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Evaluation and modelling of the separation of anthracite in the hindered-settling column

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Abstract: This study was performed to develop the method for producing industrial coal sources by cleaning Korean anthracite. Laboratory hindered-settling separation column was set and three coal samples were used for tests. Tests were conducted to evaluate the effects of the major operating variables, teeter water flow rate and relative column pressure (set point). Additional tests were performed to elevate the yield and properties of the products using air bubble injecting process. In results, nice products were obtained with high teeter water flow rate and air bubble injection. Also, model of continuous hindered-settling separation process was established to assist the evaluation of the equipment and several operating variables, such as dispersion, teeter water flow rate, feeding rate, etc.

1. Introduction

Hindered-settling separation columns are used as the equipments for many metallurgical processes, because of its simple operating process and a large capacity. And recent improvements in column design and control system make it be applied to many other industrial fields, such as environmental field. Hindered-settling separation is to separate the particles in hindered-settling conditions by their own settling velocity decided by their size and density Especially, hindered-settling condition emphasizes the effect of density in determining their final settling velocities. So hindered-settling separation processes make it easy to separate the particles having similar densities.

The objective of this study is to investigate the efficiency of hindered-settling column for recovering carbon from Korean anthracite for industrial use. Korean anthracite generally has high ash content and this can create the hindered bed that is necessary to operate the hindered-settling processes. For the study, laboratory scale hindered-settling column was set and tests to evaluate the effect of two operation variables, teeter water flow rate and relative column pressure (i.e. set point), were conducted.

Also, mathematical model of continuous hindered-settling process was constructed to evaluate the effects of several operating variables and to find optimum operating condition and design. The model is based on the convective-diffusion equation and batch hindered-settling equations. Simulations were carried out to evaluate column performance for several operating variables, such as dispersion, teeter water flow rate, set point and feeding rates.

2. Hindered-settling separation tests

Test samples

Three types of Korean anthracite coal, referred as Coal 1, Coal 2 and Coal 3, respectively, were prepared for the tests. Jaw crusher and roll crusher was used to make proper size distributions for the tests. Basic properties of each sample and size distribution is given in Table 1 and Table 2. Coal 1 and Coal 2 was classified from 0.17 to 2.0 mm and Coal 3 was classified from 0.21 to 2.0 mm.

Table 1. Basic properties of the sample materials.

Properties	Coal 1	Coal 2	Coal 3
Moisture, %	4.2	6.2	3.5
Volatile matter, %	6.5	5.1	4.8
Fixed carbon, %	41.0	52.4	41.0
Ash, %	48.3	36.2	50.7

Table 2. Size distribution of three coal samples.

Size, mm	Coal 1		Coal 2		Coal 3	
	wt.%	cum. wt.%	wt.%	cum. wt.%	wt.%	cum. wt.%
+ 1.68	18.34	100.00	7.06	100.00	16.07	100.00
1.68 - 1.19	14.68	81.66	15.17	92.94	21.65	83.93
1.19 - 0.84	12.47	66.98	15.16	77.77	19.21	62.28
0.84 - 0.61	13.66	54.51	13.91	62.61	14.70	43.06
0.61 - 0.42	10.82	40.85	14.94	48.70	13.85	28.36
0.42 - 0.30	14.74	30.03	17.46	33.77	9.18	14.51
0.30 - 0.21	9.37	15.29	12.48	16.31	5.33	5.33
- 0.21	5.91	5.91	3.83	3.83	-	-

Test equipment

The hindered-settling separation column was fabricated using 152.4mm inner diameter and 1,240mm length acrylic pipe. Volumetric feeder was set at the top of the column and pressure gauge, teeter water dispenser and pinch valve were set at the bottom of the column. Pressure gauge measures the pressure inside the column and PID controller convert it as the relative pressure value, i.e. set point. The schematic of the equipment is given in Fig. 1.

In addition, for the air bubble injection tests, in-line mixer was set inside the teeter water tube and 454g/ton Coal of MIBC was mixed with teeter water as frother.

