Chip-screening performance index

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The screen performance index gives a clearer picture of the trade-offs and their implications when comparing the performance of chip screens or chip screening systems.

Almost every time attempts are made to improve a system, the benefit is counteracted to some extent by a negative aspect. Most people find it difficult to compare a variety of alternatives by concurrently considering two opposing measures. Usually we try to combine them in some fashion to produce a single "index" value, which then allows ranking of the alternatives. For example, in a capital project, an expected dollar benefit cannot be captured without some expenditure of money. Since there are a variety of expenditures, each with various benefits, it is difficult to compare the alternatives without some index which ranks them on equal footing. In this example, we have measures such as return on investment which allow a valid comparison of various alternatives.

In a chip-screening operation we try to remove fractions of a given size from the rest of the flow. We can't do this 100% efficiently. Also, "acceptable" material will "contaminate" the rejects flow. For example, to efficiently remove fines, we must make the hole sizes so large that we will invariably lose some pin chips of acceptable size. If the goal is to remove chips that are too thick and send them back to be reprocessed, we will unavoidably introduce some chips of acceptable thickness into the flow.

Considering these tradeoffs, finding the most desirable operating point is not simple. Which would be better for a mill: a disk screen with 98% removal efficiency of overthick chips and 30% carry-over of accepts, or one with 70% removal efficiency of overthick chips and 2% carry-over of accepts?

Because of the difficulty of making such comparisons, we often concentrate on only one of the measures, usually the removal efficiency. This leads to opportunities for confusion when comparing offerings from different vendors, performance of existing systems, etc. We hear that one system gets 98% removal efficiency and that another gets only 50%, and may conclude the first is more desirable. But almost certainly the first system would have a high carry-over of accepts, and the second a very low carry-over. It is not obvious which of the systems would be better (economically) for a particular facility.

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This paper describes a method to calculate a single-number index value of screening performance. The method can be applied to individual pieces of equipment, or groups of equipment, or entire screening systems. To demonstrate the application of the method, data on various systems are displayed for reference and comparison.

Terminology

We will describe four categories of chips:

- Overthick (greater than 8 mm thick)
- Accepts (less than 8 mm thick but more than a 3-mm-round hole)[1]
- Pin chips (less than 7 mm round but more than a 3-mm-round hole)
- Fines (less than a 3-mm-round hole).

Overthick removal efficiency (ORE) is defined as the percentage of the overthick chips in the feed that are kept in the screen overflow headed for the chip slicer. It can be calculated for a single screen, for two screens acting together (e.g., gyratory-disk), or for a total system.

When screening for overthick chips, the undesirable contradicting process is the quantity of acceptably-sized chips "carried over" with the overthick flow. We don't want these chips to go to the slicer since they are already acceptably thin. Needlessly putting accepts through the slicer creates pins and fines and requires more slicer capacity to handle the flow. Accepts carry-over (ACO) is then defined as the percentage of the accepts in the feed that were carried along with the oversized chips.

For small particles we will discuss fines removal efficiency (FRE), defined as the percentage of the fines in the feed that are removed by the screen(s) or, alternatively, the relative reduction in fines in the system accepts compared to the feed.

For fines removal, the contradicting process is loss of acceptable material. Accept fiber loss (AFL) is defined as the percentage of the accepts in the feed that is removed in the screen fines flow.

[1]The definition of accepts in this paper includes pin chips.

Screen performance index for overthick-chip screening

To see how the performance indexing method is calculated, we will first illustrate an application of the method to screening for overthick chips. **Table I** lists examples of overthick-chip removal efficiencies and carry-overs of accepts for various systems.

It is difficult, from a listing such as this, to determine which system is "better" than another, much less select the "best" system. A graphic comparison of the trade-offs can be useful in sorting out the choices. **Figure 1** shows these data plotted with the two contradicting performance measures on separate axes. The goal is to have 100% overthick-chip removal efficiency, with zero carry-over of accepts.

Clearly, for a given overthick-chip removal efficiency, a lower carry-over of accepts makes a preferred system (all other things being equal). Likewise, for a given carry-over of accepts, a system with a higher overthick-chip removal efficiency gives better performance. However, when both change concurrently (as is usually the case), comparison becomes more difficult.

