Plant performance improvements using grinding circuit "classification system effciency"

by Robert E. McIvor

Abstract ■ Classification system efficiency (CSE) is a simple metric that can be used to measure and increase ball milling circuit efficiency. It is defined as the percentage of the ball mill energy being used to grind target (oversize) particles. This paper describes CSE analysis conducted for a variety of operations with related improvements in circuit efficiency ranging from 3 to 30 percent. The achievable CSE for any given ball milling circuit is described, providing the means to determine the extent to which every plant can benefit from increasing grinding circuit CSE.

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Abstracto ■ La "Eficiencia de Sistema de Clasificación (CSE por sus siglas en inglés)" es una métrica simple que puede ser usada para medir e incrementar la eficiencia del circuito de molienda con bolas. Está definida como el porcentaje de la energía del molino de bolas que se usa para moler las partículas objetivo (grandes). Este artículo describe el análisis CSE realizado para una variedad de operaciones con mejoras relacionadas con la eficiencia del circuito que puede ser de 3 a 30%. Se describe el CSE factible para cualquier circuito de molienda de bolas y además se proporciona los medios para determinar hasta dónde puede beneficiarse cada planta con el aumento del CSE de un circuito de molienda.

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Definitions and example calculation

The typical closed ball mill circuit to which CSE analysis can be applied is shown in Fig. 1. The extreme importance of the circulating load ratio (solids tonnage through the mill vs. the circuit) in determining circuit productivity was demonstrated by Davis (1925) and published by Gaudin (1939), as shown in Fig. 2. The circuit production rate increases with increased circulating load ratio, rapidly so at first and continuing to increase more gradually with higher circulating load ratio.

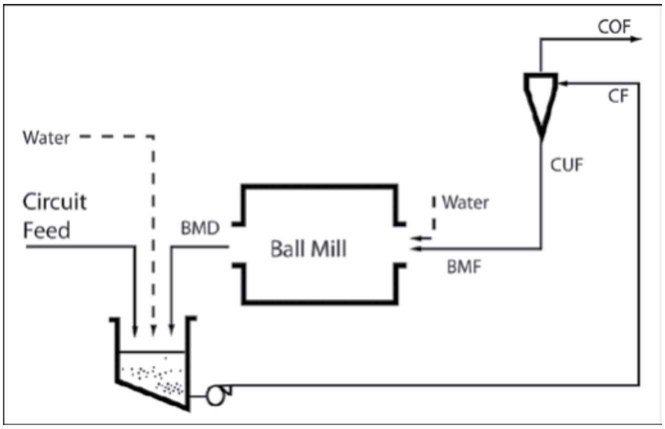
The underlying cause of this relationship is revealed by comparing the ball mill feed and product size distributions from two circuits, one with low and one with a high circulating load ratio (Fig. 3). While the two circuits' F80's and P80's were the same, the mill feed and discharge size distributions were very different. The mill with the higher circulating load ratio contained a much greater fraction of material coarser than the target P80, as shown by the respective mill feed and discharge size distributions. This fraction represents the fraction of the mill power being expended on "coarse" (say, the plus P80 size) material, defined here as circuit "classification system efficiency (CSE)." The "effective mill grinding power" is the total mill power multiplied by the CSE. The compliment of CSE, the remaining fraction of "fines" in

Robert E. McIvor, member SME, is chief metallurgist – Grinding Systems, Metcom Technologies, Inc. email: rob@metcomtech.com.

The pump (pictured), cyclones and mill work together to determine circuit classification system efficiency.

Figure 1

Typical ball mill circuit.



the mill, is the fraction of the mill power being wasted and spent on overgrinding, the "wasted/overgrinding mill power."

CSE can be used as the criterion for grinding circuit pumping and classification equipment design/optimization (McIvor 1988a and 1988b). It is calculated by taking the average of the percentage of coarse material in the ball mill feed and ball mill discharge. The cutoff size between coarse and fine material can be selected for any given circuit, but the cyclone overflow P80 size is generally suitable for these purposes. An example calculation of CSE follows:

- Cyclone overflow product sizing is 80 percent passing 106 µm.
- The ball mill feed is 60 percent plus 106 µm.
- The ball mill discharge is 50 percent plus 106 um.
- The circuit CSE is (60 percent + 50 percent)/2 = 55 percent. This is the estimated percentage of plus 106 µm solids in the ball mill, and also the percentage of the ball mill power effectively applied to the grinding of the coarse particles.

