MAGNETIC SEPARATION OF FLUID CATALYTIC CRACKING EQUILIBRIUM CATALYST[①]

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ABSTRACT Effects of magnetic field intensity and carrier air flowrate on the magnetic separation of fluid catalytic cracking(FCC) catalyst with a high gradient magnetic separator(HGMS) were studied. The activities of the equilibrium catalyst, the magnetic particles and the nonmagnetic particles were evaluated in a fixed bed microreactor. The results showed that the catalyst contaminated by heavy metal can be selectively separated by means of HGMS at magnetic field intensity $0.5\,T$ and carrier air flowrate $0.3\,m \cdot s^{-1}$, and the catalyst contaminated lightly retained high catalytic activity.

Key words magnetic separation   fluid catalytic cracking equilibrium catalyst
high gradient magnetic separator

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1 INTRODUCTION

Fluid catalytic cracking (FCC) of residual oil is developing rapidly because of the growing demand for light fuel oil and tight supplies of regular cracking stocks. However, a problem especially serious in the FCC of residual oil is the continuous deposition of Ni, Fe and V contained originally in the residual oil on the catalyst surface. Such metals play as catalyst poisons, greatly decreasing the activity of catalyst and the efficiency of cracking process[1]. To maintain the activity of the catalyst at a certain level refinery must withdraw steadily or periodically a part of the catalyst for which the fresh catalyst is substituted. The amount of the catalyst to be withdrawn is very large, and the withdrawn catalyst is usually discarded. Such means is often uneconomical because some lightly contaminated catalyst retain high catalytic activity and selectivity and can be returned back to the circulating system of the FCC unit for reuse without adverse effects on the conversion rate and the selectivi-

ty[2, 3].

The method proposed in this paper is the magnetic separation technique of equilibrium catalyst. Here studies are concerned with magnetic separation of equilibrium catalyst with a high gradient magnetic separator (HGMS) which is an effective and economical device to remove very fine, weakly magnetic catalyst particles which can not be separated with conventional magnetic separators[4- 6].

2 EXPERIMENTAL

2.1 Catalyst sample

FCC equilibrium catalyst sample was obtained from Jinan Refinery. It was actually used in FCC units processing residual oils. The catalyst was classified into several size ranges using a set of screens. The size and metal distributions, some physical and chemical properties of the catalyst sample are listed in Tables 1 and 2. As shown in Tables 1 and 2, the mean specific magnetic susceptibility of the catalyst sample is

8.9×10^{-8} m^3/kg and 90. 83% of catalyst particles are less than 75 μm in size. It is difficult to separate the fine, weakly magnetic catalyst particles using conventional magnetic separators. In our studies, a HGMS was used to separate the fine, weakly catalyst particles.

2. 2　Experimental unit and operation

Fig. 1 illustrates the experimental unit, in which the main apparatus is a HGMS. It consists of a canister, a cylinder 80 mm in diameter, packed with ferromagnetic matrices immersed in a uniform magnetic field generated by a solenoid coil. The ferromagnetic matrices in canister are induced by uniform magnetic field and generate the regions of highly nonuniform magnetic field intensity. The solenoid coil is enclosed by a magnetic iron yoke. In the present studies, the ferromagnetic matrices are the expanded metal of 800 μm wire. The operation of the unit is as follows: First, the blower and magnet of HGMS are switched on and a catalyst sample is put into the unit by a feeder, the sample is then carried down by an air current into the separation zone, particles heavily loaded with metals are held on the matrices by magnetic force while particles loaded with much less metals pass through the matrices and are collected in the receiver No. 1,

namely nonmagnetic particles (nonmags); then the magnet is switched off, the particles held on the matrices are flushed with air and collected in the receiver No. 2, those particles are called magnetic particles (mags).

2. 3　Magnetic susceptibility measurement

The specific magnetic susceptibility of FCC equilibrium catalyst sample was determined using WCF2 magnetic analyser, which is a magnetic balance usually used in laboratory to measure
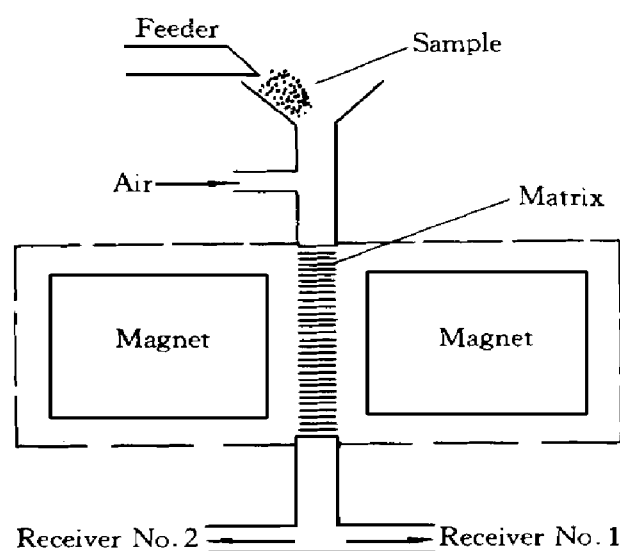

