Overview of Typical Coal Flotation Flowsheets in China's Coal Preparation Plants

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Abstract: The entrainment of high-ash fine slime severely contaminates clean coal product of traditional flotation cell, leading to serious technical problems such as high ash in clean coal, low recovery, and the sacrifice of the yield of gravity separation to lower the ash content of final product. In order to solve those issues, the performance of FCMC series cyclonic microbubble flotation column and traditional flotation cell were compared. Several typical flowsheets for the separation of coal flotation in China's coal preparation plants (CPPs) were extensively reviewed and deeply explored. Results show that FCMC flotation column is especially suitable for the beneficiation of fine and non-selective coal slime downstream the heavy medium separation. The mixed (one-stage) flotation process utilizing the combination of flotation column and clean coal quick-operating pressure filter is recommended in newly built and retrofitted CPPs. As for those utilizing one-stage flotation flowsheet equipped with traditional flotation cell and pressurized filter, either classified flotation process or secondary flotation for the filtrate of pressurized filter using flotation column and clean coal quick-operating pressure filter is recommended in their technical modifications.

Keywords: Flotation column; Flotation cell; Fine coal slime; Coal flotation process; Coal preparation plant; Pressurized filter; Clean coal quick-operating pressure filter

1 Introduction

China is the largest producer and consumer of coal resources in the world. Coal provides 65–70% of primary energy in China (Zhou et al. 2006, Chen 2012). The quality of the run of mine coal and coal slime increasingly deteriorate with the improvement of mechanization in mining and the increase in exploitation depth. Currently, more than 450 million metric tons of fine coal (the fine fraction with size smaller than 0.5 mm) presents in the raw coal produced annually in China. The fine fraction of coal is difficult to process, and its utilization efficiency is low. The recovery of -0.5 mm fine coal slime, which accounts for 15–25% of raw material, allows us to effectively utilize coal slime resources. It is of great strategic significance and realistic importance to the sustainable development of China's coal industry and environmental protection (Xie et al., 1999, Xie et al., 2004, Xie et al., 2005).

Nowadays, customers in Chinese market require strictly on the quality of clean coal product, and demands lower and lower ash in clean coal. The popularization of dense medium separation technology realizes precise beneficiation of coarse coal particles; however, coal slime entering flotation section is smaller, and its floatability becomes inferior. The entrainment of high ash fine slime in flotation significantly contaminates clean coal, making the clean coal ash of flotation 1-2% higher than that of gravity separation. It also results in low ash in tailing and low recovery of clean coal. The quality of overall clean coal product fluctuates dramatically, which affects the quality of clean coal product and economic benefit of enterprises (Ding 2010, Guo 2013). On one hand, the coal flotation section is the largest barrier for a coal preparation plant (CPP) to enhance its recovery of coal product. On the other hand, the coal flotation section has the greatest potentiality to be improved. In other words, the enhancement of coal flotation performance could be the easiest way to improve the overall recovery of the plant. The major solution to this technical dilemma is seeking a breakthrough in flotation equipment and flowsheet.

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2 Selection of and Performance Comparison between Flotation Devices in China's CPPs

Currently, the approaches for the beneficiation of fine and ultrafine coal particles primarily include froth flotation, bulk-oil flotation and selective flocculation. Among them froth flotation is the most mature and well commercialized technology. The dominant flotation devices in China's CPPs are mechanical flotation cell and flotation column. In China, the mechanical flotation cells were traditionally used as flotation equipment in CPPs. However, those devices had several disadvantages including low separation efficiency, high ash in flotation clean coal, and difficulty in regulating ash. They could not meet end users' requirements on clean coal quality (Wang et al., 2007, Liu, 2012). Therefore, they are gradually replaced by large flotation columns in China's newly built CPPs and in the technical retrofitting of existing plants. (Wang et al., 1999).

As shown in Table 1, the ash of clean coal obtained from floatation cell is 1-2% greater than the required clean coal ash. However, the ash of clean coal obtained from the flotation column can meet the requirements on clean coal quality in the CPPs. Furthermore, flotation column performs a better performance in the separation of -0.045 mm size fraction than flotation cell. Under the same conditions, the ash of the -0.045 mm fraction of clean coal of flotation column is 1-4.5% lower than the counterpart of flotation cell. Therefore, flotation column produces an overall clean coal product that has ash content 1-2% lower in comparison with flotation cell. The high ash fine slime is easier misreported to clean coal in the traditional mechanical flotation cell (equipped with shallow vessel) than in the flotation column (with thick froth layer).

