

## Research Article

### Evaluation of the Performance of Tri-Flo Separators in Tabas (Parvadeh) Coal Washing Plant

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**Abstract:** Parvadeh Coal Preparation Plant (CPP) was installed in 2008 for the production of the 750000 TPY of clean coal containing 10.5% ash from the raw feed having 44% ash and mainly coming from the long-wall mine. Three units of high capacity centrifugal separators (Tri-Flo) are used for the preparation of the coal in the size ranges of -50+6 mm and -6+0.5 mm. Tri-Flo separators are operating in double stages, so they can produce three products. The nominal feed capacities of the 700 mm Tri-Flo and each unit of 500 mm Tri-Floes are 120 and 70 TPH respectively. However, due to some of the operating difficulties in the coal mine, the current feed capacities to the separators are changed to 160 and 30 TPH accordingly. In this research, sink-float experiments on the representative samples of the Tri-Flo separators were used for the evaluation and optimization of their performance. The experiments were performed in six different densities. On the basis of the experimental results, the operating  $E_p$  (Ecart Probable) value of the 700 mm Tri-Flo was 0.075 which was more than the design figure (0.035). Such a difference was mainly attributed to the changes in the feed characteristics. In the small Tri-Flo separator,  $E_p$  values were measured as 0.062 and 0.087 for the size ranges of (-1+0.5 mm) and (-6+1 mm) respectively and were in good agreement with the design criteria. The optimization of the heavy media separation circuit of the plant is underway using the results presented here.

**Keywords:** Coal, partition curve, sink-float test, tri-flo

## INTRODUCTION

The Tabas Coal Preparation Plant (TCPP) is located in 80 Km. south west of Tabas city in Yazd province in Iran. The nominal feed capacity to the plant is about 1.5 million tons/year of raw coal with the ash content of about 44%. The plant was installed in 2008 for the production of 750000 tons/year of clean coal containing 10.5% ash. On the basis of the process flowsheet that is presented in the Fig. 1, the feed is firstly classified into three size fractions including -50+6 mm, -6+0.5 mm and -0.5 mm. Three units of Tri-Flo separators and six units of flotation columns are the major equipment used for the washing of the coarse and the fine fractions feed materials respectively. Tri-Flo separators with the diameters of 700 mm (one unit) and 500 mm (two units in parallel) are used for the rejection of the coal ash in the size ranges of -50+6 mm and -6+0.5 mm respectively. The column flotation circuit is also used for the preparation of the fine coal fraction of -0.5 mm. Screen bowl centrifuges and pressure filters are used for the dewatering of the small clean coal and the fine clean coal respectively. In order to achieve the required ash level in the clean coal product of the plant in about 10.5-11%, the ash content of the coarse, small

and fine clean coals are designed to be 11-14, 8-11 and 9-10%, respectively.

Some of the characteristics of the existing feed materials to the plant are different from the sample that was used in the laboratory and pilot plant studies prior to the basic design of the plant. Consequently, the total feed capacity is 200 TPH, instead of the nominal capacity of 300 TPH, due to the deviations in the size distribution and the ash distribution of the feed materials. The nominal feed capacities of the 700 mm Tri-Flo and each unit of 500 mm Tri-floes have been designed to be 120 and 70 TPH, respectively. However, due to some of the operating difficulties of the coal mine, the current feed capacities to the separators are changed to 130-160 TPH for 700 mm Tri-Flo and about 35-40 TPH for each of 500 mm Tri-floes.

As can be seen the operational feed rate to the 700 mm is about 16% more than the nominal capacity and for each of the 500 mm Tri-floes is one-half of the nominal feed rate. The above mentioned deviations as well as the lack of understanding of the operational parameters of Tri-Flo separators caused a considerable decrease in the performance of the gravity separation circuit in TCPP. The predicted weight recovery (yield) of the clean coal for 700 mm Tri-Flo is 24.49% with the

