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Some basic factors affecting screen performance in horizontal vibrating screens

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ABSTRACT

The objective of this work is the study of some basic factors affecting the performance of the horizontal vibrating screens, with the emphasis based on the determination of the most effective operating conditions for which the maximum screening efficiency can be achieved. The parameters examined were the intensity of vibration, the percentages of the characteristic size fractions in the feed, the screen length and the screen aperture in conjunction with the other parameters. It is found that the screening efficiency is an exponential function of the screen length and can also be correlated to the intensity of vibration. It is also established that the amount of the critical size-fractions (critical undersize and oversize) affect significantly the screen performance. The impact of each critical size-fraction is different for the various screen apertures but it may also depend on the non-identical shape characteristics (observed during the preparation process of the feed material but not examined here) of the corresponding particles contained in the feed for the various apertures used. © 2001 SDU. All rights reserved.

Keywords: Screening; Sizing; Particle size; Modelling

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1. INTRODUCTION

1.1. Earlier experimental work

Significant experimental work, referred to the screening process, has been so far performed. Many researchers (Brereton and Dymot, 1973; Rose and English, 1973; English, 1974; Ferrara and Preti, 1975; Rose, 1977; De Pretis et al., 1977; Apling, 1983; and Ferrara et al., 1988) have conducted systematic experimental work on this field.

Many attempts have been made in the past to express quantitatively the screening performance. Mathematically the screening process was considered to be effectively represented by either a probabilistic or a kinetic approach (Kelly and Spottiswood, 1982).

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In most of these studies the first-order mode of the process was used. Some researchers (Brereton and Dymot, 1973; Ferrara and Preti, 1975) showed that in screening two distinct processes take place (a zero-order process or more simple "crowded screening" near the feed end and a first-order process with separate or disperse conditions in the remainder part).

They proposed two systems of equations depicting the screening kinetics using two kinetic constants k_i and s_i for the two regions, respectively. De Pretis et al. (1977) confirmed the adequacy of the above proposed screening kinetic constants and introduced two new constants k_{50} and σ. These new constants refer to the kind of the screen and are independent of the feed size distribution. De Pretis et al. (1977) validated the approach developed in the work of Ferrara and Preti (1975), made some improvement on the solution of the model and studied the influence of some operating conditions on the screen performance.

In their book, Kelly and Spottiswood (1982) introduced another first-order process corresponding to the stratification phenomenon, taking place before the "high-rate" undersize passage begins. Subasinghe et al. (1990) proposed also two first-order processes describing the three-region behavior shown in Figure 1.

In some of these works (Rose and English, 1973; Rose, 1977; Apling, 1983), the effect of "blinding" factor (critical size or near mesh material) on screening efficiency was also studied and it was also proposed (Rose and English, 1973) a model describing the whole process.

1.2. Factors affecting screen performance

From the bibliography it arises that the screen performance is affected by the following factors:

a. The size and shape of the screen aperture
b. The relative particle size and shape of the feed material related to the aperture
c. The percentage of the critical size material, also called difficult grains or near mesh particles, in the feed
d. The amount of moisture of the material fed to the screen
e. The percentage of the open-area of the screen deck
f. The velocity of the screen and the angle of approach of the particles to the screen deck
g. The inclination of the screen
h. The intensity of the vibration (frequency and amplitude)
i. The feed rate of the material to the screen
j. The screen length

For some of the factors examined here, it was already known that; the intensity of the vibration affects the effectiveness of the screening process as follows:

- Causes stratification of the material traveling on the screen surface (the fines are presented close to the mesh wire, while the greater particles are over them). This phenomenon resembles the segregation process and is called trickle stratification.
- Affects the movement (fluidization) of the particles on the screen. The particles appear being in a loose state.

- The intensity of the vibration determines also the number of contacts between the particle and the screen surface (Wills, 1988). A high number of passing attempts increases the probability of passage of one particle. The number of contacts is also closely related to the feed rate.
- In the horizontal vibrating screens the material movement is largely affected by the mechanism producing the vibration.
- The open area of the screen surface, which is significantly dependent on the intensity of vibration, decreases when a large amount of near mesh material occurs in the feed. This decrease causes a progressive reduction of the screen efficiency with the advance of the process.
- The relationship between screen length and screen performance had been also studied. Taggart (1954) explained the increase of the screen efficiency following the increase of the screen length as due to the adequate (long) residence time of the material on the screen deck.
- It has been pointed out that the screen efficiency increases at very high rate near the feed end (Taggart, 1954; Stamboltzis, 1987; Stephens-Adamson; Tarjan, 1981; Tsakalakis, 1988). It has also been observed that for short screens, increasing the screen length results in a significant increase in the efficiency, while this increase is negligible for already long screens.
- Regarding the amount of the critical size in feed, the following can be said: Warner (1924) and Pryor (1960) have claimed that the amount of critical size in the feed plays a decisive role on the screen performance.

