

Study on beneficiation of silica sand by Wet High-Intensity Magnetic Separators (WHIMS) and reverse flotation technique for glass application: A case study from Sihanoukville, Cambodia

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Abstract: White silica sand samples were collected from Steung Hav district area. The samples were mixed and quartered to obtain a representative sample for physical and chemical characterization. Silica (SiO_2) and iron oxide (Fe_2O_3) content were measured by X-ray fluorescence (XRF) analysis. The results showed silica and iron oxide content at 94.83 wt.% and 0.189 wt.% representatively. In this study, a shaking table, Wet High-Intensity Magnetic Separators (WHIMS), and reverse flotation technique was undertaken to remove mainly iron oxide. The collectors amine (named AOA) and petroleum supinate (named NANZA), pine oil as frother, and H_2SO_4 as depressant were used to optimize the froth performance. The iron oxide content was removed from 0.189wt.% to 0.062 wt.% and the silica content was upgraded from 94.83 wt.% to 98.6 wt.% after the process.

Keywords: WHIMS, reverse flotation technique

INTRODUCTION

Silica sand is one of the essential natural material resources, which is commonly used as an ingredient in many industries such as glass, bottle, construction, ceramic and other chemical industries. The most influencing factors to the properties of glass are iron impurity, the particle size, and mineral phase during the melting process, which affects the clarity and quality of the produced glass. A typical impurity in silica sand concentrate is iron oxide (Fe_2O_3) which can usually be removed using chemical or physical process (Sereiratana *et al.*, 2013). The content of iron oxide impurity in silica sand can affect the optical properties of the glass. For example, with higher Wt. % of iron oxide, the colour of the glass produced will be brown or green (bluish-green). According to the British Standard BS29875, the standard for glass manufacture is based on allowable impurities. There are 5 out of 7 standards which is the highest grade for glass application: grade A: optical glass, $\text{SiO}_2 = 99.5\%$, $\text{Al}_2\text{O}_3 = 0.2\%$, and $\text{Fe}_2\text{O}_3 = 0.013\%$. B: tableware glass, $\text{SiO}_2 = 99\%$, $\text{Al}_2\text{O}_3 = 0.2\%$, and $\text{Fe}_2\text{O}_3 = 0.01\%$. C: borosilicate glass, $\text{SiO}_2 = 98.5$, $\text{Al}_2\text{O}_3 = 0.2\%$, and $\text{Fe}_2\text{O}_3 = 0.01\%$. D: colorless glass, $\text{SiO}_2 = 98.8$, $\text{Al}_2\text{O}_3 = 0.1\%$, and $\text{Fe}_2\text{O}_3 = 0.03\%$ (Marzia Hoque, 2014; Platias *et al.*, 2014).

Impurities in glass sands are usually present as free and coated iron oxide, clay, titanium and refractory minerals. Iron is the most harmful impurity. It can be reduced by physical, physicochemical or chemical leaching methods, depending on the real condition of the mineral form (Ibrahim *et al.*, 2013).

The measurement of separation and iron oxide removal efficiency follows PerkinElmer atomic absorption (Hacifazlioglu, 2014).

$$\eta(\%) = \left| 1 - \frac{\alpha_i}{\alpha_r} \right| \times 100 \quad \text{Equation 1}$$

Where α_i = iron oxide content in concentrate
 α_r = iron oxide content in the feed

While the liberated impurity can be reduced or removed by using physical operation such as shaking table (spiral concentrate is more efficiency liberated) and WHIMS etc., some bearing iron content cannot be removed with these processes, such as titania oxide, ilmenite, and other iron oxide still contained in the final product of the physical process. This study focused on impurities removal from silica sand to meet the specification of colourless glass industry by using physical and physicochemical processes (reverse flotation).