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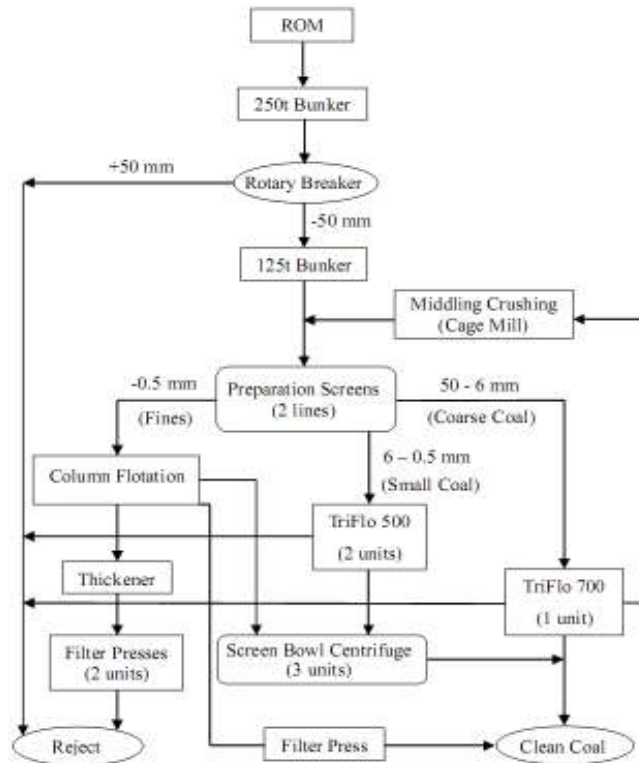


Fig. 1: The process flowsheet of the Tabas Coal Preparation Plant (TCPP)

ash content of 11.7% and the yield and the clean coal ash content for 500 mm Tri-Flo are 49.3 and 10.3%, respectively.

The monitoring of the plant operational data during 2011 April to September revealed that the process yield especially in the coarse product of clean coal (-50+6 mm) was about 5-7% lower than the expected figures. However, there were relatively good agreements for the small clean coal. Therefore, the operational performances of 700 and 500 mm Tri-floes were evaluated using wash-ability analysis and separation efficiency index of  $E_p$  (Ecart probable) and the results are presented in this study.

### TRI-FLO SEPARATORS

The Tri-Flo separator combines two stages of dense medium cylindrical cyclones separation in a single unit operation that have been installed with a slope of 20° from horizontal as shown in Fig. 2. The cylindrical body of the Tri-Flo consists of two consecutive cylindrical chambers with an axial orifice. Each cylindrical chamber is equipped with an involutes media inlet and sinks discharges. The feed is sluiced with a small amount of dense medium and added to the first chamber of the vessel at atmosphere pressure, produced float and sink 1. The float from the first stage is the feed to the second chamber, at lower specific gravity, produced a sink 2 (middling) and the final float product (clean coal) (Bozzato *et al.*, 2005). Operation of Tri-Flo cyclones in general can be fed by gravity

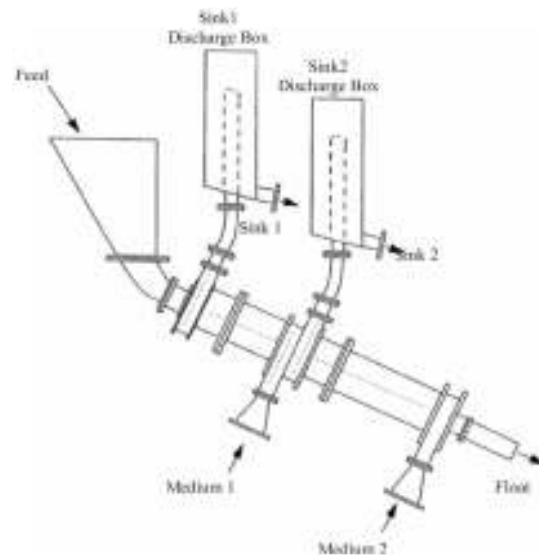


Fig. 2: Schematic diagram of tri-flo separator (Ferrara *et al.*, 2000)

flow using head tank. Thus, there is no need pumping of feed coal. It can reduce energy and wear on the pumps and any degradation of the product. Additionally, the low level feed entry makes a lower building and shorter feed conveyors, resulted in saving of space and cost.

