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Analysis of thermal insulation of pre-insulated triple pipes - preliminary numerical tests

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Abstract. Pre-insulated pipes play an important role in the energy-saving heat transport. The paper presents preliminary results of the analysis of heat losses in a pre-insulated triple pipe. The determined heat losses in the pre-insulated triple pipes were compared with the existing pre-insulated overhead network consisting of three separate single pre-insulated pipes in a meat processing plant located in north-eastern Poland, as an example of industrial plants with specific water needs for technological processes. The solution of the triple pre-insulated network was also compared with the network system built of a twin pipe pre-insulated pipe and a single pre-insulated pipe. Heat losses in a pre-insulated triple pipe turned out to be about 42% smaller than the heat losses of three pre-insulated single pipes. All calculations were made using a proprietary calculation program developed in Fortran.

Key words. Pre-insulated pipe, triple pipe, energy savings, thermal insulation, district heating.

1. Introduction

Transporting heat energy is an important part in smart energy systems. Pre-insulated pipes are most often used in district heating networks [1-3]. Currently, single [1] and double [2, 3] pre-insulated pipes are most commonly used. The global trend of energy saving aims to minimize the costs of installing heating networks and reduce operating costs [4,5]. One of the methods that allows achieving these goals is optimization based on changing the shape of the thermal insulation of pre-insulated cross-section pipes or inserting a few heating pipes into a common thermal insulation. Examples of non-circular shapes of thermal insulation in the cross-section of twin pipes can be found in papers [7-10], where in [7] the elliptical shape of thermal insulation is presented, in [8] the oval shape of thermal insulation is developed, while in [9, 10] egg shapes of thermal insulation were tested. Inserting multiple heating pipes into common thermal insulation in engineering practice usually applies to pre-insulated twin pipes, in which the supply and return heating pipes are in round thermal insulation. Pre-insulated twin pipes allow reduction of heat loss by about 30% compared to two single pre-insulated pipes [9]. Pre-insulated triple pipes are used much less often, in which a system consisting of two supply pipes and one return pipe [6, 9] is used, in which one of the supply pipes is used sporadically. The third pipe in the common thermal insulation can function as a service pipe, a pipe operating during peak heat consumption or an additional pipe supporting the heating of domestic hot water.

The purpose of this work is to present a triple pre-insulated network as an alternative to single and double pre-insulated networks for industrial plants, on the example of a meat plant located in located in north-eastern Poland. The presented publication adopts a system of three pipes in common thermal insulation (Fig. 1) as an alternative to the three existing separate single pre-insulated pipes. Heating supply and return pipes sending heat to heat the building are marked with the letter S and R, respectively, while the third pipe marked with the letter T transports technological hot water for the production of meat products. The construction of the pre-insulated triple network allows a significant reduction of heat losses in relation to individual pre-insulated networks.

2. A Simplified Methodology For Determining Heat Losses In Pre-Insulated Pipes

In order to determine heat losses through pre-insulated pipes, the Laplace equation was used to describe two-dimensional heat conduction in cross-section of thermal insulation (Fig.1):

$$k\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right)=0 \qquad (1)$$

where: x and y are the coordinates of the Cartesian system in the cross section of the pre-insulated pipe, T -

this is the temperature, while k is the thermal conductivity of the thermal insulation.

The cross-sectional diagram of the pre-insulated triple pipe is shown in Figure 1. Aboveground pipelines were used for the calculations, where the Dirichlet condition was assumed on the inner wall of the thermal insulation in the form of the temperature of the transmitted heating medium T_S, T_R and hot technological water T_T, while the outside of the insulation was assumed Robin with the formula:

$$q' = -k\frac{\partial T}{\partial n} = h(T - T_a) \qquad (2)$$

where T_a is the air temperature around the thermal insulation, while h is the convective heat transfer coefficient.

The unit heat loss due to thermal insulation of triple pre-insulated pipes is equal to the sum of:

$$q = q_S + q_R + q_T \qquad (3)$$

where q_S are the unit heat losses through the heating supply pipe, q_R are the unit heat losses through the heating return pipe, while q_T are the unit losses through the technological hot water pipe for the production of meat products.

