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Review

Recent advances in the beneficiation of ultrafine coal particles

Guichao Wang[a,b], Xuetao Bai[b], Changning Wu[b,c], Weng Li[b,c], Ke Liu[b,c,*], Ali Kiani[d]

[a] Key Laboratory of High-efficiency and Clean Mechanical Manufacture, National Demonstration Center for Experimental Mechanical Engineering Education, Shandong University, Jinan, Shandong 250061, China
[b] Department of Chemistry, Southern University of Science and Technology, Shenzhen 518055, China
[c] Clean Energy Institute, Academy for Advanced Interdisciplinary Studies, Southern University of Science and Technology, Shenzhen 518055, China
[d] Department of Chemical Engineering, The University of Newcastle, Callaghan 2308, Australia

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ABSTRACT

Only when problems in ultrafine coal particle beneficiation process are well understood and clarified, efficient methods can be devised to recover ultrafine coal particles in an economically viable way. When minerals are fully liberated from organic substances in the grinding process, coal beneficiation methods are needed to efficiently separate organic materials from mineral ones. This is necessary for clean coal technologies as the pollutants associated with coal utilization are the key factor in limiting the sustainability of coal utilization. To assess the current state of knowledge available in this area, a comprehensive literature review on the ultrafine coal particle beneficiation techniques is carried out with main focus on recent progresses. In this paper, previous studies on the ultrafine coal beneficiation have been critically analyzed with respect to the effects of particle sizes and surface properties. The techniques are classified into two categories, physical separation (including gravity, magnetic and electrostatic separation method) and physico-chemical separation (including oil agglomeration and bubble flotation method). The aim of this paper is to review developments and limitations of current ultrafine coal particle beneficiation techniques and also to identify the future development in recovering ultrafine coal particles.

1. Introduction

The application of large machinery and increasing mechanization of modern coal mines result in more ultrafine coal particles being produced. Ultrafine coal particles are discarded in general practices of coal industry because of the difficulties in their separation. This causes a waste of coal resources and contamination of the environment. Efforts, therefore, have been devoted to the beneficiation of ultrafine coal particles. The ultrafine coal particles have been increasingly becoming a major problem, which leads to poor coal recovery, excessive moisture levels and high waste disposal costs in the coal-cleaning industry [1,2]. Though there has been no consensus on the definition of fine coal particle and ultrafine coal particle, it is generally believed that a coal particle with diameter < 6 mm is defined as fine and a coal particle with diameter < 250 μm is defined as ultrafine [3]. It should be noted that the size classification for coal and mineral is different as minerals are generally ground to much smaller size to liberate metals from hosting gangue materials. Ultrafine coal particles mixed with ultrafine mineral matters cannot be efficiently processed by gravity separation techniques. This is because of the small size of the particles and the decreasing effect of gravity (i.e. hindering effects) [4]. Gravity concentration, exclusively has been used in coarse coal cleaning. Other techniques, like flotation, are employed to separate fine coal particles from fine mineral particles, taking the advantage of surface properties of different particle types. However, ultrafine coal particle separation cannot be achieved in an efficient way in a reasonable time scale when the coal to be processed contains a large amount of clays [5,6]. These ultrafine coal particles generally contain large amount of mineral matter due to non-selective caving of the coal seams, and therefore, the mineral matter must be removed to exploit these ultrafine coals. In addition, the concentration of ultrafine fraction is necessary for the prevention of environmental pollution and economic reasons [7].

In a commercial setting, coal preparation plants often discard ultrafine coal because of the high clay and high ash content. These ultrafine coal particles are classified as waste and discarded since the coal cannot be efficiently and economically separated from gangue material [8]. The problem of discarding ultrafine coal to numerous impoundments worldwide has created tremendous environmental concerns. It is estimated that some 70–90 million tons of ultrafine coal is being discarded to coal slurry impoundments annually by the United States coal

* Corresponding author at: Department of Chemistry, Southern University of Science and Technology, Shenzhen 518055, China.
E-mail address: liuk@sustc.edu.cn (K. Liu).