Imagine a line drawn on Fig. 1 which represents all combinations of overthick-chip removal efficiency and carry-over of accepts that result in chips having equal value to a particular mill ("iso-value" lines). Determining the exact position of these iso-value lines is difficult, but we can make a first-order estimate by making some simplifying assumptions.

First consider the extreme conditions. If we want 100% overthick-chip removal efficiency, then we might be willing to accept up to 30% carry-over of accepts to achieve this. If, however, we want absolutely no carry-over of accepts, then we might be willing to accept only 70% overthick-chip removal efficiency. If these assumed removals are applied to the feed material, one can calculate the composition of the system accepts under the various conditions. Assuming that either of these two conditions yields a chip mix to a particular process that has just about the same economic impact on the mill, they become endpoints of an iso-value line. For simplicity, we will also assume that the iso-value line is linear between these points. This specific iso-value relationship is shown in **Fig. 2** as the line labelled SPI = 70.

The equation describing all points on this line is:

$$\begin{aligned} \text{ORE} &= 70 + (1.0 \times \text{ACO}) \\ &= 70 + \text{ACO} \end{aligned}$$

If we assume that all other iso-value lines are parallel to this line, (i.e., they have the same rate of value change with performance measure trade-offs), then all lines have the same slope, in this case 1.0. The distinguishing difference in iso-value lines is then simply the intercept value. In this case, an easily calculable screen performance index (SPI) value is 70, because rearrangement of the equation to isolate the intercept value gives:

$$70 = \text{ORE} - \text{ACO}$$

Generalizing, in this simplest case the index value is simply the overthick-chip removal efficiency minus the carry-over of accepts. If for a given overthick-chip removal efficiency the carry-over of accepts decreases, the screen performance index increases; it produces more acceptable chips. Likewise, at a given carry-over of accepts, an increase in the overthick-chip removal efficiency also raises the screen performance index, again the correct direction. Other iso-value index lines also are shown at various levels in Fig. 2.

Table II shows the data from Table I with the screen performance index values added. This index value then allows immediate comparison of the relative performance of each system under various conditions. Each point on Fig. 2 also is labelled with its screen performance index value.

While we can debate whether the iso-value lines shown in Fig. 2 are, in fact, linear and parallel with a slope of exactly one, it is a reasonable assumption and a useful first-order estimate. The iso-value lines should be calculated specifically for each mill to the level of accuracy existing data and knowledge will allow.

To test the sensitivity of this screen performance index to cases where the equipment remains the same but the flow rates, screen hole sizes, and chip size characteristics change, we used a chip-screening computer model which is based upon extensive pilot-scale screening trials. We predicted overthick-chip removal efficiency and carry-over of accepts for a combined gyratory–disk system under "average" conditions, then varied, one at a time, high and low levels of loading rate, high and low overthick-chip and fines levels in the feed chips, and larger and smaller gyratory top-deck hole size. The results of this exercise are shown in **Fig. 3**.

The effect of these primary variables on screening performance can be seen quite clearly. The effect of gyratory hole size roughly follows an iso-value line; that is, trade-offs are made in overthick-chip removal efficiency and carry-over of accepts to yield similar screen performance index values and, by definition, approximately equal-value accepts.

The total mass rejected off the end of the disk screen changes dramatically as you move up and down a screen performance index iso-value line. As you move up an iso-value line, both the overthick-chip removal efficiency and carry-over of accepts increase; the total mass rejected increases significantly, and system elements must be sized to handle the load.

The fraction of the feed material rejected as overthick chips in the gyratory–disk system could be greatly reduced, yet similar performance achieved (as defined by the expected value of the resulting chips to the mill), by merely changing the gyratory top-deck hole sizes. This means you can relatively easily change the system capacity. For example, if the total average overthick chips in the feed increased, causing insufficient capacity at the existing slicer, you could relatively quickly and inexpensively increase the gyratory top-deck hole size and achieve a flow of accepts chips of the same value to the mill.

