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Zhi-shan Bai[a]; Hua-lin Wang[a]; Shan-Tung Tu[a]
[a] Key Lab of Safety Science of Pressurized System, Ministry of Education, School of Mechanical and Power Engineering, East China University of Science and Technology, Shanghai, PR China

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Removal of Catalyst Particles from Oil Slurry by Hydrocyclone

Zhi-shan Bai, Hua-lin Wang, and Shan-Tung Tu
Key Lab of Safety Science of Pressurized System, Ministry of Education, School of Mechanical and Power Engineering, East China University of Science and Technology, Shanghai, PR China

Abstract: Small diameter (10 mm) hydrocyclone is used for catalyst particles separations in this work. An industrial sidetrack tester was set up in 1.8 Mt/a catalytic cracking unit. When Reynolds number is invariable, the experimental results show that the pressure drop between the inlet and the overflow is not changed by changes in the split ratio. The effects of Reynolds number and split ratio on separation efficiency were studied. The removed efficiency of catalyst particle is more than 55% with Reynolds number of $850 \sim 950$.

Keywords: Catalyst particle, catalytic cracking, hydrocyclone, oil slurry

INTRODUCTION

Fluid catalytic cracking slurry (FCCS) is a by-product of petroleum refining. Oil slurry generated in the catalytic cracking process not only is the blending component of heavy fuel oil and the raw material of carbon black production, but also is the important chemical additive for aromatic hydrocarbon extraction process. However, the catalyst particle in oil slurry could abrase and block the heat exchanger, and cause serious negative effect to the aromatic hydrocarbon extraction process and quality of heavy fuel oil (1). Therefore, it is necessary to remove the catalyst particle in oil slurry.

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Address correspondence to Hua-lin Wang, School of Mechanical and Power Engineering, East China University of Science and Technology, 130 Meilong Road, Shanghai, 200237, PR China; Fax: +86 21 64253513. E-mail: fbaizs@yahoo.com.cn

A range of conventional treatment technologies for catalyst particle removal have been investigated extensively, such as sedimentation, filtration (2), electrostatic separation (3,4), and centrifuge separation (5), etc. However, most of the above methods suffer from one or more limitations and none of them were successful in completely removing the catalyst particle from the oil slurry. Compared to the conventional solutions, hydrocyclone can offer several advantages, such as compact dimensions, operational simplicity, and high separation efficiency, etc (6–8).

In the present study, an industrial sidetrack tester of oil slurry-catalyst particle separation using hydrocyclones in 1.8 Mt/a catalytic cracking unit was set up. The removal performance of the catalyst particle from the oil slurry using hydrocyclones has been investigated. The feasibility of the method was verified by experiments.

BACKGROUND

Principle of Hydrocyclones Separation

The hydrocyclone is a device that uses a centrifugal force field generated by the rotational motion of a liquid to separate materials having different properties. These properties include density, shape, size, and even magnetic field strength. The hydrocyclone has also been proposed for use in the dual role of reactor and separator.

A hydrocyclone body consists of two parts: a cylindrical part and a conical part. Design depends on both the nature of the separation and the quality of the effluent desired. The applications of hydrocyclones are principally the separation of solid suspended matter and the clarification of liquid phases. Figure 1 shows the operation of hydrocyclone designed for solid-liquid separation. The fluid is injected tangentially at the top of the hydrocyclone and causes centrifugal forces to accelerate particles towards the walls. As the fluid passes through the hydrocyclone in a spiral fashion, large or dense particles are forced against the wall and migrate downwards to the underflow. Fine or low density particles are swept into a second inner spiral which moves upward to the overflow.

