Application of thermohydraulic dispatcher for existing and new district heating systems

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Abstract. Electricity consumption represents high share of operational costs in district heating (DH) systems. Recent attempts of decreasing these costs have led to appearing the idea of systems with distributed variable speed pumps (DVSP). One of the parts of such systems is thermohydraulic dispatcher (THD). This article is concerned with application of THD for DH systems. Existing DH systems with low available hydraulic head are suitable for installing THD instead of booster pumps. Electricity consumption and cost of equipment for several schemes of heat substation are estimated. Application for low temperature district heating (LTDH) systems is considered. Further ideas of development DVSP systems are proposed. Schemes of cascade systems based on THD and hydraulic profiles are presented. In result, cascade systems can reach highest possible electricity saving effect due to eliminating of throttle valves at heat source, heat substations and heat consumers.

1. Introduction

At the present time problems of energy saving are of much importance worldwide. Particularly, in Russia several federal laws were passed recently in order to stimulate energy saving in industry and public service [1-3]. One of the areas of focus is heat supply. Heat supply systems in Russia have following problems: outdated equipment, considerable transportation energy costs, critical condition of heat supply network, ineffective building envelope, insufficient automatization, all of them leading to considerable energy loses [4-7]. Mentioned problems can be solved by large-scale refurbishment of equipment, network and buildings. During the refurbishment it is important to pay attention to modern and perspective technologies in heat supply systems.

One of devices that can be used in DH systems for increasing its effectiveness is thermohydraulic dispatcher (THD). THD is vertical or horizontal pipe manifold of large diameter with low hydraulic resistance. It is a part of hydraulic system consisting of source circuit (circuits) and consumer circuit (circuits). THD allows making circuits hydraulically independent from each other. For example, increasing mass flow in consumer circuit doesn’t affect mass flow in source circuit. Similarly, a consumer circuit doesn’t influence another consumer circuit in case of using THD. This effect can be used to avoid mutual influence of various consumers (heating, hot water, ventilation consumers) on each other [8-9].
2. Possible applications of THD

2.1. Heat source
Since THD separates circuits, it is reasonable to install THD in boiler room to separate source circuit and network. Moreover, several boilers working for the same DH system can be separated as well. Another advantage of connection to THD is constant flow rate through boiler, which helps avoid minimal flow rate regimes. Recirculation line is usually installed to increase boiler inlet temperature and prevent thermal shock and risk of sulphuric corrosion. THD installed at boiler room plays the role of recirculation line.

2.2. Heat substation
Installation of THD at heat substation allows separating main network from consumers. Besides, space heating (SH) and hot water supply systems (HWS) are separated as well, so their mutual influence, which usually leads to hydraulic and thermal disbalance, is disposed. There are several ways of connecting consumers to heat substation [10]. So, THD represents the connection similar to indirect connection, where THD replaces heat exchanger. But static pressure of primary and secondary circuits for THD connection is the same unlike with indirect connection. Since direct connection (open HWS) of HWS system is to be forbidden in 2022 in Russia [2], only indirect connection (closed HWS) is considered in this article. At the same time either direct or indirect connection of SH system is possible.

2.3. Heat consumers
SH systems are characterised by distributed network inside a building and adjusted hydraulically by balancing valves which throttle redundant hydraulic head. Although this system is common, it is not effective due to energy loss during throttling. THD can be used for SH systems to separate consumers from each other and to avoid throttling losses by using variable speed pumps for every consumer instead of balancing valves and central pump.

The same solution can be adopted for HWS systems, where THD can provide hydraulic independence to consumers. Now HWS systems are not designed properly in some cases, which results in hydraulic disbalances while several consumers are turned on. For example, having adjusted temperature of water for shower bath, consumer is likely to have to readjust it after another water consuming unit is turned on. So, application of THD for HWS systems will bring more comfort to dwellers of buildings.

