Powder Technology 277 (2015) 206–221

Contents lists available at ScienceDirect

Powder Technology

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

Review

Recent advances in beneficiation for low rank coals

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ARTICLE INFO

Article history:
Received 5 December 2014
Received in revised form 26 February 2015
Accepted 3 March 2015
Available online 12 March 2015

Keywords:
Low rank coal
Beneficiation
Gravity
Flotation
Bio-beneficiation

ABSTRACT

Coal beneficiation is one of the most effective methods for removing minerals (such as gangues and pyrite) and pollutants (such as sulfur) before the burning of coal. In general, the beneficiation process of low rank coals is more difficult to achieve than that of bituminous and/or anthracite coals. However, about 50% of the world's total coal deposits are low rank coals. It is urgently required to develop effective beneficiation technologies for low rank coals. This review highlights recent advances in beneficiation technologies for low rank coals. Physical (gravity and magnetic separation), chemical (leaching), physico-chemical (flotation and oil agglomeration) and bio-beneficiation technologies are summarized in detail. Effective beneficiation technologies for low rank coals in the future are also suggested throughout this paper.

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Contents

1. Introduction

It is well known that coal is the most abundant fossil fuel. Coal supplies about 42% of electricity for the world. Especially in China, about 70% of electricity is from the burning of coal. The known coal reserves in the world are enough for more than 215 years of consumption, which is much more than both known gas reserves and oil reserves [1]. It is predicted that coal will still play the most important role in the energy supply until 2050. Even though coal reserves are abundant, nearly half of the world's total coal deposits are low rank coals [2]. In Turkey, about 43% of fossil fuel production is lignite [1]. Meanwhile, low rank coals are very abundant in Australia, Central Europe and Eastern Europe, the northern US, Germany, Japan and China [3–6]. Due to the low price of low rank coals, using low rank coals in energy supply is inexpensive.

However, the grade of low rank coals is usually very low. The prominent problem of utilization of low rank coals is that, low rank coals always contain very high moisture content and ash content as well as sulfur content. Drying and cleaning prior to the use of lignite are urgently required. Drying low rank coals before burning is an effective method to save energy and improve energy efficiency [7,8]. Meanwhile, the transport of low rank coals will be saved after upgrading processes [9].

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http://dx.doi.org/10.1016/j.powtec.2015.03.003
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Li et al. [10] pointed out that the ash fusion temperature of lignite was affected by the beneficiation processes prior to the coal burning process. Generally, drying is to remove external moisture while beneficiation is to remove sulfur, ash minerals and also especially some harmful trace elements [11–16]. For example, the removal of Hg from raw coal is necessary and acceptable by coal upgrading processes [17,18]. In addition, primary desulfurization methods are chemical desulfurization, leaching, extraction, flotation, oxydesulfurization and biodesulfurization [18–20].

Since low rank coals are young coal and contains much more oxygen containing functional groups, the surface hydrophobicity of low rank coals is usually lower than middle/high rank coals, such as bituminous and anthracite coals [21,22]. Usually, the coal hydrophobicity is reflected by the contact angle and hydrophilic index [23,24]. In other words, low rank coals are difficult to float with the common oily collectors. Hence, many researchers try to develop flotation technologies for low rank coals. Due to the low floatability of low rank coals, heavy medium separation is considered to be more effective than flotation [25].

In the past decade, upgrading technologies have been developed. Recently, developments of drying and dewatering for low rank coals are summarized by Rao et al. [26]. It is well known that beneficiation is also a very important aspect in the upgrading processes of low rank coals. Therefore, it is necessary to summarize recent advances in beneficiation technologies for low rank coals.

The aim of this paper is to address the recent advances in beneficiation technologies for low rank coals. Due to the fact that low rank coals primarily consist of lignite, brown coal and sub-bituminous coal, there are several beneficiation methods for low rank coals. Physical (gravity and magnetic separation), chemical (leaching), physico-chemical (flotation and oil agglomeration) and bio-beneficiation technologies will be summarized in detail in this review, and beneficiation equipment and mechanisms will also be presented. Some effective beneficiation technologies for low rank coals in the future are suggested throughout this paper.