The Dimensionless Parameters

The dimensionless parameters of hydrocyclone play an important role in the separation process. Some of these parameters are utilized to develop mathematical relationships between the dimensionless performance parameters. Dimensionless parameters are based on fundamental

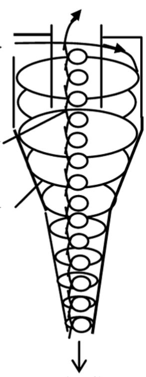


Figure 1. Fluid flow in hydrocyclone.

theory combined with dimensional analysis to produce the necessary correlations, and, in keeping with the usual practice in chemical engineering, the required constants are derived from tests rather than from theory.

Flow split of the hydrocyclone is defined the ratio of the volume flow of the underflow to feed, i.e.

$$R = Q_u / Q_i \times 100\% \tag{1}$$

where R is the flow split, and Q_u and Q_i are individually the volume flow of the underflow and feed. Under normal operating conditions, there are two distinct pressure drops across the hydrocyclone separator:

$$\Delta p_{io} = p_i - p_o \tag{2}$$

and

$$\Delta p_{iu} = p_i - p_u \tag{3}$$

where p_i, p_o, p_u are the pressure in the feed, overflow, and underflow, respectively.

The superficial velocity in the hydrocyclone body is used as the characteristic velocity, i.e.

$$v = \frac{4Q_i}{\pi D^2} \tag{4}$$

The various dimensionless groups are defined as follows.

The hydrocyclone Reynolds number could be described as follows:

$$Re = \frac{\rho D v}{\mu} \tag{5}$$

The hydrocyclone characteristic Euler number is a pressure loss factor based on the static pressure drop across the hydrocyclone:

$$Eu = \frac{p_i - p_o}{\rho v^2/2} \tag{6}$$

where D is the hydrocyclone diameter; ρ and μ are the density and viscosity of liquid, respectively.

Removal Performance

The separation capability of a hydrocyclone is strongly determined by the capacity of handling the amount of material reporting to the oversize flowstream and the size distribution of the feed. The total efficiency of catalyst particle is defined by

$$E = \left(1 - \frac{g_o}{g_i}\right) \times 100 \tag{7}$$

where g_o and g_i are the concentration of the catalyst particle in the overflow and feed, respectively.

MATERIALS AND METHODS

Mediums

Table 1 shows the technological parameters of the mediums. The catalyst particle size distribution can be seen from Fig. 2.

Table 1. Properties of materials

Materials	Density/ $kg \cdot m^{-3}$	Viscidity/ $mm^2 \cdot s^{-1}$	Size distributions/ μm	Particle concentration/ $mg \cdot L^{-1}$
Oil slurry	$993 \sim 1040$ (20°C)	43.19(80°C) 10.64(100°C)		$5000 \sim 8000$
Catalyst particle	1400		$1 \sim 30$	

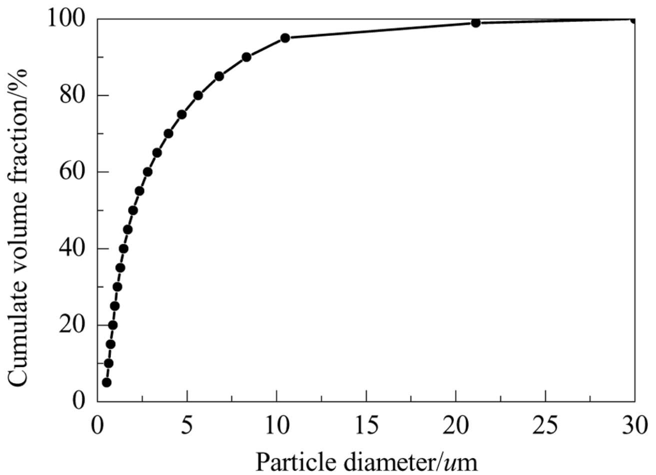


Figure 2. Measured size distributions of catalyst particle.

Hydrocyclone Design

We design a hydrocyclone with 10 mm diameter. The hydrocyclone has two symmetrical rectangular inlets (2 mm × 4 mm) and cone angle is 6°. The hydrocyclones designed are shown in Table 2.

