

## Boron Waste Concentration Using Shaking Table

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### Abstract

The most important Iranian boron reserves are in the basin of GHEZEL-OUZAN, a river in the West and Northwest area of Zanjan. The majority of these mines have been extracted with a non-advanced way. There are many great waste dumps next to the mines which are a threat to the environment for releasing boric acid and because of an average grade of Boron are valuable from financial point as well. Present paper studies possibility of concentration a low-grade boron waste from Moshampa boron mine using shaking table. In order to concentration, 6 factors in 5 levels were considered. The factors included: particle size, water flow rate, frequency, liberation range, tilt angle and feed rate. Optimization was carried out by classic method (one factor at the time). As a result, optimum condition obtained under particle size of +1.18 -2 mm, water flow rate of 3.5 lit/min, frequency of 320 cycle/min, liberation range of 15 mm, tilt angle of 8 degrees and feed rate of 250 g/min. This test yielded 58.43% of  $B_2O_3$  recovery under optimum conditions performance, and a concentrate with 26.45%  $B_2O_3$  was produced.

**Keywords:** Boron; Shaking table; Concentration; Waste recycling; Optimization

### Introduction

Boron is one of the most important industrial elements. The total world boron ore reserves are estimated to be equivalent to 1,241 million tons of  $B_2O_3$  [1]. The United States and Turkey are the world's two largest producers of boron compounds. Together, these two countries make up about 90% of the world's boron reserves [2]. Iran is one of the poorest countries in this field. There are less than 5 active boron mines in Iran. The most important Iranian boron reserves are in the basin of Ghezal-Ouzan, a river in the West and North-west area of Zanjan, the North-western region of Iran.

Boron ore upgrading generally performs by gravity methods. In industrial scale, boron minerals are generally concentrated by scrubbing followed by screening and classification to remove clay minerals [3]. In 2004 Mr. Acarkan et al. from Istanbul Technical University, verified a new process for upgrading boron content and recovery of borax concentrate using tumbling and stirring scrubbing; The content of the borax concentrate was increased from 32-33% to 34.53%  $B_2O_3$  with new method [4]. Boron compounds are found in nature in the form of metal borates, mostly as calcium, magnesium and sodium borates [5]. In Ca Borate ores, concentration is generally carried out by disintegration, washing and classification in the size fractions in large sizes, concentrate is obtained through attrition tumbling and hand sorting. In Na Borate ores, attrition scrubbing to the ore is followed by classification by the use of screens and cyclone. As Na borate is soluble in water so that all the water is kept at near saturation with boron [6]. Magnesium borates occur in small quantities in the various boron deposits of the world [7,8]. Commercial Hydroboracite deposits are found in Inder, a locality in Siberi. Hydroboracite in Turkey occurs in the Büyük Günevi mine of the Yakal Borasit Ltd [9]. Moshampa borate ore containing the minerals, hydroboracite ( $(CaMgB_6O_{11} \cdot 6H_2O)$  90.9% of all valuable mineral), boracite ( $Mg_3B_7O_{13}Cl$ ) and pandermite ( $Ca_4B_{10}O_{19} \cdot 7H_2O$ ) is located approximately 21 km northwest of ZANJAN which has been studied in this case (Figure 1). For the first-time utilization of this mine started in 2005. This mine has been extracted with a conventional method. There is a big waste dump (over than 30000 tons) next to the mine which has an average grade of 8.95%  $B_2O_3$ .

This investigation is going to verify possibility of concentrating this low-grade boron waste by shaking table. Boron ore concentration generally performs by gravity methods, but this is for the first time that

shaking table is employed for concentrating a boron ore.

### Experimental

#### Materials

Studied sample (28.300 Kg) was provided from the waste dump of Moshampa boron mine, Zanjan, Iran, through sampling methods (grinding, quartering and using riffle). Primary analysis of the boron ore (determined by XRD, XRF and ICP-AES (for boron content) methods) are shown in Table 1.

