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STAINLESS STEEL LASER-DRILLED SCREENS FOR CONTINUOUS CENTRIFUGALS

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Abstract

Stainless steel laser-drilled screens (SSL screens) for continuous sugar centrifugals are compared with several types of chrome/nickel screens. Assessments are made of trials and routine operations at several factories around the world, and results of final molasses purity analyses, screen service life, and centrifugal capacities are examined.

A semi-quantitative comparison is made between Australia and South Africa on the use of SSL screens and chrome/nickel screens in these two sugar producing regions, which share similarities. The comparison illustrates some of the cost benefits of SSL screens.

SSL screens are shown to be a cost effective alternative to both the standard and modified versions of chrome/nickel screens, in high grade and low grade continuous centrifugals.

Keywords: Screens, centrifugals, lasers, milling, purity, durability.

Introduction

Chromium-coated stainless steel laser-drilled screens (SSL screens) are well established in the sugar milling and refining industry. They are an increasingly popular alternative to chromium-coated nickel screens in high and low grade continuous centrifugals worldwide. This paper discusses the technical reasons and industry trends that are responsible for this development.

SSL screens have been available for over 12 years. They were initially developed in co-operation with the Australian sugar industry (Atherton et al 1990, Crane & Patino 1995) to overcome the problems associated with electroformed chrome/nickel screens (Atherton et al 1990, Greig et al 1984, Kelly et al 1985, Korsse 1996):
(i) distortion over the coarse backing screen, due to a lack of tensile strength of the soft nickel, causing the slots to widen; refer to Figure 1. This results in a loss of sugar crystals to molasses;
(ii) loss of the abrasion resistant chromium coating due to both galvanic corrosive action and poor adhesion, also causing the slots to widen; refer to Figure 2. This also results in sugar losses.
(iii) inadequate service life and resistance to damage, particularly in large centrifugals.

Figure 1
This illustrates the deformation and slot enlargement that occurs in chrome nickel screens.
1000 microns |————|

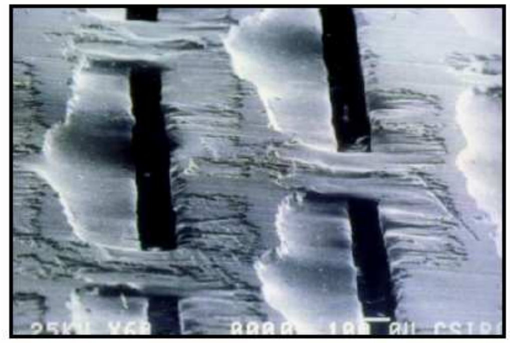

Figure 2
This shows the flaking of the chrome layer in a chrome nickel screen, and abrasion of the soft nickel base which enlarges slot widths from 60 to more than 100 microns.
100 microns |—|

An additional concern with chrome/nickel screens is the occurrence of nickel contamination in the sugar and molasses as the screens deteriorate (Korsse 1996). Nickel contamination in foods is of increasing concern, particularly for liquid or water-soluble foods (ATSDR 2002). Measurements of nickel in sugar products varies enormously. Prakash et al (1995) reported particularly high values up to 2.02 ppm. Such contamination levels may be dangerous, particularly for people sensitised to nickel.

These problems exist with chrome/nickel screens regardless of claimed improvements such as increased screen thickness to increase strength. The base material is soft nickel and the screens remain significantly inferior to stainless steel in terms of strength despite such increases in thickness, and modifications to slot geometry. Also, reducing the initial slot width in chrome nickel screens offers little overall improvement due to the rapid wear and distortion that takes place progressively during operation.

These problems can be eliminated or substantially reduced with SSL screens, which are chromium-coated sheets of stainless steel with laser-drilled slots. SSL screens have up to ten times the tensile strength of chrome/nickel screens (Greig & White 1987), and exhibit a very strong adhesion of the chromium coating, thereby affording long-term integrity of slot size. Figure 3 shows the working face of a SSL screen after 1350 hours of operation. This figure should be compared with Figures 1 and 2.

