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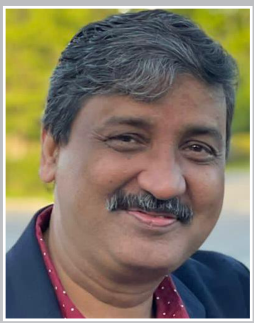
# Kraft Mill variability and efficiency benchmarking



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***Abstract:* Although the process fundamentals are very similar across many Kraft mills, process variability and efficiency key performance indicator (KPI) values vary widely within the industry. When values for these KPIs from a large number of mills are compiled, a benchmarking plot can be generated. It is useful to observe a particular mill's position on the benchmarking curve when determining where improvement opportunities may exist. This allows mills to prioritize their optimization efforts based on benchmarking and risk versus rewards equation. This leads to the most efficient application of money and resources for process improvement.**

***For over seven years, BTG Process Solutions has been compiling KPI data from a wide range of partner mills globally. This data includes process areas such as cooking, bleaching, recovery boiler, lime kiln, and recausticizing. KPIs are focused on process variability, energy efficiency, chemical usage, and other economic and environmental drivers.***

***Several examples of KPI benchmarking plots are presented in this paper along with discussion of pertinent solutions for different unit operations that kraft mills can implement to capture opportunities, thus moving "up" the benchmarking curve. Economic and environmental benefits are also discussed.***

***Key words:* Benchmarking, KPI, Kraft Pulp, Cooking, Bleaching, Recovery Boiler, Lime Kiln, Recausticizing, Variability, Efficiency, Unit Operations**

## Introduction

When Kraft pulp producers consider their mills' process performance, the question is often raised - how do we compare to others in the industry? This concern applies to many performance metrics, as the basic unit-operation design and configuration is very similar across many mills around the world. Even though every mill is unique due to its raw material, process design, equipment setup, process control strategies etc, key performance indicators (KPIs) related to variability and efficiency can be directly compared from one mill to another. Larger companies with multiple mill facilities often make these comparisons internally.

However, few organizations have the opportunity to compare KPI values against a large number of mills from all over the globe. BTG Process Solutions has provided hundreds of mills with statistical data analysis to identify opportunities for improvement via Advanced Process Control. The KPI results of these analyses since 2015 have been compiled into benchmarking plots including large numbers of mills for comparison. Data points are not labeled with specific mill names or identifying information, thus keeping each mill's data confidential.

The KPIs captured in these benchmarking plots vary by process area. Some examples are:

| | |
|---|---|
| Cooking | Kappa Coefficient of Variability (C.V.)<br>H-Factor Coefficient of Variability (C.V.) |
| Bleaching | Final Brightness Coefficient of Variability (C.V.)<br>Total $ClO_2$ Dosage<br>Total NaOH Dosage |
| Recovery Boiler | Furnace Oxygen Standard Deviation |
| Lime Kiln | Specific Energy Consumption |
| Recausticizing | White Liquor TTA and Causticizing Efficiency (%CE) on Goodwin's Curve<br>White Liquor TTA Coefficient of Variability (C.V.)<br>White Liquor Causticizing Efficiency (%CE) Coefficient of Variability (C.V.) |

*Table 1: Benchmarked KPI Examples*

Based on the results of KPI benchmark comparison and evaluation of mill-specific economic drivers and operational constraints, solutions can be developed to achieve maximum benefit for minimum cost. In many cases, relatively small investments in process instrumentation and/or Advanced Control systems can drive significant reductions in variability, increase process efficiency and productivity and in many cases remove a mill bottleneck. These serve to improve a mill's position on the benchmarking curve, making it more competitive in today's challenging business environment.

### METHODS

Timeseries data were collected from mills in tabular form. Aggregates were typically 15-min, 30-min, or 1-hour averages, depending on the process area and the mill's data historian capabilities.

Statistical analyses were performed on these data using Microsoft Excel. Datasets were filtered to remove unit operation downtime and any other periods deemed severely "abnormal" (due to some special circumstance that was not expected to be repeated). Individual parameter data were also filtered to remove high and low outliers and any periods during which the reading was un-responsive or when process conditions were non representative. Using the filtered data, statistics were calculated as follows:

| | |
|---|---|
| Average | Excel AVERAGE() function |
| Standard Deviation | Excel STDEV() function |
| Coefficient of Variability (C.V.) | [Standard Deviation]/[Average]*100% |

*Table 2: Statistical Calculations*

Resulting KPI values were entered into benchmarking tables for each process unit operation area. The Excel (RANK) function was utilized to generate rankings for each mill, and X-Y plots were generated of KPI value vs. rank. These are the benchmarking plots presented in this paper.

