Optimization of the Heating System Operation

Wenzhong Xu Shuli Mao
Associate Professor Master
College of Civil Engineering and Architecture
Shandong University of Science and Technology
Qingdao Shandong China
wenzhong_xu70@yahoo.com.cn, 0532-86057593

Abstract: A new regulation method of the heating system is presented, which is based on the variation of outdoor temperature, to improve the economical efficiency and the timing regulation of the heating system. A function is put forward between the energy loss of the heating system, the temperature difference of supply-return water and the outdoor temperature by making use of the second law of thermodynamics and analyzing the energy loss in the operating process. By means of mathematical deduction, a function is also given between the temperature difference of the supply-return water and the outdoor temperature. With the function, the economical temperature difference of the supply- return water and the correlated parameters can be determined on the basis of the variation of outdoor temperature, and in this way, the heating system can be optimized.

Key words: variation of outdoor temperature， temperature difference of supply-return water， energy loss， optimized parameters

1. INTRODUCTION

The operational regulation of the heating system mainly includes the following methods: quality regulation, quantity regulation, intermittent regulation and quality regulation combined with altering flowrate by phases. With these methods, the economy of the heating system operation can be improved to different degrees, but due to the fact that the operational regulation of the heating system is not in step with outdoor temperature, a large quantity of energy is wasted all the same. So based on the variation of outdoor temperature, a new regulation method of the heating system is presented in the paper. The function between the optimized operating parameters of the system and the outdoor temperature is deduced by making use of the second law of thermodynamics and the correlative theory of *heat transfer* and *hydrodynamics*. With the function, the optimization of the operating parameters of the heating system can be realized according to the variation of outdoor temperature so as to achieve the economical operation.

2. OPTIMIZED FUNCTION AMONG THE OPERATING PARAMETERS OF THE HEATING SYSTEM

The operational regulation of the heating system based on the variation of the outdoor temperature is an operational regulation method in which the outdoor temperature is regarded as the input variable and the parameters such as the temperature difference of the supply- return water and the flowrate as the target variables. In order to deduce the function between the input variable and the target variable, the exergy loss of the system can serve as the intermediate target variable, and the function between the exergy loss of the system, the temperature difference of supply-return water and the outdoor temperature is firstly gained. Then, by mathematical deduction, the function between the input variable and the target variable is produced.

2.1 The Function between the Average Temperature of Supply-return Water and the Outdoor Temperature

To make the analysis of the question easy, the heat system is simplified as follows:

Suppose the outdoor temperature is indicated as t_w , the reduced area of the exterior-protected construction is F_1 (the heat consumption of the cold air by intruding and infiltrating are both regarded as the heat consumption of the exterior-protected construction), the heat transfer coefficient of the exterior-protected construction is K_1 and the indoor temperature is t_n, the total heat consumption of the system can be expressed as the function of the outdoor temperature.

$$Q = K_1 \cdot F_1 \cdot \Delta t_1 = K_1 \cdot F_1 \cdot (t_n - t_w) \qquad (1)$$

Suppose the heat transfer coefficient of the radiator is K_2 and the average temperature of the supply- return water in the radiator is t_p, K_2 can be denoted by the function of the heat transfer temperature difference.

$$K_2 = \alpha \cdot \Delta t_2^{\beta} = \alpha \cdot (t_p - t_n)^{\beta} \qquad (2)$$

In addition, the heat waste of the pipe system is ignored and the total heat is assumed to give out to the heating room through the radiator entirely.

Suppose the total heat transfer area of the radiator is F_2, then the total heat transfer to the heating room can also be expressed as:

$$Q = K_2 \cdot F_2 \cdot \Delta t_2 = \alpha \cdot (t_p - t_n)^{\beta} \cdot F_2 \cdot (t_p - t_n) \qquad (3)$$

To the system in use, F_1、F_2、K_1、t_n、α、β can all be regarded as constant. So according to equation (1) and equation (3), t_p can be expressed as follows:

$$t_p = \left(\frac{K_1 \cdot F_1 \cdot (t_n - t_w)}{\alpha \cdot F_2}\right)^{\frac{1}{1+\beta}} + t_n \qquad (4)$$

2.2 The Relation between the Exergy Loss and the Temperature Difference of the Supply-return Water

Based on the simplification and suppositions of heating system, the following two parts can show the exergy loss of the system: one is the exergy loss caused by the heat release of the radiator; the other is the exergy loss caused by the fluid resistance of the system. The two exergy losses both have direct relation to the temperature difference of the supply-return water. The bigger the temperature difference, the smaller the water flowrate and the fluid resistance, thus the smaller of the exergy loss caused by the resistance energy loss, but the bigger the exergy loss caused by the heat release of the radiator. On the contrary, if the temperature difference is smaller, the exergy loss caused by the fluid resistance will increase and the exergy loss caused by the heat release of the radiator will decrease. Therefore, in theory, there must be an optimal temperature difference to make the sum of two exergy losses least.

