RADIATOR VALVES INFLUENCE TO HYDRODYNAMIC PERFORMANCE OF WATER HEATING SYSTEM NETWORK

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Abstract

Concerning practical water network section, change in local resistance factor is result of any kind of valve closings or openings. Based on the developed model of water heating system network, the matter of the study will be the influence of the in local resistance to overall network resistance, and to the pump operating point. Radiator valve movement causes changes in flow rates, i. e. velocity in all network circuits, and has its further result in change in resistance factors, of the Reynolds number and in fluid friction coefficient. This considers change of local resistance in all network sections, not in the one in which the valve is. In this paper proposed is the exact calculating procedure of the change in flow rates through water heating network, due to change in local resistance factors. Simulation of proposed hydraulic model will provide precise determination of valve and pump influence under the system transient loads to operating pump point position, providing proper equipment choice and stable hydraulic regime.

Introduction

Proper radiator valves selection and sizing are predominant for heating system performance. If they do not persist to perform in the right way, as foreseen by the design engineer, the entire system provides poor performance.

During the exploitation of the heating system network, outside conditions seldom appear to be similar to the design ones, for which the system has been sized. In practice, the said means that heating system mostly appears under the transient load conditions, but for which hydraulic regime is seldom analyzed.

Under the transient load conditions reasonable are interventions regarding the radiator valves. Radiator valves movements cause changes in flow rate (i.e. velocity) and in local resistance factor. Change in local resistance factor causes changes of the Reynolds numbers and in fluid friction coefficients, [1]. This requires changes of local resistance factors within all network sections, not only within the section in which the valve is.

Sometimes, specially in countries which are under transient conditions, supervision at equipment installing and maintenance of any engineering system, has been the weakest point so far. These problems contribute to the pure hydraulic performance of water heating network.

The aim of this paper is to enable simulation of hydraulic regime in the heating system at different heating loads and for different types of equipment (valves and pumps) in order to eliminate the said problems arising during exploitation.

Influence of Change in Local Resistance Coefficient to Pipeline Network Characteristics and Pump Operation Point

Pipeline characteristics is dependence between the liquid head H of fluid circulation and fluid flow rate m, equation (1).

$$H = k \cdot \dot{m}^2 = \left(\lambda \cdot l / d + \sum \zeta_i\right) \frac{8}{\rho \cdot d^4 \cdot \pi^2} \dot{m}^2 \qquad (1)$$

The best is to describe the influence of local resistance changes on the entire pipeline network characteristics on a simple example shown on Fig. 1.