It has been shown that the “near mesh” particles “blind” the screen apertures and roughen the screen surface causing a decrease in the traveling velocity of the material over the screen. This phenomenon is more intensive for the horizontal vibrating screens because, if the particle weight (vertical force) was analyzed into two forces (one vertical vector and one horizontal vector), the horizontal component (causing the particle motion over the screen) completely lacks.

The particles causing the blinding effect have a maximum mean size $d_m \approx 1.1a$, where a is the screen aperture.

The particles of size d where $0.71a<d<a$, have a very slow passing rate through the screen aperture, but Apling (1983) showed that sub-sieve sized (critical undersize) particles may, singly or in combination with others, cause the blinding of the aperture. Particles greater than 1.41a are considered to have a positive effect on the screen performance.

Particles smaller than 0.71a can easily pass through the loose layer and approach the screen contributing to the increased passing rate of the undersize in the initial length.

2. EXPERIMENTAL WORK

In our work, some of these factors (most applied to inclined screens), were examined for its effect on the horizontal vibrating screens-performance, for which limited data were known to us. We made an effort to determine the most proper operating conditions of these screens using a relative “difficult”, from the particle-shape point of view material (crushed quartz) and to reveal the effect of the feed characteristics on the screening efficiency for the horizontal screens.

The experiments were carried out in an experimental arrangement, which consists of:

- A horizontal vibrating screen with wire screening surface 1.0m long and 0.25m wide.
- A vibration mechanism with two counter-rotating shafts, equipped with adjustable eccentric weights for the regulation of the vibration amplitude.
- An electric three-phase motor with belt-drive system for changing the rotational speed (rpm) of the vibration mechanism.
- A silo of 0.15m^3 capacity.
- A rotary drum-type feeder.
- A collector for the passing material, divided into ten departments (each 10cm long).
- Four different screen surfaces with square apertures (openings) of 4.0mm, 2.0mm, 1.0mm and 0.6mm, respectively.

Crushed quartz, with angular and in many cases elongated particles, was used as feed material. The feed material was different for each screen aperture. The feed characteristics for each screen surface and aperture are given in Table 1. The moisture content of the feed was lower than 5%.

Table 1
Size-fraction content in screen feed

Screen aperture a mm	Critical size, %			Oversize in feed, %		Halfsize material % h	Size fraction (0.5a<d<0.71a) % k
	Total c	Undersize c_u	Oversize c_p	Total p	$p-c_p$		
4.0	32.81	18.89	13.92	26.94	13.02	45.52	8.65
2.0	35.89	19.04	16.85	21.75	4.90	52.98	6.23
1.0	49.89	40.99	8.90	18.62	9.72	19.23	21.16
0.6	51.53	24.74	26.79	45.37	18.58	12.96	16.93

The particle shape of the particles in the various size fractions used was not examined as a variable, regardless of being macroscopically noticed (during the preparation of the various feeds) that it was different.

The feed rate was constant for the tests of the same aperture, but varied from 11g.s^{-1}.cm^{-1} (aperture 4.0mm) to 3g.s^{-1}.cm^{-1} (aperture 0.6mm).

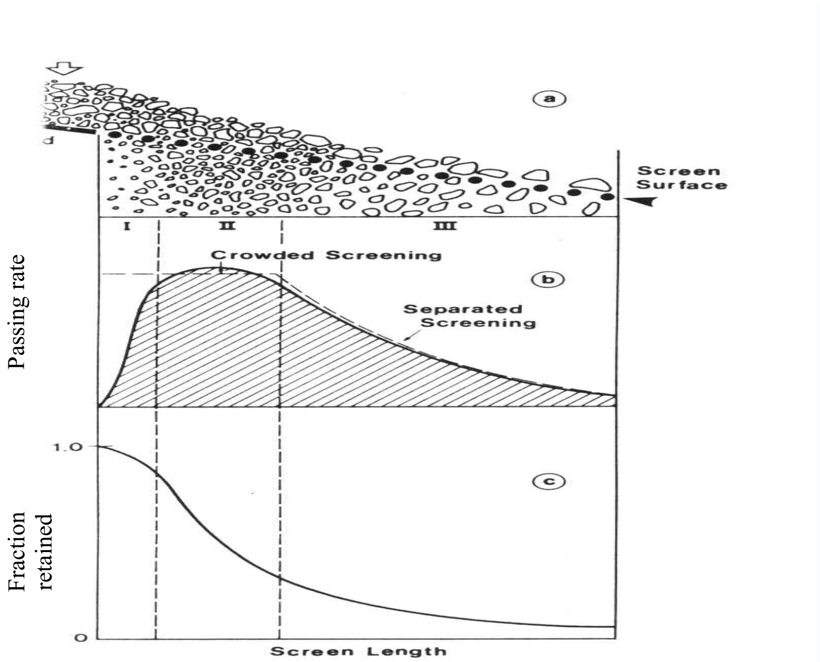
The characteristic size-fractions of the screen feed are shown in Figure 2 and the feed used is given in Table 1.

