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Three-dimensional numerical model of heat losses from district heating network pre-insulated pipes buried in the ground

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ABSTRACT

The purpose of the paper is to investigate the challenges in modelling the energy losses of heating networks and to analyse the factors that influence them. The verification of the simulation was conducted on a test stand in-situ and based on the measurements of the testing station, a database for the final version of the numerical model was developed and a series of simulations were performed. Examples of the calculated results are shown in the graphs. The paper presents an innovative method of identify the energy losses of underground heating network pipelines and quantify the temperature distribution around them, in transient working conditions. The presented method makes use of numerical models and measured data of actual objects.

The dimensions of the pipelines used were 6 m wide, 8 m high and 1 m in depth, while they were simulated under conditions of zero heat flow in the ground, in the perpendicular to the sides direction of the calculated area and considering the effects of ground's thermal conductivity. The mesh was developed using advanced functions, which resulted its high quality with the average orthogonal quality of 0.99 (close to 1.00) and Skewness of 0.05 (between 0.00 and 0.25). To achieve better accuracy of the simulation model, the initial conditions were determined based on the numerical results of a three-dimensional analysis of heat losses, in steady state conditions in a single moment. The validation process confirmed the high quality of the model, as the differences between the ground temperatures were approximately 0.1 °C.

1. Introduction

1.1. District heating and district heating networks characteristics

The heating network of Poland provides centralised district heating to more than 300 cities and 15 million residents [1,2]. Fig. 1 shows the percentage use of district heating systems for the heating needs supplement in selected countries. According to the figure, the production and distribution of heat in centralised heating systems cover 95%, 60% and 52% of the needs in Iceland, Denmark and Poland, respectively [1].

In Poland, the vast majority of district heating systems use coal as an energy source, despite the fact that the process of its combustion generates air pollution; however, it should be mentioned that such systems confer the possibility of exhaust gases purification. In addition, gases and dusts emitted to the atmosphere have adverse effects on living organisms. Furthermore, the surface of the suspended particulates can adsorb organic compounds of different chemical classes forming a complex mixture of unknown biological properties [3–9]. Even so, for many years to come coal will be one of the basic energy sources for the production of electricity and heat.

The network transmission and distribution of heat loss is one of the key factors in the optimal design of district heating systems, which includes various pipe configurations, like flexible pre-insulated twin pipes with symmetrical or asymmetrical insulation, double pipes, triple pipes and a 2D-modelling analysis of pipes in computer software with the use of the FEM (finite element method) [10–12].

One of the means to improve the energy efficiency of district heating is to reduce the heat losses at the transmission (distribution), which will lead to a more sustainable and efficient designs of

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Nomenclature

c	specific heat, kJ/(kg K)
d_{wt}	pipe wall thickness, m
DN	nominal diameter, m
D_i	outer diameter of insulation, m
D_o	outer diameter of pipe casing, m
D_{inn}	inner diameter of the pipe, m
D_{out}	outer diameter of the pipe, m
S	distance, m
T, t	temperature, °C
T_s	network supply water temperature, °C
T_r	network return water temperature, °C
t_o	outside air temperature, °C
t_a	ambient pipeline temperature, °C
T_{gs}	ground surface temperature, °C
t_{gr}	ground temperature, °C
w	soil moisture, %
w_v	volumetric soil moisture, kg/m^3
$\dot{V}_n$	network water volume flow, m^3/s
v_w	wind velocity at the ground surface, m/s
ΔX	length of the pitch element, m

Greek symbols

ρ	density, kg/m^3
α	convective heat transfer coefficient, W/(m^2 K)
λ	thermal conductivity coefficient, W/(m K)

district heating networks [13–17]. For district heating application the following types of construction may be distinguished [18,19]:

- overhead – located above the ground on poles or any other supporting structures,
- aboveground – arranged on the foundations, directly on the ground surface,
- underground – located in the ground and arranged in the tunnels or district heating channels, and placed directly in the ground (such as pre-insulated pipe technologies).

Currently, the most common configuration of placing pipelines is their direct placement in the ground. In contrast, above-ground systems are implemented only in exceptional cases, when underground systems show lack of technical feasibility or their operating cost is considered to be unaffordable.

1.2. Heat losses in district heating networks

A typical configuration of pre-insulated pipe is shown in Fig. 2. The main factor influencing the energy losses of heating networks is network leakages, which cause the water to diverge from its channel and to transfer the heat from the interior of pipelines to the environment.

Heat losses occurring as a result of network water losses refer to both network and heat distribution units, as well as internal central heating systems supplied directly from the network. The main cause of network water loss can be "micro-damages" in the pipelines; leakages of the heat sources, the heat distribution units or the main pipelines, as well as leakages of working fluid caused by a breakdown removal or planned repairs [20].

Based on the presented data of Fig. 3, the average rate of heat losses lies within the range of 7.6%–27.8%. On the basis of references and conducted analysis, it was found that [21]:

- Due to simplified assumptions concerning the input data, the theoretical calculations may not reflect the real heat losses occurring in the operated district heating systems.
- Due to the lack of clear opinion concerning the temperature of the piping surrounding used in the calculations of the heat loss, the problem of reference temperature of the ground should be solved.
- The thermal conductivity of the soil, surrounding the pre-insulated piping, may have a significant impact on the results of the heat loss calculation; for this reason, the calculations should take into account the correct thermal conductivity around the pipe buried in the ground. This is particularly important in the case of modelling the dynamic working conditions of the district heating network.
- The steady state analysis does not reflect the actual working conditions of district heating network; it represents only the state, which occurs under certain conditions.
- The described analytical methods determine the heat losses, do not provide accurate results in the case of the transient heat transfer [21]; to compensate any discrepancies between the theoretical and the actual heat losses, the application of numerical computational methods and the use of actual data should be examined.

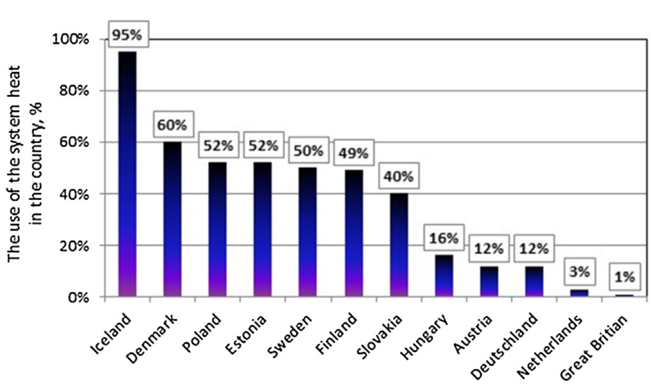

Fig. 1. The percentage share of the district heating systems use for the heating needs supplement in selected countries [11].

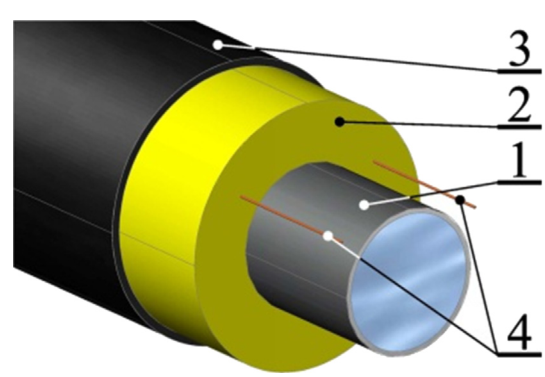

Fig. 2. Pre-insulated pipe: 1-steel carrier pipe, 2-PUR insulation, 3- PE-HD outer jacket, 4-wire alarm system [11].