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# Analysis of the Influence of Gas Leakage in The Dipleg of Cyclone Separators on Particle Properties

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**Abstract:** The FCC unit uses a cyclone separator for gas-solid separation of catalysts from flue gas or oil and gas. When the cyclone separator experiences a gas leakage fault, it directly affects its separation performance, causing excessive catalyst emissions and leading to the occurrence of catalyst running faults. However, there is currently a lack of diagnostic technology for cyclone separator equipment malfunction and gas leakage. Therefore, the influence of the dipleg of the cyclone separator on the particle loss rate under different gas leakage velocities was investigated experimentally. Experiments show that under normal conditions, particles are subject to multiple cycle separation, and fewer particles randomly enter the riser with the upward rotating flow to escape, which is mainly determined by the structure size and inlet velocity of the cyclone separator. When gas leakage occurs in the dipleg, the higher the gas leakage velocity, the higher the particle loss rate. As the number of particle cycles increases, the loss rate gradually decreases. For this purpose, the cyclone separator inside the FCC unit in the industrial site is taken as the object. In response to multiple cyclone separator loss faults, the changes in process parameters and collected catalyst particle properties of the cyclone separator are analyzed, and the changes in the running dose inside the device during operation are analyzed. Based on the analysis results, the operation of the unit is optimized and adjusted to avoid unplanned shutdown and maintenance. Therefore, based on this, a fault diagnosis technology for catalyst loss in FCC unit cyclone separators based on particle property parameters has been created, which has the characteristics of accuracy and reliability and can be applied to the analysis and diagnosis of catalyst loss faults in FCC unit.

**Keywords:** FCC unit, Cyclone separators, Gas leakage, Particle properties.

## 1. Introduction

Fluid Catalytic Cracking (FCC) process is one of the main heavy oil and light processing processes in China and even the world's refining industry [1], mainly consisting of four parts: reaction, regeneration, fractionation, and flue gas energy recovery. The cracking reaction between catalyst and oil and gas is carried out in the riser, and the separation of catalyst and oil and gas is completed in the settler; Complete the catalyst coking reaction in the regenerator to restore activity, and separate the catalyst from the flue gas in the upper cyclone separator. The FCC process is a complex cracking reaction of heavy oil under the action of high temperature and catalyst, which is transformed into cracking gas, gasoline, diesel, etc. The main reactions include decomposition, isomerization, hydrogen transfer, aromatization, condensation, coking, etc. Cyclone separator is a widely used gas-solid separation equipment. In the FCCU, cyclone separators mainly used for the separation of catalyst from oil and gas, and catalyst from flue gas. Due to the centrifugal force generated by the rotating airflow in the cyclone separator for gas-solid separation, the pressure in the central flow field area is relatively low, resulting in low inlet pressure of the dipleg and high external environmental pressure, forming a negative pressure difference distribution. Previous studies have obtained clear flow field pressure distribution through Computational Fluid Dynamics (CFD) methods [2-6] and experiments [7-10]. Usually, a trickle valve is installed at the outlet end of the cyclone separator legs. When the height of the powder material inside the legs exceeds the opening pressure of the trickle valve, the trickle valve automatically opens for discharge [11]. However, at this time, the external high-pressure airflow will carry particles and blow them into the relatively low pressure legs [12]. Gas leakage not only leads to the upward escape of particles already collected by the cyclone separator, but also reduces the efficiency of the cyclone separator, and the pressure drop will also fluctuate in the direction of decrease [13]. On the one hand, the gas leakage from the dipleg can cause changes in the cyclone separator's swirl field, weakening the centrifugal force, resulting in a decrease in separation efficiency and an increase in catalyst loss rate; On the other hand, it increases the pressure fluctuation of the internal airflow in the cyclone system, increases the secondary flow in the cone part, especially the back-mixing of the airflow at the cone bottom and ash hopper, and collides with the upward flow of the dipleg gas and the downward airflow of the cyclone rotation, making the airflow fluctuation more intense and making the internal flow field more chaotic. But there is still a lack of establishing a connection between different gas leakage velocity and running loss rates.