There are more sophisticated ways of estimating the size distribution of the mill contents, but this method has proven to provide a good relative measure of CSE for closed-circuit ball milling. Since CSE defines the useful percentage of the mill power draw, it is directly related to overall circuit efficiency and productivity. CSE is an absolute measure of efficiency, in the same way that motor output power is related to motor input power by the motor efficiency. For a mill motor directly connected to the mill drive pinion, the following relationships apply.

- Motor output power = input power x motor efficiency.
- Effective mill grinding power = motor output power x CSE/100.
- Wasted/overgrinding mill power = motor output power x (100 – CSE).

Also,

- Motor output power = effective mill grinding power + wasted/overgrinding mill power.

By increasing CSE, power that was going into overgrinding is converted into effective grinding power. In addition to increased circuit efficiency, this is important because overgrinding leads to reduced metal recovery in downstream processes sensitive to particle size, such as flotation (McIvor and Finch, 1991).

The following case study summaries are presented chronologically. They show how use of CSE has evolved from justification for increasing the circulating load ratio, where applicable, into a general tool for grinding circuit classification system optimization. The step-by-step procedures used to achieve desired CSE through manipulation of the pumps and cyclones are provided elsewhere (McIvor, 1989-2014, and McIvor, 2011).

Evaluation of increasing circulating load ratio at Craigmont Mines

Figure 3 presents the mill size distribution data reported by two operations grinding to similar circuit P80's. It suggests increasing the circulating load ratio at operations with a low circulating load ratio. To test this hypothesis on the Craigmont Mines grinding circuit, a computer model of the circuit was constructed using the population balance method prevalent at the time. It showed that increasing the circulating load ratio from 160 to 500 percent would result in an increase in circuit tonnage of 1.29 times. The comparative ball mill size distribution data showed that the CSE at 106 µm increased from 55 to 71 percent, also a factor of 1.29. Thus, this modeling study showed increased tonnage that was directly attributable to the increase in CSE (McIvor, 1988b).

Note that the wasted/overgrinding mill power fell from 45 to 29 percent. Factoring in the tonnage, it can be shown that the overgrinding energy fell by 50 percent per ton being processed, as follows. Say the initial mill power was 1,000 kWwhile the circuit was processing 100 t/h.

- Initial effective mill grinding power = 1,000 kW x 55 percent = 550 kW
- Initial wasted/overgrinding mill power = 1,000 kW x (100-55) percent = 450 kW
- Initial wasted/overgrinding mill specific energy = 450 kW / 100 t/h = 4.5 kWh/t
- New effective mill grinding power = 1,000 kW x 71 percent = 710 kW
- New wasted/overgrinding power = 1,000 kW x (100-71) percent = 290 kW
- New tonnage = 100 x 1.29 = 129 t/h
- New wasted/overgrinding mill specific energy = 290 kW / 129 t/h = 2.25 kWh/t

