REHABILITATION OF DISTRICT HEATING NETWORKS

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ABSTRACT

District heating and combined heat and power systems are becoming an attractive way of reducing greenhouse gas emissions. This has resulted in renewed interest in such systems used to provide electricity and heat to cities, and Universities, for example.

There are many district heating systems in the United Kingdom, including the cities of London, Newcastle, Nottingham and Sheffield, among others. These systems take the form of a central boiler supplying heat over a large area such as a housing estate. The distribution of hot water is by preinsulated pipelines, with the majority manufactured in steel. Primary pipelines carry superheated water from the boiler to substations where the temperature is modulated depending on demand. Secondary pipelines transport water to users and constitute the bulk of pipelines in a network. Operating temperatures of secondary pipelines can be up to 90°C but are typically at less than 80°C.

Poor installation practice in the past often means that pipelines are prematurely at the end of their lives, and require constant maintenance. Clearly the maintenance costs of such a system are very large, as the installations are in a congested urban environment. The repair costs are high due to the reinstatement costs for road, footpaths, and buildings. Such high costs can result in decommissioning the district heating network, installing individual boilers and bearing the resultant short term costs. In these circumstances there is a clear market for a rehabilitation system.

This paper describes such a system, manufactured from crosslinkable polyethylene. The general properties of PEX are reviewed and key properties for this application are selected and the requirements stated. The performance of the product against specified criteria is described in depth. The results of yard trials are reviewed and a case study of a field trial in Byker, Newcastle-upon-Tyne is given, demonstrating that the SPEX system provides the means to economically repair leaking pipework by a novel relining technique.

INTRODUCTION

District heating (DH) is a means of supplying buildings with hot water from a single, central source. Combined heat and power facilities (CHP) can be used as the central heat source, generating electricity in the same cycle. By combining the two processes, the efficiency of the plant can be as much as 85% compared with 35-55% for electricity only plants. This leads to a significant reduction of the amount of carbon dioxide produced, indeed the DTI estimate that for each 1 MW of CHP operating for one year, 1,000 tonnes of carbon dioxide are saved. There are currently 4.3 GW of CHP in the UK (1).

In 1995, approximately 1% of the UK housing stock was connected to district heating, that is 250,000 homes plus 175,000 “multi-residential dwellings”(2), with a further 1200 industrial CHP schemes. The same report highlights one of the areas where there is potential to increase the efficiency of existing systems, which is the condition of the pipework. Two thirds of DH schemes with underground pipes have not refurbished them; the average age of pipework is 22 years and is as much as 40 years in some cases.

Although this is well within the design life of a steel pipe, there were problems with poor installation practises. Poor quality insulation and overwrapping results in the ingress of ground water, which is absorbed by the porous foam insulation and begins to corrode the steel pipe from the outside in.

When all the above facts are considered, it is clear that there is quite some potential for a system that can economically repair leaking pipes with minimal disruption. The majority of pipe work in DH system is, naturally, laid in an urban environment, often underneath buildings. Many local authorities have therefore decided not to replace corroded pipework, due to the high initial cost, despite the longer term environmental and financial benefits. The SPEX system provides the means to economically repair leaking pipework by a novel relining technique. Such liner systems should be able to cope with the special set of conditions present in DH schemes.

THE SPEX SYSTEM

The SPEX system is based on silane crosslinkable PE. The unique properties of PEXb are used to manufacture a pipe of very low crosslinking, which gives the installer all the favourable properties of conventional PE. Following installation, the pipe can be run as PEX, with all the enhanced properties of that material. The installation process is similar to conventional relining, but with a larger clearance between the liner and the host; 15-20% depending on the conditions. Following pull-in, the exposed ends of the pipe are prepared using a custom expanding/flaring tool and secured using special compression fittings, that are pressed in with a hydraulic ram. A hot water boiler is attached to one end of the pipe with a compact flow and return adapter to reduce onsite clutter and complexity. Hot, pressurised water is then circulated down the entire length of the pipe, which has the effect of softening the pipe and causing it to inflate against the wall of the host. The elevated temperatures mean that the SPEX liner flows around any obstructions and is effectively free of any residual stresses as it does so. The temperature of the circulating water causes the pipe to crosslink rapidly, which in turn prevents the liner from recovering when the pressure is removed. The result of this inflation process is a very close fitting liner, essentially free of unfavourable residual stress. The fittings are then bolted or welded together using lugs and are also designed to be welded directly back to the host pipe, resulting in a fully welded system with no end loading on the liner.