Cyclone separators are often used in continuous operations and long-term operation situations. However, due to their harsh working environment, high operating temperature, high particle concentration, erosion and wear in the inlet target area, and friction and wear of the top ash ring, cyclone separators may malfunction, such as trickle valve wear, broken dipleg tension bars, perforated diplegs, blockage of the trickle valve (due to coking of the riser wall in the regenerator, the coke block falls off and blocks the trickle valve) and the opening time of the trickle valve all cause external high-pressure airflow to blow into the low-pressure area inside the feed leg, resulting in the failure of the cyclone separator[14]. Therefore, this article establishes the relationship between multiple circulation separation and loss rate under normal operating conditions of a cyclone separator, especially examining the relationship between quantified gas leakage velocity and loss rate in the event of gas leakage faults. The research results are helpful for on-site diagnosis of gas leakage faults in cyclone separators, and can also further understand the process of particle loss inside the cyclone separator[15].

## 2. Experimental

(1) Experimental device

The experimental device is shown in Fig. 1, including a PV type cyclone separation system, a gas pipeline system, a fan power source system (with a power of 18.5KW and a gas flow of 5130 m3/h), and a valve throttling control system. The cyclone separator and its associated pipelines are made of organic glass, with the origin coordinate Z set at the inlet of the riser, and the axial position pointing downwards as positive. The inlet velocity and gas leakage velocity are controlled by the butterfly valve at the outlet pipe and the gate valve at the gas flow pipe, respectively, using a pitot tube to measure the average gas velocity at the cross-section. The particle size distribution of the equilibrium catalyst was measured using a Mastersizer laser particle size analyzer (Mastersizer 2000). Prior to the experiment, ultrasonic oscillation was used to make the particle distribution more uniform and reduce the impact of particle agglomeration.

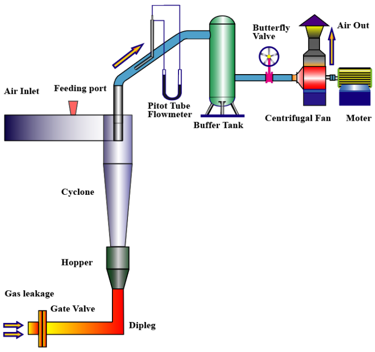

**Figure 1.** Experimental device of cyclone separator

The specific dimensions of the cyclone separator is shown in Fig. 2, which is a PV type cyclone separator with a 180 ° volute inlet and an inlet size of 176 × 84 mm, exhaust pipe diameter is 110 mm, cylinder diameter is 300 mm, connected cone height is 660 mm, cone outlet diameter is 130 mm, ash hopper diameter is 220 mm, ash hopper height is 230 mm, dipleg diameter is 80 mm, dipleg connection equal diameter horizontal pipe is a gas pipe.