The balance of the unit heat flow of the return heating pipe includes the negative heat flow flowing from the supply heating pipe to the return heating pipe q_{R1} (Fig. 1):

$$q_R = q_{R2} - q_{R1} \qquad (4)$$

The technological hot water temperature TT is lower than the temperature of the heating medium supply TS and return TR. The unit heat flux of the heating hot water technological pipe consists of a positive heat flux coming out of this pipe q_{T3} and two negative unit heat fluxes flowing to the hot water technological pipe from the heating supply pipe q_{T2} and the return heating pipe q_{T1}:

$$q_T = q_{T3} - q_{T2} - q_{T1} \qquad (5)$$

All calculations were made using the boundary element method (BEM) using the author's calculation program written in Fortran. In order to verify the results, examples from the work [11] were used, where the results of BEM calculations were compared with the results of the multipole method calculations [11]. The relative error for the boundary built of 3000 elements did not exceed 0.001%, which was also shown in [7, 8, 10]. The boundary element method is often used in many cases related to mass and heat flow [12,13]. Details on the algorithm of the boundary elements method of two-dimensional heat conduction can be found in [14, 15].

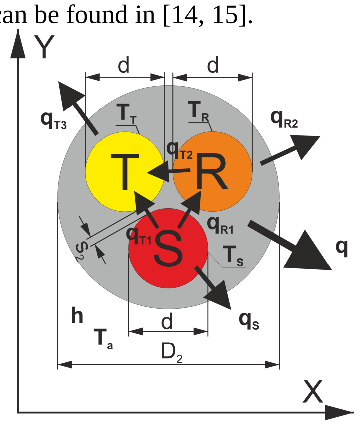

Fig. 1. Diagram of boundary conditions in a triple pre-insulated pipe

3. Analysis Of Heat Loss Of A Triple Pre-Insulated Overheat Network

In order to perform the heat exchange analysis in triple pre-insulated pipes, the geometry of the triple pre-insulated line was adopted, in which the centers of the supply and return pipes for the needs of heating the building and technological hot water for the production of meat products are located on the vertices of an equilateral triangle (Fig. 1). The smallest distance between pipes is s_2 = 9 mm, while the diameter of the thermal insulation is D_2 = 250 mm.

The thermal insulation analysis covers three variants (Fig. 2):

- Variant A, in which heat losses were determined for three existing overhead pre-insulated pipes in meat processing plants (two heating pipes and one technological hot water pipe),

- Variant B, in which it was adopted, two double pre-insulated pipes (heating network supply and return) and one single technological hot water pipe,

- Variant C, in which the pre-insulated triple pipe is adopted, where the diameter of the thermal insulation is equal to the diameter of the thermal insulation in the double conductor of variant B.

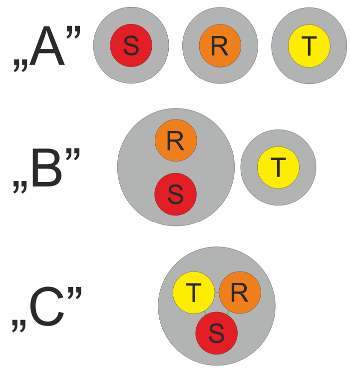

Fig. 2. Schematic diagram of three calculation variants A, B, C. Marking of pipes in the drawing: S-supply heating pipe, R-return heating pipe, T-hot technological water pipe

In all variants, equal diameters of the heating supply, return and hot technological water *d*=88.9mm, common thermal conductivity coefficient of thermal insulation made of polyurethane foam *k*=0.0265 W/(mK), common convective heat transfer coefficient *h*=25 W/(m^{2}K) and the range of external temperatures for the winter period -24^{o}C<T_a<0^{o}C. The diameter of the thermal insulation for a single pre-insulated pipe is D_1=160 mm, while for double and triple pre-insulated pipes the diameter of the thermal insulation is D_2=250 mm. The actual temperatures of the supply medium T_S=90^{o}C, return medium T_R=70^{o}C and hot technological water T_T=55^{o}C were taken for calculations.

The results of calculations of unit heat losses in the adopted variants A, B and C are shown in Figure 3. The heat losses for a triple pre-insulated joint in common thermal insulation (Variant C) are about 42% lower compared to three separate individual pre-insulated pipes (Variant A) and about 24% smaller compared to the system consisting of one twin pipe and one pre-insulated single pipe (Variant B).

