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Field measurements on a district heating pipe with vacuum insulation panels

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ABSTRACT

In Swedish district heating networks, around 10% of the supplied thermal energy is lost in the distribution system. One solution to decrease the losses is to use hybrid insulation district heating pipes, a concept where the innermost part of the thermal insulation consists of vacuum insulation panels, held in place by polyurethane foam. One problem with vacuum insulation panels are their sensitivity to high temperatures. This paper presents field measurements on a hybrid insulation district heating pipe where the temperatures have been measured continuously at various positions of a pipe section. The measurements show consistency and a large difference between hybrid insulation parts and reference parts without vacuum insulation panels. A superposition model has been used to calculate the temperature in a point and compare it to the measurement. The results are compared to the same calculation on the results from finite element simulations. The results show clearly that the vacuum panels in the pipes have not collapsed. A slow deterioration of the panels is harder to find with this model. Changes in the system, such as a return temperature which decreases over time, can give a larger impact, concealing the change in the panel performance.

1. Introduction

In Sweden, close to 10% of the energy supplied to the district heating network is lost before reaching the customer [1]. Reidhav et al. show that this number might be even higher with values between 12% and 43% for 74 investigated areas with a sparse district heating demand [2].

Zinko et al. [3] present some different solutions to reduce the heat losses from the district heating distribution pipes. Some alternatives are:

- The use of twin pipes, where both the supply and return pipes are placed within the same carrier pipe.
- Asymmetrical twin/double pipes, to optimize the insulation performance in relation to the temperature difference between the carrier pipes. Either twin pipes with an asymmetrical position within the casing pipe, double pipes with different dimensions for the supply and return pipes or an asymmetrical (for example egg shaped) casing pipe.
- More than two pipes within the same system. Then some pipes can be shut off during periods of low energy outtake.
- Using an insulation material with a higher thermal performance close to the pipe.

Point 1 is already commercially available and commonly spread in district heating systems. Point 2 and point 3 have been investigated by numerical simulations by Dalla Rosa et al. [4]. An asymmetrical positioning of the carrier pipes gave a reduction in the total heat loss of 3.2% in the best case while it for the worst case actually increased the total losses. But, the supply pipe losses were reduced by 4–8%. Point 4 will be further investigated within this paper.

The thermal performance can always be improved by an increment of the insulation thickness around the pipe. Frling et al. [5] show that the material use is the largest factor in the life cycle assessment of the district heating pipes but concludes that a reduction in insulation would lead to an increase in heat losses from the pipes which would counteract the material reduction. Also, for a cylindrical geometry, the thermal insulation has less impact on the thermal performance the further it is from the center of the cylinder [6]. This gives incentives to find a solution which exchanges the insulation closest to the carrier pipe with a better

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performing insulation. Polyurethane foam insulation is conventionally used in Swedish district heating pipes. The polyurethane is commonly blown by a mix of cyclopentane and carbon dioxide. Typical values for the 50°C thermal conductivity of commercial polyurethane foam insulation range from 23 mW/(m·K) to 27 mW/(m·K) for different pipe producers and production methods [7–9]. These can be compared to the data from litterature which shows conductivities within the same range [10–12].

The polyurethane foam gets its low thermal conductivity from the use of other gas than air in the pore system. Gas such as carbon dioxide or cyclopentane have a lower thermal conductivity than air, which is why they are used as blowing agents in the polyurethane production. Another method to decrease the influence of the thermal conduction of air would be to reduce the pore size. In cavities which are small compared to the average distance a molecule travels before colliding with another molecule, the probability of collisions between gasses is reduced leading to less heat transfer. Kistler and Cadwell [13] was first to investigate this effect in insulation materials, on Kistlers newly developed aerogel materials [14]. The same phenomenon have later been shown by Raed and Gross [15] who compares different models of the effect. For a nano-porous material, the influence of reduced gas pressure gets larger [16], which is why the pressure does not have to be reduced as much as for large pore materials to reduce the gas conduction significantly.

This principle is used in vacuum insulation panels for long life time applications (decades). Vacuum panels consist of a core material wrapped in a highly diffusion tight barrier. Fumed silica is a nano-porous material which is commonly used as core material [16]. The fumed silica have a thermal conductivity around 20 mW/(m·K) at atmospheric pressure and a thermal conductivity lower than 5 mW/(m·K) when evacuated [16,17].