The effect of loading rate is similar in direction to that of hole size but much smaller in magnitude. This again supports the contention that the assumed iso-value lines are at least useful, if not absolutely correct, because a system tends to follow them as its mechanical parameters change. If this is also true for other equipment designs, alternative system layouts with different hole sizes,

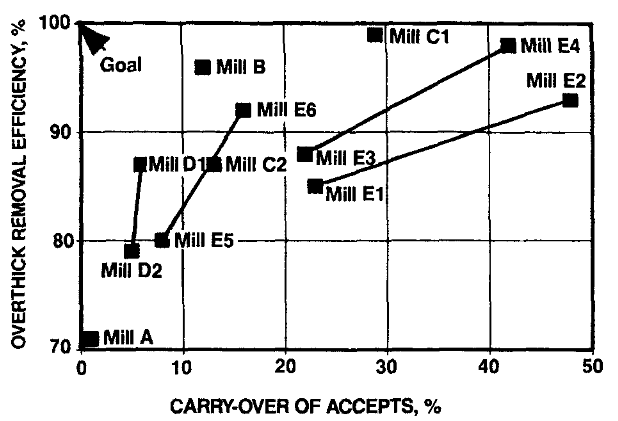
I. Observed chip-thickness screening results

Code	Screening system	Overthick chip removal efficiency, %	Carry-over of accepts, %	Comments
Mill A	Gyratory-Disk	71	1	Mill results
Mill B	Gyratory-Disk	96	12	Mill results
Mill C1	Flat disk	99	29	Pilot tests
Mill C2	V-disk	87	13	Vendor prediction
Mill C3	V-disk	80	20	Mill results, med. overthick
Mill C4	V-disk	71	19	Mill results, low overthick
Mill D1	V-disk	87	6	Mill results, new disks
Mill D2	V-disk	79	5	Mill results, after 2 years operation
Mill E1	Gyratory only	85	23	Average, southern pine, low feed rate
Mill E2	Gyratory only	93	48	Average, southern pine, high feed rate
Mill E3	Gyratory only	88	22	High overthick chips, southern pine, low feed rate
Mill E4	Gyratory only	98	42	High overthick chips, southern pine, high feed rate
Mill E5	Gyratory only	80	8	High fines, southern pine, low feed rate
Mill E6	Gyratory only	92	16	High fines, southern pine, high feed rate

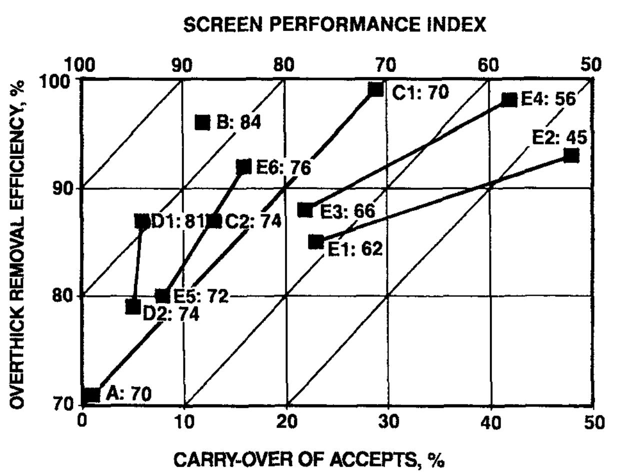
II. Observed chip-thickness screening results, with overthick-chip screen performance index added

Code	Overthick-chip removal efficiency, %	Carry-over of accepts, %	SPI, %
Mill A	71	1	70
Mill B	96	12	84
Mill C1	99	29	70
Mill C2	87	13	74
Mill C3	80	20	60
Mill C4	71	19	52
Mill D1	87	6	81
Mill D2	79	5	74
Mill E1	85	23	62
Mill E2	93	48	45
Mill E3	88	22	66
Mill E4	98	42	56
Mill E5	80	8	72
Mill E6	92	16	76

