The influence of moisture in the vibrating screen sizing and selection processes

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ABSTRACT

Vibrating screens are widely used in comminution circuits in many different applications throughout the mining industry. They can be used to classify items from large pieces of rock (in scalping screens) to tiny particles that are fractions of millimetres in size. Besides classification, they are also used in many other applications, such as dewatering, desliming, washing, and trash screening. Although the screening process is simple—and easily understood—it may involve high complexity in certain conditions that occur quite often in mining applications. One of those conditions involves high-moisture contents. This commonly occurs in tropical regions around the world, where important mineral deposits are located. For low, natural moisture, the screen-size estimates done by traditional methods normally show proper correlation when compared to actual results from industrial screens. However, when the moisture content is high, calculations may show significant deviations. This fact indicates that traditional screen design methods are not able to cover moisture issues properly. Moreover, traditional methods with high moisture ores may result in serious performance problems that will affect the entire comminution plant. The objective of this presentation is to introduce a vibrating screen-sizing method developed by Metso for difficult dry screening jobs. This method is based on laboratory testing work with a reduced quantity of samples, resulting in more accurate and reliable screen-size estimation for high moisture ores. The conclusions demonstrate the technical feasibility of the method and its application limits.

KEYWORDS: Screen; Moisture; Testing; Sizing.

INTRODUCTION

Preliminary comminution circuit selection generally involves main equipment such as crushers and grinding mills. Vibrating screens are often considered secondary or auxiliary equipment. This partially explains the reasons why current screening literature has a scarcity of technical studies—as well as few dedicated specialists—in screening.

There are several screen-sizing methods in the mineral industry, but they are considered adequate for so-called "free-flowing" particles typical in clean fresh rock or ores with low stickiness. In the case of weathered rock matrix ores, the actual screen performance may show results that are completely different from those estimated using traditional sizing methods.

Weathered ores normally include significant moisture content and a high portion of particles finer than 0.15 mm. Another important characteristic that increases the sticky behaviour is the presence of clayey material. Examples of these ores are commonly found in tropical regions with a high rainfall index, such as in the North of Brazil. The most usual cases are iron ores, nickel, phosphate, bauxite, manganese, and some gold ores.

The difficulties associated with a dry screening process of high natural-moisture ores has been the impetus for the use of wet screening processes. Even though wet processes have been used for decades, several restrictions are now imposed for water usage. These are restrictions such as the reduction of environmental impact, water scarcity, or reduction of high operational costs associated with wet processes.

To cope with the complexity associated with the naturally high moisture screening process, Metso Brazil developed a screen test at its laboratory in the Sorocaba factory. It includes a circular screen, known as Endless Circular Screen (ECS). This method has been used for approximately 10 years. It is used as the foundation for designing industrial screens for several mining projects in Brazil.

DEVICES AND METHODS

The Endless Circular Screen testing device

The ECS was developed in the Metso Brazil Technology Centre with the aim of being the prototype for industrial vibrating screen design involving high natural moisture ores.

The ECS testing device consists of three elements: two vibrating mechanisms located in the upper part, which generate a linear movement. The centre contains the circular screen—modelled on a "donut" shape—which allows particles to move endlessly on the screen surface. At the bottom is placed a bucket to collect the ECS undersize and a scale to continuously weigh the passing material. Fig. 1 select photographs of ECS device.

Fig. 1. Metso Endless Circular Screen

The main ECS features are:

- Internal radius: 0.6 m;
- External radius: 1 m;
- Linear movement;
- Adjustable amplitude: from 3 to 6 mm;
- Adjustable acceleration: generally ranging from 4 to 7 G;
- Options to attach different screening media.

ECS testing procedure

The main steps of the ECS testing procedure are:

- The screening media type and aperture size should be predefined for the test. Options for the media are standard wire mesh, rubber, polyurethane, or any other type;
- A small representative sample of 2 kg is dried for bulk density, natural moisture, and size distribution measurements;
- When necessary, the sample is dried naturally until reaching stipulated starting moisture;
- With the testing device turned off, a total amount of 50 kg of the sample is spread carefully over the screening surface, thus creating a homogeneous ore bed;
- The ECS is turned on and the vibration makes the ore bed shake and move, rotating on the donut-shaped screening surface. The fine particles start to pass through the screening media while the coarse ones keep rotating on;
- The test is finished after 60 seconds or when the undersize weight remains constant;
- The **undersize mass** and the **screening time** are measured and recorded at intervals of one second. The first cycle is finished;
- Both oversized and undersized masses are collected and homogenised in the concrete mixer and fresh water is added to adjust the moisture for next cycle;
- The sample with adjusted moisture is spread again over the screen surface and another cycle is performed following the same steps.

The three main phases of the screening test are shown in Fig. 2. In the first stage (on the left), the material bed height is high, and no particles are reported to the ECS as undersized. At the end of test, the fine particles have passed, and the undersized pile is full.