## RESULTS AND DISCUSSION

### Cooking:

Cooking is the heart of pulp making – any mistakes made in cooking are very expensive to fix downstream. Kappa is almost universally considered the primary KPI for the Kraft cooking process. Although Kappa targets vary widely based on wood species and the intended use of the pulp, Kappa variability should always be minimized. Low Kappa variability not only indicates an efficient cooking operation with consistent yield and efficient use of steam and alkali, but also leads to smoother operation of downstream processes such as bleaching and paper-making.

Since Kappa targets vary from roughly 15 for bleached pulp to over 100 for brown packaging grades, variability must be considered on a relative basis. Thus, the benchmarking plot shows the Kappa Coefficient of Variability (C.V.), which indicates variability as a percentage of the absolute average.

Each point on the plot represents a single fiber line; some mills have more than one fiber line at a single location, but each are considered separately. Points near the lower-left exhibit low Kappa variability, indicating excellent operation. Points near the upper-right represent high Kappa variability, and likely leave a large opportunity for improvement.

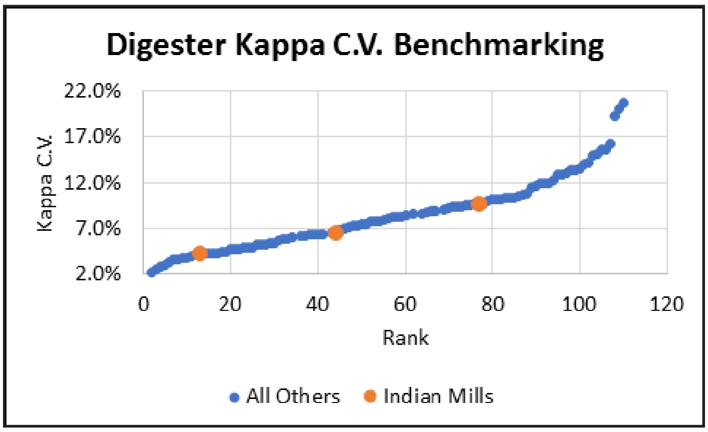



*Figure 1: Digester Kappa C.V. Benchmarking*

Data for three Indian Kraft mills were available – their positions are spread out along the lower two-thirds of the Kappa C.V. benchmarking curve. It is also important to note that data with lab testing vs online kappa measurement have a very low variability (due to frequency of measurement) and can be deceptive. Since kappa represents the yield, higher variability and shifting kappa targets has a major economic implication to a mill's survival index.

H-Factor variability is also an important consideration in Kraft Cooking. H-Factor is a measurement of the temperature-time component of the cooking phase, and typically has a strong influence on Kappa. Not all mills calculate and report H-Factor values, so the benchmarking dataset is smaller than that of Kappa.

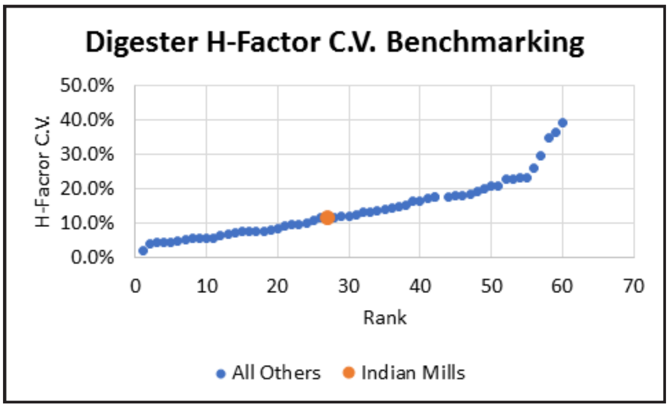



*Figure 2: Digester H-Factor C.V. Benchmarking*

The only Indian mill with H-Factor reported shows C.V. ranking just below the median along the benchmarking curve.

Mills with high Kappa variability can benefit from implementation of an improved advanced control system. If Kappa measurement is by Laboratory only, or if the existing Kappa analyzer is malfunctioning or has a long sampling interval, installation of a continuous online Kappa analyzer such as BTG's Single Point Kappa (SPK) can dramatically improve feedback for Kappa control. With continuous and reliable Kappa measurement, further variability reduction can be achieved with a multi-variable predictive model-based advanced control system such as BTG's MACS MPC. This type of advanced control can also improve H-Factor variability. A matrix of process inputs and outputs such as chip meter speed, alkali charge, circulation flows, circulation temperatures, blow flow, residual alkali, H-Factor, chip level, and Kappa are incorporated into the controller. Figure 3 displays an example of a typical digester installation, the manipulated variables are shown in blue, controlled variables are shown in yellow, and feedforward variables are shown in green.

