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Prediction of economic operating conditions for Indian coal preparation plants

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ABSTRACT

The most important optimization concept, which, has long been recognized in coal preparation with multiple cleaning circuits, is the constant incremental quality approach. However, this approach maximizes the overall plant yield for a targeted product quality, without putting any emphasis on coal value/price. So, sometimes confusion arises in the determination of the overall plant yield that would more than offset the price due to lower quality of product. In this paper a method is presented to maximize the coal value by considering the equal incremental quality approach as well. Here the predicted yield of composite coal has been calculated by using a designed probable error value, then the value of a particular coal is maximized. A case study with six different coals of different characteristics is presented to ascertain the merit of this approach. This technique offers the coal preparation engineer an effective and straight forward method for determining the optimum cut points of separation for different coals to achieve maximum economic gain.

1. Introduction

Indian coals in general are of drift origin and high ash content with poor washability characteristics, which make these unsuitable for use without further upgrading. At the same time the quality of run-of-mine (ROM) coal has progressively deteriorated due to the availability of inferior grade coal reserves and high degree of mechanization introduced in large opencast mines. Furthermore, the Ministry of Environment and Forest (MoEF), Government of India, has imposed a restriction on the use of high ash coal (>34%) in power plants located 1000 km away from the pit-head, sensitive localities, and critically polluted areas. All these factors necessitated a long term strategy for improving the quality of coal by adopting an appropriate cost effective washing technology.

Coal washing has been used since the early 1950's in India to meet the required coal quality. In fact, the coal is washed when it is beneficial to do so, and the optimum operating conditions chosen for washing are decided on a cost basis. While taking up this exercise, it was immediately realized that the solution to the cost versus quality problem came from two aspects: technological and economics vis-à-vis optimum ash level of the washed coal. The technological optimum condition addresses the concept of constant incremental product quality to maximize the plant yield [1–8], while the economic optimum condition deals with coal value/price.

Presently, some models and commercial software package, like EPRI's coal cleaning cost model [9], CCS [10], CPO [11], Utah-MODSIM [12], an Excel-based cost-estimate model developed by the United States Geological Survey [13], SIU-SIM SIMULATOR [14] and Apex provided by Western Mine Engineering, Inc., are available for economic analysis of coal preparation. However, these software packages render little practical insight for the Useful Heat Value pricing structure of coal and wide frequent variations of ROM coal qualities. Moreover, in actual practice most of the coal washing devices are not perfect and their performance depends on feed qualities, which in turn necessitates a correction to account for the extent of imperfection. In the proposed method the price structure of coal, imperfection of washing devices and variation of feed quality have been implemented and can be changed according to the process requirements. The approach adopted here is to maximize the value of coal subjected to equal quality constraint by using a spreadsheet-based program within a framework of price structure, equipment imperfection, and feed quality variation. This method has been found to be a practical approach for determining the optimum operating parameters for different washing equipment to maximize the value of coal.

2. Method

2.1. Optimum specific gravity of separation from price structure

If a sample of coal whose fractional ash content is x_1 and price y_1 rupees per ton then the mass and ash content of this coal for one rupee will be $\frac{1}{y_1}$ tons and $\frac{x_1}{y_1}$ tons respectively. Similarly another coal having ash content x_2 and price y_2 will have the mass $\frac{1}{y_2}$ tons and ash content $\frac{x_2}{y_2}$ tons for one rupee. This clearly shows that these two coals have different weights and contain different amounts of ash, although their values are

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same (one rupee). The increment having weight of $\frac{1}{y_2}-\frac{1}{y_1}$ tons containing $\frac{x_2}{y_2}-\frac{x_1}{y_1}$ tons of ash will therefore have no value. Hence the fractional ash (critical ash) content of an increment of zero value is $\frac{\frac{x_2}{y_2}-\frac{x_1}{y_1}}{\frac{1}{y_2}-\frac{1}{y_1}}$ or $\frac{x_2y_1-x_1y_2}{y_1-y_2}$. From the above derivation it is seen that if any quantity of coal containing a critical ash of $\frac{x_2y_1-x_1y_2}{y_1-y_2}$ was added to another coal, the value of the latter would remain substantially unchanged, whatever its original ash content. If a coal containing less than this critical ash had been added, the value would have been increased and conversely if coal of more than the critical ash had been added, the value would have been reduced. So every particle of coal containing less than this critical ash is therefore of some value and should be recovered. As the value of a coal was unaffected by the addition of an increment containing critical ash, then it would also be unaffected if such an increment was taken a way, and indeed it would still be unaffected if all the ash present was removed in the form of such an increment. So the separation should be made at a specific gravity of separation corresponding to this critical ash.