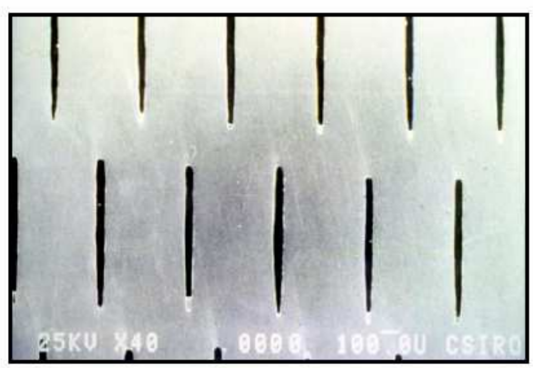

Figure 3
A SSL screen after 1350 hours of operation shows little wear or deterioration.   100 microns |—|

Despite a significantly higher screen purchase price, SSL screens are often justified in replacing chrome/nickel screens due to the significant reduction in sugar lost to molasses, particularly in low grade centrifugals, and a much greater screen life (Atherton et al 1990, Crane & Patino 1995, Kumar et al 1996, Vermeulen et al 1994). It has been shown in Australia, for example, that a mill crushing one million tonnes of cane will save approximately $US 43,000 in reduced sugar losses just by using SSL screens (Crane & Patino 1995). This result is based on a measured reduction in final molasses purity of 0.75 units and a raw sugar price of US$ 264/tonne.

A past impediment to the more widespread use of SSL screens has been the difficulty of accurately measuring these small but valuable improvements in final molasses purity. However, further independent trials have now been conducted in several other countries, in particular South Africa, the U.S.A, Mexico, Brazil, India and Korea. These trials have established similar results to those in Australia, not only with regard to screen longevity (Fioravanti Neto 2000, Son 2001) but also with regard to sugar savings (Avalos Ortiz 1996, Kumar et al 1996, Somera 1991, Vermeulen et al 1994).

On the other hand, the superior longevity of SSL screens, and their superior ability to cope with heavy or onerous centrifugal loadings, are issues which have been relatively easy to assess . Accordingly, the trend towards high grade continuous centrifugals as an alternative to batch machines (Kirby et al 1990, Greig & Belotti 1995, Grimwood et al 2000), and to larger machines for low grade applications, has prompted an increasing number of factories to install SSL screens to cope better with these more demanding conditions.

On the basis of these longevity and durability issues alone, the next section attempts to quantify the cost effectiveness of SSL screens, and ignores for the moment the cost savings afforded by reduced sugar losses.

Comparison: Australia and South Africa

In Australia, approximately 80% of all sugar processed by continuous centrifugals is processed using SSL screens, while the remaining 20% involves the use of chrome/nickel screens. (SSL screens represent 50% of the total square metres of screens used there. Because of their superior longevity, SSL screens account for at least 80% of all sugar processed.) In other countries, SSL screens are used to a much lesser extent than chrome/nickel screens.

A semi-quantitative way of assessing the longevity benefits of SSL screens is to compare the Australian situation with that of another major sugar producing region that, unlike Australia, uses few SSL screens. A suitable region for comparison is the Republic of South Africa (RSA) combined (for geographic completeness) with Swaziland. At the time of writing (April 2002), less than 10% of the sugar produced by this African region involves the use of SSL screens. This African region and Australia are roughly similar in the size and technical status of their sugar industries, and both are major sugar exporters.

Averaged over the four years 1997 to 2000, Australia produced 5.3 megatonnes of sugar, while the RSA plus Swaziland produced 3.1 megatonnes (2.3 MT in the RSA) annually.

In Figure 4, the parameter "A" is shown for each of the two regions. Here "A" is the total surface area in square metres of all continuous centrifugal screens used each year, regardless of the type of massecuite, per megatonne of sugar produced. ("A" is chosen rather than, say, the number of screens because "A" better accommodates the fact that centrifugals vary in size and capacity.) It can be seen that "A" is more than four times smaller for the Australian region.