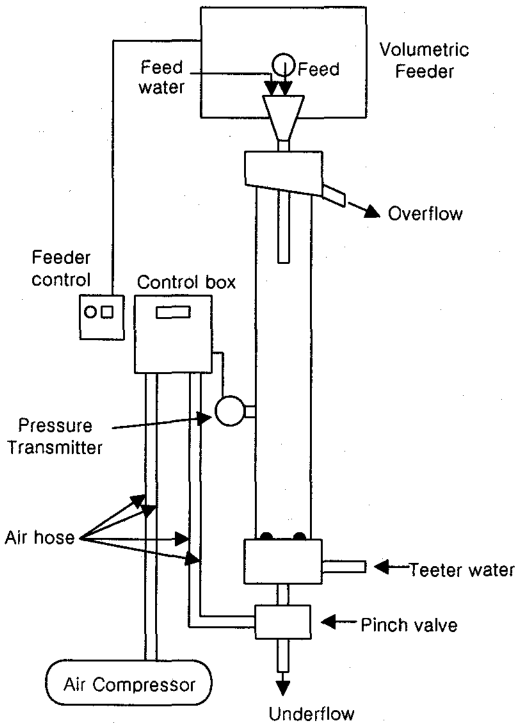

Fig. 1. Schematic of the laboratory hindered-settling separation equipment.

Test conditions

To investigate the effect of set point, 20, 25 and 30 of set point were used with 5.76L/min of teeter water flow rate and the effect of teeter water flow rate was evaluated at 3.84, 5.76, 7.68 and 9.60L/min of teeter water flow rate with set point at 30.

In all the tests, feed water flow rate for smooth material supply was 1.92L/min and feeding rate of sample was 2kg/min

3. Results and discussions

Effect of set points

Yields and ash contents with various set points are given in Table 3. There is little change in properties of products, but slight increase of yield was observed in coarse particles. Particularly, the amount of under 0.21mm materials increase, it is thought because of the breakage of the particle or dissociation of the clay particles during the tests. Compared to the raw feed material, 2~3 times of under 0.21mm material was obtained, and it affects to whole recovered material properties to the bad side. Total ash contents were about 30% in all the tests and total combustible material contents were over 70%. But for over 0.21mm materials, less than 15% of ash content was obtained whereas the combustible material contents were under 50%. So need for other methods to improve the product properties raised.

Table 3. Yields and ash contents (%); various set points.

Set point		20		25		30	
Sample	Size, mm	Yield	ash	Yield	ash	Yield	ash
Coal 1	+0.21	16.2	8.3	29.3	9.2	22.3	10.3
	-0.21	100	39.9	100	39.5	100	42.0
	Total	43.8	30.3	58.1	27.5	46.0	29.9
Coal 2	+0.21	1.55	21.1	2.3	19.5	2.61	21.3
	-0.21	78.8	29.3	68.4	32.1	94.3	29.8
	Total	13.8	28.1	16.6	30.1	22.4	28.2
Coal 3	+0.21	24.5	14.3	16.3	11.8	28.3	13.1
	-0.21	100	39.4	100	37.3	100	39.0
	Total	35.0	22.7	35.7	26.3	45.8	23.8

Effect of teeter water flow rate

Table 4 gives the result of separation tests with various teeter water flow rates of 3.8, 5.7, 7.6, and 9.5L/min at set point of 30. As teeter water flow rates increased, the yields increased continuously definitely, whereas ash contents remained at about 30%. The combustible material contents also increased with increase of teeter water flow rate, especially, 95% of total combustible material was recovered at 9.5L/min with Coal 1. In this case, with over 0.21mm material, 85% of combustible material was recovered and at that time ash content was about 14%. It indicates this condition is close to the optimum operating conditions.

Table 4. Yields and ash contents (%); various teeter water flow rates.

Flowrate(L/min)		3.8		5.7		7.6		9.5	
Sample	Size, mm	Yield	ash	Yield	ash	Yield	ash	Yield	ash
Coal 1	+0.21	6.3	7.6	22.3	10.3	30.3	12.5	41.8	14.0
	-0.21	100	34.7	100	42.0	100	45.8	100	46.1
	Total	32.8	30.6	46.0	30.0	53.1	30.9	69.0	30.8
Coal 2	+0.21	2.6	18.0	14.0	20.0	18.7	22.7	32.0	24.2
	-0.21	100	21.1	100	27.8	100	31.0	100	32.5
	Total	24.1	20.9	37.1	25.3	39.1	27.9	52.5	28.6
Coal 3	+0.21	10.2	11.2	28.3	13.1	30.0	15.5	45.4	19.1
	-0.21	100	36.3	100	39.0	100	40.1	100	41.5
	Total	26.5	27.2	45.8	23.8	46.5	25.2	61.6	25.9

Effect of air bubble injection

To obtain the improved recovery and low ash content, air bubble injection tests were conducted to increase the yield of hydrophobic carbon particles. Table 5 shows the air bubble injection tests. In all the tests, total yield increase over 60% and total combustible material contests from 65% to 90%. In the case of over 0.21mm materials, it shows low than 15% of ash content and 50~85% of combustible material content. It indicates air bubble injection process is very effective in recovering carbon. Also, with proper teeter water flow rate, air bubble injection process can achieve more effective coal cleaning process.

