THE ROLE OF SCREEN SELECTION ON MEDIUM RECOVERY

J .Bosman

Principal Consultant - PESCO

L. Mackay

Process Consultant

K. Schoepflin

C.E.O. - Kwatani

ABSTRACT

Since the 1950s, when Dutch State Mines (DSM) licensed their dense medium design technology, screens have been an integral part of medium recovery in dense medium circuits. The DSM design incorporated sieve bends and drain and rinse screens. This technology is well defined, proven and accepted in practice.

Research and innovation over the years has progressively resulted in changes to the original DSM designs. These include, amongst others, using polyurethane instead of wedge wire, replacing sieve bends with static panels, eliminating sieve bends and static panels altogether and using multi-slope screens in place of horizontal screens.

The positive and negative impacts of these changes on plant design, plant operation and medium recovery will be discussed. Design criteria to ensure that medium losses for the various screening options are kept to a minimum will also be discussed.

Keywords: dense medium separation, magnetite, screens, sieve bends, multi-slope screens, drain and rinse screens

INTRODUCTION

The development of the dense medium cyclone took place during World War 2 at the laboratories of the Dutch State Mines (DSM). The first plant was described by MG Driessen in 1945 and was a 13.6 t/h pilot plant. After the war this new technology was soon transferred to the USA and was further developed by the US Bureau of Mines. The types of coals being treated in the USA at that time were able to be processed in simple operations, which resulted in the technology only being commercialised in 1961. As the coal industry boomed in the 1970s, Utah Development Company introduced DMS cyclone technology to the coal producing countries around the world.

OVERVIEW OF MAGNETITE LOSSES IN DENSE MEDIUM CIRCUITS

Typical Flowsheet Description

A typical simplified flowsheet for a dense medium cyclone system depicting the essential equipment items in the circuit is illustrated in Figure 1.

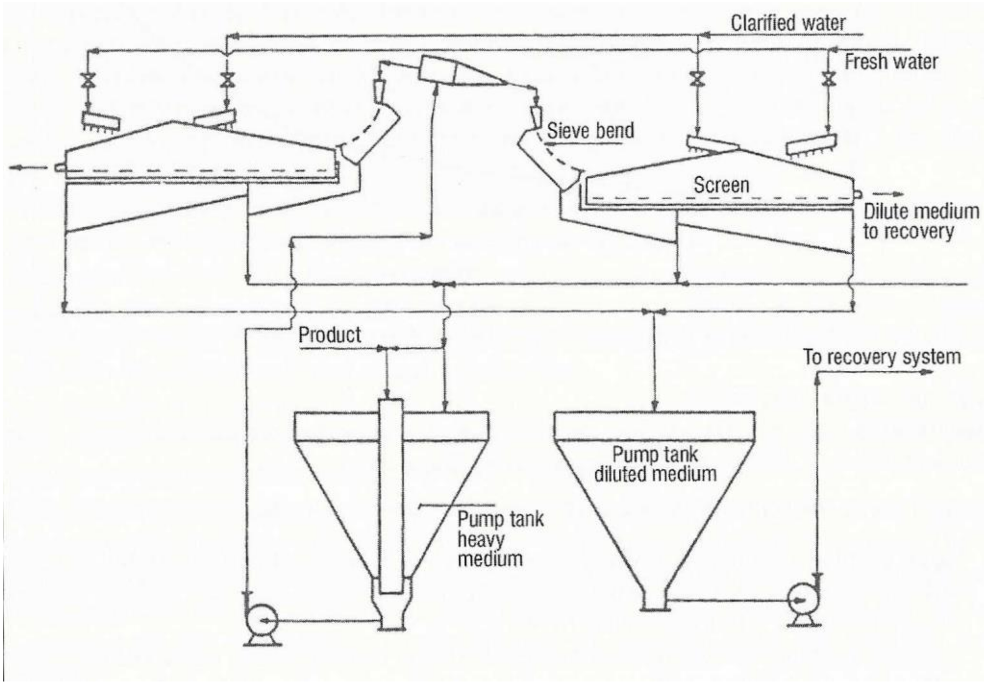

Figure 1: Typical Pump Fed Cyclone Dense Medium Circuit

Pre-sized raw coal (-50 x 0 mm) is mixed with water and passed over a deslime screen to remove the fine material i.e. below 0.5 mm or 1.0 mm in size. The undersize material passes to the fines treatment circuit(s) and the oversize 'deslimed coal' is mixed with the correct medium and pumped to a dense medium cyclone by the cyclone feed sump. The clean coal and approximately 70% of the correct medium report to the overflow of the cyclone and onto the product drain and rinse screen. The rejects and approximately 30% of the correct medium report to the spigot and onto the reject drain and rinse screen.

