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MODELING OF THE PROCESS OF MICROCLIMATE FORMATION

Introduction

While operating the steam-supply systems, the main problem is regulation. Ineffective regulation causes significant heating energy losses due to steam losses. Along with this, the efficacy degree of steam supply system is reduced, the fuel consumption is increased, and the sanitary conditions in the buildings are worsened. Therefore, the development of new steam supply system regulation methods is a vital task.

Literature review

In steam supply systems with excessive steam pressure, quantity regulation due to changing steam consumption or discreet steam supply is used [1].

For this purpose centralized and local regulation is used. When using centralized regulation, the amount of steam is regulated in boiler facility or Thermal Power Plant, i.e. at the site of steam generation; when using local regulation – in the site of heat input or connection to heat-exchange unit [2].

Local regulation is performed manually with a globe valve or automatically by a thermostatic valve with a sensor. Manual regulation with the globe valve is quite inaccurate and incorrect, as the functional purpose of the globe valve is to open or close the steam flow. The use of thermostatic valve facilitates the regulation process, but at the same time it increases the cost of the heat supply system construction [3].

Main part

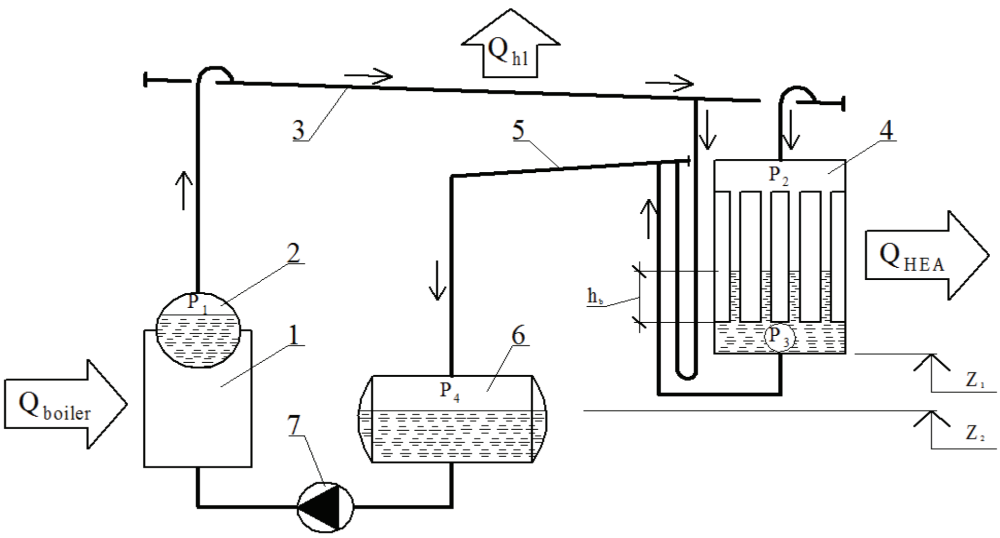

Figure 1. *Steam supply system layout: 1 – steam boiler, 2 – steam collector, 3 – steam line, 4 – steam consumer, 5 – condensing line, 6 – condensate reservoir, 7 – condensate pump, P_1-P_4 – pressure in the steam collector at the inlet and outlet of the heat exchanger, and in the condensate reservoir, respectively*

In order to develop the method of centralized regulation of steam consumption let us consider the layout of steam supply system consisting of a source (the steam boiler), a heat-exchange apparatus, a steam line for steam supply to the heating unit and a condensing line for draining condensate, which is presented in Figure 1.

Here is the equation of heat balance, which characterizes the work of steam supply system. All the heat produced in the steam boiler is expended on transferring the required heat to the heat exchanging apparatus (HEA) Q_{HEA} and heat losses in the steam supply network Q_{hl}, W:

$$Q_{boiler} = Q_{HEA} + Q_{hl} \tag{1}$$

The heat losses of the heat supply network equal to, W:

$$Q_{hl} = Q_{hl}^{steam} + Q_{hl}^{condens} \tag{2}$$

where: Q_{hl}^{steam} – is the heat loss of the steam line, W; $Q_{hl}^{condens}$ – is the heat loss of the condensing line, W.

