

## THE HEAT CARRIER FLOW CONTROL IN HEAT TRANSPORT SYSTEMS

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The problem of flow control of the heat carrier with a significant reduction of its temperature is studied. Several solutions to this problem are found taking into account the required amount of heat to the consumer. In this case, the heating supply object seems to be an equivalent heating device. An acceptable range of temperature reduction in the heat supply pipe is found in which the problem of 100 % heat supply can be solved by increasing the flow of the heat carrier. It has been shown that this range can be significantly extended if there can be some decline in the quality of the heating supply – delivered volume of heat. The results can be used in the development of low-temperature heating modes – graphs of quantitative regulation of the heating supply.

*Keywords: low-temperature heating, flow control of the heat carrier, equivalent heater, acceptable range of temperature decrease, quantitative regulation of heating load.*

### Introduction

It is known that power supplying organizations often significantly reduce the heat carrier temperature in flow pipes of heating networks, which results in breaking schedules of qualitative regulation of the heat supply [1], these organizations require 100 % payment of heating supply services from consumers who do not have heat meters. The latter is explained by the fact that the required amount of heat is supposedly delivered by means of “consumption”, however, as a rule, it is not explained how this problem can be solved. Moreover, giving the same reasons, these organizations ignore the complaints from all categories of consumers concerning the decline in the quality of heating services and hot water supply. Along with this, there is a very important question of how to change the heat carrier flow with its temperature being reduced greatly for the heating supply problem to be solved properly with the help of the available equipment.

### The first solution of the problem

Suppose there is a need to calculate such heat carrier flow with which the delivered flow of heat (the volume of heat transported through the cross-section of the heat pipe per unit time) will be the same with the temperature of the heat carrier  $t$ , as well as with its own temperature  $(t + \Delta t)$ . Obviously, there must be the ratio:

$$Gt = (G + \Delta G)(t + \Delta t), \quad (1)$$

where  $G$  – mass flow of the heat carrier,  $\Delta G$  – its increment.

That is why a new flow must be calculated according to the formula

$$G + \Delta G = \frac{Gt}{t + \Delta t} = G \frac{1}{1 + \Delta t/t}. \quad (2)$$

In this case, one can see that the relative change in the flow  $\Delta G/G$  and relative change in the temperature of the heat carrier which determines the flow  $\Delta t/t$  will be connected with the ratio

$$\frac{\Delta G}{G} = - \frac{\Delta t/t}{1 + \Delta t/t}. \quad (3)$$

In this case, it is understandable, that the limited value  $\Delta t/t$  equals  $-1$ , this is when the temperature of the heat carrier will be decreased by  $0^\circ\text{C}$  and  $\Delta t = -t$ . That is why the next limit will be equal to  $\lim_{\Delta t/t \rightarrow -1} (\Delta G/G) = \infty$ , i.e., the heat carrier flow must be increased to  $\infty$ . In Fig. 1 there is a dependency graph (3) in percentage terms.

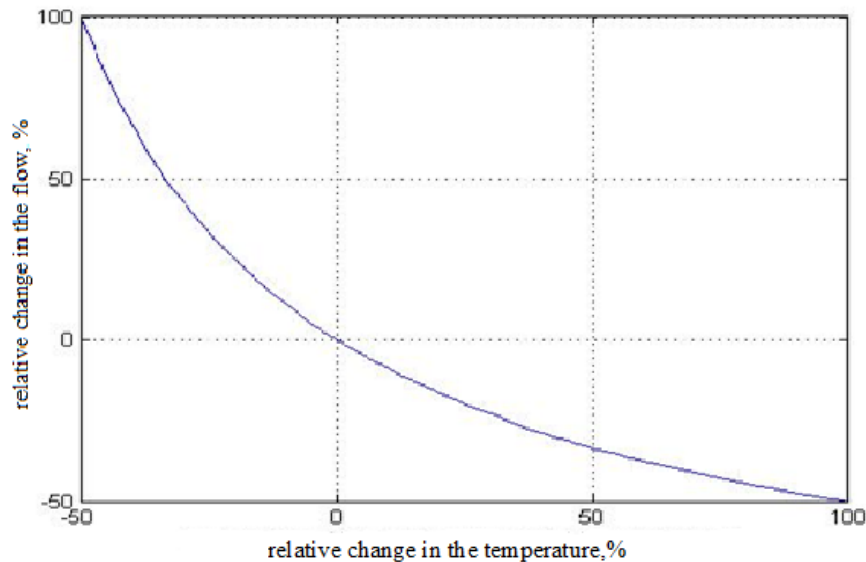


Fig. 1. The dependence of the relative change in the heat carrier flow on the relative change in its temperature

Fig. 1 shows that with the temperature increase in the heat carrier its flow should be reduced, in particular, with a 100% increase – to 50%.