2.2.1 The Relation between the Exergy Loss Caused by the Heat Release of the Radiator and Temperature Difference of the Supply-return Water

Suppose the supply-return water temperature is Δt, the flowrate can be expressed as follows:

$$\bar{m} = \frac{Q}{c \cdot \Delta t} = \frac{K_1 \cdot F_1 \cdot (t_n - t_w)}{c \cdot \Delta t} \qquad (5)$$

The supply-water temperature and the return-water temperature of the heating system can be respectively denoted as follows:

$$t_g = t_p + \Delta t / 2 \qquad (6)$$

$$t_h = t_p - \Delta t / 2 \qquad (7)$$

The exergy loss caused by the heat transfer ΔE_t is the product of the surrounding temperature T_w and the system entropy generation ΔS_t.

$$\Delta E_t = T_w \cdot \Delta S_t = (273 + t_w) \cdot \Delta S_t \qquad (8)$$

Moreover, ΔS_t is the sum of the indoor air entropy increment ΔS_1 and the heat medium entropy increment ΔS_2.

$$\Delta S_t = \Delta S_1 + \Delta S_2 \quad (9)$$

$$\Delta S_1 = Q / T_n = K_1 \cdot F_1 \cdot (t_n - t_w) / (273 + t_n) \quad (10)$$

$$\Delta S_2 = \int_{T_g}^{T_h} \frac{m \cdot c \cdot dT}{T} = \frac{Q}{\Delta t} \ln(\frac{T_h}{T_g}) = \frac{K_1 \cdot F_1 \cdot (t_n - t_w)}{\Delta t} \ln(\frac{273 + t_p - \Delta t/2}{273 + t_p + \Delta t/2}) \quad (11)$$

In this way, the function between the exergy loss caused by the heat release of the radiator and the temperature difference of the supply-return water is presented as follows:

$$\Delta E_t = (273 + t_w) \cdot K_1 \cdot F_1 (t_n - t_w) \cdot \left[\frac{1}{(273 + t_n)} + \frac{1}{\Delta t} \ln\left(\frac{273 + t_p - \Delta t/2}{273 + t_p - \Delta t/2} \right) \right] \quad (12)$$

2.2.2 The function between the Exergy Loss Caused by the Fluid Resistance and the Supply-return Water Temperature Difference

When the system is operating in gear, the flow pattern of the fluid in the pipe is in the resistance square section and the resistance Δp is in the direct proportion to the square of the flowrate of the heating system. In order to simplify the calculation, the resistance of the heat medium in the radiator is ignored because its value is very small compared to the total resistance of the system. Suppose S_g as the total impedance of the pipeline of supplying heat medium and ρ_g as the fluid density in the pipe, the resistance of the pipeline can be expressed as follows:

$$\Delta p_g = S_g \cdot \bar{V}_g^{\,2} = \frac{S_g}{\rho_g^{\,2}} \cdot \bar{m}^2 \quad (13)$$

And the entropy increment caused by the fluid resistance in the supply-pipe is gained as follows:

$$\Delta S_{pg} = \frac{g \cdot \bar{m} \cdot \Delta p_g}{10000 \cdot T_g} = \frac{g \cdot S_g \cdot \bar{m}^3}{10000 \cdot (273 + t_g).\rho_g^{\,2}} \quad (14)$$

Similarly, the entropy increment caused by the fluid resistance in the return-pipe is gained as follows:

$$\Delta S_{ph} = \frac{g \cdot \bar{m} \cdot \Delta p_h}{10000 \cdot T_h} = \frac{g \cdot S_h \cdot \bar{m}^3}{10000 \cdot (273 + t_h).\rho_h^{\,2}} \quad (15)$$

Therefore, the total entropy increment caused by the fluid resistance of the heat medium can be expressed as:

$$\Delta S_p = \Delta S_{pg} + \Delta S_{ph} = \frac{g \cdot S_g \cdot \bar{m}^3}{10000 \cdot (273 + t_g).\rho_g^{\,2}} + \frac{g \cdot S_h \cdot \bar{m}^3}{10000 \cdot (273 + t_h).\rho_h^{\,2}} \quad (16)$$

