The balance of gravitational effect and pressure loss in two-pipe heating systems

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Abstract: - The gravitational lift in two-pipe heating systems partly or totally compensates the pressure loss on the riser. The balance temperature informs us about the gravitational lift-to-pressure loss ratio. This balance temperature can be higher than the nominal return temperature in case of low outdoor temperatures and welded steel risers. As the gravitational effect is usually neglected during dimensioning, that is way the upper floors may be overheated and the room temperatures on the lower floors may be lower than the designed vaule. Thermostatic valves may worsen the situation even further.Thus, to clarify the details of this question, further investigations are needed.

Key-Words: two-pipe heating riser; gravitational effect; hydraulic balance;

1 Introduction

Vertical two-pipe pump-heating systems are usually dimensioned without the calculation of gravitational effect. The neglect of the gravitational effect can induce unexpected and disappointing heating problems first of all at the bottom radiator in case of a heating riser for several levels. According to some experimental results, the direction of the flow can turn back in the bottom radiator of the riser. The turn back of the flow causes inadequate temperature in the heated room.

We are investigating this question for years at the Budapest University of Technology and Economics Department of Building Service Engineering. The model treating the problem consists of node and loop equations. The mathematical equations were worked out by László Garbai Dr. [1],[2].

In this paper, we analyze one part of the problem: under what condition the gravitational effect is in balance with the pressure loss on the riser.

2 Problem Formulation

In Hungary from the sixties to the end of the eighties lot of flats were built using industrialised technology with the intention of social care for the inhabitants. The government's favored district heating was paid overhead; thus it was not an aim to measure the heat consumption in flats separately. The structure of heating systems was very simple. The radiators above each other in different flats were connected to one common riser; 3-6 radiators were connected to 2-4 risers in a flat. The block of flats consisted of 4, 10 or 11 floors for the sake of the building technology. Welded metal pipes were applied to build the heating system. Somewhere the diameter of the pipe was bigger than necessary from the hydraulic point of view due to construction. Manual radiator valves and return lockshields were installed in the heating systems. The systems were usually dimensioned without calculating the gravitational effect. It was thought that by neclecting this factor the dimensioning is pushed to an even safer level.

In case of such systems, compared to the calculated 20 °C the temperature of the rooms showed deviations. On the upper floor the temperature was between 26-27 °C, while at the ground floor the temperature was only between 16-17 °C. Because of the lack of suitable fittings and financial interest of the occupants at the upper floor the room temperatures were controlled by the opening and closing of windows. This resulted in significant waste of energy.

Different methods were used to solve the problem on the ground floor: by opening the return lockshields;

by increasing the mass flow on the riser, by changing the radiator; etc.

The pressure ratio may further worsen if the building is renewed. An aim of the building renewal is the reduction of heat loss thanks to the improvement of the heat insulation and the exchange of windows. Another goal is to create the conditions for local temperature control and measuring of the heat consumption. This can be accomplished by the installation of thermostatic valves and heat cost allocators. Usually the pipes that are in a good condition are not changed.

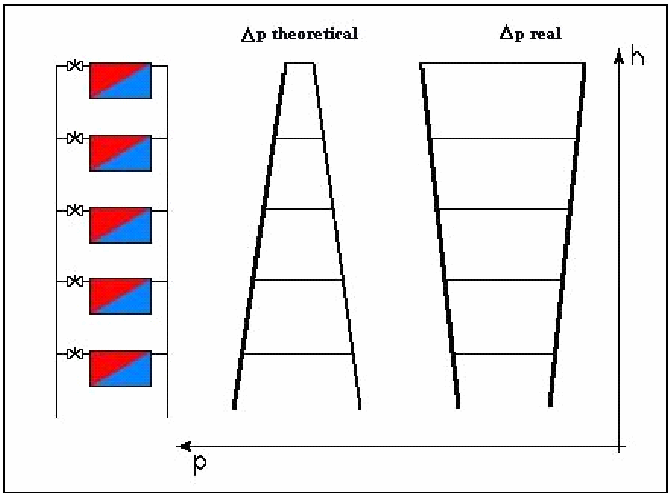

Fig.1 Theoretical and real pressure difference on the riser

Computer simulations, not detailed here, verify that the gravitational effect causes the earlier mentioned consequences in those heating systems where the system is dimensioned and balanced disregarding the gravitational effect.