The amount of heat produced in the steam boiler while fuel combustion equals to [4], W:

$$Q_{boiler} = B_e \cdot Q_{net} \cdot \eta_b \tag{3}$$

where: B_e – is the estimated consumption of fuel, nm^3/s; Q_{net} – is the net calorific value of fuel, kJ/nm^3; η_b – is the boiler efficiency.

The amount of heat consumed in the heat exchanger with partial flooding of condensate Q_{HEA}, W:

$$Q_{HEA} = G_s[r_2 + c(t_c^{''} - t_c^{'})] \tag{4}$$

where: G_s – is the steam loss in the heat exchanger, kg/s; r_2 – is the specific heat of phase transition at pressure P_2 before HEA, kJ/kg; c – is the heat capacity of condensate, kJ/(kg·°C); $t_c^{''}, t_c^{'}$ – is the temperature of condensate in the upper and the lower points of the flooding column, respectively, °C.

The heat losses of the steam lines of steam supply system [5], W:

$$Q_{hl}^{steam} = 5.82 d_o l_{sl} \tag{5}$$

where: d_o – is the outer diameter of the steam line, mm; l_{sl} – is the length of the steam line, m.

The heat losses of condensing lines when cooling the condensate are minimal; we neglect them in the first approximation.

Further analysis of the steam supply system work is performed for nominal mode with constant steam consumption $(G_s = \text{const})$, i.e. quality regulation mode. In this case the equation (1) looks as follows:

$$B_e \cdot Q_{net} \cdot \eta_b = G_s[r_2 + c(t_c^{''} - t_c^{'})] + 5.82 d_o l_{sl} \tag{6}$$

The right part of the equation (6) can be equated to:

$$G_s[r_2 + c(t_c^{''} - t_c^{'})] + 5.82 d_o l_{sl} = G_{boiler} r_1 \tag{7}$$

where: G_{boiler} – is the amount of steam produced by the boiler, kg/s; r_1 – is the specific heat of phase transition at pressure P_1 in the steam boiler, kJ/kg.

The right part of the equation (7) characterizes the amount of steam produced directly in the boiler. Taking into account the equation (3), the equation (7) looks as follows:

$$C_e \cdot Q_{net} \cdot \eta_b = G_{boiler} r_1 \tag{8}$$

In this case, the equation (8) contains two variables: the estimated consumption of fuel C_e and the specific heat of phase transition r_1 at pressure P_1 in the steam boiler.

The specific heat of phase transition r characterizes the kinetic energy necessary to turn 1 kg of liquid to saturated steam. Physical parameters that reveal kinetic energy of a substance in steam state are pressure, temperature and specific volume (density). Therefore, we can determine the dependence of phase transition specific heat, steam temperature and density on its pressure. All these dependences are known and their values are given in [6]. The known dependences are quite lengthy and inconvenient for calculations and studies.

Having analyzed the data, we obtained polynomial dependences (Fig. 2):

$$r = f(P) = 2207.44 - 0.213562P + 2.55426 \cdot 10^{-21} \cdot P^7 \tag{9}$$

where: P – is excessive water steam pressure, kPa; r – is specific heat of phase transition at pressure P, kJ/kg.

The dependence (9) was obtained for the range of pressure values from 0 kPa to 800 kPa with maximum relative error of 2.1%, which in absolute value of deviation is 48.06 kJ/kg; the minimum relative deviation is 0.07%, which in absolute value is 1.36 kJ/kg.

