Experimental Study on the Integrated Performance of Dust Removal and Water Vapour Recovery in Catalytic Cracking Gas

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Abstract. Industrial combustion flue gas contains fine dust, water vapor, in order to remove micro dust, and to recover water vapor at the same time, we have put forward a research on the technology of recovering water vapor and dust removal by using a cyclone separator for the first time. By studying the pressure drop, the separation efficiency and the efficiency of recovering condensed water of the flue gas, we can get the optimum technological parameters for the actual working conditions. The results show that the pressure drop increases with the increase of inlet velocity and temperature, and the rate of increase is increasing. When under the same cooling water flow rate, the dust separation efficiency increases first and then decrease with the inlet velocity increase. When the inlet velocity is near the 50 m$^3$/h, the separation efficiency reaches the maximum, 96%. The amount of vapor recovery increases with the increase of cooling medium flow rate in 15 minutes. When at the same cooling medium flow rate, the recovery increases first and then decrease with the inlet velocity increase, and reaches the maximum when the inlet velocity is 60-80 m$^3$/h.

1. Introduction

A large amount of dust and vapour water in the industry are directly discharged from the incineration flue gas, resulting in serious waste of resources and environmental pollution [1]. The recovery of water vapour in flue gas is not only beneficial to the recovery of latent heat of flue gas, but also can save industrial water and reduce production cost [2]. The removal of dust in the flue gas will also significantly alleviate the increasingly severe fog and haze [3]. Therefore, the research on the integration of vapour water recovery and dust removal is of great significance in exhaust gas.

In recent years, scholars have conducted a series of studies on the heat transfer and dust removal performance of cyclone separators by experiments and simulation [4] [5], Chang-Eon Lee found that condensate recovery is not only beneficial to the latent heat recovery of flue gas, but also can absorb acid gas, which had obvious significance of environmental protection [6] Jolius Gimbun et al. attempted to enhance rotating centrifugal separation by improving the separable factors of materials, for example, to reduce the viscosity of materials by adjusting the temperature [7]. Nwabunwanne Nwokolo used a cyclone to recovery the heat from the downdraft biomass gasifier [8]. R., Parke et al. had studied the separation performance of cyclone separator under the condition of high temperature and high pressure, which is of great importance to the application of cyclones in industry [9] [10].

The above research has laid a foundation for the application of cyclone separator, but there is no cyclone separator used as the tube path in the integration of flue gas condensed water recovery and
dust removal. As a common separation equipment in the modern chemical industry, cyclone separator has the characteristics of simple structure, high separation efficiency and mature technology, and is especially suitable for use in harsh environments such as high temperature. In this paper, a self-designed cyclone separator is used as a tube to study the technology of dust separation and condensation water recovery in catalytic cracking incineration flue gas, the high temperature dust laden gas is separated in the cyclone separator, and the heat is transferred with the cooling medium in the casing wall, and the flue gas temperature is reduced, so that the condensed water is precipitated. The influence of the gas velocity, cooling medium flow rate and flue gas temperature on the pressure drop, separation efficiency and vapor water recovery was experimentally determined.

2. Experiment

2.1. Design of cyclone
As shown in Figure 1, The cyclone used in this experiment reduced the diameter of the cylindrical section to enhance the centrifugal effect. In order to make the airflow steady, a parallel deflector is added at the entrance, increase the length of the cone properly, and the size parameters of the cyclone are shown in table 1. In this experiment, the cyclone separator, the tank body and the pipe are all 304 stainless steel, all of which have good heat transfer performance and corrosion resistance.

| Table 1. Dimensions(mm) of the cyclone |
|---------------------------------------|
| D | a | b | d_e | d_c | H_1 | H_2 | H_3 | S | S_1 |
|---|---|---|-----|-----|-----|-----|-----|---|-----|
| 75 | 60 | 30 | 30  | 300 | 140 | 200 | 200 | 50 | 

Figure 1. Cyclone structure

2.2. Experimental process
As shown in Figure 2, CO and air are burned in an incinerator (1), and the dust laden flue gas with high temperature is sucked into the cyclone (8) under the action of a fan (10). At the same time, under the action of the centrifugal pump (6), the liquid in the cooling medium buffer tank (2) enters the shell path (9) along the tangential direction at the lower part of the tank. The high temperature dust gas in the cyclone (8) separator for gas-solid separation, at the same time, the high temperature gas transfers the heat with the cooling medium, so that the temperature of the flue gas drops rapidly, then water vapor in the flue gas condensed rapidly into small droplets, the small droplets in the cyclone field capture dust, which further strengthen the separation efficiency. The rotating direction of the smoke in the cyclone (8) separator is opposite to the rotation direction of the cooling medium when entering the
shell path (9), thereby improving the heat transfer efficiency. The separated dust condensed water flows out from the bottom of the tank body, and the flue gas after separating and cooling enters into the lower part of the desulfurization tower (11) under the action of the fan (10). The alkali liquor (12) is transported to the upper end of the desulfurization tower (11) under the action of an anticorrosive pump (13) and is sprayed downward, and finally the purified gas is discharged after the desulfurization. A thermometer (7) is arranged at the inlet and the outlet of the high temperature flue gas for measuring the temperature before and after the heat exchange of the flue gas, as well as the cooling medium. A flow meter (5-1, 5-2) is provided on the inlet pipe of the high temperature gas and the cooling medium to measure the flow velocity of the smoke and the cooling medium. The bypass valve (3-1, 3-2) is used to regulate the flow rate and concentration of the flue gas.