Because of oversized pipes, the pressure loss on some pipe sections is less than the gravitational lift on the same section. Up the riser the pressure of the radiators increases, eventhough decreasing pressure difference was assumed during balancing. (Fig.1, schematic diagram)

All this causes that the mass flow of the upper radiators is significantly bigger, and the mass flow of the bottom radiator is less than the designed value. In renewed systems the gravitational lift can increase due to reduced mass flow and bigger fall in temperature.
The heating systems is particularly unfavorable, if the main heating pipe is under the ceiling of the bottom level and the radiator is under the main pipe. (Fig.2.)

It is important from the problem's point of view to know, under what conditions the gravitational lift is in balance with the pressure loss on the riser. It can give grounds for heating complaint, if the gravitational lift is smaller than the pressure loss. The knowledge of gravitational lift -to- pressure loss ratio may help to estimate the probability of heating complaints.

Based on the balance conditions, several conclusions can be deducted regarding the evolution of the effect.

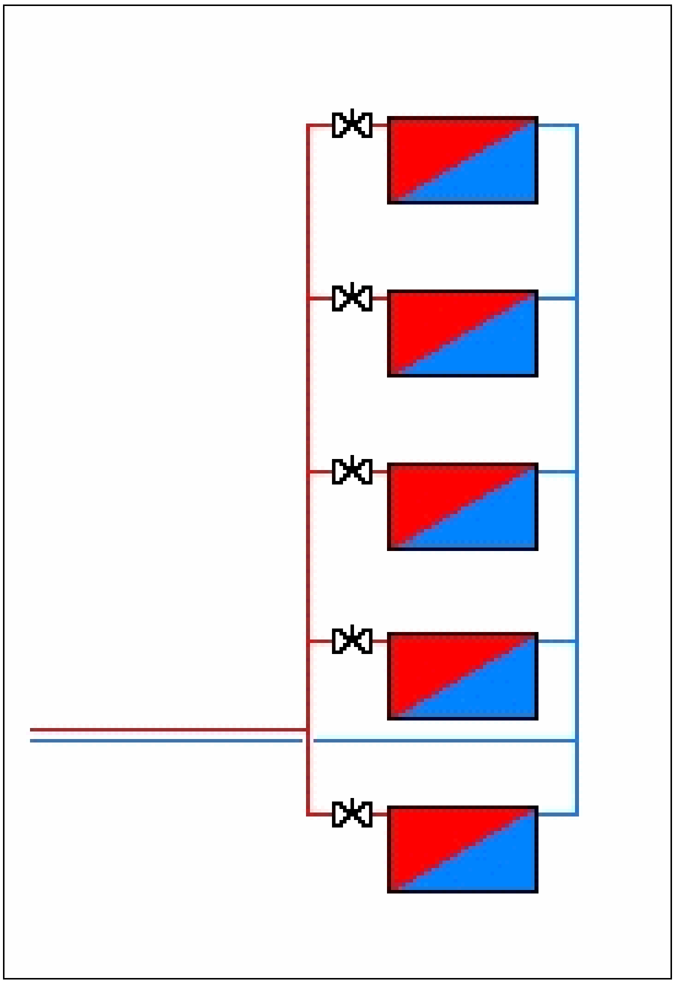

Fig. 2 The bottom radiator is under the main pipe

The pressure loss of the forward and return pipe section between two radiators that are "h" distance away above each other is:

$$\Delta p' = \Delta p'_f + \Delta p'_r \qquad (1)$$

$$\Delta p' = \frac{\rho_f}{2} w_f^2 (\lambda_f \frac{h}{d} + \zeta_f) + \frac{\rho_r}{2} w_r^2 (\lambda_r \frac{h}{d} + \zeta_r) \qquad (2)$$

In case the gravitational lift is in balance with the pressure loss:

$$\Delta p' = gh(\rho_r - \rho_f) \qquad (3)$$

The mass flow is to be substituted with the following expression:

$$w = \frac{\dot{m}}{\rho A} = \frac{4\dot{m}}{\rho d^2 \pi}, \qquad w^2 = \frac{16\dot{m}^2}{\rho^2 d^4 \pi^2} \tag{4}$$