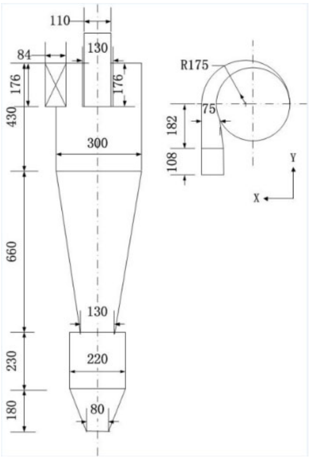

**Figure 2.** Size of cyclone separator

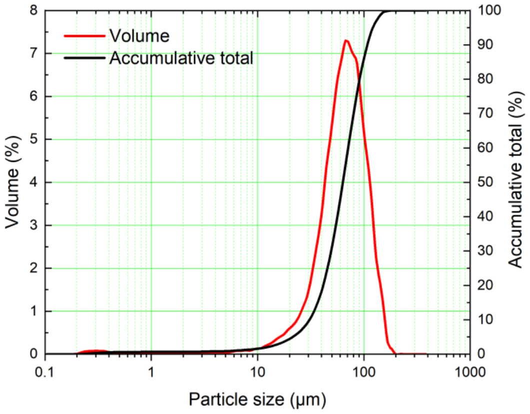

**Figure 3.** Particle size distribution

(2) Experimental parameters and methods

By adjusting the position of the air outlet butterfly valve, set the inlet velocity to $V_i$=10 m/s. By adjusting the screw velocity of the screw feeder, the feeding amount is controlled, and the inlet particle concentration is set to $C_i$=10 g/m$^3$. In the experiment, the gas velocity was controlled by adjusting the gate valve on the gas flow pipeline, and the gas velocities were set to $V_l$=0 m/s, 2 m/s, 4 m/s, 6 m/s, 8 m/s, and 10 m/s. The powder material used in the experiment is an equilibrium catalyst. Fig.3 shows the volume size distribution and cumulative distribution of equilibrium catalyst particles measured by a Marvin laser particle size analyzer, with a median particle size D50 of 66.1 μ m. The average particle size is 69.2 μ m. The smaller particle size D03 is 16.5 μ m. The larger particle size D97 is 136.4 μ m.

The experiment adopts a multiple circulation separation method, which involves using the equilibrium catalyst collected from the ash hopper as the powder material for the next spiral feeder, and separating it again at the same inlet velocity, repeating the operation multiple times. Assuming the initial material mass is $M_0$ and the material mass collected by the ash hopper is $M_1$, then the first equilibrium catalyst loss rate $\eta_1$ is:

$$\eta_1 = \frac{M_0 - M_1}{M_0} \times 100\%$$

Take the collected balance catalyst mass $M_1$ as the material for the second spiral feeder and measure the loss rate of the second balance catalyst $\eta_2$. Assuming that after the separation of the $X$ cycle, the material mass of the spiral feeder is $\mathrm{M}_{\mathrm{X}-1}$, and the material mass collected by the ash hopper is $\mathrm{M}_{\mathrm{X}}$, then the catalyst loss rate in the Xth cycle equilibrium is $\eta_X$:

$$\eta_X = \frac{M_{X-1} - M_X}{M_{X-1}} \times 100\%$$

## 3. Experimental Results and Analysis

(1) Experimental parameters and methods

In the catalytic cracking unit FCCU, due to the periodic and repeated reaction regeneration fluidization separation cycle of catalyst particles in a closed chamber. Under normal operating conditions of the device, particles are not discharged externally. The cyclone separator mainly plays a role in separating particles from oil, gas or flue gas. In order to reproduce the real operating conditions, a equilibrium catalyst material is used here, multiple particle circulation separation experiments are conducted at an inlet velocity of $V_i$=10 m/s.

Fig.4 shows the particle loss rate curve of the catalyst after multiple cycles (8 times). According to the equilibrium catalyst particle size distribution curve in Fig. 3, it can be seen that its average volume particle size is nearly 70 μ m. Due to the large particle size, the separation efficiency of the cyclone separator is high, and the particle loss rate is only about 0.1%. It can be considered that the reason for the smaller loss rate of the equilibrium catalyst in these 8 particle cycles is determined by the structural size and inlet velocity of the cyclone separator, which is unavoidable. This process is also known as the normal running loss stage.

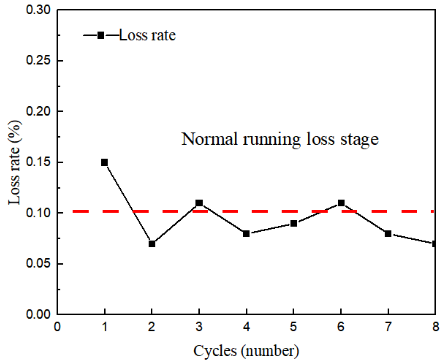

**Figure 4.** Loss rate varies with the cycle numbers

In order to study the variation law of equilibrium catalyst particle size distribution under these 8 particle cycles, the particle size distribution curve and cumulative distribution curve under the sieve were analyzed on the catalyst, as shown in Fig. 5 and 6. Among them, the curve distribution has good repeatability under different number of cycles.