Using dense medium cylindrical type cyclone separators in coal cleaning plant, the raw coal can enter

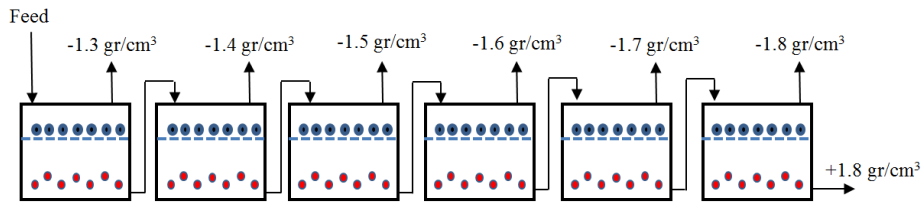


Fig. 3: Schematic diagram of the sink-float experiments

the separator at a much larger inlet compared with a dense medium conical cyclone. Typical top size for Tri-Flo separator is 45 mm for a 500 ID unit and 70 mm for a 700 mm ID unit. In Tri-Flo separator, there are two sinks outlets available. The second cleaner stage ensures that any remaining heavy materials or Near Gravity Materials (NGM) are rejected in the second stage, so it has high sinks capacity. The advantages of implementation of two-stage-in-one dense medium cylindrical vessel, Tri-Flo, have been reported by Ferrara and Ruff (1982). Replacing a Dyna Whirlpool (DWP), one cylindrical cyclone, by Tri-Flo they achieved an improvement in yield comparing a two-stage and a single stage DWP in plant operation.

### MATERIALS AND METHODS

In order to evaluate the performance of the gravity separation equipment and circuits, there are two experiments that can be used for each process stream around the equipment, including the determination of the specific gravity distribution and ash analysis of different fractions. Different samples were collected from each stream (including feed, sink 1, sink 2 and clean coal) at predetermined time intervals. Afterward, the composite sample were dewatered, dried and representative samples (weighting about 10 Kg) were obtained for sink-float experiments using standard test methods. Two identical sampling system (sampling time and weights of sub-samples) was used when sampling the circuit treating two types of the feeds A and B that were received from mechanized coal mine and conventional mining operations, respectively. Subsequently, four groups of sink-float experiments were performed on the samples around two Tri-Flo separators treating two different feed sample types A and B. Six consecutive vessels were used in these experiments according to Fig. 3.

Each fraction of the materials having a definite range of specific gravity were dewatered, dried, weighted and analyzed for the ash content. The partition curve of the separator was derived from the balanced data as a function of mean specific gravity reporting to clean coal product and refuse (ASTM No. D 4371-91, 2004). One of the most important parameters influencing the performance of dense medium separation circuits is the quality of magnetite powder (Sripriya *et al.*, 2001; Wang *et al.*, 2009). Such

a characteristics were evaluated for the magnetite under use in TCPP.

**Concept of partition curve:** The performance of each coal cleaning unit operation is characterized by a separation distribution curve, which express as the percentage of feed reporting to clean coal product or refuse as a function of mean specific gravity. For a given coal cleaning unit operation, different separation distribution curves can be obtained at various operation conditions. These distribution curves can also plotted as the percentage of feed reporting to clean coal product or refuse as the ordinate, against the normalized mean specific gravity, X as the abscissa. The result is a single unified curve named as generalized distribution curve (Gottfried and Jacobsen, 1977). Apparently, these separation distribution curves operated at various  $SG_{50s}$  are a group of family curves. The normalized mean specific gravity, X, is defined as the ratio of the mean specific gravity, SG to the specific gravity of separation,  $SG_{50}$ :

$$X = \frac{SG}{SG_{50}} \quad (1)$$

The probable error,  $E_p$  of a separation distribution curve can be defined as one half the specific gravity differences between 25 and 75% of feed reporting to clean coal product (Wills, 2006):

$$E_p = \frac{SG_{25} - SG_{75}}{2} \quad (2)$$

The generalized probable error,  $GE_p$  can then be derived as one-half normalized specific gravity difference between 25 and 75% of feed reporting to clean coal product:

$$GE_p = \frac{X_{25} - X_{75}}{2} = \frac{SG_{25} - SG_{75}}{2 SG_{50}} = \frac{E_p}{2 SG_{50}} \quad (3)$$

