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EXPERIMENTAL RESEARCH INSIDE A GAS HEATER WITH DIFFERENT INTERMEDIATE HEAT CARRIER MEDIUM

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ABSTRACT

The gas heater is one of the key equipments in gas industry, which plays the role of heating natural gas to the required processing temperature, and the application of gas heater shows a promising prospect. The cylinder-type heating device with an intermediate heat carrier medium is most widely employed. Apparently, the selection of intermediate heat carrier medium and the form of heat transfer process of the intermediate heat carrier medium, i.e. the flow field organization in the large capacity cylinder, is the key elements that greatly affect the thermal efficiency of gas heater. A real gas heater experimental system, which is the only one in China, is built. The present paper characterizes water and ethylene glycol as the intermediate heat carrier medium. Experimental measurements and analysis on the flow condition and temperature distribution between the water and ethylene glycol in the cylinder were carried out. The results shown that using ethylene glycol as the heat carrier media can widen the application range of gas heater. The efficiency of the heater with ethylene glycol as the heat carrier medium is at least 3.8% higher than that with water as the heat carrier medium under the same working conditions. The thermal efficiency of gas heater is usually less than 87%.

KEYWORDS: ethylene glycol, water, flow field, large cylinder, thermal efficiency

1. INTRODUCTION

Natural gas, as a clean energy, has been widely used in the fields of power generation, industrial combustion, civil and commercial areas. The containing hydrate will separate out and coagulate during the exploitation and transportation of natural gas as temperature falls, which will cause the blockage of pit shafts, pipes, valves and equipments. To prevent such phenomenon from happening, heating is needed [1]. In the use of natural gas, gas temperature will decrease as pressure drops. To meet the combustion needs and improve the combustion efficiency, heating is usually needed as well [2]. Besides, in LNG transmission and application system, heating is also used to gasify LNG.

The gas heater is one of the key equipments in gas industry, which plays the role of heating natural gas to the required processing temperature and the application of gas heater shows a promising prospect. Therefore, it is extremely important to design and manufacture efficient and energy saving gas heaters.

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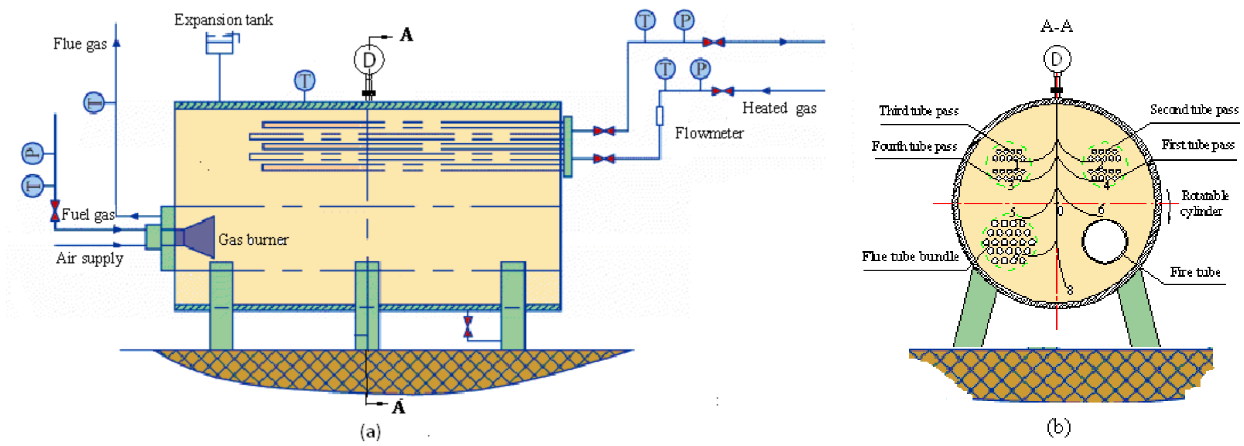
2. CHARACTERISTICS OF GAS HEATER WITH INTERMEDIATE HEAT CARRIER MEDIUM

