Journal of Mining and Metallurgy, 59 A (1) (2023) 15-24

Original research paper

https://doi:10.5937/JMMA2301015S

Journal of
Mining and
Metallurgy

RECOVERY OF TOTAL HEAVY MINERALS USING GRAVITY CONCENTRATORS ON LEAN AND OFF GRADE BEACH SANDS

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Received: June 18, 2023; Accepted: October 12, 2023

Abstract

In the present investigation, an attempt is made to synergize the effects of textural, physical and chemical characteristics of placer deposits. These deposits are associated with lean and off-grade placer heavy minerals, which typically exhibit variations in total heavy minerals, texture and composition. They are found all along the coastal stretch of the Bay of Bengal, from Chatrapur to Puri Dists, Odisha, India. The aim is the recovery of total heavy minerals using various models of gravity concentrates. The results of the present study reveal that the Mozley table produced a concentrate containing 93.2% THM. In comparison, the gravity table, HG8 spiral, CT spiral and Humphrey spirals yielded concentrates with 92.2%, 92.9%, 93.6%, and 98.2% THM, respectively, from a feed sample containing 4.72% THM. Additionally, it was observed that the performance of the spiral depends on both the feed grade and the texture analysis of the input material.

Key words: *Beach Sand, Placer, Heavy Minerals, Mineral Separator, Spiral Concentrators.*

1. Introduction

Gravity concentration has been used throughout the ages to separate minerals, with many of the historic methods still used to the current day. Pre-concentration of placer heavy minerals using gravity concentrators, especially spiral concentrators, is the primary stage of beneficiation in mineral processing plants. The spiral concentrator first appeared as production unit in 1943 in the form of Humphrey Spiral, invented by I B Humphreys for the separation of chromite from beach sands in Oregon. By 1950s spirals were the standard primary wet gravity concentrators in the Australian mineral sand industry. The Humphreys Spiral has been successfully applied to recovery of chromite from chrome sands, rutile, ilmenite, and zircon from sand deposits, tantalum minerals and lepidolite from their ores, gravity concentration of base metal minerals, and in the cleaning of fine coal [1]. The processes involved in mineral concentration by spirals are similar for all models. Particles with the greatest specific gravity rapidly settle to the bottom of the spiral and form a slow-moving fluid film. Separation is enhanced by the differences in centrifugal forces between the two: the lighter, faster flowing material is forced outward towards the surface, and the heavier, slower material remains inward towards the bottom. There are many researchers who studied the use of spirals, its design, etc. [2-4]. D Gucbilmez and S L Ergun [5, 6] studied the use of chromite sand and reported that three spiral concentrators had different geometries and concluded that the performances of three spiral concentrators were found to be different. Further, the authors reported that separation performance decreased dramatically in very fine particles. O. Y. Gulsoy and M. Kademli [7] studied the role of particle size and solid contents of feed for mica-feldspar separation by gravity concentration, using Reichert spiral (model HG7) under various test conditions. The results showed that, in a spiral concentrator, mica could be separated from feldspar owing to its laminar morphology.

Even research related to spiral concentration with particular reference to beach sand industry is also highly referred, but a few are referred to the context [8-11]. Hee-Young Shin et al., [8] studied the mineralogy of beach sand in Jumundo, Korea, and recovery of heavy

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minerals using Humphreys spiral concentrator and shaking table, followed by magnetic separation process. They concluded that the ilmenite was concentrated with a Humphrey spiral concentrator to the grade of 93%. Sunita and Rao [9, 10] studied on beach placer minerals using spirals. These authors reported that spirals are the primary unit to recover total heavy minerals from lean and off grade beach placer sand deposits.

In India, wet spiral concentrator is the primary unit operation to recover total heavy minerals which has industrial applications. In the present investigation, an attempt was made to investigate the synergising effects of textural and physical properties on different types and models of spiral concentrators and other gravity units on recovery of total heavy minerals.

2. Materials and methods

Bulk placer sands of five different grades in Total Heavy Minerals (THM) composition (4.72%, 5.6%, 9.5%, 15.7% and 19.5% THM) were collected all along the costal line (Figure1). Size analysis (the degree of liberation is 420 microns) of all five samples were carried out using IS standard sieves. THM, VHM (Very Heavy Minerals above 3.3 sp.gr.) and LHM (light heavy mineral <3.3 sp.gr but above 2.89 sp. gr) of all the samples were determined using organic liquids as media. Total Magnetic Minerals (TMM) was determined by using high intensity magnetic separator. Initially, different types of gravity units (Figure 2) were used on a single grade (4.72% THM) sample for recovery of total heavy minerals. Effect of HG8 spiral units on recovery of total heavy minerals was studied for different grade samples (Figure 3). It may be noted here that Humphreys spiral is deep deck with five helices and with two product design, whereas HG8 spiral is seven helices with three product design. CT spiral is compact design with multiple output design very high through put.

