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Insulating performance of flexible district heating pipes

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ABSTRACT

Flexible district heating pipes made of a copper service pipe, semi-flexible polyurethane foam and a low density polyethylene (LDPE) casing are widely used today. The bendable quality of flexible district heating pipes allows them to be produced and used in long lengths – thereby resulting in fewer pipe joints - and to overcome obstacles in the ground. As a result of the facilitated ground work, flexible pipes are often used when connecting detached houses to district heating systems. The distribution heat losses are considerable in these areas and there is at present no standard regulating the thermal properties of flexible pipes.

The insulation capacity of polyurethane foam decreases over time due to diffusion of gases (air and blowing agents) into and out of the foam. The change in cell gas content over time was measured and thereby the decrease of insulation capacity could be calculated.

The results show that the insulating performance of flexible pipes differs from that of straight pipes. The insulation capacity decreases more rapidly for flexible pipes, mainly due to gas transport in air gaps between the foam and the copper service pipe. The cell gases have a higher diffusivity in semi-flexible polyurethane foam compared to rigid polyurethane foam which also contributes to the faster ageing process.

1. INTRODUCTION

The bendable quality of flexible district heating pipes allows them to be produced and used in long lengths – thereby resulting in fewer joints – and to overcome obstacles in the ground. Today, flexible pipes are widely used when connecting areas with detached houses to district heating systems due to the facilitated pipe laying compared to straight pipes.

The flexible pipe construction is composed of more flexible materials compared to traditional straight pipes. A frequently used flexible pipe construction has a copper service pipe, insulation of semi-flexible polyurethane foam and a low density polyethene (LDPE) casing. European regulations regarding flexible pipes' technical functions, corresponding to those of straight pipes, EN 253, are being developed. Thus, there is at present no standard regulating the thermal properties of flexible pipes.

The long term thermal properties of flexible district heating pipes were investigated in an introductory study by Reidhav [1]. The results showed that the insulating performance of flexible pipes differ from that of straight pipes. The insulation capacity of the polyurethane foam decreases over time due to diffusion of cell gases (carbon dioxide and cyclopentane) out of the foam and of air (oxygen and nitrogen) into the foam. This ageing process of the foam is faster for flexible pipes compared to that for straight pipes. The report by Reidhav [1] was the starting-point of the present study where the thermal properties for flexible pipes have been further investigated.

2. EXPERIMENTAL

2.1 Diffusion of cell gases in the semi-flexible polyurethane foam

The diffusion of gases in the semi-flexible polyurethane foam was studied according to a method earlier described [2]. Cylinders of foam were cut out from the pipe described in paragraph 2.2. Aluminium plates were glued onto the ends of the cylinders in order to prevent longitudinal diffusion. The cylinders were stored at room temperature. The cell gas compositions of the cylinders were analysed [3] at different time intervals and the effective diffusion coefficients were calculated according to [2]. The calculated coefficients are shown in Table 1.

2.2 Diffusion of cell gases in the flexible pipe assembly

The diffusion of gases in a flexible pipe construction was studied by measuring the cell gas composition of the semi-flexible polyurethane foam at different positions (0.1, 0.5, 1.0, 2.25 and 3.5 m) from the open pipe end and after different times. The pipe construction consisted of a copper service pipe with a diameter of 22 mm and an LDPE casing with a diameter of 90 mm. The pipe was insulated with semi-flexible polyurethane foam and it had a diffusion barrier made of aluminium foil inside the casing. The pipe was manufactured and delivered coiled on a roll. The pipe was cut in 7 m long pieces at the beginning of March (=week 0, about 6 weeks after manufacturing). The pieces closest to the pipe ends were disposed. The remaining pieces were straightened to imitate the conditions in field. The initial cell gas content of the flexible polyurethane foam was analysed for one pipe piece, thus establishing the initial cell gas content (week 0), while the remaining pieces were stored at room temperature and analysed after 6, 13, 28 and 44 weeks of storage.

The cell gas content was determined according to [2]. In this method, foam cylinders are ground in a special equipment and the released cell gases are analysed by gas chromatography. This method gives the total cell gas pressure and also the shares of each gas such as the share of cyclopentane, carbon dioxide, oxygen and nitrogen. The results of the analyses are shown in Figure 1.

2.3 Air-gaps along the pipe

To investigate if any air-gaps existed between the copper pipe and the foam or between the casing and the foam, short pieces of the pipe (0.3 m) were immersed into dyed water with the intention to penetrate and colour the air-gaps. The experimental set-up and a photo of a cross-section of the foam are shown in Figure 2.

3. RESULTS AND DISCUSSION

3.1 Diffusion of cell gases in the semi-flexible polyurethane foam

The effective diffusion coefficients of cell gases in semi-flexible polyurethane foam at room temperature are shown in Table 1 and compared with diffusion coefficients for rigid foam given in literature.

