10th International Symposium on District Heating and Cooling

September 3-5, 2006

---

**Tuesday, 5 September 2006**

## Sektion 6 a

**Heat distribution – pipe properties**

# Leakage ways for ground-water in PUR-foam

S.-E. Sällberg, S. Nilsson, G. Bergström,
SP Swedish National Testing and Research Institute, Göteborg/Sweden

# Leakage ways for ground-water in PUR foam

Sven-Erik Sällberg, Dr Stefan Nilsson & Gunnar Bergström
SP Swedish National Testing and Research Institute
Box 24036, SE-400 22 Göteborg, Sweden
+46-31 7084418, sven-erik.sallberg@sp.se, www.sp.se

## ABSTRACT

Laboratory studies have shown that polyurethane insulation, PUR foam, used in district heating pipes acts as a barrier to groundwater if it is of good quality, i.e., free from cracks, cavities and other defects. However, moisture damaged foam is frequently observed in practice. It has further been observed that the interface between on-site poured joint foam and the pipe-ends comprises a significantly coarser than normal cellular structure. The purpose of this study has been to examine whether this coarser interface structure may provide a leakage way for groundwater.

The PUR foam's potential as a water barrier previously hypothesised through laboratory measurements has been confirmed by field tests. District heating pipes without casing were in service in the ground for four years in a region where ground-water occasionally entirely covered the pipes.

The results show that the inner parts of the PUR foam remains dry if no defects, such as crack and cavities, are present. Close to the service pipe, the foam actually dries out over time.

To evaluate the water permeability of the pipe/joint foam interface, a number of joints were manufactured, with variations in pipe-end treatment (regular "weather exposure", clean-cut foam or end seal), foam type and density, temperature and pipe size.

It was seen that the interface indeed was permeable to liquid water in a number of cases. Foaming against a clean-cut pipe-end with fresh foam is the safest way of foaming a joint. In all instances, these interfaces were water-tight. A coarser cellular structure in the interface appears to yield a higher leakage rate. However, a coarse structure can be seen also in interfaces with clean-cut pipe-ends without leakage. This implies that large cells are not in themselves the cause for leakage but they may promote the leakage rate.

*Keywords: District heating pipe joint, polyurethane foam (PUR), moisture.*

## 1 INTRODUCTION

Moisture in district heating joint foam caused by groundwater leaking through the casing has been the subject for extensive studies for some years. It is known that when a district heating joint starts to leak it can be filled with water if there are air-gaps or other similar defects in the foam in direct contact with the leakage (Bergström & Nilsson, 2002). Studies have also indicated that if the polyurethane (PUR) foam is free from cracks, cavities and other defects it acts not only as insulation it also acts as a barrier against water (Bergström *et al*, 2002). The PUR foam is impermeable to liquid water but permeable for water vapour. Because of the inward temperature gradient in the pipe, water vapour diffusing in from the outside is harmless concerning moisture damages.

Nevertheless, moisture damage is seen on pipe joints in service. Hence, water must enter the pipe construction in some other way than through the foam. Bergström *et al* (2002) also showed that the cell structure in PUR foam at the interface between pipe ends and on-site poured joint foam often is significantly coarser than in ordinary foam. To what extent the coarser cell structure in the interfaces provide ways for liquid water to enter the interior of the pipe has however not been previously examined.

This paper aims at clarifying whether PUR foam can be considered water tight for long-term service and if the coarser cell structure in the interface between pipe and joint foam may provide a leakage way for liquid water. The results presented here are previously reported in Swedish by Nilsson *et al* (2005) and Sällberg and Nilsson (2005).

## 2. FIELD TESTS – WATER TIGHTNESS OF PUR FOAM

In order to examine to what extent PUR foam can be regarded as water tight when used in service, two pipes without casing, i.e., with naked PUR foam, was installed on a district heating pipeline, figure 1. The pipes, of dimension DN 150/280, were approximately one meter long. They were laid in wet surroundings where the ground water level occasionally reached above pipes. The pipes were used in service for approximately four years at a continuous operating temperature of about 80 ºC.