Table 1 Comparison of Clean Coal Ash between Flotation Cell and Column

CPP	Required Clean Coal in Market	Clean Coal of Flotation cell		Clean Coal of Flotation Cloumn	
	Ash /%	Ash /%	-0.045mm Ash /%	Ash /%	-0.045mm Ash /%
Xuzhou Sanjia River CPP	9.00	10.96	13.87	8.45	11.43
Xuzhou Zhangxiaolou CPP	9.00	11.09	14.65	8.97	10.89
Hebei Dongpang Mine CPP	9.00	11.17	14.61	8.25	10.75
Xinwen Panxi Mine CPP	10.00	12.88	16.73	10.02	13.97
Linyi Gucheng CPP	9.00	10.92	14.98	9.09	10.84
Xinwen Longgu CPP	8.50	8.70	13.35	8.42	12.54
Linyi Wanglou Mine CPP	9.00	11.24	14.81	8.91	11.09
Panjiang Jinjia Mine CPP	10.50	12.95	13.88	10.47	12.83
Shanxi Lingshi CPP	9.50	11.22	14.98	9.43	13.99

3 Review on Typical Coal Flotation Flowsheets in China's CPPs

In present, CPPs in China employ primarily flotation cell and flotation column in coal flotation. Because traditional flotation cells are encountering problems including low separation efficiency and high ash in clean coal caused by serious entrainment of high ash fine slime, researchers have been seeking a solution to this technical issue through breakthrough in the design of flotation process. Three representative flotation flowsheets in China's CPPs will be deeply explored in the following section.

3.1 Mixed (one-stage) Flotation Flowsheet

Mixed (one-stage) flotation process is the most commonly used flowsheet in CPPs in China. In a mixed (one-stage) flotation process, the 0.5-0 mm size fraction is separated directly in a flotation cell or a flotation column without classification to produce clean coal and tailing. Flotation feed is prepared in a slurry preparation device or a slurry pre-processor upstream the flotation equipment. Flotation clean coal

is dewatered by a pressurized filter or a quick-operating pressure filter, while tailing is directed to a thickener for settling and clarification. The underflow of thickener is dewatered by a quick-operating pressure filter, and the overflow is recycled. Figures 1 and 2 present such a process equipped with flotation cell and flotation column, respectively.

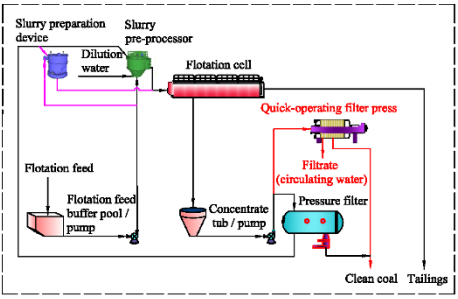

Figure 1. Mixed (single-stage) flotation flowsheet equipped with flotation cell and pressurized filter (or quick-operating pressure filter).

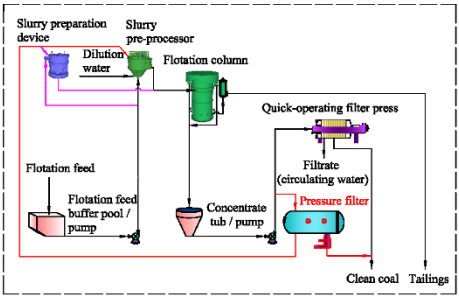

Figure 2. Mixed (single-stage) flotation flowsheet equipped with flotation column and quick-operating pressure filter (or pressurized filter).

Figures 1 and 2 show that the flotation device used in mixed (one-stage) flotation process is either flotation cell or flotation column. As mentioned above, it is concluded that cyclonic microbubble flotation column has superior performance to traditional flotation cell. The flotation column is a preferred option for coal flotation.

As for the dewatering of flotation clean coal, pressurized filter and quick-operating pressure filter are two dominant technologies used in CPPs in China.

Nowadays, clean coal quick-operating pressure filter is gradually employed in China's CPPs. Therefore, mixed (one-stage) flotation flowsheet using the combination of flotation column and quick-operating pressure filter is recommended in newly built and retrofitted CPPs. Figure 3 illustrates a typical flowsheet of the recommended process.

