Simulation of Heat Losses of a Distribution Network with Different Technical Structure and Under Different Operating Conditions for a District Heating and Cooling System

Ryszard Zwierzchowski¹, Olgierd Niemyjski¹

¹ Warsaw University of Technology, Faculty of Building Services, Hydro and Environmental Engineering. Nowowiejska Str.20, 00-653 Warsaw, Poland

ryszard.zwierzchowski@pw.edu.pl

Abstract. The paper presents a simulation of heat losses of a distribution network with different technical structure and under different operating conditions for a District Heating and Cooling (DHC) system. The DHC system consists of a Combined Heat and Power (CHP) plant and a Distribution Network (DN) with chambers and heat and cold substations. The different operating conditions of the DHC systems result in the DNs having variable transportation losses. The result of the analysis was used to verify the models and calculation methods of the fluid flow and heat losses in the DN, when cold is generated using either absorption or adsorption chillers. Different technical structure of a DN means a system of connected underground and aboveground piping with different diameters. DNs in Poland are usually installed as an underground, traditionally insulated piping placed in the concrete ducts (large diameter main pipelines) or a pre-insulated piping placed directly in the ground. The total heat losses of the DN differ according to the individual systems and depend on the size of the DHC system, its heating loads and quality of insulation of the piping. This paper presents the results of the numerical calculation of the temperature distribution in the soil around the piping channel using an FDA model. These results were utilized for numerical simulation of the water and heat flow through the DN and calculation of heat transportation losses. The numerical simulation of heat losses was performed for the particular system of connected underground and aboveground piping with different diameters. Finally, the heat transportation losses of the DN were calculated and compared for analyzed District Heating (DH) system i.e. without cold consumers and for the DHC system, when cold for consumers is generated using either the absorption or the adsorption chillers.

1. Introduction

The first District Heating System in Poland starts to operate over sixty years ago. Presently in Poland, there are over 400 District Heating Enterprises with an installed total heating capacity nearly 55 GWth in operation, the total length of the Distribution Network (DN) over 21 000 km and total heat sale over 380 000 TJ.

Implementation of Tri-generation in the District Heating (DH) Systems is still treated as innovatory technology in the Polish DH sector. Some DH Systems start already to supply heat to the customers for cooling purposes. Therefore in those cases, the DH Systems are converted to the District Heating and Cooling (DHC) systems. The attractiveness of the cooling supply generated from heat using the absorption or the adsorption chillers seems to be the correct way to improve energy efficiency for the operation of the DH System, mainly due to the reduction of heat losses of a DN during the summer.
season. The DHC system consists of a Combined Heat and Power (CHP) plant and a DN with chambers and heat and cold substations.

The different technical structure of a DN means a system of connected underground and aboveground piping with different diameters. DNs in Poland are usually installed as an underground, traditionally insulated piping placed in the concrete ducts (main pipelines with large diameters) or a pre-insulated piping placed directly in the ground [1]. The different operating conditions of the DH and DHC systems result in the DNs having variable transportation losses.

2. Description of the DH Systems

Three different DH Systems i.e., with different technical structure of a DN (percentage of underground pre-insulated and traditionally insulated piping, and aboveground piping) and heat demand of the consumers (for space heating and hot water supply) were analyzed. All these DH Systems are planned to be converted soon to the DHC Systems.

![Figure 1. Scheme of analyzed DH Systems (red points – CHP plants)](image)

Figure 1 presents the analyzed DH System in its present state. An appropriate heat demand for space heating and hot water supply in case of DH Systems and additionally, a heat demand for cold generation purposes when the Systems will be converted to DHC Systems are shown in Table 1.

### Table 1. Values of the heat demand for the space heating and hot water supply for DH Systems and the heat demand for cold generation for DHC Systems

| Description                  | Unit | System A | System B | System C |
|------------------------------|------|----------|----------|----------|
| $Q_{sh}$ (for $T_e = 0 \degree C$ and $T_s = 100 \degree C$) | MW   | 39.7     | 81.07    | 61.44    |
| $Q_{hw}$                     | MW   | 18.2     | 7.931    | 16.76    |
| $Q_c$                        | MW   | 8.6      | 7.395    | 4.44     |

Where: $Q_{sh}$ – heat demand for the space heating, $Q_{hw}$ – hot demand for the domestic hot water, $Q_c$ – heat demand for the cold generation, $T_e$ – temperature of the external air, $T_s$ - Temperature of the supply network water.
The different technical structure of the analyzed DH Systems i.e., mainly the length of aboveground piping and underground ducts and pre-insulated piping is shown in Figure 2.