It should be taken into consideration that the new flow  $(G + \Delta G)$  normally is a function of the outdoor air temperature  $t_o$ , because the temperature of the heat carrier  $t$  in the formula (2) depends on  $t_o$ , i.e., the numerical value  $t$  is calculated by means of temperature graphs of the heat supply [1–3]. That is why in general with different  $t_o$  the flow increment is necessary  $\Delta G$ . Only if  $\Delta t/t = \text{const}$  in all the range of an outdoor temperature change, then  $\Delta G = \text{const}$ , if, of course, a qualitative regulation of heat flows was used in the first place.

### The second solution of the problem

The first solution of the problem does not take into account the actual limitations on the temperature of the return water; a freezing condition of the heat carrier in the heat pipe is not allowed. Thus, we are going to solve this problem, but on condition, that the temperature of the return water  $t_{RET} = \text{const}$  with any heat supply mode. In this case, there must be the following ratio:

$$G(t - t_{RET}) = (G + \Delta G)(t + \Delta t - t_{RET}). \quad (4)$$

In this regard, the new flow should be calculated according to the formula

$$G + \Delta G = G \frac{1 - t_{RET}/t}{1 + \Delta t/t - t_{RET}/t}. \quad (5)$$

It is easy to notice, that with the low-temperature heating there is  $t_{RET} - t \leq \Delta t \leq 0$ , that is why the limit value  $\Delta t$  equals  $(t_{RET} - t)$ . Thus, the formula (5) shows that  $\Delta t \rightarrow (t_{RET} - t)$   $(G + \Delta G) \rightarrow \infty$ , which agrees with simple physical considerations.

According to (5), the formula for relative flow changes  $\Delta G/G$  will be following

$$\frac{\Delta G}{G} = \frac{-\Delta t/t}{1 + \Delta t/t - t_{RET}/t}. \quad (6)$$

This dependency graph for  $t = 150\text{ }^{\circ}\text{C}$  and  $t_{RET} = 30\text{ }^{\circ}\text{C}$  is in Fig. 2.

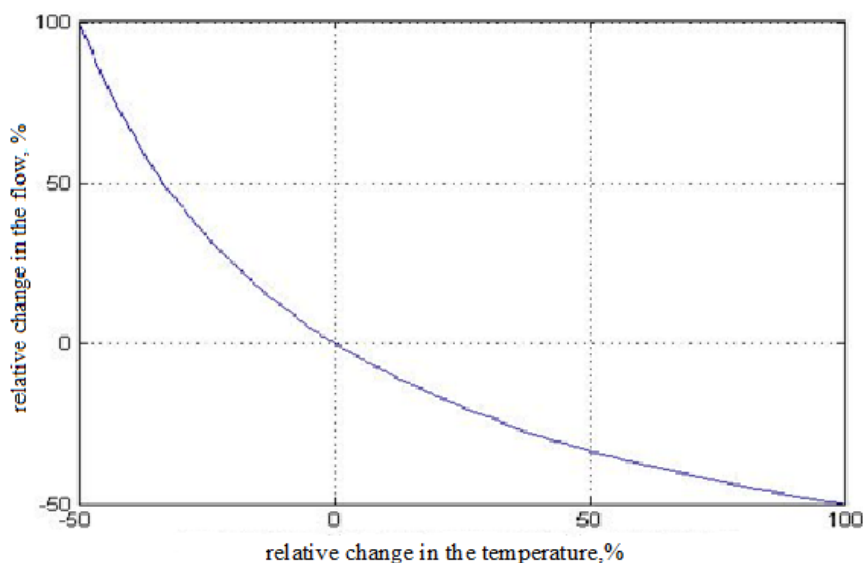


Fig. 2. The dependence of relative flow changes of the heat carrier on relative changes in its temperature at a constant temperature of the return water

Fig. 1, 2 show that under equal conditions the restriction on the temperature of the return water leads to the necessity of increasing the heat carrier flow by a greater amount compared to when there are no such restrictions.

