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Selected aspects of hydraulic issues in heating systems

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Abstract
Rational and efficient use of thermal energy in recent years has resulted in significant changes in the heating system as well as technological progress. In order to design a heating system properly and exploit it correctly, an in-depth understanding of the hydraulic issues is necessary. Application of automatic control system in various sectors of heating network has resulted in a more dynamic and efficient work of the whole system. For proper operation of a thermal system it is also necessary to compile a correct heat balance and a regulation graph that allows to determine the optimal mass and parameters of heat medium. The article discusses the problems of supplying heat process, types of thermal systems and selected problems of hydraulic issues that occur in the heating networks.

1. Introduction - issues of heat supply

Energetic security, balanced development and environmental protection play an important role in the economic development of a country. Therefore, rational energy management and secure heat supply require from energy companies integration of complex operations in the structure of district heating systems. Heat supply to customers in large urban areas in Poland is carried out through centralized heating systems. It is a group of related energetic devices and installation working together, which function is to produce and provide heat with the appropriate parameters and with sufficient amount (BARTNICKI G., NOWAK B., BOLACH M. 2013).

District heating system consists of the following elements:

- heat source with specified parameters and quantity,
- heat network, which supplies the heating medium,
- thermal centres, which transfer the heating medium,
- indoor installations in heated buildings.

An essential issue for the functioning of the economy is a stable and undisturbed supply of energy. Efficient and effective operations of heating companies enforce permanent work protection of the heating source and distribution system. At the same time it should retain the ability to satisfy the demand for heat with specific quantitative and qualitative standards, regardless of weather conditions. Safety is also provided by a reliable, steady supply of heat to final user, confirmed by a low failure rate of individual elements of production infrastructure and a transmission network (PIETRASZEWSKI M., KATOLIK Z., 2014).

The increase of the energy efficiency of heating systems is also affected by *evaluation of the potential energy efficiency*, prepared by an energy company. This allows to analyse in details the system and identify opportunities for improvement in the various sectors of the thermal system. The heating infrastructure is so significant for energy security and reliability of thermal energy supply, that all efforts should be made to improve significantly the energy efficiency of heating systems, to optimize technological processes and to undertake modernizing projects which limit heat loss in transmission networks (RAK A. 2016).

2. Structure of the heating system networks

Two methods are used to transmit heat at the distance: from centrally located heat sources, where heat is transferred to the possibly large distances and from the local network heat, installed for example in a factory, housing complex or residential building. In Poland, heat supply to a large number of receivers, which are buildings or their groups, uses the district heating system which consists of the elements shown in Figure 1.

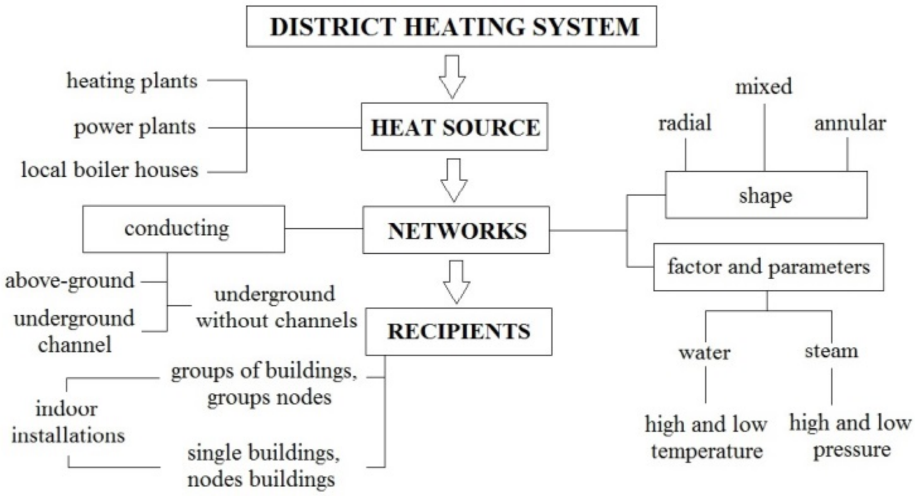

Fig. 1. Basic elements of the heating system

The configuration of heating networks depends on factors associated with the terrain, the distance from the point of delivery, consumer needs, the type of medium and the method of supplying heat. The final shape of the network also depends on whether it is designed for consumers in already existing objects or in newly implemented ones. While designing the heating network it is necessary to (NANTKA M.B. 2013, SZKAROWSKI A., ŁATOWSKI L. 2012):

