMENTS

We are grateful for the provision of field sites and the assistance given by the Staff of Mid Sussex Water Company and Yorkshire Water Western Division. This work was partially funded by the Department of the Environment.
REFERENCES


Table 1. Laboratory experiments

<table>
<thead>
<tr>
<th>Resin</th>
<th>Duration of air-cure (hr)</th>
<th>Temp of air-cure (°C)</th>
<th>Additional modifications compared to formulations used in the 4 hour cure experimental work</th>
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</thead>
<tbody>
<tr>
<td>Sikagard DW2</td>
<td>16</td>
<td>10</td>
<td>-</td>
</tr>
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<td>5</td>
<td>-</td>
</tr>
<tr>
<td>Sikagard DW2</td>
<td>16</td>
<td>10</td>
<td>Relative proportion of hardener reduced</td>
</tr>
<tr>
<td>Geopox GX-012</td>
<td>16</td>
<td>10</td>
<td>Relative proportion of hardener reduced</td>
</tr>
<tr>
<td>Geopox GX-014</td>
<td>16</td>
<td>10</td>
<td>Relative proportion of hardener reduced plus the addition of a protective agent</td>
</tr>
<tr>
<td>Geopox GX-014</td>
<td>16</td>
<td>10</td>
<td>As above, but with curing carried out in a CO$_2$-free atmosphere</td>
</tr>
</tbody>
</table>
Table 2. Results from laboratory experiments – Sikagard DW2. Effect of extended air-cure and cure temperature

<table>
<thead>
<tr>
<th>Determinand and sample time (hr)</th>
<th>16 hour air-cure 10 °C</th>
<th>24 hour air-cure 10 °C</th>
<th>16 hour air-cure 5 °C</th>
<th>4 hour air-cure 10 °C</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>conc µg.1-1</td>
<td>Leaching rate µg.1-1.hr-1</td>
<td>conc µg.1-1</td>
<td>Leaching rate µg.1-1.hr-1</td>
</tr>
<tr>
<td>Trimethylhexa methylenediamine</td>
<td></td>
<td></td>
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<td>147</td>
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<td>214</td>
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Table 3. Results from laboratory experiments - Sikagard DW2. Effect of reducing the relative proportion of hardener

<table>
<thead>
<tr>
<th>Determinand</th>
<th>Sample (hr)</th>
<th>16 hour air-cure 10 °C modified resin</th>
<th>16 hour air-cure 10 °C unmodified resin</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>conc µg.l⁻¹</td>
<td>Leaching rate µg.l⁻¹.hr⁻¹</td>
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<td>977</td>
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<tr>
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Table 4. Results from laboratory experiments – Geopox resins. The effect of reducing the relative proportion of hardener

<table>
<thead>
<tr>
<th>Determinant</th>
<th>Sample (hr)</th>
<th>GX-012 16 hour air-cure. Resin-hardener 100:40</th>
<th>GX-012 4 hour air-cure. Resin-hardener 100:50</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>conc µg.l⁻¹</td>
<td>Leaching rate µg.l⁻¹.hr⁻¹</td>
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<td>7</td>
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<td>323</td>
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<td>4</td>
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<tr>
<td></td>
<td>22</td>
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<td>300</td>
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<tr>
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<td>287</td>
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<tr>
<td></td>
<td>4</td>
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<tr>
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<td>7</td>
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Table 5. Results from laboratory experiments - Geopox resins
Effect of adding protective agent and curing in a CO₂-free atmosphere

<table>
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<tr>
<th>Determinant</th>
<th>Sample (hr)</th>
<th>GX-014 16 hour air-cure</th>
<th>GX-014 16 hour air-cure. Cured in a CO₂-free atmosphere</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td>conc µg.l⁻¹</td>
<td>Leaching rate µg.l⁻¹.hr⁻¹</td>
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<td>135</td>
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<tr>
<td>Bisphenol A diglycidyl ether + Bisphenol F diglycidyl ether</td>
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<td>979</td>
<td>65</td>
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Table 6. Results from field trial on abandoned main - Sikagard DW2