The ability to weld PEXb is well known (3), and this is utilised in the SPEX system as shown below in Figure 1. This weld was formed using SPEX pipe crosslinked to 50%, and although it has failed through the interface there is a large amount of ductility present. This means that the length that can be relined is limited only by the appropriate pulling length, not by a coil length. Indeed it has been shown that crosslinking after welding can result in stronger welds as strong primary bonds are formed across the interface.

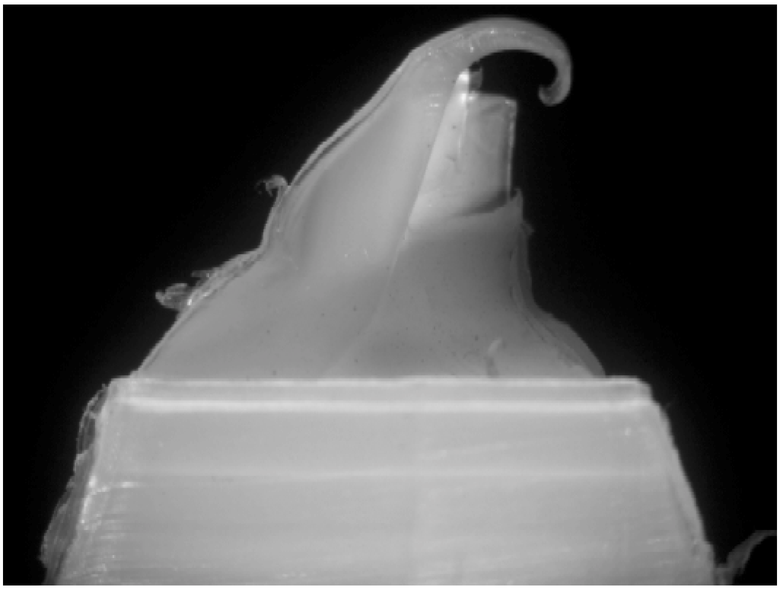

Figure 1; Yielding across the weld interface

The amount of crosslinking at installation is key in the SPEX process. Too much and welding will not be possible, too little and the liner will not lock against the host. The amount of crosslinking is determined by the type of catalyst added and in this way the ideal crosslink level can be selected as required by on-site conditions and the shelf-life needed.

The difference between two catalysts can clearly be seen in Figure 2, below. In this case, the pipe samples were immersed in water at 80°C to accelerate the process; SPEX is designed to remain below 50% for a minimum of 90 days.

LIFETIME PREDICTION

The operational life of a pipe system is of utmost importance, unfortunately it is also one of the most difficult and time consuming properties to measure. The required design life of the SPEX system was 25 years at the operational temperature, taking the field trial at Byker as an example, this means that SPEX must be able to withstand temperatures of at least 82°C for this time. A high level of certainty was required, due to the expensive nature of DH components, particularly the heat exchangers. This is clearly a challenge to complete in the short time scale required by the project, and two methods were chosen; conventional hydrostatic testing up to 120°C and a novel high temperature method. The new method was developed because time was short, but this needed to be backed up by solid results from a trusted third party. Bodycote polymer was chosen for this important task as they had extensive experience in the long term testing of PEX pipes.