*Figure 1. Installation of casing free pipes in Hisings-Backa, Sweden. North direction is towards the top of the photograph.*

After four years of service, the casing free pipes were carefully excavated and analysed with respect to moisture content. A total of 12 cylindrical samples were drilled out of the PUR foam of each of the two pipes according to figure 2, at angular positions 45 º, 135 º, 225 º and 315 º, at three sections: 120 mm from each end and at the middle. The cylindrical samples were divided into three pieces representing the hot foam layer near the service pipe, the layer in the middle of the foam and the cold layer near the outside of the foam. Each piece was immediately put in a vapour tight plastic container.

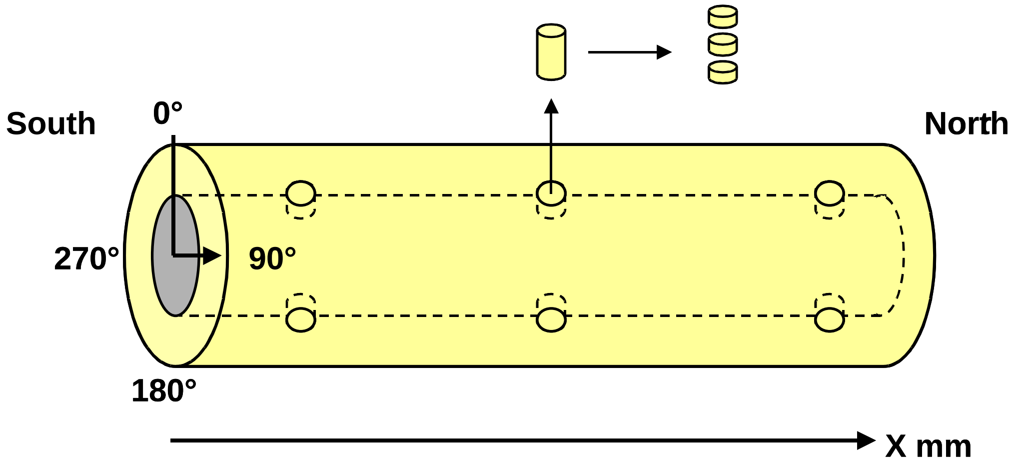


*Figure 2. Sample locations for determination of moisture content.*

At the laboratory, all pieces were weighed than dried out in 105 ºC and finally weighed again. This determines the moisture content as the ratio by weight of the water in the sample to the dry sample itself.

Reference samples were also taken from a casing free pipe which had been stored indoors at room temperature during the same four year period.

## 3. LABORATORY TESTS – LEAKAGE THROUGH INTERFACE BETWEEN PIPE AND JOINT FOAM

The laboratory test was designed to simulate the situation where the foam interface is in contact with an external ground water pressure through a leaking joint seal. In order to investigate if the water leakage through the interface depends on the conditions at joint foaming, seven specially designed joints were tested.

### 3.1 Joint types

Seven different joints were produced and a test specimen was taken from each end of each joint yielding a total of 14 samples. A number of parameters were varied during the joint production so that all test specimens were different. The parameters assumed to have a possible impact on the interface tightness was:

1. *Pipe diameter* – the flow pattern of the PUR components is different in large and small pipes and it may be more difficult to obtain a complete foam filling in a large pipe.
2. *Single/twin service pipes* – for the same reason as above, a complete foam filling may be harder to obtain with two service pipes in one casing.
3. *The pre-treatment of the pipe ends* may affect the adhesion of the joint foam. Three variants were tested: normally stored and weathered, clean cut and with a polyethylene end seal applied, cf. figure 3A, B and C respectively.

4. *The surface profile of the pipe end*. It was hypothesised that a “staircase” shape may yield a better adhesion to the joint foam, cf. figure 3D.
5. *The temperature during foaming* is known to influence the foam properties. Three alternatives were tested: room temperature, 0 °C in ambient air and on joint space surfaces and +80 °C on service pipe with room temperature in ambient air.
6. *The foam density* was varied between “normal” and “high”.
7. *The foaming method*. Two variants were used: machine injected foam and hand-mixed bottled foam.