<table>
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<tr>
<th>Sample (hr)</th>
<th>Residence Time (hr)</th>
<th>TMHD conc ug.1-1</th>
<th>Leaching Rate ug.1-1.hr-1</th>
<th>PTSA conc ug.1-1</th>
<th>Leaching Rate ug.1-1.hr-1</th>
<th>BIS A conc ug.1-1</th>
<th>Leaching Rate ug.1-1.hr-1</th>
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<td>11</td>
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<tr>
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<td>16.0</td>
<td>3</td>
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<td>&lt;5</td>
<td>-</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>16.0</td>
<td>4</td>
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<td>&lt;5</td>
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</tbody>
</table>
Table 7. Results* from field trial on abandoned main – Sikagard DW2

<table>
<thead>
<tr>
<th>Sample (hr)</th>
<th>Residence Time (hr)</th>
<th>Chlorohydroxybutyl ether</th>
<th>Compound A</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Conc µg.l⁻¹</td>
<td>Leaching Rate µg.l⁻¹.hr⁻¹</td>
</tr>
<tr>
<td>1</td>
<td>0.73</td>
<td>20</td>
<td>30</td>
</tr>
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<td>18.25</td>
<td>0.73</td>
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<td>10.35</td>
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<td>-</td>
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* These results are only semi-quantitative since no authentic standards are available for these compounds.
### Table 8. Results from field trial on abandoned main - Geopox GX-014

<table>
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<tr>
<th>Sample (hr)</th>
<th>Residence Time (hr)</th>
<th>TMHD conc µg l(^{-1})</th>
<th>Leaching Rate µg l(^{-1}) hr(^{-1})</th>
<th>PTSA conc µg l(^{-1})</th>
<th>Leaching Rate µg l(^{-1}) hr(^{-1})</th>
<th>BIS A + BIS F conc µg l(^{-1})</th>
<th>Leaching Rate µg l(^{-1}) hr(^{-1})</th>
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<tbody>
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</tr>
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</tr>
<tr>
<td>69</td>
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<td>-</td>
<td>&lt;1</td>
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<td>&lt;10</td>
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Table 9. Results from field trial on live main – Sikagard DW2 Length A

<table>
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<th>Sample (hr)</th>
<th>Residence Time (hr)</th>
<th>conc µg.l⁻¹</th>
<th>Leaching Rate µg.l⁻¹.hr⁻¹</th>
<th>conc µg.l⁻¹</th>
<th>Leaching Rate µg.l⁻¹.hr⁻¹</th>
<th>conc µg.l⁻¹</th>
<th>Leaching Rate µg.l⁻¹.hr⁻¹</th>
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</tr>
<tr>
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<td>0.32</td>
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<td>11</td>
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<td>-</td>
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<td>44</td>
<td>5.2</td>
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<td>68</td>
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<td>-</td>
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</tbody>
</table>

* A peak was present in the blank equivalent to about 0.7 µg.l⁻¹

* A peak was present in the blank equivalent to about 10 µg.l⁻¹. The results are adjusted accordingly.
Table 10. Results from field trial on live main - Sikagard DW2 Length B

