Optimisation of Operational Parameters of a Spiral Classifier Using Design of Experiment (DOE)*

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Abstract

Classifying Mn Ore to improve upon the grade and the properties has become a crucial activity for the Mn industry since it increases the market value of the ore. Ghana Manganese Company (GMC) has renovated their oxide washing plant by integrating it with a spiral classifier to make a batch system operating process. Particle size of <3.35mm (Mn grade of 43-47%) obtained from the primary section of the plant served as feed to the classifier and with the plant condition (i.e. at 60 min washing time, 30 rev/min speed of spirals and feed tonnage of 6 t), Mn grade of 49% was achieved. This paper focused on the optimisation of some selected operational parameters of the classifier to obtain a Mn grade >50% using Design of Experiment (DOE). Series of test works were designed using the DOE for the classifier using the constraints of washing time (30-90 min), speed of spirals (20-40 rev/min) and feed tonnage (6-9 t). The outcome of the test work after simulation showed that all the selected parameters had a great influence on Mn grade. The spiral speed and feed tonnage correlated negatively to the Mn grade with washing time correlating positively. Operating the spiral classifier at a feed rate, spiral speed and washing time of 6 t, 25 rev/min, and 30 min, respectively, yielded Mn grade of 53%. A Confirmatory test using the established conditions gave a Mn grade of 53%, which is a 4% increment in the previous Mn grade which was 47%. The outcome of the studies is the new established operational conditions which is adhered to by the plant, producing a manganese concentrate grade ranging between 52-54%.

Keywords: Design of Experiment (DOE), Spiral Classifier, Grade, Manganese

1 Introduction

Manganese is the 10th most abundant mineral in the world of which some are ubiquitous in the soil and exerts considerable influence on the composition and chemical behaviors of the ore itself (Skinner *et al.*, 1992). The mining of manganese ore on a large scale always comes with unwanted minerals like clay, iron, silica and phosphorus thereby requiring upgrading to separate these unwanted minerals. Beneficiation methods like concentration, classification and others can be employed to enhance the removal of these gangue minerals from the manganese ore in mineral processing.

Classification is described as the separation of mixtures of minerals into two or more products based on the velocity with which they fall through a fluid medium (Heiskanen, 1979). Following liberation of the mineral of interest from the gangue minerals by comminution and screening, removal of the gangue minerals by their physical properties like size and specific gravity is attempted by a classification process (Gupta, 2006). Wet classification methods are used during ore dressing and hydrometallurgical processes. It is employed when separating sand from slimes, concentrating of smaller heavy-gravity mineral particles from large light-gravity mineral particles and sort solids of long range screen sizes into short range fraction (Jones, 1985; Swain, 2011).

Size classification equipment are designed to split a feed of product material into coarse and fine products. They are subject to capacity limitations and must be considered when the performance of new or existing classification equipment is being evaluated (King, 2012). Many dissimilar classifiers have been built for industrial purposes. Based on their direction and flow of carrying current, they are grouped into non-mechanical classifiers, cyclones and mechanical classifiers (Wills, 2006). Spiral classifier (Fig. 1), a mechanical classifier, is one common equipment used for classification in most processing industries. This equipment has one or more spirals revolving slowly and freely on an inclined tank without touching the sides or the bottom. Its classification is based on the size and the specific gravity of the particles in the pool. It has a maintain mechanism for continuously conveying and draining of the settled material by the revolving spirals and simultaneously decants water and fine materials over the overflow weir. This equipment is generally preferred because it produces less turbulence in the settling tank, which is good for finer separations. In addition, the materials do not slide back as it occurs in the rake classifier