Most the medium drained from the clean coal and rejects screen is fed back into the correct medium circuit and a small bleed portion is split off to the dilute medium circuit. The dilute medium from the rinsing section of the screens is concentrated by means of wet drum magnetic separators. The overdense returns to the correct medium sump and the magnetic separator effluent streams are either discarded via the tailings thickener or recycled back into the appropriate circuits, i.e. wash water for the deslime screen or spray water on the drain and rinse screens.

The relative density of the recirculated (correct) medium is adjusted automatically with water to give an operating medium of the required relative density.

Dense Medium Recovery

The basic principles of medium recovery are common to all processes and these stages include:

- Recovery of magnetite from the product and reject streams using the drain and rinse screens
- Removal of fine contaminants from the magnetite. Amongst the processes that can be used are densifying cyclones and wet drum magnetic separators

- Concentration of the magnetite in the dilute medium to give a suspension of high relative density (overdense) medium, which is achieved using wet drum magnetic separators
- Controlled mixing of the correct medium, which is a combination of the drain medium and overdense medium with water to achieve the required relative density for the operating medium. This is referred to as a ‘rising density’ system.

OBJECTIVES

In a dense medium circuit, one of the major objectives following the efficient separation of clean coal is to maximize the recovery of magnetite. Under ideal conditions the clean coal and reject would be recovered with no adhering magnetite and all the magnetite would be recovered to the correct medium circuit. The reality is somewhat different and dictates the use of a two-stage process, i.e.

- A stage where the medium can drain from the clean coal and rejects, called the drain stage. The density of the medium is unaffected during this stage and the drained medium can go directly to the correct medium sump. The goal is to recover approximately 95% of the medium being discharged from the cyclone overflow and underflow
- The clean coal and reject coming from this stage are still coated with medium, which is referred to as adhering medium. Water is used to remove the adhering medium and this stage is referred to as the rinse stage. Medium removal is never one hundred percent efficient and some medium still adheres to the clean coal and reject discharging from the screen and is lost. In addition, some of the water used to wash off the medium still adheres to the clean coal and reject. The recovered medium has been diluted with water and is referred to as dilute medium. Its density is too low to be returned to the correct medium sump and the magnetite in the medium is recovered using a wet drum magnetic separator.

DUTCH STATE MINES (DSM)

In the publication “The heavy medium cyclone washery for minerals and coal. Dutch State Mines (DSM) handbook”, (Anon. 1970) that was issued as part of the licensing agreement by Stamicarbon, medium recovery is treated in detail.

Drain Stage

The drain stage consists of a sieve bend and a vibrating screen.

Sieve Bend

The sieve bend (patented in 1957 by F.J. Fontein of the Dutch State Mines) consists of a curved screen with slots which run across the width of the screen. The direction of flow is at right angles to the screen as shown in Figure 2.

Figure 2: Static Sieve Bend

The cut size for a sieve bend is half the aperture size, i.e. a 1 mm slot will have a cut size of 0.5 mm.

Both wedge wire and polyurethane can be used for the screen surface. The wedge wire has the advantage of a greater open area and therefore higher drainage capacity compared to polyurethane. The polyurethane however has better wear resistance resulting in a longer life.

Standard sieve bends have a central angle (ϴ) of 45 degrees. There are two standard radii (R) i.e. 1018 mm and 2036 mm. The arc length for the 1018 mm radius is 800 mm and the arc length for the 2036 mm radius is 1600 mm.

The drainage capacity of a sieve bend is a function of the open area of the screening surface and the arc length. The data published in the DSM handbook for a wedge wire profile of 34sb are shown in Table 1.