The material to be heated in a gas heater is medium or high-pressure raw natural gas, and it is usually flammable and explosive. For the sake of safety, related standards are promulgated to prohibit the use of open flame or direct heat from flue gas, and the raw gas must be heated by indirect heating of intermediate heat carrier medium [3].
Therefore, the gas heater usually is an overall assembled structure. In a large cylinder, heating surfaces such as fire tube and flue tube bundle, cooling surfaces such as convective tube bundle are immersed in the intermediate heat carrier medium, to help the hot and cold fluid transfer heat. Generally, the heating surfaces and cooling surfaces are axisymmetrically arranged by the central axis of the circular cross-section of the cylinder, as shown in Fig. 1(a). When the heater is at work, heat produced by the fuel combustion heats up the natural gas to the required temperature under the action of the intermediate heat carrier medium. In this process, the selection of intermediate heat carrier medium and investigation on its flow and heat transfer in the cylinder is the key elements that greatly affect the thermal efficiency of gas heater [4].

At present, heaters in oil and gas fields usually use water as the intermediate heat carrier medium, commonly known as the water jacket heater [5,6]. Water is well known for its good heat transfer performance, noncombustible, and low price, but its use is limited due to the narrow available temperature range, poor heating stability. The experiment described in the paper uses ethylene glycol and water as the heat carrier media and compare them to determine the influence of intermediate heat carrier medium on gas heater in practical usage to find out feasible improvement measures of this heater.

3. THE SIMULATION EXPERIMENTAL SYSTEM

The gas heater simulation experimental system consists of test main body, gas burner, flue exhaust system, heated gas system and data acquisition system. The experimental main body is a gas heater manufactured based on the simulated conditions [7]. Manholes have been made on the heater shell wall to facilitate improvement of the heater structure. Temperature measurement is a key factor in this testing process. Temperature measuring points were set on the outside wall of cylinder, flue gas tank, outlet of flue tube bundle, inlet and outlet of the convective tube bundle. In order to test the temperature distribution of the heat carrier medium in the cylinder, an eight-joint type armored thermocouple and a single-joint one are arranged on the section in the middle of the cylinder, so there are nine measuring points altogether on the section D, as shown in Fig. 1(b).



0-8. temperature measuring points

Fig. 1 The simulation experimental system of gas heater

4. TESTING RESULTS AND DISCUSSION

Fig. 2 and Fig. 3 show the temperature distribution in the heater cylinder and the heater efficiency with water and ethylene glycol as intermediate heat carrier medium respectively under different working conditions.

It can be seen that the temperature distribution pattern on the section is almost identical, regardless of which type of the intermediate heat carrier medium is used—water or ethylene glycol. At the different heights of cylinder’s left and right region, there is a clear stratification of temperature. Obviously the temperature of heat carrier medium, which is close to fire tube and flue tube bundle, is higher, so the temperatures of point 5, 6, and 7 are relatively higher and the highest temperature appears at measuring point 6 which is nearest to the fire tube. There is a certain temperature difference among the measuring points at different convective tube pass regions. Near the bottom of the cylinder, the space is narrow, and so the cylinder intine thermal conductivity layer overlaps with the fire tube exine thermal conductivity layer. They form a pure thermal conductivity region and become a flow dead angle. So temperature of this region is the lowest. Measuring point 8 is arranged at the bottom of the cylinder, and its temperature is 10~20 ℃ lower than that of other regions.