Table 1. Effective diffusion coefficients of gases in semi-flexible and rigid polyurethane foam at room temperature (23ºC).

Cell gas	Effective diffusion coefficient in polyurethane foam [10^{-13} m^2/s]	
	Flexible pipe	Straight pipe [4]
Cyclopentane	30	0.6
Carbon dioxide	2000	500
Nitrogen	80	25
Oxygen	600	150

The effective diffusion coefficients of carbon dioxide, nitrogen and oxygen are about 3-4 times higher in semi-flexible polyurethane foam than in rigid polyurethane foam. The difference between the coefficients of cyclopentane in the two types of foam is even greater. Thus, the gas transport is faster in semi-flexible polyurethane foam compared to that in rigid foam.

Assuming only longitudinal diffusion in the foam and using the diffusion coefficients presented in Table 1, calculations show no influence of the open pipe end at distances <6 cm from the open pipe end for semi-flexible foam and <4 cm for rigid foam after 44 weeks of storage. Thus, the measured increase of the partial pressure of nitrogen in the semi-flexible foam of a pipe, from about 3 kPa to 22 kPa along the whole pipe length after 44 weeks (see Figure 1) can not be explained by longitudinal diffusion.

3.2 Diffusion of cell gases in the flexible pipe assembly

The change of the partial pressures of the cell gases over time at different positions is shown in Figure 1. The figure shows the partial pressures in the foam cells at different positions from the open pipe end.

The partial pressures of oxygen and nitrogen are almost constant over all the pipe length. There is however, an additional increase of the partial pressures close to the pipe end, detectable up to approximately 0.5 meters from the open pipe end. The partial pressures have increased continuously and are expected to increase until equilibrium with air.

The partial pressure of cyclopentane remained almost constant at about 20kPa during the study.