The equation:

$$\frac{8\dot{m}^2}{g d^5 \pi^2}\left(\frac{\lambda_f}{\rho_f} + \frac{d\zeta_f}{h\rho_f} + \frac{\lambda_r}{\rho_r} + \frac{d\zeta_r}{h\rho_r}\right) = \rho_r - \rho_f \tag{5}$$

Substituting the heat flow on the riser:

$$\dot{m} = \frac{\dot{Q}}{c(t_f - t_r)} \tag{6}$$

Substituting to the expression:

$$\frac{8\dot{Q}^2}{g d^5 \pi^2 c^2}\frac{1}{(t_f - t_r)^2}\left(\frac{\lambda_f}{\rho_f} + \frac{d\zeta_f}{h\rho_f} + \frac{\lambda_r}{\rho_r} + \frac{d\zeta_r}{h\rho_r}\right) = \rho_r - \rho_f \tag{7}$$

The aim is to determine the return temperature, where the balance takes place. Substitute x as the searched return temperature:

$$\frac{K\dot{Q}^2}{(t_f - x)^2}\left(\frac{\lambda_f}{\rho_f} + \frac{d\zeta_f}{h\rho_f} + \frac{\lambda_r(x)}{\rho_r(x)} + \frac{d\zeta_r}{h\rho_r(x)}\right) = \rho_r(x) - \rho_f \tag{8}$$

3 Problem Solution

The λ coefficient of flow resistance due to friction is determined with the Colebrook-White relationship. The value of ζ can be determined using the Impulse Theorem. The constants are combined in the K value. The temperature-dependence of the coefficient of specific heat is neglected because it is small. The temperature-dependence of density is approximated with a second degree polynomial function. By substituting the functions in equation (8), an equation of the sixth degree has to be solved. However, the temperature dependence of flow resistance coefficient $(\lambda = \lambda(\dot{m}(x))$ causes further difficulties. Results are shown in Fig.3 for a particular case when a 1” riser is installed between the bottom radiator and the one above it.

In Fig.3, the correlation of the calculated $x = t_r$ balance temperature, to the nominal return temperature for a given forward temperature is shown as a function of heat demand. In Fig.4, the required nominal forward and return temperatures are indicated as a function of outdoor temperature in case of constant mass flow.

The temperature difference, between the calculated balance temperature and nominal return temperature is represented on the vertical axis in Fig.3. In the positive range, the calculated balance temperature is bigger than the nominal return temperature. So the nominal return temperature is lower than the balance temperature, thus the increasing pressure difference going up on the riser developes at nominal temperature, which is quite the opposite of the design condition.

In addition, it is demonstrated in Fig.3 which nominal return temperatures belong to which heat demand. From this it can be shown that the balance temperature is bigger in case of a forward temperature over about 70 ºC than the return temperature, according to Fig.4 In case of lower forward temperature the balance temperature is lower than the nominal return temperature.

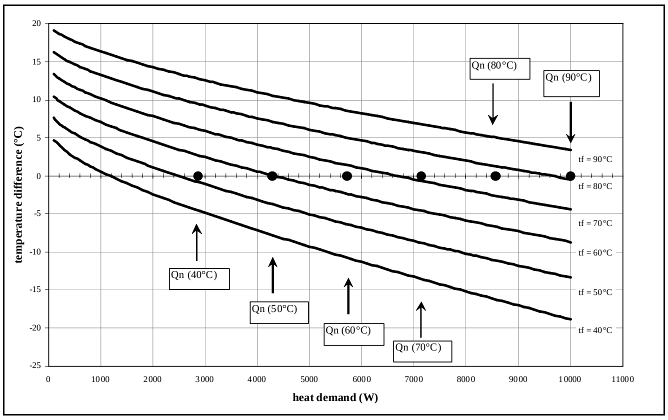

Fig.3 Temperature difference between the calculated balance temperature and nominal return temperature; 1” riser; between the bottom radiator and the one above it