Fig. 1　Magnetic separation unit

Table 1　Physical and chemical properties of catalyst sample

Metal content/%			Specific surface area $S/(m^2 \cdot g^{-1})$	Porosity $/(mL \cdot g^{-1})$	Susceptibility $X/(m^3 \cdot kg^{-1})$	conversion rate $/\%$
Ni	V	Fe				
0. 904 7	0. 013 1	0. 119	137. 8	0. 29	8.9×10^{-8}	65. 3

Table 2　Size and metal distributions of catalyst sample

Size / μm	Yield / %	Ni		V		Fe	
		Grade/ %	Distrib. / %	Grade/ %	Distrib. / %	Grade/ %	Distrib. / %
+ 75	9. 17	0. 502 4	5. 16	0. 011 5	8. 56	0. 224 5	16. 05
+ (63~ 75)	12. 18	0. 681 5	9. 29	0. 011 8	11. 67	0. 130 0	12. 34
+ (45~ 63)	50. 60	0. 891 1	50. 47	0. 012 2	50. 12	0. 113 3	44. 70
+ (38~ 45)	7. 67	0. 990 9	8. 51	0. 012 6	7. 87	0. 114 1	6. 82
- 38	20. 38	1. 164 5	26. 57	0. 013 2	21. 78	0. 126 5	20. 09
Total	100. 00	0. 893 4	100. 00	0. 012 2	100. 00	0. 128 3	100. 00

magnetic susceptibility of the weakly magnetic minerals[7].

The balance employs the Faraday method of weighing a sample in gravitational and magnetic fields. The magnetic force on FCC equilibrium catalyst sample of mass m in a non-uniform magnetic field can be written as

$$F_m = m(\chi / \mu_0) B(dB/dz) \qquad (1)$$

where χ is the specific magnetic susceptibility in m^3/kg, μ_0 is the permeability in vacuum taken as $4\pi \times 10^{-7} H/m$, B is the magnetic induction in T, and dB/dz is the field gradient in T/m. The field gradient is confined to the z direction by the shape of the pole pieces. Since the magnetic induction is constant, then

$$B(dB/dz) = \text{constant} \qquad (2)$$

Hence, the specific magnetic susceptibility can be given by

$$\chi = \frac{F_m \mu_0}{mB(dB/dz)} \qquad (3)$$

From equation 3, the susceptibility of FCC equilibrium catalyst can be calculated.

2. 4 Activity test

The activities of the equilibrium catalyst, the magnetic particles and the nonmagnetic particles were evaluated in a fixed bed microreactor under similar industrial operating conditions[8]. Dagang standard diesel oil was used in activity test. The reaction was carried out at a reaction temperature of 460 ℃, a liquid space velocity of $16\,h^{-1}$, a reaction time of 70 s and a catalyst loading of 5 g.

3 RESULTS AND DISCUSSION

3. 1 Effect of magnetic field intensity

Fig. 2 shows the effect of magnetic field strength at a constant carrier air flowrate on the mags yield, its magnetic susceptibility and the contents of nickel, vanadium and iron in the magnetic fraction. As shown in Fig. 2, as magnetic field intensity increased, mags yield also increased while magnetic susceptibility of mags decreased, because the catalyst portion of even the lower magnetic susceptibility was also caught in the matrices of HGMS. Increased magnetic field intensity also gave rise to decrease in the con-