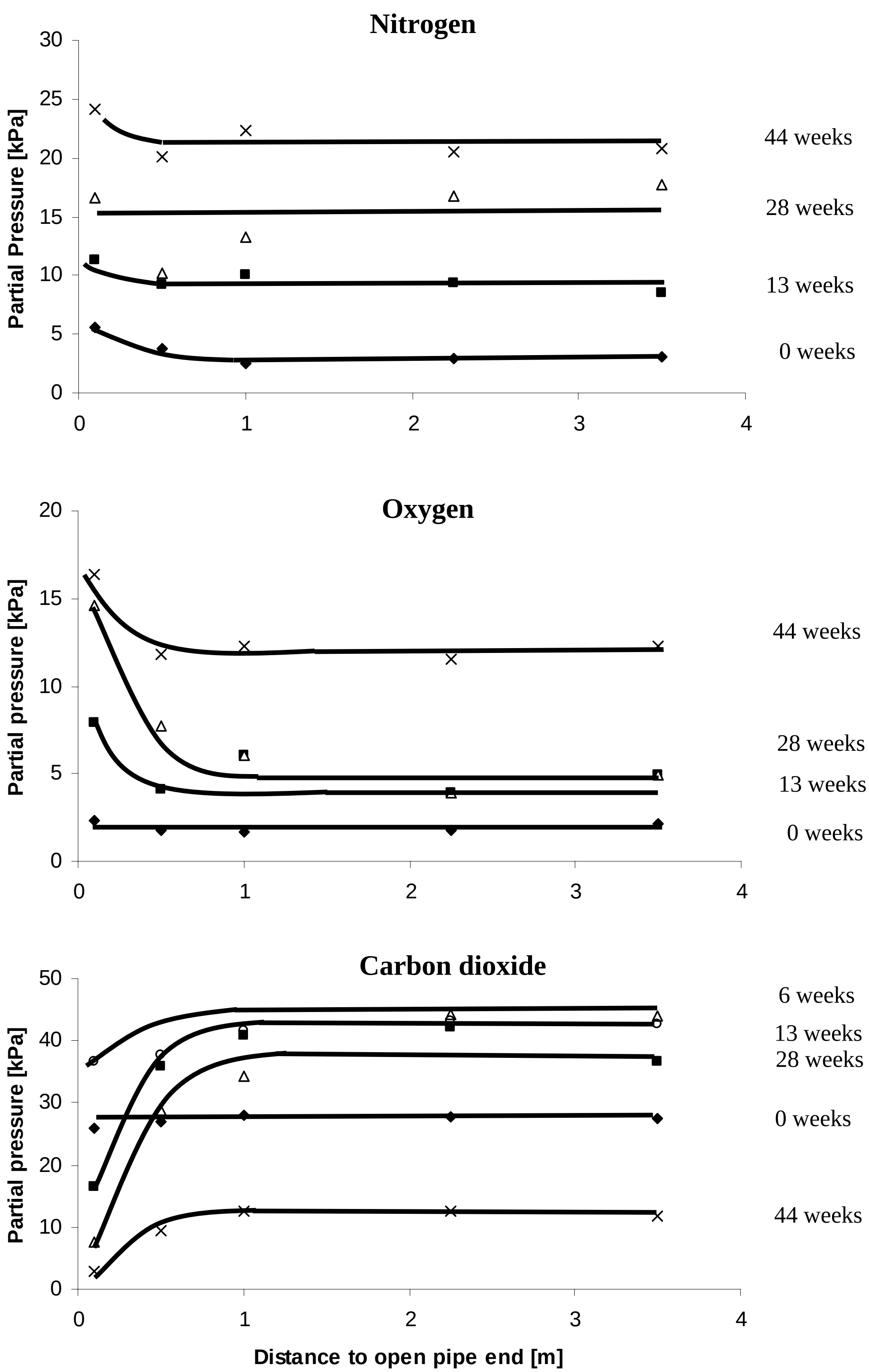

Figure 1. Change of partial pressure of nitrogen, oxygen and carbon dioxide in a semi-flexible polyurethane foam over time at different positions from the open end of the pipe assembly (22 mm copper pipe, 90 mm casing) at room temperature.

The behaviour of carbon dioxide, shown in Figure 1, differs from that of oxygen and nitrogen. During the first six weeks the partial pressure increases from around 28 kPa to 44 kPa and remains at this level until a reduction can be observed after 13 weeks of storage. The increase of carbon dioxide depends on the reaction between water and isocyanate that was not complete after normal time. This behaviour is sometimes observed for newly manufactured district heating pipes according to our experience. The initial increase of carbon dioxide is thus an effect of a chemical reaction that produces carbon dioxide in the foam. Apart from this, the behaviour is similar to the other gases with an almost constant increase/decrease over the total pipe length and an additional increase/decrease at the pipe end.

The constant increase/decrease of all the four cell gases over the pipe length can not depend on radial diffusion through the casing. The pipe has a non–permeable diffusion barrier made of aluminium foil inside the casing. The efficiency of this diffusion barrier has been confirmed in tests at elevated temperature.

Thus, the rapid change of cell gas content can not be ascribed to radial diffusion through the casing or, as earlier mentioned, it can not either be ascribed to longitudinal diffusion.

3.3 Air-gaps along the pipe length

The experimental study where a short pipe sample was immersed into dyed water demonstrated the presence of air gaps between the service pipe and the foam as shown in Figure 2. Dyed water had penetrated the air-gaps between the foam and the service pipe to the water level, about 25cm, during less than one day. No penetration of dyed water was observed between the foam and the casing.

