Energy, Mines and Resources Canada / Énergie, Mines et Ressources Canada

CANMET

Canada Centre for Mineral and Energy Technology / Centre canadien de la technologie des minéraux et de l'énergie

Coal Research Laboratories / **Laboratoires de recherche sur le charbon**

[redacted]

Canada

THE ROLE OF COAL PREPARATION PLANT PERFORMANCE TESTING IN IMPROVING CLEAN COAL RECOVERY

M.W. Mikhail, A.I.A. Salama and O.E. Humeniuk

Division Report WRC 92-43 (J)
August 1992

Submitted to CIM bulletin for publication.

THE ROLE OF COAL PREPARATION PLANT PERFORMANCE TESTING IN IMPROVING CLEAN COAL RECOVERY

by

* M.W. Mikhail, **A.I.A. Salama, and *** O.E. Humeniuk

ABSTRACT

Performance testing of preparation plants is referred to as plant audit. It evaluates plant performance under normal operating conditions and is aimed at improving yield through knowledge of actual process performance and interactions between different processes in a plant.

This paper describes the program to evaluate the performance of several Canadian preparation plants. The performance test requires the planning of a sampling campaign that would include all circuits in the plant. Samples are analyzed to determine washing characteristics (screen and float-sink), ash and per cent solids of feed and products of separation units in the plant. Performance characteristics are established based on analysis and material balance. Specific recommendations can then be made to improve recovery, and identify and explain potential causes of apparent deficiencies.

The objectives of the program are to reduce the cost of production by improving recovery of clean coal and, in turn, to reduce disposed tailings, establish baseline information on coal preparation plants performance in Canada, and define R&D work needed to optimize plant operation.

---

*Head, **Research Scientist, ***Supervisor, Coal Preparation Section, Fuel Processing Laboratory, Coal Research Laboratories, CANMET, Energy, Mines and Resources Canada, Devon, Alberta.

LE RÔLE DES ESSAIS DE PERFORMANCE DES USINES DE PRÉPARATION DU CHARBON DANS L'AMÉLIORATION DU PROCÉDÉ DE RÉCUPÉRATION DU CHARBON ÉPURÉ

par

* M.W. Mikhail, ** A. Salama et *** O.E. Humeniuk[19]

RÉSUMÉ

Les essais de performance conduits sur les usines de préparation sont le mode de vérification des opérations de cette usine. Ils servent à évaluer le rendement de l'usine dans des conditions normales de fonctionnement, et doivent aider à augmenter la production grâce à la connaissance de la performance réelle des procédés, et à la connaissance des interactions entre les divers procédés qu'emploie l'usine.

Dans cet article, on décrit le programme dont le but est d'évaluer la performance de plusieurs usines canadiennes de préparation. L'essai de performance exige que l'on planifie une campagne d'échantillonnage qui inclurait tous les circuits de l'usine. On analyse les échantillons pour en déterminer les

[19] * Chef, ** Chercheur scientifique, ** Superviseur, Section de recherche sur la préparation du charbon, Laboratoire de recherche sur le traitement des combustibles, Laboratoires de recherche sur le charbon, CANMET, Énergie, Mines et Resssources Canada, Devon (Alberta).

caractéristiques de lavage (criblage et essai de séparation par liquide de densité intermédiaire), le pourcentage de cendres et de solides que contient le minerai d'alimentation, et les produits venant des appareils de séparation dont dispose l'usine. On a établi les caractéristiques de performance en fonction de l'analyse et du bilan des matériaux. On peut alors formuler des recommandations spécifiques visant à améliorer le taux de récupération, et identifier et expliquer les causes possibles des déficiences apparentes.

Les objectifs du programme sont de réduire les coûts de production en améliorant le taux de récupération du charbon épuré, et ensuite, de réduire les quantités de stériles rejetés, d'établir de l'information de base sur la performance des usines canadiennes de préparation du charbon, et de définir la R et D nécessaire à l'optimisation du fonctionnement de l'usine.