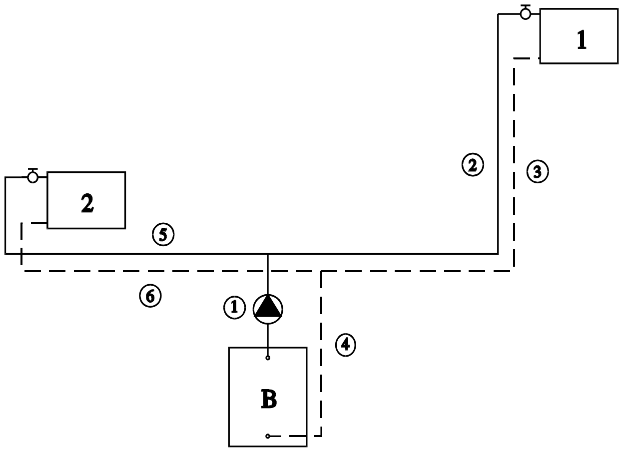

Figure 1a. Simple example of water heating network

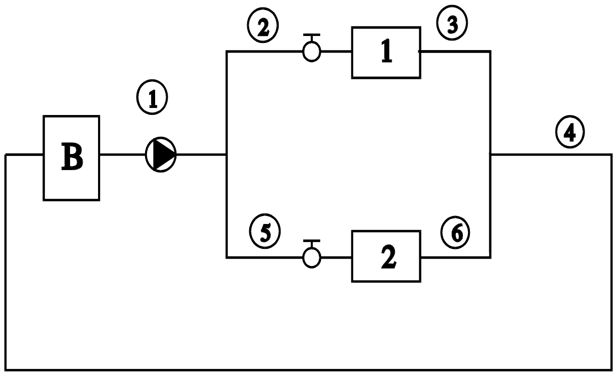

Figure 1b. Schematic view of heating network

Figure 1. Water heating network

Change in local resistance affects network (pipeline) characteristics only through change in particular local resistance coefficient. The most obvious example of local resistance changes regarding pump operation point is the influence of radiator valve to flow conditions in the entire network. Partial closing of the valve within section 2, Figure 1, leads to the increase of its resistance coefficient and the slope of its characteristic, curve 2 becomes dashed line 2' on Figure 2a. Further on, these changes influence slope of local flow circuit, involving section 2 characteristic; curve 23 becomes 23', Figure 2a. Curve 23 presents equivalent characteristics of serial sections 2 and 3, the same as curve 56 stands for equivalent characteristic of section 5 and 6, Figures 1 and 2. Final result is change of total pipeline network characteristic; 2356 becomes 2356' , Figure 2b, which implies the new pump operation point - point B on Figure 3, [3].