3.2 Classified Flotation Flowsheet

In a classified flotation process, the 0.5-0 mm wide size fraction is first divided into coarse and fine subcategory by a hydrocyclone prior to flotation. Corresponding reagent regimes, and flotation and dewatering equipment are selected for those two subcategories according to their floatability and filtration characteristics. In this manner, the advantages of separation and dewatering in each subcategory are maximized, thus, realizing the precise separation and efficient dewatering of coarse and fine coal slime, respectively. A representative classified flotation process is presented in Figure 4.

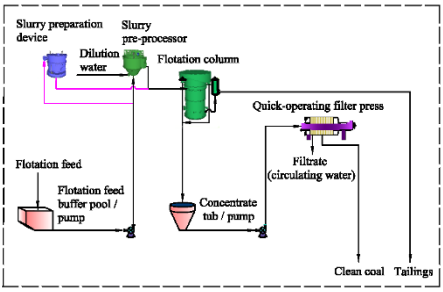

Figure 3. Optimum mixed (one-stage) flotation flowsheet using the combination of flotation column and quick-operating pressure filter.

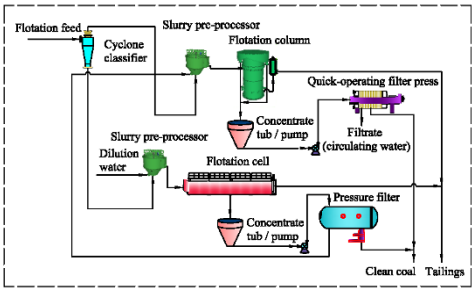

Figure 4. A representative classified flotation flowsheet.

In China, many CPPs employ one-stage flotation process equipped with traditional flotation cell and pressurized filter. The ash content and moisture of clean coal are high. Retrofitting is needed to solve this technical problem. It is preferred to take advantage of existing mechanical flotation cell and pressurized filter to reduce capital investment. Therefore, classified flotation process is adopted. The traditional flotation cell cannot effectively separate -0.074 mm fraction, particularly the -0.045 mm part, and pressurized filter suffers from inferior dewatering performance. The -0.074 mm fraction can be beneficiated by flotation column, and dewatered by quick-operating pressure filter. The coarse subcategory is still processed and dewatered by existing flotation cell and pressurized filter, respectively. Because different reagent regimes and flotation and dewatering devices are used for coarse and fine coal slime, respectively, the performance of the selected devices for flotation and dewatering in each subcategory are maximized. As a result, coarse and fine particles are precisely processed and efficiently dewatered, respectively. This classified flotation process has been successfully applied in Handan Coal Preparation Plant, Hebei, China, and has been proven suitable for the retrofitting of old CPPs.

3.3 Two-stage Flotation Flowsheet

The entrainment of high-ash fine slime seriously contaminates clean coal in traditional flotation cell. Therefore, the ash content of flotation clean coal is high and plants usually sacrifice the yield of gravity separation to lower the ash of final product. In order to resolve this issue, Guohua Technology Group Ltd. proposed the two-stage flotation process as shown in Figure 5.

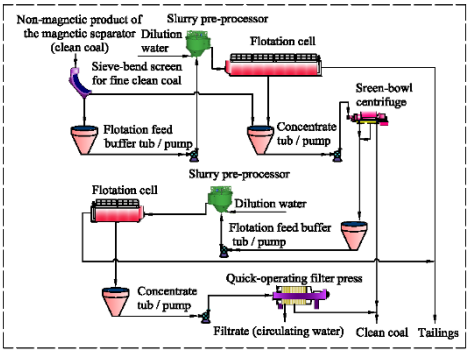

Figure 5. A representative two-stage flotation flowsheet.

Because primary flotation uses traditional flotation cell, flotation clean coal has a high ash content. The ash of the non-magnetic product of magnetic separator is also high. Therefore, the ash of dewatered clean product from the centrifuge is high. The particles in the secondary flotation cell are finer as the feed is the filtrate of centrifuge. As a result, the clean coal of secondary flotation, which will be mixed with final clean coal product, contains even higher ash. In conclusion, this process cannot effectively lower the ash content in flotation clean coal. Instead, it complicates the flotation system by using more devices. The operation and management of this flowsheet is difficult, and the capital investment is high.