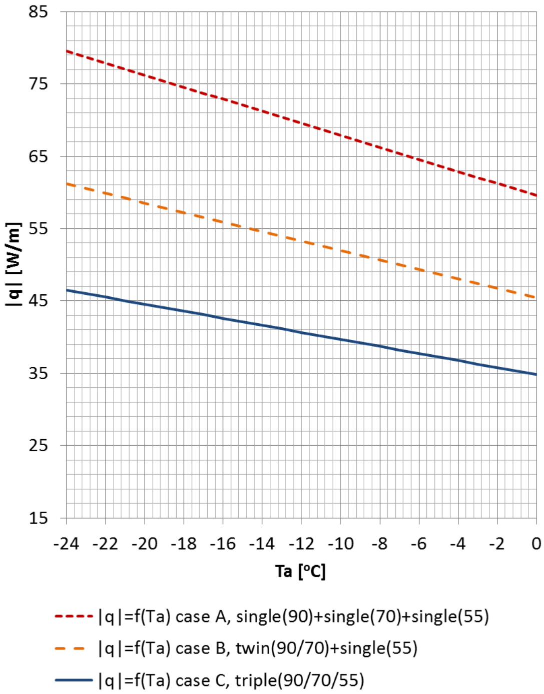

Fig. 3. Unit heat losses q as a function of outside temperature T_a for three variants A, B and C

In the literature [6], a pre-insulated triple pipe has heat loss 45% less than three single pre-insulated pipes. The differences presented in this work with literature [6] result from different thicknesses of thermal insulation. In the above example, the outer diameter of the thermal insulation was assumed for the pre-insulated triple pipe equal to the standard diameter of the twin pipe. Increasing the diameter of the thermal insulation significantly reduces heat loss as shown in Figure 4 for an outside temperature of T_a=-10°C. Increasing the diameter of the thermal insulation in a 50mm pre-insulated triple pipe reduces heat loss by 36% for this example.

The main disadvantage of heating systems, where heating pipes are placed in a common thermal insulation, is the heat exchange between these pipes, especially if the distance between heating pipes is too small. Figure 5 shows an example temperature field with heatlines for T_a=-10°C.

Heatlines indicate heat exchange between the supply and return heating pipes and between the technological hot water pipe and the supply and return heating pipes. The solution to this problem is to increase the distance between these pipes The analysis of heat transfer in double pipes has been presented in [9, 16].

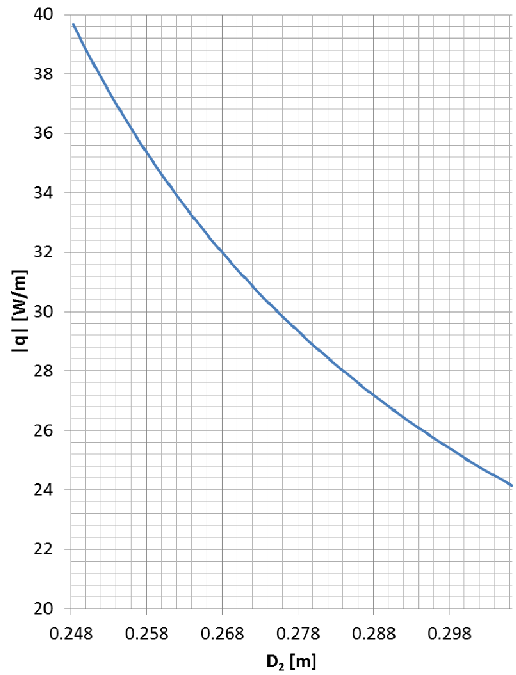

Fig. 4. Dependence of unit heat losses as a function of thermal insulation diameter for an ambient temperature of Ta=-10°C

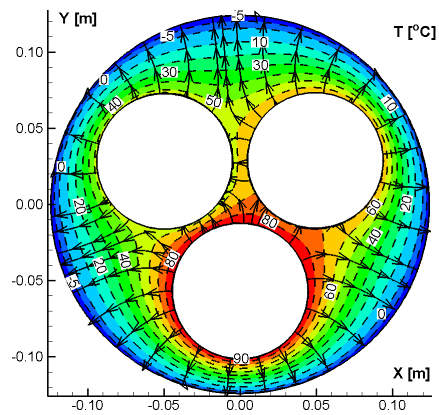

Fig. 5. Heatlines and temperature distribution in the cross-section of thermal insulation of a pre-insulated triple wire for Ta =-10°C.

4. Conclusion

Energy-efficient heat transfer pipes should be used in smart energy systems. The use of triple pre-insulated pipes can significantly reduce heat loss compared to double pre-insulated pipe and a single pre-insulated pipe. In case of the analysed network to the butcher plant, pre-insulated triple pipes generate an average of 1.7 times lower heat losses than the standard three pre-insulated single pipes. Similar reduction of heat losses could be obtained for other buildings with simiar water needs. In case of industrial plants with demand for a technological water with diferent qualitative parameters (lower or higher temperature) similar analysis should be conducted to estimate the acquirable effect.