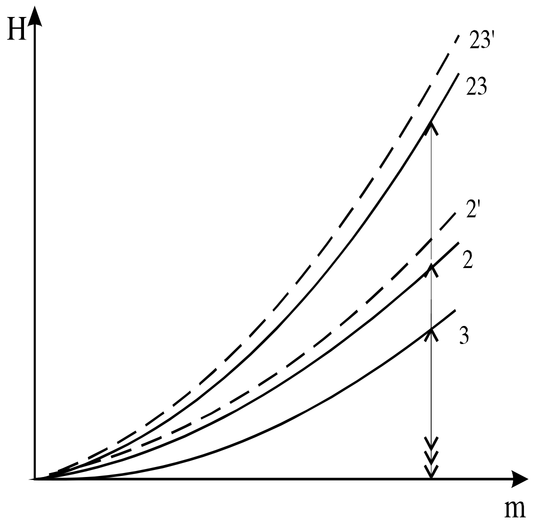

Figure 2a. Resolving series section of pipeline

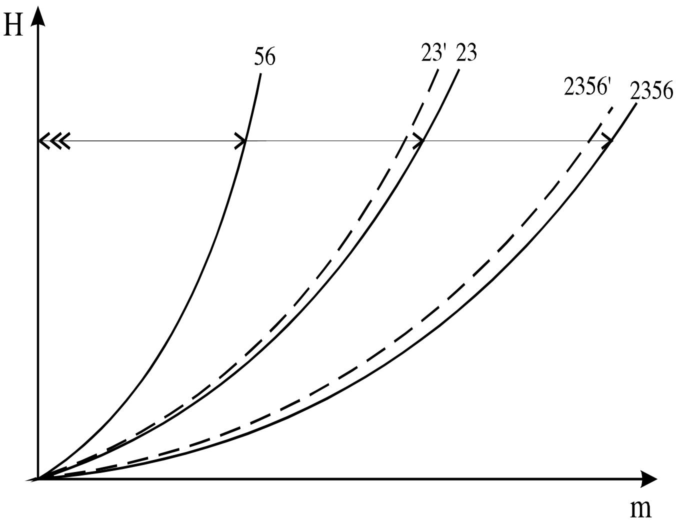

Figure 2b. Resolving parallel section of pipeline

Figure 2. Pipeline consisting of series and parallel connection of flow circuits

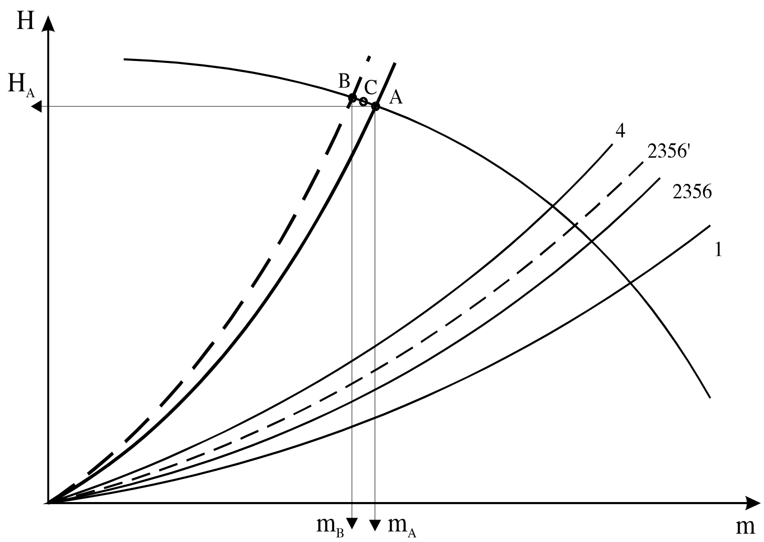

Figure 3. Pump and pipeline network characteristics

If the new pump operation point B is affected only by change of local section characteristic k_2, this would lead to inaccuracy being the result of the incorrect assumption that constant are other characteristics of local section. The radiator valve movement influences flow rates in all sections of the pipeline. Flow rates decrease through sections 1,2,3 and 4, and increase through sections 5 and 6, parallel to sections 2 and 3. Flow rate decrease in one flow circuit causes flow rate increase in the other, parallel to the first one. Any change in flow rates implies velocity change, which further causes changes of the Reynolds number, friction coefficient and resistance coefficients as depending variables. Due to change in local resistance coefficient, altered is not only the value of that particular section characteristic, but value of all other ones within the entire pipeline network also ought to be different. The exact pump operation point is somewhere between A and B point, as shown in Figure. 3. Point A corresponds to pump operation point before partial valve closing in section 2.

Precise Calculation Procedure of Change in Flow Rates through Pipeline Network due to Change of Local Resistance Factors

Pump characteristics are usually given by the pump manufacturers and may be expressed as function, equation (2), usually of exponential or cosine type.

$$H = f(\dot{m}) \tag{2}$$

The exact procedure will be explained regarding the example from fig. 1. Once determined the characteristic of the entire network *k*, one may connect it to the pump characteristic combining equations (1) and (2), which leads to equation (3).

$$\dot{m} = \frac{1}{\sqrt{k}} \cdot f(\dot{m}) \tag{3}$$

As the pump is always located on the section of a pipeline with maximum flow rate (section 1 on Figure 1.), possible is to determine flow value. Once determined overall flow rate necessary is to find out flow rates in all other sections. By computing the pump head, we follow the reverse order in determining pipeline characteristic, [3]. Starting from the fact that $m_1=m_4=m_2+m_3=m_{2356}$ liquid head in sections 2,3,5 and 6 will be:

$$H_{2356} = k_{2356} \cdot \dot{m}_1^2 \tag{4}$$

Taking as valid $H_{23}=H_{56}=H_{2356}$ and $m_2=m_3=m_{23}$, it is possible to calculate the flow rates through other sections.

$$\dot{m}_2 = \dot{m}_3 = \sqrt{\frac{H_{2356}}{k_{23}}} = \sqrt{\frac{H_{2356}}{k_2 + k_3}} \tag{5}$$

$$\dot{m}_5 = \dot{m}_6 \sqrt{\frac{H_{2356}}{k_{56}}} = \sqrt{\frac{H_{2356}}{k_5 + k_6}} \tag{6}$$

On the basis of these flow rates and the new obtained velocities in every pipeline section, it is possible to calculate new values of resistance coefficients and new value of pipeline characteristic in which way determined is the new pump operation point, C on Figure 3. Whole procedure is submitted to repetition until the exact position of pump operation point is obtained. As criteria, change in velocity may be adopted:

$$\frac{w_i^n - w_i^{n-1}}{w_i^n} < \varepsilon \tag{7}$$

The procedure may be repeated with any desired precision.

Example of the Proposed Model Application

Simulation of proposed model is made for the heating system given in Figure 4.