![Figure 2. Technical structure of the analyzed DH Systems](image)

3. Determination of heat losses of the Distribution Network

The rate of heat losses depends mainly on the quality of insulation materials of the piping and on the properties of surrounding medium i.e. an air for the aboveground piping and a soil for the underground piping. As a result of a continuous extension of DNs during last decades in Poland, their structure and the quality of insulation differ greatly due to the age and the development of insulation technology.

The fluctuations in consumer heat demand directly influence hydraulic and thermal processes in the DN [2]. These changes cause changes in the heat losses of the DN. Existing calculation methods of heat losses of the piping can be divided into two groups, i.e., simplified and exact methods [3].

3.1. Simplified methods

Mathematical models of heat losses from this group are grounded in the source and negative source methods. Simplified methods are applicable for analysis of the temperature field in the steady state heat transfer in semi-infinite homogeneous material with constant thermal properties. They could be used to calculate the temperature field in the soil where the pipe transported heat is at a particular depth.

3.2. Exact methods

The accuracy of the heat losses calculation of the DN depends on the accuracy of the simulation by the model of real heat transfer processes [4, 5]. The most accurate models are those which calculate the temperature in a cross section through the soil and a concrete duct with piping.
Figure 3. Temperature distribution in the soil around the piping duct

The calculation methods presented above are not commonly used for the heat loss estimation of the entire DN, in the light of the huge work input and computer requirements. The methods are mainly applicable to research activities and to describe the character of the heat transfer through the soil and a channel with piping [6].

Figure 3 shows the results of the numerical calculation of the temperature distribution in the soil around the piping channel using the Finite Difference Analysis (FDA) model.

4. Heat losses of DN for different technical structure and under different operating conditions
The total quantity of the heat losses of the DN is different for the individual systems and depends mainly on the size of the DH System, its heating loads and the quality of insulation of the piping.

Results of the calculation of the heat losses of the DN for three analyzed DH Systems during the heating season (for $T_e = 0 \, ^\circ C$ and $T_s = 100 \, ^\circ C$) are present in Figure 4.
Figure 4. Results of calculation of the heat losses of the DN for 3 analyzed DH Systems during the heating season

In order to compare the total quantity of the heat losses of the DN for different systems, it is necessary to refer these losses to the quantity of the heat transported through the piping. Therefore, the percentage of the heat losses in the total heat transported through the DN during the heating season (for $T_e = 0^\circ$C and $T_s = 100^\circ$C) are shown in Figure 5.

Figure 5. Percentage of the heat losses of the DN for 3 analyzed DH Systems during the heating season
Following Figures 6 and 7 present the results of calculation of the heat losses of the DN for 3 analyzed DH Systems during the summer season.

**Figure 6.** Heat losses of the DN for 3 analyzed DH Systems during the summer season

**Figure 7.** Percentage of the heat losses of the DN for analyzed DH Systems during the summer season

The percentage of the heat losses of the DN in the heating season, as shown in Fig. 5 is lower than the heat losses in the summer season. Additionally, these percentages of the heat losses strongly depend on the technical structure of the DH System. For the System A (highest part of aboveground piping), both in heating and the summer season, the percentage of the heat losses of the DN is the biggest. The percentage of the heat losses for the Systems B and C are more than two times bigger for the summer than for the heating seasons. The losses for the System C (biggest fraction of pre-insulated piping) increased less than for the System B.

After introducing of cold generation to the DH Systems i.e., after conversion of the Systems to DHC Systems, results of calculation of the heat losses of the DN for 3 analyzed DHC Systems during the summer season are shown in Figures 8 and 9.

**Figure 8.** Heat losses of the DN for 3 analyzed DHC Systems during the summer season

**Figure 9.** The percentage of the heat losses of the DN for analyzed DHC Systems during the summer season
5. Analysis of the water temperature in the DN

Due to the excessive heat losses of the DN during the operation in the summer season, the relative percentage of the heat losses of the DHN has a negative impact on the economy of operation of the DH Systems. Also, the temperature of the supply water could drop down below the required value for the production of the domestic hot water. Introducing of cold generation to the Systems could compensate for these negative factors.