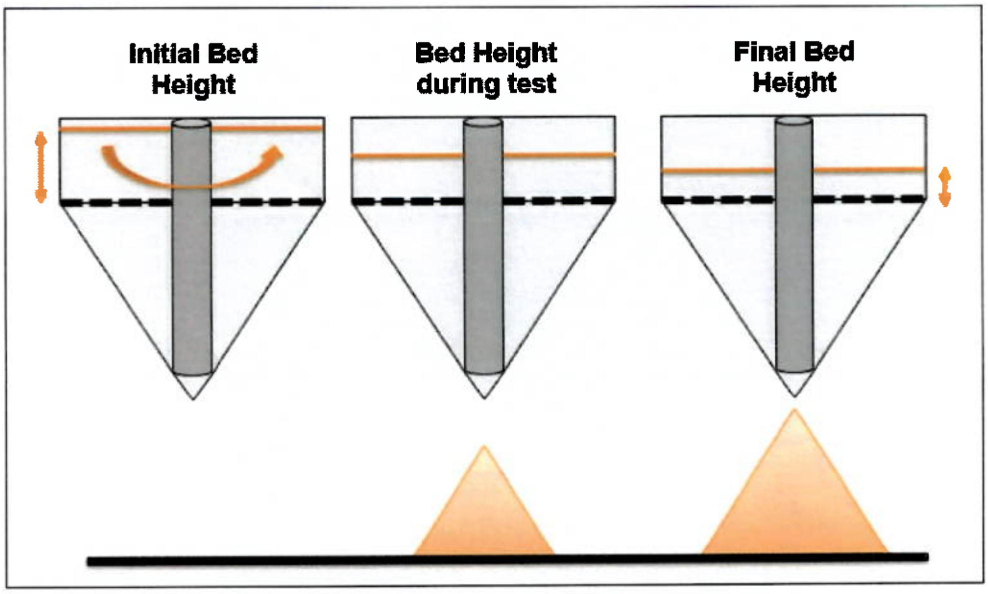

Fig. 2. ECS main testing phases

The undersized mass corresponding to each screening interval is used to calculate the screening efficiency for the entire testing period. These data are used to plot a graph of screening efficiency as a function of time. The main parameter obtained from the ECS testing is the specific screening capacity, or "screenability," expressed in the mass tonnage of the feed per hour, per square metre of screening area (t/h/m²). The theory describing the experimental screenability calculation is shown in the following section.

ECS Theory

The screening capacity (*Sc*, in m³/h) of a vibrating screen is calculated by multiplying the material transport speed (*Ts*, in m/s) by the material bed cross-section area (*Sa*, in m). The material bed cross-section area is a function of the bed height (*Bh*) multiplied by the screen width (*Sw*), both measured in metres.

Converting screening capacity from m^3/h to t/h involves multiplying it by the sample bulk density (Bd, in t/m^3) as well as by the unit factor 3600, the latter for converting hours to seconds. Therefore, the *Sc* can be expressed as:

$$Sa = Bh \times Sw$$

$$Sc = Ts \times Sa \times Bd \times 3600$$

$$Sc = Ts \times Bh \times Sw \times Bd \times 3600$$

The screen length (*SL*) is a function of material transport speed (*Ts*, in m/s), multiplied by the material residence time (*t*, in seconds), as expressed by:

$$SL = Ts \times t$$

The specific screen capacity (*Ss*) can be obtained by dividing the screening capacity (*Sc*) by the screening area (*Sa*), as follows:

$$Ss = \frac{Capacity\ (Sc)}{Screen\ Area\ (Sa)} = \frac{Ts \times Bh \times Sw \times Bd \times 3600}{Sw \times Ts \times t} = \frac{Bh \times Bd \times 3600}{t}$$

The simplified final equation shows that the specific capacity *Ss* is a function of the bed height *(Bh)* and material residence time (*t*). Therefore, the tests basically consist of measuring the undersize material mass per unit of time and its associated bed height.

The specific screen capacity, or screenability, can be measured for different screening efficiencies, for example, 80%, 90% or 95%. According to the Metso procedure the 90% efficiency figure was adopted, following a typical industrial screening process.

RESULTS AND DISCUSSION

Most of the Metso laboratory screening tests were performed with iron ores, because the ECS was developed in Brazil, a major global iron ore producer. Although less frequently, other ore types were also tested, such as: bauxite, limestone, nickel, and coal.

The testing results with iron ores presented in this work were divided in two groups. The first group consisted of three samples selected from typical Brazilian iron ores, named Case A, Case B, and Case C. Case A, Case B, and Case C were screened respectively at 16 mm, 6.3 mm and 1 mm in the ECS. The second group consisted of two samples selected from atypical Brazilian iron ores, named Case D and Case E, which were screened respectively at 25 mm and 12 mm in the ECS.

Typical Brazilian iron ores — Cases A, B and C

The Case A sample predominantly consisted of friable hematite, as obtained from a mine site located in the North of Brazil. The selected screening media was a standard wire mesh with 16 mm aperture size. The feed size distribution of the Case A sample is presented in Table 1.

The 50 kg Case A sample was sun dried for a five-hour period resulting in a 2% moisture. The sample was loaded over the screen surface and the ECS was turned on. The testing time was 60 seconds and during this period the weight of the undersize was continuously recorded for further analysis.

After the first cycle, all the 50 kg of sample was collected, and water was added to reach 6% moisture, following a new screening cycle. The same procedure was repeated for 8%, 9%, 10% and 11% moisture levels, until the critical moisture was apparent.

The recorded data were used to calculate the screen efficiency per time interval, for each moisture tested, as shown in Fig. 3.