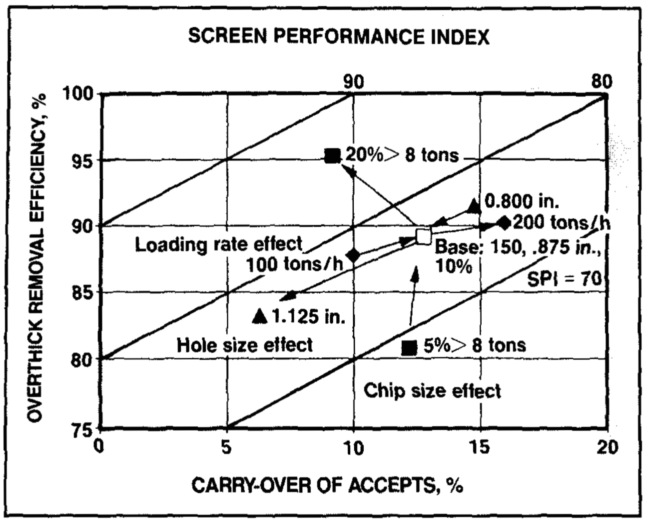
1. Overthick-chip performance for some screens



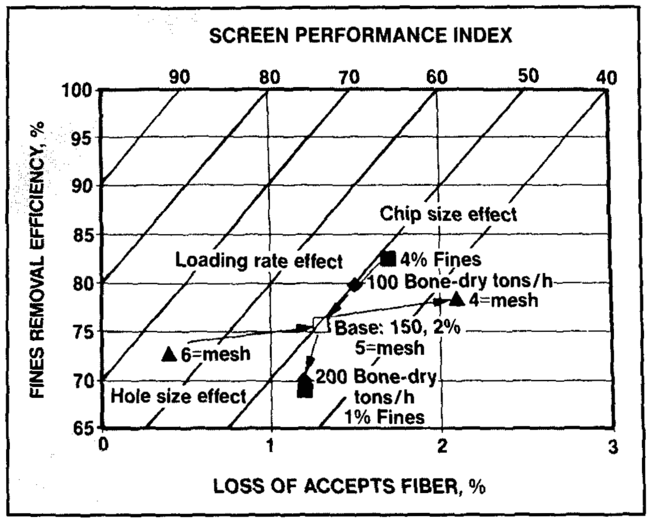
2. Conditions producing chips of equal value (iso-value lines) to a theoretical mill



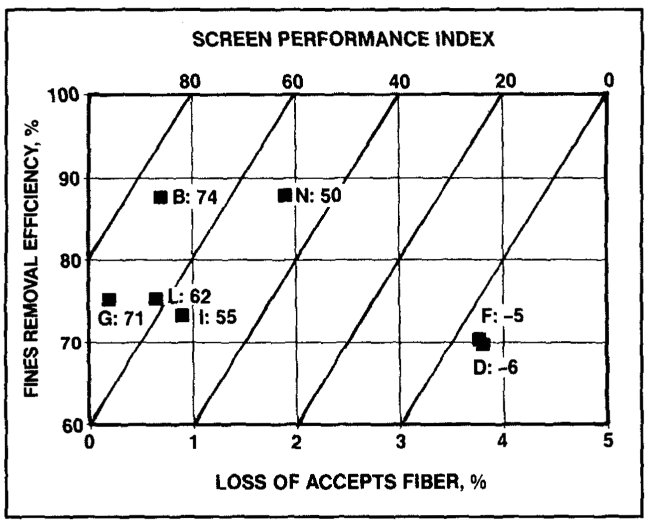
3. Effect on a gyratory screen followed by a disk for primary screening variables



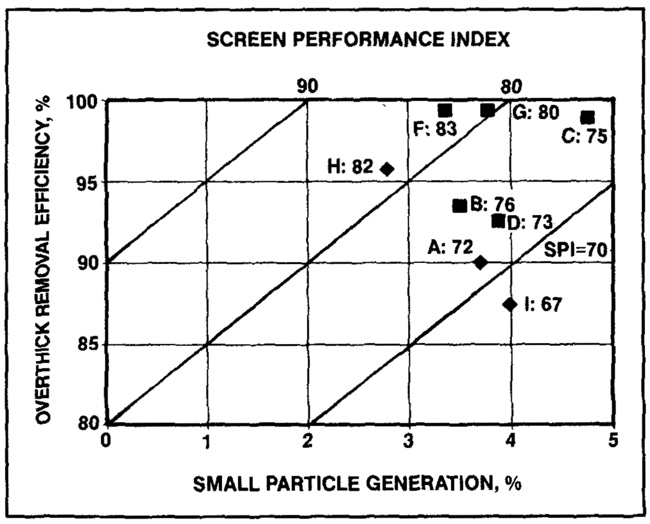
4. Effect of primary screening variables on gyratory screening for fines removal