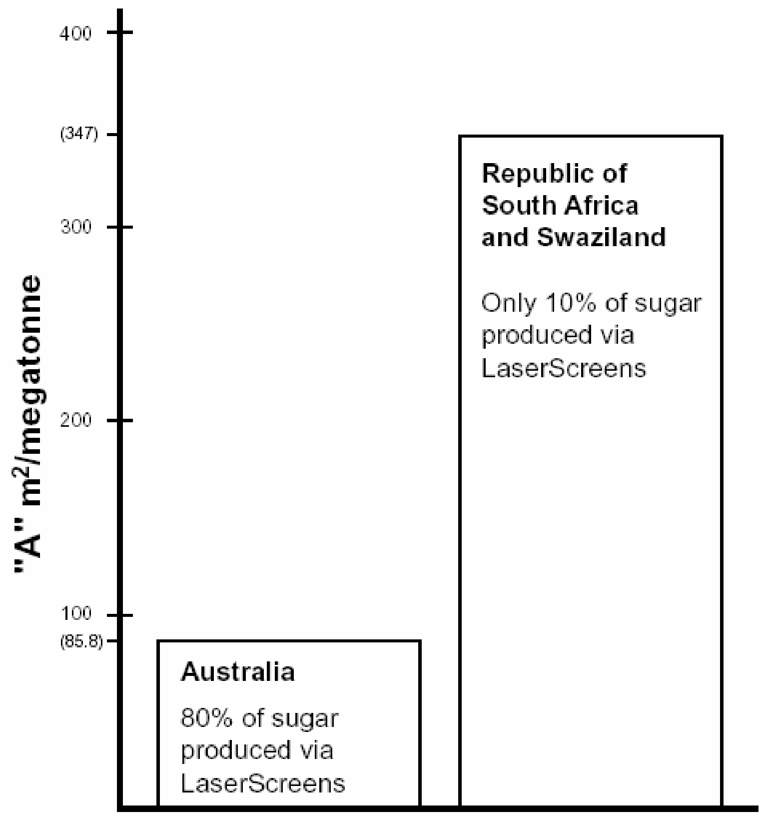

Figure 4
A comparison of "A" between two major sugar producing regions, where "A" is the total surface area of all continuous centrifugal screens used each year per unit of sugar produced. Here "A" is expressed in square metres per megatonne (averaged for the years 1997 to 2000).

LaserScreens=SSL screens

This result is due to many factors, including some unrelated to the choice of screen type. However, in order to explain such a huge difference between the two regions, the choice of screen type appears to be the main factor. Figure 4 is an approximate measure of the much greater longevity of SSL screens, both in terms of hours of operation per screen and, more significantly, in terms of tonnes of sugar processed per screen area. However, in order to properly assess the value of this longevity benefit, the analysis needs to be extended by considering the purchase price of each type of screen. This is done in Figure 5 for this African region.

In Figure 5, the left-hand bar shows the current annual expenditure on all continuous centrifugal screens by the 17 relevant African mills (based on the 4-year average screen consumption, and unit screen prices for all types of centrifugals in 2001). The right-hand bar shows what the expenditure would be if SSL screens were used to the same extent as in Australia. This right-hand bar was obtained by applying the Australian value for "A" from Figure 4 to the value of 3.1 MT of sugar produced in this African region. (Half of this value for "A" would be due to the use of short-lived chrome/nickel screens.) African prices for all screens in 2001 were applied to both bars. The price for SSL screens per sq. metre is 6.1 times higher than that for chrome/nickel screens.

It can be seen that, regardless of any other benefits of SSL screens, the African region would save US$ 50,000 per year in the total purchase price of screens if it adopted SSL screens to the same extent as Australia.