<table>
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<tr>
<th>Sample (hr)</th>
<th>Residence Time (hr)</th>
<th>TMHD conc µg.1⁻¹</th>
<th>Leaching Rate µg.1⁻¹.hr⁻¹</th>
<th>PTSA conc µg.1⁻¹</th>
<th>Leaching Rate µg.1⁻¹.hr⁻¹</th>
<th>BIS A conc µg.1⁻¹</th>
<th>Leaching Rate µg.1⁻¹.hr⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blank</td>
<td>-</td>
<td>&lt;1</td>
<td>-</td>
<td>&lt;5</td>
<td>-</td>
<td>&lt;1</td>
<td>-</td>
</tr>
<tr>
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<td>357</td>
<td>649</td>
<td>390</td>
<td>709</td>
<td>&lt;1</td>
<td>-</td>
</tr>
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<td>6.54</td>
<td>271</td>
<td>42</td>
<td>373</td>
<td>57</td>
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<td>43</td>
<td>0.53</td>
<td>16</td>
<td>30</td>
<td>16</td>
<td>30</td>
<td>&lt;1</td>
<td>-</td>
</tr>
<tr>
<td>Consumers Tap</td>
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<td>12</td>
<td>18</td>
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<td>-</td>
</tr>
<tr>
<td>67</td>
<td>1.3</td>
<td>43</td>
<td>33</td>
<td>20</td>
<td>15</td>
<td>&lt;1</td>
<td>-</td>
</tr>
<tr>
<td>166</td>
<td>0.8</td>
<td>30</td>
<td>38</td>
<td>13</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>Adjacent main lined following day</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
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<td>19</td>
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<td>7</td>
<td>2</td>
<td>0.67</td>
</tr>
<tr>
<td>Length B over-lined</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>1.5</td>
<td>0.62</td>
<td>223</td>
<td>360</td>
<td>121</td>
<td>195</td>
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<tr>
<td>48</td>
<td>2.18</td>
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<td>27</td>
<td>29</td>
<td>13</td>
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</table>

ND Not determined
Table 11. Results from field trials on live main - Sikagard DW2 Length C

<table>
<thead>
<tr>
<th>Sample (hr)</th>
<th>Residence Time (hr)</th>
<th>TNHD conc µg.l⁻¹</th>
<th>Leaching Rate µg.l⁻¹.hr⁻¹</th>
<th>PTSA conc µg.l⁻¹</th>
<th>Leaching Rate µg.l⁻¹.hr⁻¹</th>
<th>BIS A conc µg.l⁻¹</th>
<th>Leaching Rate µg.l⁻¹.hr⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blank</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>11</td>
<td>-</td>
<td>1</td>
<td>-</td>
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<tr>
<td>1</td>
<td>0.49</td>
<td>19</td>
<td>39</td>
<td>8*</td>
<td>16</td>
<td>1</td>
<td>2.0</td>
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<tr>
<td>28.5</td>
<td>2.0</td>
<td>63</td>
<td>32</td>
<td>8*</td>
<td>4</td>
<td>3</td>
<td>1.5</td>
</tr>
<tr>
<td>42</td>
<td>10.8</td>
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<td>59*</td>
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<td>1</td>
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<tr>
<td>66</td>
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<td>589</td>
<td>53</td>
<td>194*</td>
<td>17</td>
<td>22</td>
<td>2.0</td>
</tr>
</tbody>
</table>

* A peak was present in the blank equivalent to about 11 µg.l⁻¹. The results are adjusted accordingly.

+ A peak was present in the blank equivalent to about 1 µg.l⁻¹. The results are adjusted accordingly.
Table 12. Results from field trials on live mains - Sikagard DW2, chlorohydroxybutyl ether

<table>
<thead>
<tr>
<th>Length A</th>
<th>Residence time (hr)</th>
<th>Conc (µg.l⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample (hr)</td>
<td></td>
<td></td>
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<tr>
<td>1</td>
<td>0.32</td>
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</tr>
<tr>
<td>30</td>
<td>1.82</td>
<td>11</td>
</tr>
<tr>
<td>44</td>
<td>5.2</td>
<td>29</td>
</tr>
<tr>
<td>68</td>
<td>5.45</td>
<td>24</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Length B</th>
<th>Residence time (hr)</th>
<th>Conc (µg.l⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample (hr)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0.55</td>
<td>98</td>
</tr>
<tr>
<td>29</td>
<td>6.5</td>
<td>87</td>
</tr>
<tr>
<td>43</td>
<td>0.5</td>
<td>3</td>
</tr>
<tr>
<td>1 (overlined sample)</td>
<td>0.62</td>
<td>45</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Length C</th>
<th>Residence time (hr)</th>
<th>Conc (µg.l⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample (hr)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0.49</td>
<td>&lt;2</td>
</tr>
<tr>
<td>28.5</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>42</td>
<td>10.8</td>
<td>36</td>
</tr>
<tr>
<td>66</td>
<td>11.2</td>
<td>74</td>
</tr>
</tbody>
</table>
Table 13. Results from field trial on live main - Geopox GX-014 Length A