CONTENTS

TABLES

FIGURES

INTRODUCTION

The role of coal preparation is to produce a clean coal product that meets market and utilization specifications, reduces transportation cost, and minimizes the amount of coal misplaced with refuse or tailings. At the present, emphasis is placed on optimizing recovery and improving clean coal quality. This is based on economic and environmental demands. Improvement in recovery would translate to higher tonnage produced at the same costs and results in less total cost per tonne. This is important for the survival of coal companies who are faced with stiff competition and low coal prices. Also, recent emphasis on environment demands minimum accumulation of waste with little or no combustible material that could become a source of pollution to water and air.

Presently, operating coal companies are not in a position to invest significant capital to make major changes in their preparation plants due to depressed coal prices and uncertain future markets for coal. However, they welcome opportunities to optimize existing operations that require little or no expenditure. The performance evaluation project discussed in this paper is geared to meet this need. Performance testing of a preparation plant is referred to as a "plant audit". It evaluates plant performance under normal operating conditions. The main benefit of a plant audit is yield maximization achieved through the knowledge of the interactions between different processes in a plant. A first step toward yield maximization is to compare actual performance of a unit to established specifications and/or performance of the same unit in other plants.

The project was originally promoted by several coal companies along with the Coal Association of Canada (CAC) and CANMET. It was agreed that the greatest collective good would be served by carrying out plant performance evaluations. At the Coal Preparation Association meeting held on June 8, 1990 at Devon, it was recommended by several coal companies that this project should be developed by CANMET with government funding to share costs. It was agreed at that time that the coal companies would carry a share of the cost but that government funding was needed to help coal companies, most of which are in financial difficulties.

This paper describes the steps involved in performance testing, the parameters to measured, and expected benefits. An example will be given from Canadian experience with performance testing, describing the beneficial results that were achieved.

PERFORMANCE EVALUATION TESTING

Performance testing of preparation plants is aimed at evaluating the operation of different units (size and density separators) of the process flowsheet. The objective is to establish how effectively a unit is operating as compared with established characteristics based on defined criteria (discussed later on). Also, as a result of performance test, a material balance flowsheet can be established with solids and water flowrates, per cent solids, and ash content. A performance evaluation test would include the following steps:

1. Review plant flowsheet with plant staff and decide on sampling points and equipment to be evaluated.

2. Design a sampling program with required analyses of different samples. This would include sample weight (based on particle size), duration, sampling intervals, sample container size, and sampling equipment.

3. Check plant equipment to ensure normal operating conditions shortly before the performance test. This includes checking screens for damage, pump pressure, cyclone wear, spillage, leaks, plugging, etc.

4. Collect samples simultaneously during one shift (6 to 8 h), recording all operating conditions. These include flow rates of feed and products, media densities, pressures, reagent dosages, and cyclone settings.

5. Carry out detailed float-sink and size analyses and determine ash and moisture content, and sulphur if desired.

6. Based on results collected from the plant and laboratory analyses, perform computer data manipulations to determine performance parameters and calculate a material balance flowsheet for the plant.

7. Carry out a detailed performance evaluation based on the above information to characterize each unit or process with available report on the status of each circuit, and recommend means to improve performance, if applicable.

PERFORMANCE TEST MEASURES

Most coal preparation plant flowsheets include density/size separators and flotation cells to achieve optimum clean coal recoveries at specified quality (ash/sulphur) levels as stipulated by their customers. It is therefore beneficial to conduct regular (annual) performance tests on their equipment based on defined performance criteria. The performance criteria parameters are used to:

- Evaluate the separators ability to make sharp separation between coal and impurities regardless of feed characteristics.
- Assist in comparing separation performance with the performance of different separators or with industrially accepted levels of performance.
- Assist in comparing separation performance with theoretical separation based on standard float-sink data.
- Predict products yield and quality from standard float-sink data.
- Establish performance guarantee for newly installed plants.

- Provide an opportunity for improving the operating conditions/equipment or modifying circuit/plant flowsheet.

Various performance measures (parameters) are classified as separator-dependent (coal-independent) criteria or coal- and separator-dependent (coal-dependent) criteria (1, 2).

