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Assessment of District Heating Network Flow Rate – a Way to Find Out Is Heat Demand Met and as a Leak Location-Supportive Measure

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ABSTRACT

Among the many solutions envisaged for the heat market, district heating (DH) systems offer the flexibility and capacity for faster integration of low emission heat-generating activities for a smooth transition towards a low carbon society. The aim of this paper is to validate a potential for leak location and to verify a new method by applying an assessment to a real DH network with plenty consumers. The main model constraint is to always satisfy network heat demand, at any given moment of time, with a constant temperature regime (for instance, 150°C supply /70°C return temperature) in the network. An existing central plant located at Omsk, Omsk Oblast, Russia and its DH network illustrates observation methodology as a case study.

On the one hand, extreme outdoor temperatures lead to high heat consumption. This additional request is covered both through increased flow rate and supply temperature. If the heat demands of all consumers change with the outdoor temperature simultaneously in the same degree, new flow rates of all substations become up to values accordingly with their heat demands in the same relative ratio. On the other hand, negative peaks without corresponding temperature increase mean emergency situation when flow rate was restrained by means of valves next to a leak location. In this work, a holistic design for large-scale DH network is proposed capturing the needs for cross-cutting solutions including improvement of heat supply and integration of hydraulic side measures. This system has been examined in variable external conditions. The identification of the heat supply system operation process has been performed and this processes' main characteristics have been determined on the basis of data collected in the DH system of Omsk during 2017. The simulated results were compared with the measured data provided in the literature.

Key words: district heating, network, energy, flow, demand, consumption

INTRODUCTION

Among the many solutions envisaged for the heat market, district heating (DH) systems offer the flexibility and capacity for faster integration of low emission heat-generating activities for a smooth transition towards a low carbon society [1]. In order to address this problem, assessment with a goal to find out is heat demand met should be applied to energy systems on different temporal and spatial scales.

Wang et al. [2] propose criterion for analyzing the operation stability of a DH substation at all operating conditions. The relation between supply and return lines changes so that the delivery flow decreases and the return flow increases with improved building thermal performance [3]. Low-temperature DH now represents the state-of-the-art [4]. Declining return water temperatures of DH networks leads to the reduction of primary energy consumption and environmental impact [5]. Plenty of European and Swedish research in particular is related to environmental assessments [6]. The temperature of the domestic hot water (DHW) is usually assumed to be raised by electricity, to eliminate the risk of legionella [7]. In [8], the optimization results obtained using the total boiler production as the objective function are described. Tool developed by Badami et al. [9] is supportive in optimising the layout of a DH network and its maintainability, and, in particular, in identifying the best size and location of thermal energy storage (TES) systems. Integration between electricity and DH systems can be managed by heat pumps and TESs, since the latter are associated with much lower installation costs than electricity storage [10]. As for electricity, it is usually [11,12] generated by a CHP plant and integrated into the national grid after that, so the electricity on demand side is supplied by the national grid. del Hoyo Arce et al. [13] and Delangle et al. [14] review approaches related to a continuous dynamic optimisation

of a DH network. Another example of review is the one developed by Vandermeulen et al. [15]. The hydraulic simulation code of a DH network in Ref. [16] is realized in Matlab software. The model developed by Andric et al. [17] simulates heat production from the units connected to a DH system, for a given heat load profile. To calculate a demand trajectory, a typical residential heat load curve with two daily peaks is assumed in [18]. The efficiency of a DH system is a function of demand density; hence “high density” and “low density” scenarios are used in [19]. In [20] the flow rates of all substations are determined by their local heat loads. Coss et al. [21] quantify the amount of peak decrease and minimum heat demand increase needed to achieve the system improvement. Wang et al. [22] make time for heat loss assessment as well. Shan et al. [23] not only indicate the reliability of a DH network, but also an insufficient heat supply under different outdoor temperature. The developed in [24] methodology has the goal to jointly analyse the effects of components failure on the service quality. Balance-based leak detection methods are effective only in pipeline sections without consumers and require huge amount of flow meters [25]. Babiarz&Blokus-Roszkowska [26] establish a reliability model of the DH system’s operation process using the semi-Markov process. To assess the role that proper design, sizing and location of pipes can play in minimising the service outages another work [27] is intended.
The aim of this paper is to validate a potential for leak location and to verify a new method by applying an assessment to a real DH network with plenty consumers.