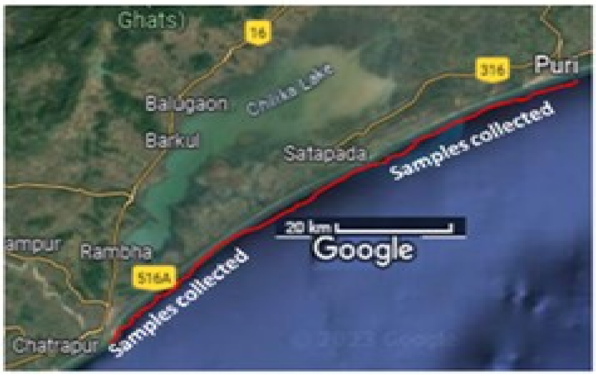

Figure 1 Sample location map

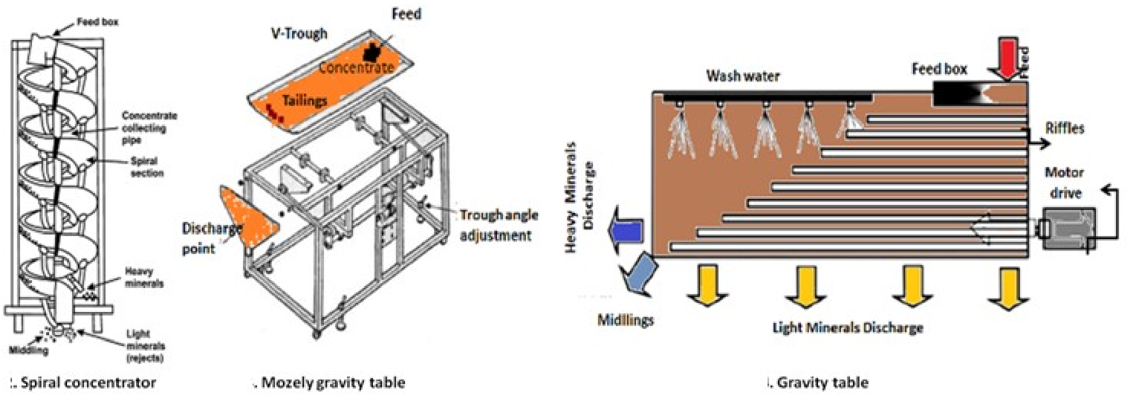

Figure 2 Gravity spiral and different types of gravity tables

Figure 3 Different models of spirals

3. Results and discussions

Physical properties, THM, TMM and size analysis of all five samples are given in Table 1 and size analysis data are shown in Figure 4. The data given in Table 1 indicate that all samples exhibit the black colour with metallic shine, and all are in free grains, with more or less same specific gravity. Further, an interesting fact observed from the data in Table 1, is that with increasing the THM content, the d80 passing size of samples decrease. For example, sample 1, containing 4.72% THM, had d80 value of 400 microns and sample 5, containing 19.5% THM had d80 value of 140 microns. The trend was similar in TMM (Total Magnetic Minerals) content. The total magnetic minerals' content increased from 2.97% for sample 1 (THM 4.72%) to 4.5% for sample 3 (THM 9.5%). But the higher THM samples 4 and 5 had almost the same TMM content (12.6% and 11.81% respectively). The content of VHM (Very Heavy Minerals), which was 3.19% for sample 1 (4.72% THM), gradually increased to VHM of 12.70% for sample 5 (19.5% THM). Similar increasing trend can be observed for LHM (Light Heavy Minerals) from 1.53% for sample 1 (4.72% THM) to 6.8% LHM for sample 5 (19.5% THM).

Particle size analysis of all different five samples is shown in Figure 4 A, B, C, D, E and F. It may be essential to explain here that the weight percent mentioned in the graph represents the fraction weight percent and the sink is THM percent in the fraction. This data indicate that from the sample A to the sample E the percentage mass share of classes decreased from 600 microns to below 5 microns. Whereas, it was found that the total heavy minerals content increased from 600 microns to below 75 microns from sample A to sample E, respectively. It indicated that the coarser fractions contained very small amount of total heavy minerals and the finer fractions contained more total heavy minerals. It can be concluded that the chosen five different samples had difference in textural and other physical properties. As per the industrial practice, it is expected that the nature of possessing total heavy minerals in fines is a challenging problem in the present mineral processing units for recovery of total heavy minerals. Therefore, the sample A, which contained the lowest THM content of 4.72%, was chosen to be treated on the gravity separation units.