Table 5. Yields and ash contents (%); air bubble injection.

Set point		20		25		30	
Sample	Size, mm	Yield	ash	Yield	ash	Yield	ash
Coal 1	+0.21	24.6	9.8	-	-	41.7	13.6
	-0.21	100	43.6	-	-	100	44.3
	Total	45.6	29.3	-	-	61.4	28.0
Coal 3	+0.21	48.6	14.5	52.7	11.3	57.1	14.6
	-0.21	100	40.5	100	40.6	100	41.6
	Total	66.1	22.4	67.2	18.8	71.5	21.2

Modelling of continuous hindered-settling separation

To develop the continuous hindered-settling separation model, hindered-settling velocity equation and batch hindered-settling separation model, established by Concha and Almendra (1979) and Lee (1989) were used with mass balance equation and convective-diffusion equation. To calculate volume balance of solid, a finite difference solution scheme was applied. Column was divided to n elements, similar to Fig. 2, and proper boundary conditions were used for special elements, such as feeding element, top element and bottom element.

To evaluate the application of the conducted hindered-settling model, simulations were carried out for several operating parameters, such as diffusion coefficient (Dc), teeter water flow rate, set point and feeding rate.

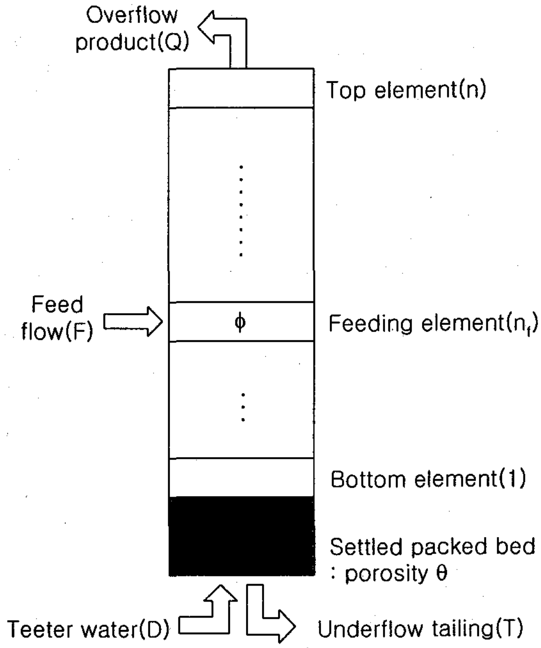

Fig. 2. Partitioning of the hindered-settling column.

Effect of diffusion coefficient (Dc)

Simulations were performed to evaluate the effect of diffusion coefficient, Dc. As shown in Fig. 3, particle recovery increased with increasing Dc, especially with lighter material. It is because lighter material affect by diffusion easily than dense particle.

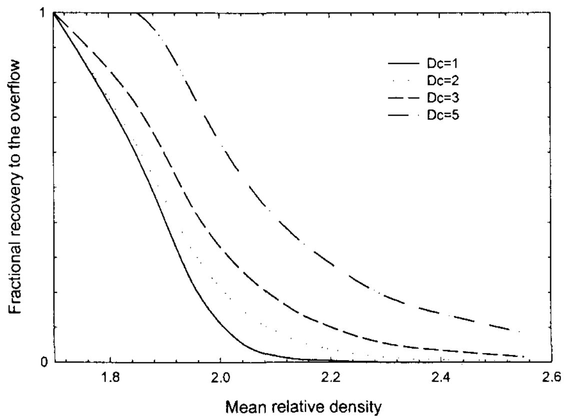

Fig. 3. Fractional recovery curves for various Dc.

Effect of teeter water flow rate

Fig. 4 gives the simulation result for various teeter water flow rate. As shown in the figure, recovery of material increases dramatically with increase of flow rate. This trend is very inspirable. But elevated yield of dense material can also increase the ash content, so the selection of appropriate teeter water flow rate, considering ash content, will be important in real operation.

