Physicochem. Probl. Miner. Process. 51(2), 2015, 427−434

www.minproc.pwr.wroc.pl/journal/

Physicochemical Problems of Mineral Processing

ISSN 1643-1049 (print)
ISSN 2084-4735 (online)

Received September 5, 2014; reviewed; accepted November 21, 2014

DESIGN AND EXPERIMENTS USING A SPIRAL-LIQUID-SOLID FLUIDIZED BED SYSTEM

Jie SHA, Long LIANG, Bo LIU, Guangyuan Xie, YAOLI PENG

Key Laboratory of Coal Processing and Efficient Utilization (Ministry of Education), School of Chemical Engineering and Technology, China University of Mining and Technology, Xuzhou 221116, Jiangsu, China, e-mail: xgywl@163.com; peng_yaoli@163.com.

Abstract: Liquid-solid fluidized bed (LSFB) has been widely known and used for separation of coarse coal particles (normally larger than 0.25 mm). The process of separation by LSFB needs fluidization water from the bottom to the top of LSFB. The fluidization water is formed by the water addition at the bottom of the LSFB. Normally the quantity of water addition is very large, which increases the burden of water treatment in coal preparation processes. In this investigation, a spiral unit was introduced into the conventional LSFB and the new separation equipment was named S-LSFB. The spiral unit could provide an upward force for the upward movement of coarse low density coals into the concentrate, and hence the quantity of water addition for fluidization water may be reduced. Samples of 0.5-0.25 mm size fraction coal were used to investigate the difference in separation performance between S-LSFB and LSFB. It was found that the separation performance of S-LSFB was nearly equal to that of LSFB. S-LSFB may be beneficial to coarse coal separation in coal preparation plant since the burden of water treatment can be reduced by the application of S-LSFB.

Keywords: *liquid-solid fluidized bed, spiral unit, coal separation, water quantity*

Introduction

Fine coal (<0.5 mm) is usually beneficiated by flotation. However, the size fraction of 0.5-0.25 mm may be difficult to float since these coals have relative high weight (Jameson, 2010; Kohmuench et al., 2012). The size fraction of 0.5-0.25 mm can also considered as coarse coal slime in coal preparation industry. The coarse coal is usually difficult to separate by both gravity separating equipment (jig and dense medium cyclone) and flotation equipment (flotation cell and flotation column) (Li, 2008; Fan et al., 2010). As a result, Knelson concentrator, spiral concentrator, small diameter cyclone and liquid-solid fluidized bed (LSFB) are used in coarse coal separation (Uslu et al., 2012; Mukherjee and Mishra, 2007; Sha et al., 2012). Liquid-solid fluidized bed

http://dx.doi.org/10.5277/ppmp150205

(LSFB) is created based on the fluidization technique and used to separate coarse coal particles ranging from 0.2 to 2 (1) mm. The separation process of coarse coal particles in the liquid-solid fluidized bed has been observed by many researchers (Chu et al., 2012; Ganguly, 1986; Mukherjee and Kumar, 2009; Sha et al., 2011). Computational fluid dynamics (CFD) simulation technologies have been used to investigate the separation performance of particles in the liquid-solid fluidized bed and also the flow behavior in fluidized bed has also been investigated (Zhang et al., 2012; Wang et al., 2012). Meanwhile, the changes in size, density and ash content of coal particles on the column axis have been observed (Li et al., 2013). Usually, a wide size range of coal particles in LSFB may worsen the separation process (Li, 2008; Sha et al., 2012; Galvin et al., 2010). The separation process in LSFB needs the fluidization water to form a separation density. The fluidization water is formed by the water addition at the bottom of LSFB. Normally the quantity of water addition is very large, which may increase the burden of water treatment in coal preparation processes. As a result, coal preparation plant makes many efforts into the dewatering of coal products and the treatment of water slurry since water should be reused in coal separation processes. Especially, water should be economized in some arid and semiarid areas. The water addition in the separation process of LSFB may be antinomy to water conservation.

The upward fluidization water, which is the main force of coarse coal particles separation in LSFB, is required to be uniform in both axial and radial directions. Usually, it is easy to provide a more even radial fluidization water with a water distributor (Maharaj et al., 2007). However the uniform of axial direction is hard to implement because of the change of solid volume concentration in the axial direction, which cause a reduction in the force to particles in the top area of the cell and thus not enough flow. Recently, a lot of attempts of changing the structure to overcome the non-uniform of axial were observed to improve the separation effect, such as using jigging water (Galvin et al.,2002), combining flotation and fluidization (Sarkar et al., 2008; Das et al., 2009), and joining a series of inclined plate (Galvin et al., 2010; Iveson et al., 2014).