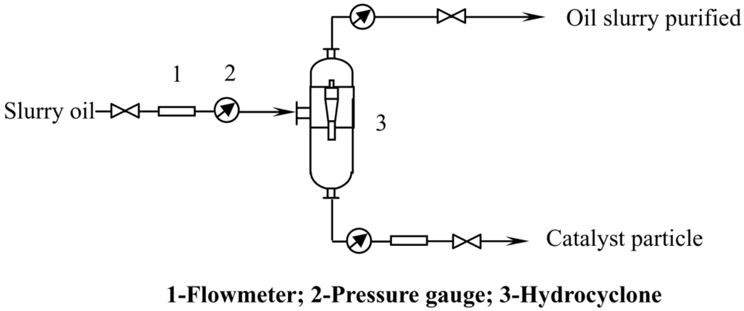
Where D, D_o, and D_u are the diameters of swirl chamber, overflow and underflow orifice respectively, L_s, L, and L_u are the lengths of swirl chamber, taper and tail pipe respectively.

Flow Diagram

An industrial sidetrack tester of oil slurry-catalyst particle separation using hydrocyclone in 1.8 Mt/a catalytic cracking unit was set up. Oil slurry was fed to hydrocyclone by self-pressure of the system. The catalyst particle removed by hydrocyclone returned to the first reaction region of pre-lift sect in the riser reactor, oil slurry purified were sent to chemical fertilizer devices as raw material of fuel oil. Work temperature

Table 2. Structural dimensions of hydrocyclone

D/mm	$\theta/°$	D_o/D	D_u/D	L_s/D	L/D	L_u/D
10	6°	0.25	0.20	1.00	7.63	1.00



1-Flowmeter; 2-Pressure gauge; 3-Hydrocyclone

Figure 3. Diagram of slurry oil separation by hydrocyclone.

of hydrocyclone is 120°C. The experiment process is showed in Fig. 3. Pressure and flow rates were monitored with accurate manometers and flowmeter.

RESULTS AND DISCUSSION

Reynolds Number vs Euler Number

Euler number is related to the pressure drop Δp_{io} and Reynolds number is related to inlet flow rate for hydrocyclone. The relationship between the Euler number *Eu* and the Reynolds number Re is shown in Fig. 4. It can

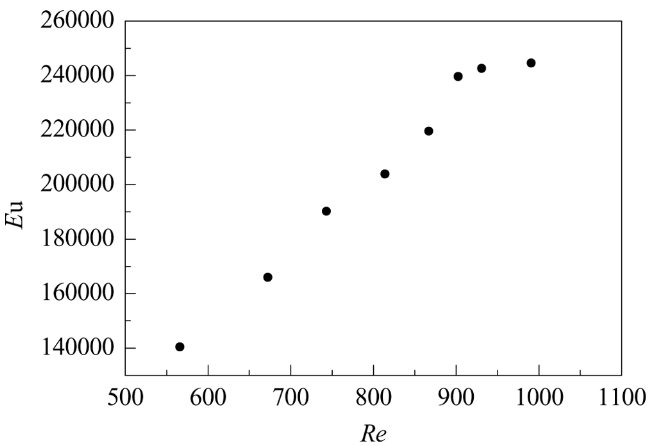


Figure 4. Euler number vs. Reynolds number.

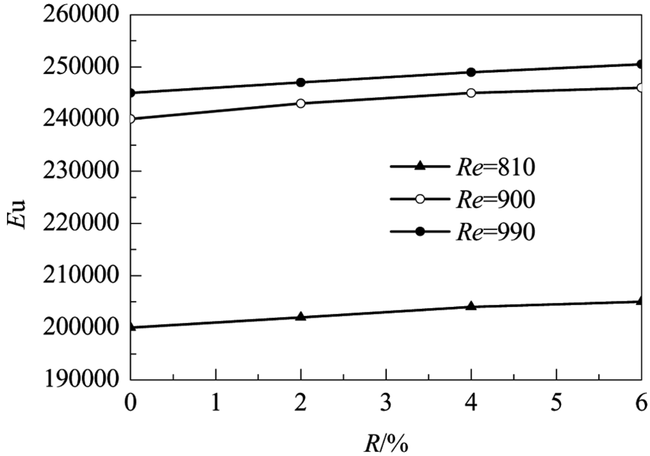


Figure 5. Reynolds number vs split ratio.

be seen that the Euler number increases gradually with the increasing of the inlet Reynolds number. This indicates that an increase of the inlet flow rate will increase the value of Δp_{io}.