Furthermore, the characterization of minerals in the boron ore was performed by X-ray powder diffraction (XRD) under the condition of Cu K $\alpha$  at 40 kV and 30 mA as shown as in the Figure 2. The results of XRD analysis revealed that  $CaSO_4 \cdot 2H_2O$  and  $CaCO_3$ , were the major,

| Content [wt.%] |       |      |                  |                                |                                |                  |                   |
|----------------|-------|------|------------------|--------------------------------|--------------------------------|------------------|-------------------|
| $B_2O_3$       | CaO   | MgO  | SiO <sub>2</sub> | Fe <sub>2</sub> O <sub>3</sub> | Al <sub>2</sub> O <sub>3</sub> | K <sub>2</sub> O | Na <sub>2</sub> O |
| 8.95           | 29.59 | 3.51 | 5.29             | 0.92                           | 0.89                           | 0.19             | 5.03              |

Table 1: Chemical analysis of the boron ore.



Figure 1: Moshampa boron mine.

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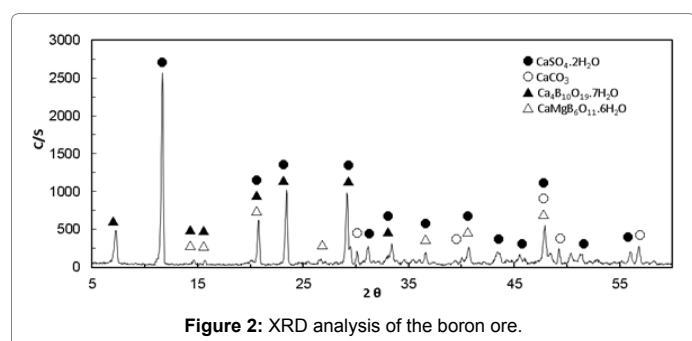


Figure 2: XRD analysis of the boron ore.

$\text{Ca}_4\text{B}_{10}\text{O}_{19}\cdot 7\text{H}_2\text{O}$  (Pandermite) and  $\text{CaMgB}_6\text{O}_{11}\cdot 6\text{H}_2\text{O}$  (Hydroboracite) were the minor mineralogical phases in Moshampa boron ore. According to the difference between specific gravities of the main minerals and gangues, it could be seen shaking table as a gravity method can be an appropriate choice to ore upgrading.

## Equipment

Shaking Table is a highly selective gravity separator. The table which was used, was made in Daneshfaravaran Co, Iran. The length of table was 126 cm and the width was 64 cm. The range of frequency, liberation and tilt were changeable. The positions of the products (tailing, middling, and concentrate) by splitters were fixed during the whole investigation. In addition, concentrate and middling were combined finally.

## Procedure

Five hundred gm of sample was selected and placed in the oven. Moisture amount obtained 17.11% (mass). Optimization was carried out by classic method (one factor at the time). In performing each experiment, considered factor was changed in its levels and other factors were kept constant. Eventually all factors were optimized one by one. In order to optimization, 6 factors in 5 levels were considered. The factors were as follows: particle size, water Q, frequency, liberation range, tilt angle and feed Q. Considered factors and their levels to concentrate are shown in Table 2.

The table was set at the pre-assigned operating conditions. Before start each experiment, frequency and liberation range and also tilt angle were set at desired amount, then water flow was adjusted and the table was started to shake. Finally, the material was continuously fed into the feed box of the table at a constant feed rate until the system attains a steady state. From this point on, experiment was carried out for 2 min. The products (tailings, middling's, and concentrate) were collected in their respective collecting pans, filtered, dried, weighed and analysed for  $\text{B}_2\text{O}_3$ . Revealing the grade at each period, recovery ( $R=Cc/Ff$ ) and separation efficiency ( $SE=100 \text{ Cm}(c-f)/f(m-f)$ ), were determined also and the most optimal mode was identified and fixed.

## Results and Discussion

Effect of particle size, water flow rate, frequency, liberation range, tilt angle and feed flow rate, were studied respectively.

### Effect of particle size

The effect of particle size on the grade and recovery of concentration was investigated in the ranges of -1.18, +1.18 -2, +2 -4.75, +4.75 -7.9375, +7.9375 -12.7 mm, under constant conditions of water Q of 2.5 lit/min (level 1), table frequency of 200 cycle/min (level 1), liberation range of 10 mm (level 1), tilt angle of 4 degrees (level 1) and Feed Q of 200 g/min (level 1). As seen in Figure 3, the grade and recovery of concentration

| Parameters                  | level 1 | level 2 | level 3 | level 4 | level 5 |
|-----------------------------|---------|---------|---------|---------|---------|
| Particle size (mm)          | 1       | 2       | 3       | 4       | 5       |
| Water rate (lit/min)        | 2.5     | 3       | 3.5     | 4       | 4.5     |
| Table frequency (cycle/min) | 200     | 240     | 280     | 320     | 360     |
| Liberation range (mm)       | 10      | 15      | 20      | 25      | 30      |
| Tilt angle (degrees)        | 4       | 6       | 8       | 10      | 12      |
| Feed rate (g/min)           | 200     | 250     | 300     | 350     | 400     |

Table 2: Considered factors and their levels.

