Recovery of Heavy Minerals from Brahmagiri Deposit, Odisha using Gravity Table

Sunita Routray¹, Ranjita Swain² and Tumula Laxmi³

¹,²Assistant Professor, C.V. Raman College of Engineering, Bhubaneswar 752054, India
³Associate Professor, Techno School, Bhubaneswar 751019, India

Corresponding author: sunitaroutray77@gmail.com

Abstract. Characterization and beneficiation studies are carried out on sand samples collected from Brahmagiri coast of Odisha. Characterization and beneficiation studies are carried out using a lab scale gravity separator. Application of Design expert is also done to find the behavior of gravity table as a function of process parameters. Optimization of response is also done by using Matlab7.1. ANOVA software is applied to compare the predicted and experimental values for grade and recovery, and the results show a good fit.

Keywords: Brahmagiri coast, Box-Behnken design, ANOVA, Matlab7.1, Heavy minerals, Gravity table

1. Introduction

With increase in demand for industrial heavy minerals, it is mandatory for mineral processing industries to exploit new resources for recovery of heavy minerals economically. The coastal sands and inland sand bodies are the primary exploration targets for placer type deposits which contain substantial amount of heavy minerals. The placer deposits are different types such as alluvial, eluvial, beach placers, eolian placers etc, out of these, beach placers form on seashores. The beaches in India contain heavy minerals such as ilmenite, rutile, garnet, zircon, monazite and sillimanite etc. The Chavara deposit has 65% – 85% THM, Manavalakurichi deposits contain ~39% THM, Chatrapur deposits contain 20%-22% THM. The mine site for Trans World Garnet at Srikurram, Andhra Pradesh deposit contains about 20%-30% heavy minerals whereas, the mining site for Trimex Industries Pvt. Ltd., Andhra Pradesh contains 23%-33% heavy minerals.

There are six beach sand plants operating in India. Out of six plants, Indian Rare Earth Limited (IREL), Government of India owns three plants. The Government of Kerala owns one plant i.e. Kerala Minerals and Metals Ltd. (KMML), Kerala. The remaining two plants, i.e. Trimex Industries Pvt. Ltd and Trans World Garnet are run by private entrepreneurs. The mineral sand plant practices in India reveals that the processes of unit operations are more or less same for recovery of individual heavy minerals in all the existing plants. The coastal sand of Odisha also possesses more or less same minerals with variable mineral composition. This state has a coastline of 480 km and heavy mineral resources of 128 Mt and
there are no mineral separation plants by private entrepreneurs for production of individual heavy mineral concentrates. The OSCOM is the only public sector producing mineral sands in south east coast of Odisha. Department of Atomic Energy, India gives information about potential resource of heavy mineral deposits along Brahmagiri to Puri coast of Odisha, but work related to R&D on beneficiation to recover heavy minerals has not been attempted so far [1-4].

To explore this new resource, in the present investigation an attempt has been made on characterization and beneficiation of heavy minerals from sand samples collected from Brahmagiri to Puri coast, Odisha, using a laboratory model gravity table. The paper also includes application of Box-Behnken design, Response surface methodology to develop response surfaces to observe the behavior of gravity table as a function of process parameters.

2. Materials and methods

Sand samples were collected from Brahmagiri to Puri coast of Puri district, Odisha, India. Figure 1 shows location of Brahmagiri coast on map of Odisha. The samples were collected in a grid pattern and sampling was done by coning and quartering method at each sample collection point. All collected samples were washed with fresh water before characterization studies to remove the salt content. Physical characterization (i.e. bulk density, true density, angle of repose, size analyses etc.) was carried out using the standard methods. The $d_{80}$ percent passing size of each sample has been calculated from the size analysis data. Heavy liquid separation studies were carried out using bromoform (specific gravity 2.89 g/cm$^3$) to determine the amount of heavies present in the samples. Physical characterization of some of the samples of the coast is presented in Table 1.

![Figure 1. Brahmagiri coast in the map of Odisha.][5]

Next a composite sample was prepared by mixing beach and dune sand samples thoroughly and representative sample was taken. Physical characterization and sink-float study was also carried out for the
composite sample to know the heavy mineral content. Again, the total heavy mineral was subjected to sink float studies using methylene iodide (specific gravity 3.3 g/cm³) to know the sillimanite percentage. Physical characterization of the composite sample is given in Table 2.

The laboratory model gravity table used for the experiment was supplied by Denver (Type Concenco, The Diester Concentrator Company Ltd, Model No. Denver 13A). The laboratory Gravity Table used for experimental studies is shown in figure 2. The schematic presentation of particle separation on a gravity table is shown in figure 3.

The pulp density of the feed to the gravity table was maintained 20%. The feed was subjected to the gravity table, wash water was supplied. Heavy minerals were collected in the form of Concentrate and light minerals as Tailings. In the present study stroke length, deck inclination and wash water rate were taken as the major variables and pulp density was maintained at 20% for all experiments.