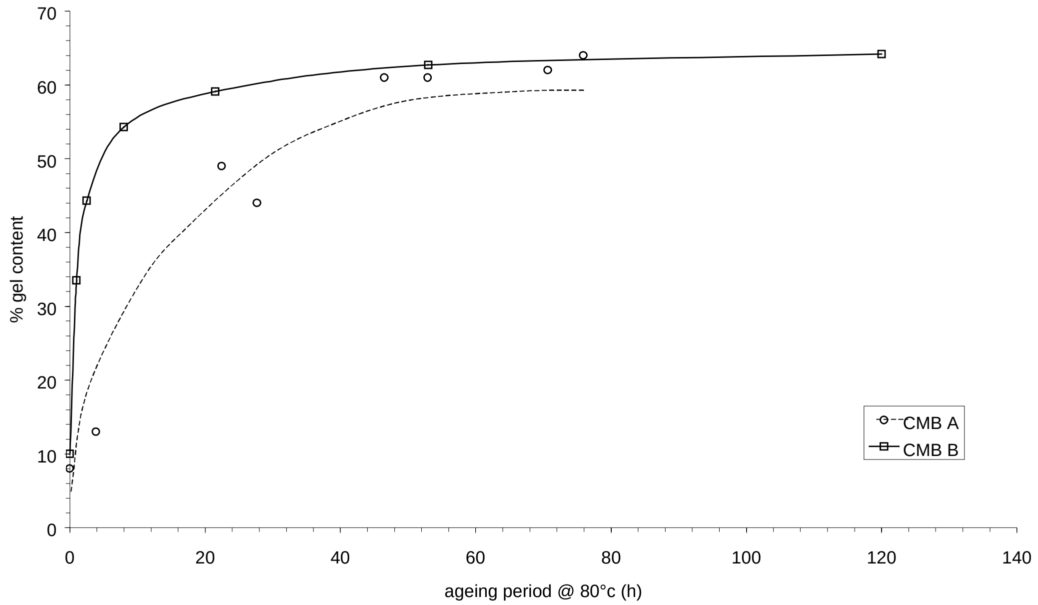

Figure 2; Comparison of crosslinking performance of two different catalysts

The results of nearly two years of hydrostatic testing are shown below in Figure 3. The temperatures range from 100 – 120°C, with stresses chosen to promote stage III failure. From these data it is possible to calculate the appropriate failure times at various temperatures, and these are shown in Figure 4. One feature of note in this graph is the flatness of the curves, even at 120°C, evidence of the excellent temperature resistance of SPEX.

Previous high temperature ageing work used a full scale PEX lined steel pipe as the test piece (4). This was considered too costly and time consuming considering the number of data points required, so it was decided to use a pressure vessel and strips of PEX 6.5mm in thickness, cut from extruded pipe. The strips were aged at various temperatures up to 190°C, the maximum temperature at which the chemistry of the antioxidant package was largely unchanged from operational temperatures (5). Strips were removed at various times and underwent oxidation induction time (OIT) analysis, to find the ageing time to failure. The failure point was defined as an OIT of 2 minutes at 220°C in pure oxygen.

The time taken to reach the failure point was then plotted against temperature and the line extended to the required temperatures. These data are plotted below in Figure 4, and compared with the Bodycote hydrostatic data it should be noted that both these sets of data include a safety factor of 1.2. As can be seen, the lines are in close agreement, with a very similar gradient. The data produced by the autoclave is shifted downwards, leading to a conservative estimation of time to failure which is most likely caused by some non-linearity in the acceleration factor of the higher temperatures. However, it should be noted that this test method is still in the very early stages of development, with further work ongoing at Loughborough University.

