Minerals Engineering 126 (2018) 74–81

Contents lists available at ScienceDirect

Minerals Engineering

journal homepage: www.elsevier.com/locate/mineng

Mineral liberation analysis on coal components separated using typical comminution methods

Zhen Li[a,b,*], Yanhong Fu[a], Chao Yang[a], Wei Yu[a], Lijun Liu[a], Jinzhou Qu[a], Wei Zhao[a,b]

[a] College of Chemistry and Chemical Engineering, Xi'an University of Science and Technology, Xi'an 710054, Shaanxi, PR China
[b] Key Laboratory of Coal Resources Exploration and Comprehensive Utilization, Ministry of Land and Resources, Xi'an 710054, Shaanxi, PR China

ARTICLE INFO

Keywords:
MLA
Method of comminution
Minerals
Separation

ABSTRACT

To study the characteristics of different comminution methods during the separation of coal components, mineral liberation analysis (MLA) was performed on typical coal variants produced in Western China. In this work, the granularity, free surface, phase specific surface area, and mineral phase interfaces of coal and its primary mineral constituents under the actions of rod milling and ball milling were investigated. For the same milling time, ball milling was found to be more effective in reducing grain sizes and producing more concentrated grain size distributions. The mineral components with different dissemination grain sizes and dissemination patterns exhibited different separation grades and responded differently to each comminution method. The recovery rates of coal and siderite monomers for rod milling were 92.85% and 61.56%, respectively. The recovery rates of pyrite and quartz monomers for ball milling were 80.52% and 52.60%, respectively. The free surface and phase specific surface areas were compressively analyzed for optimum mineral separation, and separation models were developed for typical coal components under the actions of each comminution method. The compaction forces associated with rod milling tended to induce intergranular cracks, whereas the impact forces associated with ball milling generated intragranular cracks; the latter is beneficial for separating minerals with relatively fine disseminated grain sizes.

1. Introduction

The adequate separation of useful minerals is the primary objective of mineral processing (Mariano et al., 2016; Leißner et al., 2013). The differences in the hardness, dissemination patterns, and disseminated grain size between each mineral are reflected in the differences in the grain size and mineral separation after comminution (Leißner et al., 2016), thus directly affecting the recovery rates of concentrates from subsequent sorting and refinement processes (Farrokhpay and Fornasiero, 2017). Studies have shown that comminution accounts for more than 50% of the energy consumption of beneficiation (Musa and Morrison, 2009; Vizcarra et al., 2010; Tromans, 2008). Therefore, the selection of an appropriate comminution method is essential for reducing the energy required to achieve desired levels of separation and granularity in economically valuable minerals (Sandmann and Gutzmer, 2013). The comminution and separation of multi-component mineral grains is a complex process (Partsinevelos et al., 2013). In the current literature, numerous studies have been conducted on comminution equipment and simulations, and other methods for controlling comminution outcomes (Wang et al., 2012). However, studies on the effects of different types of forces on granular fractures and their propagation are lacking (Garcia et al., 2009). Mineral liberation analysis (MLA) is a highly effective, cutting-edge technique for quantifying macroscopic and microscopic mineral properties (Leißner et al., 2016; Fandrich et al., 2007; Albijanic et al., 2011). This technique is widely used for studying the liberation, granularity, and elemental occurrences of metallic and non-metallic minerals (Zhang et al., 2015; Zhao et al., 2014; Cheng et al., 2015; Yuan and Zhao, 2011); however, the MLA is rarely employed for coal. To address this gap in literature, we used the MLA to study the characteristics and mechanisms associated with the mineral liberation of coal with respect to typical comminution methods such as ball milling (BM) and rod milling (RM). The findings of this study will contribute significantly to the technical and theoretical knowledge base regarding the liberation and beneficiation of common coal components.

2. Experimental raw materials and characterization methods

The samples used in this study were obtained from coals mined from the Yangchangwan coal mine (henceforth referred to as YCW). Table 1

* Corresponding author at: College of Chemistry and Chemical Engineering, Xi'an University of Science and Technology, Xi'an 710054, Shaanxi, PR China.
E-mail address: lizhenac@126.com (Z. Li).

https://doi.org/10.1016/j.mineng.2018.06.028
Received 27 December 2017; Received in revised form 4 June 2018; Accepted 27 June 2018

Table 1
The proximate analysis and ultimate analysis of raw coal.

Item	Proximate analysis				Ultimate analysis				
	A_{ad}%	M_{ad}%	V_{ad}/%	FC_{ad}/%	C_{ad}%	H_{ad}%	O_{ad}%	N_{ad}%	$S_{t,ad}$%
YCW	11.84	6.93	30.72	50.51	65.8	3.29	11.25	0.1	0.79

Table 2
Specifications of the rod mill and ball mill as required for the experiment.

Item	RM	BM
Model	XMB70	XMGQ-Φ305 × 610
Diameter × Length/mm	Φ132 × 150	Φ305 × 610 (barrel)
Speed/rpm	312 (Spindle roller)	46 ± 0.5
Power/kw	0.37	1.1
Outline Size/mm	760 × 510 × 520	930 × 610 × 1185

lists the specifications regarding the proximate and ultimate analyses of the coal samples. The YCW has high carbon and fixed-carbon contents and low hydrogen, ash, and sulfur contents. First, the raw coal (> 6 mm) was crushed into −0.5 mm using a jaw crusher, and the whole sample was mixed and divided into the required quantity by cone and quartering techniques. After then, dry milling was used for the experiment. The feeding amounts of BM and RM were 1200 g and 400 g, respectively. Table 2 gives the details of BM and RM.