1.1. Hybrid insulation district heating pipes

A concept of hybrid insulation for district heating pipes has been tested by Berge and Adl-Zarrabi [14,15]. In the concept, a layer of high performance insulation, like vacuum insulation panels, are enveloped around the carrier pipe. The carrier pipe(s) is placed within a casing pipe cavity between the pipes is filled with polyurethane foam insulation. The idea is to get the effect of the high performance insulation close to the center of the cylinder. At the same time the polyurethane will hold the high performance insulation in place and fulfill the demands on mechanical performance of the pipes. The concept, for both a single pipe and a twin pipe is shown in Fig. 1. For the twin pipe concept, the high performing insulation is placed around the supply pipe which has the higher temperature and thereby higher heat losses.

Berge and Adl-Zarrabi [18,19] investigated the base concept of the hybrid pipes where some various properties are measured, i.e. thermal properties and properties related to compatibility between polyurethane foam and high performance insulation. In the study, the use of vacuum insulation panels decreased the heat losses from a single pipe with around 15–25% measured with a guarded hot pipe apparatus, depending on the dimensions of the pipes. The

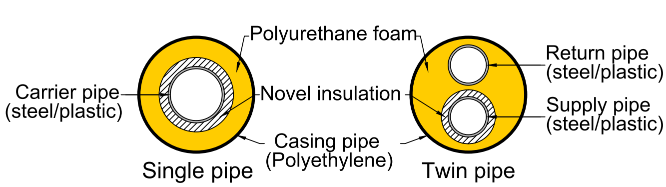

Fig. 1. Description of the concept for hybrid district heating pipes.

hybrid district heating pipes were further studied by simulating hybrid concept in a twin pipe, where the vacuum insulation panel is mounted around the supply pipe [20]. The study shows a decrease of over 20% in the heat losses from the whole system and over 50% reduction in the losses from the supply pipe.

Twin pipes were also investigated by measurements with two guarded hot pipe heating rods, one in each carrier pipe. The measurements showed a decrease around 12%–17% in the total loss and 29%–39% reduction for the supply losses for the dimensions DN 2*100/315 with 10–15 mm thick vacuum insulation panels [21].

While those result show promise for the hybrid pipes, one of the main concerns for the concept is the durability of the panels. The performance of the vacuum insulation panels will decrease over time by air getting in through the diffusion barrier film. The diffusion rate is strongly dependent on temperature which might be an increased risk in the hot temperature inside a district heating pipe. The high temperature might also lead to an instant collapse of the panels, caused by a total destruction of the enveloping diffusion barrier.

Simmler and Brunner [22] have measured the Pressure increase in Vacuum insulation panels up to 80 °C where the annual pressure increase is shown to be 15 kPa which would correspond to 15% of the total atmospheric pressure. This rate will allthough depend on the properties of the diffusion tight layer. Also, in the experiment by Simmler and Brunner [22], the humidity was 80%. In district heating pipes the vapor content would strive for equilibrium with the ambient air leading to very dry conditions at the high temperature. Started field measurements by Berge and Adl-Zarrabi [20] had already shown indications of a better performance in the field. This made it interesting to investigate the real situation performance of the district heating pipes more in detail.

1.2. Scope

This paper presents the measurements on two district heating pipes connected to a district heating network in Varberg, a city on the south west coast of Sweden. Both pipes are twin pipes with the dimensions DN 2*80/250 and DN 2*25/140 [23]. In both pipes, the supply pipe has been enveloped in a vacuum insulation panel and the rest of the casing pipe is filled with polyurethane foam insulation. The measurements started 26th January 2012 for DN 2*80/250 and 7th November 2012 for DN 2*25/140 and the latest measurements were retrieved 17th February 2015. The paper does also cover the development of a method to assess the state of the vacuum insulation panels.

2. Method

The heat conduction through a homogenous and isotropic material is described by the law of Fourier [6] in Equation (1):

$$q = -\lambda \nabla T \tag{1}$$

where q is the heat flow (W/m^2), is the thermal conductivity of the material in the point (W/(mK)) and ∇T is the temperature gradient (K/m). One consequence of Equation (1) is that the temperature can be used as an indicator for relative differences in heat flow. For two identical geometries with the same materials the difference in heat flow depend on the temperature difference between the boundaries. If the difference in the temperature is higher the heat flow will be larger.

2.1. In-situ set-up

Two 6 m sections, one for each of two pipe dimensions have