Table 1. Feed size distribution for the Case A sample

Size (mm)	Cumulative percent passing
50	100
31	96
25	95
19	93
13	88
4.75	78
1.19	49

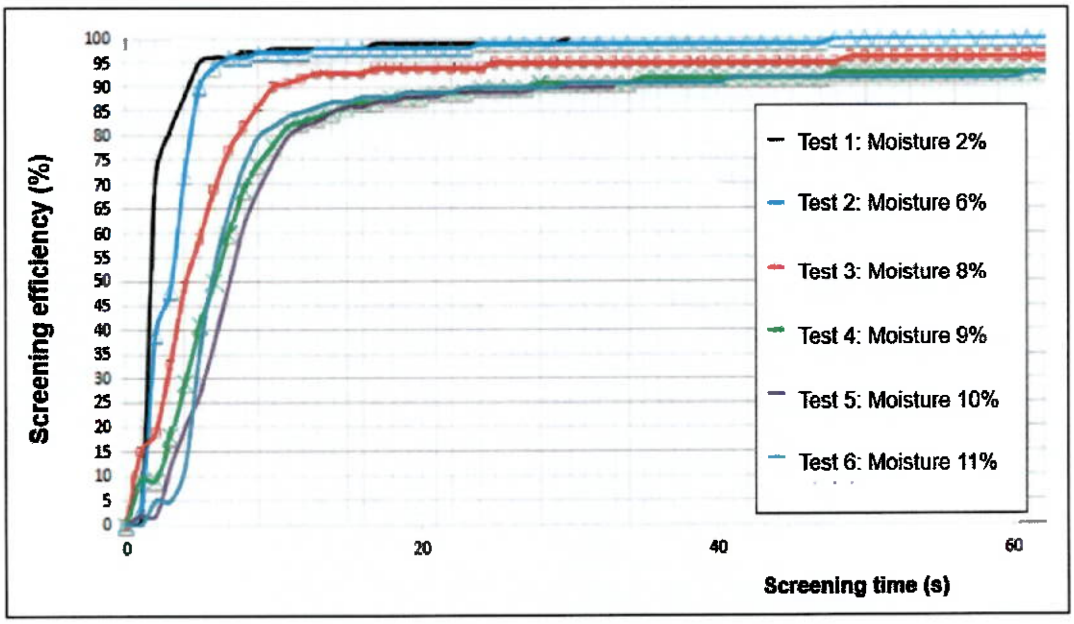

Fig. 3. Screening efficiency as a function of screening time.

Fig. 3 shows that the screening time to achieve 90% efficiency was 10 s or less for moistures of 2%, 6% and 8%, thus indicating easy screenability.

The screening time to achieve the same 90% efficiency increased to 24 s for 9% moisture, showing a substantial reduction in the classification performance for only 1% moisture increase. The 10% moisture test reached the maximum screening time, which was 28 s.

For 11% moisture, the screening time reduced to 23 s. This test generated an inflection in the screenability curve, indicating that such a moisture level was higher than the critical value.

Table 2 shows the main ECS testing parameters. As an example, 28 s were necessary to achieve 90% efficiency at 10% moisture, resulting in a 0.038-m remaining bed height. Thus, the specific capacity or screenability was calculated as follows:

$$Sc = \frac{0.038 \times 2.88 \times 3600}{28} = 13.9\ t/h/m^2$$

Table 2. Screenability calculation for Case A sample.

Test Description	Bed Height (m)	Bulk Density (t/m^3)	Timing to 90% efficiency (s)	Screenability ($t/h/m^2$)
2% moisture	0.043	2.34	4.3	83.7
6% moisture	0.047	2.22	5.0	75.0
8% moisture	0.045	2.38	10	38.3
9% moisture	0.040	2.70	24	16.1
10% moisture	0.038	2.88	28	13.9
11% moisture	0.037	2.96	23	17.2

The same calculation was executed for all moisture levels tested, which resulted in the screenability results shown in Fig. 4. The higher the moisture content is, the lower the calculated screenability is, down to the critical moisture value. The graph indicates significantly easy screening for moistures smaller than 6%, relatively easy for 8% moisture and extremely difficult screening for 9% to 11% moisture levels.