<table>
<thead>
<tr>
<th>Sample (hr)</th>
<th>Residence Time (hr)</th>
<th>TMHD conc µg.1⁻¹</th>
<th>Leaching Rate µg.1⁻¹.hr⁻¹</th>
<th>PTSA conc µg.1⁻¹</th>
<th>Leaching Rate µg.1⁻¹.hr⁻¹</th>
<th>BIS A + BIS F conc µg.1⁻¹</th>
<th>Leaching Rate µg.1⁻¹.hr⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<td>33</td>
<td>83</td>
<td>70</td>
<td>175</td>
<td>11</td>
<td>28</td>
</tr>
<tr>
<td>31.5</td>
<td>0.6</td>
<td>7</td>
<td>12</td>
<td>5</td>
<td>9</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>42</td>
<td>3.0</td>
<td>41</td>
<td>14</td>
<td>57</td>
<td>19</td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td>68</td>
<td>3.1</td>
<td>17</td>
<td>6</td>
<td>21</td>
<td>7</td>
<td>3</td>
<td>1</td>
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</tbody>
</table>
Table 14. Results from field trials on live main - Geopox GX-014 Length 3

<table>
<thead>
<tr>
<th>Sample (hr)</th>
<th>Residence Time (hr)</th>
<th>TMHD conc µg.l⁻¹</th>
<th>Leaching Rate µg.l⁻¹.hr⁻¹</th>
<th>PTSA conc µg.l⁻¹</th>
<th>Leaching Rate µg.l⁻¹.hr⁻¹</th>
<th>BIS A + BIS F conc µg.l⁻¹</th>
<th>Leaching Rate µg.l⁻¹.hr⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.6</td>
<td>39</td>
<td>65</td>
<td>76</td>
<td>122</td>
<td>10</td>
<td>16</td>
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<tr>
<td>30</td>
<td>9.5</td>
<td>71</td>
<td>7</td>
<td>69</td>
<td>7</td>
<td>13</td>
<td>1</td>
</tr>
<tr>
<td>44.5</td>
<td>11.6</td>
<td>123</td>
<td>11</td>
<td>137</td>
<td>12</td>
<td>18</td>
<td>2</td>
</tr>
<tr>
<td>68</td>
<td>32.0</td>
<td>77</td>
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<td>101</td>
<td>3</td>
<td>11</td>
<td>0.3</td>
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</tbody>
</table>
Table 15. Results from field trial on live main - Geopox GX-014 Length C

<table>
<thead>
<tr>
<th>Sample (hr)</th>
<th>Residence Time (hr)</th>
<th>THHD conc µg.l(^{-1})</th>
<th>Leaching Rate µg.l(^{-1}).hr(^{-1})</th>
<th>PTSA conc µg.l(^{-1})</th>
<th>Leaching Rate µg.l(^{-1}).hr(^{-1})</th>
<th>BIS A + BIS F conc µg.l(^{-1})</th>
<th>Leaching Rate µg.l(^{-1}).hr(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.5</td>
<td>30</td>
<td>60</td>
<td>39</td>
<td>74</td>
<td>6</td>
<td>11</td>
</tr>
<tr>
<td>28.5</td>
<td>6.1</td>
<td>27</td>
<td>4</td>
<td>29</td>
<td>5</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>41</td>
<td>10.6</td>
<td>34</td>
<td>3</td>
<td>22</td>
<td>2</td>
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<td>0.7</td>
<td>8</td>
<td>1</td>
<td>6</td>
<td>1</td>
</tr>
</tbody>
</table>
Figure 1. Results from Laboratory experiments: Sikaguard DW2