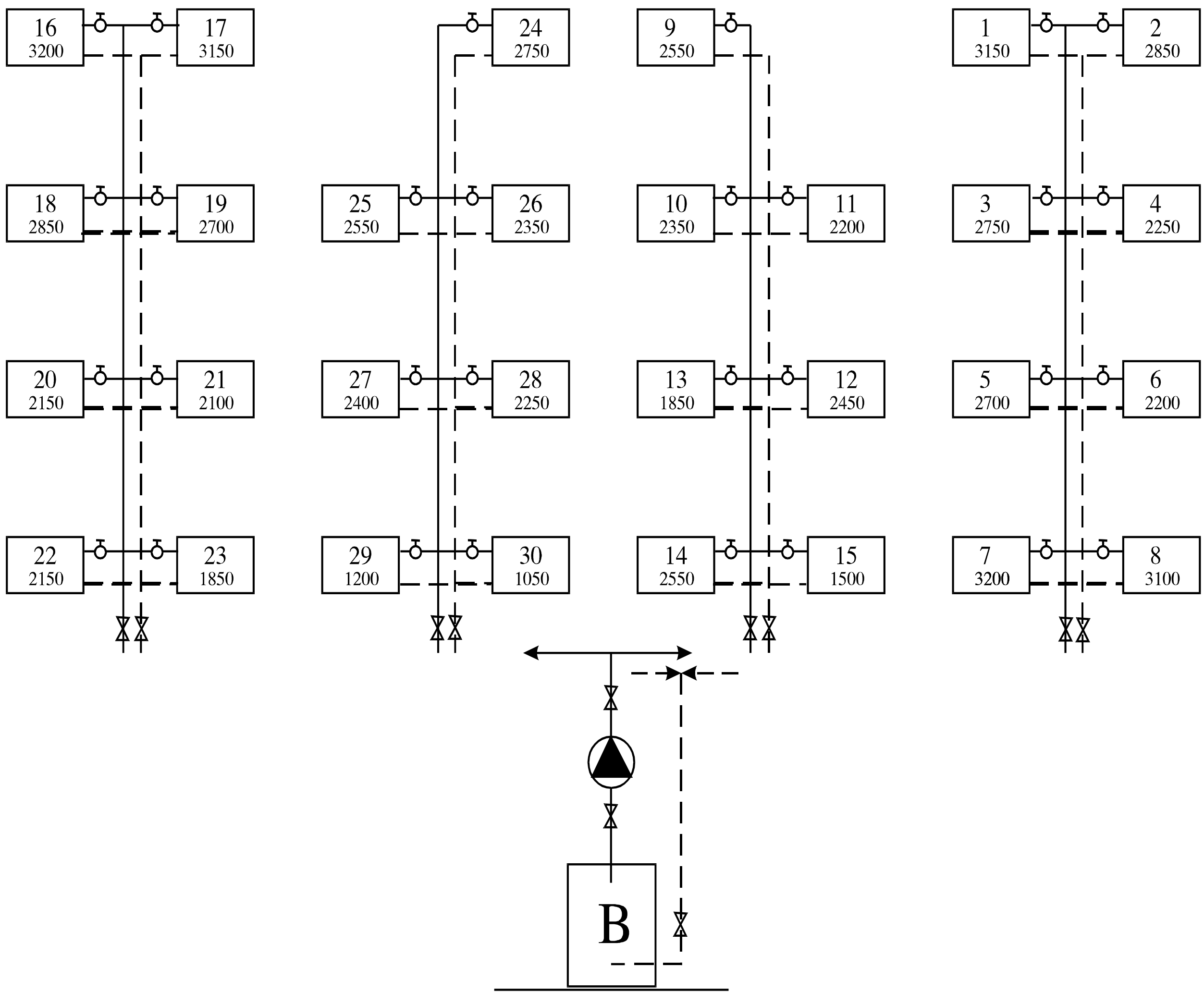

Figure 4. Heating System

Radiator valves are supposed to be of equal percentage, manually controlled. Pump characteristic is simulated using cosines function, equation (8). Both constants in equation (8) can be obtained from manufacture's pump characteristics. Results of dimensioning procedure are presented in the first part of Table 1. Design pump flow rate is 0.864kg/s, and pump head 15.535kPa.

$$H = Const_1 \cdot cos(Const_2 \cdot \dot{m}) \qquad (8)$$

Flow rates through radiators are then calculated for valve positions different from the design ones: relative movement (position) of valve seat, h, is set on approximately 80%, 50%, 20% of the design ones, h_{des}. Calculation is made using the usual procedure and the proposed, exact, procedure. The difference in water mass flow rates, Δ, is presented in the second part of Table 1.