### The third solution of the problem

In fact, during the flow control, it is important for the heat-transfer equipment of the consumer to “get” a necessary amount of warmth from the heat carrier. Therefore, we consider the solution of the problem of heat carrier flow control in these conditions; and the heat-transfer equipment of the consumer, as it has already been tested, will be an equivalent heating device [1–4].

That is why we are going to find the new flow  $(G+\Delta G)$  for the new heat carrier temperature  $(t+\Delta t)$  on the basis of the ratio [5–8]:

$$\frac{kF(t-t_I)}{1+kF/(2cG)} = \frac{kF(t+\Delta t-t_I)}{1+kF/[2c(G+\Delta G)]}, \quad (7)$$

where  $kF$  – the product of the heat-transfer coefficient in the area of the heat-transfer surface of the equivalent heating device [5–8],  $c$  – the specific heat capacity of the heat carrier,  $t_I$  – the internal air temperature of a heat supply facility.

The ratio (7) states the fact, that the heat-transfer of the equivalent heating device should be the same with the former heat carrier flow and its temperature as well as with the new heat carrier flow and its new temperature. Having done some transformations, we will get that

$$G+\Delta G = \frac{kF(t-t_I)}{2c\Delta t + kF(t+\Delta t-t_I)/G}. \quad (8)$$

The formula for a relative flow change  $\Delta G/G$  will be the following

$$\frac{\Delta G}{G} = \frac{-\Delta t/t - (kF)/(2cG) \cdot \Delta t/t}{\Delta t/t + (kF)/(2cG) \cdot (1+\Delta t/t-t_I/t)}. \quad (9)$$

The formula (8) shows what the new heat carrier flow should be  $(G+\Delta G)$  when the temperature decreases  $t$  to the value  $\Delta t$ .

According to the condition of physical realization in the ratio (7), there must be  $\Delta G > 0$  with low-

temperature heat supply  $\Delta t < 0$ . The numerator of the formula (9) is a positive value; therefore, its denominator must also be a positive value that means that there must be

$$\Delta t/t + (kF)/(2cG) \cdot (1 + \Delta t/t - t_I/t) > 0. \tag{10}$$

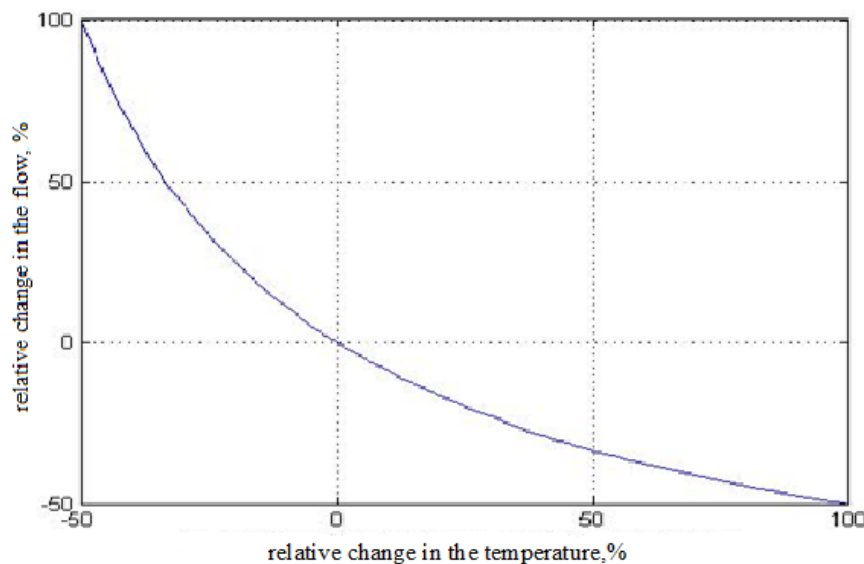
This implies that with the low-temperature heat supply the value  $\Delta t$  must correspond to the inequality:

$$\Delta t > -\frac{t - t_I}{1 + (2cG)/(kF)}. \tag{11}$$

Thus, it is possible “to take” the necessary amount of warmth from the heat carrier only in case of the inequality (11). If  $\Delta t$  will be equal to the value on the right side of the inequality (11), then the function (9) will have a break of 2-nd type, because  $\Delta G/G \rightarrow \infty$  when  $\Delta t \rightarrow -\frac{t - t_I}{1 + (2cG)/(kF)} + 0$ .