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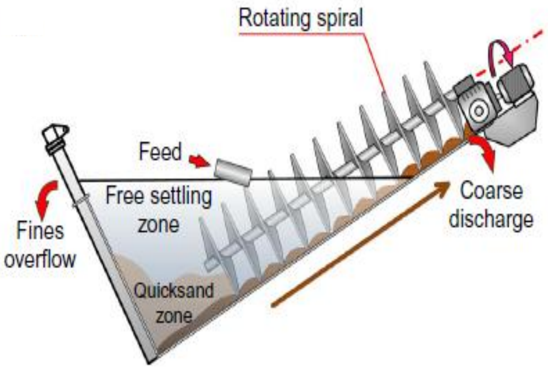

Fig. 1 A typical Spiral Classifier (Wills, 2006)

Records indicate that since 1916 when exploitation began, over 27 million tonnes of high grade (52% Mn), low grade (48-50% Mn) and other grades (46% Mn and 42-45% Mn) manganese oxides were produced from Ghana Manganese Company, GMC (Nsuta mine) for the mineral market (Kesse, 1985). This was after beneficiation methods like concentration, classification and others have been utilized to enhance and enrich the manganese ore from its associated gangue minerals during processing. This spiral classifier was recently integrated into the processing plant at Ghana Manganese Company, Nsuta mine (GMC) to make a batch processing plant to serve the purpose of upgrading their manganese ore for the mineral market. Intermediate product with particle size of <3.35 mm and manganese grade of 43.9% - 47.8% obtained from the primary section served as feed material to the spiral classifier. Processes at the spiral classifier was adjusted to give final product grades ranging between 50 – 52% Mn after commissioning but recently the grade has reduced to 48 – 49% Mn.

This paper therefore seeks to optimize the operational parameters (speed of the spirals, feed tonnage and the resident time for washing) of the spiral classifier incorporated in the oxide washing plant to upgrade the final product grade (grade >51) by employing the Design of Experiment, DOE.

2 Resources and Methods Used

2.1 Materials and Equipment

Intermediate product with particle sizes ranging from 0.075-3.35 mm and manganese grade of 43.9% - 49.8% obtained from the primary crusher section served as feed material to the Spiral Classifier. The Spiral Classifier used for the study was manufactured by Nick and Paul.

2.2 Designing of Test Works

Prior to test work design, visit to the oxide plant at Ghana Manganese Company (GMC) were made with the aim of getting acclimatize with the current operations at the plant. The Spiral classifier was operated in batch mode. The control parameters of the spiral classifier were critically observed and studied to understand spiral classifier operation. The adjustable parameters at the classifier section were the feed particle size, amount of water supplied to the classifier, angle of inclination of the classifier, feed tonnage, the speed of the spirals and the washing time.

This study focused on feed tonnage into the classifier, the speed of the classifier spirals and washing time since the plant was already in operation. The design of experiment (DOE), which uses statistical technique in designing experiments to get a controlled set of tests designed to model and explore the relationship between factors that affects a process, was used to design an organized and controlled series of test work (Table 1). During the design of test work, the spiral speed, feed tonnage and washing time were varied using DOE between 20-40 rev/min, 6-8 t and washing time respectively. After washing period for every test run, a speed of 40 rev/min was used to discharge the classified product from the classifier.

Table 1 The Test Works for the Classifier

Test	Spiral speed, (rev/min)	Feed rate, (T)	Washing time, (min)	Manganese grade (%)
1	40	6	90	-
2	20	8	90	-
3	30	7	90	-
4	30	7	60	-
5	40	6	30	-
6	20	7	60	-
7	30	6	60	-
8	30	8	60	-
9	40	7	60	-
10	30	7	60	-
11	40	8	30	-
12	30	7	30	-
13	20	6	90	-
14	20	6	30	-
15	40	8	90	-
16	20	8	30	-

3 Results and Discussion

3.1 Manganese (Mn) Grade

Intermediate product with particle size of <3.35 mm and manganese grade of 43.9% - 47.8% served as feed material to the spiral classifier. Samples that were taken for chemical analysis and particle size analysis during the commissioning gave results within the ranges stated above. Fig. 2 shows the Mn grade for the different test conditions designed with DOE. The ore sample was subjected to classification using the spiral classifier at varying washing speed (20-40 rev/min), washing residence time (30-90 mins) and the feed tonnage also (6-8 t) to determine the optimum operational conditions for maximum Mn grade. The result of the various test gave Mn grade (%) ranging between 49% and 53% (Fig. 2).