Experiments were carried out with Mozley gravity separator using V tray, gravity wet table (shaking table) and Humphreys' spiral concentrator. The results obtained by the treatment of sample 1 on the Mozely separator are shown in Figure 5. The data shown in Figure 5 indicate that one rougher unit and 4 cleaner units were required to achieve 93.15% grade with 4.2% overall yield and 82.8% recovery. The results would have been much better if the sample was classified at 100 microns size and +100 micron sample subjected to V tray and -100 micron sample subjected to flat tray as per the design aspects. It is suggested here for better grade and recovery the feed to be classified at 100 micron size and the +100 size to be treated on V separator and -100 sizes to be treated on flat tray. However, Mozley separator indicated that above 90% THM grade can be recovered.

Table 1 Physical properties of different grades [THM] of beach placer deposit

Details	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Colour	Black	Black	Black	Black	Black
Nature	Free grains	Free grains	Free grains	Free grains	Free grains
Bulk Sp. gr.	2.89	2.91	2.93	2.96	2.96
d80 passing size µm	400	380	360	340	140
THM %	4.72	5.6	9.5	15.7	19.5
TMM %	2.97	3.01	4.5	12.6	11.81
VHM %	3.19	3.82	2.30	11.40	12.70
LHM%	1.53	1.78	2.2	4.3	6.8

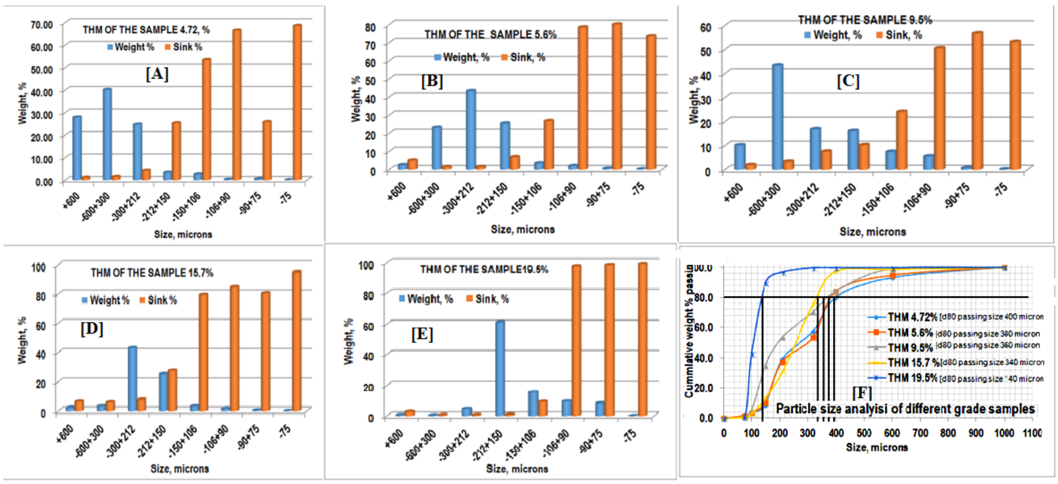

Figure 4 Particle size analysis of all five grades (THM) of samples

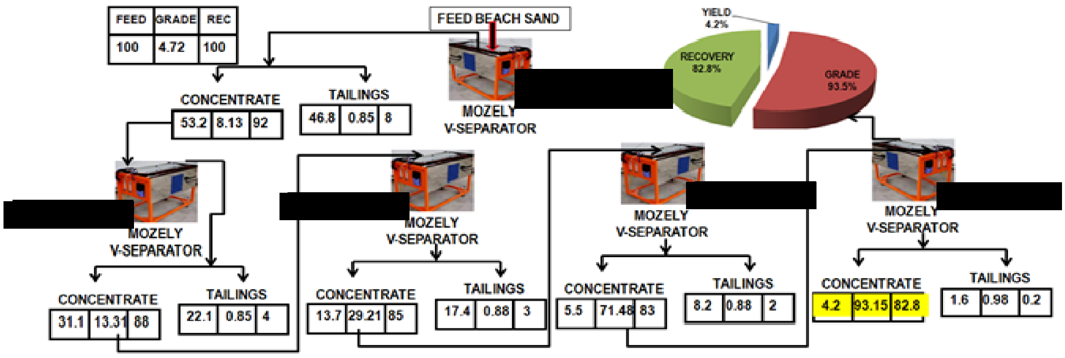

Figure 5 Flowsheet with mass balance achieved on sample-1 (4.72% THM) by using Mozley gravity separator

The results of the gravity wet table separation on sample 1, which contained 4.72% THM, using sand table tray, is shown in Figure 6. The test results obtained from gravity table indicate that one rougher table and one cleaner table was sufficient to achieve the 92.2% THM grade with 3.9% yield and 59% recovery. The gravity sand table also indicated that there was a possibility to recover high grade THM using sand and slime table on classified feed at 100 microns. Since these Mozley and gravity tables have limitations in all aspects of size of particles and capacity of the units, the other alternative unit is spiral concentrator.