*Table 1. Tested joints.*

| Joint | Joint end | Dimension | Pipe end treatment | Pipe end profile | Foaming method | Temperature | | Foam density |
|---|---|---|---|---|---|---|---|---|
| | | | | | | Steel pipe | Ambient | |
| A | 1<br>2 | DN 65/160 | Stored<br>Clean cut | Plane<br>Plane | Machine | +23 °C | +23 °C | Normal |
| B | 1<br>2 | DN 2×40/160 | End seal<br>Clean cut | Plane<br>Plane | Machine | +23 °C | +23 °C | Normal |
| C | 1<br>2 | DN 300/500 | Stored<br>Clean cut | Plane<br>Plane | Machine | +23 °C | +23 °C | Normal |
| D | 1<br>2 | DN 65/160 | Stored<br>Clean cut | Plane<br>Plane | Machine | 0 °C | 0 °C | Normal |
| E | 1<br>2 | DN 50/160 | Stored<br>Stored | Plane<br>Staircase | Machine | +23 °C | +23 °C | High |
| F | 1<br>2 | DN 65/160 | Stored<br>Stored | Plan<br>Staircase | Bottle | +80 °C | +23 °C | Normal |
| G | 1<br>2 | DN 2×40/160 | Clean cut<br>End seal | Staircase<br>Plan | Machine | +80 °C | +23 °C | Normal |

*Figure 3. Examples of pre-treatments of pipe ends: A) Normally stored. B) Clean cut. C) Polyethylene end seal. D) Staircase surface profile.*

### 3.2 Test method

For the water permeability measurements, disc-shaped test specimens were sawed out from the foam covering the interface, figure 4. Reference samples were also taken, containing only joint foam and pipe foam respectively.. All test specimens were 20 mm thick with a diameter of 81 mm.

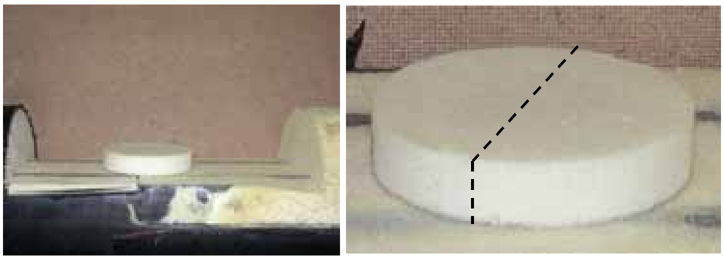

*Figure 4. Test specimen for water permeability measurements. The dashed line indicate the foam interface. Hence, there is pipe foam to the left of the line and joint foam to the right.*

Each test specimen was then fixed in a plastic cylinder with inside diameter 81 mm, figure 5. At its top end, the cylinder was tightened by a lid with a pressure inlet.

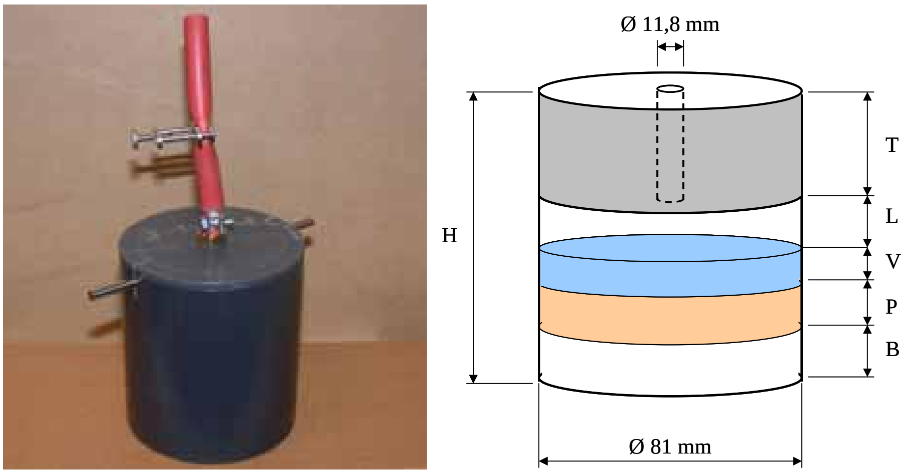


*Figure 5. Test rig for water permeability measurements. H is the cylinder's total height, T is the thickness of the lid inside the cylinder, L is pressurised air volume, V is the water depth when the test starts, P is the PUR samples thickness and B is the height of the volume open to the ambient air.*

Before starting the measurements, each test rig was filled with a known quantity of water and its weight was determined. The test rigs were then pressurised through the rubber tube to 0.05 bar above atmospheric pressure to obtain a water pressure equal to that from a ground water level 500 mm above a leaking joint in service.