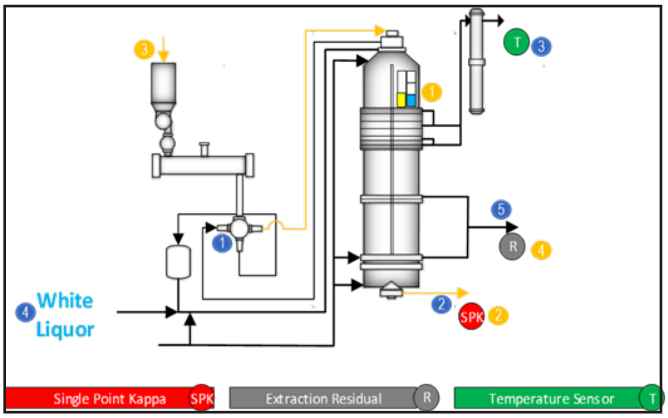



*Figure 3. Example Kraft cooking MPC Control Overview*

With reduced Kappa variability, the Kappa target can be shifted higher or lower (depending on a particular mill's economic optimum) without exceeding the specification limits. This translates into yield improvement and/or downstream chemical savings and increased recovery boiler steam generation.

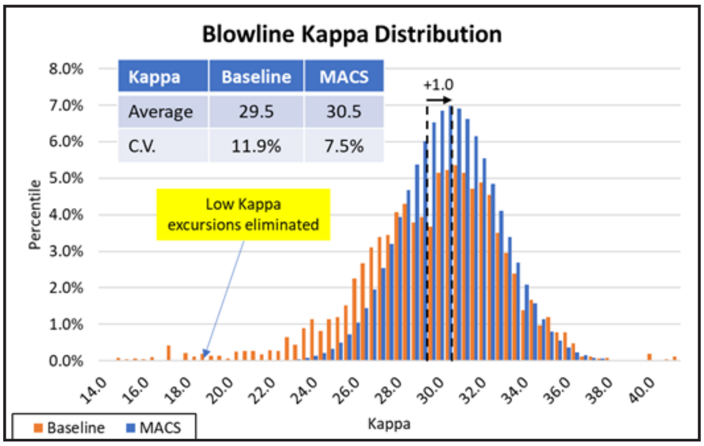



*Figure 4: Digester Kappa variability reduction example with target-shift*

**Bleaching:**

Bleach Plant benchmarking is complicated slightly by the differences between various bleaching sequences employed by mills around the world. However, comparisons can be made if mills are grouped by common bleach sequence. For the example presented here, we will focus on mills utilizing the DED sequence, which is most common.

Final Brightness variability is perhaps the most informative parameter for benchmarking, but $ClO_2$ and NaOH dosages are also important, as they are typically the largest cost drivers in bleaching. Similar to digester Kappa, relative Brightness variability should be utilized for benchmarking so that variations in Final Brightness targets do not impact the results.