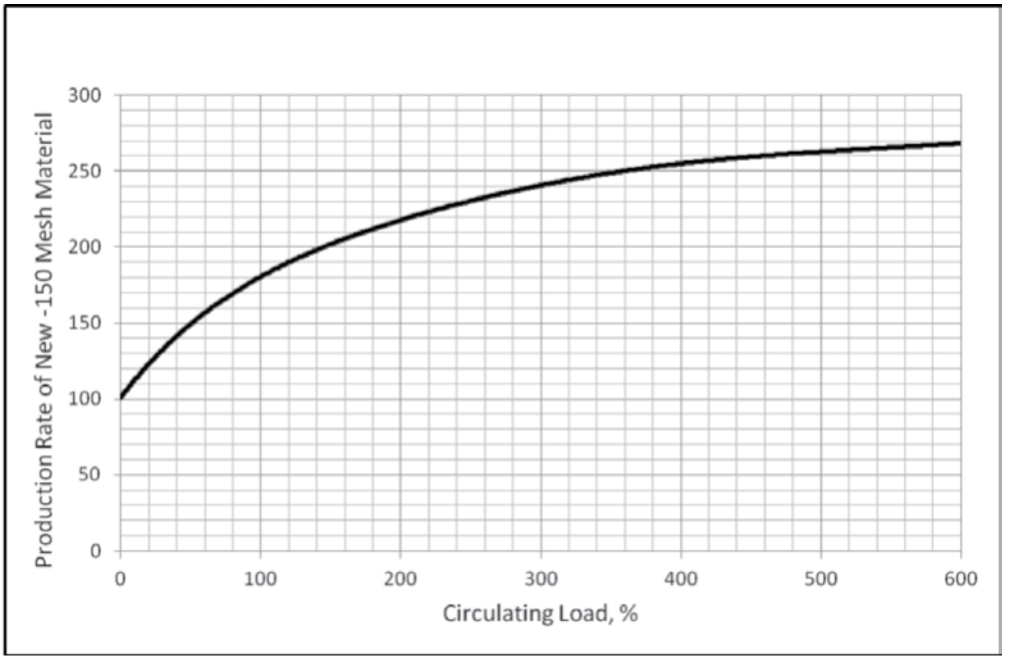
Table 1

Optimum* economic circulating load ratio analysis at Kidd Creek.

C. L. ratio, %	Relative circuit CSE, %	Relative operating costs (¢/ton processed) Grinding	Pumping/Class.	Total
250	93.4	57.4	5.2	62.6
350	98.1	54.6	6.7	61.3 (min.)*
450 (base survey)	100.0	53.6	8.2	61.8
550	102.4	52.3	9.7	62.0

Figure 2

Circuit production rate vs. circulating load (Davis, 1925; Gaudin, 1939).



Optimum economic circulating load ratio at Kidd Creek

When increasing pumping energy and pump and cyclone maintenance costs are balanced against decreasing grinding energy and media costs, all as circulating load increases, the optimum economic circulating load can be identified, as it was at Kidd Creek (Table 1). Limited availability of maintenance personnel meant that significant operating time was being lost for equipment maintenance. This was the first of two stages of grinding, so downstream processing effects were considered negligible. The circulating load ratio was lowered from approximately 450 to 350 percent through pump and cyclone adjustments. This resulted in decreased pump and cyclone wear and reduced downtime for maintenance, which more than offset the small loss in circuit efficiency. This demonstrates that it is the circuit economics that dictate the "optimum" design and operating conditions, rather than any specific technical performance criterion (McIvor, 1988b).

Table 2

Selbaie and Dome circuit survey comparisons.

Survey Ident.	Bond W.I. eff.	CLR	COF percent solids (w/w)	CSE @ P80
Selbaie No.2	101 percent	333 percent	42 percent (2.8 SG)	69 percent
Dome No.1	134 percent	313 percent	21.5 percent(2.8 SG)	85 percent

Table 3

Tilden pebble milling circuit performance with pump speed increase.

Pump RPM	CLR	COF percent solids (w/w)	CSE @ 25 um
750	144	6.1 percent	52.6 percent
835	173	5.8 percent	54.6 percent

Diagnosis of high circuit efficiency at Dome vs. Selbaie

Grinding circuit evaluations were carried out at two nearby locations, Les Mines Selbaie and Dome Mines, in northern Canada. During Selbaie Survey No. 2, the test work index of the ore and the operating work index of the circuit were essentially equal. During Dome Survey No.1, the circuit was using approximately 30 percent less than the expected Bond energy.

The Selbaie flowsheet is the same as that shown in Fig. 1. At Dome (Fig. 4), the primary cyclone underflow underwent gravity separation for gold, with significant water addition. This called for a second stage of cycloning to increase slurry density before the ball mill. It was shown that that CSE was the main contributor to the high Bond efficiency of the Dome circuit (Table 2). Simulation of the Selbaie circuit showed its CSE (at its respective P80) could be increased to 80 percent by water addition up to a similar cyclone overflow percent solids as Dome. Unfortunately, this could not be implemented due to required percent solids to flotation. The remaining five percentage points of CSE were attributable to two-stage, versus single-stage, classification.

Modified cyclone installation at Gibraltar

An outcome of investigations into the performance of the original rod-ball milling circuits at Gibraltar (Blythe, 1992) was the conversion to larger, inclined cyclones. The proposition was that CSE would be improved by improved water balance, the larger dimensions and inclination coarsening the cut size, while increased feed water would return it to the correct value for the desired P80 at the same circulating load, as well as potentially improve sharpness of reduced separation. Higher achievable underflow percent solids for cyclones in the inclined versus vertical orientation would also contribute to the improved water balance (reduction of bypass).

A survey on the test circuit recorded an all-time high value of CSE, approximately 15 percent (relative) above the average for 12 earlier surveys. This was associated with both the improved water balance and improved sharpness of cyclone reduced separation, as the circulating load ratio was unchanged. These cyclones were subsequently installed on all three circuits. CSE and overall ball milling circuit efficiency

Figure 3

Mill feed and product size distributions at high and low circulating loads.