The experimental results show that the temperature of the intermediate heat carrier medium, which is close to the fire tube wall and flue tube bundle wall, is higher and the intermediate heat carrier medium forms an uprising flow, and that around the fire tube is stronger. While the temperature of the intermediate heat carrier medium, which is close to the convective tube bundle is lower and the intermediate heat carrier medium will form a descending flow. These two flows will collide and cannot form a circulation. Besides, there exist temperature differences between the fire tube and flue tube bundle, among the multi-passes of the convective tube bundle. Collision will happen too. In the whole flow field, there are many flow dead angles, such as at the bottom of the cylinder and so on. Every above reason can cause a poor flow in the cylinder. In addition, the temperature difference between the upper part and lower part of the flow field is insignificant—less than 15 ℃; moreover, the cylinder is not very high, so the drive force for the natural convection is small too. Just because of this reason, it took four to six hours for every test condition to reach a stable condition. The start-up of the heater is very slow.

Apparently, defects exist in the conventional symmetrical arrangement of heat-exchange surfaces in gas heater. It is not conducive to the formation of heat flow field and may lead to the heat transfer flow field organization chaos in the cylinder. Thus, natural gas heater efficiency decreases greatly and energy consumption is high.

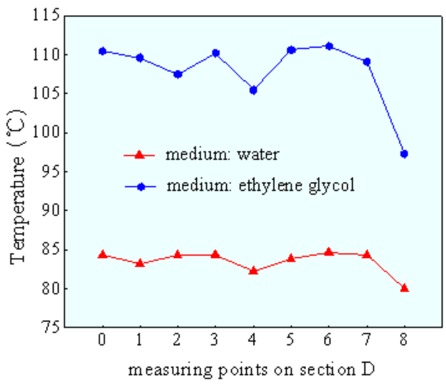


Fig. 2 Temperature distribution of different medium

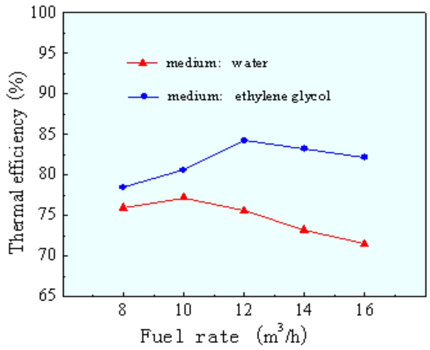


Fig. 3 Thermal efficiency of different medium

Fig. 2 also shows that measuring points' temperatures of ethylene glycol are 15~30 ℃ higher than that of water. This is because the heat capacity of water is much higher than that of ethylene glycol. Besides, the working temperature range of ethylene glycol is much bigger than that of water due to high boiling point and low vapor pressure [8,9]. But the temperature of ethylene glycol in the local area near to the bottom of the cylinder, is much lower than that of other measuring points. This is because the viscosity of ethylene glycol is big and this weakens the buoyancy force, so it's easy to form flow dead angle.

As shown in Fig. 3, under the same working conditions, the efficiency of the heater with ethylene glycol as the heat carrier medium is at least 3.8% higher than that with water as the heat carrier medium. As mentioned above, under all corresponding operating conditions, the operating temperatures of ethylene glycol are higher than that of water. So, the temperature difference between water and heated gas is small when using water as the medium, thus the lower efficiency. While using ethylene glycol as the heat carrier medium, the operating temperature is high (with the highest of 170 ℃), so the temperature difference will be larger and the thermal efficiency is relatively high. It is one of the reasons to choose ethylene glycol as the intermediate heat carrier medium.

Nevertheless, due to the defects of the conventional heater structure and the big viscosity of ethylene glycol, it is difficult to form an effective heat flow field, and the thermal efficiency is usually less than 87%.

5. MERITS AND DEMERITS WITH ETHYLENE GLYCOL AS THE HEAT CARRIER MEDIUM

For gas heater adopting intermediate heat carrier medium as the heat transfer media, it is of great importance to select proper heat carrier medium. The selection of intermediate heat carrier medium mainly depends on the operation temperature, the convenience of temperature adjustment, heat capacity, vapor pressure, boiling point, freezing point, thermal stability, toxicity, corrosiveness, and price etc. Among them, the heat transfer performance, pressure and temperature range of intermediate heat carrier medium determine the efficiency of the gas heater and its application scope.

