LOW-TEMPERATURE DISTRICT HEATING WITH DECENTRALIZED GENERATION BY HEAT PUMPS AT A RAILWAY STATION: OPTIMIZING THE SYSTEM AND CALCULATING GREENHOUSE GAS EMISSIONS

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Abstract: *This paper discusses a heat pump subsystem within an existing high-temperature DH system located at a railway station in Omsk, Russia. The goal is to increase the efficiency of an existing high-temperature DH system by describing decentralized heat generation from an environmental point of view. We obtain a balance method whereby the heat loss (or the thermal energy loss) is expressed dependent on the supply and return temperatures so as to reduce operating costs of heat supply. The outcome of calculating the heat loss by this method is a relation that is valid typically for all DH networks. Findings beneath show that switching to a low-temperature DH can decrease operating costs and increase overall heat production efficiency. The reason for the latter is a known logarithmic heat flux-temperature correlation. This paper concludes that the idea of decentralized generation has a great potential for the future, as the implementation of this concept is closely related to a low-temperature DH.*

Keywords: DISTRICT HEATING; NETWORK; OPERATION; TEMPERATURE

1. Introduction

Although district heating networks have a key role to play in tackling greenhouse gas emissions associated with urban energy systems, little research has been carried out on district heating (DH) networks expansion and integrating decentralized thermal energy generation[1].

Ideas of low-temperature DH [2] with decentralized generation by means of heat pumps [3] are running high. Nevertheless, Bolonina et al. [4] found some reasons to increase network temperature curves. Albeit the paper [5] figures out a leak detection method based on the idea of total metering, which suits well the concepts of 4th generation DH, it emphasizes hydraulic rather than thermal concerns. Zarin Pass et al. [6] contributed the industry a lot by putting effort into a thermodynamic analysis of a novel bidirectional district heating and cooling network. Petrovic et al. [7–9] studied heat demand (load) fluctuations. On the one hand, Petrichenko et. al. [8] have developed a model for short-term thermal load prediction. On the other hand, Verrilli et al. [9] made longer-term forecasting possible.

Guy et al. [10] have made publicly available their development forecasts for a certain DH system (Hague), which is similar to what we are doing. Latosov et al. [11] solely address the issue of parallel energy use with no emphasis on parallel energy production. See Ref. [12] for an overview of fast simulation of district heating and cooling networks. Wu et al. [13] proposes that DH systems consist of CHP units, electrical boilers, and thermal storage facilities, but excludes heat pumps. Akhmetova et al. [14–16] describe existing high-temperature systems though being helpful with heat loss calculation.

The resulting optimization problem shown below is a Linear Programming (LP) problem that can be generalized to become a Mixed Integer Linear Programming (MILP) for which lots of general, robust and scalable approaches exist. The framework presented in this article is particularly based on a Microsoft Office Excel sheet and the Visual Basic for Applications macro language. By way of contrast, Austrian-Swedish researchers [17] have based their solution on the Modelica simulation language and the Python scripting language.

Refs [18] и [19,20] do not seem well matched to key topics of European science, namely advanced engineering and environmental technologies. Like in our research, Operation & Maintenance (O&M) is the topic of [21], but that paper dwells upon building-scale heat distribution systems. Simonovic et al. [22] and Geysen et al. [23] present a sophisticated but promising approach utilizing Artificial Neural Networks (ANN) and using machine learning and expert advice respectively.

2. Materials and Methods

We first discuss the use of a heat pump in a centralized DH system (fig. 1).