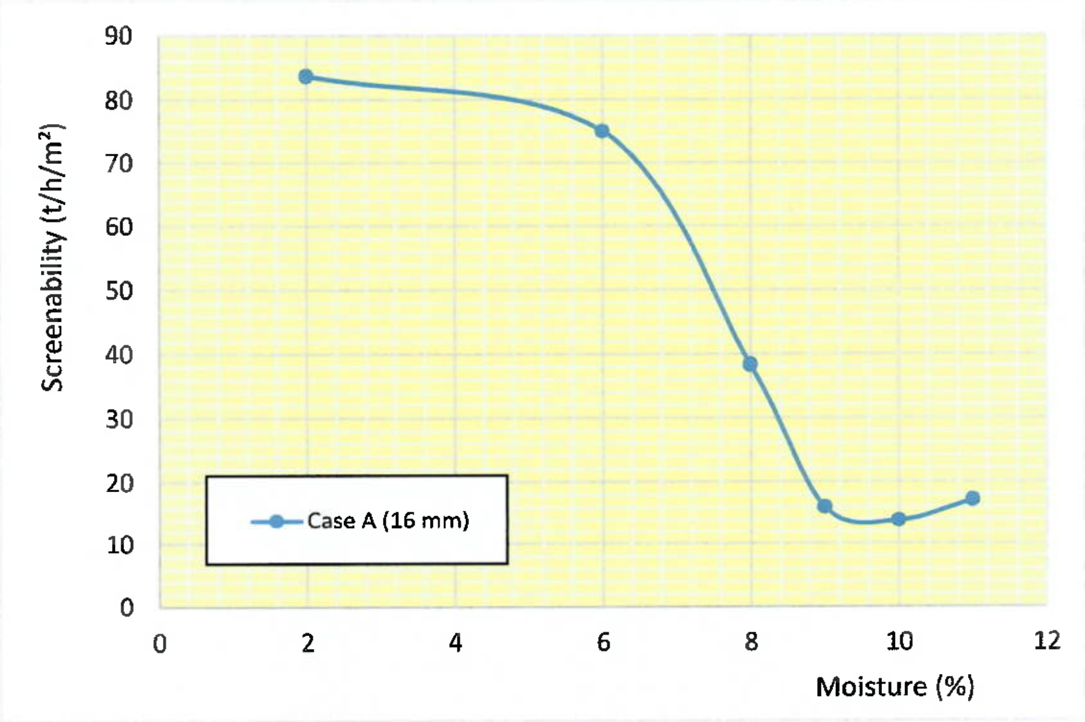

Fig. 4. Screenability as a function of moisture for 16 mm aperture.

Case B testing was carried with an iron ore sample consisting predominantly of semi-compact itabirite, obtained from the "Quadrilátero Ferrífero" region, at Minas Gerais state. The selected screening media was a standard wire mesh with 6.3 mm aperture size.

Case C testing was carried out with a friable iron ore blend consisting of itabirite and hematite, from the Brazilian semi-arid area, at Northeast region. The selected screening media was a wire mesh with 1.0 mm aperture.

Similar ECS testing procedures performed for Case A were also accomplished for Cases B and C. Fig. 5 presents a comparative graph showing the screenability results for the three typical Brazilian iron ores.

The screenability results for the Case A sample were significantly higher than for Case B which were significantly higher than for the Case C sample. While the screenability for the Case A sample was considered extremely easy for 5% moisture, the same moisture was considered critical for Case C (smallest aperture tested).

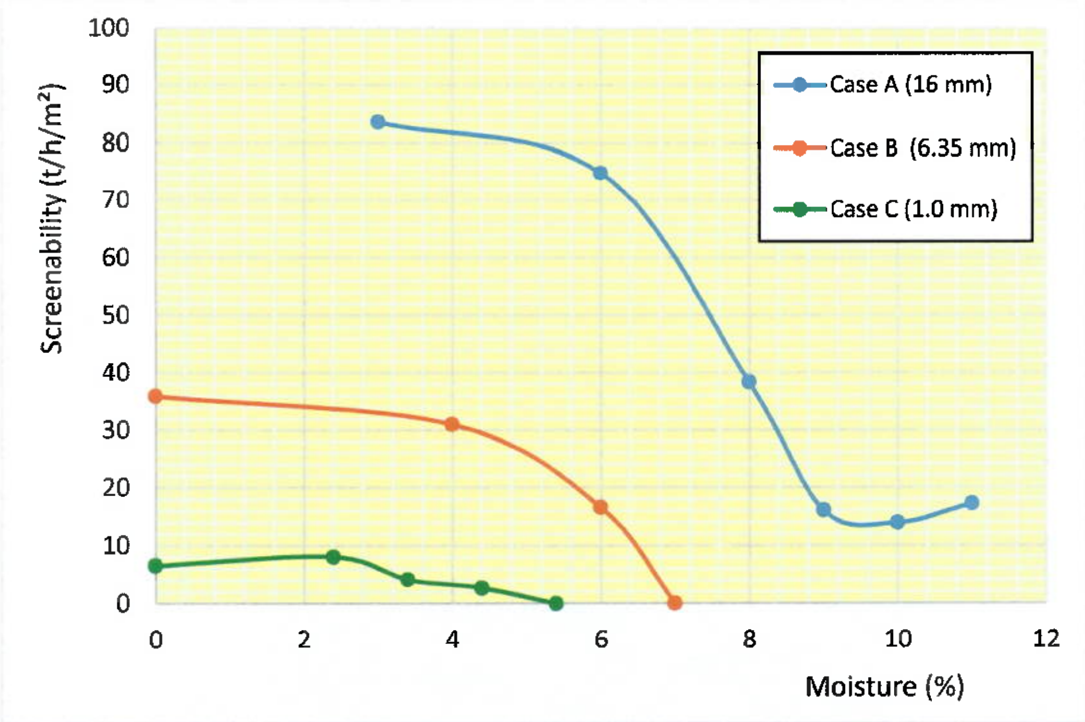

Fig. 5. Screenability as a function of moisture for Cases A, B and C.

Atypical iron ores—Cases D and E

Case D testing was carried out with an iron ore sample consisting predominantly of friable itabirite, containing a significant amount of goethite, obtained in the "Quadrilátero Ferrífero" region. Goethite, together with other hydrated oxide contents, result in sticky properties for high moisture iron ores, which impact negatively on the screening performance.

The ECS screening media was a standard wire mesh with 25 mm aperture, which was the largest aperture used throughout this work. Fig. 6 shows the screenability results for Case D as a function of moisture. The Case A curve was also plotted for comparison.

The behaviour of the Case D sample was significantly different from the Case A sample, as shown in Fig. 6. Up to 6% moisture Case D screenability was extremely high, as expected for such a relatively large aperture size. However, from 7% moisture onwards the screenability value was reduced dramatically, achieving the critical value at 8% moisture.

Such a result was interpreted as increasing goethite adherence forces, thus reducing the screening performance.

