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Influence of Inlet Parameters on Performance of Vortex Pilot Gas Heater

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Abstract

Vortex pilot gas heater (VPGH) is an application of vortex tube in natural gas transmission and distribution regulation system. By closing the hot end of vortex tube and installing vortex heater on the outer layer to form a pilot gas self-heating device, the pilot gas and vacuum nozzle can be heated to prevent freezing blockage caused by Joule-Thomson effect. In this paper, the numerical simulation method of CFD software is used to simulate its internal flow field based on the standard k-epsilon model, and the influence law of different inlet working parameters on its working performance is analyzed by controlling a single variable.

Keywords

VPGH; CFD Simulation; Expansion Ratio; Inlet Velocity; Working Medium.

1. Introduction

Vortex Pilot Gas Heater (VPGH) is an application of vortex tube in natural gas transmission and distribution pressure regulation system. It can heat pilot gas and vacuum nozzle to prevent freezing blockage. And has the characteristics of energy saving and environmental protection, no moving parts, free maintenance, insensitive to humid gas, easy installation, no gas loss, no overheating, easy to reform and so on [1]. This paper studies the product structure of VPGH-SP developed by Universal Vortex Inc.

2. Numerical Simulation

The inlet working parameters that affect the performance of the vortex pilot gas heater include vortex tube expansion ratio, inlet velocity of the pilot gas and the type of working medium.

2.1 Effect of Expansion Ratio on Performance

The expansion ratio of vortex tube was defined as the ratio of high-pressure gas inlet pressure and low-pressure gas outlet pressure of vortex tube, the heating effect of pilot gas was defined as the difference between the temperature of pilot gas outlet and the temperature of inlet, denoted by ΔT_p, the temperature drop of low-pressure gas outlet was defined as the difference between the lowest temperature of low-pressure gas outlet and the temperature of inlet gas, denoted by ΔT_c, and the temperature separation effect is defined as the difference between the highest temperature in the hot end of the vortex tube and the lowest temperature at the outlet, denoted by $\Delta T_{\hbar}$. This section discusses the influence of expansion ratios of 2, 3, 4, 5, 6, 7 and 8 on the temperature in vortex tube under the condition that the outlet pressure of low-pressure gas is kept at standard atmospheric pressure. Fig.1 shows the variation curve of temperature in vortex tube with expansion ratio.

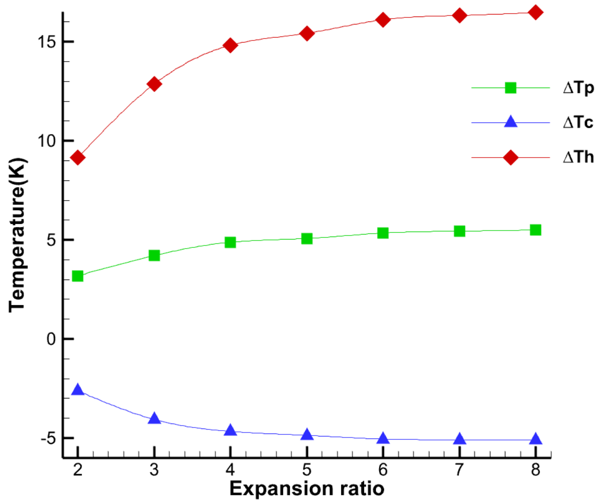

Fig 1. Influence of different expansion ratios on temperature

According to Fig.1, changing the expansion ratio will affect the heating effect and temperature separation effect in the vortex pilot gas heater. In the expansion ratio range of 2 to 8, the heating effect has a range of about 3 to 6K, while the temperature separation effect has a range of about 9 to 17K. Therefore, the expansion ratio has a significant effect on the energy separation effect. When other conditions remain unchanged, the heating effect of pilot gas, the temperature difference between low pressure gas outlet and inlet, and the temperature separation effect in tube will increase monotonically with the increase of expansion ratio. When the expansion ratio is small, the slope of the temperature curve is larger, and increasing the expansion ratio will gradually smooth the curve. The reason for this change is that the pressure energy of the high-pressure fluid entering the vortex tube is the energy represented by the input system. Therefore, when the inlet pressure is higher, the kinetic energy obtained by the gas in the vortex chamber is larger, and the energy separation effect is more obvious. In practical applications, increasing pressure will lead to an increase in gas velocity, while eddy wall roughness exists. The higher the velocity, the greater the resistance, and the higher the energy loss. In addition, the structural parameters of the vortex tube also determine the upper limit of the flow capacity in the tube. When the high-pressure gas exceeds the upper limit of the flow capacity of the vortex tube, the excess gas will be forced out of the system in a compressed state, resulting in the incomplete utilization of pressure energy. Therefore, by combining the above two points, it can be concluded that the increase of expansion ratio will enhance the energy separation effect of vortex pilot gas heater, but there is a critical value [2].