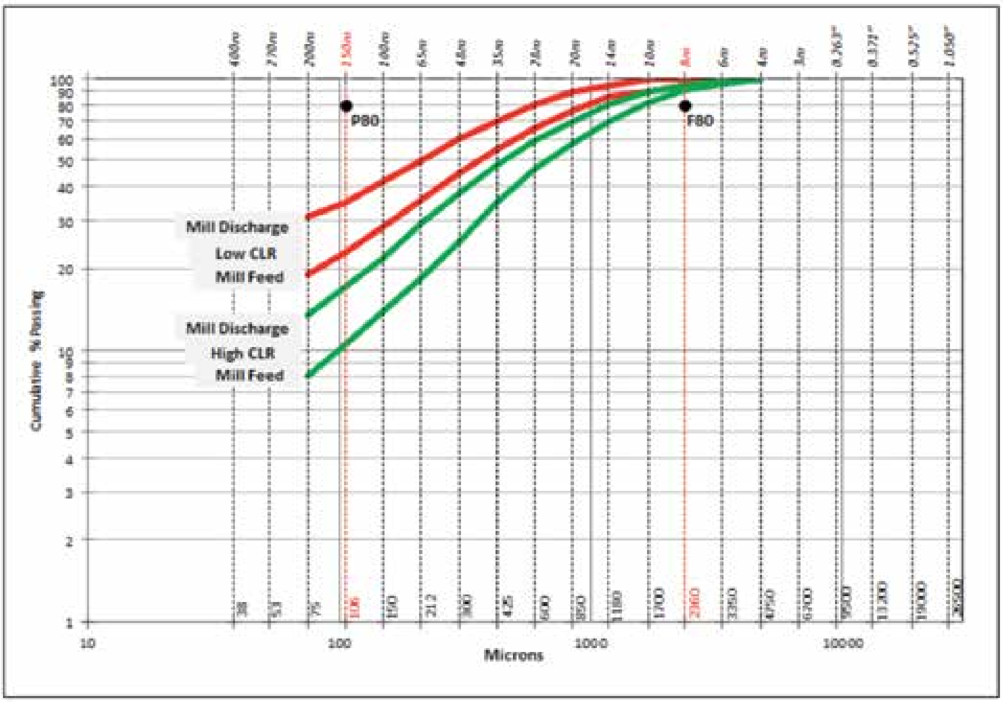


Table 4

Circuit improvements with added water and high-efficiency cyclones.

	COF % solids	Cyc. water rec. to U.F.	CSE @ 212 um	COF % - 212 um	COF % + 600 um
Reference Survey	51.5%	42%	56.6%	80%	2.3 %
Circuit Perf. Pred.*	47%	38%	60.9%	84%	0.1 %

increased closer to 10 percent, on average. With the 50-50 split of rod and ball milling power, the net result was a 5-percent increase in tonnage with no increase in mill powers (J. Hoffert, 1997).

Cyclone feed pump speed increase at Tilden

Consecutive surveys were carried out on a pebble milling circuit at the Tilden concentrator, interrupted only long enough to make a pump sheave change and for the circuit to stabilize. The control system was set to automatically add water to the cyclone feed sump to maintain level for this testing, and every endeavor was made to hold all else constant. However, the pump speed increase was associated with a slight increase in tonnage. Note that the P80 was measured to be 13 microns for both surveys, while CSE was traditionally evaluated at 25 µm for these circuits (McIvor et al, 2000).

The CSE increased by 2 percentage points, a relative increase of 4 percent. While small, this was determined to exceed the experimental error in the CSE measurements, which are simply based on mill feed and discharge size distributions.

New "high-efficiency" cyclones at Strathcona

Plant testing was carried out to establish cyclone separation performances for existing and a new generation of "high-efficiency" cyclones. These showed a significant improvement in the sharpness of the reduced cyclone separation curve, and fewer coarse oversize particles (relative to the P80 size) reported to the cyclone overflow (flotation feed). The flotation circuit at Strathcona was tolerant of slightly decreased percent solids, especially given the reduction in the amount of coarse particles. Adding more water was achievable with the existing pump because of the lower pressure drop characteristics of the new cyclones. A plant survey and a computer simulation of circuit performance with the higher efficiency cyclones and increased water addition were carried out. Circuit tonnage was held constant (McIvor and Finch, 2008). It provided the results shown in Table 4.

The cyclones were installed and the expected results have been achieved (Tuzun, 2008).