tents of nickel and iron in the magnetic fraction, which suggested that a separation according to
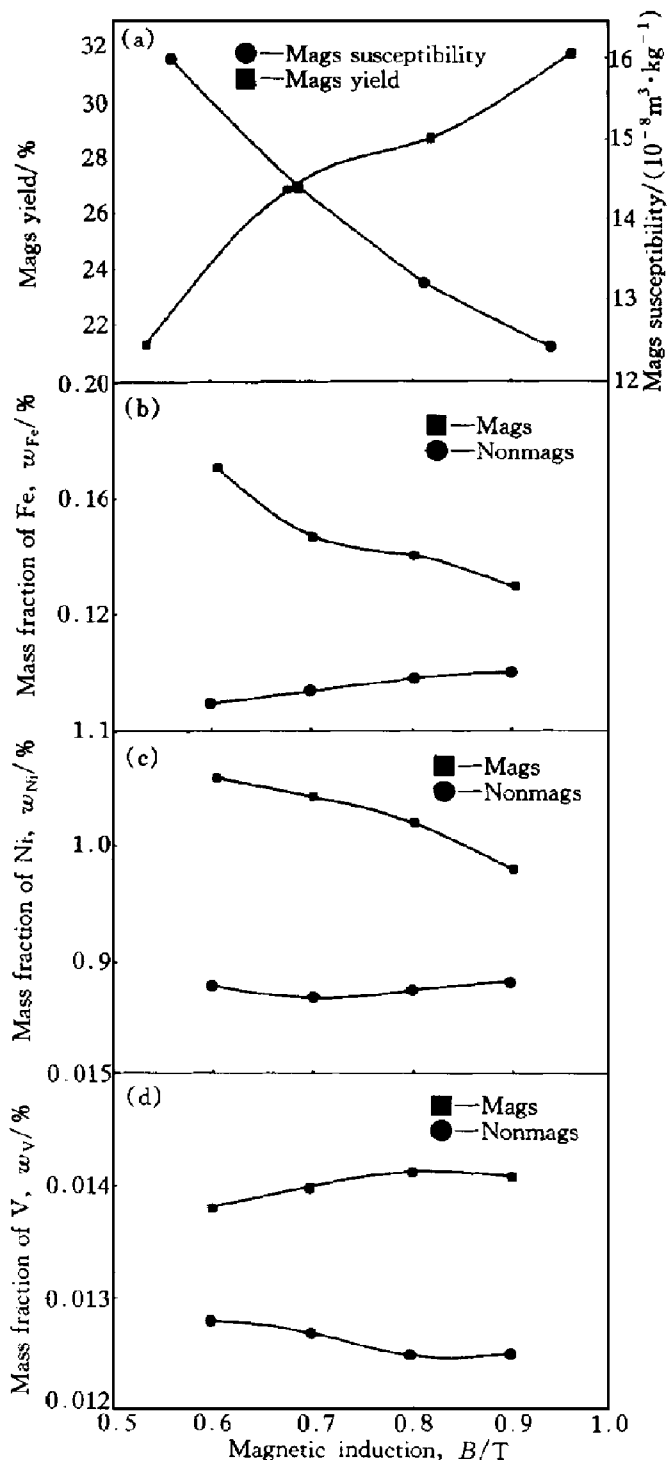

Fig. 2 Effect of magnetic induction on mags yield and susceptibility
(a) and on contents of iron (b), nickel (c) and vanadium (d) in magnetic and nonmagnetic fractions at carrier air flowrate 0. 25 m/ s

susceptibility is the same as the separation according to the metal contents of the catalyst. It is also noticed that vanadium was less sensitive to the variations of magnetic field intensity, due to the small vanadium content and the low magnetic susceptibility of vanadium.

3.2 Effect of carrier air flowrate

In Fig. 3, the mags yield and the contents of iron, nickel and vanadium in the magnetic fraction are plotted against the flowrate of the carrier air at a constant magnetic field intensity. As seen in Fig. 3, the higher carrier air flowrate was, the lower the mags yield was and the higher the contents of iron, nickel and vanadium became in the magnetic fraction. The results indicate that only catalyst particles of higher magnetic susceptibility can be captured on the matrices at the carrier air of higher velocity.

3.3 Magnetic separation of FCC equilibrium catalyst

Magnetic separations of FCC equilibrium catalyst were carried out using high gradient magnetic separator under various operating conditions. Contents of iron, nickel and vanadium are summarized in Table 3. As shown in the table, catalyst of higher metal content can be obtained as mags and catalyst of lower metal content as nonmags. These results suggest that the catalyst contaminated highly by metal can be selectively removed by adjusting magnetic field intensity and the carrier air flowrate.

3.4 Activity evaluation

The activities of equilibrium catalyst, mags and nonmags were evaluated in a fixed bed microreactor. These results are summarized in Table 4. A clear difference is noticed between the conversion rates of mags and those of nonmags. The results of Table 4 show that in tests No. 1 to 3, the conversion rates of the nonmagnetic particles are close to those of fresh catalyst, which suggests these nonmagnetic particles retain high catalytic activity and can be returned to FCC unit for recycling, which will permits much saving of the amount of the make-up fresh catalyst and give rise to a considerable reduction of

