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An optimization study of yield for a coal washing plant from Zonguldak region

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ABSTRACT

In this study, a coal washing plant in Zonguldak was optimized using equalization of incremental product quality approach which maximizes plant yield for a given ash constraint based on float–sink data. By maximization of yield using Solver which is an optimization routine available in Excel® for the identical elementary ash content and the specified ash level of 9.50%, the optimum cut points were determined for washing of coarser size fraction (100-18 mm) and finer size fraction (18-0.5 mm) by Drewboy Heavy Medium (HM) Bath and HM Cyclone, respectively. The results were compared with the plant operations in terms of product yield and ash content. Calculated yield % and ash % values with experimental yield % and ash % values from float–sink data of the used coal were also compared and they were in good agreement ($R^2 > 0.99$). By equalization of the incremental ash in order to get composite ash of 9.5%, the composite yield was maximized to 30.71% while the plant's yield was about 24.00%. This approach identified the optimum operating conditions for individual cleaning circuits as 1.693 and 1.682 for Drewboy HM Bath and HM Cyclone, respectively. It is worth pointing out that, this increase (6.71%) in the yield would be remarkable when considering the whole life of the washery and the annual production of the plant (about 700000 tons). In addition, the yield was maximized to 33.41% for the target ash of 11.61% by similar optimization studies. The optimum operating cut points for HM Drewboy Bath and HM Cyclone was determined as 1.900 and 1.888, respectively. Yield optimization was also performed by taking α equals to 80, which can be assumed ideal for HM separators. The results obtained by the two different calculations were very close to each other.

1. Introduction

In coal washing plants raw coals are generally crushed, screened into size fractions and beneficiated by using suitable washing equipment based on the laboratory float–sink test results in order to obtain clean coal which has desired ash content. Graphical methods are commonly used for yield calculation of coarse and fine coals, and the information generated would help the operator in yield calculation of composite clean coal [1,2], but it is not so practical considering the large number of feed coals [3]. Furthermore, the process is time-consuming and prone to human error [4,5]. Instead, the concept of equalization of incremental ash is being used to maximize plant yield for a desired ash constraint [1–4,6–12]. The incremental ash concept which has important implications related to product blending practices and plant control strategies, provides extremely useful information regarding the design, optimization and control of density-based separation processes leading to potential financial gains that may be realized [11]. This concept expresses that the clean coal yield for parallel operation is at its maximum when all circuits are operated at the same incremental ash [11,13–18]. It has direct practical utility although it recommends a numerical approach to the constrained non-linear optimization problem [3,4].

"Solver" which is one of the tools of MS Excel® can be used to solve simple non-linear problem. It is easy to minimize and maximize a cell in a spreadsheet. This routine makes it possible to quickly identify an optimal value for a formula in a target cell which is related either directly or indirectly to other cells in the spreadsheet. These cells can be adjusted by the Solver to produce the result specified in the target cell subject to user-defined constraints [19]. It was used for the yield maximization of Indian origin coal [20]. This paper aims to determine the optimal operating cut points of Drewboy Heavy Medium (HM) Bath and HM Cyclone for the Zonguldak Coal Washing Plant so as to maximize the yield at a specified ash content of a final clean coal by solving constrained nonlinear optimization problem using Solver.

2. Theoretical background

In order to maximize the possible clean coal yield, the concept of constant incremental ash is utilized for the washing circuits in the washeries, where the run-of-mine coals are crushed, screened and

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each size fractions are treated separately in the suitable washing circuits based on the washability data. The Osborne's [21] approach is used for the variation of probable error (Ep) with particle size, equipment size and separation density as given in Eqs. (1) and (2) for HM Vessel and HM Cyclone, respectively. Osborne's approach was previously used [10,20] for determination of Ep.

$$Ep = f_1 . f_2 (0.047\,D_{50} - 0.05) \quad (1)$$

$$Ep = f_1 . f_2 . f_3 (0.027\,D_{50} - 0.01) \quad (2)$$

where f_1 is the factor affecting for the variation of Ep with particle size, f_2 is the factor affecting for the variation of Ep with equipment size and f_3 is the manufacturer's guarantee factor.

The sharpness factor (α) is calculated from the following Eq. (3) [5,22] by using Ep values of the HM Vessel and HM Cyclone:

$$E_p = \frac{1.0986 D_{50}}{\alpha} \quad (3)$$

where D_{50} is the relative density of separation.

The predicted cumulative yield and cumulative ash of the coarse and fine size fractions are calculated at each relative density (D_{50}) by using modified Lynch Eq. (4) [2,10,23] which is fitted to the normalized partition data obtained from the tests conducted by HM Vessel and HM Cyclone.

$$PN(\text{float}) = y = 1 - \frac{(e^{\alpha x} - 1)}{(e^{\alpha x} + e^{\alpha} - 2)} \quad (4)$$

where α is the fitting constant which is different for all density based separators, and x is the specific gravity of separation and can be calculated from Eq. (5):

$$x = \frac{D}{D_{50}} \quad (5)$$

where D is the specific gravity and D_{50} is varied from 1.4 to 2.0.