The passing material reported to each department of the collector was sized in various size-fractions.

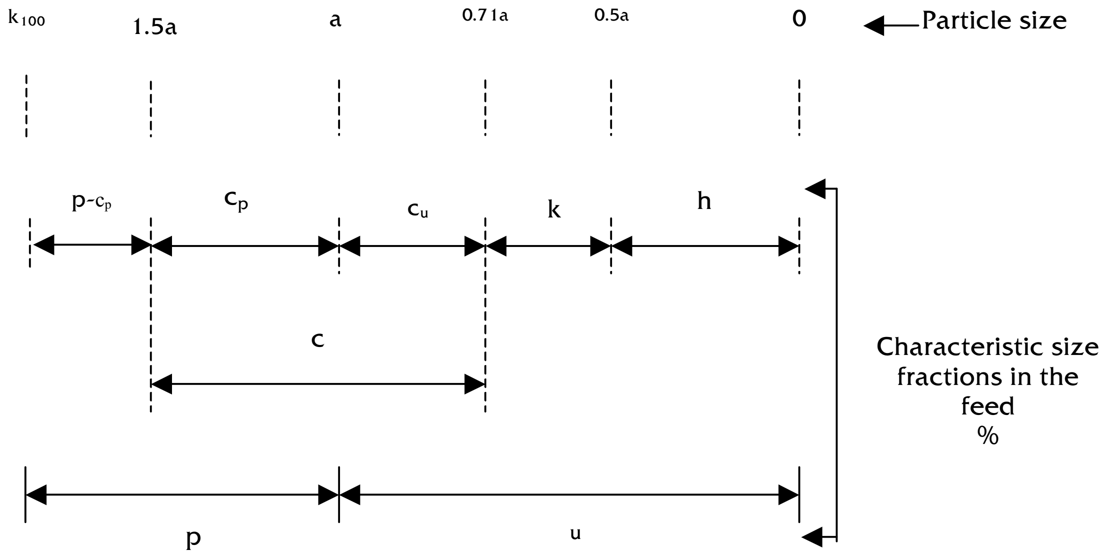
The study was focused on the basic factors that affect screening efficiency E (cumulative undersize recovery), under constant feed rate for each screen aperture.

The factors examined here were:

- The intensity of vibration ($2\varepsilon\nu$), where 2ε and ν are the amplitude and the frequency of the vibration, respectively.
- The percentages of the characteristic size-fractions (critical size, critical undersize and oversize, half-size and oversize material) in the feed.
- The screen length L.
- The size of the screen aperture a in conjunction with the above mentioned factors.



Figue 1. The three major regions occurring along a screen, (a) their relationship to the rate of passage (b) and the fraction retained on the screen surface (c) after Kelly and Spottishwood (1982)



where p feed oversize, u feed undersize, c critical size, c $_p$ critical oversize, c $_u$ critical undersize, h halfsize material,
k undersize material with particle size d (0.5a<d<0.71a), a screen aperture and k $_{100}$ maximum particle size.

Figure 2. Characteristic size fractions in the screen feed

Forty different tests were carried out, ten for each screen aperture used. During these tests the vibration frequency v and the vibration amplitude (2ε) were modified in order to change the vibration conditions of the screen.

3. RESULTS AND DISCUSSION

From the whole experimental work the following results were come up:

The relationship between screening efficiency E (cumulative undersize recovery) and screen length L is an exponential curve of the form shown in Figure 3.