In this investigation, a spiral unit was introduced into the conventional LSFB and the new separation equipment was named S-LSFB. The spiral unit could provide an upward force for the upward movement of coarse low density coals into the concentrate, and hence the quantity of water addition for fluidization water may be reduced. The separation performance of S-LSFB will be compared with that of LSFB and some constructive suggestions will be obtained throughout this paper.

Materials and experimental procedure

Materials

Samples of 0.5-0.25 mm size fraction coal were used to investigate the difference in separation performance between S-LSFB and LSFB. The results of the float-sink tests are shown in Table 1. Table 1 is a summary of the cumulative floats at a specific density. It indicates that a clean coal with yield of 86.02% and 11.89% ash content can be obtained at a separation density of 1.8 g/cm^3. The theoretical clean coal yield is 79.10% with ash content of 9.36%. The coal samples contain many low density and ash coal particles. In addition, the yields of near-gravity materials at gravities of 1.5 to 1.7 g/cm^3 range from 15.65% to 6.92%. It shows that the coal samples are easy to separate.

Table 1 Float-sink test results of 0.5-0.25 mm size fraction

Gravity range (g/cm^3)	Float		Cumulative floats		Cumulative sinks	
	Weight (%)	Ash (%)	Weight (%)	Ash (%)	Weight (%)	Ash (%)
<1.30	31.57	3.24	31.57	3.24	100.00	19.76
1.30-1.40	31.88	8.80	63.45	6.03	68.43	27.37
1.40-1.50	9.42	19.05	72.87	7.71	36.55	43.58
1.50-1.60	6.23	28.57	79.10	9.36	27.13	52.10
1.60-1.80	6.92	40.84	86.02	11.89	20.90	59.11
>1.80	13.98	68.15	100.00	19.76	13.98	68.15

Experimental system

Figure 1 is a picture of the LSFB. The LSFB is 100 mm in the diameter and 810 mm in the height. The coal slurry was fed into LSFB from the feed inlet. The upward water quantity was fixed at 400, 500, 600 and 700 dm^3/h from the bottom of the liquid-solid fluidized bed. The pulp taken from concentrate and tailings was collected, filtered, dried and analyzed by the float-sink tests.

Figure 2 is the picture of S-LSFB. S-LSFB is 100 mm in the diameter and 700 mm in the height. The coal slurry was fed into S-LSFB from the feed inlet. The upward water was fed into S-LSFB by a tube and the quantity of water was adjusted by a valve. The upward water quantity was fixed at 100, 150 and 200 dm^3/h from the bottom of the liquid-solid fluidized bed. A spiral unit was introduced into the conventional LSFB. The diameter of spiral blade is 96 mm and the pitch is 100 mm. The blade has a thickness of 2.5 mm. The revolution speed of spiral blade was adjusted by a motor with a power of 1.5 kW. The direction of rotation was at a counterclockwise direction. The revolution speed was fixed at 247, 261 and 276 rpm. The feed density of LSFB or S-LSFB is 300 g/dm^3. The pulp taken from concentrate and tailings was collected, filtered, dried and analyzed by the float-sink tests. Both the results of LSFB and S-LSFB are obtained by dozens of measurements (in a period of 30 min) and representative and reproducible.

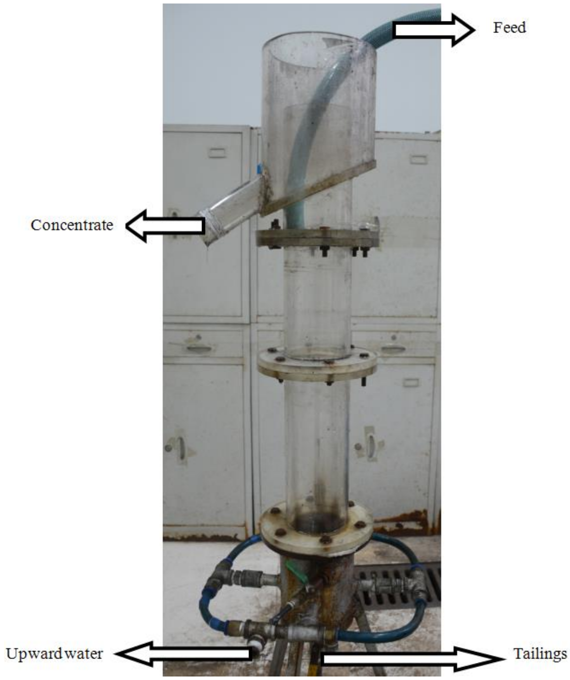

Fig. 1. Picture of liquid-solid fluidized bed (LSFB)