These data are used to calculate the incremental ash to each separation density using Eq. (6) below [10]:

$$IA_{k+1} = \frac{Y_{k+1}A_{k+1} - Y_k A_k}{Y_{k+1} - Y_k} \quad (6)$$

where Y_k and A_k are the cumulative yield and cumulative ash at the kth density cut point or separation density, respectively. Y_{k+1} and A_{k+1} are the cumulative yield and cumulative ash at the (k+1)th density cut point or separation density, respectively. IA_{k+1} is the incremental ash at (k + 1)th density cut point.

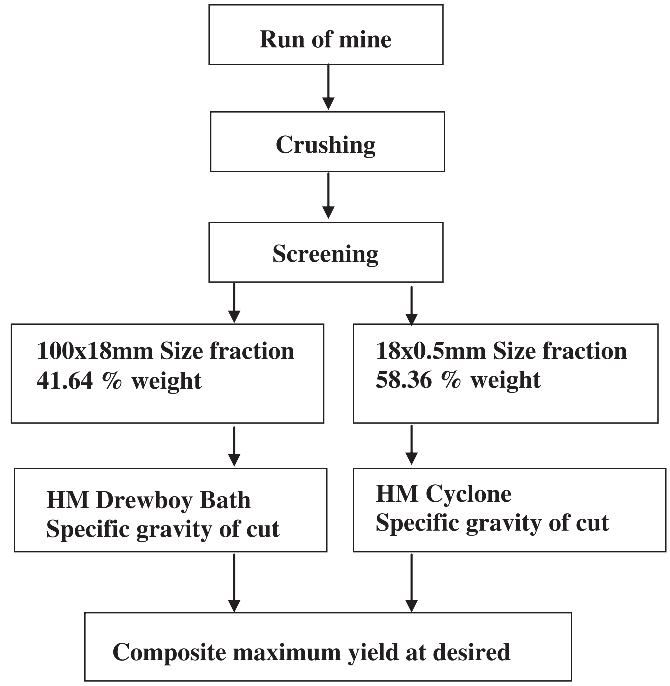

Fig. 1. Optimization in composite washing of feed coal.

These data are utilized to calculate the incremental product ash corresponding to each separation density. Cubic relationships are assumed between Yield (Y), Yield × Ash (Y.A), and Incremental Ash (IA) with the separation density in the range from 1.4 to 2.0 since the presence of different proportions of the variety of minerals in a coal would allow specific coal or specific size fractions of a coal to have different densities even when their ash contents are the same and vice-versa [3,18]. Polynomial equations up to a third degree are fitted to the cubic relationships for the different coal size fractions treated in the density-based processes [18,24] as Eq. (7):

$$Yr_{ij} = x_0 + \sum_{k=1}^{3} x_k d_{ij}{}^{k} \quad (7)$$

where r = 1 refers the equation for cumulative yield and r = 2 refers to the equation for cumulative yield × cumulative ash and d_{ij} is the specific gravity. Model parameters (x_0, x_1, x_2, x_3) for cumulative yield × ash, and elementary ash of clean coals are estimated for different coal size fractions. The approach utilized in this study is to maximize the objective function (yield) subject to the quality constraints ($IA_1 = IA_2$; $1.40 \le \rho_1, \rho_2 \le 1.90$; average ash % = target ash %) by using Solver.

Then, optimization of a plant is performed by the maximization of yield at a specified ash content of commercial clean coal by using an optimization tool such as Solver.

Table 1
Float–sink data[a] of a coal washing plant in Zonguldak of Turkey.

Size		Sp. gr.	Wt. (%)	Ash (%)
100–18 mm		Float–1.45	10.61	6.75
		1.45–1.60	7.03	21.21
Ash %	72.55	1.60–1.75	3.41	30.61
Ratio %	32.90	1.75–1.90	1.88	39.39
Spec. gr.	1.75–1.80	1.90–sink	77.07	88.96
18–0.5 mm		Float–1.45	43.80	5.50
		1.45–1.60	7.32	19.71
Ash %	43.07	1.60–1.75	3.06	29.58
Ratio %	46.12	1.75–1.90	2.29	43.69
Spec. gr.	1.45–1.50	1.90–sink	43.53	85.72
0–0.5 mm				
Ash %	32.31			
Ratio %	20.98			
Washery yield %	~24.00	Annual average production tpa	700000	

[a] Monthly average values of July.

Table 2
Values of the factors used for the calculation of Ep (Osborne, 1998).

Type of HM equipment	f_1	f_2	f_3
Drewboy Bath	0.91	1.15	–
Cyclone	0.848	1.15	1.15