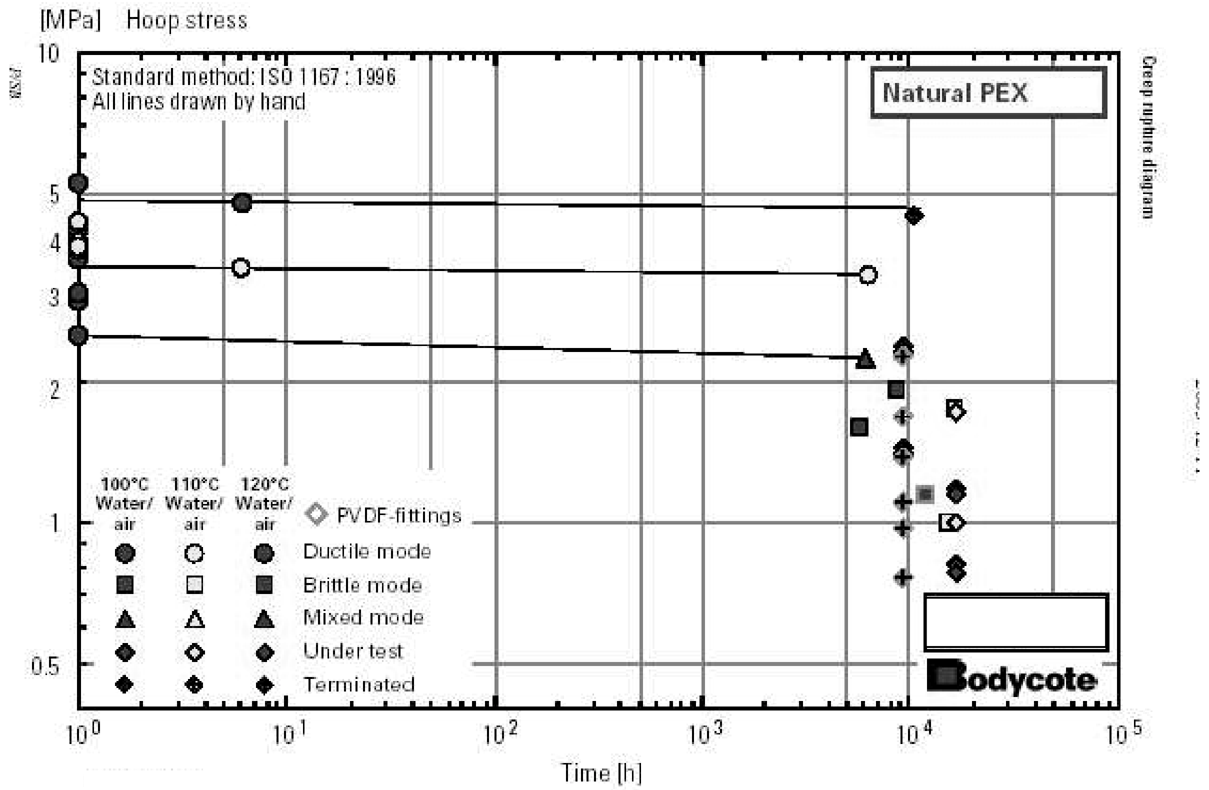

Figure 3; Results of elevated temperature hydrostatic tests

INSTALLATION TRIALS

In order to determine the correct installation regime for SPEX, it was necessary to perform extensive small-scale trials. The purpose of these trials was to answer the following questions:

- How large a clearance is acceptable?
- At which temperature and pressure and for how long should the installation take place?
- What is the effect of inflating notched or butt-welded samples?
- What is the minimum crosslink level required?

For this purpose a high temperature boiler with nitrogen pressurisation was used to heat a 1.5m pipe section. Holes cut round the circumference of the host allowed monitoring of the inflation process, and the crosslink level was measure using the solvent extraction method. Some typical results are shown below in Figure 5. The changes in expansion rate can be clearly seen, indeed at low pressures the pipe stabilises due to the increase in crosslink level. In order for the liner to hold itself against the wall of the host after the removal of the pressure, it should have at least 50% crosslinking throughout the wall. Less than this and some recovery will occur, reducing the effective bore of the relined section of pipework. The results of the small scale trials was then applied to longer lengths of pipe and a commercially available boiler was used to supply the hot water.

