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The technology of isothermal pressure regulation of natural gas based on temperature stratification

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Abstract

The paper introduces a new technology of isothermal pressure regulation of natural gas based on temperature stratification which combines the vortex effect temperature stratification and supersonic gas-dynamic temperature stratification. The authors simulate physical and numerical controllers work. As a result of the experiments the most effective operating principles of the isothermal controller (based on the vortex tube temperature stratification) are introduced. The paper also presents calculations of the described pressure regulation controller while applying gas-dynamic temperature stratification. The authors conclude that the usage of the introduced technology of isothermal pressure regulation of natural gas will reduce expenses of gas transportation systems for their own needs (by 0.08-0.2 % of natural gas to their carrying capacity).

Keywords: Gas; Pressure control; Isothermal regulator; Gas-dynamic temperature stratification; Vortex effect; Prototype; Investigation; Economy.

1. Introduction

Natural gas is transferred through gas main lines with 3-4 MPa pressure and even more. Pressure in a gas main line is determined by transportation distance according to technical and economical ground based on appropriate balance between flow efficiency of a gas pipe line and energy demands for transportation. As the main constituent of the gas natural price that is given to consumers is expense for gas transfer and gas pipe line system demands [1]

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these expenses should be reduced. Nowadays several directions on natural gas usage for gas pipeline system demands may be distinguished. The following issues are referred to gas pipeline system demands: gas consumption for gas compression; gas consumption for extra technological demands of compressing stations; technological gas losses; natural gas consumption for technological demands of line gas main lines as well as natural gas consumption for functioning gas distribution stations (GDS), for heating natural gas, for blowing elements of gas and transport systems, etc. It should be determined which decisions will let reduce natural gas consumption for gas and transport systems demands further on by means of carrying out new technological decisions.

Nomenclature

|   |   |
|---|---|
| 1 | compressor |
| 2 | faucet |
| 3 | reference pressure gauge |
| 4 | thermocouple |
| 5 | controller on the base of a vortex tube |
| 6 | body of a regulator |

Natural gas consumption for natural gas heating is connected with peculiarities of the technologies of pressure control in natural gas supply systems. A consumer uses natural gas of significantly less pressure than natural gas pressure transferred through main gas lines. According to these facts both single-stage and multi-stage pressure regulations are fulfilled [2].

Pressure reduction is implemented through several stages at gas distribution stations (GDS) and gas-adjusting stations (GAS). At gas distribution stations (GDS) natural gas pressure goes down till 0.3–1.2 MPa. Further pressure release is implemented at gas-adjusting stations (GAS). Reduction is carried out by valve controllers. Such controllers bring down natural gas pressure in the process of Joule–Thomson effect implementation with temperature release [3]. It has negative issues at exploitation: temperature release of natural gas, condensate and ice formation of pressure controllers, appearing fatigue stresses in structures of controllers and pipe lines, hydrate formation [4]. Preliminary (before reduction) gas heating is used for negative issues compensation of pressure valve controllers usage. For these needs 0.08…0.2 % natural gas from flow efficiency of a pipe line is spent [4,5]. The usage of pressure energy of a main gas line for electrical energy production with the help of turbo-expander installations is connected with significant natural gas consumption for preliminary heating [6]. In this case gas consumption goes significantly beyond natural gas needs at throttle control pressure. According to this fact, the works at implementation of technologies on isothermal controller pressure are significant. An elaboration of such a technology on the base of temperature stratification of natural gas may become one of the trends [7, 8, 9].

2. Technology of pressure control

It should be marked that technologies of natural gas reduction on the base of temperature stratification are divided into two types according to the principle of operation. Technologies using Ranque-Hilsch vortex effect for regulation may be referred to the first type [10, 11]. Ranque-Hilsch effect is represented by the process of temperature division of a swirling stream of high pressure gas into hot and refrigerated streams in the separation chamber. In the process of temperature division by implementing the Ranque-Hilsch effect the pressure of hot and refrigerated streams reduces. Temperature and pressure of received streams are determined by the vortex tube geometry where the process of division takes place and by the working conditions of a device.