5. Some screening performance index values for fines removal



6. Chip slicer performance index comparisons



loadings, etc., can be equitably compared merely by comparing the screen performance index values.

The effect of chip size distribution on the screen performance index is quite different from the other parameters. Not only is the response significantly nonlinear, but it often goes almost perpendicular to the iso-value lines. This means that screen performance index will not give directly comparable results between systems that have significantly different chip size distributions in the feed.

While this might seem to be a significant limitation of the screen performance index, it is hardly a surprising result. It is intuitively obvious that a given screening system would be more valuable to a mill when the overthick-chip level is high compared to when it is low. Similarly, a system should be more valuable to a mill which historically has high overthick-chip levels than to one which has low levels. Thus, the screen performance index is useful for comparing systems for a given chip flow at a specific site. As always, however, you must consider the feed chip size when comparing results reported from different mills, species, etc.

Screen performance index for fines screening

The same philosophy can be applied to fines removal, where the contradictory process is loss of accepts (generally, pin chips).

Since the desired process is fines removal efficiency (FRE), it becomes the y-axis variable in the performance index figure. The x-axis is the contradicting process—acceptable fiber loss (AFL). We can again view the situation based upon computer screening-model results to examine the effects of loading rate, hole size, and feed characteristics. This is shown for gyratory screening of Douglas-fir chips in **Fig. 4**.

To calculate the iso-value lines shown we decide what two extremes of performance might be about equally

III. Reported chip fines screening results, with fines screen performance index added

Code	Screen type	Chip source	Prescreen	*Fines removal efficiency, %*	*Accept fiber loss, %*	*Fines SPI, %*
B	Linear	Pulp chips	None	88	0.7	74
C	Rotary	Pulp chips	None	92	11.4	-137
D	Gyratory	Pulp chips	None	70	3.8	-6
E	Rotary	Pulp chips	5-mm Disk	78	20.9	-340
F	Disk	Rechipper	None	70	3.8	-5
G	Vertical	Pulp chips	7-mm Disk	75	0.2	71
H	Flex	Pulp chips	6.5-mm Disk	97	16.4	-232
I	Rotary	Pulp chips	4.5-mm Disk	73	0.9	55
L	Gyratory	Pulp chips	None	75	0.6	62
M	Roll	Gyrafines	5-mm diam.	94	48.6	-.878
N	Roll	Pulp chips	None	88	1.9	50

IV. Observed chip slicer performance results

Code	*Slicer manufacturer*	*Chip species*	*Slicer gap, mm*	*Overthick-chip removal efficiency, %*	*Pin-chip generation, %*	*Fines generation, %*	*Slicer small particle generation, %*	*SPI, %*
A	B	Douglas-fir	7.0	90	15	2.2	3.7	72
B	A	Douglas-fir	7.0	94	16	1.9	3.5	76
C	A	Douglas-fir	5.0	99	18	3.0	4.8	75
D	A	Douglas-fir	7.0	93	13	2.6	3.9	73
E	A	Douglas-fir	9.0	40	10	1.9	2.9	25
F	A	Hardwood	6.5	99	15	1.8	3.4	83
G	A	Softwood	6.5	99	17	2.1	3.8	80
H	B	Hardwood	6.5	96	13	1.5	2.8	82
I	B	Softwood	6.5	87	15	2.5	4.0	67

valuable to a particular facility. In a mill situation, these would be set by relative costs of chips and the alternative disposal of the screen fines, yield and quality impacts of the fines in the mill, etc. Here we will assume that if we desired 100% fines removal efficiency, then we would be willing to endure an accept fiber loss of about 1.5%. An approximately equal value option would be to remove only 70% of the fines but lose none of the accepts (AFL = 0). The equation for this linear iso-value line is then:

$$\text{FRE} = 70 + ((100\text{-}70)/(1.5) \times \text{AFL}) = 70 + (20 \times \text{AFL})$$