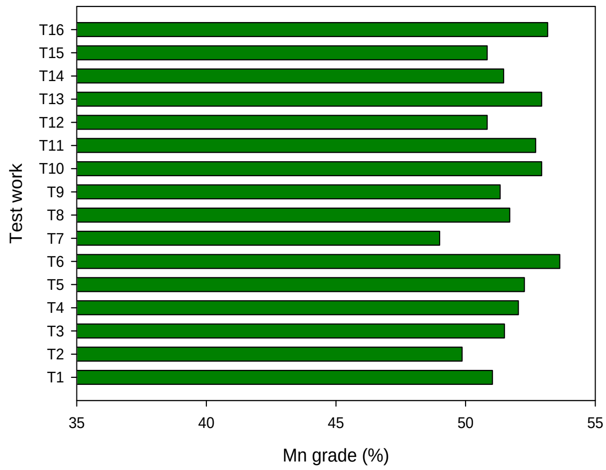

Fig. 2 Mn grade (%) for various Spiral Classification Test

3.2 Influence of Operational Parameters on Spiral Performance

The results (Fig. 2) obtained were modelled using the Design of experiment (DOE) to ascertain the influence of each parameter (feed rate, spiral speed and washing time) on the spiral classifier performance. Fig. 3 shows the prediction profile for manganese grade as function of spiral speed, feed rate and washing time. The solid black lines show the changes to expect in manganese grade when a parameter is varied and all other parameters held constant. The blue lines represent the 95% confidence band. The steepness of the black line for any of the parameters signifies its importance or effect on manganese grade.

From Fig. 3, it is clear that all the parameters selected had an influence on the performance of the classifier. Speed of the spirals has negative correlation with Mn grade. An increase in the spirals speed significantly decreases the manganese grade. The function of the spiral during classification is to agitate the pulp and transport the settled grains away from the separating zone. Therefore, with increased spiral speed during washing, the materials do not get enough time at the classification section to undergo classification. This causes the spirals to carry all the gangue and concentrate to the discharge end of the classifier and report as product. The later contributing to a reduction in the overall manganese grade. The data in Fig. 3 also show that the amount of material fed into the classifier correlate negatively to Mn grade. This is expected since increasing the amount of material in the classifier causes crowding and increased pulp density at the classification section of the classifier.

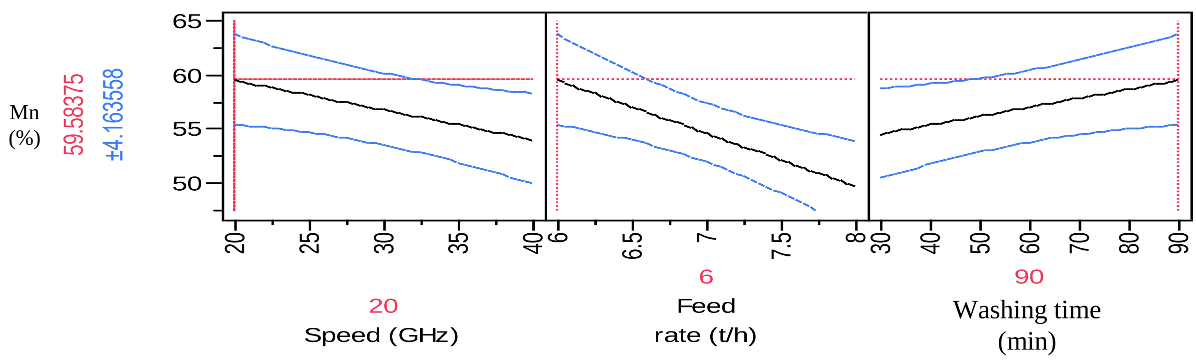

Fig. 3 Prediction profile for Mn grade (%) as A Function of Speed, Feed Rate and Washing Time