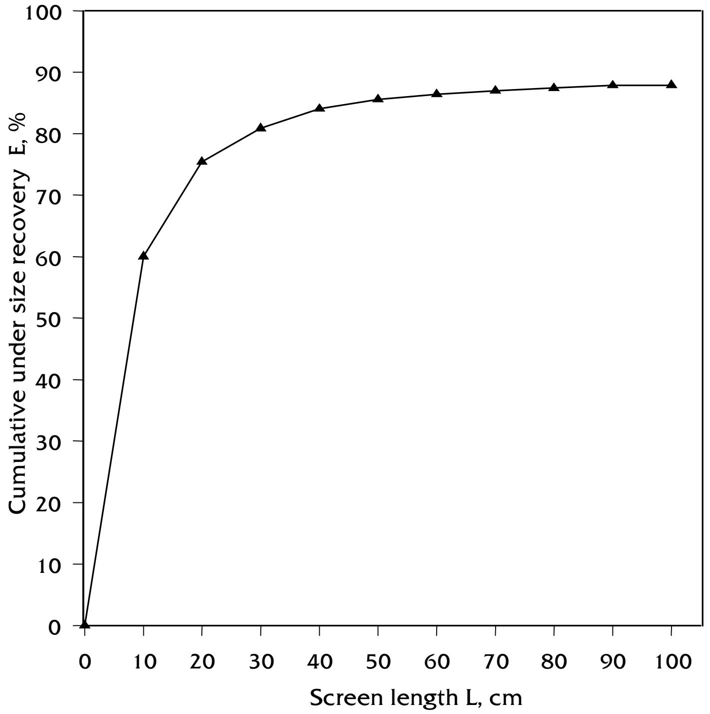


Figure 3. Experimental cumulative undersize recovery E versus screen length L

By the trial and error method various exponential functions were tested and it was shown that the curve in Figure 3 is given by

$$E = 1 - e^{-\frac{L}{A \cdot L + B}} \quad , \qquad (0 < E \leq 1) \qquad (1)$$

where E is the fraction of screening efficiency (cumulative undersize recovery), L is the screen length and A and B parameters (B>0) depending on the screen aperture a and the intensity of vibration (2ε.v).

The function given in Eq. (1) goes asymptotically to the value E=100% (1 as fraction) for L→∞, while for L=0 E=0% (zero undersize recovery).

In our tests it was observed that almost over 50% of the undersize material passes having traveled only ¼ of the whole screen length (Figures 5, 9 and 10).

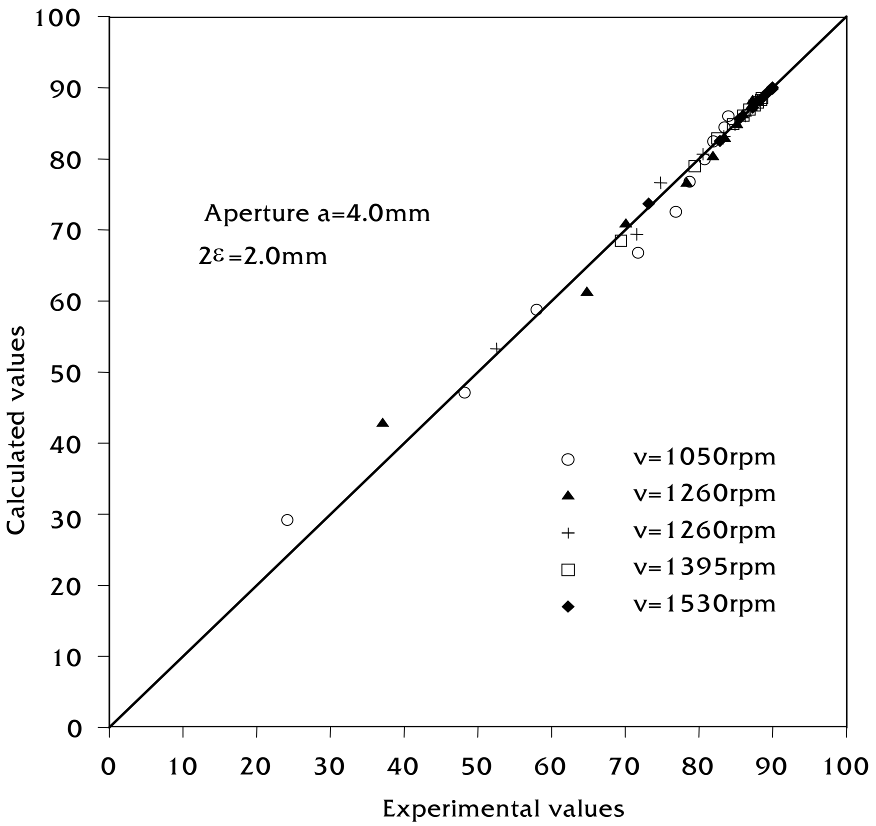


Figure 4. Experimental versus calculated values of undersize recovery % for various vibration intensities

Figure 4 shows that eq.1 correlates very well the experimental with the calculated values of the cumulative undersize recovery for the screen aperture a=4.0mm. The same equation was also found to describe very well the relationship between the E and L for the other screen apertures (2.0, 1.0 and 0.6mm) used in the experimental work.