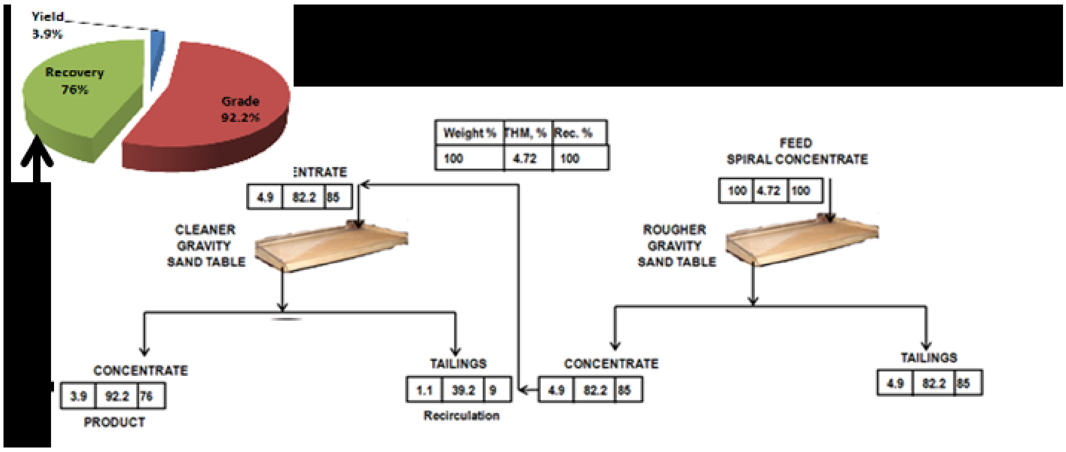

Figure 6 Flowsheet with mass balance achieved on sample-1 (4.72% THM) by using wet gravity sand table

Beneficiation studies, carried out on low grade beach sand sample 1 (4.72% THM), using HG8 spiral separator are shown in Figure 7. This figure indicates that one rougher unit, three cleaner units, and two scavenging cleaner units were required to achieve 92.9% grade with 3% overall yield and 59% recovery. Similarly, the beneficiation studies carried out with Humphreys spiral concentrator on the sample 1 (Figure 8), reveal that one rougher spiral and three cleaner spirals were required to achieve the grade of 92.1% THM, with overall yield of 3.3% and 74.1% recovery. On the other hand, the results shown in Figure 9 indicate that application of CT spirals can provide the grade of 93.6% THM with overall yield 3.9% and 77% recovery. This data supports the results obtained with laboratory gravity table data (Figure 6). Summary of results obtained from different gravity units with mono feed grade [THM 4.72%] of beach placer deposit is shown in Table 2. The data reveal a fact that lower capacity unit operations such as Mozley and gravity shaking tables produced similar grade 92.2% -93.2% THM with same recovery. HG 8 spiral also produced same grade but the recovery fell to a level of 52%. Among all the unit operations, Humphreys spiral concentrator produced higher grade 92.1% THM and CT spiral produced higher recovery 77%.

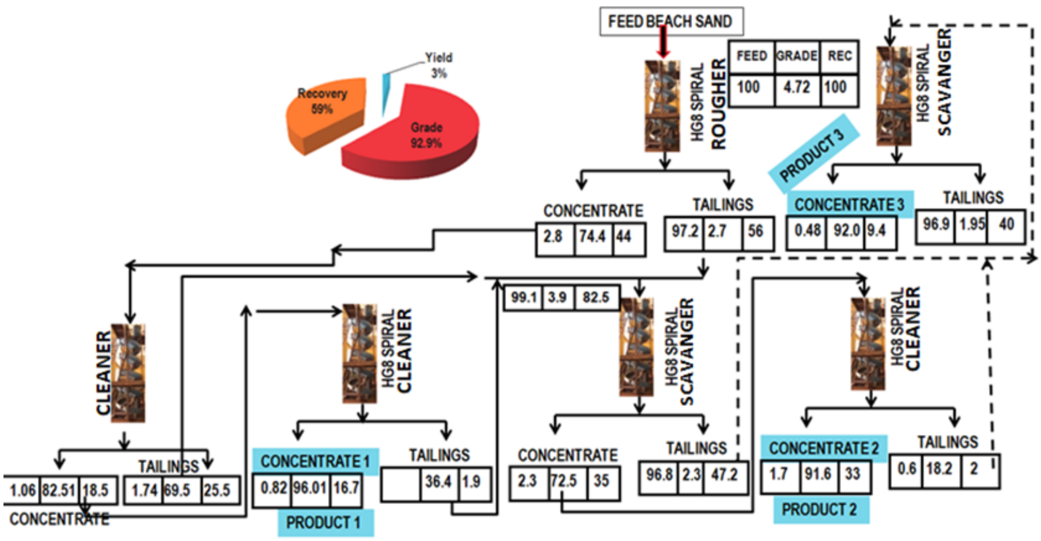

Figure 7 Flowsheet with mass balance achieved on sample-1 (4.72% THM) by using HG 8 spirals