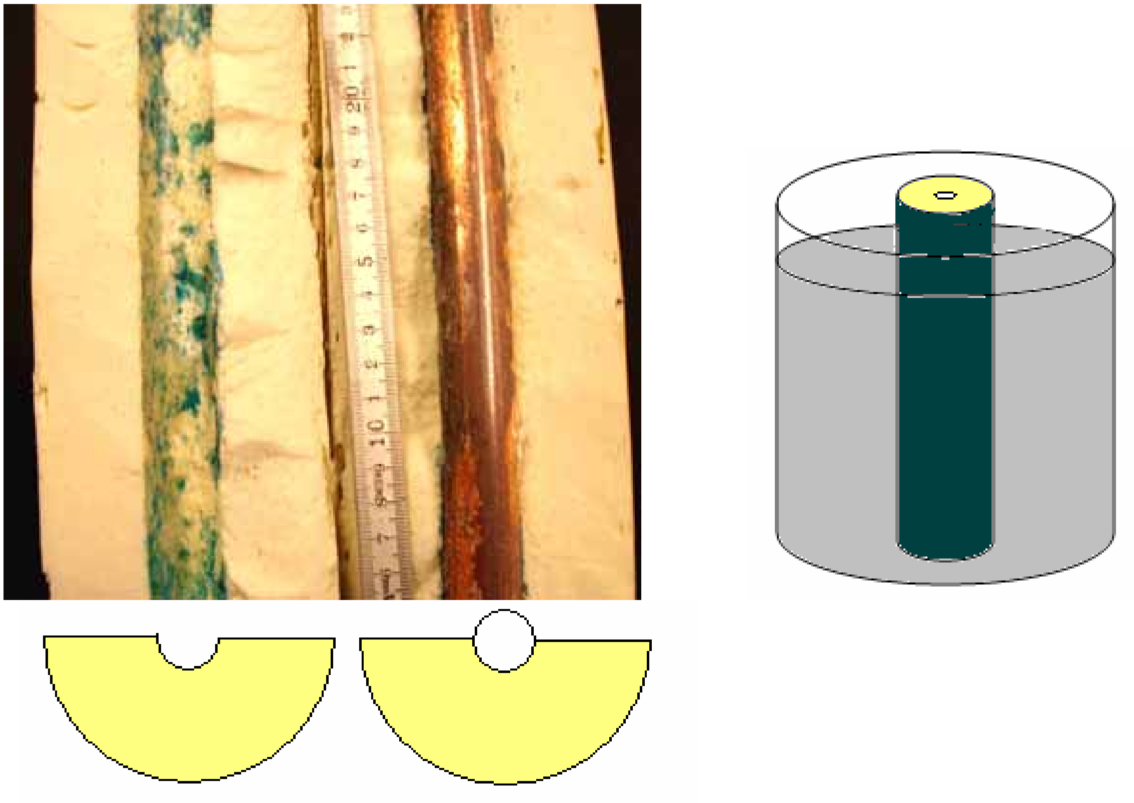

Figure 2. Semi-flexible polyurethane foam peeled off the casing and divided into two half pipes, shown along the pipe (above) and from the short end (below). The extension of the air-gaps between the service pipe and the insulation is illustrated by the dyed areas (dark coloured areas) on the left half pipe. Notice also the shiny surface of the copper pipe which indicates that the adhesion to the foam was imperfect.
The experimental set up with the immersed pipe is shown to the right.

The maximal effect of radial diffusion of cell gases through the air-gaps between the service pipe and the foam has been estimated. It was assumed that all the surface of the foam surrounding the service pipe was open to diffusion to air. Equations describing a step-change in concentration regarding a slab were used [5].

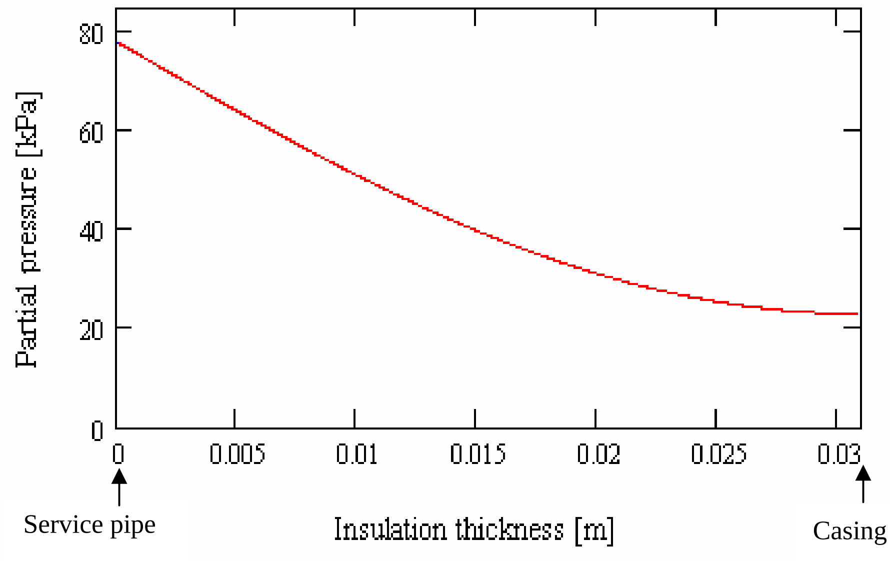

Figure 3. The partial pressure of nitrogen in a cross section of the semi-flexible polyurethane foam after storage at room temperature during 44 weeks. The foam surface surrounding the copper pipe is assumed to be completely open to diffusion of air. The initial partial pressure of nitrogen was assumed to be 3 kPa.

If there was no adhesion between the service pipe and the foam, the average partial pressure of nitrogen would be about 40 kPa after 44 weeks of storage as seen in figure 3. The measured partial pressure of the nitrogen was about 20 kPa, as showed in figure 1. A comparison of these cases indicates that the adhesion between the service pipe and the polyurethane foam was imperfect, but the connection was not totally open to diffusion. It can thus be concluded that there are air-gaps between the foam and the service pipe in the flexible pipe construction. The fast diffusion of gases and consequently ageing of the flexible pipe is primarily due to the presence of these air-gaps.

4. CONCLUSIONS

The reduction of the insulating performance of semi-flexible polyurethane foam in flexible district heating pipes progresses faster than observed for rigid polyurethane foam in straight district heating pipes. After 44 weeks of storage at room temperature the insulation capacity of the flexible pipes was reduced by 25% which represents half of the total reduction of insulation capacity during the life time. This fast ageing process is primarily due to air-gaps open to diffusion between the foam and the service pipe. The fast decrease of insulating capacity is also an effect of the higher diffusivity in semi-flexible polyurethane foam than in traditional rigid polyurethane foam.

5. REFERENCES

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