HEAT AND GAS SUPPLY, VENTILATION, AIR CONDITIONING, GAS SUPPLY AND ILLUMINATION

УДК 625.435.004

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MATHEMATICAL MODELING OF THERMOPHYSICAL PARAMETERS OF VORTEX HEAT EXCHANGER OF HEATING SYSTEMS OF GAS DISTRIBUTION POINTS PREMISES

The mathematical model of heat transfer in vortex heat exchanger using natural gas energy which is released under decompression in gas-main pipelines for consumers of gas supply systems (dwellings, public and industrial buildings).

Keywords: autonomous heat supply, regulation of gas pressure, heat exchange, mathematical modeling, natural gas, heat carrier.

Introduction

Energy efficiency enhancement of use of natural gas delivered to consumers from gas-main pipelines is one of the most important problems of energy saving in gas supply. Characteristic feature of design decision in the field of gas supply is multi-choice. Separate structural components, manufacturing schemes, facilities can be executed with different parameters: thermodynamic, aerodynamic, hydrodynamic, etc.

The task of technical and economic optimization is to determine the system parameters which require the least material, energy, and money to obtain the result.

Recently, gasification in Russian Federation has been performed at a quickened pace: more than 30.000 towns, settlements and villages have from 1 up to several tens of gas distribution points (GDP) located in heated premises.

Specificity of gas distribution points is conditioned first of all by explosion hazard under natural gas leak which leads to necessity of its placement in separate buildings with individual heating, i. e., with autonomous heat supply. Capacitive water heaters Automatic gas water heater have received wide acceptance as heat supply sources which provide obtaining of hot water of preset temperature and volume for heating system of GDP. But such heat exchanger requires gas flow for combustion in its firebox at water heating.

Therefore, reduction in energy inputs when delivering gas to consumers (dwellings, industrial and community enterprises) with further drop in pressure from high and mean values to low value in gas networks and gas distribution system is urgent.

Specificity of GDP operation is that pressure regulators work under high (from 3.5 and more) drop of inlet and outlet pressure [1].

The use of the energy of moving gas stream is possible when vortex tube is applied for partial reduction of excessive pressure. The aim of the researches is mathematical modeling of vortex heat exchanger with the use of unclaimed pressure drop which is regulated, for example, by pressure regulator РДУК-2В-50/35 with maintenance of gas temperature $T_{вх} = 100\ ^{o}C$ (at the inlet) and $T_{вых} = 70\ ^{o}C$ (at the outlet) for its further use as heat sources for heating system of GDP premise (Fig. 1).

The problem is formulated in the following way. Gas volume V is delivered in vortex heat exchanger (VHE) from external gas main through nozzle with twisted blades and section parameters d, P_{con} (Fig. 1), T_{con}, constant second charge G. Mass of VHE walls is m_c, heat capacity C_c, initial temperature T_c is equal to environment temperature T_o of the gas of heated premise.

It is required to determine G и T_{con}, providing given level of initial temperature $T^{г}_{вх}$, taking into account heat exchange $Q_н$ through the walls of VHE with air of heated premise.

Holding that VHE receives ideal gas, which obeys Clapeyron law, we set up the equation of system energy balance.