- determine the right system of pipes, configuration and laying out networks,
- determine mutual position of the main heat pipes and lateral pipes,
- define appropriate parameters of the heat transfer medium,
- designate the advantageous flow rate of the medium which determine the diameters of pipes,
- select the type of a pipe material,
- determine the way of laying out the pipes,
- determine type and arrangement of the thermal insulation,
- determine the type and efficiency of hydro-insulation and protective cover,
- determine the optimal avoidance of collisions with other urban network engineering cables.

To ensure the efficient transfer of heat to each recipient, heating networks are built up by giving them different shapes as shown in Figure 2.

Division of district heating network can also be made depending on the type of heat transfer medium (GRZEGORCZYK W. 2007):

- water heating network: $T \leq 115^{\circ}$C low temperature and high temperature $T > 115$ C to 150°C
- steam heating networks: low-pressure $p \leq 70$ kPa and high-pressure $p > 70$ kPa

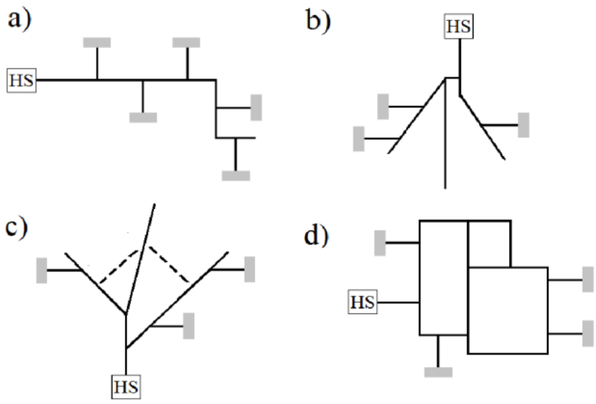

Fig. 2. Basic shape of a horizontal heating networks: a) line, b) branched (radial), c) branched connecting, d) annular

Water heating networks may have a different number of pipes. Depending on the number of pipes in the system, the networks are divided into (SZKAROWSKI A., ŁATOWSKI L. 2012):

- single-pipe water network,
- two-pipe water network,
- water network with three-, four- and multi-pipes,
- steam network with single-pipe (without return condensate), steam networks with two- and multi-pipes,
- mixed network with a combination of different plural water and steam pipes.

The most commonly used solutions are two or three pipes. Two-pipe system is mainly used for heating, ventilation and hot water in municipal construction. The heating medium is brought to the heat consumers through the power pipe and after putting the heat back to the source, it returns by the parallel return line (NANTKA M.B. 2013).