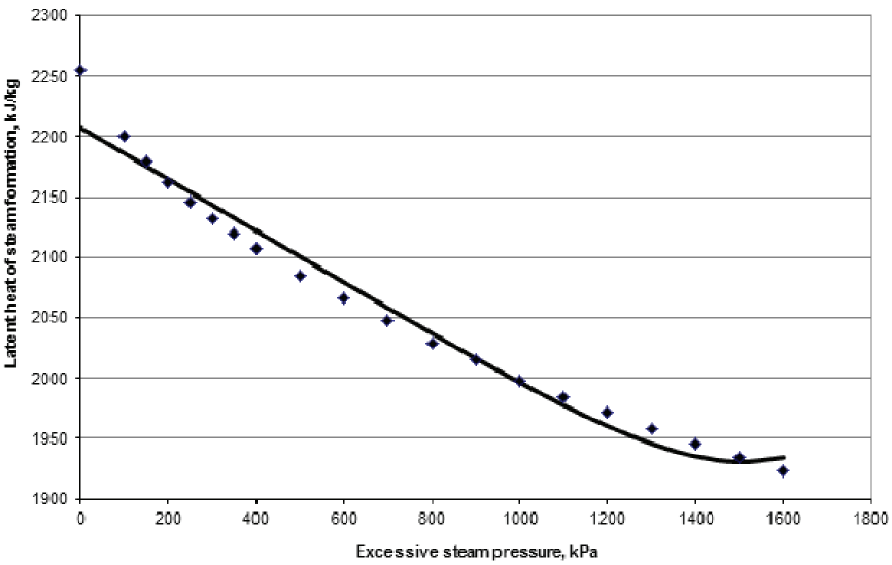

FIGURE 2. *Dependence of specific heat of phase transition on excessive pressure of water steam: line is polynom, squares are tabulated values*

That is the equation (8) when taking into account (9) will look as follows:

$$B_e \cdot Q_{net} \cdot \eta_b = G_{boiler}\left(2207.44 - 0.213562P_1 + 2.55426 \cdot 10^{-21} \cdot P_1^7\right) \tag{10}$$

The obtained equation (10) contains two variables: pressure in the boiler drum and gas consumption. To solve it, one more equation is necessary, it characterizes the hydraulic control of steam supply system, Pa:

$$\Delta P = P_1 - P_4 \tag{11}$$

where: P_1 – is pressure in the steam boiler, Pa; P_4 – is pressure in the condensate reservoir, Pa.

General losses of pressure in the system, Pa:

$$\Delta P = S_{sl}G_{boiler}^2 + S_{cl}G_{boiler}^2 + S_{HEA}G_{boiler}^2 - g\rho_c\left[h_c + (z_1 - z_2)\right] \quad (12)$$

where: S_{sl}, S_{cl}, S_{HEA} – are the characteristics of hydraulic resistance of the steam line, the condensing line and the heat exchanging apparatus (*HES*), respectively, Pa/(kg/s)²; ρ_c – is condensate density, kg/m³; z_1, z_2 – are height marks of HEA output and the condensate reservoir, respectively, m.

Taking into account the equation (11), the equation (12) will look as follows:

$$P_1 - P_4 = (S_{sl} + S_{cl})G_{boiler}^2 + S_{HEA}G_{steam}^2 - g\rho_c\left[h_c + (z_1 - z_2)\right] \quad (13)$$

The steam losses in heat exchanger can be presented as follows:

$$G_s = \frac{G_s^{boiler} r_1 - 5.82 d_o l_{sl}}{r_2 + c(t_c^{''} - t_c^{'})} \quad (14)$$

To determine the heat of phase transition in the heat exchanger, it's necessary to know the steam pressure before the heat exchanger P_2, that is

$$P_2 = P_1 - S_s G_{boiler}^2 \quad (15)$$

Simultaneous solution of equations (13), (14), (15), taking into account (19), permits us determine the necessary steam pressure in the steam boiler:

$$\begin{cases} P_1 = (S_{sl} + S_{cl}) \cdot G_{boiler}^2 + S_{HEA} \cdot G_{steam}^2 - g \cdot \rho_c \cdot \left[h_c + (z_1 - z_2)\right] \\ G_s = \dfrac{G_s^{boiler} \cdot r_1 - 5.82 \cdot d_o \cdot l_{sl}}{r_2 + c \cdot (t_c^{''} - t_c^{'})} \\ P_2 = P_1 - S_s \cdot G_{boiler}^2 \\ r = f(P) = 2207.44 - 0.213562P + 2.55426 \cdot 10^{-21} \cdot P^7 \end{cases} \quad (16)$$