2.4. Application of THD for LTDH systems
Low temperature district heating (LTDH) is promising technology which is actively being researched in Europe [11-15]. It is well-known fact that electricity consumption in DH system can be decreased by increasing supply temperature and decreasing return temperature. So, cases of low available hydraulic head may occur during transition from existing DH systems to LTDH systems. Since existing DH systems were designed for particular temperature difference, decreasing of temperature in supply line can lead to lower temperature difference and result in higher flow rate causing bottlenecks [16]. Application of THD for such cases can be a good solution for tackling bottlenecks problem. Moreover, THD allows systems to operate under lower differential pressure, which can be used for creating low temperature and pressure district heating systems.

3. Methods
THD suits well for distant consumers with low hydraulic head. So, abstract heat substation with available hydraulic head of 10 kPa was analysed. Three schemes of heat substation were considered: indirect connection, direct connection, and THD connection. Design temperatures of supply and return lines for primary circuit are 130°C and 70°C accordingly; for secondary circuit those temperatures are 95°C and 70°C. Different heat outputs were considered: 800 kW (300 kW for SH and 500 kW for HWS), 2400 kW (900 kW for SH and 1500 kW for HWS), and 4800 kW (1800 kW for SH and 3000 kW for HWS).
kW for HWS). The equipment was chosen and prices for heat exchangers, pumps, pipes, valves, controls and instruments were received from producing companies. Then electricity consumption during heating period in Moscow was estimated. tables 1, 2 and 3 show input data and the results of calculation of electricity consumption during heating period for different connection schemes and different heat output. Electricity consumption was estimated under condition that all pumps work in nominal mode. But HWS circulating pumps may require less energy during night time which is not considered in this paper. Also electricity consumption of make-up pumps for indirect scheme was neglected. Although coefficient of performance (COP) of pump depends on its construction, the same value (0.6) was taken for every considered pump. Power of pump was calculated as

\[ N = \frac{Q \cdot \Delta P}{3600 \cdot \eta} \]

\( N \) is power of pump, kW,
\( Q \) is volume flow rate, m³/hr.
\( \Delta P \) is pump head, kPa.
\( \eta \) is COP of pump.

Electricity consumption was calculated as

\[ E = N \Sigma \cdot \tau \cdot 24 \]

\( E \) is electricity consumption, kW*hr,
\( N \Sigma \) is total power of pumps, kW,
\( \tau \) is duration of heating period, which is 205 days for Moscow [17].

4. Results

Figure 1 shows estimated cost of equipment for mentioned schemes of heat substation in dependence of heat output. While cost of equipment for schemes with direct connection and THD connection is almost identical for considered range of heat output, indirect connection scheme costs much more because of high heat exchangers price.

**Table 1.** Electricity consumption of different heat substation schemes. Total heat output is 800 kW.

|                      | Indirect | Direct | THD  |
|----------------------|----------|--------|------|
|                      | Volume flow rate (m³/hr) | Pump head (kPa) | COP of pump | Power of pump (kW) | Volume flow rate (m³/hr) | Pump head (kPa) | COP of pump | Power of pump (kW) |
| Booster pump (primary circuit) | 11.5 | 100 | 0.6 | 0.532 | 11.5 | 100 | 0.6 | 0.532 | – | – | – | – |
| HWS circulating pump (primary circuit) | – | – | – | – | – | – | – | – | 7.2 | 50 | 0.6 | 0.167 |
| DH circulating pump (secondary circuit) | 8.6 | 100 | 0.6 | 0.398 | – | – | – | – | 10.3 | 50 | 0.6 | 0.238 |
| Mixing pump | – | – | – | – | 6 | 50 | 0.6 | 0.139 | – | – | – | – |
| HWS circulating pump (secondary circuit) | 2.2 | 100 | 0.6 | 0.102 | 2.2 | 100 | 0.6 | 0.102 | 2.2 | 100 | 0.6 | 0.102 |
| Total power | – | – | – | 1.032 | – | – | – | 0.773 | – | – | – | 0.507 |
| Electricity consumption during heating period, kW*hr | – | – | 5079 | – | – | – | 3804 | – | – | – | 2494 |
### Table 2. Electricity consumption of different heat substation schemes. Total heat output is 2400 kW.