Euler Number vs Split Ratio

The relationship between the Euler number *Eu* and split ratio *R* is shown in Fig. 5. For the same Euler number, an increase in the split ratio has little influence on the Euler number value. This indicates that the pressure drop Δp_{io} is not changed by changes in the split ratio when the Reynolds number is invariable.

Separation Efficiency vs Split Ratio

In order to acquire the optimum split ratio, the effects of split ratio on separation efficiency were studied at different Reynolds number. Figure 6 shows the relationship between the separation efficiency and the split ratio. It can be seen that an optimum split ratio corresponding to maximum separation efficiency is obtained. We can also see from Fig. 6 that the optimum split ratio is 3% when the Reynolds number ranges from 800 to 900.

At the same inlet flow rates, an increase in the split ratio will improve the separation efficiency under the condition if the split ratio is less than the optimum split ratio, beyond which further increase in the split ratio

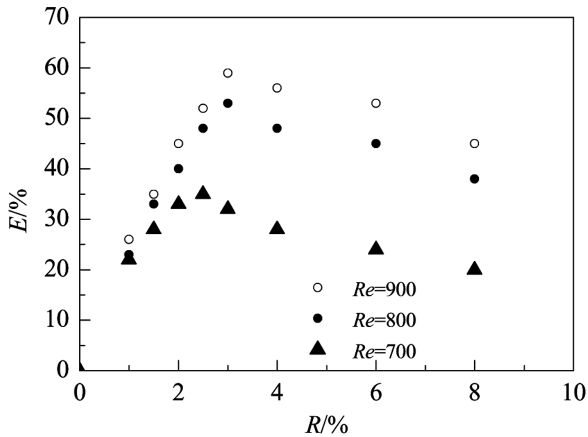


Figure 6. Separation efficiency vs split ratio.

will decrease the separation performance. A possible explanation of the observed effect of split ratio on separation efficiency is as follows. When the split ratio is too small, the underflow rate could not make solid particles removed report to underflow in time. At a very high split ratio, underflow rate over the large and the centrifugal force over small in the hydrocyclone, makes it impossible for a small particle to move into the underflow, thus reducing the separation efficiency.

Separation Efficiency vs the Reynolds Number

The Reynolds number has a distinct effect on the removed efficiency of the particle. Figure 7 shows the relationship between the Reynolds number and the separating efficiency when the split ratio is 3%. Under the condition the Reynolds number is less than 900, an increase in the Reynolds number will improve the separating efficiency. This is because the increasing of the inlet flow rate will provide a higher centrifugal force on the catalyst particle, and will make it possible for the finer particle to move into the wall, thus improving the separation efficiency. The figure shows that an optimum Reynolds number of 900 can provide maximum separation efficiency.

The separating efficiency reaches a maximum when the Reynolds number is close to 900, beyond which further increases in the Reynolds number will cause performance deterioration. At very high flow rates, intense turbulence will make the particle removed remix to liquid and reduce the separating efficiency.