SEPARATOR-DEPENDENT (COAL INDEPENDENT) SEPARATION CRITERIA

In theoretical separation, all particles of density less than the relative density of separation (dp) report to the clean coal stream while all particles of density higher than dp report to the reject stream. If the percentage recovery of reject stream is plotted against the density variable d, we obtain a step function with ordinate 0 per cent for d less than dp and ordinate 100 per cent for d greater than d_p (Fig. 1). In practice, however, some of the clean coal reports (is misplaced) to the reject stream and some of the reject reports to the clean stream. The plot of the percentage of feed reporting to the reject stream against the mid-point of each density fraction produces what is known as the separation curve (SC) or Tromp distribution curve (TDC). This curve is considered to be a characteristic of the separator and is independent of the characteristics (i.e. washability) of the coal being processed.

Several criteria can be derived from TDC and are listed in Table 1. These criteria are the most common and accepted by the industry. It is obvious that the probable error (E_p) is directly proportional to the slope of the middle portion of the TDC. The lower the E_p , the steeper the TDC and the sharper the separation. Consequently E_p does not reflect the separator performance represented by the tail portions (less than d_{25} and higher than d_{75}) of TDC. This handicap is overcome by the use of error area parameter A_e, which is defined as the area between the theoretical and normal TDC as shown in Fig. 1. The lower the A_e, the steeper the TDC and the sharper the separation.

The probable error and error area are both useful for making broad comparisons between various types of cleaning equipment. Probable error is determined entirely by the sharpness with which the near-density material is separated and ignores the recovery of the light coal and the rejection of the heavy impurities. The probable error and error area analyses can give opposite relative evaluations but the error area takes into account how the entire feed is treated and therefore gives a more accurate evaluation.

The sharpness of separation, whether measured by probable error or error area, decreases with an increase in the relative density of separation (3). CERCHAR investigators developed a criterion called the "Imperfection" which takes into account this relationship between cutpoint (relative density of separation) and probable error for jig and HM washers and are defined in Table 1. Imperfection varies between different washing units. For jigs, the imperfection remains constant with increasing cutpoint (3) whereas the imperfection for the heavy medium bath gets larger with increasing cutpoint. However, the change is often so small that it can be neglected. The imperfection of the heavy medium cyclone is essentially the same as for the heavy medium bath. Nevertheless, because of the dependence of the imperfection on the cutpoint, the use of distribution curves to compare separations at high and low cutpoints involves an element of error that varies in magnitude with the type of cleaning process.

COAL - AND SEPARATOR-DEPENDENT (COAL-DEPENDENT) SEPARATION CRITERIA

Coal- and separator-dependent criteria are based on the efficiency of separation and are influenced by feed characteristics (washability), separator characteristics, and density of separation dp. Separation efficiencies are evaluated in a variety of ways utilizing mass recovery and quality (ash content) of clean coal stream and/or reject stream. The yield and quality of washed coal are the factors of direct and practical interest in any washing operation. They are directly dependent on the washability characteristics of the raw coal and thus unsuited to comparing the performance of different wash plants and even inadequate for routine day-to-day control. Some criteria, such as organic efficiency, misplaced material, and ash and yield errors, are dependent criteria although they are not directly dependent on the washability of the feed.

Table 2 presents the most common dependent parameters for evaluating separator performance; however, a complete list can be found in reference (4).

Ash reduction must be considered along with organic efficiency in characterizing performance because, unless the desired ash reduction is achieved, a high organic efficiency is not an indication of satisfactory performance. To account for the liberation of coal particles from intergrown middlings and reject particles by degradation during washing (in case of friable coals), it is necessary to calculate the organic efficiency from the reconstituted feed. The reconstituted feed is calculated on the basis of the composite data from the product and refuse rather than from the raw feed data itself. Failure to calculate efficiency from the composite feed analysis may result in efficiencies of over 100 per cent because of the influence of degradation.

The misplaced material is the sum of the mass per cent of the sink material in the washed coal and the float material in the refuse at the operating cutpoint, expressed as a percentage of the feed which can be determined by scaling the products mass distributions by mass yields. The misplaced material criterion is a simple one since it does not take into account the quality of the material that is misplaced, only the quantity.

Ash error is a direct measurement of the degree to which the ash content of the cleaned coal is raised by imperfect washing. It is the numerical difference between the actual and the theoretical ash contents of washed coal at the yield obtained. Yield error is the difference between the wash plant yield of clean coal and the theoretical yield (from the float-sink data) at the actual ash content of the washed coal.