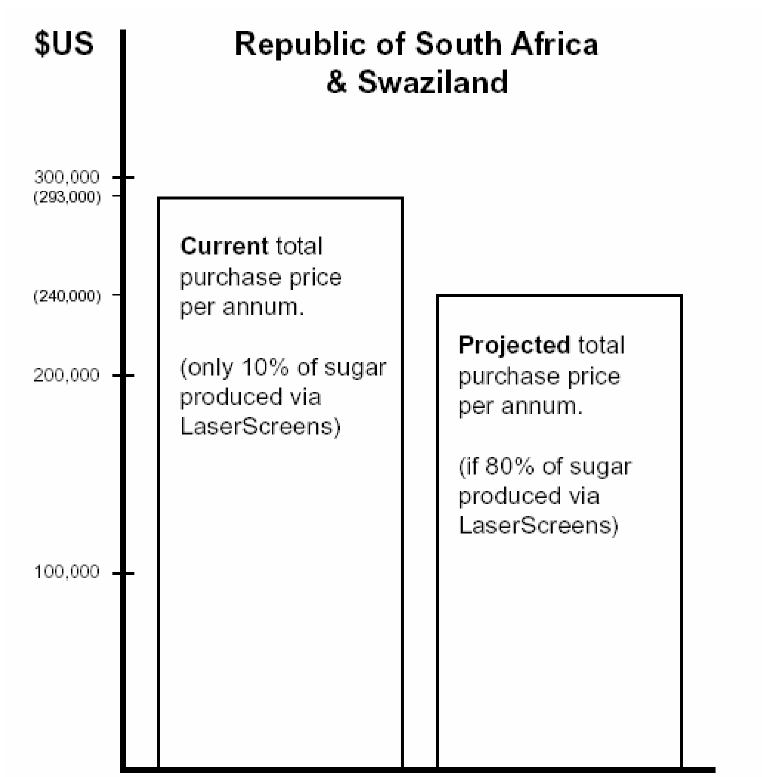

Figure 5
The current total purchase price per annum of screens in the Republic of South Africa and Swaziland is compared with the projected total purchase price p.a. that would apply if this region adopted SSL Screens (LaserScreens) to the same extent as Australia.

Accurate information exists regarding the numbers, types and prices of screens in the two regions. Nevertheless, Figures 4 and 5 are of course only semi-quantitative because sugar processing differences exist between the two regions considered. For example, Australia produces a slightly lower quality (pol) raw sugar than the African region, and the use of batch fugals compared with continuous fugals is not identical between the two regions. In addition, African centrifugals generally operate at a lower throughput rate than those in Australia. (However, this last aspect is of little relevance to this analysis because the lifetimes of both types of screens are effectively defined above in terms of total throughput of sugar.)

In any case, the difference between the two regions in Figure 4 (due largely to the better durability of SSL screens) is so large that it cannot be lightly dismissed. Further, Figure 5 illustrates that SSL screens offer a cost benefit on the basis of their longevity alone. Note the additional major advantages of SSL screens, such as the reduced loss of sugar to molasses and the reduced cost of screen changeovers, have been ignored in this section of the paper.

Developments in SSL screens and Chrome/Nickel Screens

Within the last decade in particular, millers have sought improvements in continuous centrifugal screens to improve process efficiencies and to cope with the heavier throughputs applicable to larger, more modern centrifugals.

For example, it has become more evident that continuous centrifugals should be run at maximum load, not only to reduce the number of machines required, but to provide a thicker, more uniform layer of massecuite on the screen (Payne 1992). Such a layer affords a more efficient removal of molasses and less passage of fines through the screen. Further, increasing numbers of continuous high-grade centrifugals are replacing batch machines, and these continuous centrifugals are invariably large and heavily loaded compared with earlier low-grade machines (Grimwood et al 2000, Kirby et al 1990).

These modern process requirements strengthen the reasons for favouring SSL screens over the less robust chrome/nickel screens. However, some manufacturers of the chrome/nickel screens are producing an increasing number of screen versions to address the concerns of millers (Korsse 1996). Compared with "standard" chrome/nickel screens (0.3 mm thick, 60 micron slots, 6.5% open area, 7 micron chromium coat), newer nickel versions are slightly thicker, or have more open area, or have narrower slots, or thicker chrome. (The pattern or design of the screen slots is also varied.) These versions are not necessarily significant improvements over standard chrome/nickel screens, as will be discussed below on a point-by point basis.