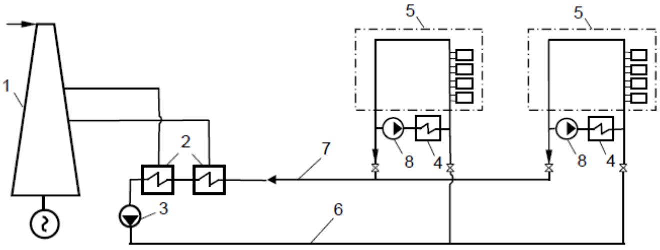

Fig. 1 *Illustration of the district heating network configuration used in this research: (1) steam turbine with an off-take, (2) main heat exchangers, (3) DH network pump, (4) local heat sources, (5) consumer interconnection, (6) heat network supply, (7) heat network return, (8) consumer pump*

A heat-pump system configuration can be categorized as open-loop or closed-loop. In an open-loop system, water is withdrawn from a surface water body, passed through a heat exchanger, and then returned to the surface water body. Closed-loop systems circulate the same water between a heat exchanger and the environment. Open-loop systems may be used in almost any application including urban construction, and sub-urban buildings, both DH and district cooling systems. However, we dwell upon economics of scale and therefore consider four ground-source heat-pump systems integrated into urban infrastructure. Georg K. Schuchardt [24] applied similar concept but his system consisted of decentralized thermal storages.

Such implementation creates a low-temperature concept [2] ensuring heat pump operation with the most efficient coefficient-of-performance values. Historically all DH systems have been “unidirectional”, meaning that the water in each pipe segment only flows in one direction. Separate circuits are needed for heating and cooling. In this paper we refer to a ‘bidirectional distribution’ system [6] as one in which water in each pipe segment can flow in alternating directions, depending on the net thermal fluxes on the system. In this case, there is a single network for both DH and district cooling.

For the sake of simplicity, we consider all the buildings being Thermostatically Controlled Loads (TCLs) as in [25] or [26] thus the amount of heat produced matches the amount of heat required at each moment of time t. A consumer interconnection (fig. 1, 5) is assumed to be typical even though simulation results show that controllers tuned to specific operating conditions can’t ensure operation stability of heating substation if operating conditions vary in a great range [27].

The minimization problem is solved by means of Mixed Integer Linear Programming (MILP). Numeric values are obtained by means of a Microsoft Office Excel sheet and the Visual Basic for Applications macro language. See Ref. [17] for an overview of different numerical optimization methods. The only operating costs are heat losses and electricity consumption, others are neglected.

What is crucial is the rate of heat flow through the pipe at the position x, and the moment of time t. There are the two terms on the right-hand side of the equation related to the thermal energy loss corresponding to the advective contribution (which may also be called mass or hydraulic contribution) and convective contribution (the turbulent one) [16]. M. Chertkov and N. Novitsky measured heat-flow rate in Watts, however we represent a heat loss measured in Gcal/h. Heat carrier fluid density and the area of the pipe cross-section are taken into account. We also make a comprehensive assessment of the heat carrier (water), eventually re-using their method. For the present paper as in [23] a certain area (fig. 2) was used as a case study.

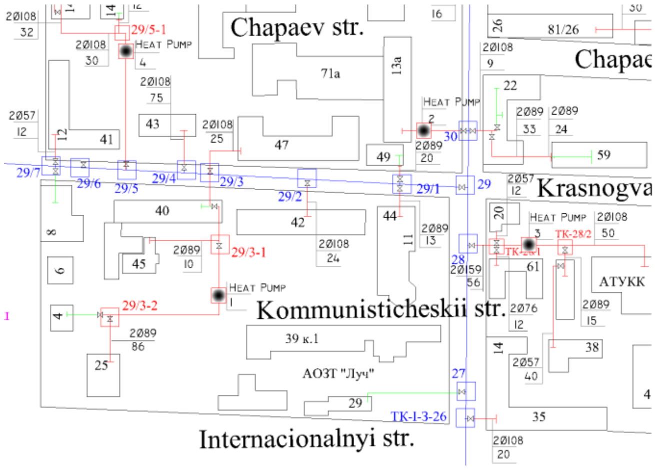

Fig. 2 *Chart of the investigated district*

Hereafter we describe a 41.2 MW district heating system at a railway station in Omsk, Russia, that utilizes a heat pump and coal-fired CHPP to supply heat to a heating district. With ammonia as the refrigerant, the three-stage heat pump is able to supply hot water for a maximal heat output of 10 MW and a designed heat pump coefficient of performance of 3, using groundwater as its source.