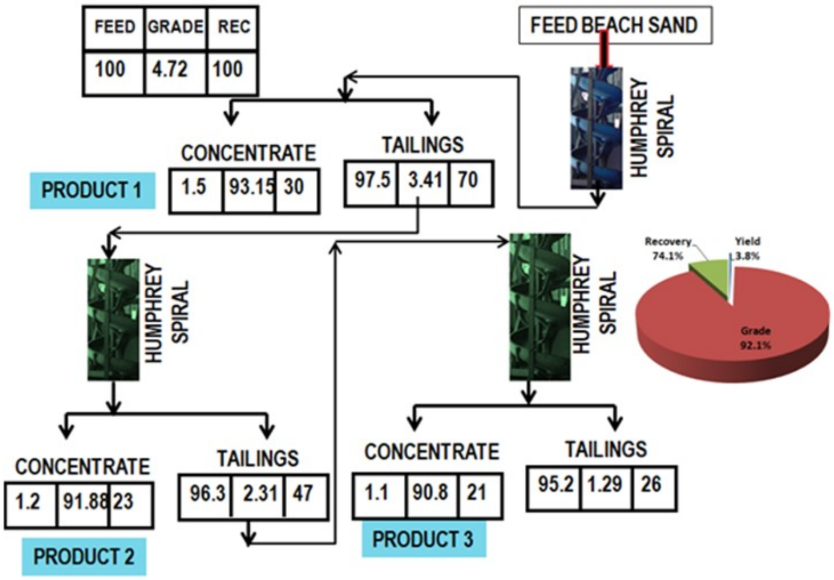

Figure 8 Flowsheet with mass balance achieved on sample-1 (4.72% THM) by using Humphreys spiral

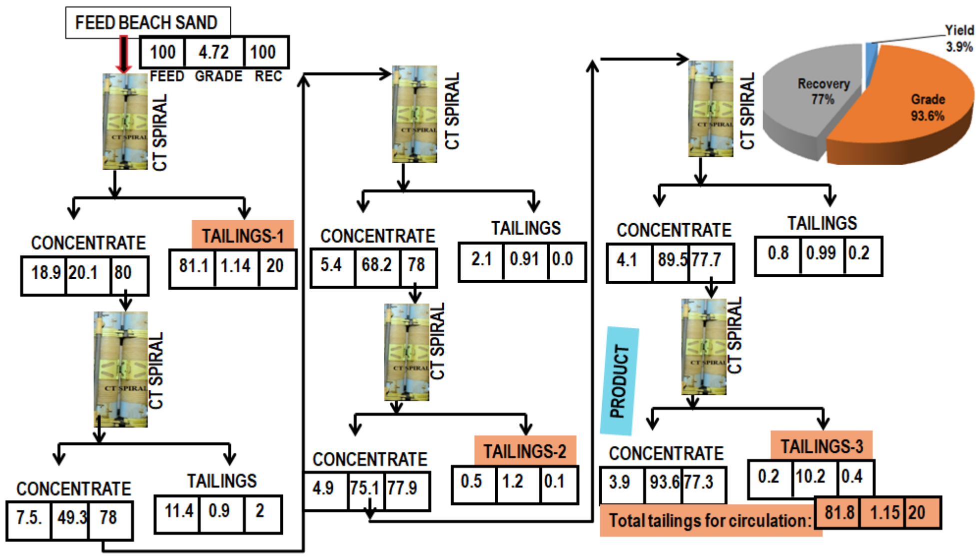

Figure 9 Flowsheet with mass balance achieved on sample-1 (4.72%THM) by using CT spirals

Table 2 Summary of results of different gravity units with feed mono grade [THM 4.72%] of beach placer deposit

Details	Mozely Table	Gravity Table	HG8 Spiral	CT Spiral	Humphrey Spiral
Yield %	4.2	3.9	3	3.9	3.8
Grade %	93.15	92.2	92.9	93.6	92.1
Recovery %	82.8	76	59	77.3	74.1
Rougher	1	1	1	1	1
No. of cleanings	4	1	2	5	3
No. of scavengings	-	-	3	-	-