### RESULTS AND DISCUSSION

The raw coal feed to the TCPP is provided from four local coal mines, from which two mines are using mechanized mining equipment and methods (long-wall mining) and the other two mines use conventional methods for the coal extraction in lower capacities. Therefore, two type of the feed with different

Table 1: In-plant measured process characteristics of the tri-flo separators in TCPP

Feed sample type	Tri-flo 700 mm		Tri-flo 500 mm	
	Yield (%)	Clean coal ash content (%)	Yield (%)	Clean coal ash content (%)
A	32.13	13.41	47.07	10.55
B	42.62	11.70	52.09	9.38

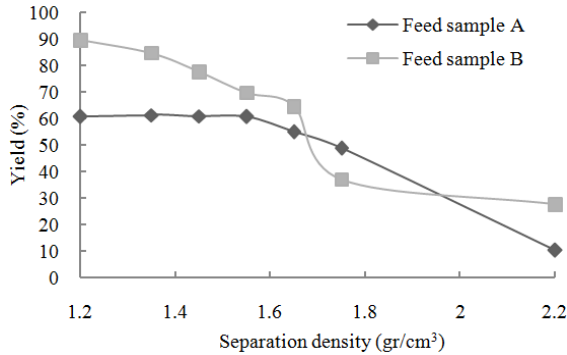


Fig. 4: Comparison of wash-ability curves for coarse coal fraction (-50+6 mm) of feed samples A and B

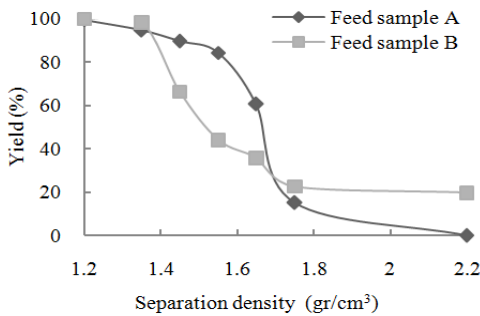


Fig. 5: Comparison of wash-ability curves for small coal fraction (-6+0.5 mm) of feed samples A and B

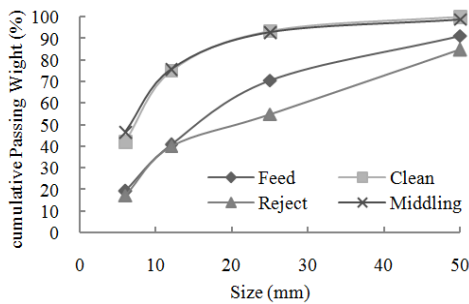


Fig. 6: Size distribution curves of different streams around Tri-flo 700 mm operating using feed sample A

characteristics must be cleaned separately in the TCPP, namely feed sample A (from the mechanized mines) and feed sample B (from the conventional mines). Obviously, the capacity of the feed sample type A as well as its ash content is higher and the plant is working with this feed type in most of the times.

According to the results of sampling and sample characterization in gravity separation circuit of TCPP,

the measured values of clean coal yields clean coal ash contents are presented in Table 1 for both of 700 and 500 mm separators.

Wash-ability curves of the coarse fractions of the coal (-50+6 mm) in the feed samples A and B are compared in Fig. 4. As can be seen the raw coal feed from the long-wall mechanized coal mine (sample A) has the lower wash-ability than the sample B that is coming from the conventional mining operation.

It could be inferred that the coal particles in the coarse fraction of sample B are more liberated and has been separated more easily in lower specific gravities. Figure 4 is in accordance with the measured yield values of Tri-Flo700 mm (Table 1) that is 10% higher when it was operated using feed type B. However, according to Fig. 5, there was lower differences in wash-ability of the coal samples in small fraction (-6+0.5 mm).

In order to examine the operational behavior of Tri-Flo 700 mm when treating the feed sample A in more detail, the representative samples from all of the streams around the separator were sieved and the ash distribution in different size fractions were evaluated. The size distribution curves are compared in Fig. 6. Clean coal and middling are obviously finer than the feed and about 90 weight percent of the clean coal was smaller than 20 mm. This means that most of the coal particles in the size range of -50+25 mm were rejected to tailings.