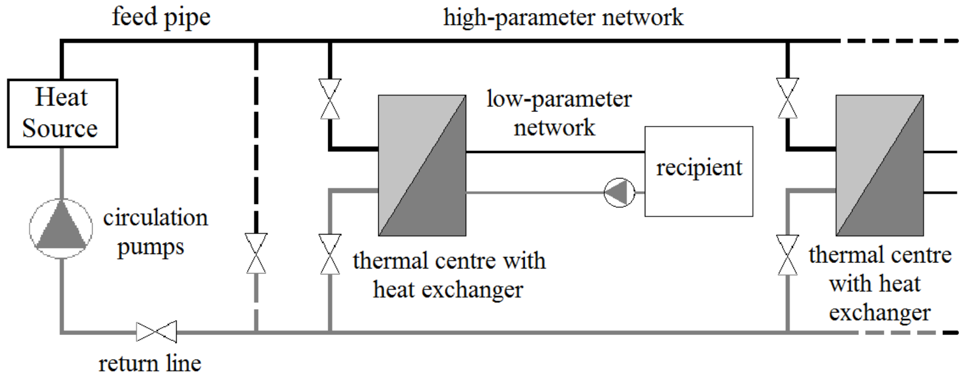

Fig. 3. Diagram of two-wire heat networks in a closed system

Because of the high pressures and temperatures of the heat carrier in network, heat receivers are usually connected by an adapter, which is the thermal centre. The main element of the heat centre is a heat exchanger or jet pump. Besides lowering the pressure and temperature of the heat carrier, thermal centres play the role of settlement points and regulators of networks. The illustrative picture of the heating system based on the two-pipe network in a closed system is shown in Figure 3 (CZEMPLIK A. 1999).

3. Selected aspects of hydraulic issues in heating systems

Water heating systems are closed circuits of the water cycle, the state of static of which is described by the equilibrium equation: $\Sigma\Delta p = 0$. Because of the specific characteristics of each heating system and a variety of hydraulic system components, design variations and the ways of conducting water heating installations are very different. Basic division of hydraulic network of water heating is shown in Figure 4 (ROOS H. 1997).

Three parts of the network are connected to each other at points A, B, C, D. Usually the distribution network is finished by multi-point heat reception (C_1, C_2, ... , C_n). The flow of water in the district heating network is caused by the action of circulation pumps. The energy necessary for the heat transfer may be produced in various parts of the entire network: in part (1) from the boiler pump P_K, in part (2) by the pump in distribution network P_S and in part (3) by the pump in the customer circuit P_O (ROOS H. 1997).

Figure 5 shows pressure distribution in the district heating networks during the flow of water through the network. While the circulation pumps stop, pressure in the entire network has the same value. The pressure is called the stabilization pressure P_{St}. If the exchange of heat between the network and the heat centre is carried out in the heat exchanger centres, the value of the stabilization pressure at each point of the network should not be lower than the pressure corresponding to the boiling temperature. Pressure distribution in district heating systems also carry the name of the piezometric pressures chart (GRZEGORCZYK W. 2007).