Plot of leaching rate versus time for trimethylhexamethylene diamine
Figure 2. Results from laboratory experiments: Geopox

Plot of leaching rate against time for trimethylhexamethylene diamine
APPENDIX A

EPOXY RESIN RELINING METHOD FOR WATER MAINS

Any cast or ductile iron water main of 75 mm to 150 mm diameter can be rehabilitated using epoxy resin provided the pipe is sound enough to withstand the rigors of scraping and lining. The method for in situ spray applied relining with epoxy resin can conveniently be broken down into 3 broad categories; scraping to remove corrosion debris, relining the main and a period of cure incorporating chlorination and flushing. These categories are described below:

(i) Scrapping

Lengths of water main of up to approximately 120 m can be scraped and lined in one operation. The corrosion debris is removed by a process called power boring which is suitable for mains in the diameter range 75 mm-300 mm. The technique involves driving oversized spring cutters into the main against a flow of water. The flow of water ensures rapid and effective removal of corrosion debris and a negligible incidence of blocked service connections. The spring cutters are rotated using steel drain rods powered either by a diesel boring 'pram' or a rack feed borer.

Before boring, the main is isolated by closing upstream, downstream and branch valves, and consumers' stop cocks are turned off. The latter precaution ensures that water from the relined main is not consumed before the applied resin is cured and the main has been chlorinated and flushed. In
addition, the risk of accidentally damaging the fresh lining by allowing water from a service pipe to run back into the main is removed.

The main is entered at the downstream end of the section to be bored and boring proceeds against a flow of water controlled by an upstream valve until the cutters can be heard in the upstream excavation. On completion of the boring, the cutters are rotated out of the main and the main is flushed until the water runs clear. The main can then be inspected to ensure complete removal of corrosion debris and, if satisfactory, the upstream section is removed to allow access to be gained to the entire pipe length for relining.

Since epoxy resin cannot be applied over standing water, nor can it tolerate passing water, care is taken to 'dry' the main before lining. This is facilitated by blowing foam swabs through the main until the last one appears relatively clean and dry. The main is then ready for relining.

(ii) Relining with epoxy resin (Geopox-GX014)

Lining equipment consists of a rig containing heated reservoirs for the resin and hardener components, a suitable pump arrangement to meter the component at the required mix ratio of 100.42 (by weight) and separate lining hoses mounted on a drum with suitable winch control.

The resin and hardener are stored separately and are heated to increase pumping and mixing efficiency. When the resin and hardener are
mixed, this added heat also initially accelerates the cure rate. To ensure an even distribution of heat, resin and hardener are recirculated continuously through the lining hoses. It is possible at this point to check the mix ratio of the rig by weighing the output of the two hoses. Once warmed and fully operational, the hoses are inserted into the main using rods and are drawn to the furthest access hole where the spinner application head and a suitable static mixer are attached.

The air driven application head is checked for malfunctions, charged with mixed resin and spun up. This procedure continues for some minutes until the resin and hardener are correctly mixed. During this time excess resin should be deposited in a waste container. The Geopox-GX014 resin system comprises a red resin and a white hardener which, when correctly mixed, produces a pink colour. When an even pink colour is observed, lining may begin. The lining is centrifugally spray applied and the withdrawal speed and the pump stroke rate are controlled to ensure a 1 mm ± 0.2 mm lining thickness. On completion of the lining both ends of the main are capped-off to avoid contamination.