Screen Thickness:
The distortion of a centrifugal screen into the mesh of the support basket may in some cases be decreased by increasing the thickness of the screen. Versions of nickel screens are available which are up to 50% thicker than standard nickel screens, although 20% is more typical if open area, slot width and slot taper are to be maintained. The question arises therefore as to how much tougher these versions are compared with SSL screens. Simplistically, text-book mechanical theory may be applied to estimate the distance any tiny part of the screen may be displaced by a force acting on an unsupported part of the screen.

This analytical approach has been used by at least one manufacturer of nickel screens (Korsse 1996). It shows that the displacement (distortion) is inversely proportional to the third power of the screen thickness. For example, it is claimed that an increase in thickness of 20% will increase the "stiffness" (resistance to distortion) by 80%. The problem with this simplistic analysis is that it is fundamentally invalid. It does not represent the situation for a centrifugal screen with any reasonable accuracy, and is certain to be far too optimistic. A fundamental flaw is that the abovementioned inverse-cube relationship only applies for metal stressed below its elastic limit, which would imply no permanent deformation of the metal. In fact, as is well known, permanent dimples appear in nickel screens shortly after use commences, particularly if lumpy massecuite is being processed. This confirms that the screens are routinely stressed beyond their elastic limit.

A more appropriate analysis requires consideration of many factors, including in particular the elastic limit of the metal. The elastic limit can be approximated by the yield stress for present purposes. Yield stress (which is related to the tensile strength of the metal), varies enormously between different metals. The cold-rolled stainless steel used in SSL screens has a yield stress which is in the vicinity of five times greater than that for electroformed soft nickel. Compared with this differential any increase in strength obtained in nickel screens, due to a 20% increase in their thickness, is negligible.

Tensile strength measurements have been conducted comparing results for various nickel screens and SSL screens (Greig & White, 1987). The influence of thickness on the results is small compared with material considerations, percentage open area, slot pattern or slot orientation. SSL screens were found to be up to ten times stronger than nickel screens having similar slot width and open area.

Percentage Open Area:

Some people in the sugar milling industry directly and unconditionally relate high percentage open area of screens with high fugalling capacity. However this relationship is a complex issue, where the intuitive conclusion is not necessarily correct. For example a South African study on lightly loaded centrifugals showed evidence of increased throughput with higher open area screens (Vermeulen et al 1986). However, contrary results were obtained in a study by the Bureau of Sugar Experiment Stations (Queensland, Australia) on more heavily loaded C-grade centrifugals (Atherton 1987). These latter tests were conducted for several months in two mills using screens with open areas of 6%, 10% and 15% and concluded that no significant difference in throughput could be measured. The logical conclusion is that, depending perhaps on machine loading, once the open area is greater than a certain value (in the latter case 6%, or less), the resistance to molasses drainage of the layer of massecuite on the screen dominates the resistance of the screen itself.

At this point, it is important to note that all screens become progressively more subject to distortion and wear as their specified open area increases, and their purchase price also increases significantly. For perhaps no increase in capacity, the result of purchasing the more expensive (high open area) screens can be a counter-productive reduction in screen lifetime and increase in sugar losses resulting from more rapid distortion and wear.

This conclusion applies to both SSL screens and chrome/nickel screens, but, as noted elsewhere here, SSL screens suffer much less distortion and wear. This advantage is primarily due to the far higher tensile strength of stainless steel compared with soft nickel, and the far better adhesion of chrome on stainless steel.

Slot Width:

Sugar losses to molasses can be reduced by reducing the screen slot width, and this reduction can be very valuable in the case of C-massecuite centrifugals at least. However, if the screen open area is to be maintained, such reduction in slot width necessarily requires more slots per unit area and consequently a reduction in screen strength (assuming no other screen parameters change). During use, such screens may quickly suffer distortion of slots producing widths much greater than their original value. Screens with these characteristics also have a higher purchase price. Thus the higher price for screens having smaller slot widths may not be justified, and may even be counter-productive.

Once again, this conclusion applies to both SSL screens and chrome nickel screens, but SSL screens have a huge advantage in regard to screen strength.