Rearranging to get a screen performance index value that is numerically equal to the intercept:

$$\text{SPI} = 70 = \text{FRE} - (20 \times \text{AFL})$$

This essentially weights the loss of each one percent of acceptable fiber at 20 times the value of each one percent of increased fines removal efficiency. Given the relative quantities of accepts and fines in typical flows, this is not unreasonable. Each other iso-value line is parallel to the SPI = 70 line and is identified by the intercept value.

In Fig. 4, we can see that the effect of hole size (woven wire mesh in this case) is not exactly parallel to the iso-value lines, so if the iso-value lines are correct for the facility, mesh selection could have a significant impact on the value of the screened chips produced by the system. In the case shown, the 6-mesh screen reduces the accept fiber loss to a level which more than compensates for the small reduction in fines removal efficiency and would be a better operating position for this facility.

The loading rate effect essentially parallels the iso-value lines, indicating that the system is not going to return chips of much different value regardless of how it is loaded (although low loading, as expected, is somewhat more preferable than high loading). This means, for example, that such a system could be sized based primarily on physical screen volumetric capacity, as opposed to basing it upon performance.

The effect of feed material concentration of fines has an effect very similar to the loading effect, with high fines levels giving a somewhat better performance index than low levels, just as was the case with overthick chips.

To illustrate how this method can be applied, some fines removal performance data from the literature[2] for different screen types with different feed materials are shown in **Table III**.

Screen performance index values have been calculated from their data by performing a mass balance based on the reported fines flow composition, assuming that no fines were created or lost during screening. Several cases reported in that paper[2] have been omitted here due to missing data or because of illogical mass balances (i.e., both the output flows had higher fines percentages than the input flow, which cannot happen unless fines were generated during screening).

The screen performance index values vary widely. This is due principally to the fact that the data are from various primary, secondary, and tertiary screening operations; the size distribution of the material fed to the screen varies widely. To give an equitable comparison of the fines removal efficiency and accept fiber loss, the screens would have to be compared on the same feed material, for example, feed to the entire system. **Figure 5** shows selected data from Table III that is in the realm of the primary fines screening operation we have been examining.

Figure 5 shows that, based strictly on performance, there are quite a range of performance values, and the field is not dominated by any single screening technology. Of course, this view doesn't take into account other factors which also must influence the final selection of screening technology; items such as purchase price, installation cost, maintenance costs, and runnability under adverse environmental conditions all will be a factor, but it does help simplify the comparison of one critical aspect of the situation.

Performance index for chip slicing

The performance indexing method also can be applied to another critical process in a chip-thickness screening system: the chip slicing operation.

Here the desired process is overthick-chip removal efficiency (the overthick chips are "removed" by slicing them to a thickness of less than 8 mm). Our y-axis in the performance index figure is then obviously overthick-chip removal efficiency. The contradicting process is generation of small particles, both fines and pin chips. Our x-axis in the performance index figure must somehow combine the two small particle generation effects into a single factor.

Generally, pin chips are not considered nearly as undesirable as fines. In addition, they are typically generated in slicing at levels about 6–10 times the magnitude of fines. To weight both of these effects, we can divide the percentage of pin-chip generation (PCG) by 10, and add it to the percentage of fines generation (FIG) to get an overall small particle generation (SPG) number. That is:

$$\mathrm{SPG} = (\mathrm{PCG}/10) + \mathrm{FIG}$$

On this basis, data for a variety of feed material types (species, overthick-chip levels, etc.) at different slicer gap settings and for slicers from two different manufacturers are shown in **Fig. 6** and **Table IV**.

Observation E, slicing for 8-mm removal with a 9-mm slicer gap, really isn't practical since the reduction in small particle generation is not significant for the dramatic drop in the overthick-chip removal efficiency; the point is off the scale in Fig. 6.