Excess internal energy from elementary mass $G \cdot d\,\tau$ is equal

$$(U_{con}\text{-}U)\ G \cdot d\,\tau. \qquad (1)$$

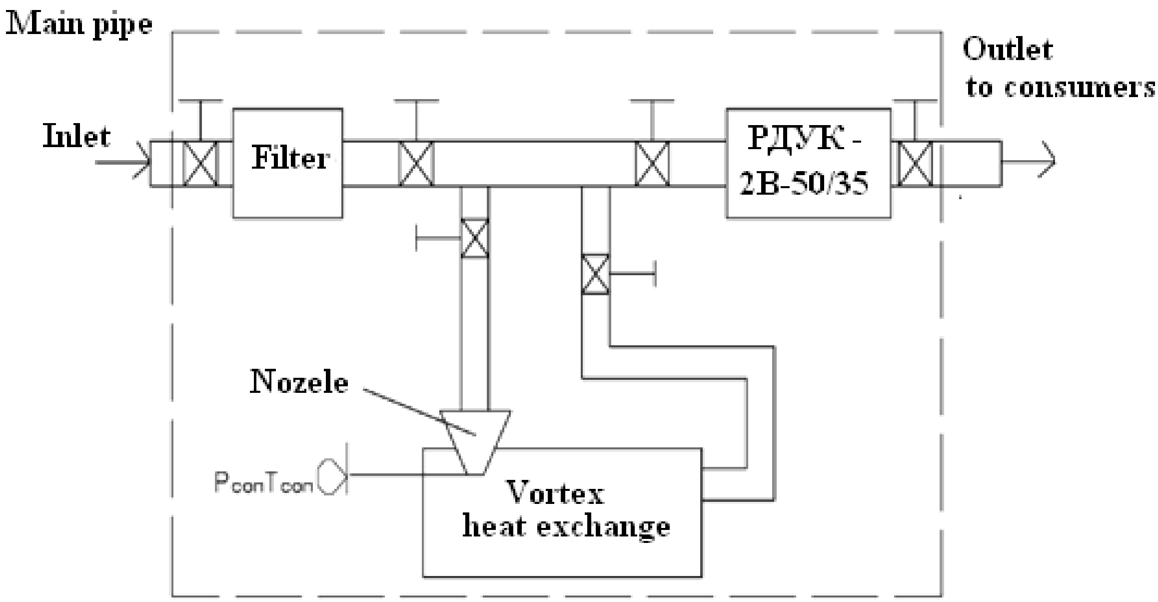

Fig. 1. Conceptual sketch of vortex heat exchanger attachment to gas-flow regulator in GDP

Elementary pushing work passed by ambient to the system equals to

$$P_{con}\vartheta_{con} \;\; G\cdot d\tau. \tag{2}$$

Increment of gas internal energy in VHE

$$G\cdot \;\tau\cdot dU. \tag{3}$$

We consider that coefficient of wall-to-gas heat-transfer is high; temperature of the wall T_c is close to current gas temperature T because of high rate of inflow and considerable rates of forced turbulent movement inside of VHE.

Elementary heat for walls equals to

$$m_c c_c \left(\frac{dT}{d\tau}\right) d\tau. \tag{4}$$

Thermal resistance can be neglected with the small thickness of the walls of VHE. Coefficient of the heat transfer is equated to coefficient of heat emission α. Then elementary heat transferred from gas to ambient through the walls of VHE with area F is determined as

$$\alpha F(T - T_o)d\tau. \tag{5}$$

Based on the law of conservation and summing (1), (2), (3), (4), (5), we obtain the equality which can be written after rearrangements as

$$(\mathrm{U}_{\text{соп}} + \mathrm{P}_{\text{соп}}\vartheta_{con})G \cdot d\tau - U \cdot G \cdot d\tau + G \cdot \tau \cdot dU + m_c c_c (\frac{dT}{d\tau})d\tau + \alpha F(T - T_o)d\tau = 0. \quad (6)$$

In equation (6) we substitute sum $(U_{con} + P_{con}\vartheta_{con})$ for $h_{con} = C_{pcon}T_{con}$, values $U = C_\vartheta T$ and $dU \cdot \frac{C_\vartheta dT}{d\tau}d\tau$, where C_ϑ is the process average isochoric heat capacity.