By weighing the test rig, the amount of water escaping through the foam can then be determined. Even a water tight foam will lose weight from diffusion of vapour, but if permeation of liquid water takes place, the water loss will be significantly faster.

## 4. RESULTS

### 3.1 Water tightness of PUR foam

The diagrams in figures 6 and 7 illustrate the moisture content in the different parts of the foam of the two casing free pipes. They display the foam surface "rolled out" as a two-dimensional plane. Each group of three results represent the three layers of a sample from one location with the outer third up to the left in the group, the inner third down to the right and the middle third in between. The numbers show moisture content in percentage by weight and the colours indicate the order of magnitude. 10 % by weight is approximately equivalent to 0,8 % by volume.

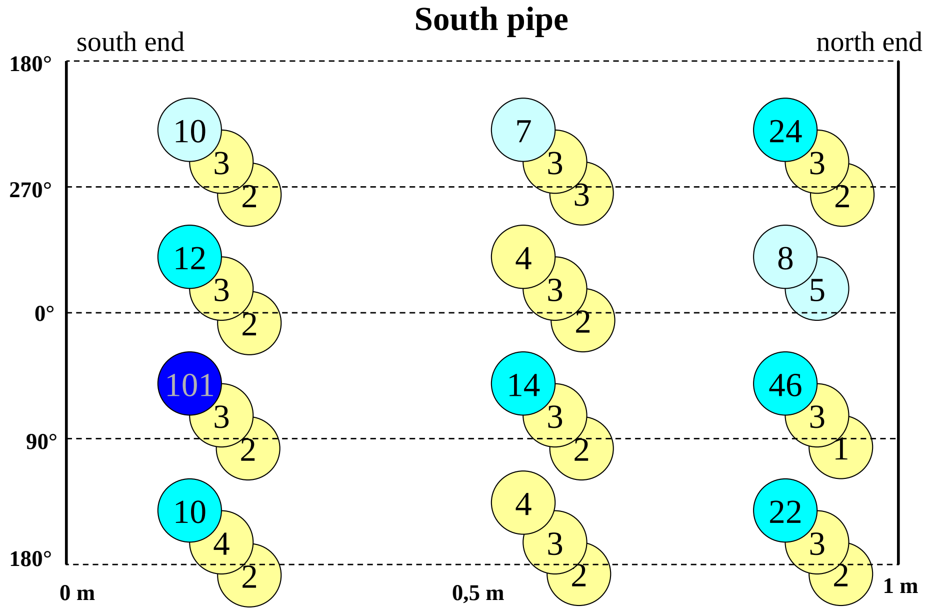


*Figure 6. Moisture content (% by weight) in the foam of the south pipe.*

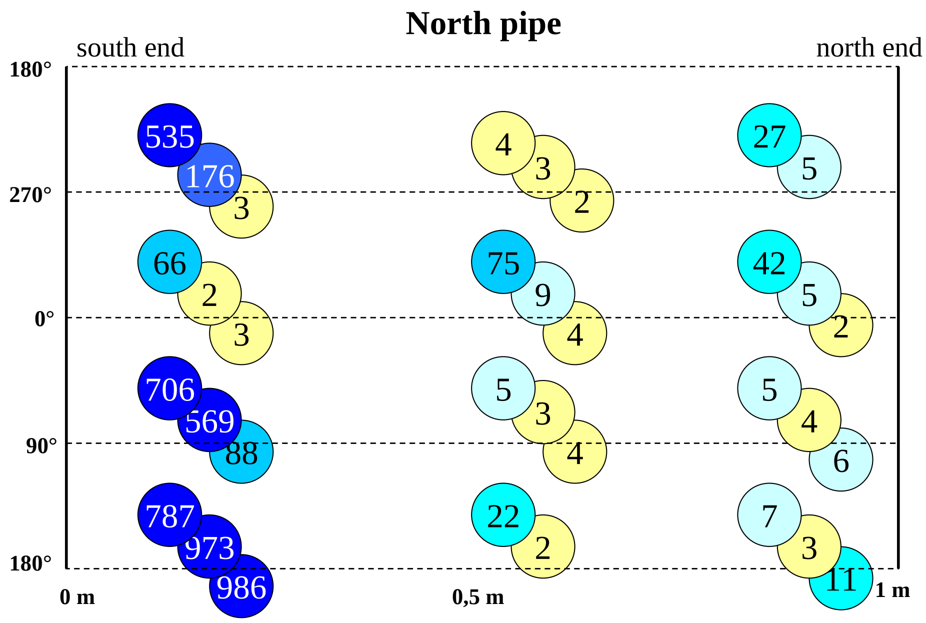


*Figure 7. Moisture content (% by weight) in the foam of the north pipe.*

The mean moisture content in the foam from the reference pipe was 2.4 %, and this did not change from when the pipe was newly manufactured until the tests were made four years later. As is seen in figure 6, the moisture content in the inner parts of the foam is about 2 %. Hence, one may conclude that no moisture has migrated from the wet surroundings into the inner parts of the foam. An increase in moisture content can be seen in the outer layer. This is probably a consequence of leakage into small cracks and defects near the surface. A similar pattern is seen in the north pipe, figure 7, except for one region (at the lower left), where moisture has penetrated the foam and reached all the way into the inner parts. At this location, some crumpled polyethylene foil[1] had been moulded into the foam. It is likely that this have caused passage ways for water into the inner parts. Note that the moisture has not spread. The dam-