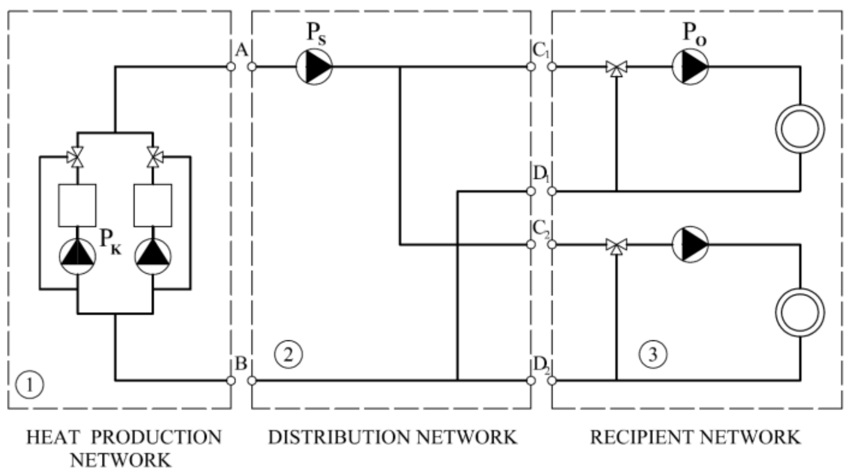

Fig. 4. Hydraulic division of the network water heating systems

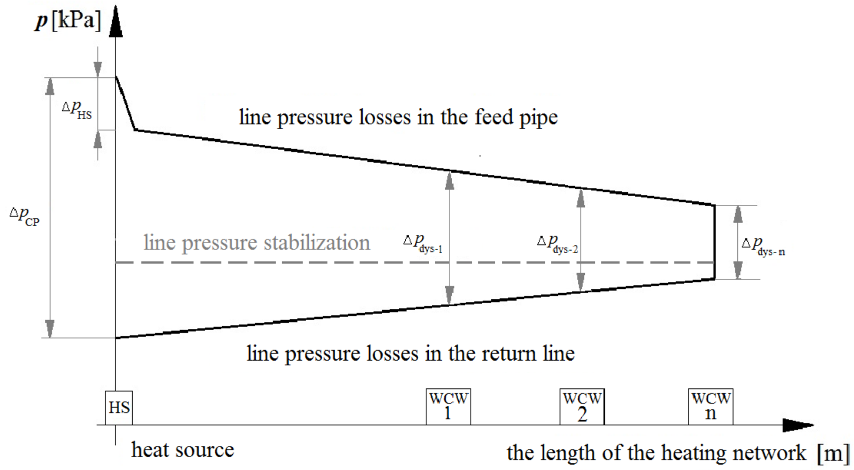

Fig. 5. Pressure distribution in the heating network: ΔP_{HS} - the value of pressure loss in the source, ΔP_{CP} - the value of pressure in circulation pumps, ΔP_{dys} - the value of disposable pressure for each heating node, WCW - substation with heat exchanger

For proper operation of external heat sources and efficient heat transfer to recipients, the knowledge of the hydraulic conditions of the network is necessary. Hydraulic calculations are used to determine the pipe diameters, network capacity, pressure loss and to determine the places where the pressure compensation is needed. It results in (NANTKA M.B., 2013; SZKAROWSKI A., ŁATOWSKI A. 2012):

- plotting a pressure graph and selecting the installation pumps,
- elaborating the hydraulic operating states of network,
- selection optimal equipment for automatic control.

The flow of medium in heating network is accompanied by heat losse and linear pressure drop Δp. Figure 6 shown a graph pressure supply and return on the selected track power.

One of the means to improve the energy efficiency of district heating is to align the flow of heat, reduce the heat losses and pressure drop at the transmission (distribution), which will lead to a more sustainable and efficient work of district heating networks. For the analysis of thermal and hydraulic operation of the network mathematical models which allows to perform calculations and simulation are used (PINI PRATO A., STROBINO F., BROCCARDO M., PARODI GIUSINO L. 2012, DANIELEWICZ J., ŚNIECHOWSKA B., SAYEGH M.A., FIDORÓW N., JOUHARA H., 2016).