The organic efficiency suffers from the handicap that it does not have any bearing on the quality of raw and products streams. To overome this handicap, the separation efficiency was introduced. This efficiency can be interpreted as the product of the organic efficiency multiplied by the ratio of ash reduction in normal to theoretical wash. In case of no change in washability during processing as a result of size degradation, it can be shown that the separation efficiency varies between 0 and 100%.

Coal is sold on the basis of ash and sulphur content and the porduction costs are affected directly by yield. Organic efficiency, ash error and yield error, are related to impairment in yield and ash caused by imperfect washing. Since these criteria are influenced by the relative density composition of the raw coal and the cutpoint of separation, equipment treating coal with different washabilities or washed at substantially different cutpoints cannot be compared directly on the basis of these criteria. For these comparisons, independent criteria discussed earlier are required.

MATERIAL BALANCE

The material balance flowsheet represents the solids mass flow and water volume in the feed and products of each process unit. Also it includes per cent solids and quality of solids (ash or sulphur). Material balance calculations require sampling many points in the plant to determine quality, per cent solids, and water flow rates. The feed flow rate to the plant and products are measured using weigh belts in the plant. Intermediate values are based on calculated yields of separating units (size and density separators). Some points are calculated from combined flow from different units. Calculated material balance values can be checked by comparing actual feed and calculated (reconstituted) feed based on combined products mass and quality.

Material balance calculation is essential in determining the following:

1. Mass distribution to different processes
2. Contribution of each process to the overall quality of final products
3. Comparison between designed material flow and actual (measured) material flow
4. Causes of a particular problem or defficiency such as overloading, solids concentrations, and water flow.
5. Whether changes in a plant circuit are necessary.
6. Calibration of some on-line instruments e.g., weigh conveyor, flowmeters, and density gauges, and overall plant recovery.

BENEFITS OF PERFORMANCE TESTING

Studies in the USA and Australia show that the clean coal yield can be improved by one to five percentage points by applying certain adjustments and proper maintenance (7, 8). Performance testing is the main step toward achieving that objective. The performance test may be used for one or more of the following purposes:

1. Regular testing: annually or biannually as part of an ongoing optimization plan.

2. Diagnosing and addressing existing operating problems that adversely affect clean coal recovery.

3. Evaluating old plants that are processing coal seams that might be different from the ones on which the plant design was based.

4. When upgrading an existing plant by making changes in process flowsheet or increasing the capacity of the plant (performance tests are carried out before and after implemented changes).

5. Evaluating a newly installed process control system, by carrying out performance tests before and after the implementation of the control system.

Benefits to the coal company can be summarized as follows:

1. Reduced cost of production of saleable coal through improved recovery of clean coal.

2. Reduced environmental impact through reduction of tailings.

3. Information provided on the interaction between processes or circuits within the plant.

4. Material balance data provided to determine bottle-neck points and potential for increasing or decreasing plant feed rate.

5. A check on on-going maintenance work.

6. Evaluation of plant performance in relation to changes in raw feed washability.

ACTUAL PERFORMANCE TESTING OF A PLANT

Recently a performance evaluation test was carried out at a western Canadian preparation plant. The objective was to determine material balance flowsheet and performance parameters of cleaning equipment. The plant flowsheet includes heavy medium cyclone, water-only cyclones and froth flotation as the main cleaning processes. Results of the performance test indicated the following:

1. The heavy medium cyclone performance was below what can be expected. Several factors were suggested as potential causes of the low recovery, including low cutpoint of separation with high near-density material, apex diameter, and possibly the coal to medium ratio. It was recommended that the operation of the heavy medium circuit be examined to find means to improve the recovery.

2. The water-only cyclone circuit indicated very high recovery but with limited cleaning. The actual performance was below what can be expected based on measured performance parameters. The poor selectivity could be a result of high recirculation load, the presence of particles coarser than 0.5 mm in the feed, and/or high per cent solids in the feed. Improvement in performance would result in improved selectivity but not in higher recovery.