Figure 5 shows corresponding results for a screen aperture a=4.0mm, where eq. 1 has been used to calculate the cumulative undersize recovery for various vibration intensities, under constant amplitude of vibration 2ε=2.0mm. In these tests, the frequency of vibration v was varying. The comparison between experimental and calculated values of the tests given in Figure 5 has already been shown in Figure 4.

From the graphs in Figure 5 it is clear that an increase in the vibration intensity causes a similar behavior (increase) on the passing rate of the undersize material. The increased passing rate is due to the high fluidization of the bed (material on the screen surface), which permits the fine material to pass through the voids produced from the increase in the frequency of vibration.

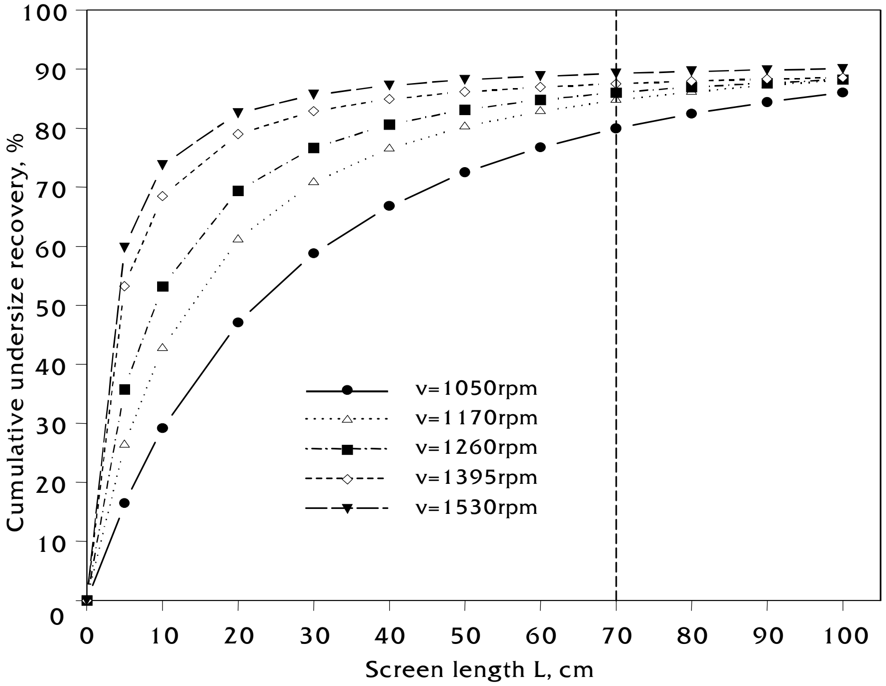


Figure 5. Calculated cumulative undersize recovery as a function of screen length for various vibration frequencies (test with screen aperture a=4.0 mm and vibration amplitude 2ε=2.0mm)

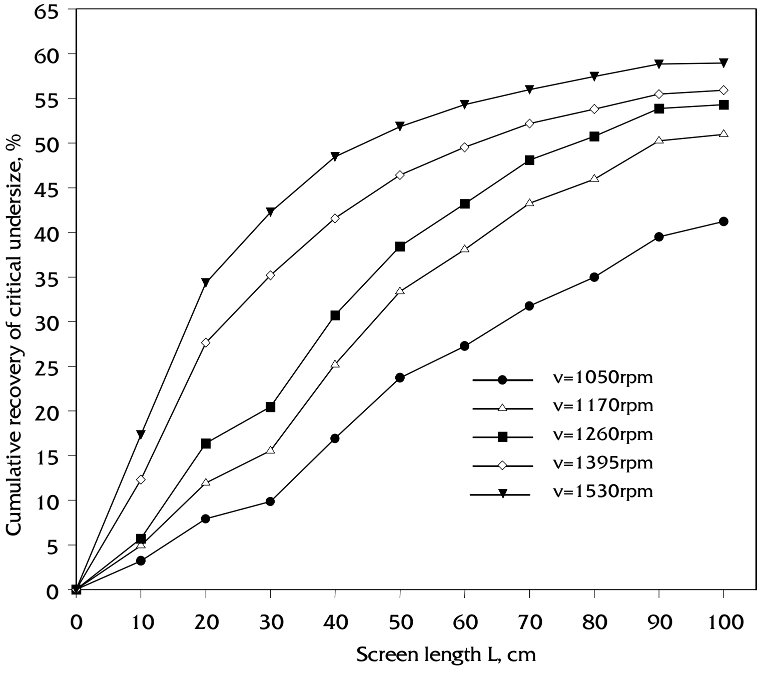


Figure 6. Experimental values of critical undersize recovery as a function of screen length (tests with aperture a=4.0mm and vibration amplitude 2ε=2.0mm at various vibration frequencies)

This behavior can be interpreted observing Figure 6, which gives the critical undersize recovery as a function of the screen length. From Figure 6 it is noted that an increase in the vibration frequency contributes to the increased recovery of critical undersize particles, which is the result of the greater number of contacts between particles and screen surface.