2.2 Influence of Inlet Velocity of Pilot Gas on Performance

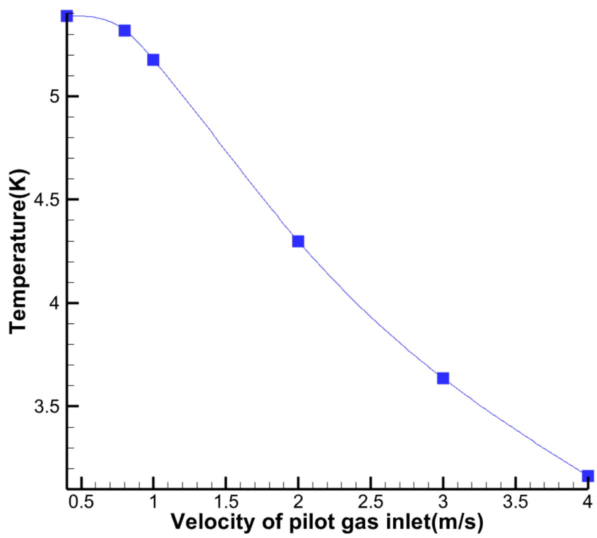

Fig 2. Influence of inlet velocity of pilot gas on heating effect of pilot gas

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From the structure of the vortex pilot gas heater, it can be seen that the heat source in the tube is generated by the temperature separation effect, and the heat source producing high temperature is distributed inside the tube. However, in the outer vortex heater, there is only heat transfer between the fluid and the inner structure, and there is no significant influence on the internal flow. Therefore, if the velocity of the pilot gas is changed, it will only cause the change of the heating effect of the pilot gas, and will not affect the heat source distribution in the vortex tube. The following is the variation curve of the heating effect of the pilot gas when the inlet velocity of the pilot gas is respectively 0.4m/s, 0.8m/s, 1m/s, 2m/s, 3m/s and 4m/s.

According to the curve in Fig. 2, it can be found that, with the increase of the inlet velocity of the pilot gas within the study range, the heating effect of the pilot gas gradually decreases and has monotonicity. This is because the temperature rises of the low-pressure gas passing through the tube wall or heat sink fins is a heat transfer process, and the heat transfer efficiency depends on the gas velocity and the temperature difference between the fluid and the heat source surface. Without changing the working parameters of the inner vortex tube, the internal temperature does not change significantly, and the inlet velocity of the pilot gas directly affects the flow velocity of the gas in the vortex heater. When the gas flow velocity is low, heat is more easily transferred to the gas due to the longer heat transfer time between the gas and the heat source, so the temperature of the gas will increase by a larger amount. When the gas velocity increases, the heat transfer time between the gas and the heat source becomes shorter, the transfer efficiency decreases, the heat transferred to the fluid per unit heat source area will also decrease, and the temperature rise of the gas will also decrease. Predictably, as the inlet velocity continues to increase, the temperature of the outlet gas will be infinitely close to the initial temperature.

2.3 The Influence of Working Medium Type on Working Performance

Define the dimensionless parameter r*=r/R, where R is the radius of the vortex tube heat pipe, define the dimensionless parameter L*=l/L, where L is the length of the hot end tube of the vortex tube. In this section, different types of working medium are simulated to obtain the influence of working medium type on temperature separation effect. Below is the temperature curve with axial distance at the dimensionless radius r*=0.9 when the fluids in the vortex tube are hydrogen, helium, nitrogen, oxygen and chlorine, respectively.

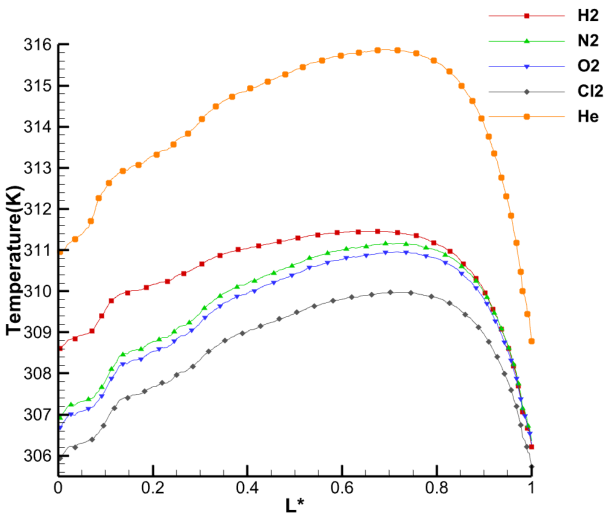

Fig 3. Axial distribution of temperature of different working media at r*=9

By observing Fig.3, it can be found that the temperature variation law of different working media in the tube is the same. It is known that the molar mass of hydrogen is 2g/mol, the molar mass of helium is 4g/mol, the molar mass of nitrogen is 28g/mol, the molar mass of oxygen is 32g/mol, and the molar mass of chlorine is 71g/mol. In the given diatomic gas molecule, the lower the molar mass of gas is, the higher the temperature of the working medium is, and the stronger the temperature separation effect is. Although the molar mass of helium is close to that of hydrogen, because it is a monatomic molecular gas, the specific heat capacity of helium is smaller than that of hydrogen, so its heating effect is better. In conclusion, the influence of the type of working medium on the performance of vortex pilot gas heater mainly depends on its molar mass. When the molar mass is similar, the gas with smaller heat capacity has better temperature separation effect. This conclusion is consistent with Tang's research on traditional vortex tubes [3], and Wu's article also has similar conclusions [4].

3. Conclusion

In this paper, the influence of different inlet parameters on VPGH performance is simulated by CFD simulation method, and the following conclusions are drawn: under the condition of no change in structural parameters, due to the upper limit of the flow capacity of vortex pilot gas heater, increasing the inlet and outlet gas expansion ratio can strengthen the energy separation effect in the tube, but there is a critical value. Increasing the inlet velocity of pilot gas will reduce the heating time of gas per unit volume, resulting in lower outlet temperature of pilot gas. The larger the molar mass is, the weaker the energy separation effect is. When the molar mass is close, the main influencing factor is the specific heat capacity of different working media. The energy separation phenomenon is more obvious in the working medium with smaller specific heat capacity.

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