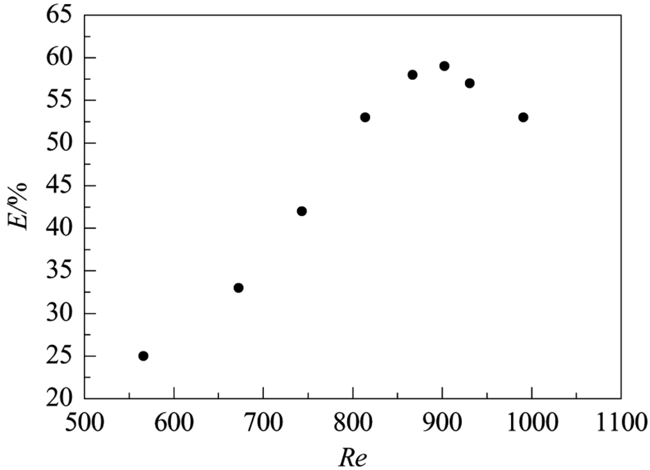


Figure 7. Separation efficiency vs the Reynolds number.

It can be seen from the figure that the removed efficiency of the catalyst particle is more than 55% with the Reynolds number of 850 ~ 950.

According to the data of inlet and overflow particle distribution, the grade efficiency curve (GEC) is drawn for different Reynolds numbers, as shown in Fig. 8. The particle size distribution was obtained by using a

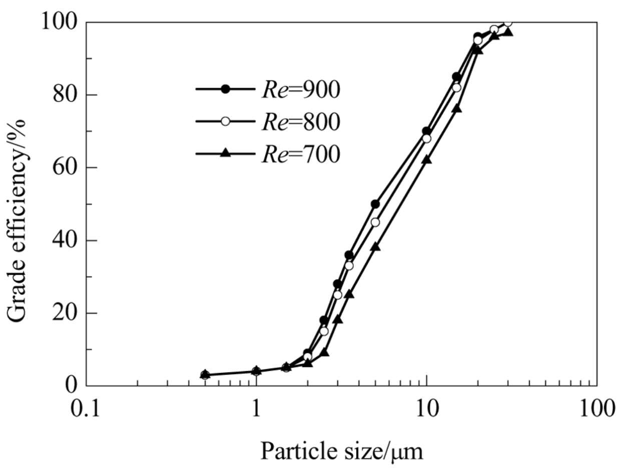


Figure 8. Grade efficiency curve with different Reynolds number.

laser analysis method. It can be found that the removal efficiency of the particle increases with the increasing of the particle diameter. For the particles that are smaller than 1.5 μm, the removal efficiency is much less, which is due to the particle being too small to be separated. For the particles larger than 20 μm, the increasing in removal efficiency is gently with the increasing of particle diameter, because the original separation efficiency for this part of the particles was very high.

The figure shows that the Reynolds number at 900 can provide maximum grade efficiency, it is similar to Fig. 7. The cut size is 5 μm for the oil slurry-catalyst particle separation using hydrocyclone with a 10 mm diameter when the Reynolds number at 900.

CONCLUSIONS

An industrial sidetrack tester of oil slurry-catalyst particle separation using hydrocyclone in 1.8 Mt/a catalytic cracking unit was set up. The removal performance of the catalyst particle from the oil slurry using hydrocyclone has been investigated. The following conclusions can be drawn from the study.

1. An increase of the inlet flow rate will increase the value of Δp_{io}. The pressure drop Δp_{io} is not changed by changes in the split ratio when the Reynolds number is invariable.
2. An optimum split ratio corresponding to maximum separation efficiency is obtained. At the same inlet flow rates, an increase in split ratio will improve the separation efficiency under the condition of split ratio is less than the optimum split ratio, beyond which further increase in the split ratio will decrease the separation performance.
3. An optimum Reynolds number of 900 can provide maximum separation efficiency. The removed efficiency of catalyst particle is more than 55% with the Reynolds number of $850 \sim 950$. The cut size is 5 μm for the oil slurry-catalyst particle separation using hydrocyclone with a 10 mm diameter.

The present work verified the effectiveness of oil slurry-catalyst particle separation using hydrocyclone with 10 mm diameter. However, further researches should be needed in order to achieve an optimal design:

1. The effects of structural dimensions on separation efficiency;
2. The flow field in hydrocyclone should be studied.

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