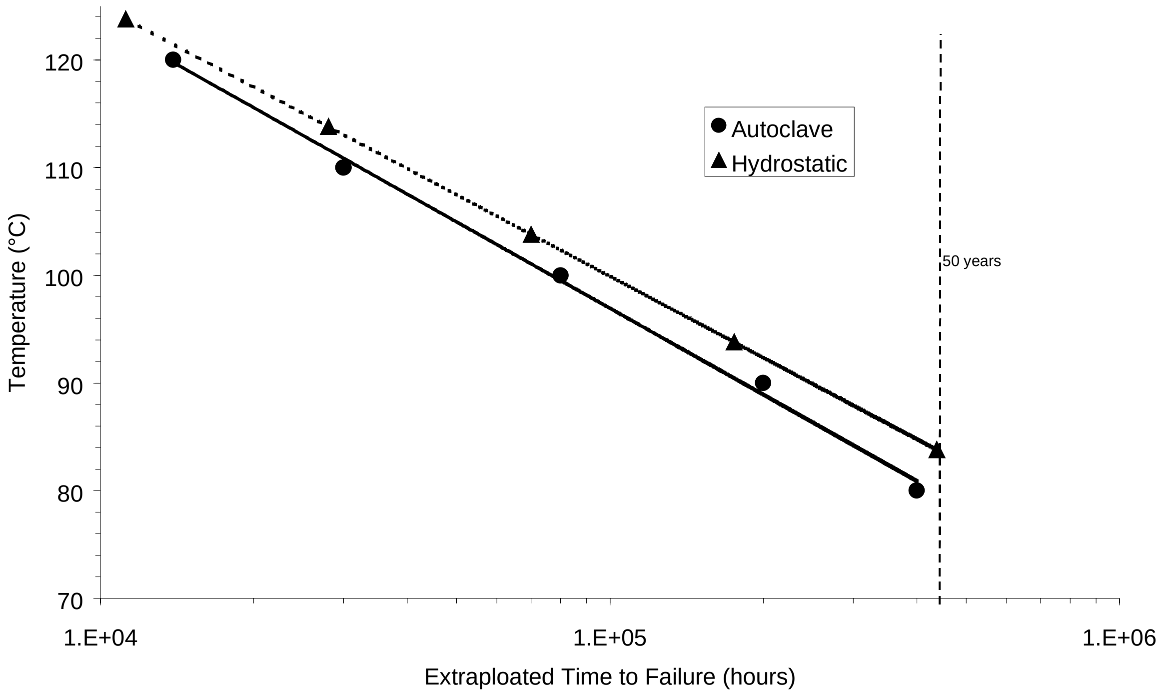

Figure 4; Comparison of initial autoclave results

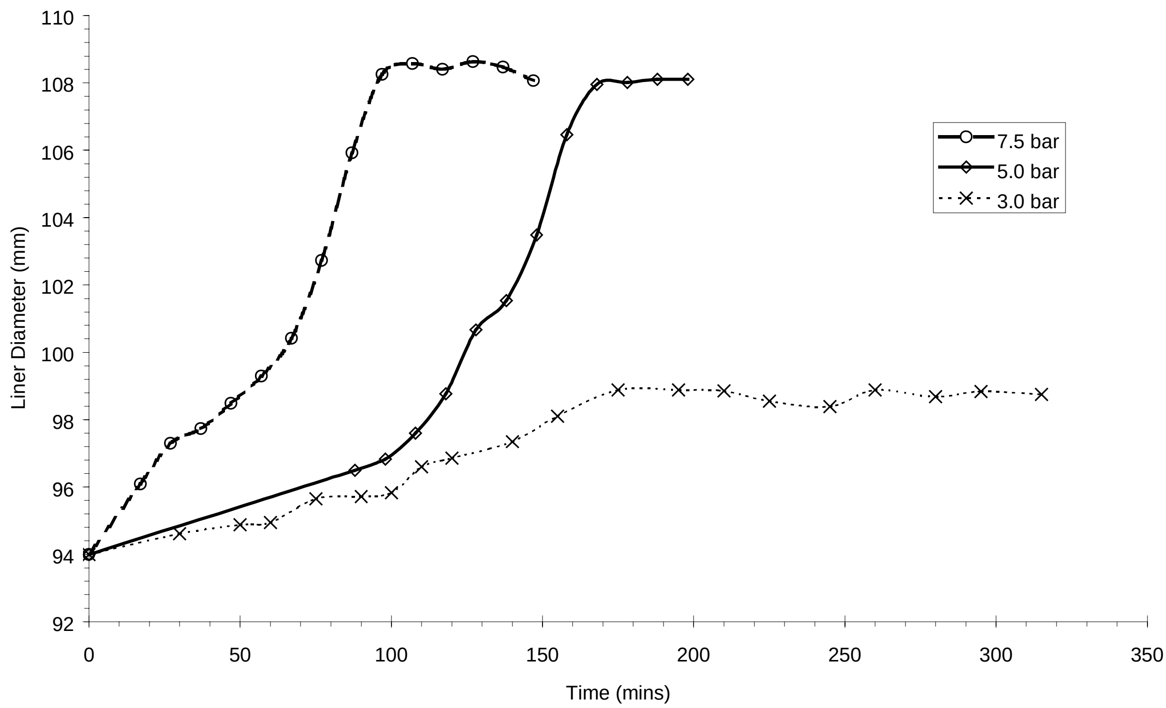

Figure 5; Typical expansion curves at 110°C and varying pressure

The butt-welded pipes had exactly the same installation behaviour as continuous lengths. Some reduction in the maximum expansion was seen in pipes notched to 10% of their wall thickness, but at lower expansion levels, the heat and pressure tend to flatten and round off the notch base, reducing the stress concentration at the root. No thinning of the wall thickness was noted at any part of the circumference.

FIELD TRIAL

Situated in Newcastle-upon-Tyne in the Northeast of England, the Byker District Heating scheme is one of a limited number of waste to energy plants in the UK. Its design follows the Scandinavian perspective of its designer Ralph Erskine, with a central boiling providing the village with district heating.

Commissioned in 1979, there are three key elements in the Byker plant, the reclamation plant, the combined heat and power station, and the district heating network itself. The reclamation plant screens and sorts 2000 tonnes of waste per week to form compressed refuse derived fuel (RDF) pellets for the CHP station. The heat station underwent refurbishment in 1992 and now provides 17,500 MW hours of electricity for the National Grid, along with enough hot water for the entire DH system. The district heating network consists of 2km of primary mains, feeding several sub-stations where the heat is transferred via heat exchangers to the secondary network.

The secondary network is of greatest interest in terms of rehabilitation, although is not without its challenges. At Byker there are 12 km of secondary mains, up to 150mm in diameter. Due to the way the pipework was installed, access is extremely limited. In many cases the secondary system runs underneath buildings and roads. When the primary mains were replaced in the early 1990's, the old pipes were left in place. This has resulted in a situation where maintenance has become extremely costly, and made the district heating scheme at Byker an ideal location for a SPEX field trial. The layout of the field trial site is shown in Figure 6, below.

This location was chosen because the pipe run contained a leak as identified by thermographic survey, which was pinpointed to somewhere in a length of the 54mm flow and return pipes. The pipes to be relined were buried at 2 metres depth along with several other pipes, including those that had not been removed after replacement. It is also worth noting that the asphalt surface was laid on around 150mm of steel bar reinforced concrete, clearly an open cut replacement in this type of ground would be prohibitively expensive. The trial had to be finished in a time frame of 10 hours, the maximum time that the hot water supply could be cut off for, before compensation had to be paid and alternative provisions made.