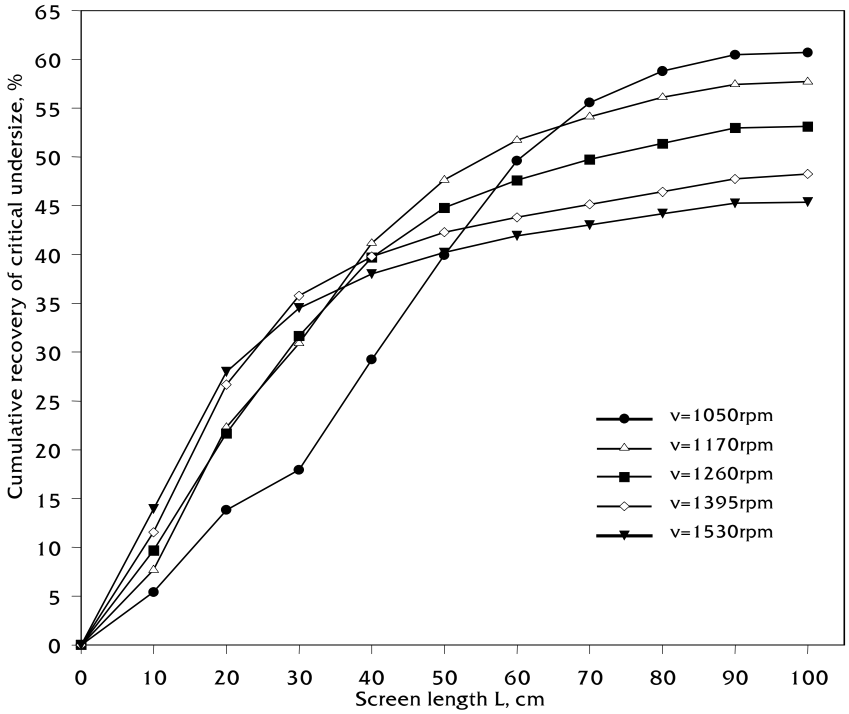


Figure 7. Experimental values of critical undersize recovery as a function of screen length (tests with aperture a=4.0mm and vibration amplitude 2ε=2.0mm at various vibration frequencies)

Figure 7 shows the critical undersize recovery for the same vibration frequencies as before, but for a double vibration amplitude (2ε=4.0mm). It can be pointed out that, increasing (through the frequency) the vibration intensity, an increase in the undersize passing rate occurs until L=40cm. After that point, which probably is the limit between crowded and separated region (transition point), a reverse behavior starts taking place. This is due to the fact that intensive vibration conditions do not give enough time to the particles being in contact with or coming close to the mesh wire to pass through.

The above observation is also evident in Figure 8, in which the cumulative undersize and critical undersize recovery are plotted against vibration intensity. The region between 3100 and 4200mm.cm^{-1} in the x-axis (vibration intensity) is probably more effective for screening with screen aperture a=4.0mm. It is expected that a combination of a vibration amplitude 2ε=3.0mm and vibration frequency v=1150rpm (vibration intensity 2ε.v=3450mm.cm^{-1}) may give higher screening efficiency than those observed under the experimental conditions.

