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Influence of packed honeycomb ceramic on heat extraction rate of packed bed embedded heat exchanger and heat transfer modes in heat transfer process ☆

Gao Zengli, Liu Yongqi *, Gao Zhenqiang

Shandong University of Technology, 12 Zhang Zhou Road, Zibo 255049, China

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ABSTRACT

Under the condition that the transient oxidation heat extraction process of coal mine ventilation air methane (VAM) is equivalent to a series of steady state process, the steady state heat extraction experiment platform is built. The influence of the honeycomb ceramic packed in heat extraction zone and its two-side space on heat extraction rate and heat transfer modes is investigated. The experimental results show that the honeycomb ceramic packed in heat extraction zone two-side space can always strengthen heat extract ion of heat exchanger by increasing gas physical flow velocity in bed and radiation heat exchanging area and disturbing heat exchanger leeward side flow field. The contradictory dual characteristic of the influence of the honeycomb ceramic packed in heat extraction zone on heat exchanger heat extraction rate determines that the honeycomb ceramic has no great influence on heat extraction rate and doesn't always strengthen heat exchanger heat extraction. Contribution of heat transfer modes on packed bed embedded heat exchanger heat extraction is investigated using the method of coating heat exchanger outer surface silver; the experimental result shows that 55% contribution of packed bed embedded heat exchanger heat extraction rate is from radiation when gas mass flow rate is 0.15 $kg \cdot s^{-1} \cdot m^{-2}$ and its temperature is 1113 k; with the gas temperature being increased further, radiation will become the main way of packed bed embedded heat exchanger heat extraction.

1. Introduction

At present, the packed bed embedded heat exchanger is usually used in traditional combustion and reciprocating flow surface combustion heater so as to lowering bed layer temperature peak and reducing the NOx production [1,2]. In addition, it is also used in heat extraction after low calorific value gas is oxidized, especially coal mine ventilation air methane (VAM). Many scholars have done the research, for example, Krzysztof [3] studied the influence of gas extraction and heat extraction on bed layer temperature symmetry; Fabiano [4] regarded the heat extraction region as the larger cold source region and investigated bed layer combustion and temperature characteristic with the numerical method; Junrin Shi [5] studied the influence of bed geometrical characteristic size and equivalence ratio on packed bed combustion characteristic and heat efficiency; and Bin Zheng [6] carried out the experimental study on coal mine VAM thermal regenerative oxidation with embedded heat exchanger. Liu Ruixiang [7,8] numerically investigated lean methane combustion and bed temperature distribution character. The above research mainly concentrated in the influence of heat extraction on bed layer combustion and temperature distribution, and involved very little specific heat extraction process. Zengli Gao [9] numerically investigated the influence of heat extraction zone gas shunt characteristic on heat exchanger heat extraction. The experiment results proved that as long as the methane concentration is higher than 0.2% [10,11], after methane oxidation heat is partly used to maintain autothermal reaction in packed bed and make up the heat loss, there will be some excess heat, and the excess heat can be extracted to use. Therefore, the heat extraction is moderate heat extraction under the condition of ensuring the complete oxidation of methane [12–15]. The moderate heat extraction lacks corresponding theoretical basis. The paper is based on thermal oxidation heat extraction process of coal mine VAM, under the condition that the transient oxidation heat extraction process of coal mine coal VAM is equivalent to a series of steady state process, sets up the experimental plat form, and investigates the influence of honeycomb ceramic packed in different zones on heat extraction and contribution of heat transfer modes on packed bed embedded heat exchanger heat extraction using the method of coating heat exchanger outer surface silver.

2. Steady state heat extraction experimental plat form and test method

The heat extraction experimental plat form is shown in Fig. 1; the heat exchanger is embedded in heat extraction zone whose

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* Corresponding author.
E-mail addresses: gaozengli_10@163.com (Z. Gao), liuyqo5@163.com (Y. Liu).

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Fig. 1. Experimental platform.