To the left of the breakpoint, the formulas (8) and (9) according to the condition of physical realization cannot be used.

In Fig. 3 there is a dependency graph (9) for  $t = 150^\circ\text{C}$ ,  $t_I = 18^\circ\text{C}$  and  $(kF)/(2cG) = 0.1938$ . In this case, there must be  $\Delta t > -21.43^\circ\text{C}$ .



**Fig. 3. The dependence of a relative change in the heat carrier flow on a relative change of its temperature taking into account characteristics of consumer's heat-transfer equipment**

As one can see in Fig. 3 the decrease in temperature of the heat carrier in this case requires a quite significant increase in its flow, for example, decreasing the temperature only by  $10^\circ\text{C}$  the heat carrier flow must be increased more than by 87%. Only, in this case, the consumer with the heat-recovery equipment will get the necessary amount of warmth.

If we denote the temperature of the return water for the first mode of heating supply as  $t_{RET1}$ , and for the second mode as  $t_{RET2}$ , then it is easy to understand that there must be the following ratio:

$$G(t - t_{RET1}) = (G + \Delta G)(t + \Delta t - t_{RET2}). \tag{12}$$

From this formula, it follows that

$$t + \Delta t - t_{RET2} = \frac{G}{G + \Delta G}(t - t_{RET1}). \tag{13}$$

With low-temperature heating supply there is  $G/(G + \Delta G) \leq 1$ , then it turns out that  $(t + \Delta t - t_{RET2}) \leq (t - t_{RET1})$ , i.e., the flow increase leads to temperature difference being reduced between the direct and return water.

From the formula (12), it follows that

$$t_{RET2} = (t + \Delta t) - \frac{G}{G + \Delta G} (t - t_{RET1}). \quad (14)$$

That is why

$$t_{RET1} - t_{RET2} = \frac{\Delta G}{G + \Delta G} (t_{RET1} - t) - \Delta t. \quad (15)$$

Since  $t_{RET1} - t < 0$  and  $\Delta t < 0$  with the low-temperature heating supply, thus, it means that  $(t_{RET1} - t_{RET2})$  which can be more or less than zero, i.e. the temperature of the return water in the second low-temperature mode can be higher or lower than the temperature of the return water in the first (basic) mode of the heating supply.

It is known that the capacity of the heat-transfer equipment (heat flow) of the client can be described with the help of the following formula [2, 3, 5]:

$$W_{CL} = \frac{kF(t_{RET1} - t_I)}{1 - kF/(2cG)} = \frac{kF(t_{RET2} - t_I)}{1 - kF/[2c(G + \Delta G)]}, \quad (16)$$

and it is also known, that in the operating range  $kF/(2cG) < 1$ , therefore, both denominators in the ratio (16) are positive, thus (taking into account that  $W_{CL} > 0$ ), in both modes  $t_{RET1} > t_I$  and  $t_{RET2} > t_I$ , which agrees with the simple physical reasoning, and therefore confirms the validity and the physical realization of the above-mentioned results.

### The fourth solution of the problem

The inequality (11) shows the limit value  $\Delta t$ , in which from the heat carrier with its flow one can “get” the right amount of warmth. This value is not big, for example, when  $t = 150^\circ\text{C}$ ,  $t_I = 18^\circ\text{C}$  and  $kF/(2cG) = 0.1938$  there must be  $\Delta t > -21.43^\circ\text{C}$ . The practice usually allows some reduction in consumption of heat and the consequent slight decrease in the temperature of the internal air. Therefore, we assume that with the low-temperature heating supply the consumed heat can be a certain proportion  $\varphi$  of the basic mode heat, it is clear, that  $0 \leq \varphi \leq 1$ .