On the basis of the results of sink-float experiments, partition curves were obtained for both Tri-Flo separators (700 and 500 mm) when treating two different feed sample types A and B. Afterwards, Ecart probable ( $E_p$ ) were calculated according to Eq. (2). Also the normalized partition curves were drawn for Tri-Flo separators. An example of these curves is presented in Fig. 7. Meanwhile,  $SG_{50}$  and  $E_p$  values were calculated and the results are presented in Table 2. Comparing the acquired  $E_p$  values of Tri-Flo 700 mm (column 3) with the maximum permitted values provided by the suppliers of Tri-Flo separators (column 4), it is clear that 700 mm Tri-Flo represented lower performances especially on the feed type A.

The reasons of the lower product yields achieved in gravity separation circuit of TCPP were identified which was mainly attributed to the low performance of Tri-Flo 700 mm and the optimization of the process is underway using the results presented here. The standard magnetite must have the size distribution of ( $d_{95} = 40 \mu m$ ) and its recovery in 700 Gauss magnetic field intensity must be more than 97% (Klein, 1992). The

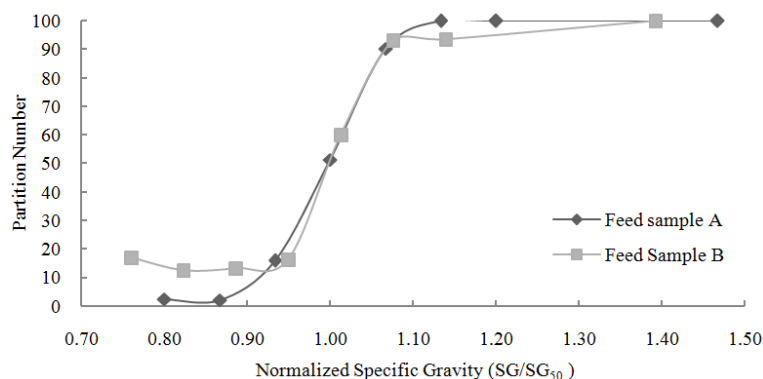


Fig. 7: Generalized partition curves of tri-flo 700 mm with feed types A and B

Table 2: Comparison of Ecart probable (E<sub>p</sub>) values of tri-flo separators in TCPP with the maximum permitted values

Feed sample type	Tri-flo 700 mm (1.5 gr/cm <sup>3</sup> )			Tri-flo 500 mm		
	SG <sub>50</sub> (gr/cm <sup>3</sup> )	E <sub>p</sub>	Max. permitted E <sub>p</sub>	SG <sub>50</sub> (gr/cm <sup>3</sup> )	E <sub>p</sub>	Max. permitted E <sub>p</sub>
A	1.50	0.075		1.52	0.055	
B	1.58	0.060	0.035	1.51	0.050	0.062

Max.: Maximum

corresponding size distribution and recovery for the magnetite under use in TCPP were ( $d_{75} = 40 \mu\text{m}$ ) and 85%.

### CONCLUSION

This research proposed a simple systematic study for performance evaluation of the Tri-Flo separators in coal preparation plants. On the basis of the coal washability analysis and in-plant evaluations, we outline the following conclusions:

- The coarse coal fraction of the feed in sample B coming from conventional mining operation has better wash ability in comparison to the raw feed from long-wall mining operation. So, different operating conditions should be used in Tri-Flo 700 mm for the feed coal from mechanized mines to improve its performance.
- Better operational performances were achieved in both Tri-Flo separators of 700 and 500 mm when treating the feed type B.
- The lower performance of Tri-Flo 700 mm when treating feed type A was mainly attributed to the coal in +25 mm size range and most of the coal particles in the size range of -50+25 mm were rejected to the tailings possibly due to the poor liberation.
- E<sub>p</sub> values of operations were used to compare the performance of two Tri-Flo separators, which revealed the lower performance of Tri-Flo 700 mm especially for the feed type A.
- The low quality of magnetite powder under use in TCPP was the other reason of the low performance of the circuit.

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