(iii) Curing, chlorination and flushing

Once capped-off the lining is allowed to cure overnight (a minimum of 16 hours). After this period the main is inspected visually for lining quality in terms of thickness, smoothness and cure. A further check on the state of cure and mix efficiency may be obtained by blowing a swab down the pipe.
When recovered, the swab should be clean, dry and free from resin material. Once inspected the main is pieced-up using either the pipe sections that were removed (these should be relined above ground with epoxy resin) or new cement lined ductile iron pipe. The main is then charged with chlorinated water (25-20 mg.l⁻¹ free chlorine) for a contact time of 15-30 mins. The main is then flushed to waste at 0.5 m.s⁻¹ for 1 hour, after which stop cocks may be opened and main is returned to service. If the relined main supplies a dead-end, precautions are taken to ensure there is no risk of overnight stagnation during the first night in service. This is achieved by inducing a low flow of water on the main sufficient to give a residence time of not less than 1 hour for the first 24 hours in service. In practice for a 100 mm diameter main this amounts to a flow of about 13 l.min⁻¹.
APPENDIX B

QUALITY CONTROL

On two occasions during the course of experimental observations on the lining process, faults in the lining equipment occurred. Investigation of these faults has resulted in the development and use of certain quality control procedures. These are designed to decrease the risk of 'faulty' linings being returned to service and to improve the reliability of the process. A brief description of the faults observed and the quality control measures now employed are given below.

1. THE PRESENCE OF UNMIXED MATERIAL

During the course of a CCTV survey of a main reclined with Sikaguard DW2, a small amount of unmixed resin was observed on the centralising brushes of the TV camera. The source of this material was not positively identified but was thought to be on the make-up pipe installed after the completion of the lining. This small section of pipe may have been dropped into the access hole and became contaminated with unmixed resin deposited in the excavation during 'pumping-up'. A number of precautions are now taken to avoid the possibility of unmixed resin contaminating the relined main.

a) All pumping-up operations are now conducted in a waste container well away from the access excavation thus ensuring that if accidental contamination of make up pieces occurs the contaminant is properly mixed.

b) Before returning a relined main to service a dry swab is blown down the line. This swab will
stick to large areas of unmixed material or will emerge from the main showing evidence of contamination from one component. In either case the main would not be returned to service. Following investigation of the cause of the fault, the entire length would be overcoated.

c) CCTV inspections can now be routinely employed if the water utility wishes. This technique is suitable for identifying gross lining faults and, while not necessary for every lining length, it is of great value for occasional quality inspection.

2. CONTROL OF MIX RATIO

The Geopox-GX014 resin is designed to be used at a mix ratio of 100 parts of resin to 42 parts of hardener. Recent experiments as yet unreported, suggest that a 10% tolerance on this ratio will not markedly effect the leaching potential of the lining or its strength and integrity. However, one length of main was relined with a resin mix which was some 20-25% out of specification. This resulted in a short term increase in leaching rate and a lack of strength resulting in a stripped lining when charged with water. The main in question was not returned to service but was re-bored and overcoated before being put back into use.

To avoid this problem the WRc and one of the contractors are developing a flow monitor that will warn the operatives and water utility supervisors when a ratio fault occurs. Since this equipment is not yet operational, the following precautions are being taken:

a) Lining rigs are checked before leaving the contractors premises by spot weighing delivery
from the hoses. The rigs can be accurately set at 100:42 ratio and it is not easy for operatives to alter these settings.

b) Staff at water utilities can request spot checks of weight on the delivery hoses before lining occurs, and while it is not practicable to check before every lining, a weekly test (ie every 6-8 linings) is reasonable. Tests carried out by WRc showed that good consistency in mix ratio was maintained.

3. OTHER QUALITY ASSESSMENT

The WRc has recently developed a rapid test for THM. This test is simple and cheap and whilst it has limited sensitivity (about 10 μg.l⁻¹) it will be suitable for use by authorities for diamine monitoring immediately after the main has been returned to service.

Progress is being made on the establishment of a BSI Registered Company Scheme for epoxy resin contractors. When fully implemented in 1987 it will ensure that only approved contractors and materials will be used by the water utilities and the routine inspection of individual relining gangs by the BSI will ensure good quality linings.
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