Table 1: Standard Sieve Bend Drainage Capacities

	1018 mm Radius	2036 mm Radius
Slot width (aperture) mm	1.0	1.0
Wedge wire profile	34sb	34sb
Bar/Head width (mm)	2.8	2.8
Angle of sieve bend (degrees)	45	45
Radius (mm)	1018	2036
Arc length (mm)	800	1600
Area per m width (m^2)	0.8	1.6
Open area (%)	21.1	21.1
Drainage rate (m^3/h/m width)	90	150
Drainage rate ($m^3/h/m^2$ open area)	533	444

For the same slot width (aperture), the drainage capacity of a polyurethane sieve bend with a continuous slot is estimated to be 60% of that of a wedge wire sieve bend.

The high drainage capacity of a sieve bend is related to the way medium is recovered to the screen undersize as shown in Figure 3.

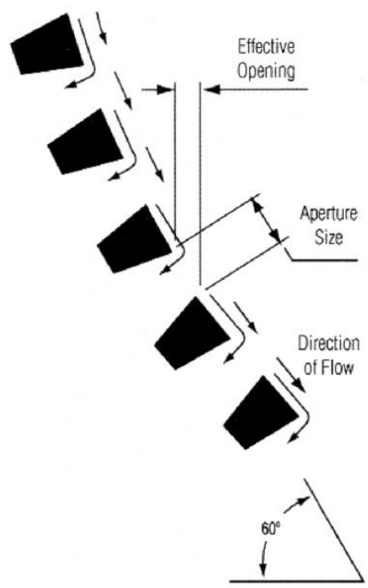

Figure 3: Sieve Bend Operation

As medium flows down the screen, the change in angle due to the curved surface results in the leading edge of the slot ‘cutting’ medium to the undersize. As this is happening, the leading edge becomes worn and blunt and its ability to remove medium to the undersize is impaired. To overcome this, a sieve bend needs to be rotated on a regular basis. When it is rotated, the flow is exposed to a sharp leading edge and the worn slot which was at the top is sharpened due to the surface of the screen wearing. In this manner, the efficiency of undersize removal is maintained by rotation until the slots become too big.

The sieve bend is designed to recover between 80 and 85% of the medium being fed to it.

Vibrating Screen

The specification of the vibrating screen in the handbook is very clear: "*Horizontal vibrating screens with a minimum vertical acceleration factor of 2.5 g and a screen length of 4.8 m; the width of the screen depends upon the tonnage to be handled by it*"

It is important to note that the length of 4.8 m is for the combined drain and rinse sections.

The relationship between vertical acceleration and acceleration in the direction of throw is shown in Figure 4.

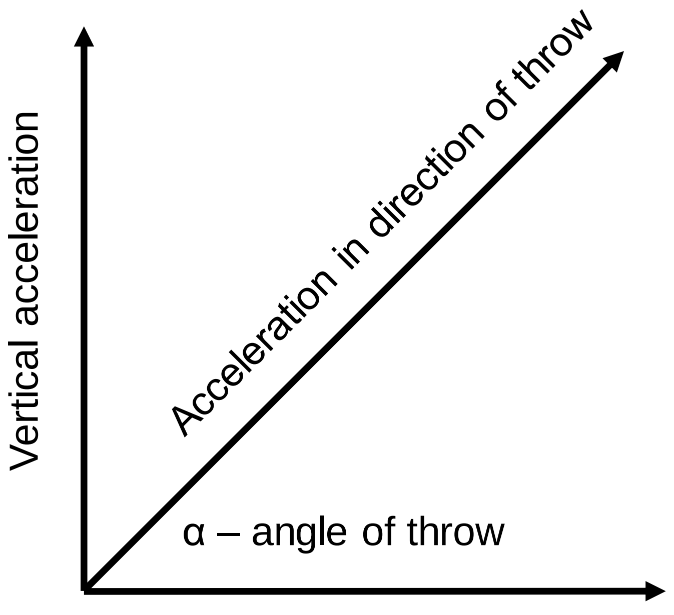

Figure 4: Vertical Acceleration and Angle of Throw

For a throw angle of 45 degrees, a vertical acceleration of 2.5 g corresponds to an acceleration in the direction of throw of 4 g. The formula is:

$$Acceleration\ in\ angle\ of\ throw = \frac{vertical\ acceleration}{sine(throw\ angle)}$$

An acceleration of 5 g in the angle of throw corresponds to a vertical acceleration of 3.5 g.