Case E testing was carried out with a very friable itabirite, from Minas Gerais state. Such an ore was chosen due to its unusually low bulk density, high porosity and absence of hydrated minerals.

The selected media was a wire mesh with 12.0 mm aperture. Fig. 7 shows the screenability curve for Case E as a function of moisture. The Case B curve was also plotted for comparison.

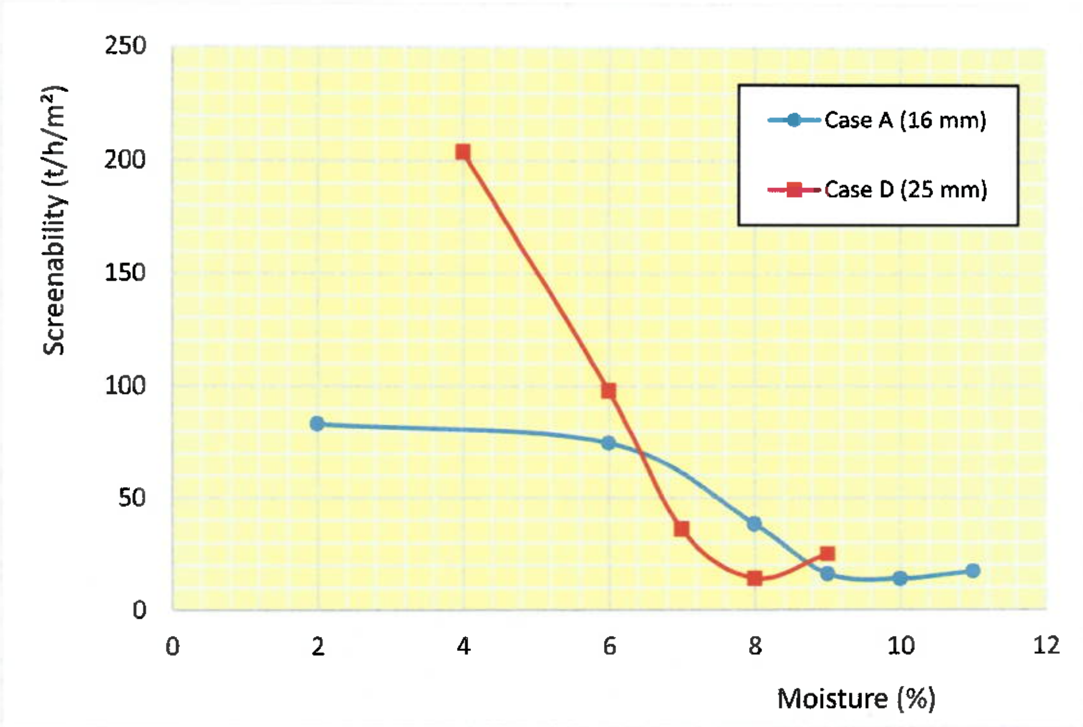

Fig. 6. Screenability as a function of moisture for Cases A and D.

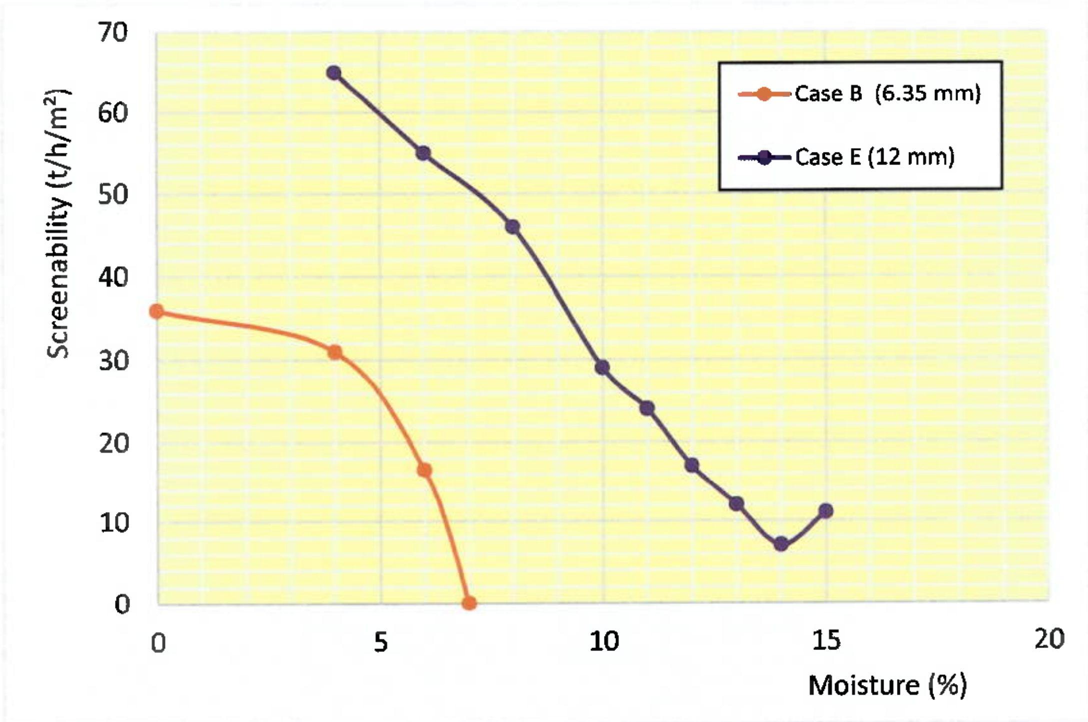

Fig. 7. Screenability as a function of moisture for Cases B and E.