Then the equation (6) can be written as

$$\mathrm{Cp}_{\text{соп}}T_{con} \cdot G \cdot d\tau - C_\vartheta TGd\tau = \tau GC_\vartheta \frac{dT}{d\tau}d\tau + m_c c_c \frac{dT}{d\tau}d\tau + \alpha FTd\tau - \alpha FT_o d\tau. \quad (7)$$

Or
$$(C_\vartheta G + \alpha F)T \cdot dF + (C_\vartheta G\tau + m_c c_c)\frac{dT}{d\tau}d\tau = Cp_{\text{соп}} \cdot T_{\text{соп}} \cdot \mathrm{G} + \alpha FT_o d\tau .$$

After division of the equality by $(C_\vartheta G + \alpha F)d\tau$, we obtain

$$T + \varphi(\tau)\frac{dT}{d\tau} = A., \quad (8)$$

where
$$\varphi\left(\tau\right) = \frac{C\vartheta \cdot G\tau + m_c C_c}{C_\vartheta G + \alpha F} = a\tau + в . \quad (9)$$

Here
$$a = \frac{C_\vartheta \cdot G}{C_\vartheta \cdot G + \alpha F},\ в = \frac{m_c c_c}{c_\vartheta \cdot G + \alpha F}. \quad (10)$$

$$A = \frac{Cp_{con}T_{con} \cdot G + \alpha FT_o}{C_\vartheta \cdot G + \alpha F}. \quad (11)$$

Dividing right and left sides of the expression (8), that is the heterogeneous linear first-order differential equation by *φ(τ)* and solving for *T*, we obtain

$$T = exp(-\int_o^\tau \frac{d\tau}{\varphi(\tau)})\left[A\int_o^\tau \frac{\exp(\int_o^{\tau_o} \frac{d\tau}{\varphi(\tau)})}{\varphi(\tau)}d\tau + C \right]. \quad (12)$$

The solution of the equation (12) subject to (9), (10), (11) with determination of integration constant *C* from initial conditions allows to obtain dependence

$$T = A + (T_o + A)(\frac{в}{\varphi(\tau)})^{\frac{1}{a}}. \quad (13)$$

Or (in expanded form)

$$T = \frac{Cp_{con}T_{con}\cdot G + \alpha F T_o}{C_\vartheta \cdot G + \alpha F} + (T_o + \frac{Cp_{con}T_{con}\cdot G + \alpha F T_o}{C_\vartheta \cdot G + \alpha F})\cdot$$
$$\cdot(\frac{m_c c_c}{G_\vartheta G\cdot\tau + m_c c_c})^{\frac{C_\vartheta\cdot G + \alpha F}{C_\vartheta\cdot G}}. \qquad (14)$$

The equation (14) is plotted for different values of in *G* (in Fig. 2) and T_{con} (in Fig. 3), given m_c, c_c, α and *F* defined from known criterion relationship [2], [3] and heat exchange conditions. Plots show that efficiency of VHE work in the section of heat supply of GDP premises is considerably influenced by material heat capacity and heat exchanger mass.

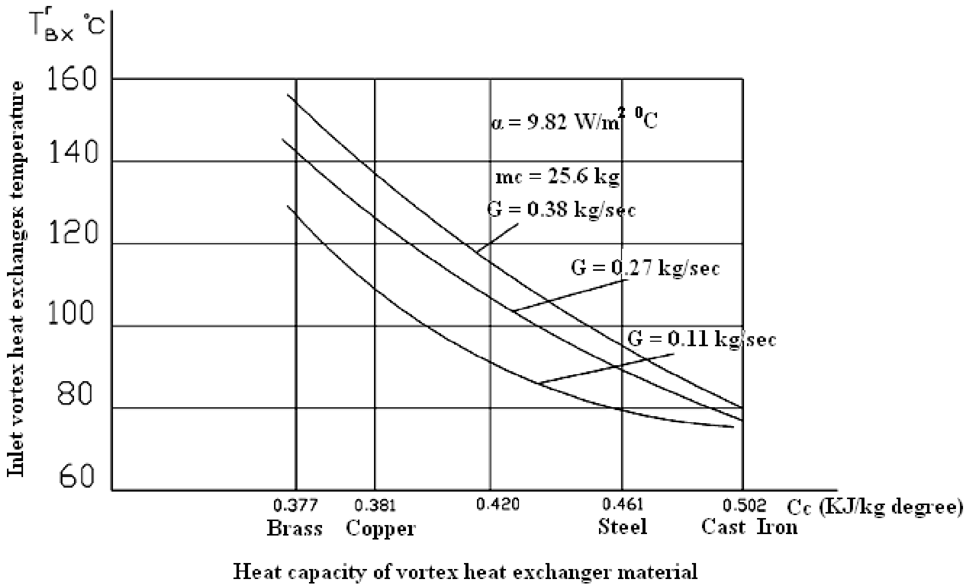

Fig. 2. Dependence of gas temperature change at the inlet of heat exchanger for standard gas-flow regulator in relation to the heat capacity of vortex heat exchanger material

