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Oil shale separation using a novel combined dry beneficiation process

Xiaodong Yu, Zhenfu Luo *, Xuliang Yang, Haishen Jiang, Enhui Zhou, Bo Zhang, Liang Dong

School of Chemical Engineering & Technology, China University of Mining and Technology, 221008 Xuzhou, China

HIGHLIGHTS

- A combining dry separation process for oil shale of 100–0 mm was proposed.
- The probable error (*E*) was 0.155–0.21 when oil shale was cleaned by compound dry cleaning.
- The probable error (*E*) was 0.16–0.185 when oil shale was cleaned by a VADMFB separator.
- Oil shale can be separated effectively by the combined dry beneficiation process.

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ABSTRACT

Significant mineral impurities are produced during oil shale mining. However, inorganic minerals can be partially discarded, with an improvement in oil shale quality, through physical separation methods. Based on analysis of physical properties of oil shale, this paper firstly proposes a separation process combining compound dry cleaning and vibrated air dense medium fluidized bed (VADMFB) separation, for separation of oil shale across the full size range of 100–0 mm. We systematically analyzed the effects of changes in vibration amplitude and frequency on separation results and oil ratios for both systems. When oil shale with a size range of 100–6 mm was separated using compound dry cleaning, using optimal vibrational parameters of f = 53 Hz and A = 3.6 mm, yields of concentrate was 20.49%, respectively, with corresponding oil content of 11.20%, The probable error (*E*) was 0.155–0.21 with the largest oil content segregation degree. Oil shale with a size fraction of 6–0 mm was separated in a VADMFB separator at optimal vibrational conditions (f = 36 Hz and A = 2.5 mm). Resultant yields of concentrate was 21.70%, respectively, with corresponding oil content of 10.1%. *E* was 0.16–0.185 with the largest oil ratio segregation intensity. This study thus confirms that the proposed combined dry beneficiation process can effectively separate oil shale along the full size range of 100–0 mm.

1. Introduction

Energy resources provide one of the most important material foundations for social development. Oil and coal are still the main energy resources at present, but these fossil energy resources are non-renewable and will eventually be used up. A high rate of coal production is still presently maintained in China, but overall, coal production and consumption are progressively decreasing. As a result, it is becoming necessary to develop non-conventional energy sources. Oil shale is a particular type of sedimentary rock containing abundant organic matter. Shale oil and gas can be attained after pyrolysis of organic matter [1–3]. Oil shale is a combustible solid and is mainly composed (>70 wt% content) of inorganic minerals. Of the latter, clay minerals predominate, in addition to quartz, mica, carbonate rocks, and pyrite.

Reserves of oil shale, a form of non-conventional energy, far exceed those of petroleum. Based on exploration to date, America has the most abundant oil shale resources in the world with ascertained geological resources of 33,400 billion tons. Geological reserves in China total 719.9 billion tons, equivalent to 47.6 billion tons of oil. In the latter country, oil shale is mainly used for power generation by combustion and to produce oil by pyrolysis. Gasoline, kerosene, diesel oil, paraffin, and other types of chemical products can be attained after hydro-cracking of shale oil [4–6], which therefore has significant value. Kerogen in oil shale is derived from macro-molecular organisms; it is dispersed within sedimentary rock and is not soluble in organic solvents. This is the most common form in which organics are present within rock strata [7–10].

* Corresponding author.
E-mail address: zfluo@cumt.edu.cn (Z. Luo).

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Significant inorganic minerals are produced when oil shale is mined, leading to a decrease in the grade of oil shale and in oil yield, and increasing the cost of production during pyrolysis; this leads to the disadvantages in terms of comprehensive utilization of oil shale energy. Some comparisons can be drawn between coal and oil shale. The density of oil shale is around 2.35 g/cm^3, generally higher than that of coal; the principle of coal beneficiation, however, provides insights that are relevant to oil shale separation processes. Traditional water separation processes mainly include the jigging washing process and heavy medium separation. Both of these process are barely able to reach the required oil shale separation density and the separation effects they produce are therefore poor and inadequate for upgrading of oil shale. The oil content is inversely proportional to the density of oil shale. The density of inorganic mineral impurities is higher, and these should be discarded to attain pure oil shale with low density. Oil shale can be separated effectively from inorganic mineral impurities through dry separation methods. Based on studies using compound dry cleaning apparatus [11], the lower separation size limit of this method is 6 mm; materials with a size range of 0–6 mm can, however, be separated after compound dry cleaning in a vibrating air dense medium fluidized bed (VADMFB) separator. Dry separation processes can therefore be used to separate oil shale across the full particle size range of 0–100 mm. In this paper, based on the laboratory experiments, we propose a novel dry beneficiation process combining the compound dry cleaning with VADMFB separation to beneficiate oil shale. The effects of main factors including vibration frequency and amplitude, on oil shale separation were systematically investigated and the optimal operational parameters were identified in the laboratory separation process, providing technological support for the industrialization promotion of dry oil shale separation technologies.