Table 1. Results of the proposed model

radiator no.	Q	design throttle on valve	w_{des}	h_{des}	ζ_{des}	$\Delta_{0.8\ hdes}$	$\Delta_{0.5\ hdes}$	$\Delta_{0.2\ hdes}$
-	[W]	[Pa]	m/s	-	-	[%]	[%]	[%]
1	3150	0	0.20	1	4.0	-0.3	0.4	0.0
2	2850	213	0.18	0.89	18	-0.2	0.5	0.0
3	2750	901	0.29	0.86	26	-0.2	0.4	0.0
4	2250	1711	0.23	0.79	68	-0.3	0.3	0.0
5	2700	2502	0.28	0.79	69	-0.2	0.4	0.0
6	2200	3077	0.23	0.75	124	-0.4	0.2	0.0
7	3200	2234	0.33	0.82	45	-0.2	0.4	0.0
8	3100	3181	0.32	0.80	67	-0.4	0.4	0.6
9	2550	1439	0.27	0.82	46	5.4	2.1	0.5
10	2350	2585	0.25	0.77	93	5.3	2.0	0.5
11	2200	2790	0.23	0.76	113	5.3	2.0	0.0
12	2450	4454	0.26	0.74	144	5.2	1.9	0.6
13	1850	5460	0.19	0.69	306	5.2	2.1	0.0
14	2550	5642	0.27	0.73	168	5.3	1.8	0.6
15	1500	6858	0.16	0.64	581	5.0	2.1	0.0
16	3200	525	0.33	0.91	14	0.0	1.4	0.0
17	3150	832	0.33	0.88	20	0.0	1.4	0.0
18	2850	2844	0.30	0.79	70	0.0	1.2	0.0
19	2700	3161	0.28	0.78	86	0.0	1.5	0.0
20	2150	4821	0.22	0.72	201	0.0	1.4	0.6
21	2100	4970	0.22	0.71	217	-0.1	1.4	0.0
22	2150	5579	0.22	0.71	232	-0.1	1.2	0.0
23	1850	5839	0.19	0.68	327	-0.2	1.2	0.5
24	2750	181	0.17	0.90	16	-0.2	4.7	0.8
25	2550	241	0.27	0.93	11	0.1	4.6	0.4
26	2350	483	0.25	0.88	21	0.2	4.7	0.5
27	2400	3195	0.25	0.76	109	0.1	4.3	0.5
28	2250	3387	0.23	0.75	131	0.1	4.3	0.5
29	1200	7422	0.13	0.60	979	-0.3	1.3	0.5
30	1050	7506	0.11	0.58	1292	-0.1	1.3	0.4

The obtained results suggest that for the transient loads close to the design ones, the greatest difference between usual and exact procedures relates to the biggest design flow resistance coefficients. If the flow resistance coefficient is high for design conditions, the difference between proposed and usual procedure decreases with flow are, that id heating load. When radiator's valves are almost completely closed difference between the two procedures is slight, but suggests that the biggest one is in case of riser with the smallest design heating loads. It may be noticed that the smallest difference is for the cases where design load is reasonably big and the flow resistance moderate.

The most dominant influence is big flow resistance resulting in over 5% difference in flow rates obtained by usual and proposed procedures for some cases. If design flow resistance coefficients are moderate, for transient loads close to design one, the difference is rather small suggesting that whole system still operates in design manner. As the load decreases, moving further from design conditions, the difference increase and the dominant influence suggested by results is riser heating load - smaller the load, bigger is the difference. Very small heating loads results in smaller flow rates which further imply small differences.

Pump flow rates are presented in Table 2.