The iso-value lines here may be established by assuming that approximately equivalent values are achieved at 100% fines removal efficiency and 4% small particle generation or, alternatively, zero small particle generation and 80% fines removal efficiency. Thus, the equation for the iso-value line is:

$$\begin{aligned}\mathrm{ORE} &= 80 + (100 - 80/4) \times [(\mathrm{PCG}/10) + \mathrm{FIG}] \\ &= 80 + (5 \times \mathrm{SPG})\end{aligned}$$

As before, using the intercept as the label for the iso-value line, the value for this line is:

$$\mathrm{SPI} = 80 = \mathrm{FRE} - (5 \times \mathrm{SPG})$$

All other iso-value lines are parallel. By studying data similar to that in Fig. 6, we can draw conclusions about which slicer manufacturer is better, which slicer gap is better, etc., for a particular facility. Again, feed material characteristics have a significant impact on the performance index.

This view doesn't consider the other significant factors such as maintenance but, given correctly scaled iso-value lines, it does give a correct view of performance comparisons, which should be a very important factor in equipment selection.

Using screen performance index for system selection

So far, we have discussed performance indexing as applied to individual operations within a screening system. By using the same method, we can index the performance for a complete overthick-chip and fines screening system. The system performance index, including the slicer and recombination of flows into system accepts, can be calculated by using the overthick-chip removal efficiency for the overall system as the desired process and some combination of the net system pins and fines level as the contradicting process.

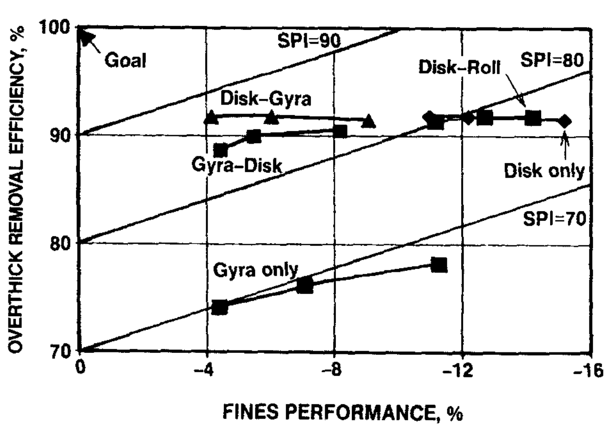
This method was used in a recent mill project to select the process equipment flow. The first step was to create a matrix of all conceivable (but reasonable) primary and secondary screening equipment alternatives. Considered, for example, were a flat disk primary with flat disk secondary, a gyratory primary with flat disk secondary, and a V-disk primary with no secondary. This resulted

[2]Smith, D. and Golgert, D., 1988 Pulping Conference Proceedings, TAPPI PRESS, Atlanta, p. 439.

V. System performance results for various configurations

System	Chip feed	Overthick-chip removal efficiency, %	Fines removal efficiency, %	Loss of accepts fiber, %	Fines performance, %	SPI, %
			Total system values			
Disk only	High fines	92	-10	0.0	-11	81
Disk only	Average	92	-22	0.0	-12	80
Disk only	High overthick chips	92	-52	0.0	-15	76
Disk-Gyra	High fines	92	66	0.4	-4	88
Disk-Gyra	Average	92	46	0.3	-6	86
Disk-Gyra	High overthick chips	92	12	0.1	-9	82
Disk-Roll	High fines	92	79	6.1	-14	78
Disk-Roll	Average	92	67	4.7	-13	79
Disk-Roll	High overthick chips	92	38	2.5	-11	80
Gyra only	High fines	74	63	0.3	-4	70
Gyra only	Average	76	35	0.3	-7	69
Gyra only	High overthick chips	78	-11	0.1	-11	67
Gyra-Disk	High fines	89	61	0.3	-4	84
Gyra-Disk	Average	90	49	0.2	-5	85
Gyra-Disk	High overthick chips	91	20	0.1	-8	82

7. Performance index comparisons for entire screening systems. Points in each set are, (left to right): high fines, average, high overthick chips.



in a matrix of 16 potential arrangements.