Fig. 1 shows the relationship between the net energy consumption and the particle size under the effect of BM and RM, and the formula of energy consumption was quoted from Sabah et al. (2013):

$$E_m = \frac{P \cdot t}{M} \quad (1)$$

where E_m is the net energy consumption, KWh/kg; M is the mass of the coal, Kg; and t is the grinding time, h.

In the process of grinding, a part of the energy input is used to reduce particle size to produce new surface, and another part contributes to unnecessary energy consumption, such as heat, chemical energy, and the energy consumed by the newly formed crystal structures (Sverak et al., 2013). Different net energy consumption levels of 0.46 KWh/kg, 0.62 KWh/kg, 0.77 KWh/kg and 0.92 KWh/kg in Fig. 1 correspond to different milling time of 30 min, 40 min, 50 min and 60 min, respectively. Fig. 1 shows that the slope of the net energy consumption-particle size curve changes with the increasing of grinding time. The greater the slope, the more energy is used to reduce the particle size to produce new surfaces. When the net energy consumption is 0.77 KWh/kg (with a grinding time of 50 min), the corresponding particle size decreases the fastest. Combining with previous experiments (Fu et al., 2017), it is known that the separation and liberation responses of minerals are the most significant at the grinding time of 50 min. Hence, the grinding time in the experiments was set to 50 min.

The mineral liberation analyzer 250 (FEI, USA), from the Oil Sands and Coal Interfacial Engineering Facility of the University of Alberta, Canada, was used to study the liberation characteristics of each coal component.

A quantitative characterization of the dissemination and liberation degree of the minerals was performed on the basis of the free surface (*FS*) (Quinteros et al., 2013). Fig. 2 shows the FS calculations. In this figure, A and B represent the mineral of interest and other interlocked minerals, respectively.

The phase specific surface area (*PSSA*) of coal components are calculated using Eq. (2).

$$PSSA = \frac{Mineral\ boundary}{Mineral\ Area} \quad (2)$$

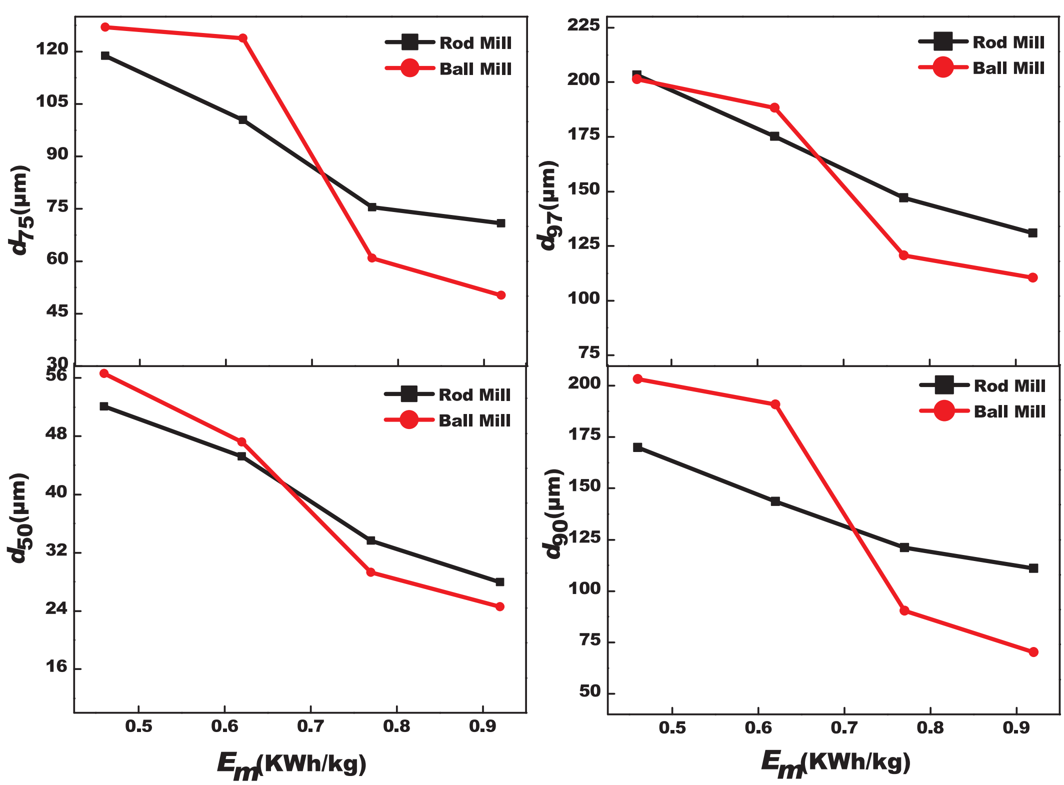

Fig. 1. Relationship between the net energy consumption and the particle size under the effect of BM and RM.