It was noted that up to 8% moisture Case E screenability was very easy, with values higher than 40 t/h/m². Even with 11% moisture, the screenability was satisfactory. In contrast, Case B screenability was impractical for 8% moisture.

The high Case E critical moisture was interpreted as a function of three main factors: (a) high proportion of fines in the feed and (b) high porosity, increasing the water absorption capability and (c) the absence of hydrated minerals, minimising the adherence effect.

SCREENABILITY COMPARISONS—ECS VERSUS ALLIS-CHALMERS METHOD

The screenability results obtained from the experimental tests were compared to the screenability calculated using the Allis-Chalmers method, the latter being the most traditional screen design technique used.

According to the Allis-Chalmers method the required screen surface area (A) is calculated with the following formulas:

$$A = \frac{T}{Cn} = C \times M \times K \times Qn$$

where:

- A = screen surface area required, in ft²;
- T = screen deck feed, in st/h;
- Cn = screen feed specific flowrate of solids, in st/h/ft².

Cn is calculated as follows:

$$Cn = C \times M \times K \times Qn$$

- Factor C is an empirical value of the amount of feed in tons per hour one square foot of screen surface can handle for different size open separations. It is based on a feed containing 25% oversize and 40% passing holes half the size of the opening.
- M is the factor for retained material.
- K is the factor for % of the particles passing in half aperture in the feed material.
- Qn (Q) is a correction factor, resulting from the multiplication of product between Q1, Q2, Q3, Q4, Q5, and Q6. (Allis Chalmers Theory, 1953).

Comparison of Typical Iron Ores—Cases A, B, and C

The Cn, or **calculated screenability,** is the product of factors: C, M, K, and Qn. For Case A, the factor values were determined as:

- Factor C = 4.4 st/h/ft²
- Factor M = 0.95
- Factor K = 1.83
- Q1 = 1.56; average bulk density of 156 lb/ft³
- Q2 = 1.0; square opening
- Q3 = 0.9; slabby elongated
- Q4 = 1.0; 50% open area
- Q5 = 1.0; dry screening
- Q6 = 1.0 up to 3%, 0.85 up to 6%, and 0.75 up to 9% moisture.

The screenability (Cn) value for Case A was calculated by multiplying C, M, K, Q1, Q2, Q3, Q4, Q5 and Q6, resulting in 10.7 st/h/ft² for 3% moisture (Q6 = 1.0). The experimental result converted to mt/h/m² was 10.7 × 9.78 = 104 t/h/m².

For 6% moisture, the Cn value was reduced to 89 mt/h/m² resulting from a Q6 value equal to 0.85. For 9% moisture and Q6 value of 0.75, the Cn was 78.5 mt/h/m². Fig. 8 shows the comparison between experimental and calculated screenabilities. Fig. 9 indicates similar trends between calculated and experimental results up to 6% moisture, diverging for higher moisture levels.

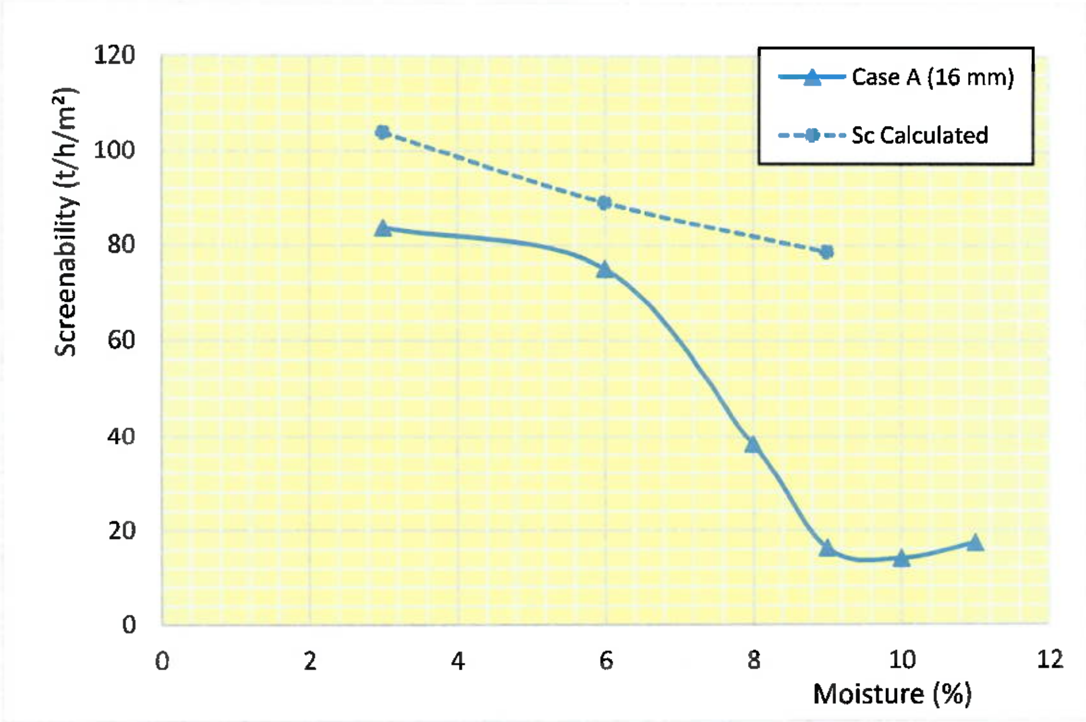

Fig. 8. Case A experimental screenability versus calculated by Allis-Chalmers method.