The technology of the second type is based on the usage of the effect of supersonic gas-dynamic temperature stratification that was invented by Leontyev A.I. [12]. The process of temperature division takes place because of heat transfer through a thermally conductive border between gas streams with subsonic and supersonic speeds. This effect is implemented in a supersonic tube of temperature stratification. Effectiveness of temperature division is not so great and depends on the surface area of heat exchange between gas streams, pressure and a speed of a working material at the entrance to the device, characteristics of a heat transfer agent and other factors [13, 14]. A lot of scientific works try to solve the problem of increasing the effectiveness of a supersonic temperature stratification.
Constructive and regime methods of effectiveness increase can be distinguished as trends of temperature division intensification of temperature stratification in a supersonic tube. The methods elaborating the structure of Leontyev’s supersonic tube (presence of dimples, perforation holes, ribs, shock generators and other) are constructive methods. Regime methods influence characteristics of a working material with the aim of controlling the processes of temperature stratification (usage of hydrogenous and xenon, hydrogenous and argon, helium and xenon mixtures, dispersed flows). But gas pressure control systems impose limitations on the possibilities of using intensification methods of a temperature stratification process [18-21].

We will take into consideration structural features of the offered gas pressure controllers on the base of temperature stratification and the principle of their work.

The device for gas pressure reduction on the base of Ranque-Hilsch vortex tube is represented in fig. 1, a and the controller on the base of a supersonic tube of temperature stratification is represented in fig. 1, b.

Fig. 1. (a) a pressure controller on the base of a vortex tube; (b) a controller on the base of a supersonic tube of temperature stratification.

The work of a pressure controller on the base of a vortex tube is implemented in the following way. Natural gas of high pressure goes from main gas lines into a controller through a pup joint 1. Further on, natural gas goes into a vortex tube 2 placed in the body 6 of the controller. In the vortex tube 2 in the process of a vortex effect the gas is divided into a refrigerated stream 3 and a heating stream 4. The pressure of these streams will be lower than gas pressure at the entrance of the controller. These streams go into the body 6 of the controller from the vortex tube. Inside the body the streams of low pressure with different temperature mix. Gas of low pressure with almost the same temperature as at the entrance of the device goes from the device through a branch 5. The control of device work is carried out due to the change of usage of refrigerated and heating streams in a mixture created in the body of the device. Relative usage of the refrigerated stream $\mu$ is calculated in the following way:

$$\mu = \frac{G_{\text{cold}}}{G_{\text{in}}} \approx \frac{T_{\text{heat}} - T_{\text{in}}}{T_{\text{heat}} - T_{\text{cold}}}$$

where $G_{\text{cold}}$ – the usage of the refrigerated stream from the vortex tube which is the main element of the controller, kg/s; $G_{\text{in}}$ – the usage of the gas stream at the entrance of the controller; $T_{\text{in}}$ – gas temperature at the entrance of the device; $T_{\text{heat}}$ – the temperature of the heating gas stream from the vortex tube, K; $T_{\text{cold}}$ – the temperature of the refrigerated gas stream from the vortex tube, K.
The principle of the pressure controller work on the base of the supersonic tube of temperature stratification is as follows. When the supersonic speed (Mach number is more than 1) and Prandtl Pr number are less than 1 there is the temperature difference between gas recovery on the wall and the temperature of slowdown for supersonic and subsonic streams divided by the wall. For heating the stream with the number \( M > 1 \) the temperature driving force is:

\[
\Delta T' = T' - T_{w2},
\]

where \( \Delta T' \) – the temperature driving force in the supersonic tube of temperature stratification, K; \( T' \) – the temperature of a stagnant flow, K; \( T_{w2} \) – the temperature of the wall from the side of a supersonic stream, K.