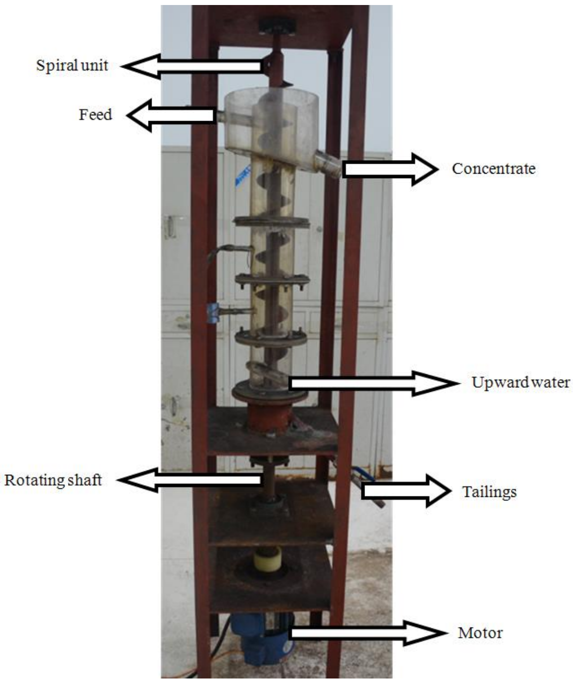

Fig. 2. Picture of spiral-liquid-solid fluidized bed (S-LSFB)

Results and discussion

Separation of LSFB

As shown in Table 2, both the concentrate yield and concentrate ash increase with the increase of upward water quantity. The organic efficiency is also increased. In this investigation, the concentrate ash should be controlled below 10%. Therefore, the concentrate obtained at the upward water quantity of 600 dm^3/h is used as the result at the optimum operating condition. The upward water flow velocity increases with the increase of upward water quantity. Higher flow velocity can lift more coal particles (especially, low density coal particles). It means that high upward water flow velocity can produce a high separation density (Wang et al., 2009). The separation efficiency of liquid-solid fluidized bed is affected by many factors, such as particle size, yield of near-gravity materials and particle density distribution (Mukherjee and Mishra, 2007). In some cases, some larger particles with low density are lost in tailings while some smaller particles with high density are carried into concentration. This causes a mismatch of both tailings and concentration. However, the separation efficiency in this investigation is very high compared with other liquid-solid fluidized beds in the literature (Sha et al., 2011; Li, 2008). The high separation efficiency in this investigation is due to the size composition of coal samples is 0.5-0.25 mm which is a narrow size range. A narrow size range is suitable and easy to separate compared with wide size range (Mukherjee et al., 2009).

Table 2. Separation results of coal samples in liquid-solid fluidized bed (LSFB)

Upward water quantity (dm^3/h)	Concentrate		Tailings		Organic efficiency (%)
	Ash (%)	Yield (%)	Ash (%)	Yield (%)	
400	7.09	55.37	35.47	44.63	78.65
500	8.57	63.86	39.52	36.14	83.58
600	9.96	68.77	41.32	31.23	84.59
700	11.07	78.19	50.89	21.81	92.65

Separation of S-LSFB

Table 3 shows the separation results of coal samples in spiral-liquid-solid fluidized bed (S-LSFB). Both the concentrate yield and concentrate ash increase with the increase of revolution speed at the same upward water quantity. A higher revolution speed produces a higher upward water flow, and hence more coal particles (especially, low density coal particles) can be lifted into the overflow. Meanwhile, both the concentrate yield and concentrate ash increase with the increase of upward water quantity at the same revolution speed. It indicates that a higher quantity of upward water can also increase both the concentrate yield and concentrate ash. The best result can be obtained at the upward water quantity of 150 dm^3/h and the revolution speed of 247 rpm since the concentrate ash should be controlled below 10% in this investigation.