For comparison purposes, it should be noted that SSL screens have slots which are not quite rectangular (see Figure 3), narrowing slightly at the slot ends. Slots in chrome/nickel screens, prior to use, are rectangular. The SSL screen specification on slot width refers to the width at the widest part of the slot (at the middle); the average slot width is less. Thus a SSL screen specification of, say, 60 microns refers to slots which have an average width closer to 50 microns.

Chrome Coating:

When used in sugar centrifugals, a hard chrome coating is applied to the working face of SSL screens and nickel screens in order to resist the abrasive effects of sugar crystals. In the case of chrome/nickel screens, any small area which has lost its coating immediately experiences rapid wear because of the softness of the exposed nickel.

The mechanisms for wear of chrome nickel screens are understood (Greig et al 1984, Greig et al 1985, Kelly et al 1985, Korsse 1996). As a coating, chromium is relatively brittle and contains microcracks. In the case of chrome on nickel, the bond between the two materials is relatively poor. A fine pattern of distortion occurs over much of the screen during use, as it is pressed against the support basket and pummelled by lumps of massecuite. Such distortion further cracks open the coating, and it flakes off the surface. Further, the microcracks and cracks allow ingress of molasses, which results in a galvanic corrosive action between the nickel and chrome. The corrosion causes a swelling of material at the interface between the two metals, and the coating comes away from the screen.

Because of the nature of the wear mechanisms described above, increasing the chrome layer thickness on nickel screens does little to improve the longevity of the screen. In any case, because the layer is applied after the nickel screen has been electroformed, there is a limit to how much chrome can be applied before the desired slot width and open area are compromised.

The abovementioned wear mechanisms are virtually absent in SSL screens for several reasons: Chromium bonds tenaciously to stainless steel; relatively little distortion is experienced by SSL screens; and negligible galvanic corrosive action takes place at the bi-metal interface because of the proximity of chrome and stainless steel in the electrochemical series. Wear rates of SSL screens are reduced significantly by increasing the chromium thickness, provided the thickness of the stainless steel is adequate. Standard SSL screens have 15 microns thickness of chrome while versions used in some heavily loaded high-grade continuous centrifugals have 30 microns of chrome, more than four times that on standard chrome/nickel screens.

Slot pattern:
The fine-scale arrangement of slots in a screen can have a dramatic influence on screen strength (Greig & White 1987, Korsse 1996). SSL screens invariably have a pattern with distinctly-separated rows of short (1 mm length) slots. This pattern is superior in strength to patterns involving interlaced rows (staggered slot arrangement) or patterns involving longer slots, as are commonly used in nickel screens. Limitations associated with the electroforming method mean that nickel screens cannot easily have slot lengths less than about 2.2 mm.

Considering now the large-scale arrangement of slots, it is evident that the slots can be arranged to have their length roughly parallel to the massecuite flow, or at other angles. In the case of the weaker nickel screens, it is particularly important that the former orientation prevails as much as possible because this reduces to some extent the sugar lost through slots which may have stretched open. This orientation of slots also reduces the chipping away of the chrome layer at slot edges. Because SSL screens are more resistant to slot distortion, there is no similar mechanical imperative to orient the slots in a particular direction. Nevertheless, standard SSL screens have slots generally oriented parallel to the massecuite flow, although different orientations are provided for special applications.

Experimental comparisons have been conducted (Noble 1992) in which two sets of SSL screens were used in a C-massecuite centrifugal for 1700 hours. One set had slot lengths arranged almost parallel to the massecuite flow, and the other set had slots at right angles to the flow. No significant difference in performance was measured.

Reduction in sugar losses

Continuous centrifugals constitute one of the main causes of sugar losses in the manufacturing process (around 3% if controlled properly). Therefore they represent one of the few opportunities for significant overall yield improvement. To control losses here, it is essential to routinely monitor final molasses purity and ensure that screens are kept in good condition, regardless of the type of screen used (Payne 1992). However, to minimise the loss of sugar to molasses, particularly in C grade centrifugals, operating with SSL screens affords substantial benefits.