The following formula is given for calculating the allowable screen load:

$$C = k\sqrt[3]{(d_a^2 \times \rho_{coal}^2)}$$

C – loading (t/h/m width) with a maximum of 80 t/h/m width

k – screen load factor which is equal to 12

d_a – average particle size (mm)

ρ_{coal} – particle density of coal (t/m^3)

The allowable screen load for a coal density of 1 5 t/m^3 as a function of average particle size is shown in Figure 5Figure 1.

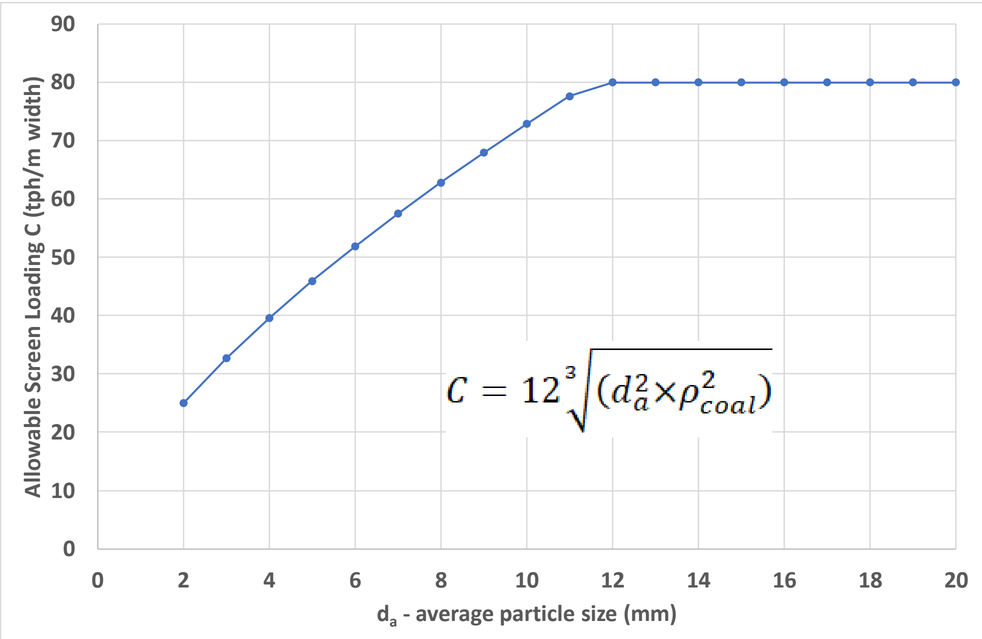

Figure 5: Allowable Screen Loading C

The transport velocity for particles across the screen with weir bars installed is given as 0.15 m/s. In operational plants transport velocities up to 0.3 m/s have been measured.

Bed depth can be calculated using the formula:

$$h = \frac{T}{3.6 \times \rho_{bulk} \times W \times v}$$

h – bed depth (mm)

T – coal tonnage (tph)

ρ_{bulk} – coal bulk density (t/m^3)

W – total screen width (m)

v - transport velocity (m/s)

The bed depth corresponding to the allowable screen loading as a function of average particle size and transport velocity for a bulk density of 0.8 t/m^3 is shown in Figure 6.