Thus, the exergy loss caused by the fluid resistance is:

$$\Delta E_p = T_w \cdot \Delta S_p = (273 + t_w) \cdot \Delta S_p = [\frac{g \cdot S_g \cdot \bar{m}^3}{10000 \cdot (273 + t_g).\rho_g^{\,2}} + \frac{g \cdot S_h \cdot \bar{m}^3}{10000 \cdot (273 + t_h).\rho_h^{\,2}}] \cdot (273 + t_w) \quad (17)$$

Then, the function between the exergy loss caused by the fluid resistance and the supply-return water temperature difference can be expressed as:

$$\Delta E_p = [\frac{g \cdot S_g \cdot [K_1 \cdot F_1 \cdot (t_n - t_w)]^3}{10000 \cdot (273 + t_p + \Delta t/2).\rho_g^{\,2} \cdot (c \cdot \Delta t)^3} + \frac{g \cdot S_h \cdot [K_1 \cdot F_1 \cdot (t_n - t_w)]^3}{10000 \cdot (273 + t_p - \Delta t/2).\rho_h^{\,2} \cdot (c \cdot \Delta t)^3}] \cdot (273 + t_w) \quad (18)$$

2.2.3 The Function between the Total Exergy Loss of the System and the Temperature Difference of the Supply-return Water

After the analysis above, the function can be obtained between the total exergy loss of the system and the temperature difference of the supply-return water:

$$\Delta E=\Delta E_t+\Delta E_p=(273+t_w)\cdot K_1\cdot F_1\cdot(t_n-t_w)$$
$$\cdot\left[1/(273+t_n)+\frac{1}{\Delta t}\ln\left(\frac{273+\left(\frac{K_1\cdot F_1\cdot(t_n-t_w)}{\alpha\cdot F_2}\right)^{\frac{1}{1+\beta}}+t_n-\Delta t/2}{273+\left(\frac{K_1\cdot F_1\cdot(t_n-t_w)}{\alpha\cdot F_2}\right)^{\frac{1}{1+\beta}}+t_n+\Delta t/2}\right)\right]$$
$$+\left[\frac{g\cdot S_g\cdot[K_1\cdot F_1\cdot(t_n-t_w)]^3}{10000\cdot\left(273+\left(\frac{K_1\cdot F_1\cdot(t_n-t_w)}{\alpha\cdot F_2}\right)^{\frac{1}{1+\beta}}+t_n+\Delta t/2\right).\rho_g{}^2\cdot(c\cdot\Delta t)^3}\right.$$
$$\left.+\frac{g\cdot S_h\cdot[K_1\cdot F_1\cdot(t_n-t_w)]^3}{10000\cdot\left(273+\left(\frac{K_1\cdot F_1\cdot(t_n-t_w)}{\alpha\cdot F_2}\right)^{\frac{1}{1+\beta}}+t_n-\Delta t/2\right).\rho_h{}^2\cdot(c\cdot\Delta t)^3}\right]\cdot(273+t_w)$$

(19)

2.2.4 The Functional Relation between the Optimized Value of the Supply-return Water Temperature Difference and the Outdoor Temperature

In condition that F_1, F_2, t_n, K_1, S_g, S_h, α and β are all given, the function between the total exergy loss of the heat system ΔE, the temperature difference of the supply-return water Δt and the outdoor temperature t_w can be presented as follows:

$$\Delta E = f(\Delta t, t_w) \tag{20}$$

Based on the extremum theory of the advanced algebra and after the mathematics treatment to equation (20), the functional relation can be obtained between the temperature difference of supply-return water Δt and the outdoor temperature t_w under the minimum value of the total exergy loss of the system. The solving procedure is as follows:

Partial derivative is solved of the equation (20) and at the same time $\frac{\partial(\Delta E)}{\partial(\Delta t)}=0$ is requested.

$$\frac{\partial(\Delta E)}{\partial(\Delta t)}=0 \tag{21}$$

Where,

$$\frac{\partial(\Delta E)}{\partial(\Delta t)}=\frac{\partial(\Delta E_t)}{\partial(\Delta t)}+\frac{\partial(\Delta E_p)}{\partial(\Delta t)} \tag{22}$$

$$\frac{\partial(\Delta E_t)}{\partial(\Delta t)}=(273+t_w)K_1F_1\Delta t^{-2}\left[\begin{array}{l}-\dfrac{273+t_p}{(273+t_p+\Delta t/2)(273+t_p-\Delta t/2)}\\ -\ln\dfrac{273+t_p-\Delta t/2}{273+t_p+\Delta t/2}\end{array}\right] \tag{23}$$

$$\frac{\partial(\Delta E_P)}{\partial(\Delta t)}=(273+t_w)\left\{\begin{array}{l}\dfrac{gS_g[K_1F_1(t_n-t_w)]^3}{10^4\rho_g^2c^3}\dfrac{-[3(273+t_p)+2\Delta t]}{(273+t_p+\Delta t/2)^2\Delta t^4}\\ +\dfrac{gS_h[K_1F_1(t_n-t_w)]^3}{10^4\rho_h^2c^3}\dfrac{-[3(273+t_p)-2\Delta t]}{(273+t_p-\Delta t/2)^2\Delta t^4}\end{array}\right\} \tag{24}$$