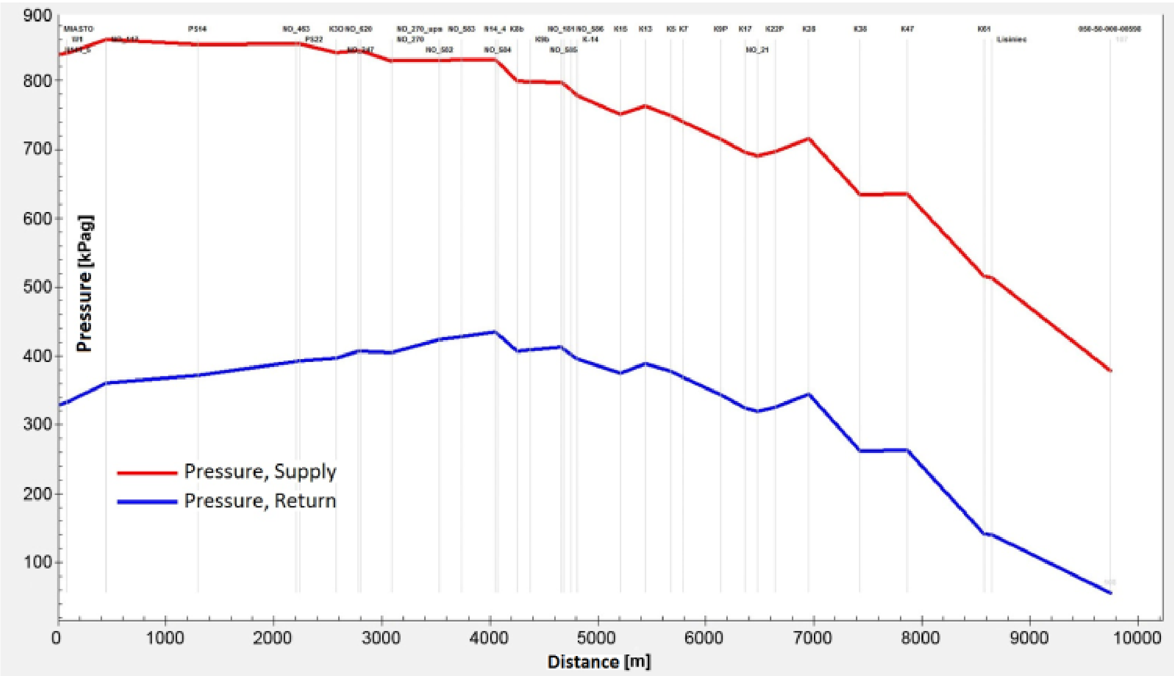

Fig. 6. A graph pressure supply and return on the selected track power from the heat source to the final heat substation

The calculation of pipe diameters begins after determining computational intensity of flow *G*, expressed in [kg/s] or [t/h], for each part of the network (Equation 1). It should be noted that because of the pressure loss, noise and other adverse effects, the flow rate in the main line cannot be overestimated. Selecting the diameters of pipelines in distribution networks and connections should be subject to the size of the disposable pressure. Linear and local losses are calculated according to PN-76/M-34034 - *Pipelines. The principles calculations of pressure losses* (SZKAROWSKI A., ŁATOWSKI L. 2012).

$$G = \frac{Q_o}{\Delta\tau_o^{obl.} c_p} + \frac{Q_{cw}}{\Delta\tau_{cw}^{obl.} c_p} + \frac{Q_w}{\Delta\tau_w^{obl.}} \quad (1)$$

where:

$$\Delta\tau_o^{obl.} = \tau_1^{obl.} - t_2^{obl.} \quad (2)$$

- the difference of a water computational temperature for central heating: supplying from the heat network and returning from central heating (during the calculation period),

$$\Delta\tau_{cw}^{obl.} = \tau_{1cw}^{obl.} - \tau_{2cw}^{obl.} \quad (3)$$

- the difference of a water computational temperature for hot water: supplying from the heat network and returning from the exchangers of hot water central installation (temperature shall be adopted for a transitional period at the beginning and end of the heating season),

$$\Delta\tau_w^{obl.} = \tau_{1w}^{obl.} - \tau_{2w}^{obl.} \quad (4)$$

- the difference of a water computational temperature for ventilation: supplying from the heat network and returning from the ventilation system heaters (with the external air computational temperature for ventilation).

The flow of liquid through the heating network is accompanied by both: a distributed pressure losses Δp_d (depending on the specific characteristic of the pipe, such as its diameter and length) and localized pressure losses Δp_l (in parts of the network reinforcement and changes of the pipelines configuration) which is described by the equation: (BORDIN CH., GORDINI A., VIGO D. 2016):

$$\Delta p = \Delta p_d + \Delta p_l \quad (5)$$

Whereas on the basis of the *Darcy-Weisbacha* equation, total losses can be determined by the formula (KAMLER W. 1979):

$$\Delta p = \left(\frac{\lambda l}{d} + \Sigma\zeta\right)\frac{w^2\rho}{2} \quad (6)$$

where:

λ – the hydraulic friction coefficient,
l – the length of pipes section [m],
d – the internal diameter of pipes [m],
ζ – the local resistance coefficient,
w – the liquid flow velocity [m/s],
ρ – the liquid density [kg/m^3].