The operating temperature range of water as heat carrier medium is narrow so it can only be used as heat carrier medium in a limited range (50~100 ℃). When the operating temperature exceeds 100 ℃, steam or ethylene glycol must be used as heat carrier medium. When steam is used as the heat carrier, it must be watched constantly [10], but not necessary for ethylene glycol [11]. So it's safe and reliable to use ethylene glycol as the heat carrier medium.

Ethylene glycol is a colorless transparent syrup-like liquid. It has the merits of high boiling point and low vapor pressure, so under the operating temperature, there is no phase change happening during the heat absorbing and releasing process even though temperature changes. Moreover, the working temperature and pressure range of ethylene glycol are both wide and its properties are relatively stable as long as the temperature is lower than 177 ℃. Its lifetime can reach 20 years. Even in low temperature environment it does not freeze. However, ethylene glycol is combustible, so flame-resistant components—water must be added into it. In other words, using ethylene glycol solution can increase operating temperature and is safer. In addition, certain amount of preservative needs to be added into it.

To sum up, ethylene glycol can work in a wide temperature range and keep the system under normal atmosphere. If the design of the heat transfer components can be improved [12], the thermal efficiency of the heater will be improved too and the application range will be wider.

7. CONCLUSIONS

The experimental investigation with water and ethylene glycol as the intermediate heat carrier medium establishes that the symmetrical arrangement of the heating and cooling surfaces is not conducive to the formation of heat flow field and gas heater efficiency is low (less than 87%) and energy consumption is high.

The experiments also show that the working temperature range of ethylene glycol is larger than that of water. But, ethylene glycol, because of its big viscosity, weakens the action of buoyancy force, and makes it easier to form flow dead angles.

For gas heater, the advantages of using ethylene glycol as the intermediate heat carrier medium is dependent on its operating temperature and the design of heat transfer components.

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REFERENCES

[1] Qi B., "Prediction and prevention of natural gas hydrate formation," *Natural gas industry*, 29, pp. 89-90, (2009).
[2] Yuan B., Yang D.M., Wang Y., and Wang J.R., "Supply processing of Gas Generator Set," *Oil and Gas Field Surface Engineering*, 20, pp. 30-32, (2001).
[3] Hong L., "Application of heat transfer medium in oil field design," *Journal of Shengli Oilfield University*, 17, pp. 51-52, (2003).
[4] Guo Y., Cao W.W., Yan P., Yu C.X., and Qian S.Y., "The structure and heat transfer analysis on natural gas heater," *Journal of University of Shanghai for Science and Technology*, 31, pp. 251-254, (2009).
[5] Song B., Chen J., "The choice on gas field natural gas heater,". *Oil-gasified surface engineering*, 26, pp. 59, (2007).
[6] Luo L.B., Liu Y.H, Wang Y., "Temperature control and energy saving technology in gas water jacket furnace," *Journal of Oil and Gas Technology*, 31, pp. 360-361, (2009).
[7] Guo Y., Cao W.W, Yan P., Yu C.X., and Qian S.Y.,"Visualizing experimental investigation on the natural gas heater," *Journal of University of Shanghai for Science and Technology*, 31, pp. 47-51, (2009).
[8] ASHRAE, *Physical properties of secondary coolants*, *Handbook fundamentals*, Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., (2005).
[9] Ma Y.X., *Handbook of chemical products*, Beijing: Chemical Industry Press, (1985).
[10] Cen Z.H., Xie L., "Application of ethylene glycol in natural gas purification plant," *Oil and gas chemical industry*, 21, pp. 34-37, (1992).
[11] Yang X.P., Wang T.X., "Application of ethylene glycol as heat carrier in natural gas purification plant," *Natural gas industry*, 17, pp. 70-74, (1997).
[12] Guo Y., Guo Z.X., "Flow and heat transfer inside a new diversion-type gas heating device," *Num. Heat Transfer*, 70(1), pp. 1-13, (2016).