The results of analytical calculation of heat engineering parameters of VHE based on developed mathematical model showed possibility of its application in the heating system of GDP premise. In this case unproductive discharge of natural gas for heating of water in heating system is nil; this is not only economy in energy sources but also maintenance of pollution-free zone in location of GDP premise. In addition, reduction in gas pressure at the outlet of discharge regulator, against its value decreased in gas pipeline ahead of filter at the cost of partial use to provide turbulence in VHE, is an aid to more reliable operation of GDP automatic assembly under long-term service.

In the case of thermodynamic state change of heat carrier with variable mass in VHE frame, i. e. its gas discharge change in time, pattern of its interaction with ambient differs from one in the nozzle by availability of heat-mass exchange division of vortex-like axial and peripheral flows. This fact allows identification of heat carrier state change as a whole and state change of heat carrier thermodynamic stratified flows. The solution of the problem is difficult enough and is not considered in present article.

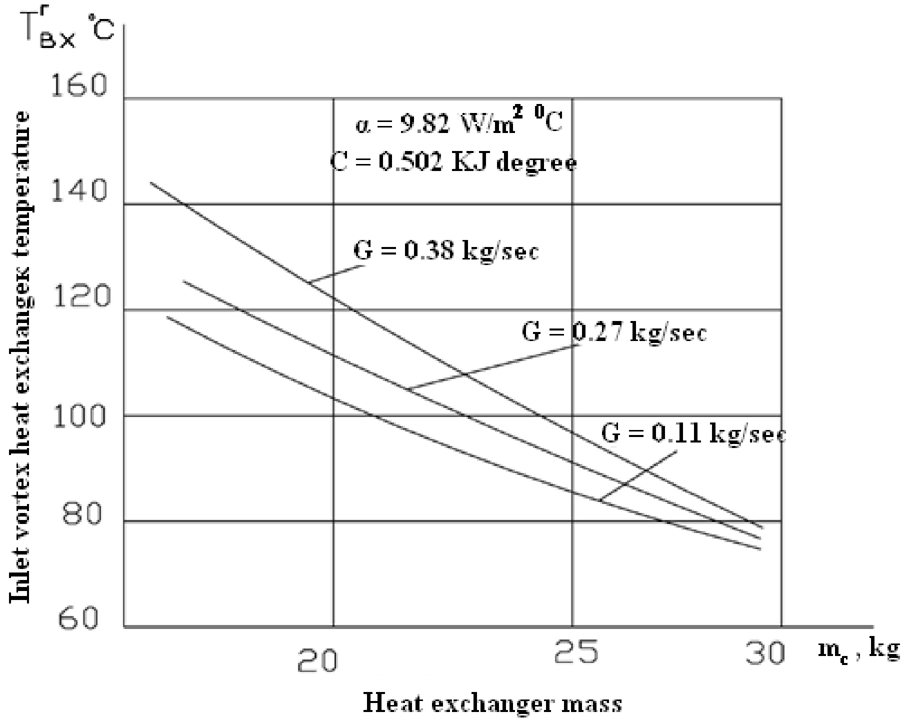

Fig. 3. Dependence of gas temperature change at the inlet of heat exchanger for standard gas-flow regulator in relation to the frame mass of BT

Conclusion

The mathematical model of heat exchange between swirling vortex-like flow of the heat carrier and air of heated premise showing applicability of the use of energy efficiency of air heater which uses natural gas flow movement energy as heat carrier is proposed as solution of the problem stated above.

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