It can be concluded from the data presented in Figures 7 to 9 and Table 2 that the lower capacity gravity units were restricted for low tonnage samples, where spiral was designed for high tonnage samples. The data given in Table 2 indicate that from a feed sample which contained 4.72 percent total heavy minerals, the Mozely table gave a product of 93.2%, whereas gravity table, HG8 spiral, CT Spiral and Humphrey spirals gave a product of 92.2%, 92.9%, 93.6% and 98.2%, respectively. It may be noted here that the designed spirals were not suited for low grade samples with finer heavy particles. In view of this, it is essential to understand the relation between the different densities or different grades of feed samples and design aspects of the gravity unit operations. Thus, an attempt was made further on different grades of THM samples which were subjected to relatively low efficiency model HG8 spiral, and the data are given in Table 3 and shown in Figures 10 to 13. It is clearly seen from the data given in Table 3, that using HG8 spirals for feed samples with different densities or grades (THM), provided product grades of 92.9%, 82.8%, 90.7%, 98.2% and 98.1% for the feed samples contain 4.72% THM, 5.6%THM, 9.5%THM, 15.7% THM and 19.5% THM, respectively.

Table 3 Summary of results of HG8 Spiral with different feed grades [THM] of beach placer deposits

Details	4.72 THM	5.6 THM	9.5 THM	15.7 THM	19.5 THM
Yield %	3	4.9	8.5	15.3	19.0
Grade %	92.9	82.8	90.7	98.2	98.1
Recovery %	59	72	81	95	95
No. of cleanings	3	4	3	1	1
No. of scavenging	3	-	-	1	-

Data shown in Table 3 indicate that with increasing the grade (THM) of the feed sample, the achieved outputs (concentrate grades and recoveries) are higher. It may be noted here that feed sample with 4.72% THM can be concentrated to the grade of 92.9% THM with 59% recovery, while the sample containing 19.5% THM, can be concentrated to the grade of 98.1% THM with 95% recovery, using HG8 spiral. Data shown in Figures 10 - 13 indicate that lower concentration of feed (containing below 6% THM) needs six stages of concentration in spirals, where higher concentration feed (19.5% THM) requires 2 stages of concentration in spirals to achieve desired grade.

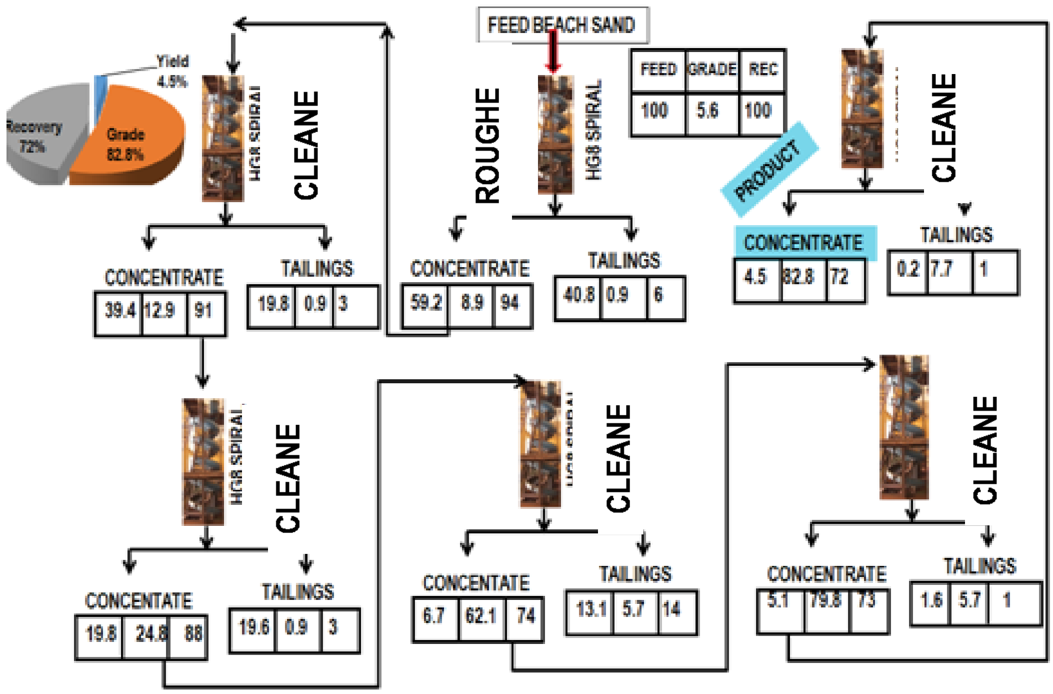

Figure 10 Flowsheet with mass balance achieved on sample-2 (5.6%THM) by using HG8 spirals

