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# Influence of oxidation on radiative heat transfer in polyurethane insulation used for district heating pipes

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**Abstract**

Thermal conductivity of cellular rigid polyurethane foam (PUR) increases by time which leads to higher heat energy losses in district heating pipe networks. The main reason for increased thermal conductivity is diffusion of low conductive gases out of the PUR and diffusion of surrounding air into the PUR. However, oxidation of the PUR occurs during the service-life of the PUR and is accelerated by the higher temperatures close the fluid pipe. The effect that oxidation has on the thermal conductivity is not yet fully understood and existing models for prediction of long-term thermal performance of PUR insulation in district heating applications does not take oxidation processes into account. It is possible that the radiative heat transfer is affected by the oxidation and changes over the service-life of the PUR. In order to investigate the influence of oxidation on thermal conductivity, the *extinction coefficient* was therefore calculated for samples subjected to different levels of ageing. The input data for the calculations were measured by FTIR. The extinction coefficients were then used to calculate the overall thermal conductivity of the PUR with typical gas compositions. Results indicated that the *extinction coefficient* was 22 % higher in the samples exposed to lower temperatures. However, the effect on the overall thermal conductivity of the same samples was an increase of about 1.8 %. Since the comparison was made between two samples subjected to different levels of ageing, the increase in total thermal conductivity should be interpreted as a minimum if considering the total service lifetime of the PUR insulation.


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*Keywords: Extinction coefficient, Polyurethane, District heating, FTIR, Thermal Conductivity, Radative heat ransfer*

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## 1. Introduction

Heat losses in the Swedish district heating network is estimated to be about 10-15 % of the total heat production. District heating pipes are often insulated by cellular rigid polyurethane insulation, PUR (Figure 1.a), where the operation temperature is between 80-120 °C. This means that the PUR insulation is exposed to high temperatures which leads to accelerated ageing and degradation of insulation performance with higher heat energy losses in the district heating networks as a consequence.

In recent decades the end users, buildings, have become more energy efficient resulting in an increased ratio between heat losses in the district heating network and the energy demand for the end users. Thus, the efficiency of the district heating network becomes essential for energy companies in order to be competitive with other heating systems.

Improving the performance of the PUR insulation used in district heating pipes is not possible without a good understanding of the parameters that influences the thermal performance of the insulation. The heat transport mechanisms involved in PUR insulation are heat radiation between cell walls (both transmission and emission), heat conduction through the cell matrix and heat conduction in the gas enclosed in the cell matrix. A photo of the cells in PUR taken with SEM can be seen in Figure 1.c. Results obtained in previous research projects indicates that the most influential transport mechanism is the heat conduction in the gas phase which represents between 60 % to 80 % of the total thermal conductivity of the PUR foam [1].

In order to improve the insulation properties it is common to use physical blowing agents which produce low conductive gases such as *cyclopentane* (Cp), and *carbon dioxide* in the production of pre-insulated district heating pipes. However, concentrations of the low conductive gases in the surrounding environment are much lower than the gas concentrations in the cells which leads to diffusion of the low conductive gases to surrounding and diffusion of the surrounding gas (e.g. air) into the cells. The thermal conductivity of the air is higher than thermal conductivity of *cyclopentane* and *carbon dioxide* thus, diffusion of gases leads to higher total thermal conductivity. The diffusion process is very slow. However, if given enough time, the cell gases will eventually be replaced by air.

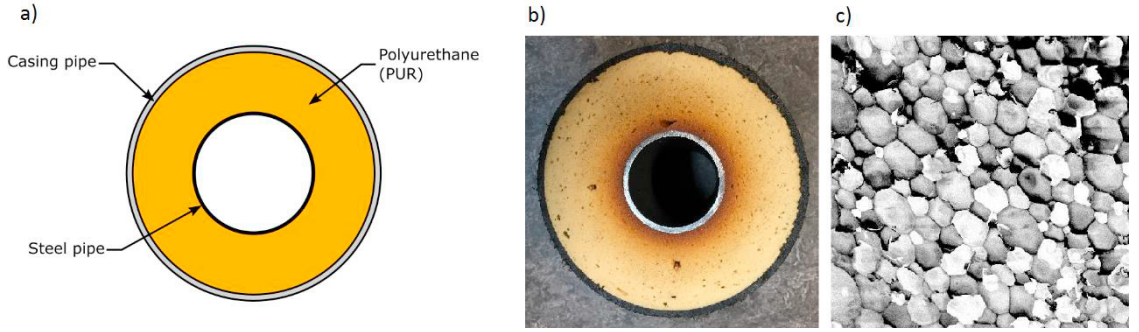


Fig. 1. (a) Structure of a district heating pipe (b) Photo of a cross-section of an aged district heating pipe insulated with PUR (c) Photo of PUR insulation taken with Scanning Electron Microscopy

Generally, long term thermal performance of district heating pipes is determined by estimating the content of the gases in the PUR insulation. In these estimations it is assumed that thermal conductivity of the cell matrix and the contribution of radiative heat transfer are constant.

Over time a discoloration of the PUR foam occurs where the foam typically turns from light yellow to dark brown. It has been shown that the discoloration is a result of oxidation of the PUR cell walls [2]. Here the oxidations process is accelerated by the higher temperatures close to the steel pipe (supply pipe) and clearly visible since the discoloration is more distinct compared to areas closer to the casing pipe, see Figure 1.b.

Estimations of the long term performance of the pre- insulated district heating pipes is vital for economic and environmental reasons. Decisions about the optimal time for renewing an old district heating network relies on accurate estimations on the status of the pipes both thermally and mechanically. It is therefore important to understand the