3. The water-only cyclone overflow was separated at 0.25 mm and fed to a flotation circuit. Froth flotation performance compared favourably with other similar operations in western Canada. However, it was found that losses of coarser particles were significant. It was recommended that feed to flotation circuit be changed from 0.25 mm to 0.15 mm by changing the sizing screen.

4. It was found that optimizing the fines cleaning circuits would marginally increase the recovery of fine coal but would produce clean coal at lower ash content. This would allow the increase of heavy medium separation cutpoint resulting in significantly higher recovery which, when blended with the low-ash fine clean coal, would give the same overall ash content of the final product. The improvement in plant recovery was estimated from 3 to 5%.

Changes in the fines circuit were implemented and improved the plant recovery by 1 to 2%. This resulted in increase of 30,000 to 60,000 t/year of clean coal. Changes in the heavy medium circuit are underway and expected to increase the plant recovery by 5% or approximately 180,000 t/year. The cost to the company to carry out performance test was about $60,000. Based on approximately $50/t, the payback of the performance test corresponds to an increase in clean coal recovery of 1200 t. As a result, the company is planning to perform a performance test on a regular basis as part of an ongoing optimization plan.

REFERENCES

1. Yancey, H.F., and Geer, M.R. "Some practical aspects of appraising coal washing results"; U.S. Bureau of Mines; Report of Investigations 5153; 1955.

2. Geer, M.R., and Yancey, H.F. "Evaluation of washery performance"; U.S. Bureau of Mines, Report of Investigations, 8093; 1962.

3. Belugau, P., and Ulmo, M., "Representation of washing results"; Proc, 1st Int Conf on Coal Prep in Cong, A-3, Paris; 1950.

4. Leonard, J.W., Chief Editor, "Coal preparation"; AIME, Fourth Ed, Ch 18; 1979.

5. Yancey, H.F. and Geer, M.R., "Efficiency and sharpness of separation in evaluating coal - washery performance"; Trans AIME 190: 507-517; 1951.

6. Fraser, T. and Yancey, H.F., "Interpretation of results of coal washing tests"; Trans AIME 69: 447-482; 1923.

7. Bradley, N.C., Allgood, G.O., and Moyers, J.C. "Potential economic benefits from process control of coal preparation plants"; ORNL 5736; 1981.

8. Bensley, C.N., Vince, A., Keant-James, R., and Nicol, S.K. "Preparation plant metallurgical audits - a proven tool for maximizing coal recovery"; 8th Int Conf on Coal Res; 1988, Tokyo, Japan.

Table 1 - Independent separation criteria (4)

Critereon name	Expression
Probable error (E_p)	$E_p=(d_{75}-d_{25})/2$
Error area (A_e)	$\int_{d_f}^{d_{50}} PN(\rho)d\rho + \int_{d_{50}}^{d_s} [100-PN(\rho)]\, d\rho$
Imperfection (I)	$I=E_p/(d_{50}-1)$ Jig $I=E_p/d_{50}$ HMC

d_{75} = Density corresponds to partition number=75

d_{50} = Density corresponds to partition number=50

= Cutpoint

d_{25} = Density corresponds to partition number=25

d_f = The least density of coal particles

d_s = The highest density of coal particles

$PN(\rho)$= Partition function (number) at density ρ

Table 2 - Dependent separation criteria

Critereon Name	Expression
Organic efficiency (OE) Recovery efficiency (RE)	$OE,RE = \frac{Y_c}{Y_{fl}} . 100$ (at same A_c) in % (5)
Efficiency (E)	$E = Y_c . \frac{A_t}{A_c}$ (4)
Misplaced material	Based on Feed, clean coal and tailings streams mass distributions (4)
Ash reduction (AR)	$AR = A_r - A_c$ (6)
Ash error (AE)	$AE = A_c - A_{fl}$ (at same yield) (6)
Yield error (YE)	$YE = Y_c - Y_{fl}$ (at same ash content) (6)
Separation efficiency (SE)	$SE = \frac{Y_c}{Y_{fl}} \frac{A_r-A_c}{A_r-A_{fl}} . 100 = OE . \frac{AR}{AR + AE}$. (6)

Y_c = % Mass yield of clean coal product (Mass Recovery-Actual)

Y_{fl} = %Mass yield of float (Mass Recovery - Theoretical)