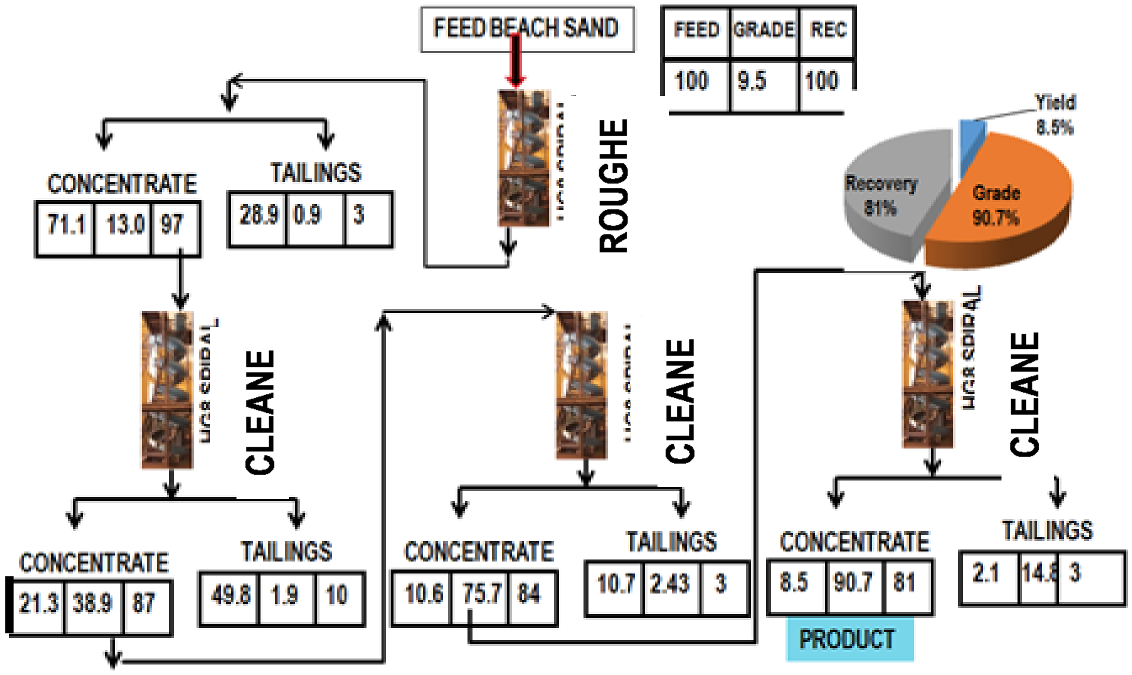

Figure 11 Flowsheet with mass balance achieved on sample-3 (9.5%THM) by using HG8 spirals

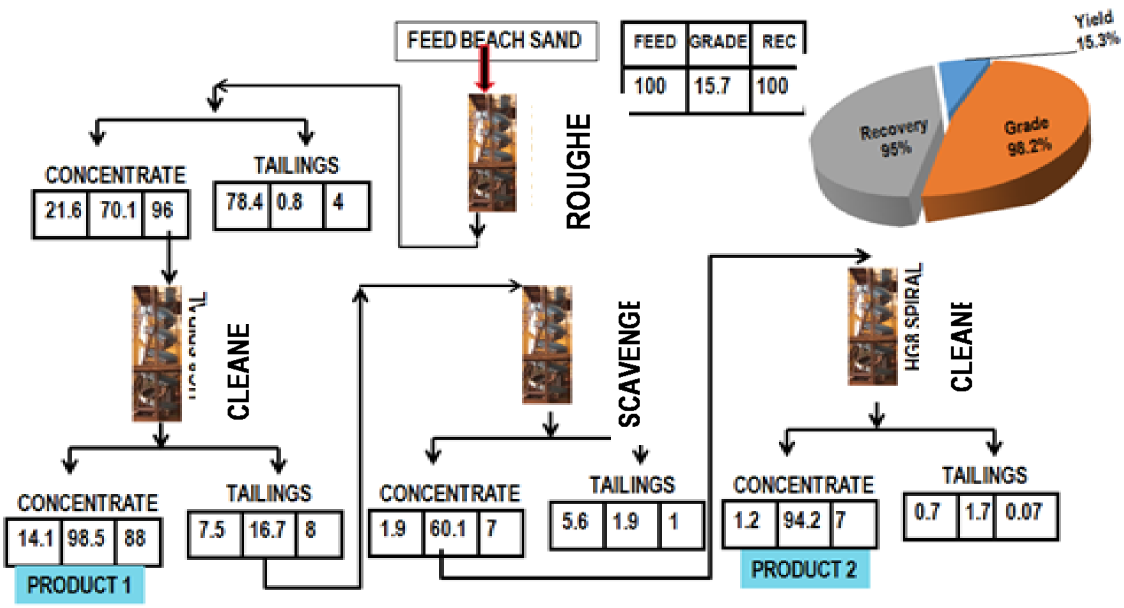

Figure 12 Flowsheet with mass balance achieved on sample-4 (15.7%THM) by using HG8 spirals

