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Comprehensive study of process parameters affecting oil agglomeration using vegetable oils

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HIGHLIGHTS

- ▶ Response of Assam coal to oil agglomeration has been investigated.
- ▶ Both edible and non-edible vegetable oils are equally good as agglomerants.
- ▶ Anionic surfactant usage did not improve the agglomerate yield.
- ▶ Use of sea water improves the coal recovery by oil agglomeration.

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ABSTRACT

Spherical agglomeration is a size enlargement process in which the disperse medium is held together in aggregates by liquid bridges of an immiscible agglomerating agent in the dispersion medium in general, an aqueous environment. Extensive studies on the process have shown that the process is affected by a number of process parameters. In the present paper, a large number of process parameters such as agitation speed, oil dosage, agglomeration time, coal particle size, slurry pulp density, pH and temperature of the dispersion medium, oil type, surfactant (anionic) use, and sea water usage as pulping medium. affecting the oil agglomeration of Indian bituminous coal procured from North-Eastern region of the country were investigated. Initially, the process parameters were optimized for maximum coal recovery with significant ash rejections. Subsequent experiments to study the effect of surfactant, oil type and sea water usage as pulping medium were performed under the optimized conditions. All the experiments were performed under batch mode of operation. The coal–oil agglomerates were recovered by screening using a standard test sieve whose pore size was same as the maximum size of feed coal particle. The overall agglomeration performance was studied in terms of efficiency index which took into account both combustible recovery and ash rejection, the two important process estimates of the agglomeration process. The experimental results showed that the Indian bituminous coal used in the study was quite receptive to oil agglomeration process and significant recovery of coal fines with considerable ash rejections was possible through this clean coal technology.

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1. Introduction

The term "clean coal" applies to the coal with reduced mineral matter as compared to the raw coal. Clean coal technologies have become a buzz word across the world in combating the climate change as coal is the most widely used fossil fuel. These technologies are meant for enhancing the efficiency of coal utilization, thereby decreasing the adverse impact of environmental pollution. Coal beneficiation is one such technique, which helps in addressing the problems created by coal utilization. Basically, coal beneficiation is a process of separation of pure organic matter of coal from the associated inorganic mineral impurities like shale, sand, and stones. The separation can be effected by various physico-chemical and/or microbial techniques. Majority of the washing techniques like heavy media separation, jigging, etc. exploit the differences in specific gravity of coal and mineral matter. However, fewer techniques like oil agglomeration, froth flotation utilize the differences in physico-chemical properties like hydrophobicity, and coal–oil–water interfacial tensions However, the choice of the beneficiation technique primarily depends on the coal particle size. For coarse (−75 + 13 mm) and intermediate size (−13 + 0.5 mm) coals, jigging, heavy media separators and cyclone separators are used. Froth flotation, flocculation and oil agglomeration techniques are being used for fine coals (−0.5 mm). In the Indian context, jigs,

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heavy media separators (shallow bath) and cyclones are the most commonly used techniques, while oil agglomeration is still being explored for fine coal beneficiation.

In India, coal seams are believed to be of drift origin resulting in intimate mixing of mineral matter with coal. In such coals, the ash is very much interwoven in the coal matrix which is essentially required to be crushed to smaller sizes for better liberation of mineral matter. This would result in the generation of huge quantities of coal fines and coal dust, which requires to be suppressed by water spraying. The disposal of huge volumes of coal water slurries generated in the process will be an enormous task. The recovery of coal fines from these coal–water slurries is usually done by settling which is, however limited to a certain particle size beyond which the coal dust remains in suspension and is difficult to recover. It may also be noted that the greater the fineness to which the coal is grinded the greater will be the ash rejection capacity of coal. Thus, fine grinding would indirectly aid in the process of obtaining clean coal, albeit the serious environmental pollution caused by fine coal slurries. The solution to tackle these fine coal slurries lies in the technique of oil agglomeration which helps in recovery of these coal fines from the slurries by preferential wetting of coal fines by oil and retaining the mineral matter in the water phase. The oil wetted coal fines will come together upon agitation to form clusters of coal–oil bridges called agglomerates which are screened and harvested to produce clean coal with lower ash content. The process although appears to be simple, but is influenced by a number of process parameters like agitation speed, agglomeration time, oil dosage, type of oil, and slurry pulp density [1–6].