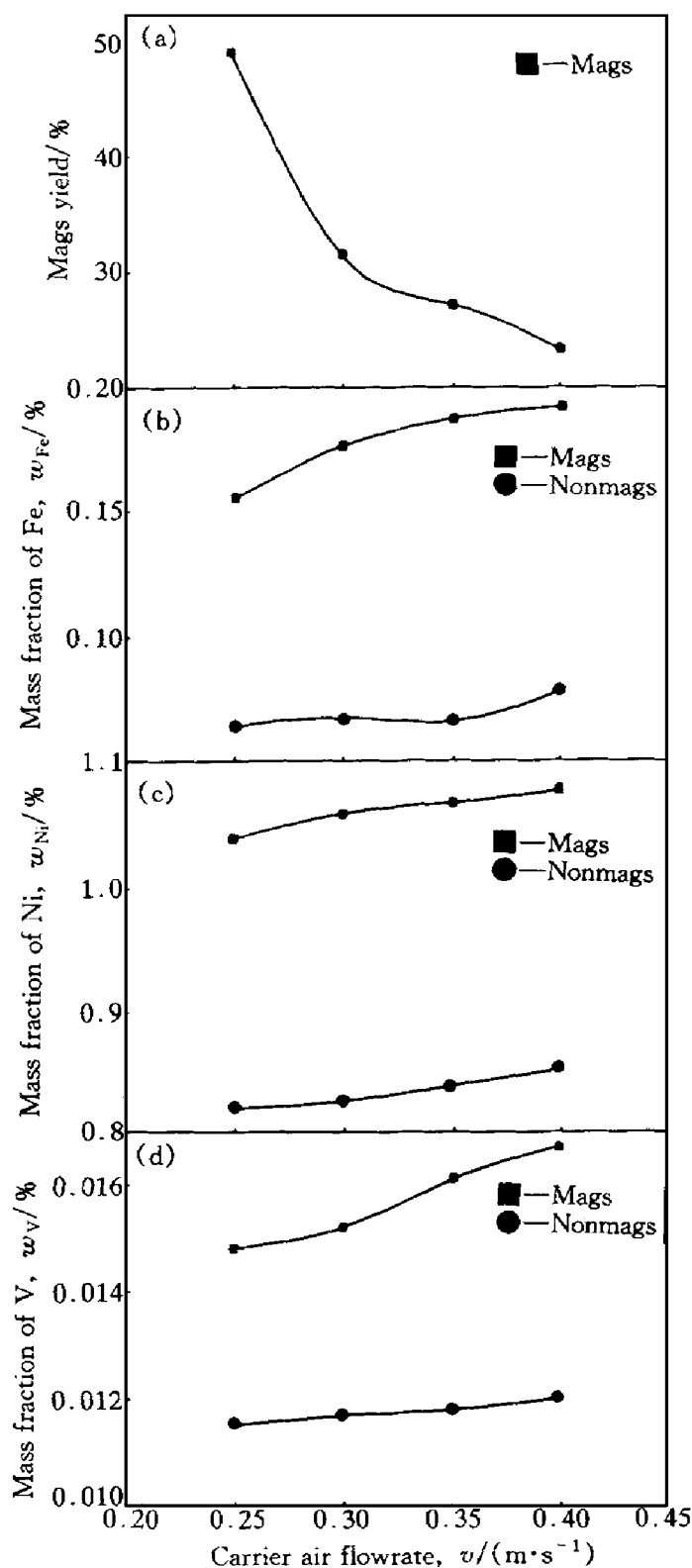total catalyst consumption in residual oil FCC processing.

Fig. 3   Effect of carrier air flowrate on mags yield (a) and on contents of iron (b), nickel (c) and vanadium (d) in magnetic and nonmagnetic fractions at magnetic induction 0.5 T

Table 3　Results of magnetic separation

Test No.	Magnetic induction B/T	Air flow rate V/(m·s^{-1})	Feed m/g	Yield /%	Metal Ni	Metal Fe	Metal V
						w/%	
1	0.5	0.30	25	M 17.2 N 82.8	1.443 8 0.807 2	0.203 1 0.096 4	0.017 5 0.013 4
2	0.5	0.25	20	M 25.4 N 74.6	1.085 2 0.835 1	0.179 2 0.089 7	0.015 1 0.012 7
3	0.6	0.25	15	M 34.7 N 65.3	1.078 3 0.821 4	0.146 5 0.090 5	0.014 2 0.013 2

Note: M —Mags; N —Nonmags

Table 4　Micro-activity test results

Test No.	Conversion rate/%			
	Mags	Nonmags	Withdrawn catalyst	Fresh catalyst
1	59.6	70.3	65.3	72.0
2	62.4	68.8	65.3	72.0
3	62.0	68.1	65.3	72.0

4　CONCLUSIONS

(1) The catalyst contaminated highly by metal can be selectively separated from the cata-lyst contaminated lightly by means of high gradi-ent magnetic separation.

(2) The conversion rates of nonmagnetic particles are close to those of fresh catalyst. These particles retain high catalytic activity and can be returned back to the circulating system of FCC unit for reuse.

(3) A magnetic separation of the with-drawn equilibrium catalyst by HGMS can give rise to a considerable reduction of total catalyst consumption in residual oil FCC processing and it is advantageous economically.

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