| Indirect | Direct | THD |
|----------|--------|-----|
| Volume flow rate (m³/hr) | Pump head (kPa) | COP of pump | Power of pump (kW) | Volume flow rate (m³/hr) | Pump head (kPa) | COP of pump | Power of pump (kW) | Volume flow rate (m³/hr) | Pump head (kPa) | COP of pump | Power of pump (kW) |
| Booster pump (primary circuit) | 34.4 | 150 | 0.6 | 2.389 | 34.4 | 150 | 0.6 | 2.389 | 21.5 | 100 | 0.6 | 0.995 |
| HWS circulating pump (primary circuit) | - | - | - | - | - | - | - | - | - | 100 | 0.6 | 1.431 |
| DH circulating pump (secondary circuit) | 25.8 | 200 | 0.6 | 2.389 | - | - | - | - | 30.9 | 100 | 0.6 | 1.431 |
| Mixing pump | - | - | - | 18 | 100 | 0.6 | 0.833 | - | - | - | - |
| HWS circulating pump (secondary circuit) | 6.4 | 200 | 0.6 | 0.593 | 6.4 | 200 | 0.6 | 0.593 | 200 | 0.6 | 0.593 |
| Total power | - | - | - | 5.370 | - | - | - | - | 3.815 | - | - | 3.019 |
| Electricity consumption during heating period, kW*hr | - | - | - | 26422 | - | - | - | - | 18769 | - | - | 14851 |

### Table 3. Electricity consumption of different heat substation schemes. Total heat output is 4800 kW.

| Indirect | Direct | THD |
|----------|--------|-----|
| Volume flow rate (m³/hr) | Pump head (kPa) | COP of pump | Power of pump (kW) | Volume flow rate (m³/hr) | Pump head (kPa) | COP of pump | Power of pump (kW) | Volume flow rate (m³/hr) | Pump head (kPa) | COP of pump | Power of pump (kW) |
| Booster pump (primary circuit) | 68.7 | 200 | 0.6 | 6.361 | 68.7 | 200 | 0.6 | 6.361 | 43 | 150 | 0.6 | 2.986 |
| HWS circulating pump (primary circuit) | - | - | - | - | - | - | - | - | - | 150 | 0.6 | 4.299 |
| DH circulating pump (secondary circuit) | 51.6 | 250 | 0.6 | 5.972 | - | - | - | - | 61.9 | 150 | 0.6 | 4.299 |
| Mixing pump | - | - | - | 36.1 | 150 | 0.6 | 2.507 | - | - | - | - |
| HWS circulating pump (secondary circuit) | 12.9 | 250 | 0.6 | 1.493 | 12.9 | 250 | 0.6 | 1.493 | 250 | 0.6 | 1.493 |
| Total power | - | - | - | 13.826 | - | - | - | - | 10.361 | - | - | 8.778 |
| Electricity consumption during heating period, kW*hr | - | - | - | 68026 | - | - | - | - | 50977 | - | - | 43187 |
Figure 1. Dependence of equipment cost for different connection schemes from heat output.

![Figure 1](image1.png)

Figure 2. Dependence of electricity consumption during heating period for different connection schemes from heat output.

![Figure 2](image2.png)

Figure 2 shows estimated electricity consumption during heating period for different connection schemes from heat output. Scheme with THD connection has less electricity consumption among all considered heat outputs. The difference between electricity consumption of different schemes increases with increase of heat output. Since available hydraulic head is low, it is necessary to apply booster...
pumps in schemes with both direct and indirect connections. The scheme with THD connection can work without booster pumps, because usually THD operates under low differential pressure. That is the explanation for the best performance of scheme with THD connection in terms of electricity consumption. The scheme with indirect connection has the highest energy consumption because of high hydraulic resistance of heat exchangers.