The same comparison was conducted for samples of Cases B and C. Fig. 9 shows experimental results versus calculated by the Allis-Chalmers method. Dotted lines were obtained for 3%, 6% and 9% moisture levels as resulting from calculations based on the Allis-Chalmers method.

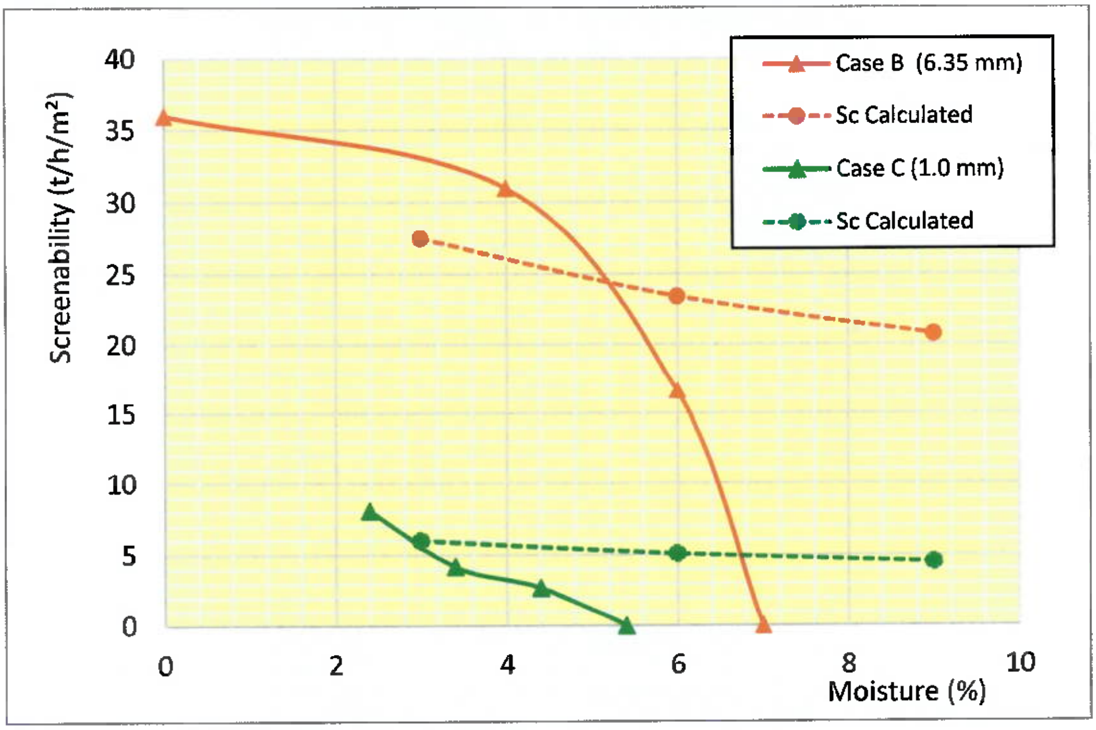

Fig. 9. Cases B and C experimental versus calculated screenability.

In general, the Allis-Chalmers screening sizing method resulted in reasonable correlation only with experimental data obtained for very low moistures, up to 3%. The experimental screenability results for medium and high moistures showed virtually no correlation, especially for Case C, which was carried out with the smallest aperture size.

The Allis-Chalmers method resulted in overestimated screenability for moistures higher than 7% in both cases, 6.3 mm and 1.0 mm. Such results may negatively affect industrial screen designing.

Comparison of Atypical Iron Ores—Cases D and E

The Case D iron ore sample showed a significant amount of goethite. Fig. 10 shows Case D experimental versus calculated screenability by the Allis-Chalmers method.