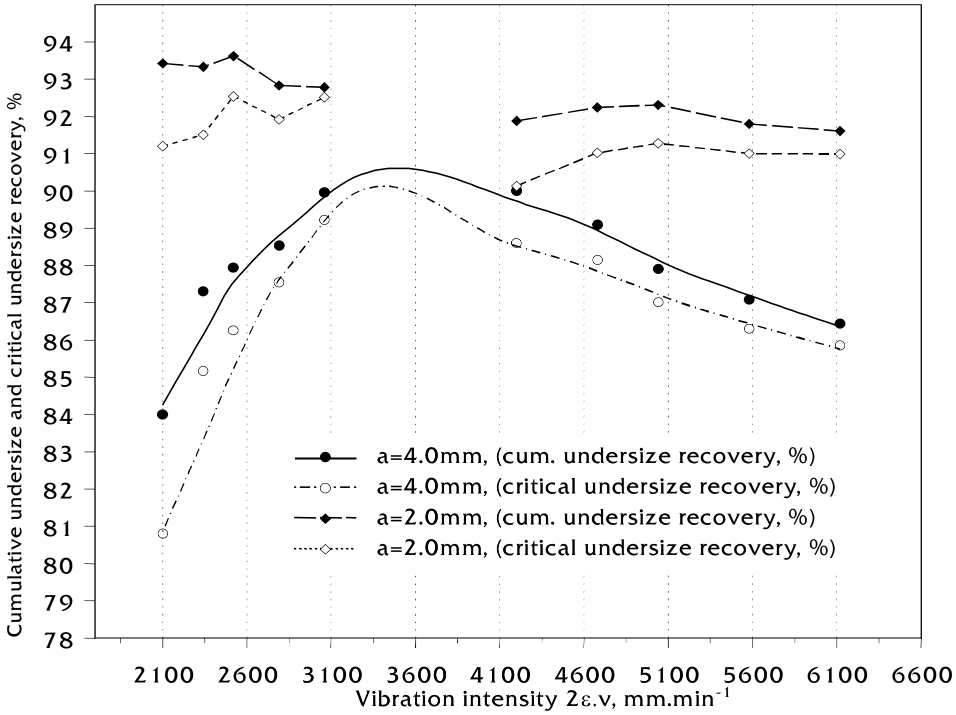


Figure 8. Experimental cumulative undersize and critical undersize recovery as a function of vibration intensity for screen apertures 4.0mm and 2.0mm

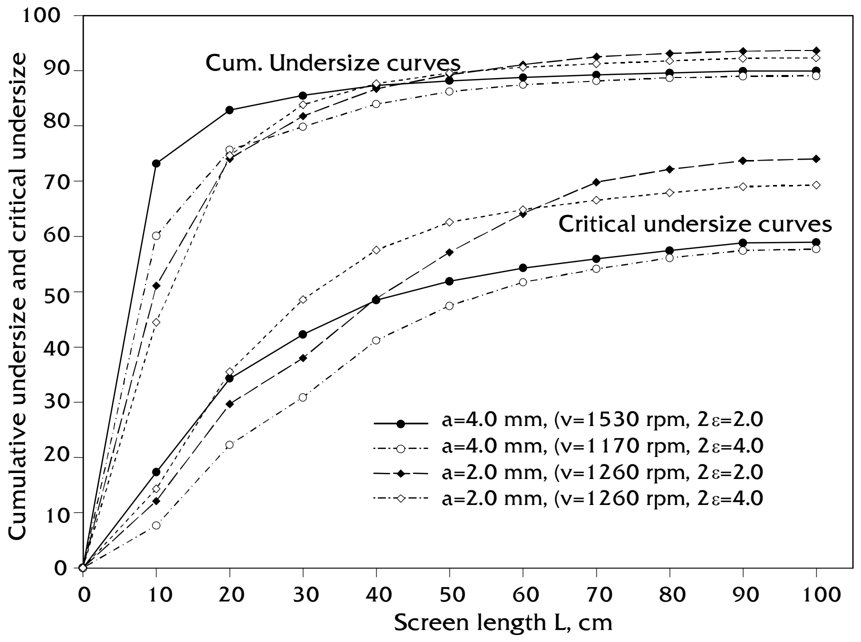


Figure 9. Experimental cumulative undersize and critical undersize recovery versus screen length for the best tests (highest recoveries) referred to screen apertures 4.0mm, 2.0mm