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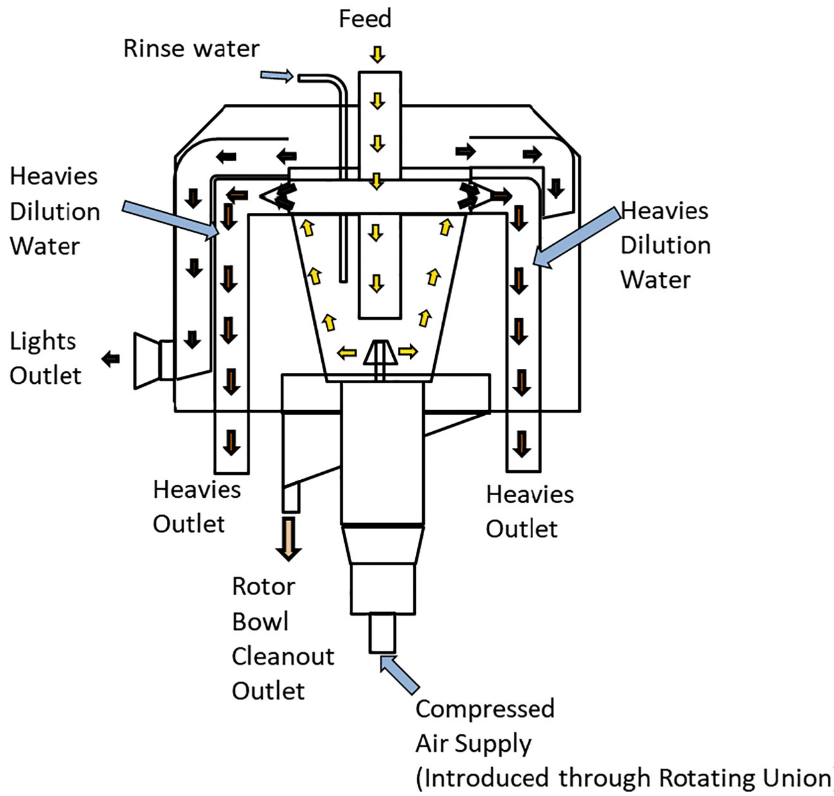

Fig. 1. Schematic of the Falcon concentrator [18].

industry [8]. Approximately 2 billion tons of ultrafine coal have been discarded in abandoned ponds, and 500–800 million tons are in active tailing ponds [8]. This represents a loss of a valuable energy resource, and the creation of a potential environmental liability.

The loss of ultrafine coal particles in the tailing not only causes a problem to the recovery of coal but also results in the loss of the purest coal because coal particles at small size are liberated extremely well from raw coal. In other cases, ultrafine coal beneficiation is required to achieve low ash content likewise in coking coals. When minerals are disseminated finely in the coal, it is necessary to grind coal into small sizes so that organic matters can be liberated from mineral matters. Ultrafine coal beneficiation is virtually essential in the later process. Therefore, an ultrafine coal processing technique is required to effectively separate coal particles from mineral particles. Ultrafine coal beneficiation can not only recover ultrafine coal that are currently lost in the tailings, and therefore increase plant yield, but also promote clean coal technologies to reduce pollutant emissions. Nevertheless, study of ultrafine coal beneficiation has its historical origins in the research of particle agglomeration using oil. Mechanism of particle agglomeration is complex because of the different surface properties of particles and selective attachment of binder to the targeted particles. Selective agglomeration of ultrafine coal particles is a technique which has received considerable attention in the past. It takes the advantages of the differences in the surface properties of particles to achieve high selectivity in beneficiation.

According to the classification of beneficiation technologies, coal particles can be beneficiated using physical, chemical, physico-chemical and bio-beneficiation methods [9]. Physical method includes gravity separation, which can be wet or dry methods, and magnetic separation (dry). Physico-chemical method, which uses the differences between surface properties of coal and mineral particles, includes flotation and oil agglomeration. Due to the small inertia of ultrafine coal particles, physical methods extend limitations in treating coal particles in small size fraction by introducing enhanced field, which can be either magnetic field or centrifugal field. In the contrast, coal particles are generally liberated from mineral particles in ultrafine size range. This contributes to a better liberation of coal particles from mineral particles, which can be well taken advantages by flotation and oil agglomeration methods. Small inertia of ultrafine coal particles makes the particle-bubble collisions in flotation process a limiting factor in recovering ultrafine coal particles. Nevertheless, this problem can be resolved by effective collectors [10].

Over the past decade, beneficiation technologies for ultrafine coal particles have been developed. Substantial amount of work has been carried out to study the beneficiation of coal in different size ranges. Good comprehensive review work has been carried out in recent years in beneficiation technologies for low rank coal [9,11], oil agglomeration [12], flotation of low rank/oxidized coal [10,13]. This paper highlights advances in beneficiation technologies as having the potentials to solve the aforementioned problems in ultrafine coal processing ($< 250\,\mu m$). This requires the identification of the most relevant and reliable information to allow appropriate comparisons between different technologies. From the perspective of ultrafine coal beneficiation, various techniques and mechanisms involved are compared and discussed.

2. Physical separation

2.1. Gravity method

A comprehensive review on the developments of advanced gravity separation techniques for processing fine particles was published recently [14]. Processing ultrafine coal particles is a problem mainly because they have a small mass, high specific surface area and high surface energy per surface area [15]. Due to these factors, gravity separation, which has been widely applied in coarse coal particle processing, becomes inadequate in the treatment of ultrafine coal particles. To overcome the weak gravity effect of ultrafine particles, enhanced