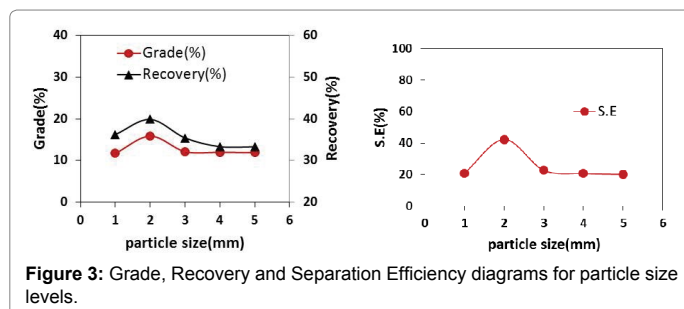


Figure 3: Grade, Recovery and Separation Efficiency diagrams for particle size levels.

has a Maximum amount in the range of +1.18 -2 mm. Therefore, separation efficiency obtained maximum in this level as well. In further experiments particle size was fixed at +1.18 -2 mm.

### Effect of water flow rate

Figure 4 shows the effect of water Q on the grade and recovery of concentration. As it shown in Figure 4, increasing the flow of water up to 3.5 lit/min resulted in an increase in the grade and recovery. From this point on, due to increasing water turbulence on the table the grade and recovery decreased but in the next, increasing water flow, the majority of feed moved to the concentrate part and caused an increase in recovery. The maximum amount of S.E was noticed in the particle size range of +1.18 -2 mm (level 2), frequency of 200 cycle/min (level 1), liberation range of 10 mm (level 1), tilt angle of 4 degrees (level 1) and Feed Q of 200 g/min (level 1) that was equal to 57.04%. For the next experiments water flow was fixed at 3.5 lit/min.

### Effect of frequency

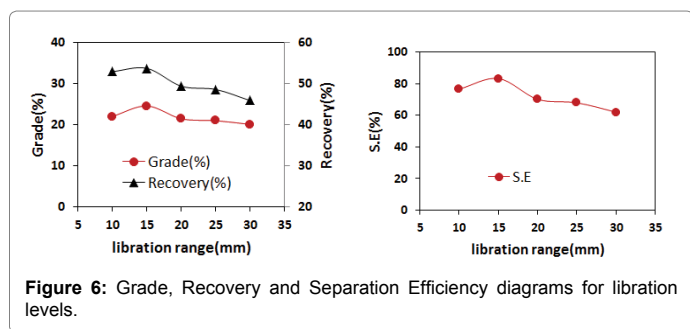
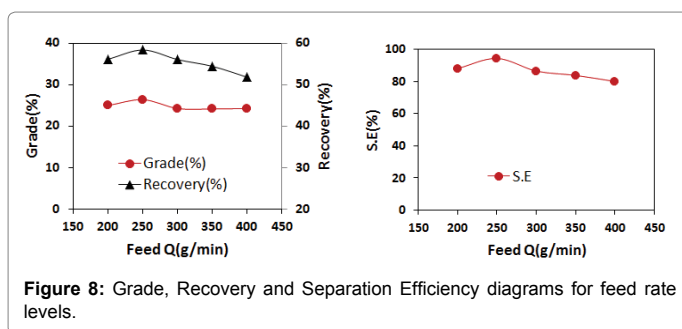
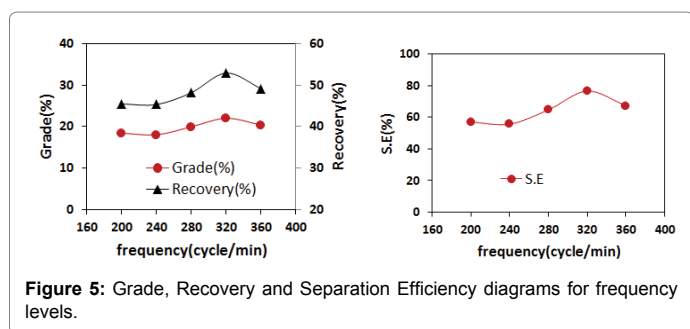
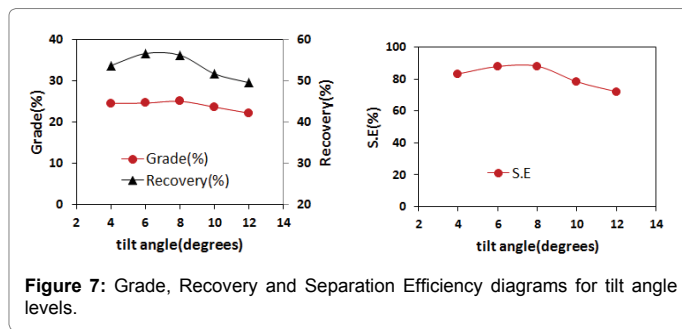
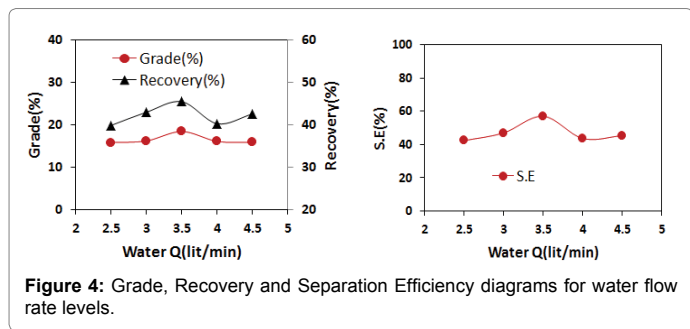
Experiments were carried out to investigate the effect of frequency. As it shown in Figure 5 the optimal mode for grade, recovery and separation efficiency was 22, 52.91 and 76.52%, respectively, at frequency of 320 cycle/min. Therefore, this frequency was chosen as optimum frequency. Constant factors in this experiment were as follows: particle size range of +1.18 -2 mm (level 2), water Q of 3.5 lit/min (level 3), liberation range of 10 mm (level 1), tilt angle of 4 degrees (level 1) and Feed Q of 200 g/min (level 1).