The access pits were pre-dug, and once the secondary pipework had been broken into, the female part of the fittings were welded to the host. A quick inspection showed that there were no obstructions, apart from some minor silting, in the host, and the liners were easily inserted by hand from a coil. The pipe end was flared using a special tool and the male part of the fittings hydraulically pressed into the liner. Following blanking off the far end of the pipe, the flow and return adapters were fitted to the near end and connected to the boiler. Once the required temperature and pressure were reached the inflation proceeded for 1 hour, to guarantee the required crosslink level. The pipes were then cooled, drained and made ready for welding back to the host and re-insulation.

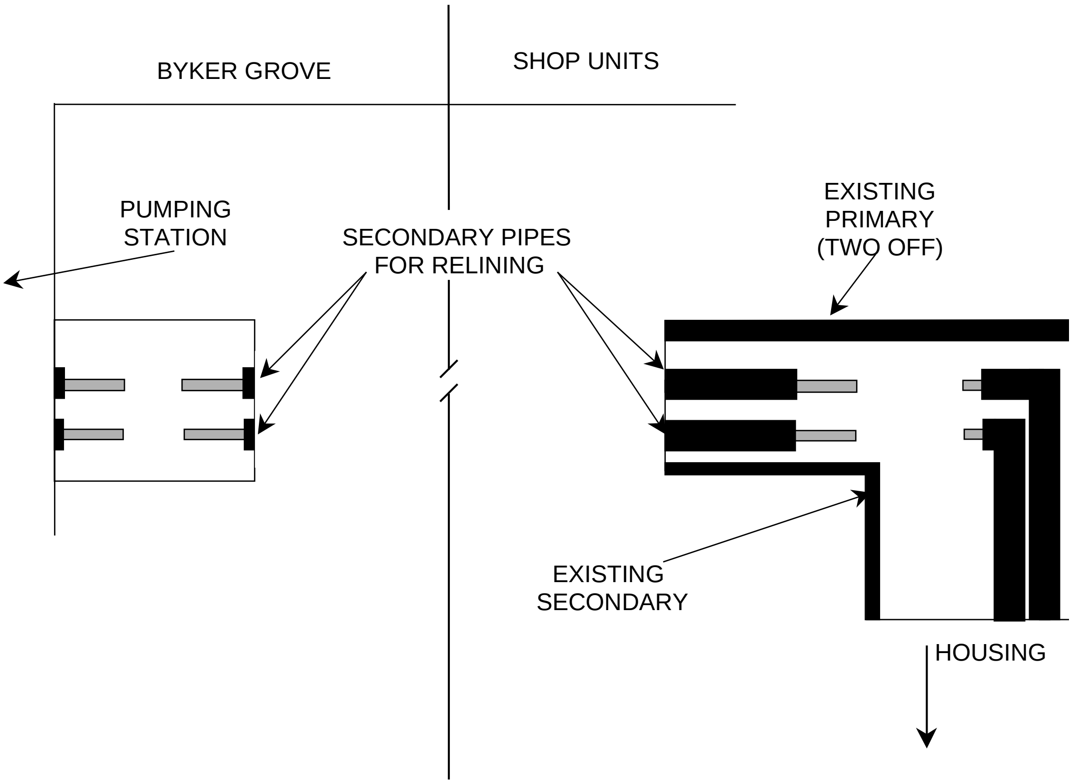

Figure 6; Layout of the Byker field trial site

Both flow and return legs were relined and reinstated in the required time frame, and the operator of the system, Newcastle City Council's Housing Department, have since reported that the leak can no longer be detected.

CONCLUSIONS

- A successful field trial at Byker, Newcastle-upon-Tyne has shown that the SPEX rehabilitation system is capable of repairing leaking DH pipes, resulting in a fully welded system.
- The lifetime of PEXb has been shown to be well in excess of the design requirements, the 50 year temperature for *continuous operation* is now above 70°C which includes a safety factor of 1.2.
- A high temperature ageing method has given good time to failure results in a short time. However, further work is required.

ACKNOWLEDGEMENTS

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