In this investigation, a spiral unit was introduced into the conventional LSFB. The spiral unit can produce a lift force for the upward moving of coal particles. Duan et al. (2014) used an inflatable unit to produce bubbles for improving the separation efficiency of liquid-solid fluidized bed. The bubbles could increase the lift force for particles into the concentration and save the upward water quantity. The upward water is needed in the separation process of LSFB, which increase the burden of water treatment in coal preparation processes. Therefore, the water used in coal preparation processes should be controlled to save both the water resource and the economy.

Table 3. Separation results of coal samples in spiral-liquid-solid fluidized bed (S-LSFB)

Upward water quantity (dm^3/h)	Revolution speed (r/min)	Concentrate		Tailings		Organic efficiency (%)
		Ash (%)	Yield (%)	Ash (%)	Yield (%)	
100	247	8.31	54.35	35.77	45.65	71.98
100	261	8.95	56.43	36.27	43.57	72.35
100	276	10.41	63.57	39.07	36.43	77.06
150	247	9.89	67.27	43.38	32.73	83.15
150	261	10.22	69.10	44.63	30.90	84.37
150	276	12.03	73.40	45.18	26.60	85.06
200	247	11.29	73.15	46.90	26.85	86.47
200	261	13.37	83.46	58.58	16.54	93.88
200	276	13.91	85.03	60.26	14.97	94.69

Comparison of LSFB and S-LSFB

Table 4 shows the best results from LSFB and S-LSFB. It indicates that the organic efficiency of LSFB is 84.59% which is a little higher than that of S-LSFB (83.15%). Even though the organic efficiency of S-LSFB is a little lower than that of LSFB, the upward water quantity for S-LSFB is a lot lower than that of LSFB. The upward water quantity for LSFB is four times as large as that of S-LSFB. It is believed that the burden of water treatment using LSFB is much higher than that using S-LSFB. However, an additional energy input is given into the separation process of S-LSFB. Maybe the comprehensive benefits of using S-LSFB instead of LSFB should be considered further.

Table 4. Comparison of the best results from LSFB and S-LSFB

Separation system	Upward water quantity (dm^3/h)	Revolution speed (r/min)	Concentrate		Organic efficiency (%)
			Ash (%)	Yield (%)	
LSFB	600		9.96	68.77	84.59
S-LSFB	150	247	9.89	67.27	83.15

Conclusions

A spiral unit was introduced into the conventional liquid-solid fluidized bed (LSFB) and the new separation equipment was named spiral-liquid-solid fluidized bed (S-LSFB). The spiral unit can produce the upward water flow, which may reduce the burden of water treatment in the conventional LSFB. A comparison of separation performance of LSFB and S-LSFB was conducted. It was found that the separation performance of S-LSFB was nearly equal to that of LSFB. The organic efficiency of LSFB is 84.59% which is a little higher than that of S-LSFB (83.15%).

With a similar concentrate ash, the upward water quantity for LSFB is four times as large as that of S-LSFB. It indicates that using S-LSFB can reduce the burden of water treatment in the conventional LSFB. The burden of water treatment using LSFB is much higher than that using S-LSFB. However, an additional energy input is given into the separation process of S-LSFB. Maybe the comprehensive benefits of using S-LSFB instead of LSFB should be considered further.

Acknowledgements

This work was supported by the National Natural Science Foundation of China (51374205) and the National Natural Science Foundation of China (51474213). We also want to thank the support of A Priority Academic Program Development of Jiangsu Higher Education Institutions.

References

CHU, Z.F., XIE, J.X., LI, Y. F., 2012, *Effect of properties of materials on solids distribution in a binary mixture liquid-solid fluidized bed,* Journal of China University of Mining and Technology 41(4), 620-623.

DAS, A., SARKAR, B., MEHROTRA, S.P., 2009, *Prediction of separation performance of floatex density separator for processing of fine coal particles,* International Journal of Mineral Processing, 91, 41-49.

DUAN, C.L., ZHAO, Y.M., WU, L.L., SHENG, C., ZHOU, C.Y., CAI, L.H., 2014, *Research on separation of waste printed circuit boards by an inflatable liquid-solid fluidized bed,* Journal of China University of Mining and Technology 43(5), 915-919.

FAN, M.M., TAO, D., HONAKER, R., LUO, Z.F., 2010, *Nanobubble generation and its applications in froth flotation (part IV): Mechanical cells and specially designed column flotation of coal,* Mining Science and Technology, 20(5): 641-671.