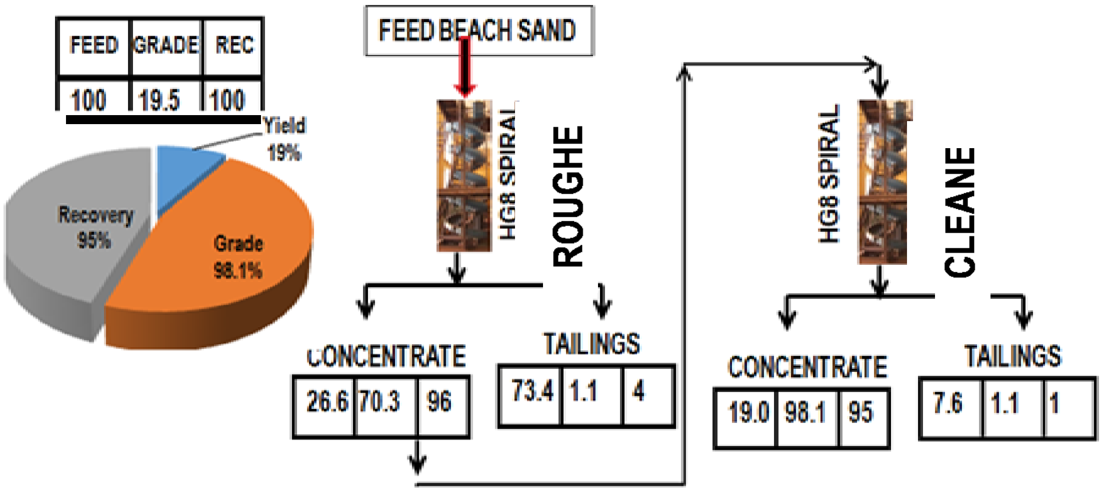

Figure 13 Flowsheet with mass balance achieved on sample-5 (19.5%THM) by using HG8 spirals

4. Conclusions

The conclusions drawn from the study of synergizing placer heavy minerals with physical and textural characters of minerals for up gradation of lean grade beach sand deposits using different gravity concentrators are summarized.

Regarding the feed sample which contained 4.72% of total heavy minerals, the Mozely table gave a concentrate containing 93.2% THM; while gravity table, HG8 spiral, CT spiral and Humphrey spirals provided concentrates containing 92.2%, 92.9%, 93.6% and 92.1% of THM, respectively.

By using HG8 spirals on various feed samples (with different densities and grades), concentration results showed that products containing 92.9%, 82.8%, 90.7%, 98.2% and 98.1% of THM could be obtained from the feed samples containing 4.72% THM, 5.6%THM, 9.5%THM, 15.7% THM and 19.5% THM, respectively.

The performance of spirals is much significant at higher grade and coarse size of feed.

Thus, it is concluded that the performances of spiral also depend on the feed grade and texture analysis of the feed.

Acknowledgments

Authors are thankful to IREL (India) Limited for providing funding and facilities to carry out the research work. One of the authors is duly acknowledging his research supervisors. He also sincerely thanks his parental organisation for providing research and financial facilities for this work.

Note

A part of this study was presented at the XV International Mineral Processing and Recycling Conference, organized by the University of Belgrade, Technical Faculty in Bor, from 17th to 19th May 2023, Belgrade, Serbia.

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IZDVAJANJE TEŠKIH MINERALA KORIŠĆENJEM GRAVITACIONIH KONCENTRATORA IZ SLABO I NISKOKVALITETNOG PESKA SA PLAŽE

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Primljen: 18. juna 2023.; Prihvaćen: 12. oktobra 2023.

Izvod

U ovom radu autori su istraživali sinergetske efekte teksturnih, fizičkih i hemijskih karakteristika sedimentacionih nanosa teških minerala. Ovi nanosi se nalaze u pesku sa plaže koji je siromašnog i niskog kvaliteta i koji obično pokazuje varijacije u sadržaju teških minerala, teksturi i sastavu. Nalaze se duž celog Bengalskog zaliva, od Čatrapura do distrikta Puri u Orisi, Indija. Cilj istraživanja je ekstrakcija teških minerala korišćenjem različitih modela gravitacionih koncentratora. Rezultati su pokazali da se Mozlijevom uređaju dobija koncentrat sa 93,2% ukupne količine teških minerala. U poređenju sa tim, spiralni HG8, spiralni CT i Hamfrijev spiralni koncentrator dali su koncentrate sa 92,2%, 92,9%, 93,6% i 98,2% ukupne količine teških minerala iz uzorka peska koji sadrži 4,72% teških minerala. Takođe je primećeno da karakteristike spirale zavise kako od kvaliteta peska, tako i od analize teksture ulaznog materijala.

Ključne reči: *pesak sa plaže, sedimentacioni nanosi, teški minerali, separator minerala, spiralni koncentratori.*