So we are going to find the new flow  $(G + \Delta G)$  for the temperature of the heat carrier  $(t + \Delta t)$ , according to this ratio:

$$\varphi \frac{kF(t - t_I)}{1 + kF/(2cG)} = \frac{kF(t + \Delta t - t_I)}{1 + kF/[2c(G + \Delta G)]}. \quad (17)$$

Having done some transformations, we will get that

$$G + \Delta G = \frac{\varphi kF(t - t_I)}{2c[(1 + \frac{kF}{2cG})(t + \Delta t - t_I) - \varphi(t - t_I)]}. \quad (18)$$

So, the value  $\Delta t$  must satisfy the inequality:

$$\Delta t > -\frac{(t - t_I)[1 + 2cG/(kF)] \cdot (1 - \varphi)}{1 + 2cG/(kF)}. \quad (19)$$

Comparing the inequalities (11) and (19), we have come to the conclusion, that the limit value  $\Delta t$  became bigger, in particular, for  $t = 150^\circ\text{C}$ ,  $t_I = 18^\circ\text{C}$ ,  $kF/(2cG) = 0.1938$  and  $\varphi = 0.8$  must be  $\Delta t > -43.55^\circ\text{C}$ .

It is necessary to pay attention to the fact that solving this problem there was made the assumption – it is considered that some decrease in the temperature of the internal air with the low-temperature heating supply does not affect the result very much. In fact, it is unlikely that the value  $(t + \Delta t - t_I)$  will change greatly due to this (due to  $t_I$ ). Moreover, it is necessary to keep in mind that with the decrease  $t_I$  the actual value of the variable will be a little bit bigger than the value in the formula (17), that is why

the actual heat-transfer of a heating supply system will also be higher than it is supposed to be when solving a problem.

However, if one solves this task carefully, it turns out that the new reduced temperature of the internal air  $t_I^R$  can be calculated according to the equation

$$t_I^R = t_O + \varphi \frac{kF(t-t_I)}{1+kF/(2cG)} \frac{1}{q_V V}, \quad (20)$$

where  $t_O$  – the outdoor area temperature,  $q_V$  – the average specific heat characteristic of buildings of the area, and  $V$  – their total volume. The new flow should be calculated according to the equation

$$G + \Delta G = \frac{\varphi kF(t-t_I)}{2c[(1 + \frac{kF}{2cG})(t + \Delta t - t_O) - \varphi(t-t_I)(1 + \frac{kF}{q_V V})]}. \quad (21)$$

Thus, the acceptable range of the decrease in the temperature of the heat carrier, when the consumer can get the necessary amount of warmth according to the weather ( $t$  of the basic mode is a function of the temperature of the outdoor air  $t_O$ ), is very limited. If  $\Delta t$  decreases by a big value, then there is a decline in the quality of heating supply and only less amount of heat can be delivered to the consumer.

### Conclusion

There have been found four solutions to the problem that deals with the heat carrier flow control with its temperature being decreased in flow pipes. It has been concluded that the acceptable range of the decrease in the temperature of the heat carrier, when the consumer can get the necessary amount of warmth according to the weather, is very limited. If the temperature decreases by a big value, then there is a decline in the quality of the heating supply and only less amount of heat can be delivered to the consumer – a proportion of the basic mode heat.

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## УПРАВЛЕНИЕ РАСХОДОМ ТЕПЛОНОСИТЕЛЯ В ТЕПЛОТРАНСПОРТНЫХ СИСТЕМАХ

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Рассмотрена задача управления расходом теплоносителя при существенном снижении его температуры. Разработано несколько вариантов решения этой задачи, в том числе и при условии съема потребителем требуемого по погоде количества теплоты. При этом, как это и общепринято, объект теплоснабжения представляется эквивалентным отопительным прибором. Найден допустимый диапазон снижения температуры в подающем теплопроводе, при котором задача 100%-ного теплоснабжения еще может быть решена за счет увеличения расхода теплоносителя. Показано, что этот диапазон может быть заметно расширен, если допускается некоторое ухудшение качества теплоснабжения – количества доставляемой теплоты. Результаты работы могут быть использованы при разработке режимов низкотемпературного теплоснабжения – графиков количественного регулирования отпуска теплоты (тепловой нагрузки).

*Ключевые слова: низкотемпературное теплоснабжение, управление расходом теплоносителя, эквивалентный отопительный прибор, допустимый диапазон снижения температуры, количественное регулирование тепловой нагрузки.*

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