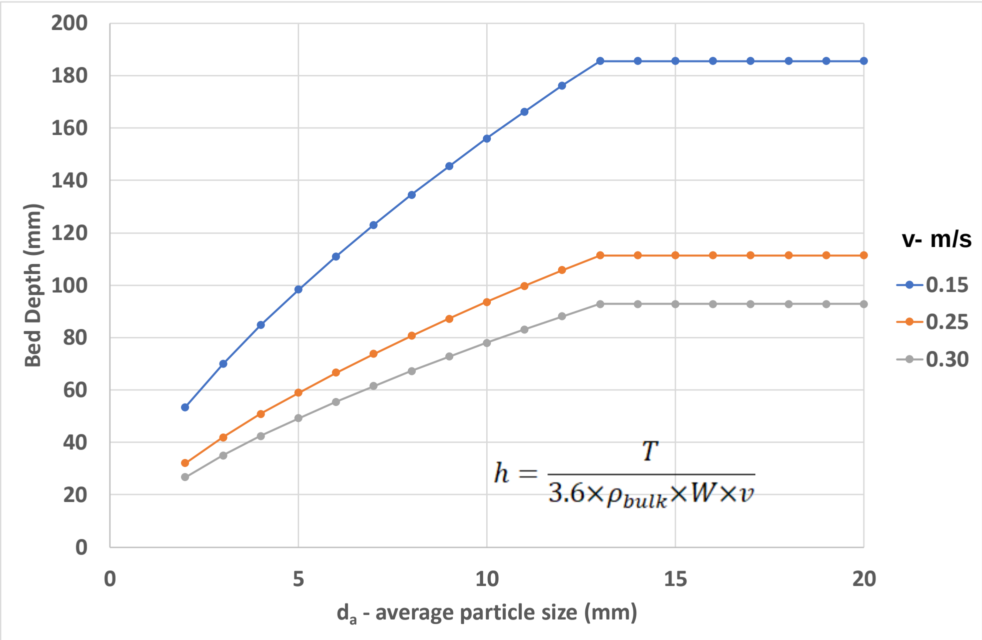

Figure 6: Bed Depth as a Function of Transport Velocity for k=12

As bed depth is the critical parameter for efficient screening, medium drainage and medium adhesion, it can be deduced from Figure 6 that provided the screen velocity is greater than 0.15 m/s (as stated by DSM), the allowable screen load constant can be increased in proportion to the transport velocity as shown in Table 2 to maintain the same bed depth as indirectly specified by DSM.

Table 2: Screen Load Factor

Transport Velocity (m/s)	Screen Load Factor (k)
0.15	12
0.25	$12 \times \frac{0.25}{0.15} = 20$
0.30	$12 \times \frac{0.30}{0.15} = 24$

The length of the drain section of the screen is given as 1.2 m out of a total of 4.8 m. This equates to one quarter of the screen being used for drainage and three quarters of the screen being used for rinsing.

For a 22sb wedge wire profile with a 0.5 mm slot (open area = 21.7%), the given drainage rate is 20 $m^3/h/m^2$ screen area. For design purposes, it must be assumed that the sieve bend will only drain 75% of the medium being presented to it and that the remaining 25% must be drained on the drain section of the drain and rinse screen.

Rinse Stage

The amount of medium still adhering to the clean coal and the rejects after drainage on the sieve bend and drain section of the drain and rinse screen can be calculated using the following formula:

$$Q = \frac{950}{d_a \times \rho_{coal}}$$

Q – adhering medium (litre/ton product)

Other symbols as previously defined

Water Requirement

The total water requirements for rinsing are given in Figure 77.

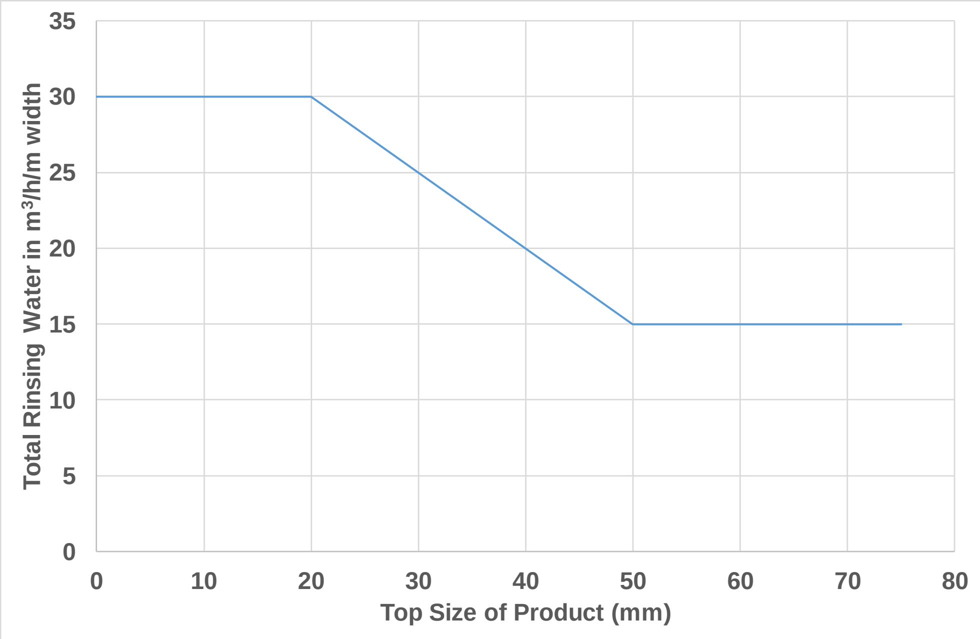

Figure 7: Total Rinsing Water Requirements

The rinsing water must comprise 75% clarified water (magnetic separator effluent) and 25% fresh water.