Further advantages of using triple pre-insulated pipes are the smaller volume of thermal insulation used to build these pipes and less space consumption for installation compared to three single pre-insulated pipes.

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References

[1] J. Danielewicz, B. Śniechowska, M.A. Sayegh, N. Fidorów, H. Jouhara, Three-dimensional numerical model of heat losses from district heating network pre-insulated pipes buried in the ground. Energy (2016) 108, pp. 172-184. DOI= https://doi.org/10.1016/j.energy.2015.07.012.

[2] B. van der Heijde, B., A. Aertgeerts, L. Helsen, Modelling steady-state thermal behaviour of double thermal network pipes. Int. J. Therm. Sci. (2017) 117, 316-327. DOI= https://doi.org/10.1016/j.ijthermalsci.2017.03.026.

[3] M. Khosravi, A. Arabkoohsar, Thermal-Hydraulic Performance Analysis of Twin-Pipes for Various Future District Heating Schemes. Energies (2019) 12, 1299. DOI= https://doi.org/10.3390/en12071299.

[4] M. Pirouti, A. Bagdanavicius, J. Ekanayake, J. Wu, N. Jenkins, Energy consumption and economic analyses of a district heating network. Energy (2013) 57, 149-159. DOI= https://doi.org/10.1016/j.energy.2013.01.065.

[5] D. Maljkovic Modelling Influential Factors of Consumption in Buildings Connected to District Heating Systems. Energies (2019) 12, 586. DOI= https://doi.org/10.3390/en12040586.

[6] B. Bøhm, H. Kristjansson, Single, twin and triple buried heating pipes: on potential savings in heat losses and costs. Int. J. Energy Res. (2005) 29 (14), 1301-1312. DOI= https://doi.org/10.1002/er.1118.

[7] D.A. Krawczyk, T.J. Teleszewski, Optimization of Geometric Parameters of Thermal Insulation of Pre-Insulated Double Pipes. Energies (2019) 12, 1012. DOI=https://doi.org/10.3390/en12061012.

[8] T.J. Teleszewski, M. Zukowski, Modification of the shape of thermal insulation of a twin-pipe pre-insulated network. AIP Conference Proceedings (2019) 2078, 020030. DOI= https://doi.org/10.1063/1.5092033.

[9] H. Kristjansson, B Bøhm Optimum design of distribution and service pipes. Technical Paper EH&P IV/2006. Technical University of Denmark.

[10] D.A. Krawczyk, T.J. Teleszewski Reduction of Heat Losses in a Pre-Insulated Network Located in Central Poland by Lowering the Operating Temperature of the Water and the Use of Egg-shaped Thermal Insulation: A Case Study. Energies (2019) 12, 2104. DOI= https://doi.org/10.3390/en12112104.

[11] J. Bennet, J. Claesson, G. Hellström, Multipole Method to Compute the Conductive Heat Flows to and between Pipes in a Composite Cylinder. Notes on Heat Transfer (1987) 3-1987, Dep. of Building Technology and Mathematical Physics, Lund Institute of Technology, Sweden.

[12] T.J. Teleszewski, Effect of viscous dissipation in stokes flow between rotating cylinders using BEM, International Journal of Numerical Methods for Heat & Fluid Flow, (in Print) https://doi.org/10.1108/HFF-11-2018-0622.

[13] M. Zukowski, Forced convection heat transfer in square duct with heated and adiabatic walls at constant axial heat flux. AIP Conference Proceedings 2078, 020028 (2019). DOI= https://doi.org/10.1063/1.5092031.

[14] C.A. Brebbia, J.C.F. Telles, L.C. Wrobel, Boundary Element Techniques-Theory and Applications in Engineering, Springer-Verlag (1984), Berlin, Heidelberg, New York, Tokyo, Chap. 2.

[15] T.J. Teleszewski, S.A. Sorko, Effect of viscous dissipation on forced convection for laminar flow through a straight regular polygonal duct using BEM method. International Journal of Numerical Methods for Heat & Fluid Flow (2018), 28(1), 220-238. DOI= https://doi.org/10.1108/HFF-09-2017-0371.

[16] D.A. Krawczyk, T.J. Teleszewski. Effects of Some Geometric Parameters in Energy-Efficient Heat Distribution of Pre-Insulated Double Pipes. Proceedings (2018) 2, 1520. DOI= https://doi.org/10.3390/proceedings2201520.