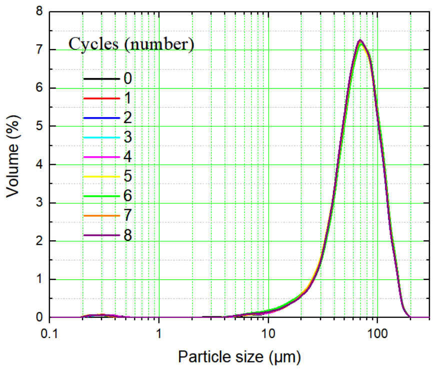

**Figure 5.** Particle size distribution curve varies with the cycle numbers

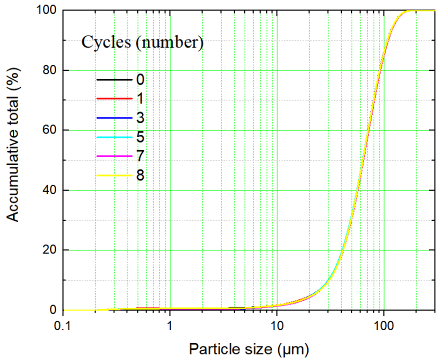

**Figure 6.** Cumulative undersize distribution curve varies with the cycle numbers

Fig. 7 shows the collected equilibrium catalyst particle size under 8 cycles. Starting from the first particle cycle, the average volume particle size and median particle size D50 of the catalyst tend to be consistent without significant changes, which also verifies the results shown in Fig. 5 and 6. At this time, only some particles randomly enter the riser and escape as they rotate upwards.

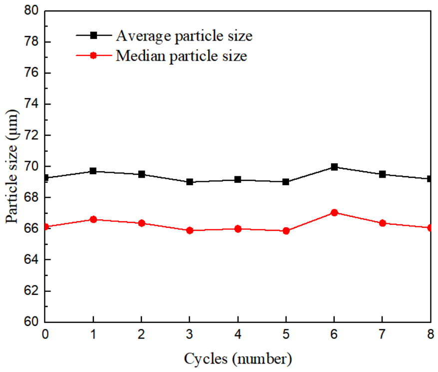

**Figure 7.** Particle size varies with the cycle numbers

(2) Analysis of multiple cycle results under gas leakage

Gas leakage of dipleg is an inevitable phenomenon in cyclone separators, and it is also a common fault. When there is hole in the dipleg or the valve plate seal is worn and fails, the above situation can also occur. Gas leakage causes separated particles to be entrained into the upward internal cyclone, ultimately escaping from the riser, resulting in an increase in the particle loss rate of the cyclone separator.

The experimental material used was equilibrium catalyst, with the typical fault feature of cyclone separator gas leakage of dipleg. Multiple particle circulation separation experiments were conducted when the gas leakage velocities $V_l$ were 0 m/s, 2 m/s, 4 m/s, 6 m/s, 8 m/s, and 10 m/s, respectively, and the inlet velocity $V_i$ was 10 m/s and the inlet concentration $C_i$ was 10 g/m$^3$. The experimental results are shown in Fig. 8. Experiments have shown that as the gas velocity increases, the loss rate increases. However, when the gas velocity is less than 4 m/s, the loss rate does not change significantly. When the gas leakage velocity $V_l$ is 10 m/s, the initial particle loss rate reaches nearly 60%, and then the loss rate decreases linearly with the increase of the number of cycles. This also reflects that the higher gas flow velocity weakens the separation efficiency of the cyclone separator, resulting in an increase in particle loss rate. Although the loss rate is lower than the gas flow velocity of 8 m/s after four cycles, the actual net mass of the remaining catalyst is already very small.