Although not stated explicitly, the same drainage rate as given for the drain section can be assumed to apply.

The moisture content of the clean coal and reject discharging at the end of the rinse section is given as 16 to 20%.

DEVELOPMENT OF MULTI-SLOPE SCREENS

History

The design concept of a multi-slope screen consists of several multi-angled screen decks with decreasing angles of declination from the feed end to the discharge. The first such screen was developed by HCC (Hautéur de couché croisant ou constante) in 1973 and consisted of a combination of three screens with the first screen sloped at approximately 34 degrees to the horizontal. This screen was used in the screening of iron ores marketed by Procédés Burstléin, Paris, France and was significantly smaller compared to the conventional screen. It was claimed that for the same feed rate, the screen area was reduced from 630 m^2 to 240 m^2 on the HCC.

In the 1980s, a screen resembling a combination of a sieve bend and a horizontal vibrating screen was used in a dewatering application. This screen was known as the Tarbo Radii-Vib screen and incorporated an adjustment on the discharge end of the flat bed so that it could be raised or lowered to optimise bed depth.

Mutil-sloped screens were first used for desliming coal in Canadian preparation plants in the mid 1980 and were introduced in sizing applications in the Australian coal industry in the late 1980s and into drain and rinse applications in the early 1990s.

Development

The first multi-sloped screen consisted of three screen decks with the feed slope from 35 to 30 degrees, the intermediate slope from 25 to 15 degrees and the discharge slope from 15 to 0 degrees.

The design concept soon changed with the number of slope angles increasing first from 3 to 4 and then from 4 to 5. This also resulted in a reduction of the starting feed end angle down from 34 to 30 degrees and eventually 30 to 25 degrees with step angles ranging from 7.5 to 5 degrees.

Optimisation was largely driven by the following factors:

- Reduction in the screen panel wear rate
- Increasing the drainage capacity and reducing screen discharge product moistures.

Most 6.1 m long multi-sloped screens used in the coal industry consist of five slopes with the following angles: 25, 20, 15, 10 and 5 degrees.

On-site test work it was also established that the minimum screen length for a multi-slope screen should be 6.1 m and that in a drain and rinse application, the drain section length needs to be approximately 4 m with a rinse section of 2 m i.e. two thirds drain and one third rinse.

Recent developments include the use of 7.3 m long screens for both desliming and drain and rinse applications. The additional screen area and increased residence time increase the drainage rate.

To maximize medium recovery and minimize magnetite losses, the drain section needs to recover approximately 95% of the correct medium being fed to it.

Comparative site test work was done on a 6.1 m long multi-slope screen and a DSM design 1600 mm sieve bend with 4.8 m long horizontal vibrating section, both with 0.5 mm apertures. The multi-slope screen recovered 72% of the medium. The sieve bend on its own recovered between 89 and 94% of the medium.

The drainage rate of the multi-slope screen increases with increasing aperture size and the target 95% medium recovery for a 6.1 m long screen is achieved with effective aperture sizes of 1.2 mm and greater. For Australian coal operations, midsize circuit technology development i.e. large diameter spirals, teetered bed separators and reflux classifiers, have resulted in the aperture sizes being increased to 1.4 mm and in some cases 1.8 mm, which has further assisted with the drain rates on multi-slope screens due to increased open area. For South African coal operations, the maximum aperture size is normally 1.0 mm.

Design Criteria

Ongoing site testing and laboratory scale test work on multi-slope screens has enabled both the equipment suppliers and designers to develop the necessary design criteria for dense medium circuits.

Drainage Rates

The drainage rates are often expressed as $m^3/h/m^2$ of screen area for a nominated wedge wire aperture size. However, this figure can vary significantly depending on the actual open area, which is dictated by several factors:

- The type and head width of the wedge wire used
- Standard wedge panel versus a polywedge panel
- Standard polyurethane panel and/or a continuous slot design etc.

A more universal approach would be to express drainage rates per square metre of open area (Clarkson et.al, 2012).