Added the equation (23) and (24), the value equal to zero, so the function is like this:

$$F(\Delta t,t_w)=(273+t_w)K_1F_1\Delta t^{-2}\left[\begin{array}{l}-\dfrac{273+t_p}{(273+t_p+\Delta t/2)(273+t_p-\Delta t/2)}\\ -\ln\dfrac{273+t_p-\Delta t/2}{273+t_p-\Delta t/2}\end{array}\right]$$
$$+(273+t_w)\left\{\begin{array}{l}\dfrac{gS_g\left[K_1F_1(t_n-t_w)\right]^3}{10^4\rho_g^2c^3}\dfrac{-\left[3(273+t_p)+2\Delta t\right]}{(273+t_p+\Delta t/2)^2\Delta t^4}\\ +\dfrac{gS_h\left[K_1F_1(t_n-t_w)\right]^3}{10^4\rho_h^2c^3}\dfrac{-\left[3(273+t_p)+2\Delta t\right]}{(273+t_p-\Delta t/2)^2\Delta t^4}\end{array}\right\}=0 \tag{25}$$

The equation (25) can explain the functional relation between the optimized value of the supply-return water temperature difference Δt and the outdoor temperature t_w when the total exergy loss of the system is a minimum value. The curve corresponding to the function can be got with Matlab, by which the optimized temperature difference Δt is presented under a random t_w. In this way, a series of the parameter values of the heating system correlative to Δt can be obtained, such as circulation flowrate and the temperature of the supply-return water and so on. According to these parameters, the work condition can be regulated and the heating system can be operated economically.

3. CONCLUSION

A new regulation method of the heating system is presented, which is based on the variation of outdoor temperature, to improve the economical efficiency and the timing regulating of the heating system. A function is put forward between the exergy loss of the heating system, the temperature difference of supply-return water and outdoor temperature by making use of the second law of thermodynamics and analyzing the exergy loss in the operating process. By means of mathematical deduction, a function is also given between the temperature difference of the supply-return water and the outdoor temperature. With the function, the economical temperature difference of the supply-return water and the correlated parameters can be determined on the basis of the variation of outdoor temperature, and in this way, the heating system can be optimized.

Symbol:

T_p （t_p） :the average temperature of supply-return water, K（ ℃）;

T_w （t_w） : the outdoor temperature, K（℃）;

T_n （t_n） : the indoor temperature, K（℃）;

T_g （t_g） : temperature of the supply-water, K（℃）;

T_h （t_h） : temperature of the return-water, K（℃）;

Δt : temperature difference of the supply-return water, ℃;

Δt_1 : temperature difference of indoor and outdoor, ℃;

Δt_2 : temperature difference of the heat transfer of the radiator,℃;

α 、 β : The constant fixed on the radiator.

$\bar{V}$:the volume flowrate of the heat medium, m^3/s ;

$\bar{m}$:the mass flowrate of the heat medium, kg/s ;

ρ : water density under the average temperature of supply-return water, kg/m^3;

ρ_{h} :The water density under the return-water temperature, kg/m^3;

S_{h} : The total impedance of the pipe line of returning heat medium;

Δp : The fluid resistance of the heat system, Pa ;

REFERENCE:

[1] Wei-dao SHEN, Pei-zhi ZHEN. Engineering thermodynamics [M].Beijing: Higher Education Press, 1983.(In Chinese)

[2] Shi-ming YANG, Wen-quan TAO. Heat transfer [M]. Beijing: Higher Education Press, 1998(In Chinese)

[3] Zeng-ji CAI, Tian-yu LONG. Hydromechanics, pump and fan [M]. Beijing: China Architecture University, 2004. (In Chinese)

[4] Zhen-wei NI, Zhi-lin JIAO. The calculation of the entropy increment and the total entropy increment rate of the heat exchanger [J]. Journal of Engineering Thermophysics.1988, 9(1): 4-6. (In Chinese)

[5] Wen-zhong XU. The Monitor Parameter Optimization and the Object Function Research of the Heat Exchange System [D].Jinan: Shandong Industry Press, 1999. (In Chinese)