### Effect of liberation

The effect of liberation investigated in the ranges of 10, 15, 20, 25 and 30 mm. The results are presented in Figure 6. As it can be seen, the range of 15 mm is optimal mode for Grade (24.55), Recovery (53.71) and Separation Efficiency (83.20). This test carried out under these conditions: particle size range of +1.18 -2 mm (level 2), water Q of 3.5 lit/min (level 3), frequency of 320 cycle/min (level 4), tilt angle of 4 degrees (level 1) and Feed Q of 200 g/min (level 1).

### Effect of tilt angle

The table was tilted at five different tilt angles: 4, 6, 8, 10 and 12



of 15 mm, tilt angle of 8 degrees and feed rate of 250 g/min. With the operationalizing this investigation, the volume and acidity of waste dumps will be reduced and it will benefit from the financial point as well.

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degrees. Figure 7 shows the grade and recovery of the concentrate obtained at each tilt angle. The amount of S.E at 6 and 8 tilt angles was very close, 87.83% and 88%, respectively. Constant factors in this experiment were as follows: particle size range of +1.18 -2 mm (level 2), water Q of 3.5 lit/min (level 3), frequency of 320 cycle/min (level 4), liberation range of 15 mm (level 2) and Feed Q of 200 g/min (level 1). For the next experiment tilt angle was fixed at 8 degrees.

**Effect of feed rate**

Feed Q was the last factor which tested. As it shown in Figure 8 the optimal mode for grade, recovery and separation efficiency was 26.45, 58.43 and 94.24%, respectively, at feed Q of 250 g/min. Constant factors in this experiment were as follows: particle size range of +1.18 -2 mm (level 2), water Q of 3.5 lit/min (level 3), frequency of 320 cycle/min (level 4), liberation range of 15 mm (level 2) and tilt angle of 8 degrees (level 3).

**Conclusions**

There are less than 5 active boron mines in Iran. High price of boron compounds propels industries to extract mines efficiently. From the environmental point producing less waste has priority as well. The result of this study revealed shaking table as an appropriate gravity method can produce a concentrate with grade of 26.43% and recovery of 58.43%. Optimum condition obtained under particle size of +1.18 -2 mm, water flow rate of 3.5 lit/min, frequency of 320 cycle/min, liberation range