MATERIAL AND METHODOLOGY

Sample preparation

The sand sample used in the experiment was taken from Steung Hav district, Cambodia. The sample was taken at a depth of 2 m. Eight samples were taken to represent many areas, named P34, P40, P46, W5, W7, W11, W27 and W28. They consisted iron oxide ranging from 0.12-0.29 Wt.% with an average of 1.89 wt.% and

silica oxide ranging from 91.5-98.28 wt.% with 94.7 wt.% as an average value, as shown in Table 1. The chemical composition of the material was analyzed using X-ray fluorescent. The particle size distribution was investigated using sieve analysis method. Only grain size less than 20 mesh was used in this study.

Experiment

This study was conducted with a physical and physicochemical method to remove the iron oxide from sand to meet the specification of grade D of the standard glass manufacture, as shown in Figure 1.

This experiment was conducted on a laboratory scale. Samples received from the field was directly

dried at 115°C for 24 hours to determine the particle size using sieve analysis, and followed by wet sieve to reject the particles with size greater than #20 mesh (841 μm). The samples was subjected to shaking table (ST) (Wilfley model) with 8, 10, 12, and 15 degrees of inclination to figure out the effect of each inclination to the removal of iron oxide to determine the optimised condition for further experiments (Ibrahim *et al.*, 2013). All compositions were checked through the Wavelength Dispersive X-Ray Fluorescence Spectroscopy (WDXRF) machine. Then, the products from the ST were transferred to the attrition scrubber using the Denver Flotation machine for cleaning the surface of the particles with 60% solid. In this case, the optimization of the attrition process was applied by studying the effect of impeller speed, and time of scrubbing before we directly put it in WHIMS with the magnetic current at 14 Amp. The wet processing using WHIMS involves two coils of magnetic forces. There many factors effecting this process, such as form of matrix, feed rate, water flow rate, rinse water and magnetic field intensity. As the feed pulp passed through the matrix, magnetic particles are held on to the matrix field while non-magnetic particles go through to be collected (Haniza & Idham, 2014).

Reverse flotation was conducted using WEMCO flotation cell with a capacity of 4L. To remove impurities from silica sand to meet the specification of colorless glass, the promoters chemical name AOA (named by a local company in Thailand, which is an amine, a cation collector), and NANZA (petroleum supinates, anion collector), and pine oil as a frother collector as depressants (Win, 2015) were used. The representative sample from the WHIMS process ranged from 700-1000 g of each condition within 4000 ml slurry sample in the flotation cell. In this experiment, eight conditions were carried out to get the optimization condition for further experimentation. AOA and NANZA solution used was in the range from 40 and 50 ml. While the speed of agitator was 1200 rpm, and sulfuric acid H₂SO₄ solution 20 ml regularly with pH value of 1-2.

Table 1: Chemical composition of original sand sample.

SAMPLE ID	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	ZrO ₂	TiO ₂
P34	98.28	0.26	0.16	0.04	-
P40	95.8	2.1	0.18	0.05	0.22
P46	94.86	1.94	0.26	0.05	0.14
W5	91.5	4.06	0.29	0.05	0.25
W7	92.3	4.58	0.23	0.06	0.32
W11	93.4	2.59	0.14	0.19	0.53
W27	94.8	3.07	0.14	0.05	0.2
W28	96	2.46	0.12	0.04	0.17
Mean	94.61	2.63	0.19	0.06	0.26
Median	94.83	2.52	0.17	0.05	0.22
Min	91.5	0.26	0.12	0.04	0.14
Max	98.28	4.58	0.29	0.19	0.53