Evaluation of addition of a thickener for Barrick Gold

The need to feed carbon leach circuits at very high (50 percent w/w) percent solids, and the difficulty this presents for grinding circuit CSE, led to the request for a general evaluation of the effect of water addition rate on grinding performance. The key question was whether the difference in circuit efficiency with substantially more cyclone water addition could justify the installation of a thickener between the grinding and the carbon leach circuits. To carry out this evaluation, Selbaie Survey No. 2 was chosen as the basis for circuit performance simulations using the Finch-McIvor circuit modeling system (McIvor and Finch, 2008). The circulating load ratio (330 percent), underflow percent solids and overflow product sizing (percent minus 106 um) were held constant, while the cyclone water balance and sharpness of separation were changed to match the new water usage as cyclone overflow percent solids was lowered. Since the grind and tonnage was held constant, the resulting mill power requirement is then directly proportional to the circuit efficiency. The results are shown in Table 5.

Although not fully tuned and optimized, and also combined with a mill feed percent solids adjustment, rearranging the flowsheet to position a thickener ahead of carbon leach at Tulawaka facilitated lowering the COF percent solids initially from approximately 47 to 35 percent solids by weight. This has resulted in achievement of unprecedented fineness of grind (6 to 11 percentage points finer on 106 µm) and approximately a 2-percent increase in gold recovery (Frostiak, 2007).

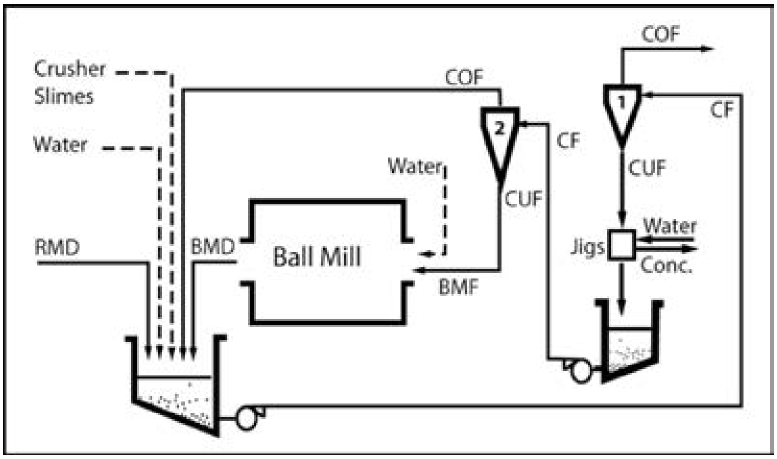
Table 5

Grinding circuit steady state conditions at different COF percent solids.

COF % sol. w/w	Cyc. feed % sol. v/v	Cyc. water rec. to U.F.	Mill kW	CSE @ 106 µm	Rel. circ. eff.
50%	42%	49%	580	64%	Base Line
42% (B2)	38%	41%	523	71%	+11%
40%	37%	39%	515	72%	+12.5%
30%	30.5%	29%	478	78%	+22%
20%	23%	20%	454	82%	+28%
10%	13%	10%	430	86%	+34%

Figure 4

Dome Mines, grinding circuit.



Achievable CSE

Table 5 provides achievable CSE as a function of cyclone overflow percent solids in a circuit using traditional cyclones with a circulating load ratio of 330 percent. It, therefore, provides plant metallurgists with a readily achievable target value for the CSE of their ball milling circuit(s) (excluding fine regrinding). For example, a ball mill circuit ahead of flotation requiring 40 percent feed solids can readily attain a CSE of 72 percent. By comparison with their current CSE, the scope for increased circuit efficiency can be determined. Pump and cyclone adjustment steps, including the roles of circulating load ratio, cyclone water balance, and cyclone design features affecting sharpness of separation and capacity, are provided elsewhere (McIvor, 2011).

Summary and conclusions

CSE provides a direct, absolute measurement of the efficiency of the ball mill circuit classification system. Increasing CSE provides increased grinding circuit efficiency while reducing overgrinding.

CSE was initially utilized to optimize grinding circuit circulating load ratio. It is now also used to explore the benefits of increased cyclone water usage and the use of modern "high-efficiency" cyclones. It can be used to define the benefits of any changes to circuit pumping and classification equipment.

These case studies demonstrated improvements in CSE varying from 3 to 30 percent. Every plant ball mill circuit can similarly be evaluated for the potential benefits offered by increasing its CSE. ■

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