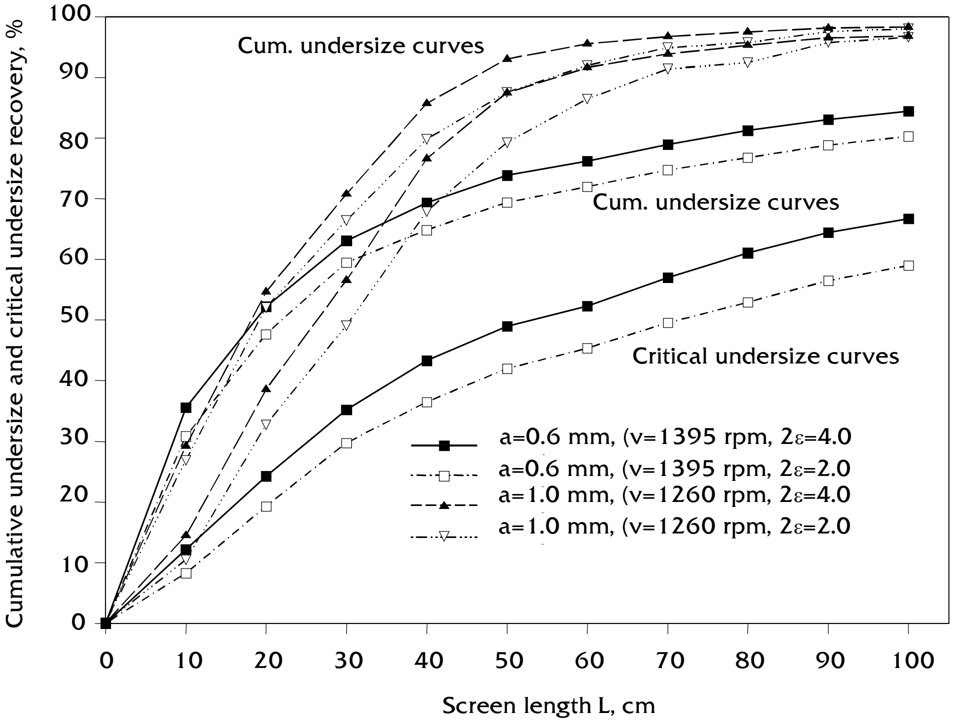


Figure 10. Experimental cumulative undersize and critical undersize recovery versus screen length for the best tests (highest recoveries) referred to screen apertures 1.0mm, 0.6mm

Figures 9 and 10 show the most efficient tests (highest undersize recoveries) for all apertures (4.0, 2.0, 1.0 and 0.6mm) used in the experimental work and for different vibration conditions. It can be easily pointed out that, the highest cumulative undersize recoveries always occur at the 1260rpm for a=2.0 and 1.0mm and at 1395 for a=0.6mm. For screen aperture a=4.0mm (Figure 9), a proper combination between amplitude and frequency is necessary for the most effective operation of the screen. A combination of high vibration amplitude (2ε=4.0mm) and low vibration frequency (1170rpm) produces the same result as that of low vibration amplitude (2ε=2.0mm) and high vibration frequency (1530rpm).

From Figures 9 and 10 it can be pointed out that the critical undersize percentage recovered during the screening process varies for different screen apertures. The percentage of the recovered undersize feed content depends on various parameters except those for operational conditions of the screen. It certainly depends also on the screen feed characteristics. Table 1 contains the characteristics of the feed used in the tests. The critical size percentage of the feed used for screen apertures a=1.0 and 0.6mm was approximately the same (≅50%), but the recovered percentage (L=70cm) was 75-80% and 45-50%, respectively (Figure 10). The significant difference observed is due to the increased critical oversize content (≅27%) of the 0.6mm feed against the 9% of the 1.0mm feed (Table 1). It could be said that the critical oversize feed content is more important for the screening efficiency than the critical undersize content.

A slight difference (≅2-3%) is observed in the undersize recoveries between 4.0 and 2.0mm apertures for screen length to width ratio higher than 2.8 (70/25). It would be expected that, due to the favorable feed contents (critical undersize and oversize) of the 4.0mm over the 2.0mm feed (Table 1), the recovery for 4.0mm aperture would be higher than that of 2.0mm. But, during the preparation process of the different feed material for the various screen apertures, it was observed that the particles in the 4.0mm feed (particle size -9.5mm) were angular and elongated, which probably makes more difficult the screening process for this screen surface (a= 4.0mm).

4. CONCLUSIONS

From the experimental work most of the conclusions initially referred were confirmed for the horizontal vibrating screens and it was also shown that:

- The screening efficiency E (cumulative undersize recovery) increases asymptotically with the screen length L and the relationship between them was found to be:

$$E = 1 - e^{-\frac{L}{A \cdot L + B}} \quad , \qquad (0 < E \leq 1)$$

where A and B parameters (B>0) depending on the screen aperture a and the intensity of vibration (2εv).

- Increasing the intensity of vibration, the screening efficiency E increases for screen length less than L/2.
- For screen apertures 2.0mm (feed size -4.0mm), 1.0mm (feed size -2.36mm) and 0.6mm (feed size -1.4mm) the most important factor determining the efficiency E is the vibration frequency v, while for the screen aperture of 4.0mm (feed size -9.5mm), the most important factors are the frequency and also the amplitude (2ε).
- The percentage of the critical oversize (particles of size a<d<1.41a) in the feed is more important for the efficiency E than that of the critical undersize (0.71a<d<a).

The results of this work have to be evaluated using other materials presenting more “difficult” characteristics (higher moisture content, flat particles etc.) in order to be evaluated the applicability of the above discussed findings.

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