Results in Australia with regard to sugar savings and screen lifetimes achieved with SSL screens have been supported by trials and the results of routine mill operations in many countries including:

Australia	Bureau of Sugar Experiment Stations (Noble 1987);
South Africa	C.G.Smith Sugar Ltd (now Illovo Sugar) with the Sugar Milling Research Inst. in Durban (Vermeulen et al 1994); Transvaal Sugar Limited, Malelane Mill (Singh 2001);
U.S.A. (Hawaii)	Oahu Sugar Company with the Hawaiian Sugar Planters' Association (Somera 1991);
India	Daurala Sugar Mills (Kumar et al 1996);

Mexico	Ingenio Tamazula (Avalos Ortiz 1996);
	Ingenio Adolfo Lopez Mateos (Zepeda Montiel 2001);
Brazil	Usinas Itamarati (Fioravanti Neto 2000);
Korea	Cheil Jedang Inchon Sugar Plant (Son 2001).

Screens in Continuous High Grade Centrifugals

There is an increasing trend towards fully continuous centrifugal processing in the sugar industry. Although batch centrifugals are still the general standard for high grade applications, high grade continuous centrifugals are replacing batch machines due to reductions in overall capital cost, power consumption and operating costs (Greig & Belotti 1995, Grimwood et al 2000, Kirby et al 1990). The continuous high-grade machines are designed to work best with capacities in the vicinity of 22 tonnes/hour and subject screens to more onerous conditions than is the case in low-grade machines. (However, there is also a strong progression towards larger low-grade machines which are similarly more punishing on screens.)

With these more demanding conditions, SSL screens are proving most suitable due to their durability and efficiency.

Australian mills have led the adoption worldwide of high grade continuous centrifugals. The NQEA "Super Fugal", first used in 1989, included the specification of SSL screens in its original design and operating criteria (Kirby et al 1990). All these NQEA machines continue to use SSL screens exclusively. In addition to the NQEA machines, Australian mills also operate 35 continuous high grade centrifugals originally developed by STG.FCB Pty Ltd, and approximately 10 "Silver 5000" continuous machines. SSL screens are the preferred choice in almost all these machines and are used exclusively in most.

One of the most recently developed high grade continuous machines is the Broadbent SPVH 1100, which was largely based on the Australian NQEA "Super Fugal" design (Grimwood et al 2000). Recent experience at Ingenio Adolfo Lopez Mateos in Mexico (Zepeda Montiel 2001) shows that with a high grade Broadbent SPVH 1100, chrome/nickel screens can last 50 days at best, while a single set of SSL screens operated for the entire 2001 season (160 days), and remained in good condition at the end of the season.

At Malelane Mill in South Africa, similar excellent results were obtained in BMA K1500-DS and BMA K2300 high grade machines where chrome/nickel screens typically last two to three weeks (about 350 hours). A set of SSL screens installed in a K2300 in October 1999 was still in use in July 2001 (Singh 2001). When checked on July 4, 2001, this set had registered 6034 hours of use, already equivalent to the combined life of 17 sets of chrome/nickel screens.

Conclusions

SSL screens for low grade and high grade centrifugals have been extensively tested and adopted for use in the sugar industry worldwide. Comparisons with standard and modified chrome/nickel screens in tests and in routine mill operations have shown substantial advantages. These advantages include a reduction in the sugar lost to molasses, which is particularly important in low grade applications, and a much greater screen longevity, particularly for high capacity centrifugals.

A broad comparison of the Australian sugar industry (where SSL screen usage is very high) with that in South Africa / Swaziland (where SSL screen usage is currently low) demonstrates that the higher unit purchase price of SSL screens is justified. This justification is established even though the comparison considers only the enhanced longevity of SSL screens, not their other major advantages, such as reduced sugar loss.

When more recent versions of standard chrome/nickel screens are examined in detail, it is concluded that such versions afford minor improvements in performance compared with those available by using SSL screens.