In the present paper, a comprehensive study has been carried out on the effect of various process parameters on the oil agglomeration of a typical Indian bituminous coal. The effects of agitation speed, oil dosage, coal particle size on oil agglomeration process using this coal have been studied earlier by the present authors [7–9]. However, more in-depth analyses of the results have been presented in the current manuscript. In the present study, additionally various process variables like agglomeration time, slurry pulp density, temperature and pH of pulping medium, effect of surfactant (anionic), effect of oil type, effect of sea water were examined systematically to study the agglomeration capability of Indian coal using the conventional experimental approach in which one parameter is varied at a time keeping all other parameters constant. Besides, the comparative performance of various edible and non-edible oils as agglomerants has been thoroughly investigated. The first-time usage of sea water as pulping medium in the coal–oil agglomeration process was a different application of the vast unused natural resource. Thus, the studies carried out in the present paper will provide a deeper insight into the oil agglomeration performance of Indian coal under study.

2. Experimental

2.1. Coals

A high sulfur and low ash content coal procured from coal fields of Assam in North-Eastern India was used for oil agglomeration experiments. Raw coal, originally available in lumps was ground and subsequently sieved to obtain different size fractions i.e., −75 μm, +75–200 μm, +200–500 μm. The motive behind choosing such wide range of coal particle size fractions was to simulate the actual coal water slurries which contain non-uniform sizes of coal particles. The sieved samples were later preserved in air-tight plastic containers to ensure inert atmosphere. Proximate and ultimate analyses of coal carried out in the current study are tabulated in Part-A of Table 1.

Table 1
Characteristic properties of coal and oils.

Part-A: Coal characteristics (Air-dried basis)

Parameter	Indian bituminous coal
Proximate analysis (% by wt.)	
Moisture	1.9
Ash	10.18
Volatile matter	41.56
Fixed carbon	46.36
Ultimate analysis (% by wt.)	
Carbon	63.16
Hydrogen	5.2
Nitrogen	1.15
Sulfur (total)	1.39
Oxygen	17.02
Other properties	
O/C ratio	0.269
Gross calorific value (kcal/kg)	6351

Part-B: Oil characteristics

Oil	Density (g/l)	Surface tension (mN/m)	Oil Water Interfacial tension (mN/m)	Viscosity (mm^2/s)	Degree of unsaturation (FTIR analysis)
Jatropha	0.914	31.55	22.92	71.6	0.1813
Rubber seed	0.911	30.76	5.36	80.6	0.1800
Karanja	0.928	31.48	8.48	120	0.1748
Cotton seed	0.911	30.78	5.97	65.6	0.1697
Soya	0.91	32.42	22.57	65.2	0.1520
Sunflower	0.907	31.99	23.57	77.3	0.1438
Sesame	0.91	31.48	10.95	73.2	0.1270
Castor	0.952	35.05	4.78	909	0.1120
Palm	0.908	32.62	8.08	140	0.0310
Coconut	0.92	28.84	7.8	52	0.0291

2.2. Oil

In the present study, a number of vegetable oils namely, Jatropha oil, Karanja oil, Rubber seed oil, Cotton seed oil, Sunflower oil, Soya oil, Castor oil, Palm oil, Sesame oil, Coconut oil, were used as agglomerants in the agglomeration of coal fines from coal–water slurries. The primary focus is on understanding the agglomerating capabilities of non-edible oils, in particular, oils namely, Jatropha oil, Karanja oil and Rubber seed oil. These oils recently have gained importance for bio-diesel production, which is being used in IC engines [10,11]. Renewable and biodegradable nature of these oils coupled with negligible S, N and metal contents favor their usage as agglomerating agents [12]. Speedy growth of their plants on waste lands accompanied by cheaper cost of these oils further justifies their selection as agglomerants. However, initial runs to optimize the process parameters for maximum agglomerate yield with considerable ash rejections, were performed with Jatropha oil. Besides, the comparative performance of non-edible oils like Cotton seed oil and edible oils like Sunflower oil, Soya oil, Castor oil, Palm oil, Sesame oil, and Coconut oil as agglomerants have been thoroughly investigated. The physico-chemical properties of all the oils used in the present study are summarized in Part-B of Table 1.

2.3. Methods

Each oil agglomeration experiment was carried out in a 1 l cylindrical plastic vessel using requisite amount of coal immersed in 200 ml of water. Provision was made for agitating the contents of the vessel by an impeller mounted on a vertical shaft driven by a gearbox. The coal water mixture was initially agitated at a desired speed for a period of 2 min. The contents of the vessel were

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