In this experiment, the Box–Behnken factorial design was used to observe the association between response functions and the variables of gravity table. Grade and recovery were taken as the response functions and stroke length, deck inclination and wash water flow rate were taken as the variables for the unit operation. The variables and their minimum and maximum values considered for the experiments are presented in Table 1. The concentrate and tailings were collected after each experiment, dried and sink-float studies were carried out to get grade and recovery values.

The experimental results were analyzed to develop 3D response surfaces (variation of grade and recovery with respect to variables) using Box–Behnken factorial design and optimized values of response functions such as grade and recovery were calculated using mathematical software Matlab 7.1.

Some researchers also carried out the optimization of different unit operations using Box–Behnken factorial design [6,7].
The quadratic equation developed to generate the 3D response surfaces is presented in equation 1.

\[ Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_{12} X_1 X_2 + \beta_{13} X_1 X_3 + \beta_{23} X_2 X_3 \]  

Where \( \beta_0 \) is the model constant; \( X_1, X_2 \) and \( X_3 \) are independent variables; \( \beta_1, \beta_2, \beta_3 \) are linear coefficients; \( \beta_{12}, \beta_{13}, \beta_{23} \) are cross product coefficients and \( \beta_{11}, \beta_{22}, \beta_{33} \) are the quadratic coefficients.

3. Results and discussion

The physical characterization of some of the samples of Brahmagiri coast is presented in Table 2. It is observed that the dune sand samples contain higher THM than beach sand samples. Physical characterization data from Table 3 shows that, the heavy minerals content is 14.3\%, out of which LHM is 5\% and VHM is 9.3\%.

The sand samples were subjected to gravity table to separate the heavy minerals and light minerals. Some of the variables of gravity table are chosen for optimization of the unit operation and the variables chosen for the experiment with their minimum and maximum values are presented in Table 3. The experimental results are given in Table 4 and also compared with the predicted value. The second order quadratic equation for grade and recovery of the product is presented in equation (2) \& (3) respectively.

Table 2: Physical properties of samples collected from Brahmagiri coast

| Sample          | Angle of repose (°) | Bulk density [g/cm³] | True density [g/cm³] | THM, %  | d₈₀ passing size, μm |
|-----------------|---------------------|----------------------|----------------------|---------|---------------------|
| Beach sand      | 30.89               | 1.50                 | 2.66                 | 05.88   | 370                 |
| Beach sand      | 27.39               | 1.59                 | 2.70                 | 09.75   | 450                 |
| Beach sand      | 32.15               | 1.36                 | 2.60                 | 08.60   | 330                 |
| Dune sand       | 29.51               | 1.69                 | 2.79                 | 16.98   | 460                 |
| Dune sand       | 30.44               | 1.65                 | 2.68                 | 08.79   | 475                 |
| Dune sand       | 30.95               | 1.85                 | 2.93                 | 29.40   | 350                 |

Table 3: Physical characterization of the composite sample
From the above equations, it is seen that grade of the concentrate increases with stroke length and wash water rate, whereas the recovery increases with the deck inclination. The other interaction effect and quadratic effect can be explained based on the nature of the coefficient. Figure 4 shows the comparison of observed values and predicted values by using ANOVA. \( R^2 \) value of 0.95 is achieved for grade, and 0.96 is for Recovery, indicating a good fit.

\[
Y_1 = 60.0 + 1.38 \cdot X_1 - 0.12 \cdot X_2 + 0.25 \cdot X_3 - 2.38 \cdot X_1^2 - 1.88 \cdot X_2^2 - 2.12 \cdot X_3^2 + 1.25 \cdot X_1 \cdot X_2 + 0.0 \cdot X_1 \cdot X_3 + 0.5 \cdot X_2 \cdot X_3 \quad \text{eq (2)}
\]

\[
Y_2 = +89.8 - 0.29 \cdot X_1 + 0.025 \cdot X_2 - 0.063 \cdot X_3 + 0.80 \cdot X_1^2 + 0.57 \cdot X_2^2 + 0.90 \cdot X_3^2 + 0.075 \cdot X_1 \cdot X_2 + 0.25 \cdot X_1 \cdot X_3 + 0.075 \cdot X_2 \cdot X_3 \quad \text{eq (3)}
\]

Figure 4 (a & b). Relation between test results and predicted values of response functions using ANOVA.

Table 4.Box Behnken experiment design given by the software and performance of gravity table
Experimental Design