Table 2. Pump flow rates

h	m	m_{exact}	Δ
-	[kg/s]	[kg/s]	[%]
$0.8h_{des}$	0.70	0.69	0.9
$0.5h_{des}$	0.44	0.43	1.8
$0.2h_{des}$	0.17	0.17	0.5

It is not possible to obtain the exact energy demand, i.e. energy consumption, without data regarding real flow velocities. Heat released by water in radiators is defined as:

$$Q = \dot{m} \cdot c_p \cdot (t_{in} - t_{out}) \tag{9}$$

where m and t_{out} depend on flow velocity. Without regard to small corrections in flow rates and velocities, considering the size of real plant, number of heating plants and number of days they are in operation, the smallest relative saving presents reasonably large absolute amount. The proposed method may be used for energy analyses implementing thermodynamic model together with the hydraulic one.

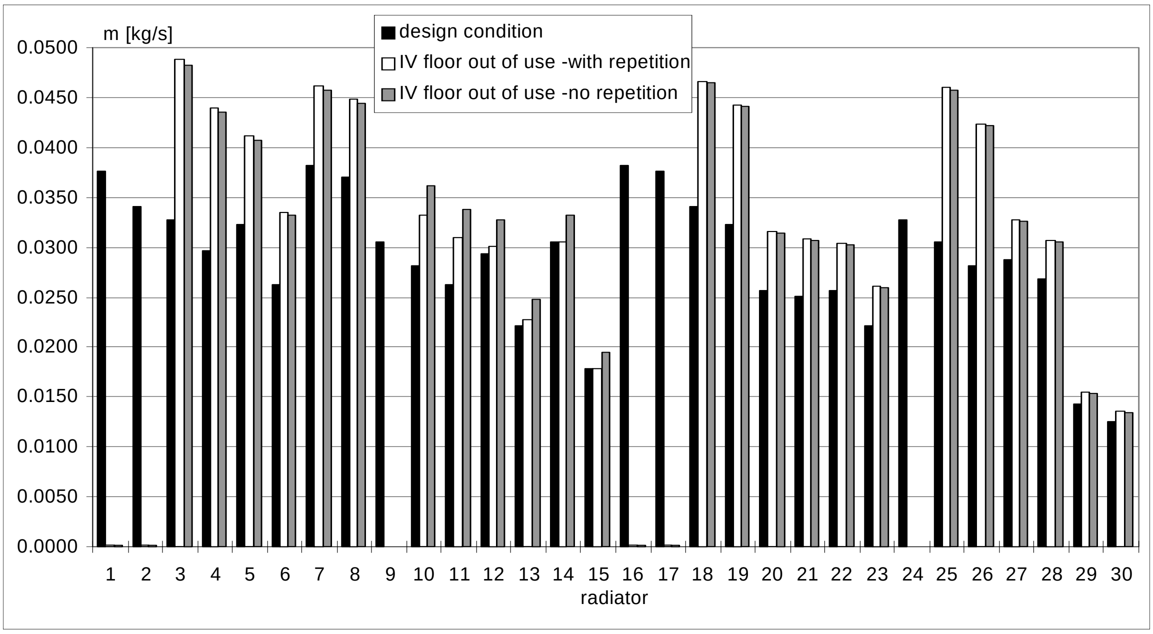

Figure 5. Flow rates for design conditions when all radiators are in operation

and when the last floor is out of use

Figure 5. shows water flow rates for the design conditions when all radiators are in operation and when the IV floor is out of use. When the IV floor is out of use, pump flow rate, following the exact procedure, is calculated to be 0.7976 kg/s, and under the usual routine 0.808 kg/s, making the difference of 1.3%.