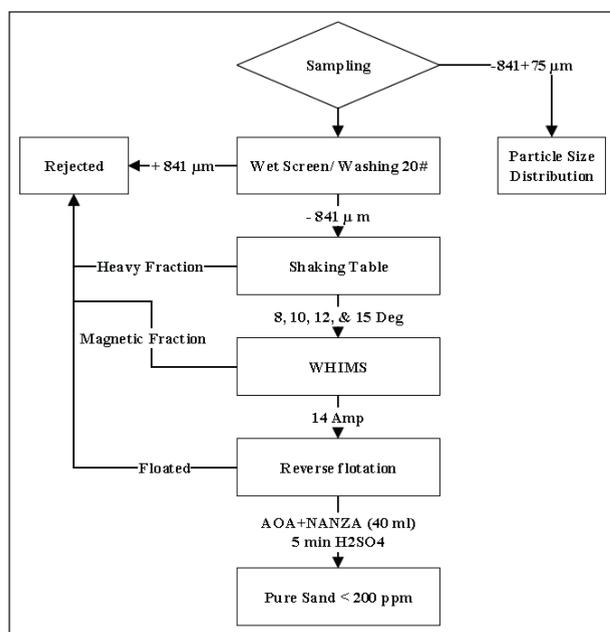


Figure 1: The flowchart of this study.

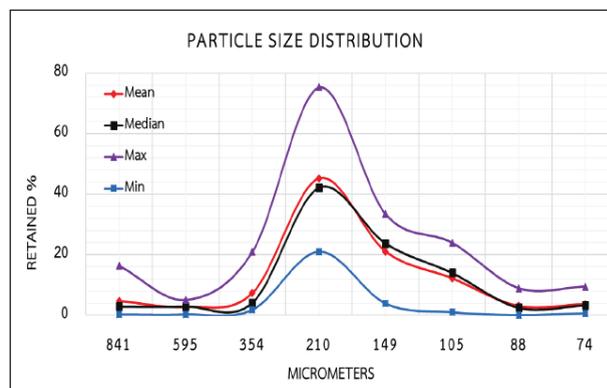


Figure 2: Particle size distribution.

RESULT AND DISCUSSION

Sample characteristic

The result of particle size distribution presented as 200 g of silica sand check through the dry sieve analysis within aperture range from 0.841 mm, 0.6 mm, 0.425 mm, 0.212 mm, 0.15 mm, 0.106 mm, and 0.075 mm within 20 minutes. After rejecting particles +0.85mm fraction, the sample size is commonly ranging from -0.425mm to + 0.106mm. From the XRF analysis, the composition of Al₂O₃ (0.26-4.5%), Fe₂O₃ (1.89 -0.286 wt. %) and SiO (91.5-98.8) was obtained. For raw silica sand as shown in McLaws (1971), it is classified as high-grade silica sand, based on the component SiO₂ = 99 wt. % (Ibrahim *et al.*, 2013). In Figure 3, the impurities in raw silica sand which is associated with siliceous during the geological weathering process of sands can be noted.

Shaking table

This experiment was conducted with various deck inclinations, such as 8, 10, 12 and 15°, with water flowrate of 0.22 l/s. The representative sample was 1 kg of each condition. The process of shaking table was performed until having no middling fraction or less amount, then repeated for 5 times of middling fraction. With the frequency of shaking around 276 rpm, it has created a length of stroke 10 mm in order to do a pretreatment of purities in silica sand. From the result of the previous condition, it is shown that the highest removal of iron oxide occurred when the deck is inclined at 12°, shown in Figure 4. When the inclination is increased to 15°, the percentage of iron removal gradually decreased from 72.11% to 58.78%. Thus, the suitable condition of the shaking table is 12° with an acceptable yield percentage of 93.71 %.

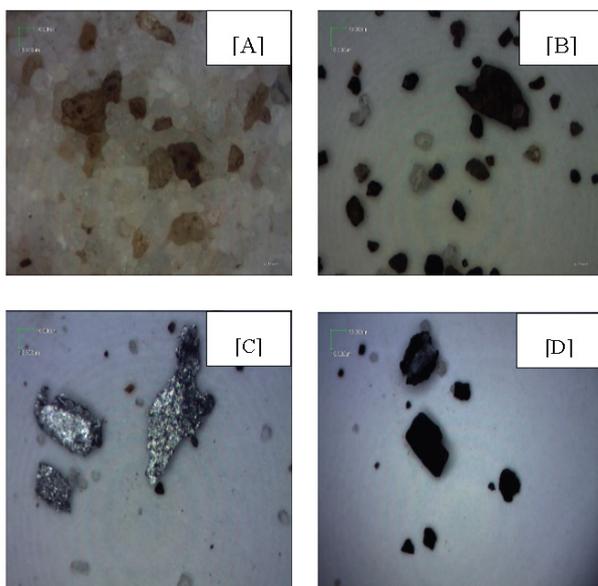


Figure 3: [A] quartz and garnet, [B] tourmaline and hematite, [C] alumina oxide, [D] ilmenite.