Table 3: Drainage Rates for Wedge Wire Screens

Aperture Size (mm)	Drainage Rate ($m^3/h/m^2$ of screen)	Open Area (%)	Drainage Rate ($m^3/h/m^2$ open area)
0.5	40	15.2*	263
1.0	65	20.8**	312
1.4	80	26.9**	297

* 34SB, ** 42SB

Based on the test work between a multi slope screen and a sieve bend screen combination previously discussed, the drainage rate for a 1600 mm arc length sieve bend with 0.5 mm aperture and 34SB profile is 91 $m^3/h/m$ width or 445 $m^3/h/m^2$ open area. As the multi-slope screen drained 74% of the medium compared to the 89 to 94% for the sieve bend, the drainage rate for the multi-slope screen should be closer to 360 $m^3/h/m^2$ open area.

However, factors such as higher than optimum feed velocities (should be less than 0.4 m/s) onto the multi-slope screen and/or near size blinding of the apertures reduce the effective drain rate of the screen which suggests the figures quoted in Table 3 are reasonable and accepted by the coal industry.

A simulation of multi-slope screens that looked at both particle classification and water drainage was done by the CSIRO (Fernandez et. al., 2011). The flow simulations provided some interesting insights as to drainage over the length of the screen as shown in Figure 8.

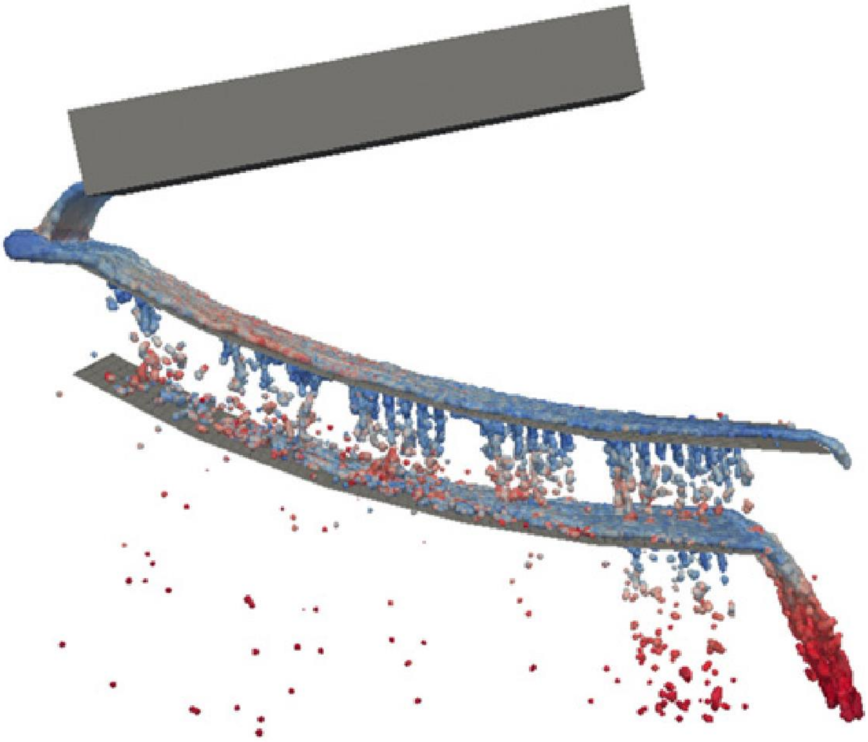

Figure 8: Simulation of Drainage on a Multi-Slope Screen

In the article, the following conclusion is drawn:

"*The fluid passed over the first panels on the upper deck where the velocity was highest. As the fluid slowed due to the deck curvature the flow rates through the panel grates increased with the highest flow through the last panel*."

Screen Loading

The DSM formula (C) is also used to determine the width. A multi-slope screen factor of 1.5 is sometimes applied to the DSM formula (Clarkson et. al. 2012), but this can negatively affect bed depth.

DRAIN AND RINSE SCREENS

Drain and rinse screens can be configured in many ways depending on whether the DSM, multi-slope screen or a combination of the two approaches is used.

Drain Section

The following configurations can be used:

Sieve Bend and Horizontal Vibrating Screen

This conforms to the standard DSM approach as discussed previously. The advantages of this configuration are:

- Proven. It has withstood the test of time

- The sieve bend does most the work with the drain section on the screen mopping up the balance
- The vibrating screen split of one third for drainage ensures sufficient drainage area to minimize carryover of medium to the rinse section
- The location of a weir bar between the drain and rinse section of the vibrating screen provides a positive barrier and assists with reducing the amount of adhering medium
- If a plant trip occurs, the sieve bend will still recover most of the medium and medium carry over from the drain to the rinse section will be minimized.