[1] The polyethylene foil was used for producing the casing free pipes. The production process was identical as for regular pipes, but with the foil applied on the inside of the casing to facilitate its removal later on.

age is limited to a small region. This can be explained by the fact that no casing is present to trap the moisture. When water enters the foam through the defect in figure 8, it will vaporise and diffuse quite rapidly to condense near the cold surface.

*Figure 8. Crumpled polyethylene foil. Defect in the PUR foam from the production process.*

### 4.1 Leakage through interface between pipe and joint foam

The results from the water permeability measurements are summarised in table 2 and figure 9.

None of the reference samples, with pipe or joint foam only and no interface present, exhibited any leakage of liquid water. From table 2 it is obvious that the interface indeed does constitute a passage way for water. In order to obtain a water tight interface, clean cut pipe seem to be the best choice since all of these were tight. All specimens, except one, with interface against plane stored pipe foam turned out to be leaking. Of the specimens with staircase profiled interface two of three were tight. The interfaces with end seals turned out to be so un-tight on the pipe foam side that measurements were impossible. Therefore end seal specimen G2 was modified so that only the joint side was measured. G2 turned after the modification out to be tight, only diffusion was measured.

*Table 2. Results from water permeability measurements. A diffusion rate of 0.4 – 0.5 g/week is in line with previous measurements of vapour permeability (Bergström et al, 2002).*