This critical ash depends upon the pricing structure of the coal. For example, the pricing mechanism for non-coking coal in India is grade-based as shown in Table 1. The Useful Heat Value (UHV) is calculated on the basis of an empirical relationship given by

$$\mathrm{UHV} = 8900-138(A + M) \tag{1}$$

where A and M are ash and moisture contents, respectively. In the case of a coal having moisture less than 2% and volatile matter content less than 19%, the UHV would be the value arrived as above, reduced by 150 Kcal/kg for each 1% reduction in volatile matter content below 19% fraction pro-rata [15]. Based on this pricing mechanism the critical ash content of Indian non-coking coal (5% moisture content) is found to be 59.49% as shown in Table 2. The price of a coal sample depends on its UHV only. The UHV of a coal sample is decreased by 138 units if its ash or moisture content is increased by one unit. The moisture and ash have equal impact on UHV. But in the process of coal washing only the ash content of clean coal is decreased by selective separation of ash-forming materials from the combustible materials. So the critical ash content of the coal depends on its moisture content as shown in Fig. 1. But as the pricing structure is grade-based the critical ash will no longer remains the same when it is maximized for its value.

2.2. Optimization approach

In composite washeries, the raw coals received are crushed and screened into several size fractions. Each size fraction is then treated separately in a suitable washing circuit that operates according to parameters determined by laboratory float-and-sink tests, and every effort is made to obtain the maximum possible yield of the primary clean product. The exercise undertaken here is to utilize the concept of constant incremental ash for all parallel circuits to maximize the price of clean coal within a framework that is not only practical but also makes it accessible for the coal preparation engineers to determine the optimum cut points for washing of different coals. But in actual practice most of the coal washing devices are not perfect. This happens due to the fact that a greater portion of the lower density middlings is misplaced into the refuse stream compared to the higher density middlings getting misplaced to the clean coal stream. The misplacement of higher quality (lower ash) material lowers the effective incremental ash. Hence a correction must be made to account for the impact of misplaced solids on incremental quality. It was also realized that the efficiencies of density-based separators tend to decline as the particle size decreases [16]. To over come this, finer particles must be treated at a higher specific gravity cut points to maintain optimum yield (same incremental quality) [6,17]. Here, we follow Osborne's approach (1988) for the variation of probable error or Ecart probable moyen (E_p) with particle size, equipment size, and separation density which is

$$E_p = f_1 f_2 f_3 E_s \tag{2}$$

where f_1 is a factor accounting for the variation of E_p with particle size, f_2 is a factor accounting for variation of E_p with equipment size, f_3 is

Table 1
Gradation of noncoking coal in India and current basic price*.

Grade	UHV (Kcal/kg)	Current price in Rupees/ton	
		Non-long flame	Long flame
A	>6200	1160	1300
B	>5600 to ≤6200	1030	1170
C	>4940 to ≤5600	860	980
D	>4200 to ≤4940	720	840
E	>3360 to ≤4200	560	–
F	>2400 to ≤3360	440	–
G	>1300 to ≤2400	320	–

* Only valid for coal of Mahanadi Coalfield Ltd.

Table 2
Critical ash content for Indian coal.

Ash %	C.V as received in Kcal/kg	Weight of coal for equal value	Weight increment	Weight of ash content	Ash weight increment	% ash in increment (critical ash)
20	5450	94.936	5.064	18.987	3.013	59.493
22	5174	100.000	5.635	22.000	3.352	59.493
24	4898	105.635	6.308	25.352	3.753	59.493
26	4622	111.943	7.109	29.105	4.229	59.493
28	4346	119.052	8.073	33.335	4.803	59.493
30	4070	127.125	9.248	38.138	5.502	59.493
32	3794	136.373	10.699	43.639	6.365	59.493
34	3518	147.072	12.521	50.005	7.449	59.493
36	3242	159.593	14.851	57.453	8.835	59.493
38	2966	174.444	17.898	66.289	10.648	59.493
40	2690	192.342	21.991	76.937	13.083	59.493
42	2414	214.333	27.669	90.020	16.461	59.493
44	2138	242.002	35.871	106.481	21.341	59.493
46	1862	277.873	48.356	127.822	28.768	59.493
48	1586	326.230		156.590		
					Average	59.493

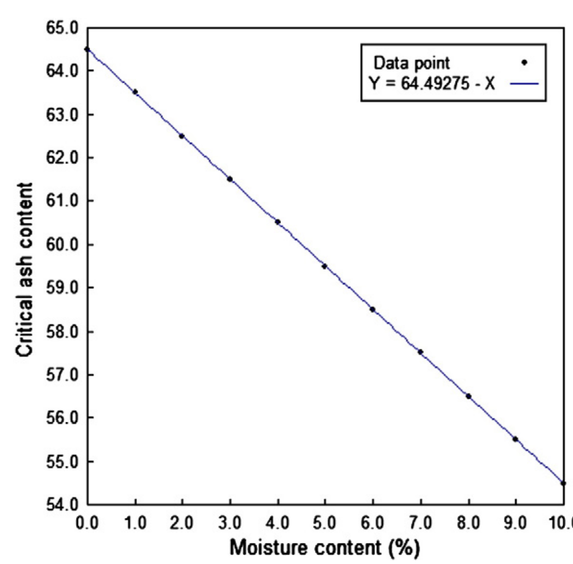

Fig. 1. Critical ash of coal at different moisture contents.