Generally, an increase in the proportion of solids in a pulp causes hindered settling and consolidation trickling, which subsequently decreases the settling rate of the particles. Besides, at high feeding rate, the system begins to behave as a heavy liquid whose density is that of the pulp rather than that of the carrier liquid. Because of the high density and viscosity of the slurry through which a particle must fall, selectivity between the gangue and value materials reduces (Marsden and House, 2006). The resident washing time for the batch process had a positive correlation with the Mn recovery. This is obvious because when the material is allowed to stay in the classifier for a longer period, there will be enough time for efficient separation between valued and gangue materials to take place.

3.3 Optimisation of Spiral Performance

The prediction profile in Fig. 4 clearly showed that all the operational parameters considered in the study greatly influence the performance of the spiral classifier used at GMC. To determine the optimum conditions for high Mn grade, simulation of the data in Fig. 2 was done using the simulation package of the DOE at the current plant feed rate of 6 t/h. The outcome of the simulation is presented in Fig. 4. At 6 t/h feed rate and a reduced spiral speed and washing time of 20 rev/min and 30 min respectively, the spiral classifier was optimized to produce Mn grade of approximately 54% ±0.5.

Based on the predicted optimal operational conditions obtained from DOE, a confirmatory test was performed at the classification plant of GMC. Results from the confirmation test run at feed rate of 6 tonnes showed significant improvement in the Mn grade at the selected spiral speed of 20 rev/min and washing time of 30 min (Fig. 5). By changing the baseline conditions of the spiral clasifier to current condition, gave a 4% increment in Mn grade. Thus, the Mn grade increased from 49% under the baseline condition (plant condition) to 53% as against the predicted value of 53.7%. Again, the use of the current condition will significantly reduce the plants operational cost and increase throughput since less energy and washing time is required compared to the baseline conditions employed at the plant. Currently the plant has adhered to the new parameters that have been provided and they are getting a Mn grade of between 53-54%.

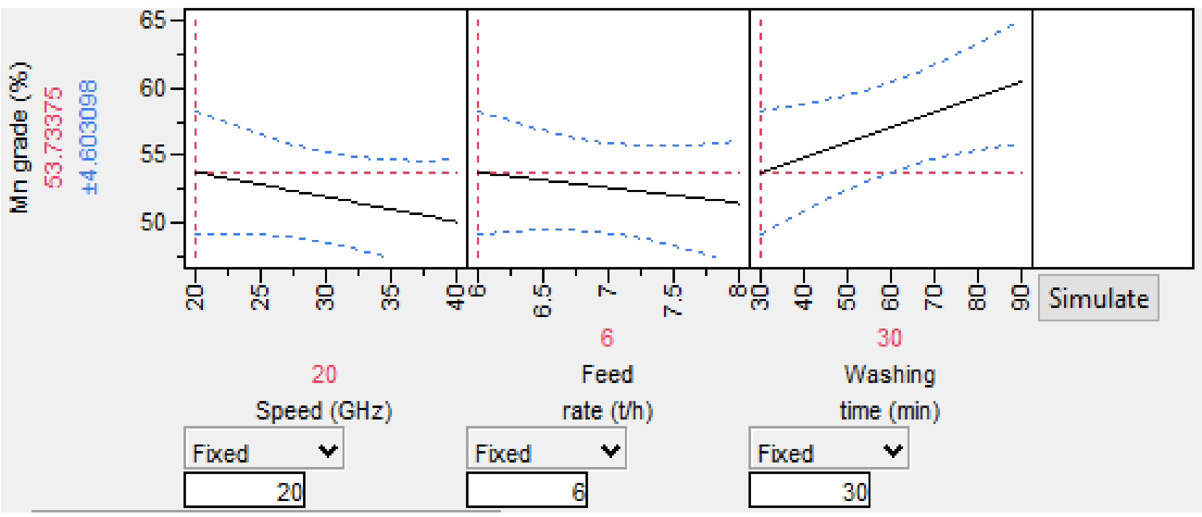

Fig. 4 Simulated Prediction Profile for Mn Grade (%) as a Function of Spiral Classifier Operational Parameters