| Joint | Joint end | Dimension | Interface | Profile of interface | Foaming method | Perme-ability | Water loss rate g/week |
|---|---|---|---|---|---|---|---|
| A | 1<br>2 | DN 65/160 | Stored<br>Clean cut | Plane<br>Plane | Machine foamed at 23 ºC | **Leakage**<br>Diffusion | **48**<br>0.5 |
| B | 1<br>2 | DN 2×40/160 | End seal<br>Clean cut | Plane<br>Plane | Machine foamed at 23 ºC | <br>Diffusion | <br>0.5 |
| C | 1<br>2 | DN 300/500 | Stored<br>Clean cut | Plane<br>Plane | Machine foamed at 23 ºC | **Leakage**<br>Diffusion | **>10**<br>0.4 |
| D | 1<br>2 | DN 65/160 | Stored<br>Clean cut | Plane<br>Plane | Machine foamed at 0 ºC | Diffusion<br>Diffusion | 0.5<br>0.5 |
| E | 1<br>2 | DN 50/160 | Stored<br>Stored | Plane<br>Staircase | Machine foamed at 23 ºC to high density | **Leakage**<br>**Leakage** | **>700**<br>**>60** |
| F | 1<br>2 | DN 65/160 | Stored<br>Stored | Plan<br>Staircase | Bottle, at 23 º with pipe temperature 80 ºC | **Leakage**<br>Diffusion | **20**<br>0.5 |
| G | 1<br>2 | DN 2×40/160 | Clean cut<br>End seal | Staircase<br>Plan | Machine foamed at 23 ºC with pipe temperature 80 ºC | Diffusion | 0.5 |

Figure 9 shows curves representing the progress of water leakage through the untight specimens and the progress of water vapour diffusing through the tight specimens. The coloured curves represent the samples where water leaked through cavities in the interface, cf. figure 10, except specimen E1, for which the leakage rate was so great that it did not fit in the diagram.

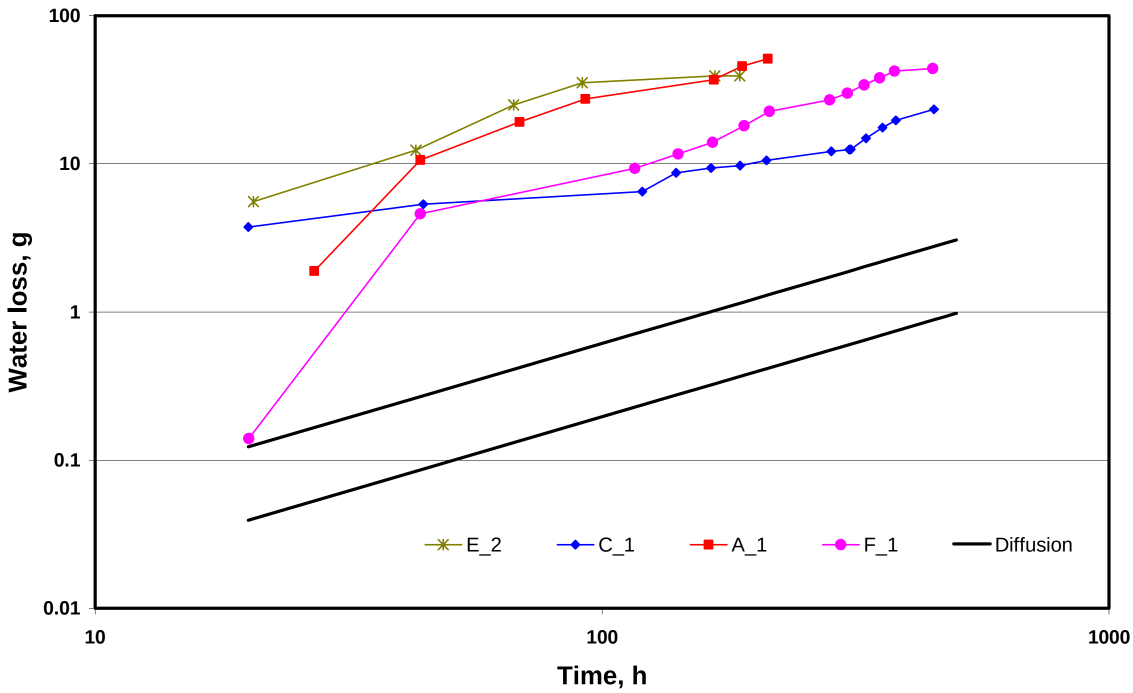


*Figure 9. Water loss through foam interface vs. testing time for selected samples. The black lines indicate expected water loss rate for vapour diffusion only.*