A_c = % Clean coal product ash content

A_t = Tailings product ash content

A_r = % Raw coal ash content

A_{fl} = % Float ash content

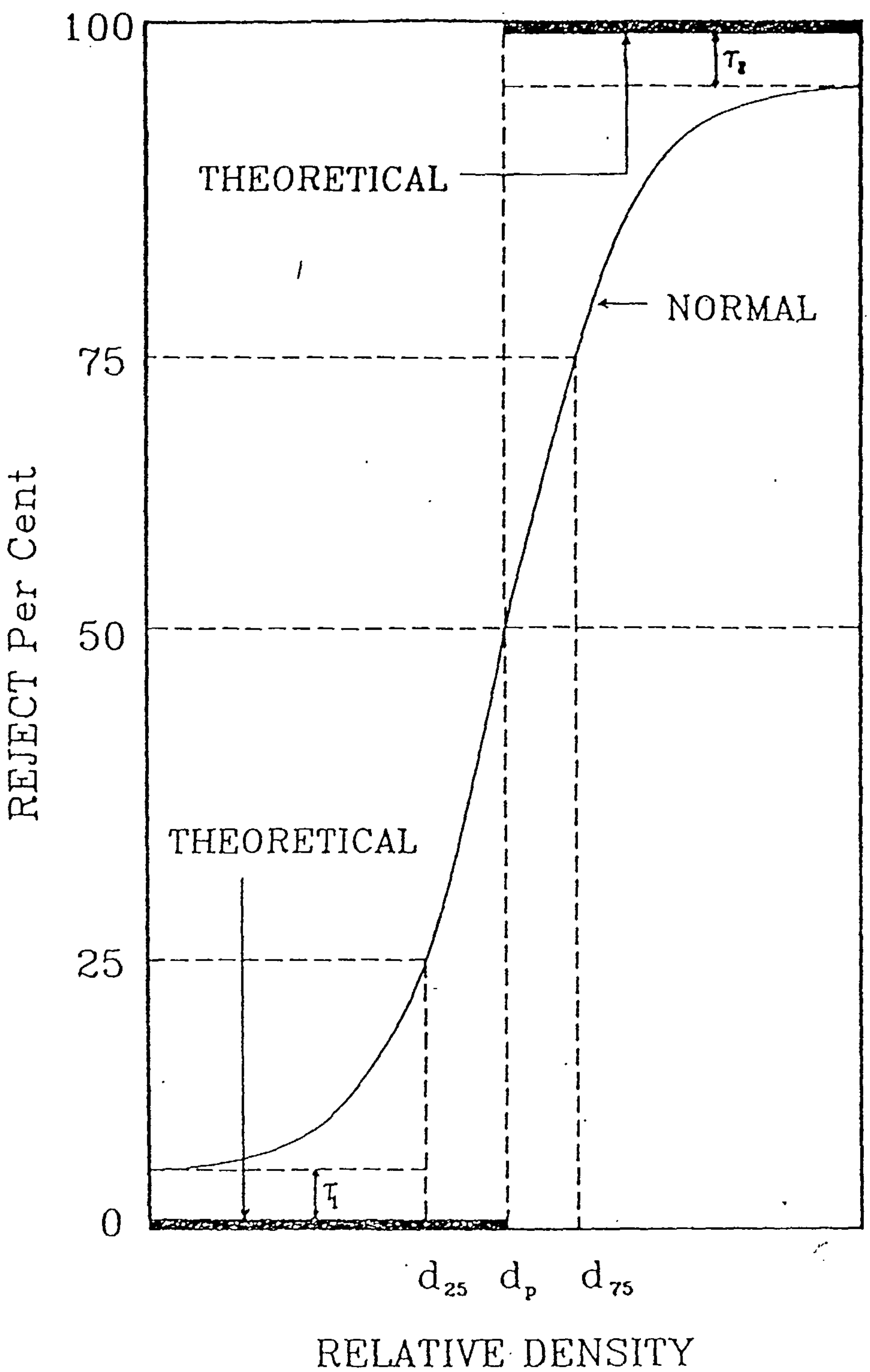

Fig. 1 - Tromp distribution curve