From this list, 11 of the alternatives were eliminated immediately for various reasons. Some combinations were illogical, some were known to have unacceptably poor performance at the same cost, some were judged to have excessive wear in use, etc. This left us with five alternatives to compare in more detail:

1. Flat disk screen only for overthick chips, no fines removal
2. Flat disk screen followed by a gyratory screen for fines removal
3. Flat disk screen followed by a knurled-roll screen for fines removal
4. Gyratory screen only for both overthick chips and fines removal
5. Gyratory screen followed by flat disk screen for both overthick chip and fines removal.

These alternatives were compared by predicting system performance for various conditions specific to the mill. Since we had observed that performance index values were relatively insensitive to machine loading and machine settings (hole size, etc.) but quite sensitive to feed-chip characteristics, we predicted performance of a single set of screen-hole-size conditions at the designed average loading rate for three of the mill's chip types (average, high fines, and high overthick chips).

The system performance predictions were based upon the best available empirical predictive equations for each machine type, which were invariably from pilot trials. Where possible, each equipment type—when used in different configurations—used identical predictive equations, maximizing the probability that predicted differences in performance were in fact due to the layout and fundamental equipment performance capabilities and were not the result of using different predictive equations in different systems.

In addition to performance, a major decision criteria which is relatively easy to quantify—the capital cost of equipment—was also estimated. Costs were estimated from prices in recent equipment quotes but were scaled for differences in equipment sizes among the alternatives. For example, gyratory screens were priced at a fixed cost per square foot of screen area, disk screens at a base cost plus a fixed cost per shaft thereafter, slicers at a unit cost per slicer, etc. While not absolutely correct, this approach should give very good relative costs among the alternatives. Although these cost estimates were essential to making the layout comparisons, they are not shown here since up-to-date values should be obtained separately for each project.

The overall system performance factor of significance to this project, to be used as the positive measure in the performance index, was overthick-chip removal efficiency. For the system, this is easily measured as the net mass quantity of overthick chips "missing" from the system accepts, relative to the amount in the feed.

The contradicting process, dealing with the amounts of pins and fines left in the system accepts, is rather complicated since it depends on the net effect of carry-over of accepts by the screen(s), the small particle generation in the slicer, and fines removal efficiency, if any, of the screen(s). Thus, the algorithm for the weighting of the small particle effect requires a more detailed explanation.

For the mill under consideration, we decided that fines removal was valuable. To put this on a scale comparable to the overthick-chip removal efficiency, it was scaled such that fines removal efficiency, expressed as a percentage, was reduced by a factor of 10. That is, each 10% increase in fines removal efficiency was judged to give accept chips equal in value to a 1% increase in overthick-chip removal efficiency. To arbitrarily adjust the index to simple intercept values, 10 was then subtracted from this value.

Pin chips were considered acceptable, and we wanted to retain them. To factor this into the equation, we judged that each percentage of the fines feed material that was lost with the screen fines was doubled for weighting, and this value subtracted from the overall screen performance index. The resulting equation is:

System screen performance index =
System ORE + [(0.1 × %FRE) - 10] -
(2 × AFL)

The data for each system for the three chip feed types is shown in **Table V** and **Fig. 7**.

Two of the system alternatives, a disk screen followed by a gyratory screen for fines removal and a gyratory screen followed by a disk screen for both overthick-chip and fines removal, have similar (high) levels of performance, but the former, due to higher capital and maintenance costs, higher disk screen wear, and an inability to alter the primary screen hole size, was much less desirable. For this facility, the latter option was clearly the preferred alternative, and it was selected for installation.

This example shows how very complicated data can be combined using an indexing scheme, which includes a particular mill's sensitivities, to make overall system performance selection decisions based upon the value of the resulting chips to that specific mill.

Summary and recommendations

The screen performance index has proven very useful for comparing different screening system alternatives. It can be applied to either individual pieces of equipment or total systems and is adaptable to the specific economics of each particular facility.

The benefit of using this indexing method relies heavily on the accurate location of the iso-value lines; they should be customized for each facility using the best information on relative value trade-offs that is available. This approach allows an equitable performance comparison among all the alternatives.□

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