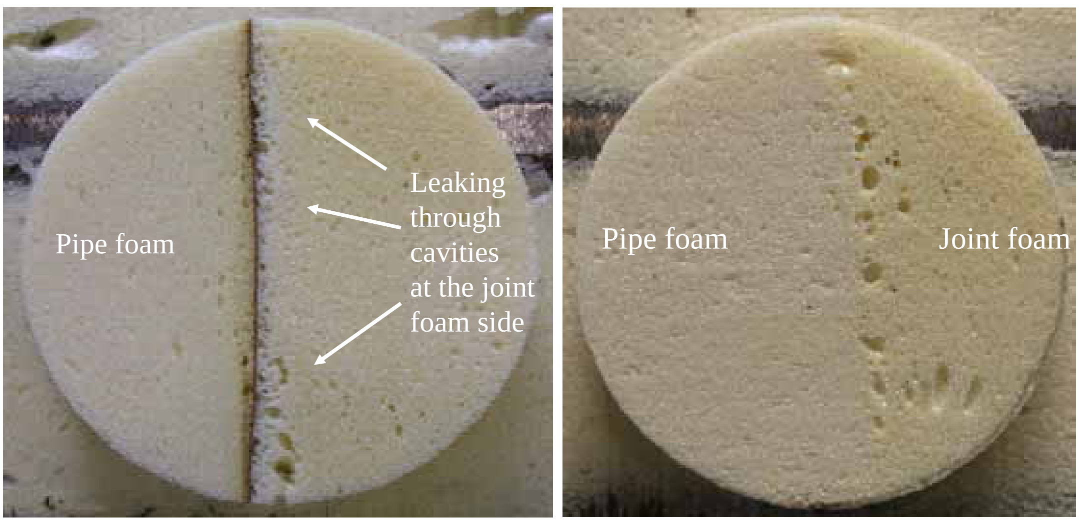


*Figure 10. Examples of leaking and tight interfaces between pipe and joint foam.*

## CONCLUSIONS

The result from the examination of the casing free pipes shows that if the foam is free from cracks, cavities or other defects it remains dry as long as the service pipe is warm even if the ground water level rises above the pipe. Water can however pass into the foam if there are defects present. It is interesting to note that, if the pipe has no casing, water entering the inner parts of the foam spreads only to a limited region. In regular pipes with casing, water usually tends to spread long distances along the pipe.

It was shown that the interface between pipe ends and joint foam can provide a leakage way for water. The tightness of this interface can be improved with correct treatment of the pipe ends. Joint foaming against a clean cut pipe end is the safest way of obtaining a tight joint. Using end seals on the pipe end can also be a good solution, but care must be taken to ensure the adhesion between the seal and the foam in the pipe itself.

Comparing single pipe and double pipes no significant differences were shown. Neither does the steel pipe dimension seem to have any influence on the tightness. The staircase shaped ends in themselves do not seem to have a significant impact other than the clean cut part of the profile. Foaming at low temperature seems to give a tighter interface. It should be noted, though, that the foaming here was done under dry conditions. During normal field work, moisture in the joint sleeve can be a big problem when foaming at low temperatures.

Looking at the leakage rates, the results indicate that coarser cell structure gives faster leakage. It was observed, though, that a coarser cell structure also is formed against clean cut foam ends not yielding any leakage. Hence, a coarse cell structure is not the primary cause for a permeable interface but it may promote a faster leakage.

## REFERENCES


Bergström ,G. & Nilsson, S., 2002. Groundwater leakage in pipe joints due to temperature variations, *Euroheat & Power – Fernwärme International*, **31**(1-2).

Bergström, G., Nilsson, S. & Sällberg, S.-E., 2002. *Moisture transfer in joint foam* (in Swedish), Swedish District Heating Association FOU 2002:67.

Nilsson S., Sällberg S-E. & Bergström G., 2005. *Leakage of ground water in joint foam* (in Swedish), Swedish District Heating Association FOU 2005:127.

Sällberg S-E. & Nilsson S, 2005. *Casing free district heating pipes* (in Swedish), Swedish District Heating Association FOU 2005:139.


## ACKNOWLEDGEMENTS


The Swedish District Heating Association, the Swedish Energy Administration and SP Swedish National Testing and Research Institute funded the research work presented in this paper.