Wet high-intensity magnetic separator

The second step of physical treatment was conducted using a Wet high-intensity magnetic separator (WHIMS) to reach the requirement of a high grade sand. The result showed a significant change from the shaking table, siliceous increased from 96.6 wt.% to 98.5 wt.%, and iron oxide gradually decreased from 0.09 wt.% to 0.06 wt.%, which is represented by iron removal (64.78%) and the yield percentage reached 99% (Figures 6 and 7).

Reverse flotation

The third process, reverse flotation, is a physicochemical method to remove the iron oxide as the physical methods

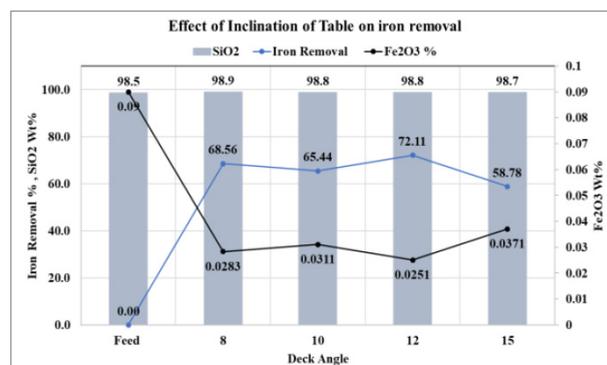


Figure 4: Effect of deck inclination of shaking table.

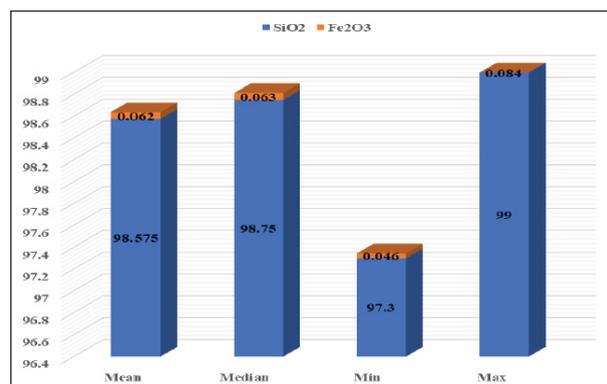


Figure 5: Result of XRF.

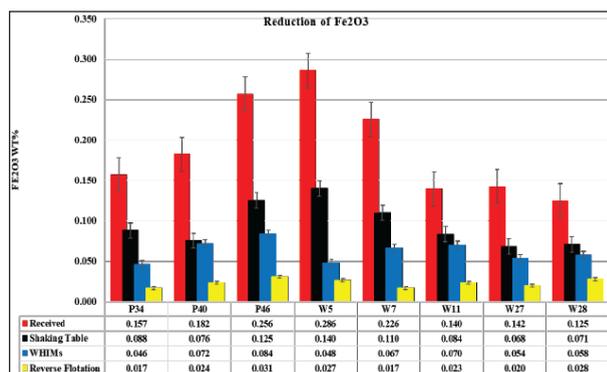


Figure 6: Significant removal.

could not achieve the target of grade D glass. The results showed that the siliceous content increased from 99.03 wt.%, and iron oxide was reduced from 0.06 wt.% to 0.023 wt.%, with an average removal percentage value of 86.77%. As mentioned earlier, this silica grade can be considered as a very pure silica sand, after going through the third treatment process. The chart in Figure 9 shows the significant reducing of iron oxide from the original sample to the final product.