Disposable pressure in the source is selected in accordance with the principle of hydraulic stability for the adverse thermal centre in the entire heating system. Surplus of disposable pressure in the heat centres are choked by (MAZUREK M., PIĘKOŚ M. 2016):

- pressure reducers,
- differential pressure control valves,
- weather regulators valves.

Providing all the recipients (in thermal centres) with adequate thermal (temperatures) and hydraulic (pressures, differential pressures) conditions, require proper heating systems control. Because of the variable occurrence in time by phenomena affecting the heat requirement and the complexity of the structures and functions of heating systems, properly implemented control includes the entire heating system from the sources, wired network to thermal centres supplying the customers. There are three types of control systems at different levels of heating system (NANTKA M.B. 2013; CZEMPLIK A. 1999; SZKAROWSKI A., ŁATOWSKI L. 2012):

- central regulation - in a heat source where it is possible to change both: the temperature and the flow of the network water,
- local control - implemented directly at the heat consumers, it can be performed in two stages: by means of valves placed on radiators and by automatic control devices installed in the group of thermal centres,
- mixed regulation - combines elements of central and local regulation, it is the most common variant of regulation in district heating systems.

The heat supply amount also depends on the temperature and the flow of the heating medium. Figure 7 shows how to control the temperature of the heating medium depending on weather conditions (NANTKA M.B. 2013):

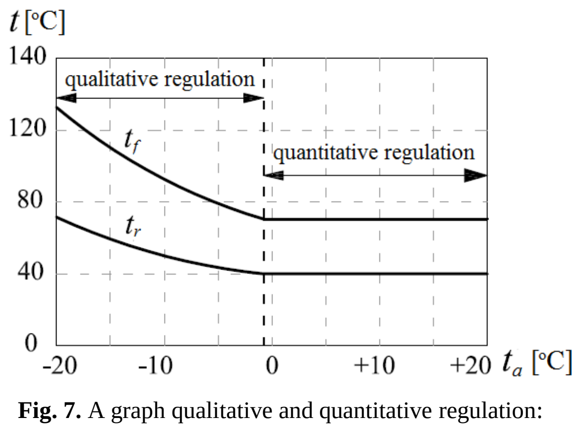

Fig. 7. A graph qualitative and quantitative regulation: t_a - ambient temperature, t_f - the temperature in the feed pipe, t_r - the temperature in the return pipe

4. Summary and conclusions

In recent years, many innovations have been introduced in heating systems and their principal purposes were: economization of the preparation process and heat supply to the receiver, losses minimization and reducing energy costs.

The existing heating networks are often the subject to modernization and extension. Changes in the network impose changes of individual system components, such as pipe diameters, wall thicknesses but also pumps or regulators.

Any of those modifications can stimulate the formation of various hydraulic phenomena. Within decades, the existing district heating systems in cities will develop. New recipients will be connected, although it should be expected that the heating needs of new buildings will be significantly lower than in the buildings currently operating. The development of the district heating system will be preceded by detailed hydraulic, economic and technical analysis.

Today's task for heat engineering is to modernize heat sources by replacing old, exploited devices whose advanced age results in low efficiency of heat production and high level of contamination emission.

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供熱系統水力問題的某些方面

關鍵詞
供熱系統
供熱問題
供熱管網的結構
液壓問題

摘要

近年來合理有效利用熱能，導致在加熱系統的重大變化，以及技術進步。為了正確地設計加熱系統，正確利用它，液壓問題的深入理解是必要的。在供熱管網中各行業自動化控制系統中的應用已導致整個系統的一個更具活力，高效的工作。用於熱系統的正常運行，還必須要編譯一個正確的熱平衡和的曲線圖即調節允許它決定最佳的質量和熱介質的參數。文章論述了供熱過程中，熱系統的類型和，在供熱管網水力發生的問題中選擇問題的問題。