METHODS

The distribution pipe pressure loss of 200 Pa/m is a typical design value [19] and the heat exchanger pressure losses are design values based on engineering judgment. Minimum supply water temperatures and pressure differences for all consumers were recorded based on existing network constraints to satisfy the consumers' demand.
The main model constraint is to always satisfy network heat demand, at any given moment of time, with a constant temperature regime (for instance, 150°C supply /70°C return temperature) in the network. In Malmö, Sweden [7] the supply temperatures is established as low as 65C and the return temperatures from all the new buildings is established as 30C.
An existing central plant and its DH network illustrates observation methodology as a case study. Omsk HPS-5 Coal Power Plant is located at Omsk, Omsk Oblast, Russia. Location coordinates are: 55.0016 latitude, 73.4877 longitude. This infrastructure is of TYPE Coal Power Plant with a design capacity of 695 MWe. In the base year, the efficiency of units of this CHP fluctuated between 54.3 and 63.7%, and averaged at 56.1% [27], which is higher than the corresponding values in [11]: 45.4%, 51.7%, and 48.1%, respectively. The Omsk city combines a mix of different buildings characterized by different energy consumption, activities and heating systems. HPS-5 provides hot water to consumers for the use of ventilation, DHW and space heating (SH). In Russia 95/70◦C is the common practice for building radiators. On contrary, in well-developed DH markets as in Denmark radiators are designed for typical heat supply at 70/40 ◦C [1].
The total installed capacity of the HPS-5-supplied buildings is 1264.583 Gcal/h, of which 934.116 Gcal/h is needed for space heating. The annual heat demand of the area was 7,952,957 Gcal [27]. The total length of the pipes is 110.7 km.

RESULTS AND DISCUSSION

The graph in Fig. 1 presents operational state transitions based on the statistical data of the heat supply system operation process.