2. Experimental

2.1. Dry separation apparatus

Fig. 1 shows the oil shale dry separation system. This is composed of a crude ore preparation system, a separator system, a medium purification, circulation and density control system, and an air supply and dust removal system. The crude ore preparation system contains a pre-classification screen, crusher, surge bin, and other related elements. Crude ore is pre-classified and crushed before it is conveyed to the surge bin for separation preparation. The separator system is composed of compound dry cleaning apparatus and a VADMFB separator. The compound dry separator and VADMFB separator deployed in this study are both laboratory equipment, and the bed form of compound dry separator is right-angled trapezoid, with an upper length of 0.2 m, a lower length of 0.5 m, a height of 1 m, an effective separating area of 0.35 m^2. The bed form of a VADMFB separator is rectangle, with a length of 1.876 m, a width of 0.4 m and an effective sorting area of 0.75 m^2. Different particle sizes of oil shale can be separated effectively by the combined operation of a compound dry separator and a VADMFB separator. The medium purification, circulation, and density control system is used to purify and recycle the heavy medium discharged from the VADMFB separator through a scalping screen, magnetic separator, and diverter. The density and height of the vibrated fluidized bed can be adjusted by controlling heavy medium circulation content and the purification ratio in accordance with separation demand. The air supply and dust removal system contains an air blower, induced draft fan, dust collector, air bag, and valve, among other elements; it is used for air supply and dust collection.

2.2. Experimental process

The raw ore is first delivered onto the classifying screen, which has a diameter of 100 mm. The screen overflow is crushed to a grain size <100 mm, and this is then mixed with the screen underflow, which is separated using the compound dry cleaning apparatus. Under the joint effects of vibration and wind, and due to the buoyancy effect of the autogenous medium, tailings are discharged and remaining middlings are concentrated. As noted above, minerals with a particle size of 6–0 mm cannot be separated using the compound dry cleaning apparatus [11], and concentrate, middlings, and tailings are therefore separated using a classifying screen with a diameter of 6 mm. The underflow is processed in the VADMFB separator under the influence of vibration and buoyancy of the air dense medium (ferro-silicon powder). The separation process is dependent on the density of the fluidized bed. After separation, dense media in the concentrate, middlings, and tailings are separated using the scalping screen, and final products can then be attained. One part of the dense medium is separated using a magnetic separator to discard non-magnetic material and attain ferro-silicon powder; the other part is circulated for separation. The dust captured by the dust separator is recycled and reused.

2.3. Material properties

The physical properties of oil shale affect separation results; of particular importance are its density composition and oil ratio changes. Oil shale is a particular type of geo-material and its density, oil content, and other physical properties exhibit aeolotropism and nonlinearity in terms of the effects of geological structures [12]. As the temperature changes, the thermal stress generated by mismatch of thermal deformation in internal regions of oil shale

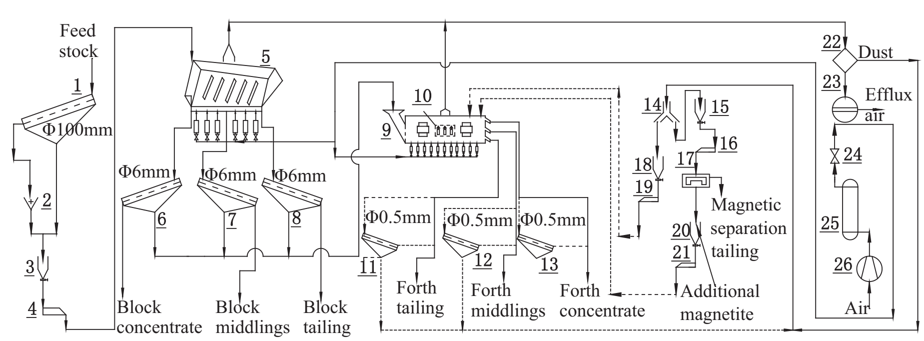

Fig. 1. Diagram of the oil shale dry separation system.1-classifying screen (¢100 mm), 2-crusher, 3-surge bunker, 4-feeder, 5-compound dry cleaning apparatus, 6/7/8-classifying screen (¢6 mm), 9-VADMFB separator, 10-pressure transducer 11/12/13-scalping screen (¢0.5 mm), 14-diverter, 15-cycling medium bin, 16-feeder, 17-magnetic separator, 18-cycling medium bin, 19-feeder, 20-medium bin, 21-medium feeder, 22-dust collector, 23-induced draft fan, 24-valve, 25-air bag, 26-air blower.