| stroke length | deck inclination | wash water flow | X1 | X2 | X3 |
|---------------|------------------|-----------------|----|----|----|
| 4 2.25 4.5    | -1 0 +1         | 54 54.38 91.5  |    |    |    |
| 6 2.25 3.5    | 0 0 0           | 60 60.00 89.8  |    |    |    |
| 6 3.00 4.5    | 0 +1 +1         | 56 56.62 91.2  |    |    |    |
| 8 2.25 4.5    | +1 0 +1         | 58 57.13 91.3  |    |    |    |
| 6 2.25 3.5    | 0 0 0           | 60 60.00 89.8  |    |    |    |
| 6 2.25 3.5    | 0 0 0           | 60 60.00 89.8  |    |    |    |
| 6 1.50 2.5    | 0 -1 -1         | 57 56.37 91.5  |    |    |    |
| 8 3.00 3.5    | +1 +1           | 58 58.25 91.3  |    |    |    |
| 6 2.25 3.5    | 0 0 0           | 60 60.00 89.8  |    |    |    |
| 6 1.50 4.5    | 0 -1 +1         | 56 55.87 91.3  |    |    |    |
| 4 1.50 3.5    | -1 -1           | 56 55.75 91.2  |    |    |    |
| 4 3.00 3.5    | -1 +1           | 54 53.00 91.4  |    |    |    |
| 6 2.25 3.5    | 0 0 0           | 60 60.00 89.8  |    |    |    |
| 6 3.00 2.5    | 0 +1 -1         | 55 55.12 91.1  |    |    |    |
| 8 2.25 2.5    | +1 0 -1         | 57 56.63 90.8  |    |    |    |
| 8 1.50 3.5    | +1 -1           | 55 56.00 90.8  |    |    |    |
| 4 2.25 2.5    | -1 0 -1         | 53 53.88 92.4  |    |    |    |

The figure 5 shows the 3D plots for grade with the variation of any two variables at the middle value of the third variable using Box-Behnken factorial design. Figure 5a shows the effect of stroke length and deck inclination on grade of the product at the middle value of wash water rate. It is noticed that higher grade is achieved at centre level of stroke length and intermediate value of deck inclination. Recovery of minerals can be influenced by the length of stroke. Generally, stroke in a gravity table helps the particles to move forward during the backward stroke due to built-up momentum \(^8\). In case the stroke length is too small, the particle movement is not proper and results in lower grade of the concentrate. When the stroke length is on higher side, due to faster movement of the deck the grade also decreases. At higher value of wash water rate, the particle movement on the deck increases and at lower level of wash water rate, the particle movement on the deck is also affected adversely, which affect the grade of the concentrate.
Figure 5. 3D plots for grade with the variation of any two variables at the middle value of the third variable using Box-Behnken factorial design (the variables are presented in their coded form).

The figure 5b shows the effect of stroke length and wash water rate on grade of the product at the middle value of deck inclination. It is found that higher grade is achieved at centre level of stroke length and at an intermediate value of wash water rate. With increase in wash water rate, the gangue minerals are easily transported to the tailing launder, thereby improving the grade of the concentrate. The increase in wash water rate after a certain limit decreases the grade of concentrate, because gangue minerals may report in the concentrate side due to higher water force.

The figure 5c shows the effect of variables such as deck inclination and wash water rate on grade at middle value of stroke length. It is observed that higher grade is achieved at centre level of deck inclination and centre level of wash water rate. Generally, the gravity table is slightly elevated towards the concentrate end, which facilitates the denser particles to climb the deck more easily than the lighter particles. This behavior of particles allows a better separation of heavy and light minerals [8].

Figure 6. 3D plots for Recovery with the variation of any two variables at the middle value of the third variable using Box-Behnken factorial design (the variables are presented in their coded form).

The figure 6 shows the 3D plots for recovery with the variation of any two variables at the middle value of the third variable using Box-Behnken factorial design. Figure 6a shows the effect of stroke length and deck inclination on recovery of the product at the middle level of wash water rate. It is observed that higher recovery is achieved at highest value of stroke length and highest value of deck inclination.
inclination. Figure 6b shows the effect of stroke length and wash water rate on recovery of the concentrate when deck inclination is constant at its centre value. It is observed that higher recovery is achieved at highest level of stroke length and highest level of wash water rate. Figure 6c shows the effect of deck inclination and wash water rate on recovery of the concentrate when stroke length is maintained constant at the centre level. It is observed that higher recovery is achieved at highest value of wash water rate and highest level of deck inclination. The graphs in figure 6 can be understood as per the explanation given for figure 5.

Applying Matlab 7.1, the maximum grade of 69.4% can be achieved, at stroke length 8 cm, deck inclination 1.5 degree and wash water rate 4.5 lit/min. The maximum recovery of 89.8% is achieved at stroke length 4 cm, deck inclination 1.5 degree and wash water rate 2.5 lit/min.

The results for recovery of heavy minerals using gravity table is presented in the figure 7. The gravity table experiments are carried out taking random values of the variables. The composite sample containing 14.3% THM is subjected to the number of stages of gravity table operation. It is found that a concentrate is resulting with 92.5% grade and 91.2% recovery.

**Figure 7.** Flowsheet shows recovery of heavies from a composite sand sample using gravity table.
4. Conclusions

After the detailed study the following conclusions are listed below:

- The maximum grade of 69.4 % is achieved at stroke length 8 cm, deck inclination 1.5 degree and wash water rate 4.5 lit/min.
- The maximum recovery of 94.8 % is achieved at stroke length 4 cm, deck inclination 1.5 degree and wash water rate 2.5 lit/min.
- The composite sample prepared contains 14.3% total heavy minerals.
- The concentrate from gravity table shows 92.5 % grade and 91.2% recovery.
- Brahmagiri coast of Odisha is a new resource for heavy minerals which has a future scope.

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