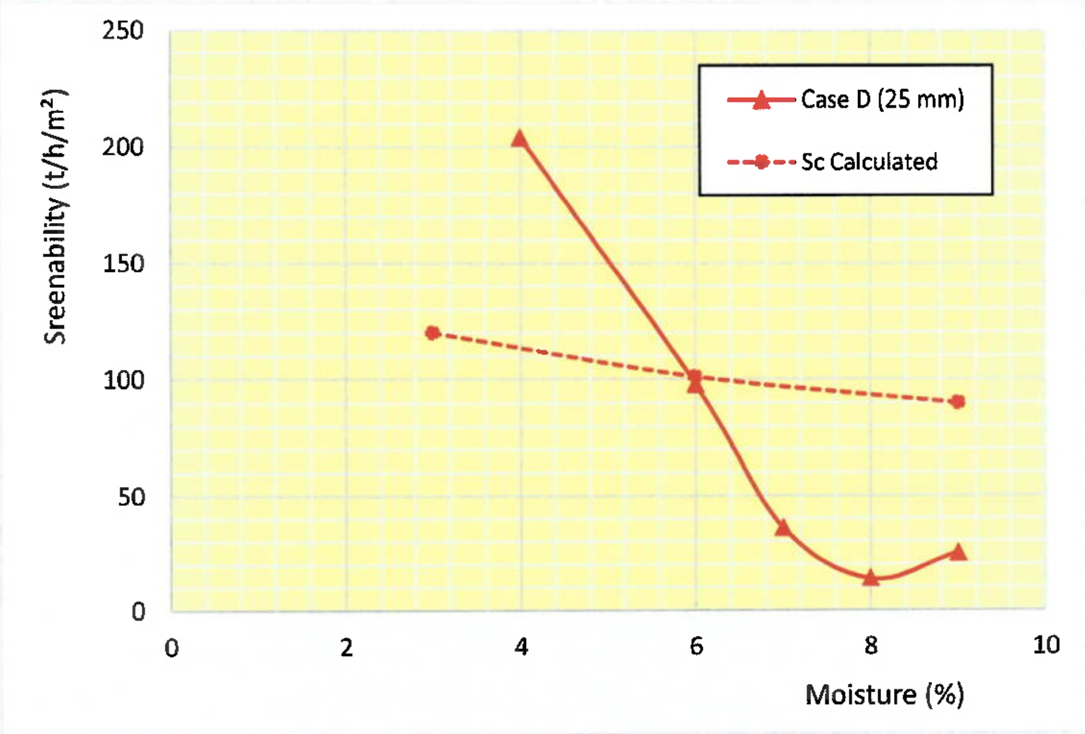

Fig. 10. Case D experimental versus calculated screenability.

The ECS results showed a relatively wide screenability range as compared with the Allis-Chalmers method results for highly hydrated content ores, as indicated in Fig. 11. Accordingly, the Allis-Chalmers method underestimated screenability for moistures smaller than 6%, while overestimated such an index for moistures higher than 6%.

The iron ore sample of Case E showed low bulk density, high porosity and absence of hydrated minerals. Fig. 11 shows experimental versus calculated screenability by the Allis-Chalmers method.

Very close values for both the Allis-Chalmers method and ECS experimental results for moistures lower than 6% were observed. However, due to its intrinsic limitations, no screenability was estimated by the Allis-Chalmers method for moisture levels higher than 9%. The 14% moisture level in particular shows a critical level, as obtained from ECS testing.

CONCLUSIONS

The screening performance for five different iron ore types has been assessed using the Endless Circular Screen testing device. The experimental results with different screen aperture sizes and moisture conditions were analysed and compared among each other. Furthermore, the testing results were compared with calculations conducted according to the traditional Allis-Chalmers screening sizing method, still largely used in the mining industry.

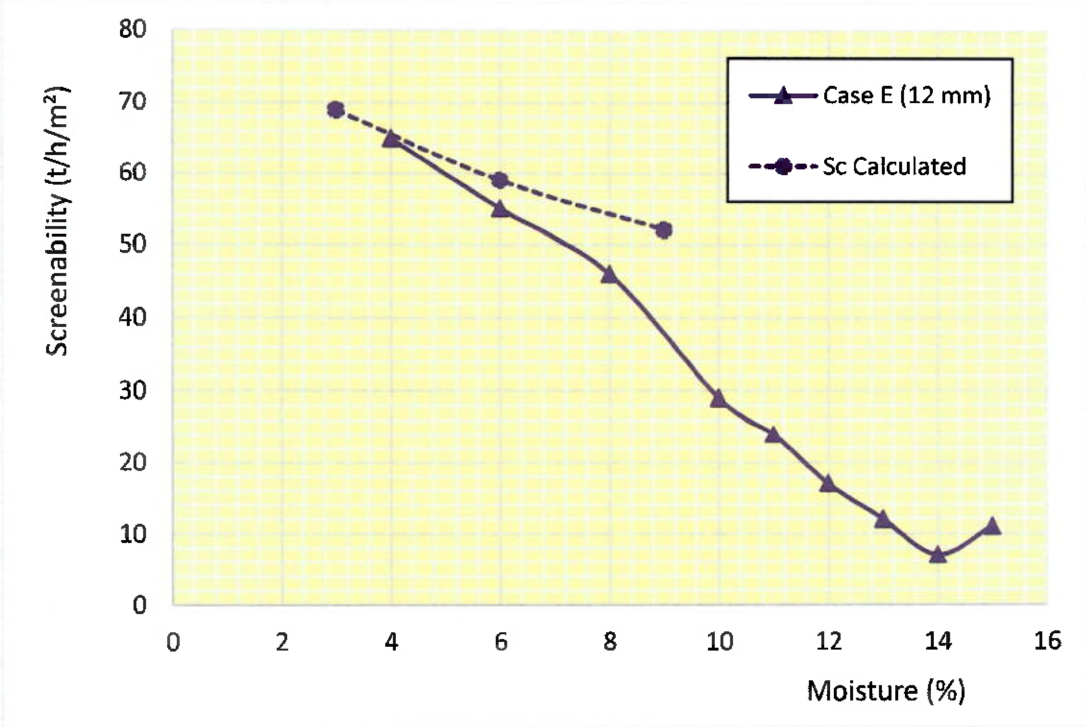

Fig. 11. Case E experimental versus calculated screenability.

The calculated screenabilities obtained from the selected traditional empirical screen sizing method were significantly different from the ECS testing results, especially for high moisture iron ore samples. Significant content in hydrated minerals resulted in sticky ores, which showed even higher deviations from ECS testing results, as compared with the selected Allis-Chalmers method.

The ECS testing method was successful in predicting critical moisture levels for various iron ore types, which reduces the risks associated with designing industrial screens for such applications.

The results obtained from ECS testing are considered very useful for conceptual level projects, where there is little information on ore properties and scarce sample availability. The ECS test can be also an important tool for optimization projects, mainly when ore properties change, or optimisation exercises are required in existing screening processes.

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