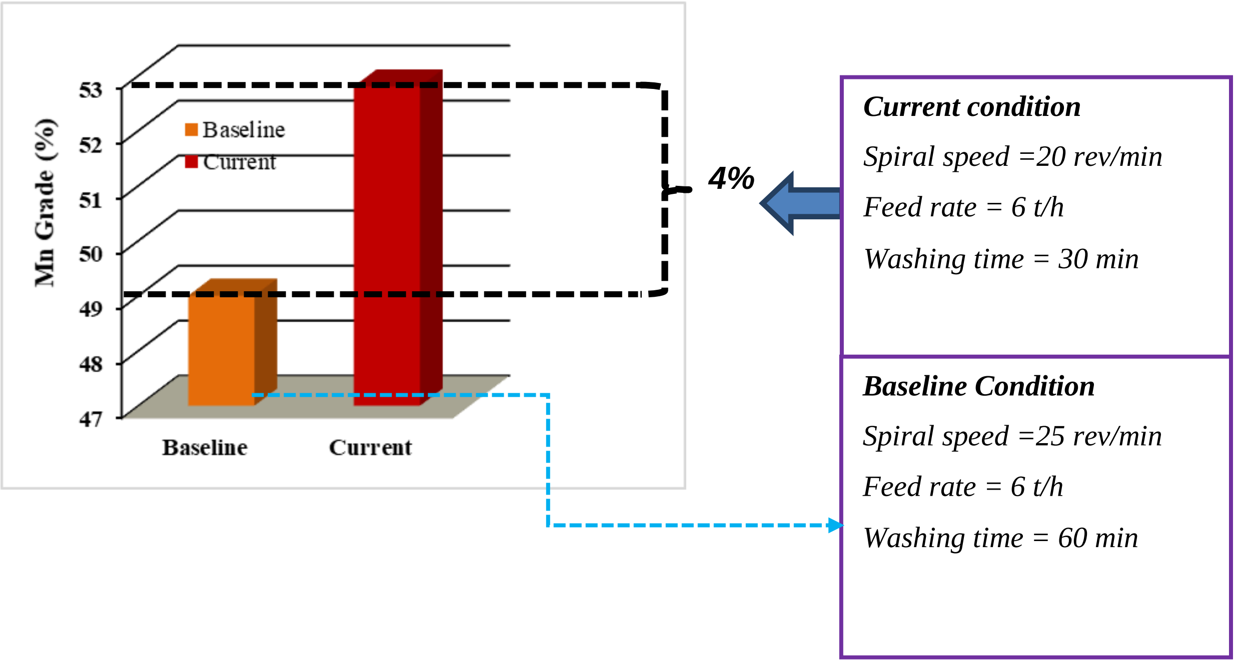

Fig. 5 Mn Grade (%) as a Function of Plant Condition and Simulated Condition

4 Conclusions and Recommendations

The goal of the study was to access the influence of operational parameters such as spiral speed, feed tonnage rate and washing time on the performance of the Spiral classifier installed at Ghana Manganese Company (GMC) and improve on the manganese grade. Through the use of Design of Experiment (DOE) an organized and series of controlled test were run and results modelled.

The outcome showed that Mn grade (%) is greatly influenced by the spiral speed, feeding rate and washing time. Whereas a positive correlation was observed between washing time and Mn grade, feed rate and spiral speed correlated negatively to the manganese grade.

Improvement in Mn grade (from 49% to 53%) was achieved at spiral speed, feed rate and washing time of 20 rev/min, 6 t/h and 30 min, respectively. A confirmation test run also confirmed the claim. Currently the plant has adhered to the new parameters that have been provided and they are getting a Mn grade of between 52-54%.

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