Having inserted equation (16) into the equation (10), we obtain:

$$\begin{cases} B_e \cdot Q_{net} \cdot \eta_b = G_{boiler}\left(2207.44 - 0.213562P_1 + 2.55426 \cdot 10^{-21} \cdot P_1^7\right) \\ P_1 = (S_{sl} + S_{cl})G_{boiler}^2 + S_{HEA}G_{steam}^2 - g\rho_c\left[h_c + (z_1 - z_2)\right] \\ G_s = \dfrac{G_s^{boiler} r_1 - 5.82 d_o l_{sl}}{r_2 + c(t_c^{''} - t_c^{'})} \\ P_2 = P_1 - S_s G_{boiler}^2 \\ r = f(P) = 2207.44 - 0.213562P + 2.55426 \cdot 10^{-21} \cdot P^7 \end{cases} \quad (17)$$

Taking into account that the obtained equations are quite lengthy, we simplify the physical picture by neglecting heat losses of the steam line. Then, the equation can be represented as follows

$$\Delta P = (S_{sl} + S_{cl} + S_{HEA})G_{boiler}^2 - g\rho_c\left[h_c + (z_1 - z_2)\right] \quad (18)$$

Let us denote the characteristics of system resistance S_{syst} as:

$$S_{syst} = S_{sl} + S_{cl} + S_{HEA} \quad (19)$$

Then

$$P_1 - P_4 = S_{syst} G_{boiler}^2 - g\rho_c \left[h_c + \left(z_1 - z_2 \right) \right] \quad (20)$$

Simultaneous solution of equations (20) and (10) permits us determine the dependence between fuel consumption in the steam boiler and pressure in it at a given level of flooding of condensate in the heat exchanging apparatus.

$$\begin{cases} B_e \cdot Q_{net} \cdot \eta_b = G_{boiler} \left(2207.44 - 0.213562 P_1 + 2.55426 \cdot 10^{-21} \cdot P_1^7 \right) \\ P_1 - P_4 = S_{syst} G_{boiler}^2 - g\rho_c \left[h_c + \left(z_1 - z_2 \right) \right] \end{cases} \quad (21)$$

Solution of equations (21) permits analytically describe the quality regulation of steam supply systems, which in future will help form the engineering recommendations.

Conclusions

The article contains the analysis of work of steam supply system from the point of view of centralized regulation at constant steam losses. A mathematical model of quality regulation has been suggested with and without taking into account steam line heat losses. The dependence of phase transition coefficient on excess steam pressure has been obtained.

The obtained model makes possible a more flexible and efficient regulation of steam supply system.

References

[1] Tsvetkov V.V., *Heat treatment of products at prefabricated reinforced concrete plants* / V.V. Tsvetkov, K.:Budivelnyk, 1978, 112 p.

[2] Krongauz S.D., *Heat treatment of products at prefabricated reinforced concrete plants* / S.D. Krongauz, M.: Stroyizdat, 1961, 267 p.

[3] Tsvetkov V.V., *Organization of steam supply at industrial enterprises* / V.V. Tsvetkov. – M.: Energia, 1980, 206 p.

[4] Sebastian T., *Boiler Calculations*/ T. Sebastian, A. Kulla. – Helsinki: Helsinki University of Technology, 2002, 16 p.

[5] Indoor sanitary ware. B 60 B 3 p. 4.1. Heating / V.N. Bogoslovskiy, B.A. Krupnov, A.N. Skanavi et al.; Ed. By I.G. Staroverova and Yu.I. Shiller. – 4th edition, revised and enlarged. – M.: Stroyizdat, 1990, 344 p: il/ - (Handboor of Design Engineer).

[6] Rivkin S.L., *Thermodynamic properties of water and steam: Reference book*. Recom. by State Service of standard reference data – 2nd edition, revised and enlarged/S.L. Rivkin, A.A. Aleksandrov – M.: Energoatomizdat, 1984, 80 p.