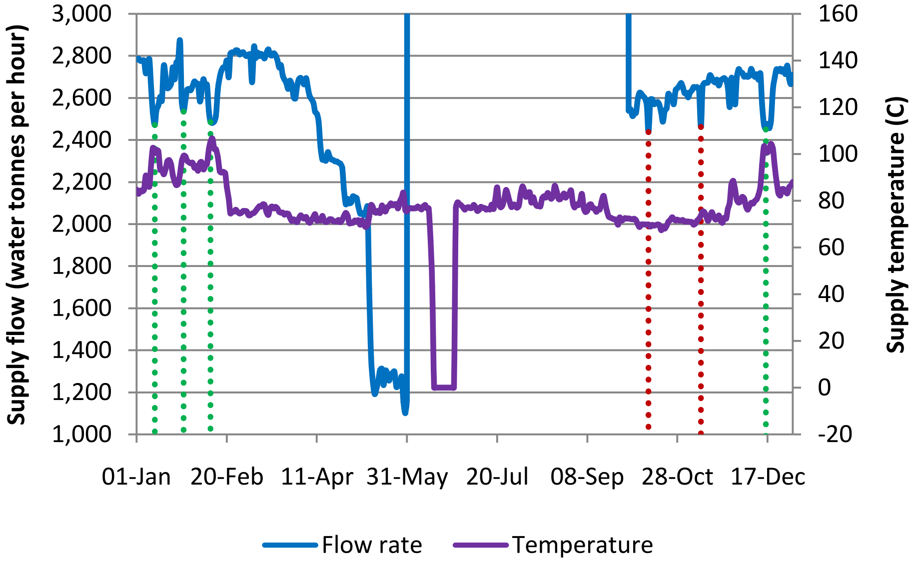

Fig. 1 Data collected at the heat plant collectors in Omsk

The pressure and flow rate values of the heat source and heating substations under different operating conditions can be calculated with the hydraulic simulation code [16]. The heating substation controller tuned at certain working conditions may be unstable when operating condition changes in large range [2]. The network itself is the other well-known source of flexibility [15]. On the one hand, extreme outdoor temperatures lead to high heat consumption. This additional request is covered both through increased flow rate and supply temperature. These situations are represented by green lines. If the heat demands of all consumers change with the outdoor temperature simultaneously in the same degree, new flow rates of all substations become up to values accordingly with their heat demands in the same relative ratio. Andric et al. [17] conclude that the evolution of heat demand has a strong impact on energy production mix. As shown in Fig. 1, the requested supply temperature and the obtained flow rate are identical, that means that the consumers receive almost the same amount of load demanded whatever outdoor temperature is. This is truly only when the extreme cold comes.

On the other hand, negative peaks without corresponding temperature increase (depicted with red) mean emergency situation when flow rate was restrained by means of valves next to a leak location. In operational states, defined by the system infrastructure and external conditions, a DH system changes its reliability structure and its components' reliability indicators [26]. Moreover, reliability indicators are weighted by a water flow rate [9]. The same, the location of the leak is traced remotely by employing an automatic algorithm considering hydraulic issues (pressure and flow distributions) in [25]. At the meantime, Zhou et al. [5] call leak location by means of an unmanned aerial vehicle (UAV), commonly known as a drone the most promising. The presence of a peak limits the opportunities for network enlargement, because of the limitation on the mass flow rates in the existing pipeline [8]. However, the manipulation of the load profile through decreasing maximum load only does not (always) shows a benefit [21].

DHW load creates the lower limit of the supply temperature for all consumers and it was set to 70 °C. Low-temperature DH now represents the state-of-the-art [4]. These systems have supply temperatures varying between 70°C (winter) and 55°C (summer) to ensure thermal comfort and a safe production of DHW and are suitable for both new and existing buildings. This concept depends on a deep refurbishment of a current system so that the technical parameters of a network and the profile of the heating requirement can be redesigned in order to maximise the input from the heat pump [10]. According to Brange et al. [7] buildings may be adapted to a 30C supply temperature and the temperature of the DHW is raised by electricity.

Another scenario is use of an existing DH system supplied by high-temperature heat pump facilities [28]. If the hot side of the network is maintained above the building SH temperature, then the buildings don't need units for boosting temperature and have simple heat exchangers for free-heating. The operation of heating substation remains stable even when primary supply temperature becomes very high [2]. The total heat consumption corresponding with the spring is clearly lower than in the winter case, due to the declined consumption associated with anticipated ending of the heating season.

To guarantee smooth operation, pressure tests take place every spring, thus the blue line (fig. 1) is gradually declining. During this time, the SH systems are shut off and thus not consuming any heat. Monitoring of the DH system in Omsk shows no supply water heating in June (recorded as 0°C, violet line) with a great flow rate peak during the entire summer (blue line). The latter anomaly was due to setting the DHW supply blending-valves to consume water directly from the network that in the long term could affect the durability of the internal elements and possibly cause excessive make-up. Addressing this issue next year would probably have a lower environmental impact, since measures that influence the winter peak loads have higher emission reductions [6]. The reason for 0◦C outage is centralized pressure tests at the transmission line which occur annually.

Finally, the January-February thermal peak is often higher than the other peaks due to colder outdoor weather. The annual water volumes also may decrease with improved building thermal performances [3].

CONCLUSION

In this work, a holistic design for large-scale DH network is proposed capturing the needs for cross-cutting solutions including improvement of heat supply and integration of hydraulic side measures. This system has been examined in variable external conditions. The identification of the heat supply system operation process has been performed and this processes' main characteristics have been determined on the basis of data collected in the DH system of Omsk during 2017. The simulated results were compared with the measured data provided in the literature.

Applying obtained results to simulation or modelling a DH system could lead to interesting ramifications about layout and retrofit strategies. For instance, the latest research [18] shows the dynamic optimization method is able to handle mass flow dependent delays in a very precise way.

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