Fig. 3. Thermopile in experimental platform.

height is 100 mm (Fig. 2), the snake tube heat exchanger specification is Φ32 mm × 3.5 mm, total length of heat exchanger heated is 2900 mm, honeycomb ceramic is packed in heat extraction zone and its two-side space, the gas vertically crosses the snake tube heat exchanger, honeycomb ceramic is made of mullite, honeycomb ceramic specification is 150 × 100 × 100 mm^3, whose open porosity is 0.64, and honeycomb hole is hexagon whose inscribed circle diameter is 4 mm and wall thickness is 1 mm. The heat extraction rate η is used to measure the heat exchanger heat extraction ability whose calculation formula is as follows:

$$\eta = \frac{m_w c_{w,p} \Delta t_w}{m_g c_{g,p} t_g} \times 100\% \quad (1)$$

where η is heat exchanger heat extraction rate; m_w is water mass flow in heat exchanger; $c_{w,p}$ is mean specific heat of water; Δt_w is water temperature rise in heat exchanger; $c_{g,p}$ is gas specific heat entering bed; and t_g is gas temperature entering bed. Δt_w is measured by thermoelectric pile (Fig. 3), and two independent thermocouples are installed at both ends of thermoelectric pile so as to measure water the average temperature in the heat exchanger, and get the $c_{w,p}$ value. m_w is measured by WL–LK intelligent flow totalizing control instrument. m_g is obtained by measuring gas volume flow and temperature t_g, the temperature t_g is used to get gas density and $c_{g,p}$, and gas volume flow is measured by MP200 type multi-function differential pressure instrument whose built-in thermocouple can measure gas temperature t_g. The maximum relative error of respective test is shown in Table 1. According to error transfer character, the η maximum relative error is plus the respective test maximum relative error, that is 2.50%.

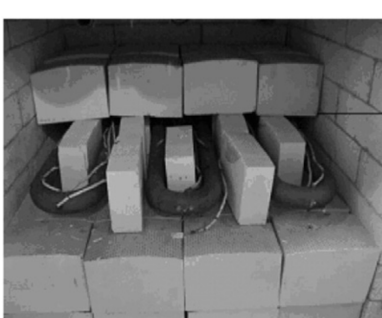

Fig. 2. Embedded heat exchanger in honeycomb ceramic packed bed.

3. Experimental test results and analysis

3.1. Influence of honeycomb ceramic packed in bed on heat exchanger heat extraction rate

The honeycomb ceramic packed in bed includes the honeycomb ceramic packed in heat extraction zone and its two-side space (Fig. 2); the influence mechanism and degree on heat extraction rate are different. Heat extraction rate change is investigated experimentally when the honeycomb ceramic is packed in each zone exists alone, and compared with the heat extraction rate in empty bed so as to analyze the influence of honeycomb ceramic packed in different position on heat extraction.

3.1.1. Influence of the honeycomb ceramic packed in heat extraction zone two-side space

During the course of coal mine VAM oxidation, the thermal dam effect of the honeycomb ceramic packed in oxidation bed is utilized to intercept the heat produced in methane oxidation cource so as to preheat incoming flow coal mine VAM. The honeycomb ceramic which has thermal dam effect is mainly the honeycomb ceramic packed in heat extraction zone two-side space. In the course of the experiment, honeycomb ceramic is only packed in heat extraction zone two-side space (Fig. 4), and supported with grate. When gas mass flow rate is $0.15\ kg \cdot s^{-1} \cdot m^{-2}$ and $0.30\ kg \cdot s^{-1} \cdot m^{-2}$, the comparison of heat extraction rate when honeycomb ceramic is only packed in heat extraction zone two-side space to the heat extraction rate of empty bed heat exchanger is shown in Fig. 5. Fig. 5 shows heat exchanger heat extraction rate decreases with the gas mass flow rate increasing, which is mainly due to that gas mass flow rate increasing makes the heat extraction time relative short. In addition, the increasing extent of heat extraction volume caused by gas mass flow rate increasing is less than that of gas enthalpy caused by gas mass flow rate increasing. Fig. 5 also shows that the honeycomb ceramic packed in heat extraction zone two-side space always can strengthen heat exchanger heat extraction, and so the heat extraction rate is always higher than that of empty bed heat

Table 1
The maximum relative error of measurement.

Maximum relative error/%	
Water mass flow	0.64
Water temperature rise	0.41
Water mean temperature in heat exchanger	0.75
Gas volume flow entering bed	0.20
Gas temperature entering bed	0.50