5. Discussion
The problem of electricity saving in DH systems is paid increased attention to. One of the ways to tackle this problem is to utilise redundant heat carrier pressure in district heating by using a pump with rotor wheel designed to work as turbine thus generating electricity instead of throttling redundant hydraulic head [18-19].

Figure 3. Scheme and hydraulic profile of DVSP system proposed in [20] (on the left) and scheme and hydraulic profile of modified DVSP system (on the right). 1 – heat source, 2 – THD, 3 – circulating pump, 4 – water tank, 5 – make-up pump, 6 – circulating pumps, 7 – heat consumers.

Another way is to install new DH systems with distributed variable speed pumps (DVSP), where THD is used. The concept of DVSP systems is to eliminate regulating valves and throttling losses and rely on variable speed pumps as devices for control and regulation [20-24]. In article [20] Chinese researchers proposed new DH system which is shown on the left side of figure 3. The device called hydraulic connector in the article seems to be the same as THD. Although proposed scheme has electricity saving effect, the effect is not as great as possible. Hydraulic profile tends to widen after zero pressure difference point, which contributes to more electricity consumption. This tendency can be decreased by either using main network pipes of larger diameter or connecting all consumers to THD.
which is shown on the right side of figure 3. Nevertheless, both methods might have significant capital costs due to increased pipe diameters or number of pipes accordingly. On the other hand, increased number of pipes may result in increasing of overall heat supply reliability as every consumer has its own independent pipelines and breakdown of one consumer doesn’t affect the others. So, these factors should be taken into account when estimating operational benefits and assessing overall efficiency of modifications to DVSP scheme.

**Figure 4.** Cascade scheme with pumps on return line and its hydraulic profile (on the left) and cascade scheme with pumps on supply line and its hydraulic profile (on the right).

**Figure 5.** Cascade schemes with pumps on both return and supply lines and its hydraulic profiles.
Figure 6. Principal cascade scheme of DH system. 8 – hot water consuming units, 9 - heat exchanger.

In articles [21-24] electricity consumption, economic and energy saving analyses of DVSP systems are considered as well as method of system regulation. But the articles’ main focus is investigation of Source-Substation chain. One of the aims of this article is to propose Source/Substation-Consumer chain based on THD application. Such cascade scheme may have highest possible electricity saving effect due to avoiding of throttle valves in the whole DH system. Cascade schemes based on THD application are illustrated on figure 4. The scheme on the left side includes pumps installed on the return line after THD. It makes hydraulic profile go down and pressure in supply line declines which can cause evaporation of water. However, this is not going to be a problem for low temperature district heating systems. The scheme on the right side includes pumps installed on the supply line after THD. It makes hydraulic profile go up and pressure in return line increases which can cause breakdown of customer’s heating units. In order to avoid these disadvantages cascade schemes with pumps on both return and supply lines are proposed and illustrated on figure 5. Hydraulic profile of such systems goes both up and down and pressure in supply and return lines is more stable. Figure 6 summarizes previous information. It describes SH and HWS systems connected to TDH at consumer’s side, then there is another THD at heat substation, and one more THD at heat source, all of them installed in series.

6. Conclusion
THD can be installed at consumer’s side, heat substation, and heat source separating hydraulically all of them from each other. At the same time it leads to electricity saving effect due to avoiding of throttle valves. Existing DH systems as well as LTDH systems with low available hydraulic head are suitable for installing THD instead of booster pumps. Result of estimation shows that it has significant electricity consumption reduction without increasing of capital costs. Cascade systems based on THD application were proposed. It seems to be perspective way of combining benefits of installing THD and distributed variable speed pumps in DH systems leading to the highest energy saving effect for the whole DH system.

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