References

ATSDR (Agency for Toxic Substances & Disease Registry, USA) (2002). Toxicological profile for nickel. http://www.atsdr.cdc.gov/toxprofiles.
Atherton, P.G., Brandt, M., Crane, K.C.A., Noble, A.G.(1990). Laser-cut screens for continuous centrifugals. Int. Sugar Jrnl.v.92, 243-248.
Atherton, P.G., Steindl, R.J., Congden, G.F., Jones, R.A.(1987). Evaluation of high open area screens, BSES Report, Queensland, Australia. (Confidential).
Crane, K.C.A. and Patiño, E. (1995). Stainless steel laser-drilled screens for continuous sugar centrifugals. XXII ISSCT Congress. Int. Sugar Jrnl.v.97, 671-678.
Greig, C.R., Kelly, G.J.,White, E.T., Kirby,L.K. (1984).Corrosion and erosion of fugal screens. Australian Soc. Sugar Cane Tech. 7th Conf. Proc. 243-249.
Greig, C.R., White, E.T., Kirby,L.K. (1985). Effect of screens on fugal performance. Australian Soc. Sugar Cane Tech. 8th Conf.Proc. 179-187.
Greig, C.R. & Belotti, A. (1995). Continuous centrifugal for high grade sugars. XXII ISSCT Congress.
Greig, C.R. & White, E.T. (1987). Corrosion testing of centrifuge screen materials. Dept. Chemical Eng. University of Queensland.
Grimwood, G.C.,Thompson, P.D.,Thewlis, M.J. (2000). The development and use of high grade continuous centrifugals. Int. Sugar Jrnl., v.102, 639-645.
Kelly, G.J.,Casey, T.G.,Kirby, L.K. (1985). Contributing factors in fugal screen corrosion. Proc. 8th Conf. Australian Soc. Sugar Cane Tech. 8th Conf.Proc. 161-168.
Kirby, L.K.,Greig, C.R.,Atherton, P.G.,White,E.T.,Murry,C.R. (1990). The performance of a new design of continuous centrifugal. Australian Soc. Sugar Cane Tech. 13th Conf.Proc. 232-244.
Korsse, J. (1996). Nickel chromium screens for the sugar industry. Brasil Soc. Sugar Tech. 6th Meeting.
Noble, A.G. (1992). Influence of slot configuration on the performance of laser-cut stainless steel centrifugal screens, Bingera Mill 1990 season. BSES Techn.Report, Queensland, Australia.(Confidential).
Noble, A.G. (1987). Factory scale trials with laser produced stainless steel screens, Bingera Mill 1987 season. BSES Techn.Report, Queensland, Australia. (Confidential).
Payne, J.H. (1992). Continuous low grade centrifugals. Int. Sugar Jrnl., v. 94, 298-300.
Prakash, S.P.K.,Mohan,R.M.,Rao,B.S. (1995). Trace metals in cane juice and sugar factory products; analysis by direct current plasma atomic emission spectrometry; Int. Sugar Jrnl., v.97, 362-369.

Vermeulen, P.L.M.,Mack,C.,Ramphal,R. (1986) Continuous centrifugal screen evaluation. S. Afr. Sugar Tech.Assoc.Proc. 47-51
Vermeulen, P.L.M.,Dairam,N.,Moodley,M. (1994). Evaluation of stainless steel laser-cut centrifugal screens. S. Afr. Sugar Tech.Assoc.66th Ann.Congress Proc.

Unpublished Data References

Avalos Ortiz, J. (1996) Written communication. Ref. JAO - 067/96. Ingenio Tamazula, Mexico.
Fioravanti Neto, J. (2000). Written communication. Report Ref G00/020, Usinas Itamarati, Brazil.
Kumar, R.,Singh, V.,Jain,R.K. (1996). Initial trials with laser cut stainless steel screen at C-foreworker centrifugals, Daurala Sugar Mills Internal Report - DCM Shriram India.
Singh, I. (2001). Written communication. Transvaal Sugar Limited, Malelane Mill, South Africa.
Somera, B. (1991). Written communication. Hawaiian Sugar Planters' Assoc. Project No. 22-7073.
Son, D.H. (2001). Written communication. Cheil Jedang Inchon Sugar Plant, Korea.
Zepeda Montiel, R. (2001). Written communication. Ingenio Adolfo Lopez Mateos, Mexico.