GALVIN, K.P., CALLEN, A.M., SPEAR, S., 2010, *Gravity separation of coarse particles using the Reflux Classifier,* Minerals Engineering 23, 339-349.

GALVIN K.P., ZHOU J., WALTON K., 2010, *Application of closely spaced inclined channels in gravity separation of fine particles,* Minerals Engineering, 23:326-338.

GALVIN, K.P., PRATTEN, S.J., LAMBERT, N., CALLEN, A.M., LUI, J., 2002, *Influence of a jigging action on the gravity separation achieved in a teetered bed separator,* Minerals Engineering; 15, 1199–1202.

GANGULY, U.P., 1986, *Elutriation characteristics of solids from liquid-solid fluidized bed systems; part iii: a study of the possible causes of non-linearity in the elutriation of fine particles from fluidized beds,* Canadian Journal of Chemical Engineering 64(1), 171-174.

IVESON, S. M., MASON, M., GALVIN, K.P., 2014, *Gravity separation and desliming of fine coal: pilot-plant study using reflux classifiers in series,* International Journal of Coal Preparation and Utilization 34, 239-259.

JAMESON, G. J., 2010, *New directions in flotation machine design,* Minerals Engineering, 23(11-13): 835-841.

KOHMUENCH, J.N., MANKOSA, M.J., 2012, *Christodoulou L. Practical and proven methods for improving ultrafine and coarse particle recovery,* Separation Technologies for Minerals, Coal, and Earth Resources, 447-456.

LI, Y.F., 2008, *Study on the separation mechanism and application of liquid-solid fluidized bed coarse slime separator,* Xuzhou: China University of Mining and Technology.

LI, Y., ZHAO, W., XU, S., XIA, W., 2013, *Changes of size, ash and density of coal particles on the column axis of a liquid–solid fluidized bed,* Powder Technology, 245:251-254.

MAHARAJ, L., POCOCK. J., LOVEDAY. B.K., 2007, *The effect of distributor configuration on the hydrodynamics of the teetered bed separator,* Minerals Engineering 20,1089-1098.

MUKHERJEE, A. K., KUMAR, A., 2009, *Liquid/solid fluidization its role and limitation in fine beneficiation-A review,* Mineral Processing and Extractive Metallurgy Review 30(3), 280-306.

MUKHERJEE, A.K., MISHRA, B.K., 2007, *Experimental and simulation studies on the role of fluid velocity during particle separation in a liquid–solid fluidized bed,* International Journal of Mineral Processing 82, 211-221.

MUKHERJEE, A. K., MISHRA, B. K., KUMAR, R. V., 2009, *Application of liquid/solid fluidization technique in beneficiation of fines,* International Journal of Mineral Processing, 92(1), 67-73.

SARKAR, B., DAS, A., MEHROTRA, S.P., 2008. *Study of separation features in floatex density separator for cleaning fine coal,* International Journal of Mineral Processing. 86,40-49.

SHA, J., XIE, G., WANG, H., LIU, J., TANG, L., 2012, *Effect of the column height on the performance of liquid-solid fluidized bed for the separation of coarse slime,* International Journal of Mining Science and Technology 22(4), 585-588.

SHA, J., XIE, G.Y., PENG, Y.L., SHI, B.X., 2011, *Hydrodynamics of Coarse Coal Slime and Quartz Particles in a Liquid-Solid Fluidized Bed Separator,* Mechanics, Solid State and Engineering Materials, Advanced Materials Research, 279, 350-355.

WANG, X., JIN, B., ZHONG, W., XIAO, R., 2009, *Modeling on the hydrodynamics of a high-flux circulating fluidized bed with Geldart group A particles by kinetic theory of granular flow,* Energy & Fuels, 24(2), 1242-1259.

WANG, S., GUO, S., GAO, J., LAN, X., DONG, Q., LI, X., 2012, *Simulation of flow behavior of liquid and particles in a liquid-solid fluidized bed,* Powder Technology 224, 365-373.

USLU, T., SAHINOGLU, E., YAVUZ, M., 2012, *Desulphurization and deashing of oxidized fine coal by Knelson concentrator,* Fuel Processing Technology 101, 94-100.

ZHANG, K., WU, G., BRANDANI, S., CHEN, H., YANG, Y., 2012, *CFD simulation of dynamic characteristics in liquid–solid fluidized beds,* Powder Technology 227, 104-110.