CONCLUSION AND RECOMMENDATION

The experiment was conducted at a laboratory scale using the shaking method with 12° deck angle and has highly removed the iron oxide. Moreover, the physicochemical method of reverses flotation with some parameters consumption of collector AOA+NANZA = 40

ml, acid sulfuric 20 ml, and pine oil 0.1 ml can further remove the iron oxide to 86.7%. The wet high-intensity magnetic separator followed by reverse flotation is a high performance in terms of iron oxide removal, but it could be a costly operation due to the collector and acid demand. Therefore, further researches would be conducted with the spiral gravity and followed by WHIMS to optimize the cost of processing.

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REFERENCES

Hacifazlioglu, H., 2014. Enrichment of Silica Sand Ore by Cyclojet Flotation Cell. *Separation Science and Technology*, 49(10), 1623-1632. doi:10.1080/01496395.2014.893357.

Haniza, M. & Idham, M., 2011. Development of Tritan Crystal Glass Using Local Processed Silica Sand for Tablewares. *Solid State Science and Technology*, 19(2), 40-47.

Ibrahim, S. S., Selim, A. Q. & Hagrass, A. A., 2013. Gravity Separation of Silica Sands for Value Addition. *Particulate Science and Technology*, 31(6), 590-595. doi:10.1080/02726351.2013.800930.

Marzia Hoque, T., 2014. Upgradation of locally available silica for the production of solar grade silicon. Master science thesis, Bangladesh University of Engineering and Technology, Bangladesh.

Platias, S., Vatalis, K. & Charalampides, G., 2014. Suitability of quartz sands for different industrial applications. *Procedia Economics and Finance*, 14, 491-498.

Raghavan, P., Chandrasekhar, S., Chandra, A. I., John, V. & Antony, V., 2006. Development of a beneficiation flow sheet for processing silica sand from Chertala Area of Kerala. <http://eprints.nmlindia.org/6253/1/320-327.PD327>.

Sereiratana, E., Bharum, K. A., Rezan, S. A., Othman, R., Takahashi, F. & Boné, P., 2013. Comparison of Silica Sand Properties from Kandal Province, Cambodia and Tapah, Perak, Malaysia and Characterization of Soda Lime Silicate Glass Produced From Cambodian Silica Sand. *Advanced Materials Research*, 858, 248-253. doi:10.4028/www.scientific.net/AMR.858.248.

Win, E.E., 2015. An upgrading of low quality silica sand from Thung Tago deposit in Thailand. Thesis, Chulalongkorn University.

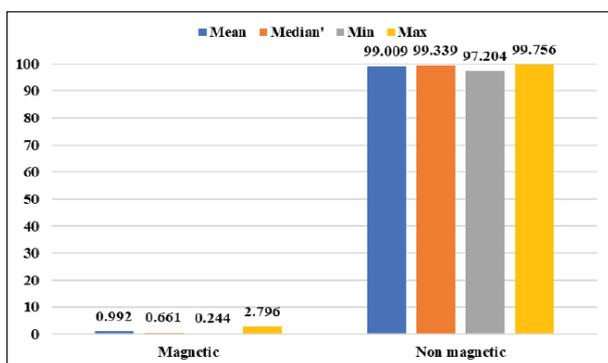


Figure 7: Yield percentage from WHIMS process.

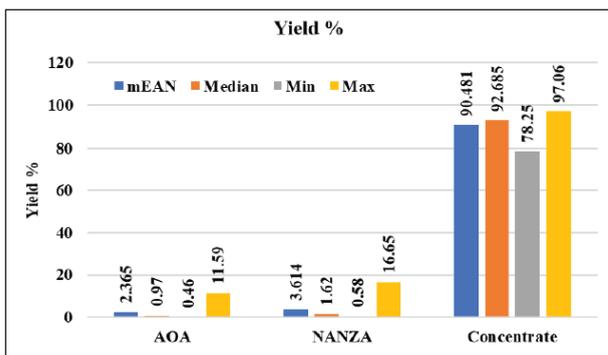


Figure 8: Yield percentage of reverse flotation.

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