The disadvantages are:

- The sieve bend has to be rotated frequently to maintain its drainage rate. If this is not done, the load on the drain section of the vibrating screen will increase and the probability of medium carry over from the drain to the rinse section will increase. This can affect plant availability.

Flat Static Screen and Horizontal Vibrating Screen

In this configuration, the sieve bend is replaced with a flat static screen that is installed at an angle between 25 and 30 degrees. Some models are equipped with a mechanism to enable the angle to be adjusted on site. An example is shown in Figure 99.

Figure 9: Flat Static Panel

In both theory and practice, the sieve bend with its curved screen has a greater capacity compared to a flat panel due to the forces exerted as the material flows across the screen. Also, like the sieve bend, if panels with a slot across flow aperture configuration are installed, the leading edge becomes blunt and the screen must be rotated to maintain the drainage rate,. For a flat static panel this is not practical and this limits the aperture configuration to slot with flow.

The advantages are similar to those listed for the sieve bend and horizontal vibrating screen listed above.

Compared to a sieve bend, the disadvantages are:

- Restricted to slot with flow panel configuration which has a smaller open area for the same cut size
- Reduced drainage rate for the same open area due to the lack of curvature on the screen
- Loading on the drain section of the horizontal vibrating screen is increased. If the drain area is limited, this can lead to medium carry over onto the dilute section with increased medium losses.

Horizontal Screen Only

In this case the area of the drain section of the horizontal screen must be sized to drain all the free draining medium so that only adhering medium reports to the dilute section. In this case the ratio of screen length between the drain and rinse section can increase from one third up to more than half. Depending on the medium loading, it is often possible to use a single split screen for both floats and sinks.

The advantages of this option are:

- Simplified plant layout i.e. fewer pieces of equipment and reduced maintenance
- Reduced head room requirement.

The disadvantages are:

- If the plant trips, medium will be carried over onto the dilute section and sometimes run over the end of the screen
- If a split screen is used, changes in yield can lead to either the floats or sinks side becoming overloaded with the associated increase in medium losses.

Multi-slope Screens Only

The advantages of using a multi-slope screen are:

- Simplified plant layout
- Reducedfoot print but with increased height
- Change in slope, similar to the curvature on a sieve bend, can improve drainage rates with the lower angles draining better than the higher angles.

The disadvantages are:

- High velocities at the feed end lead to high wear rates
- During a plant trip, medium will be carried over from the drain to the rinse section leading to increased losses
- Elevated platforms to access drive motors and exciters
- Limited head room at the feed end when changing out panels due to the feed box arrangement.

Static Screen and Multi-Slope Screen

The advantages of combining a static with a multi-slope screen are:

- The load on the drain section of the drain and rinse screen is reduced which can result in a smaller size screen being required
- During a plant trip, medium carry over from the drain to the rinse section can be eliminated.

The disadvantages are:

- Increase in plant height
- Additional pieces of equipment.

Rinse Section

The rinse section is normally combined with the drain section on a single vibrating screen whether it be a horizontal or multi-slope screen. The rinse section must be designed to achieve the following:

- Have sufficient length to install the required rinse water configuration
- Have sufficient area to drain the rinse water and medium washed of the coal and discard
- Have sufficient area after the rinse water has been applied to enable the adhering water on the coal and discard to drain to reduce the surface moisture.

CONCLUSION

Regardless of which screening arrangement is chosen, the following fundamentals must be observed to ensure that magnetite losses are restricted over the life of the plant:

- The feed arrangement onto the screen must ensure that the full width of the screen is utilized.
- Low feed velocities are critical for maximizing the drainage rate on sieve bends and multi-slope screens.
- The drain section must have sufficient area to recover 95% of the medium being fed to it. Allowance must be made for potential blinding which will reduce open area.
- The selection of screen width must take the average particle size and bed depth into account. Running at too high a bed depth will increase medium carry over from the drain to the rinse section and also reduce the efficiency of the rinse water in washing off the medium, which will lead to increases in magnetite losses.
- Sufficient rinse water must be used to wash off the adhering medium without overloading the wet drum magnetic separators.
- Provision must be made at the end of the screen after rinsing for the clean coal and reject to dewater before being discharged off the end of the screen.

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