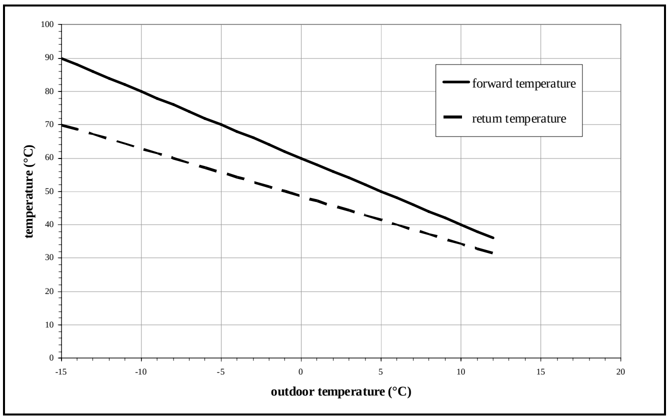

Fig.4 Nominal forward and return temperature as function of outdoor temperature

If the size of the riser is one size bigger, the pressure ratio is even more unfavorable: in case of 50ºC forward temperature the balance temperature is already bigger than the nominal return temperature (Fig.5).

In case of thermostatic valves the situation worsens even more. The thermostatic valve uses the interior heat gain in the heated room. Reduction of the heat demand in the heating system reduces the mass flow and return temperature. In case of a lower heat demand the balance temperature is higher (Fig.3); at the same time the decreasing mass flow results in decreasing return temperature. When using thermostatic valves it is expected that the gravitational lift increases and that the conditions for the unfavorably situated radiators also grow bad even further.

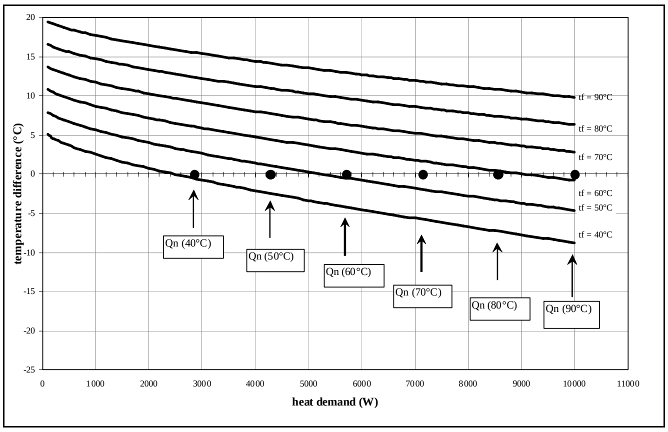

Fig.5 Balance temperature difference, 5/4" riser

The results verify the practical experience that doing away with the balance of the radiators – which of course takes place without taking into account the gravitational effect - does not cause considerable heating problems. Complaints are expected just after the precise balancing. At the same time complaints are not expected if the mass flow of the radiators is oversized, because it increases the return temperature.

Further investigations are needed to work out what kind of balance strategy must be followed to adjust the required mass flows on radiators. If the balancing values are determined with the calculation of gravitational lift in case of nominal outdoor temperature, the ratio of the mass flows between the radiators changes for other outdoor temperature and heat demand. The situation is more difficult if thermostatic valves are installed. In this case the changes of interior heat flows influence the balance over the outdoor temperature.

4 Conclusion

The gravitational lift in two-pipe heating systems partly or totally compensates the pressure loss on the riser. The balance temperature informs us about the gravitational lift-to-pressure loss ratio. This balance temperature can be higher than the nominal return temperature in case of low outdoor temperatures and welded steel risers. As the gravitational effect is usually neglected during dimensioning, that is way the upper floors may be overheated and the room temperatures on the lower floors may be lower than the designed vaule. Thermostatic valves may worsen the situation even further.Thus, to clarify the details of this question further investigations are needed.

Symbols:

$\Delta p'_r$	pressure loss
ρ	density
w	velocity
λ	coefficient of flow resistance due to friction
ζ	drag coefficient
g	acceleration due to gravtity
h	height between floors
$\dot{m}$	mass flow
d	pipe diameter
A	pipe cross-section
$\dot{Q}$	heat flow
t	temperature

in the indices:

f	forward
r	return

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