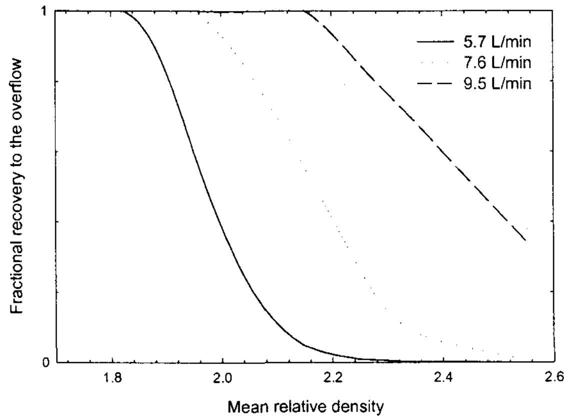

Fig. 4. Fractional recovery curves for various teeter water rates.

Effect of set point

Effect of set point is not remarkable. But change in set point affect to the point which most separation process takes place. This is thought what influence in separating process.

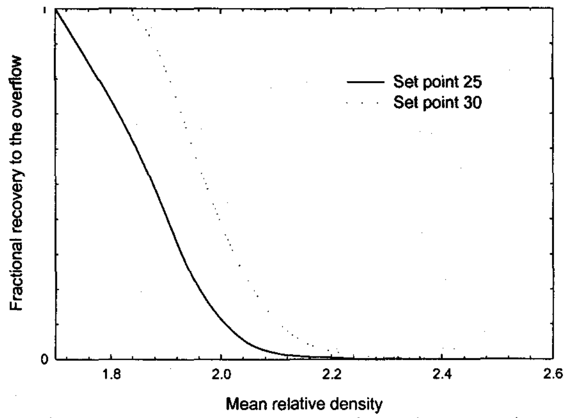

Fig. 5. Fractional recovery curves for various set points.

Effect of feed rate

Feed rate is one of the factors, which decide the average solid content when the process reaches at the steady state If feed rate increase, generally solid content increase, and it makes dense particles move to upward. Fig. 6 gives the result of simulation with 2.0kg/min and 2.5kg/min of feed rate. Increasing rate in yield of dense particles is more notable because of the characteristics of hindered-settling process that emphasize the effect of density.

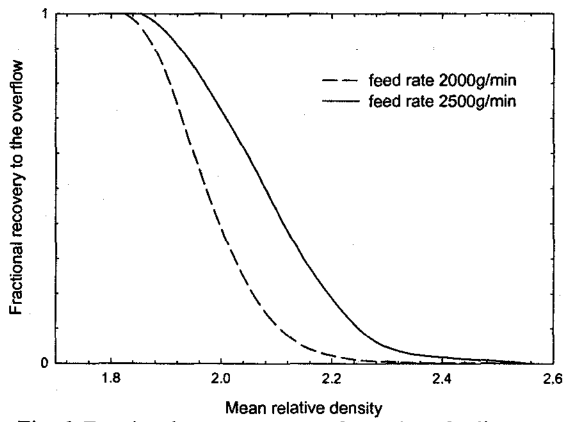

Fig. 6. Fractional recovery curves for various feeding rates.

4. Conclusions

Tests were conducted to evaluate the effect of teeter water flow rate and set point in operating hindered-settling separation process. Set point has little influence in efficiency, whereas increase of teeter water flow rate increases the recoveries and ash contents. Especially, with high teeter water flow rate, 45% of yield, 85% of combustible material content and 15% of ash content was obtained for over 0.21mm material. It implies this condition can be optimum operating condition. But most of the tests the efficiency is not up to the expectation. So additional tests were conducted using air bubble injection process, which improves the yield of hydrophobic carbon particles. In these tests, combustible material contents were increased to about 50~87% in over 0.21mm particles.

Simultaneously with the experimental work, modelling of the continuous hindered-settling separation was developed. Using the model, simulations were carried out to evaluate the column performance for several operating variables, such as dispersion, teeter water flow rate, set point and feed rate.

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References

Young, M. L., 1999, Evaluation of a hindered-settling column for size/density separations, M.S. thesis, Pennsylvania state university, University Park, Pennsylvania

Concha, F. and Almendra, E. R., 1979, Settling velocity of particulate systems, 2. Settling velocity of suspension of spherical particles, International journal of mineral process, No. 6, 31-41.