The main element of this isothermal controller (fig. 1, b) is de Laval nozzle 7 placed in the body 6. Nozzle 7 is set in a such way that the entrance of nozzle 7 is connected with the subsonic track 8 connected with the main line of high pressure through the pup joint 1; and supersonic track 9 of de Laval nozzle 7 is connected with the main line of low pressure through the pup joint 5. So pressure release is performed in the critical section of de Laval nozzle and effectiveness of the work of gas pressure isothermal controller (fig. 1, b) depends on the quality of the gas-dynamic temperature stratification process and intensity of the energy exchange between supersonic and the subsonic tracks of the gas pressure controller.

3. Experimental research

The prototype of the gas pressure controller was invented. It works due to implementing the vortex effect of temperature stratification. The work features of it have been exposed to experimental investigation. The scheme of test installation on the pressure controller investigation (fig. 1, a) is presented in fig. 2, a; in fig. 2 b the results of hot and cold streams temperature measures from the vortex tube are shown. Experimental investigation was carried out in compressed air. The air temperature at the entrance of the device was \( T_{in} = 294 \) K, the pressure in front of the controller - \( p_{in} = 364167 \) Pa. When the experiment was being done the following dimensions were measured: pressure and temperature of air at the entrance of the device, temperature of heating and refrigerated air streams from the vortex tube, pressure and temperature of the air at the exit of the controller, air temperature inside the body of the controller, atmosphere pressure, temperature of the cold lap.

Temperature measurement was performed with the help of chromel-copel thermocouple with displaying the data on a digital millivoltmeter with division value 0,01 mV. An error of measurements of air temperature was \( \pm 0,5 \) K. Extra air pressure in measure points was determined by a reference pressure gauge of accuracy class 0,6.

![Fig. 2. (a) the scheme of test installation; (b) temperature of streams at the exit of the vortex tube.](image)

The results of experimental investigation of the gas pressure isothermal controller on the base of the vortex tube are represented in fig. 3.
Fig. 3 shows the influence of operating conditions of the vortex tube work of temperature stratification on gas temperature change at the exit of the taken controller for different variations of pressure in the device. The difference of temperatures at the entrance and at the exit of the controller is determined by the expression:

$$\Delta T = T_{\text{in}} - T_{\text{out}},$$  \hspace{1cm} (3)

and pressure variation:

$$\pi = \frac{P_{\text{in}}}{P_{\text{out}}}$$  \hspace{1cm} (4)

where $P_{\text{in}}$, $T_{\text{in}}$ – pressure (Pa) and temperature (K) at the entrance of the device; $P_{\text{out}}$, $T_{\text{out}}$ – pressure (Pa) and temperature (K) at the exit of the device.

Analyzing the experimental investigation results represented in fig. 3a the following points should be marked: 1) gas temperature variation at the exit of the device depends on the relative usage of a refrigerated stream from the vortex tube; 2) gas temperature remains constant at the relative usage of the refrigerated stream $\mu = 0.18...0.3$.

Thus, the investigation shows that in the sphere of the vortex tube work with the maximum value of temperature stratification the offered controller makes it possible to decrease gas pressure at constant temperature. According to the investigation results (fig. 3, b) increasing pressure variation $\pi$ in the gas pressure controller on the base of the vortex tube doesn’t lead to gas temperature decrease at the exit of the device for $\mu = 0.18...0.3$ [22].

4. Conclusion

The usage of the gas pressure isothermal controller on the base of the vortex tube of temperature stratification will lead to the reduction or refusal from preliminary gas heating, refusal from local heating of gas controller bodies. In other words, the economy of natural gas will be from 0.08 to 0.2 % flow efficiency of gas distribution stations [22]. The scheme of the gas controller point [23] with the offered and investigated pressure controller is patented.

It should be mentioned that the system analysis of energy consumption in the sphere of gas and energy supply [1, 24] makes it possible to plan the ways of increasing energy efficiency of the gas and transport system [7–9,22,23], buildings and structures on the stage of their planning, construction and exploitation [25-28]. Ultimately, it leads to
the development of future-oriented national technologies, decrease of energy consumption of objects of infrastructure, successful import substitution politics on the territory of the Russian Federation.

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