![Flow chart of experiment](image)

Figure 2. Flow chart of experiment

3. Experimental results and discussions

3.1. Pressure drop
When the cooling medium velocity is 2.1 m³/h and the flue gas temperature is 120, 100, 80 C°, respectively, the pressure drop between the inlet and outlet of the experimental equipment is measured. As shown in Figure 3, the pressure drop increases as the inlet velocity increases, and the rate of increase is accelerating. When at the same inlet velocity, the pressure drop will increase as the inlet temperature increases. Generally, the pressure loss of the cyclone mainly consists of the overflow pipe, the air inlet, and the loss caused by the vortex flow. But the higher the flue gas temperature is, the greater the viscosity of the dust in the flue gas is, the friction resistance between the flue gas and the side wall of cyclone separator increases, so that the pressure drop increases.

3.2. Separation efficiency
When the temperature of inlet gas is 120C°, we can see from Figure 4, In the same cooling medium flow rate, with the inlet velocity increased, the dust removal efficiency increased first and then decreased rapidly, and the air velocity in the vicinity of 50 m³/h dust removal efficiency reached the maximum. This is because the proper increase in inlet velocity can increase the centrifugal force of the dust in the rotation. When the inlet velocity is too high, it is easy to cause a sharp increase in the resistance in the cyclone separator, and the dust rebound and the small dust droplets are broken down, so as to reduce the dust removal efficiency. When under the same air inlet velocity, the separation
efficiency increases with the increase of cooling medium flow rate. This is mainly because the larger the cooling medium flow is, faster the high temperature smoke is cooled, small droplets are faster condensed, which strengthen the separation efficiency. When the flow rate of cooling medium is 2.1 m³/h and the inlet gas velocity is 50 m³/h, the removal efficiency reach the maximum is 96%. Under the different cooling medium flow rate, the maximum change rate of dust removal efficiency is more than 18% at the same gas inlet velocity.

![Figure 3. Relationship of V and ΔP](image)

![Figure 4. Relationship of V and E](image)

3.3. *Recovery efficiency of vapor water*

As shown in Figure 5, the inlet temperature is 120°C, when the flow rate of the cooling medium is 0.3, 0.9, 1.5, 2.1 m³/h and the inlet gas velocity is 20-100 m³/h. The recovery of condensed water is studied with the change of inlet gas velocity and cooling medium flow rate in 15 minutes. The results show that under the same cooling medium flow rate, with the increase of inlet velocity, the recovery of condensed water increases first and then decreases, and greater the flow velocity of cooling medium is, the faster the increase rate of condensed water. This is because when the cooling water flow rate is lower, the cooling effect is poor, and the amount of condensation water is less. With the increase of cooling medium flow rate, the cooling effect is enhanced, and the water vapour in flue gas is condensed easily. When the flue gas velocity is less than 80 m³/h, higher the gas velocity is, larger the volume of condensed water we can get in the unit time. When the flue gas velocity is larger than the
80 m³/h, gas residence time is too short, so the water vapor is not condensed in time, and is discharged before precipitation, which result in a sharp drop in the amount of condensed water recovery.

4. Conclusion
Study on the integration of dust removal and condensed water recovery of catalytic cracking flue gas by cyclone separator. Through the study of pressure drop, dust removal efficiency and recovery efficiency of vapor water, the optimum parameters under industrial conditions are obtained.

(1) When under the same inlet speed, the pressure drop increases with the increase of inlet gas’ temperature; when at the same inlet temperature, the pressure drop increases with the increase of the inlet velocity, and the rate of increase is accelerating.

(2) Under the same cooling medium flow rate, the separation efficiency increases first and then decrease with the increase of inlet velocity. When the inlet velocity is near the 50 m³/h, the dust removal efficiency is the highest. Under the experimental conditions, when the flow rate of cooling medium is 2.1 m³/h, the separation efficiency of flue gas is the highest. When the inlet velocity near the 50 m³/h, the separation efficiency is highest of 96%.

(3) When under the same cooling medium flow rate, the recovery efficiency of condensed water first increases and then decreases with the increase of inlet velocity, and when the inlet velocity is 60-80 m³/h; the recovery of condensed water is the maximum. When at the same inlet velocity, the recovery of condensed water increases with the increase of cooling medium flow rate.

5. Reference
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