Data and the results of the network water temperature (supply piping) in the present state (cold is not generated) and for the analyzed future state for DHC System “B” in the case when the cold will be generated by the absorption chillers or by the adsorption chillers are presented in Table 2 and are shown graphically in Figures 10-12.

**Table 2.** Data and the results of calculation for DH System (present state) and for analyzed future state for DHC System in the case when the cold will be generated by the absorption chillers or by the adsorption chillers.

|                         | DH System present state | DHC System absorption chillers | DHC System adsorption chillers |
|-------------------------|-------------------------|--------------------------------|--------------------------------|
| Flow rate of network water, Mgt/h | 326                     | 789                            | 990                            |
| Heat power of substations, MW | 7.931           | 15.326                         | 15.326                         |
| Power of the heat losses, MW | 2.119              | 2.826                          | 2.352                          |
| Temperature of supply/return T_s/T_r | 72.0/45.4       | 85.0/65.1                       | 72.0/56.6                       |
| Percentage of the heat losses, % | 21.0              | 15.6                           | 13.3                           |

If the cold is generated using the absorption chillers, it is necessary to use the supply network water with a temperature of around 85 °C and the temperature drop on the chillers is approximately 15 °C. If the cold is generated using the adsorption chillers the water temperature could be around 70 °C and the temperature drop on the chillers is app. 10 °C.

**Figure 10.** Results of calculation of the network water temperature for the DH System “B”
Figure 11. Results of calculation of the network water temperature when cold is generated by absorption chillers

Figure 12. Results of calculation of the network water temperature when cold is generated by adsorption chillers

In Table 1 basic data and results of the calculation are presented for the analyzed DHS in the present state and for the case when the system is supplied with the heat for cold generation purposes as well. Two alternatives were analyzed, i.e., the cold is generated by absorption or adsorption chillers. Total heat demand in the summer season for the DHS is around 8 MW, while for the DHCS it is approximately 15.4 MW. The results of the computer simulation for the DHS and for the two alternatives for DHCS presented in Table 1 indicate that the heat losses increased slightly (from 2.1 MW for DHS to 2.8 MW and 2.4 MW respectively for DHCS), though, the total heat power of the system increased nearly twice, from 7.9 to 15.3 MW.

Finally, the relative percentage of the heat losses of the DN which was 21% for the DHS in the present state significantly decreased to 15.6% in the case of the DHCS with the cold generation by the absorption chillers and to 13.3% in the case of the DHCS with the cold generation by the adsorption chillers. Total error of the presented calculation method is below 5%. The results of the water temperature (supply piping), when the cold is generated by the absorption and the adsorption chillers, are shown in Figure 6 and Figure 7.

6. Conclusions
Presented analyses were performed for three DH Systems (A, B and C) in the present state and for the case when the systems supply heat for the cold generation purposes as well. Real technical structure of the DN for each System i.e., the percentage of the underground pre-insulated and traditionally insulated piping, and aboveground piping were applied for calculation of the heat losses and the temperature for supply piping. Two alternatives were analyzed for the DHC System “B”, i.e., the cold will be generated by the absorption or the adsorption chillers.

The results of the numerical calculations show that:

- The percentages of the heat losses in the total heat transported through the DN in the analyzed DH Systems are in the range of 6.3-20.6% for the heating season and 17.3-29.6% for the summer season,
- The percentages of the heat losses in the total heat transported through the DN in the analyzed DH Systems strongly depend on the technical structure of the DN.
- For the System A i.e., with the highest part of aboveground piping, both for the heating and the
summer season, the percentage of the heat losses of the DN is the biggest. The percentage of the heat losses for the Systems B and C is bigger for the summer than for the heating seasons. The losses for the System C (biggest fraction of pre-insulted piping) increased less than for the System B.

- Numerical calculation of the temperature distribution in the soil around the piping can be used to improve the mathematical models for the heat losses of the piping, traditionally insulated and placed in the concrete ducts [7],
- The results of the computer simulations for the analyzed DH System and for the system converted to DHC show that the power of the heat losses increased slightly (from 2.119 MW for DH System to 2.826 MW and 2.352 MW respectively for DHC Systems), while the total heat power of the substations increased nearly twice,
- Conversion of the DH to the DHC System could significantly increase heat selling to the heat and the cold consumers and decrease the relative percentage of the heat losses by the DHN [8].

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