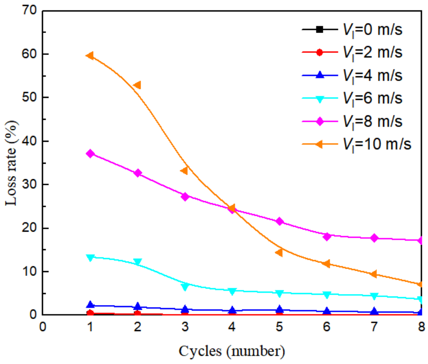

**Figure 8.** Loss rate varies with the cycle numbers at different gas leakage velocity

Taking the gas leakage velocity $V_l$ as an example, analyze the particle size distribution curves of catalyst particles under different cycle times, as shown in Fig. 9. As shown the overall distribution shows a good Gaussian distribution. As the number of particle cycles increases, the highest peak gradually shifts to the right and upwards, indicating that the proportion of peak particle size particles in the equilibrium catalyst gradually increases, and the size gradually increases. This also indirectly indicates that at higher gas velocities, small particles are more likely to escape from the riser, leading to a higher loss rate.

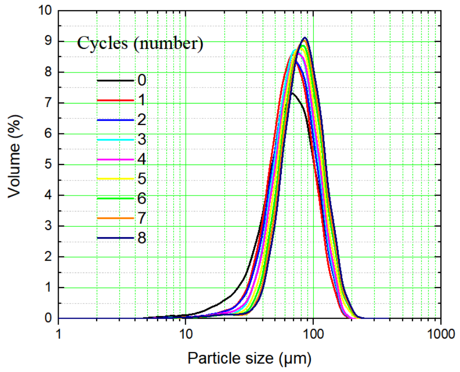

**Figure 9.** Particle size distribution curve varies with the cycle numbers($V_I$=8 m/s)

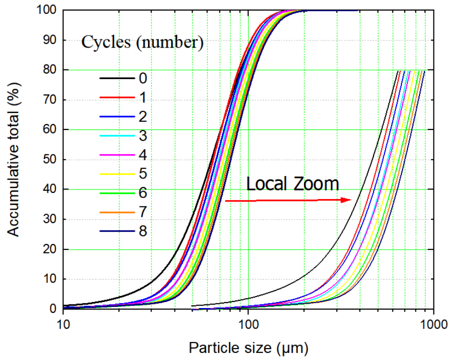

**Figure 10.** Cumulative undersize distribution curve varies with the cycle numbers ($V_I$=8 m/s)

In order to investigate the effect of particle size on the running loss rate of catalyst, the cumulative distribution curve of catalyst particles under different cycles and its local enlargement were analyzed, as shown in Fig. 10. As the number of cycles increased, the proportion of small particle size particles in catalyst particles gradually decreased, especially in the first cycle of particles, the area occupied by small particle size particles was much smaller than the original particle size distribution, This indicates that the proportion of small particle size in the equilibrium catalyst gradually decreases, which also indirectly indicates that under higher gas flow rates, small particle size is more likely to escape from the cyclone separator, leading to a higher loss rate.

## 4. Industrial Site Situation and Analysis

(1) Analysis of Agent Runout Caused by Wall Wear of Cyclone Separators

Fig. 11 shows the wear and tear on the wall of the cyclone separator during maintenance. The wall wear of a cyclone separator not only causes equipment aging and shortens its service life, but also roughness and unevenness of the wall surface, resulting in a decrease in the intensity of swirling flow. This is the main reason for the decline in the separation performance of a cyclone separator. The wall wear and damage of a cyclone separator is a long-term and gradual process. As the roughness of the wall surface increases, the efficiency of the cyclone separator slowly decreases, and the increase in catalyst loss is also a gradual process of change. For example, the fine powder content of the equilibrium catalyst gradually decreases, the large particle content gradually increases, and the average particle size gradually increases. The large particles in the fine powder recovered by the three cyclone separator gradually increase, indicating slow wear of the lining and wall of the secondary cyclone separator. At this point, it is necessary to monitor the catalyst running process of the cyclone separator, pay attention to the changes and development of catalyst physical parameters, supplement fresh catalyst at any time, adjust the particle size distribution and wear index of fresh catalyst, and ensure the catalyst storage capacity of the device.