2. Beneficiation technologies

In order to highlight recent advances in beneficiation technologies for low rank coals, it is necessary to make a classification of beneficiation technologies. The classification of beneficiation technologies for low rank coals is shown in Fig. 1. The beneficiation technologies include physical, chemical, physico-chemical and bio-beneficiation technologies. Physical methods are gravity separation and magnetic separation. Chemical methods are chemical leaching by acid or alkali while physico-chemical methods are flotation and oil agglomeration. At last, bio-beneficiation technologies are achieved by specific bacteria. Sometimes the combination of two or three beneficiation technologies is needed to achieve an effective beneficiation process of low rank coals.

2.1. Physical methods

2.1.1. Gravity separation

Gravity separation technologies include wet and dry density-based separation technologies. Wet density-based separation technologies consist of heavy media separator, heavy media cyclone (HMC), shaking table, spiral separator, multi-gravity separator (MGS), Knelson concentrator and Falcon concentrator, while dry density-based separation technologies include air jig, air table, air dense medium fluidized bed and dry vibration fluidized bed.

Like middle and high rank coals, sink and float experiments show the washing possibilities of low rank coals. Before the design of a coal preparation plant, the washability of raw coal must be obtained. The raw coal is classified as "easy to clean" or "difficult to clean" based on the content of near-gravity materials at specific gravities. The lignite taken from Tunçbilek coalfield in Kütahya-Turkey was recognized as "difficult to clean" due to its high near-gravity materials at gravities below 1.7 g/cm^3 [2]. Meanwhile, based on sink and float experiments, the washability of Azad Kashmir (Pakistan) lignite was acceptable if by gravity separation since low ash content of clean coal could be obtained based on sink and float experiments[27]. Furthermore, the removal of trace elements from Soma lignite was evaluated using float–sink studies, which showed that the removal of trace elements (vanadium, chromium, copper, arsenic, thorium, and uranium) could be reduced from 15% to 83% using heavy liquid of 1.3 and 1.9 specific gravities [28].

2.1.1.1. Wet methods. The Stripa as a heavy media separator was developed in Sweden for the processing of iron ores. The Stripa could employ heavy medium or iron ore itself. Yildirim et al. [29] applied this

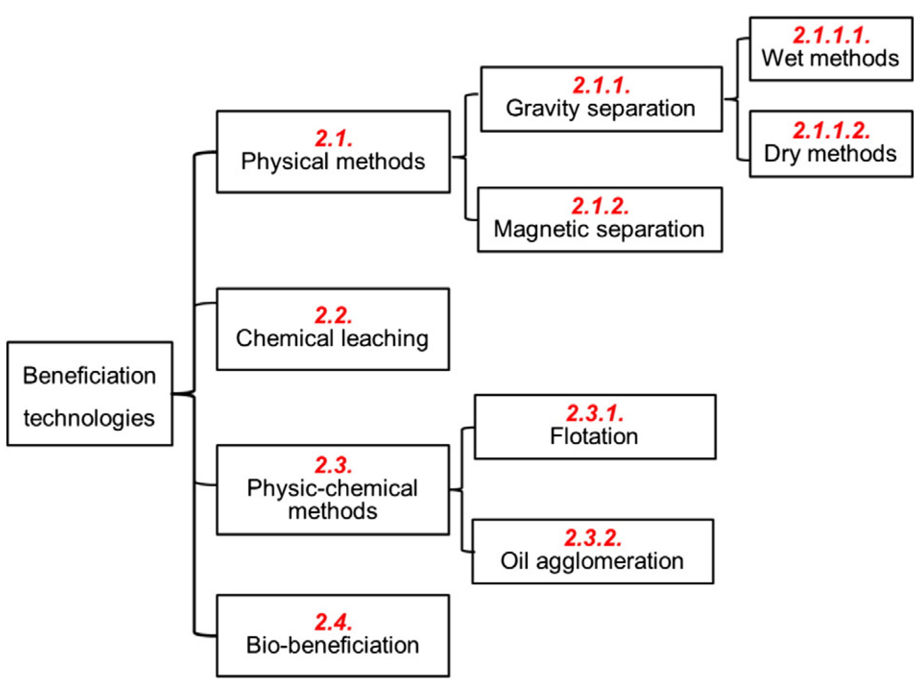

Fig. 1. Classification of beneficiation technologies for low rank coals.

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