However, if the flotation cell in the secondary flotation circuit is replaced by flotation column, the ash of secondary flotation clean coal might be effectively reduced. It is recommended to use flotation column in secondary flotation circuit, while remain primary flotation circuit unchanged. The modified two-stage flotation flowsheet is depicted in Figure 6.

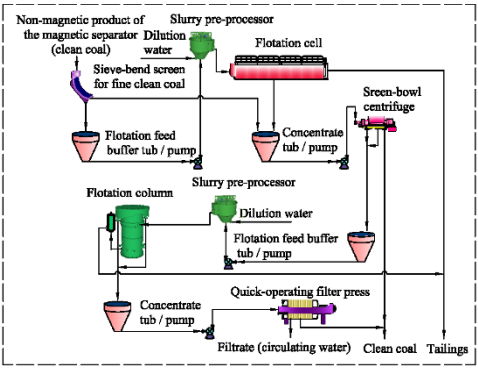

Figure 6 Variant (I) of two-stage flotation flowsheet.

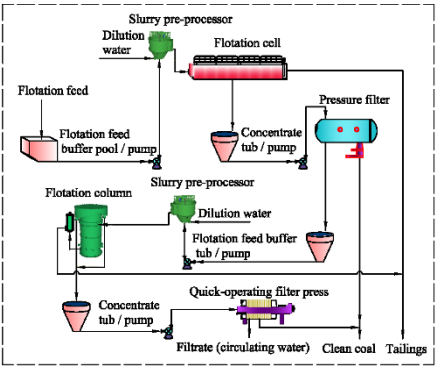

Figure 7. Variant (II) of two-stage flotation flowsheet.

In China, a number of CPPs utilize one-stage flotation circuit equipped with traditional flotation cell and pressurized filter. In addition to the methods described above, another variant of two-stage flotation flowsheet as shown in Figure 7 can be used to reject the ash in flotation clean coal. In this variant, plants use existing flotation cell and pressurized filter for primary flotation and dewatering. Filtration mesh with larger pores is preferred in pressurized filter to allow fine particles in primary flotation clean coal to penetrate to filtrate. The primary flotation circuit focuses on the recovery of coarse particles in flotation clean coal, and the improvement of dewatering performance, thereby mitigating the ash and moisture of filtration cake. The filtrate is then introduced to secondary flotation circuit, and its clean coal is dewatered by quick-operating pressure filter. The advantages of flotation column and quick-operating pressure filter in the treatment of fine particles are well utilized in this improved two-stage flotation flowsheet. Therefore, the ash and moisture in flotation clean coal are effectively reduced. This variant of two-stage flotation flowsheet has been successfully applied in the coal preparation plants of Bayi Mine within Shandong Zaozhuang Mining Group.

In summary, two-stage flotation scheme and its Variant I are not recommended. Instead, as for those utilizing mixed (one-stage) flotation flowsheet equipped with traditional flotation cell and pressurized filter, the Variant II of two-stage flotation process is highly recommended in their technical modifications. It will effectively reject ash and moisture in flotation clean coal.

4 Conclusions

(1) The efficient flotation and recovery of coal slime is an important part in coal preparation. Enhancing the performance of flotation circuit has the greatest potentiality to improve the recovery of clean coal in a CPP.

(2) Under the same conditions, the ash of the -0.0045 mm fraction in the clean coal of FCMC series cyclonic microbubble flotation column is 1-4.5% lower than the counterpart of traditional flotation cell. Flotation column produces an overall clean coal product that has ash content 1-2% lower in comparison with flotation cell. FCMC series column has obvious advantages over traditional flotation cell in reducing ash for the -0.045mm size fraction. It is especially suitable for the beneficiation of fine and non-selective coal slime downstream the heavy medium separation. It is a promising and efficient flotation device to reject ash in flotation clean coal.

(3) The mixed (one-stage) flotation process utilizing the combination of flotation column and clean coal quick-operating pressure filter is recommended in newly built and retrofitted CPPs. As for those using one-stage flotation flowsheet equipped with traditional flotation cell and pressurized filter, either classified flotation process or secondary flotation for the filtrate of pressurized filter using flotation column and clean coal quick-operating pressure filter is recommended in their technical modifications. These recommended solutions can effectively reduce ash and moisture in flotation clean coal product.

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