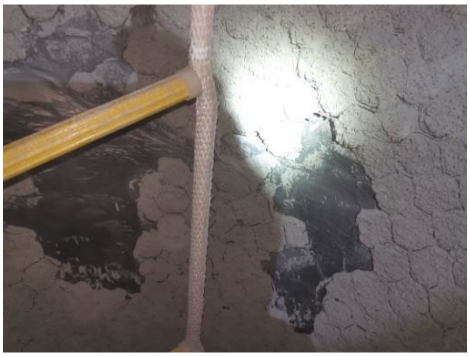

**Figure 11.** Wall wear of cyclone separator

(2) Analysis of agent runout caused by wall wear of cyclone separators

The wall wear and perforation of the cyclone separator is a sudden process, and the amount of catalyst loss is also a sudden increase change. When there is a significant pressure fluctuation in the cyclone separator, the amount of fresh agent used in the device begins to increase. Based on this, it is judged that there is perforation in the wall of the cyclone separator. The gas flow leaks through the perforation, causing interference with the swirling flow inside the cyclone separator, resulting in the oscillation of the rotating flow and pressure oscillation. With the detachment of the cyclone separator lining and continuous wear of the wall, the perforation area increases and the air leakage rate increases, resulting in a rapid decrease in the separation efficiency of the cyclone separator and a significant decrease in the recovery efficiency of large particle catalysts, indicating severe perforation of the cyclone separator wall. At this time, the FCC unit adopts maintenance operation and does not require unplanned shutdown maintenance until the planned shutdown maintenance time. At the same time, pay attention to the changes and development of catalyst dosage, monitor the changes in catalyst particle size distribution at the inlet of the smoke hood, and constantly supplement equilibrium catalyst to ensure the catalyst storage capacity of the device. As shown in Fig. 12, there is wear on the cone section of the second stage cyclone cylinder of the regenerator, and a perforation with a diameter of about 60 mm appears on the outside of the cylinder. The internal lining is severely worn, and the lining has fallen off extensively.

**Figure 12.** Wall wear and perforation of cyclone separator

# 5. Conclusion

(1) Under normal operating conditions ($V_l$=0 m/s), multiple particle circulation separation experiments were conducted on the cyclone separator. The experimental results showed that the particle loss rate was only about 0.1% each time. This is mainly because the cyclone separator cannot achieve a 100% separation efficiency, and the size of the loss rate mainly depends on the structural size and operating process parameters of the cyclone separator. Through the analysis of the particle size distribution curve and the trend chart of particle size, it was found that the proportion of each particle size remained almost unchanged under different cycle times. The reason for particle loss was that some particles randomly entered the riser with upward rotating flow and escaped.

(2) When there is a gas leakage fault in the diplegs of the cyclone separator, the loss rate increases with the increase of gas leakage velocity. However, when the gas leakage velocity is small ($V_l$<4 m/s), the loss rate relatively does not change much; When the gas velocity $V_l$ reaches 10 m/s, the first cycle particle loss rate reaches nearly 60%, exceeding half of the particle loss. By comparing the particle aggregation morphology at the cone and the particle emission images at the riser, it can be concluded that when the gas velocity $V_l$=0 m/s, the particles spiral downward along the inner wall of the cone, forming a relatively regular and clear spiral gray belt. There is no obvious particle display in the gas discharged from the riser; When the gas velocity $V_l$ is 8 m/s, particles form flocculent particles that move downwards against the inner wall of the cone, forming a divergent and fluctuating gray band. Significant particle loss can be seen at the riser.

(3) Through industrial data analysis, the wear of cyclone separators is a gradually accumulating process, and the amount of catalyst loss slowly increases with the increase of wear degree. When the wall or lining of the cyclone separator is worn, the amount of catalyst loss increases but remains within a controllable range; When the perforation area of the wall reaches a certain critical value, the catalyst loss shows a sudden increase. At this time, process adjustment cannot reduce the loss, which can be used as a basis for judging the wear fault of the cyclone separator.

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