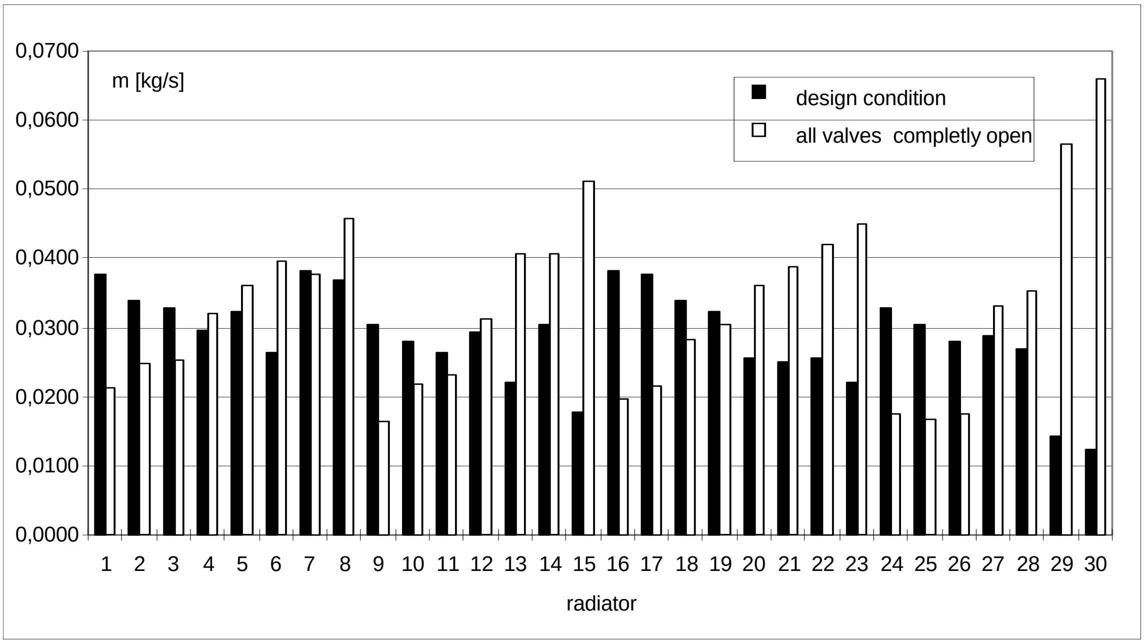

Figure 6. Flow rates for the heating system with properly adjusted and completely open radiator valves

In case of completely opened (instead of properly adjusted) radiator valves, Figure 6, radiator on lower floors are supplied with greater and on higher ones with smaller quantity of water compared to the designed mass flow rate. As all vertical columns (risers) have similar values of heat load, the overall column mass flow remains the same regardless the position of radiator valves. Difference in mass flow rates through radiators directly depends on design flow resistance coefficient. The said is most obvious in case of radiators no. 30 and no. 15. Higher the values of ζ_{des} are consequence of their lower design heating load compared to the average vertical column load. In respect of the maintenance and supervision problems, Figure 6. illustrates the importance of valve balance as required in design conditions.

Conclusion

In this paper the thorough analyses of influence of local resistance change to overall heating network characteristic for two-pipe heating system is presented. The analyses may also be easily applied to one-pipe systems. It is shown how the change in characteristic of local section influences the pump operation point. Also given is the exact method of flow rates calculation through all sections of the network. The use of this method enables to simulate hydraulic regimes in heating system for different load conditions thus providing proper equipment choice and stable hydraulic regime.

Nomenclature

H [Pa] - pump head or liquid head
k [1/kgm] - network characteristic
m [kg/s] - mass flow rate
ζ [-] - flow resistance coefficient
λ [-] - fluid friction coefficient
d [m] - pipeline section diameter
l[m] - pipeline section length
H_i [Pa] - liquid head at the pipeline sections i
k_i [1/kgm] - characteristic at the pipeline sections 2356
m_i [kg/s] - mass flow rate at the pipeline section 1
w_i^n [m/s] - flow velocity at the pipeline section "i" calculated for the moment "n"
ε [-] - desired accuracy
$Const_1$ [Pa] - constant in equation (8)
$Const_2$ [s/kg] - constant in equation (8)
Q [W] - heat quantity
h [-] - relative movement (position) of valve set
h_{des} [-] design relative position of valve set
ζ_{des} [-] - design flow resistance coefficient
Δ [%] - relative error in mass flow rate
$\Delta_{0.8\ hdes}$ [%] - relative error in case of relative valve seat movement set to 80% of the design ones
$\Delta_{0.5\ hdes}$ [%] - relative error in case of relative valve seat movement set to 50% of the design ones
$\Delta_{0.2\ hdes}$ [%] - relative error in case of relative valve seat movement set to 20% of the design ones
m_{exact} [kg/s] - exact pump mass flow rate
c_p [kJ/kgK] - specific heat at constant pressure
t_{in} [K] - inlet temperature
t_{out} [K] - outlet temperature

Literature

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