The piping in the network is about 392 m in length, with a total volume of about 64 m3. The transmission lines (the blue ones in the figure) became operational in 1988 and are currently fed by CHPP #5 with a coal burner. In 2004, the main part (the red one in the figure) was retrofitted to work with lower operating temperature. Another (green) part is to be installed this year with a capacity of 0.7 MW.

The supply temperature used was based on a conventional linear relationship of the outdoor temperature [21] taken from a data set with actual data [28]. A supply temperature of 78 C was first used to simulate the conventional high-temperature DH system in our calculations. Then we studied the energy efficiency of a multisource system where supply temperatures of 62 and 57 C were used for modeling. For the simulation of an ultra-low-temperature DH system, supply temperatures of 41 and 39 C were used. [21] The given approach is still being modified: ANN [22] and using machine learning and expert advice [23] are probably coming in the future.

3. Results and Discussions

Figure 3 shows the investigated relation of operating costs (thermal energy losses) and environmental impact of pollutions that could be served with DH at a given constraints in a commercially mature way.

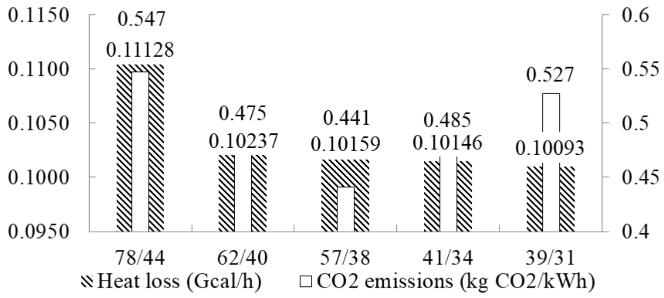

Fig. 3 *Spectrum of heat losses and CO2 emissions vs. supply/return temperature*

The 57/38 curve ended up being the optimal solution because lower temperatures force heat pumps to operate with a coefficient of performance (COP) outside its best range. This results in greenhouse gas emissions increasing up to 0.527 kg CO2/kWh in case of 41/34 and 39/31 curves; moreover, heat losses stop to decrease significantly at such curves. The reason for latter is a known logarithmic heat flux-temperature correlation. These results are in good agreement with other studies which have shown that heat losses in Russia [14] are basically higher than, for instance, in Europe and Czech Republic [15]. Moreover, calculation of GHG emissions outlines that the values obtained are similar with the average European CO_2 emission factor.

4. Conclusions

Calculating heat losses by the approach herein presented has resulted in a relation that is valid typically for all DH networks. We have considered the technical aspects such as the energy performance of a heat pump as well as the environmental ones (e. g. the evaluation of the greenhouse gas emissions for this or that temperature performance). Findings beneath show that switching to a low-temperature DH can decrease operating costs and increase overall heat production efficiency. Therefore, in the situation where Thermostatically Controlled Loads (TCLs) are introduced, the novel DH system (with lower temperature) becomes the most efficient option due to heat losses dropping from 0.11128 to 0.101159 Gcal/h in the optimal case. We have tried to show that the idea of decentralized generation has a great potential for future, because the implementation of this concept is closely related to a low-temperature DH. With the development of energy efficient networks and renewable-energy facilities at railway stations, railway companies will be definitely interested in lowering the temperature parameters of a distribution system, as it can decrease CO2 emissions by more than 23% as in the case study.

Acknowledgements

This research was supported by the Government of the Russian Federation under Project No. 860 (Decree dated August, 8 2017). The Author thanks Russian Railways ('RZhD', JSC) for cooperation and kindly provided information. The Author would like to acknowledge the valuable comments and suggestions of the reviewers, which have improved the quality of this paper. The Author also expresses gratitude to the unnamed editor who has proof-read and edited the text.

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