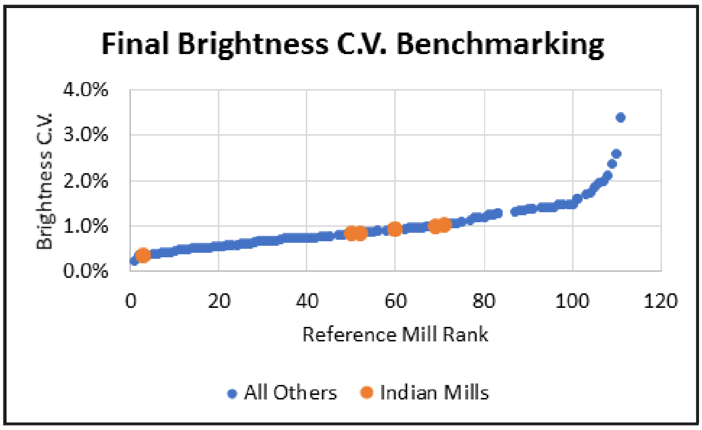



*Figure 5: DED Bleaching Final Brightness C.V. Benchmarking*

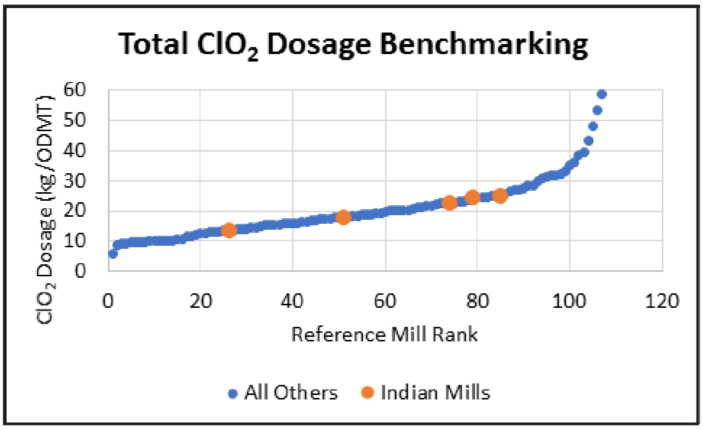



*Figure 6: DED Bleaching Total ClO2 Dosage Benchmarking*

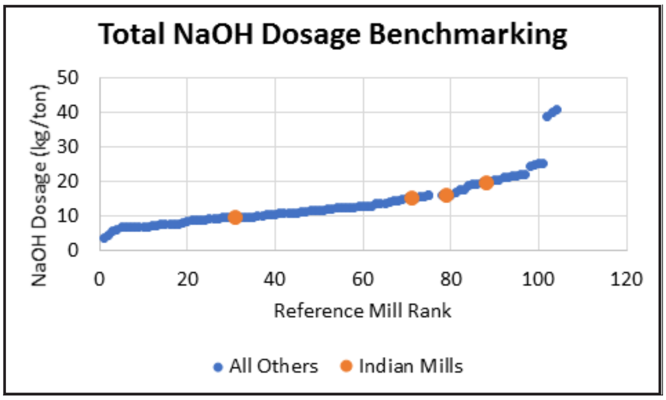



*Figure 7: DED Bleaching Total NaOH Dosage Benchmarking*

Most of the Indian mills included in the DED Bleaching benchmarking fall near the center of the benchmarking range, with the notable exception of one which exhibits very low Final Brightness variability, due to lab measured brightness and not inline brightness measurement.

Advanced control solutions, including a full suite of Brightness, Kappa, and Bleach Load measurement at D0, E-Stage, and Final Bleached pulp can serve to reduce variability and chemical dosage via multi-variable optimization. The plot below shows an actual example of how BTG's MACSbleach optimized chemical usages to reduce cost across the incoming Kappa spectrum.

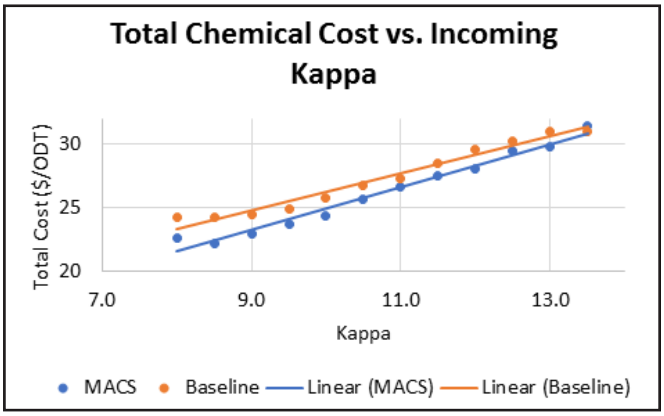



*Figure 8: Example of MACSbleach chemical usage reduction*

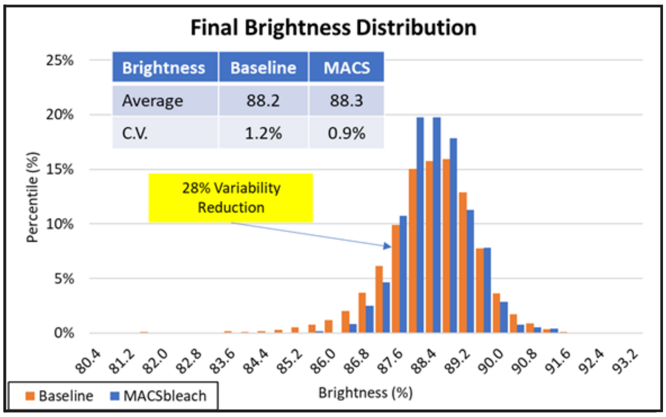



*Figure 9: Example of MACSbleach Brightness variability reduction*

In the MACS bleach plant solution, each stage efficiency and $ClO_2$ loading is optimized throughout the plant to reduce the final brightness variability and reduce the final brightness target while ensuring not to increase off-grade product. Figure 9 displays a typical 3 stage bleach plant implementation. The manipulated variables are shown with blue numbers, controlled variables are shown with yellow numbers, and feedforward variables are shown with green numbers.

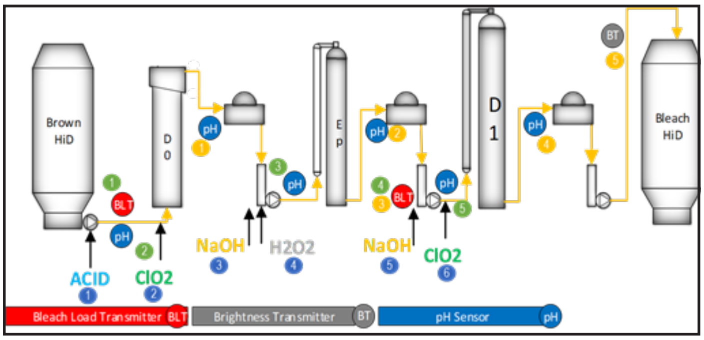



Figure 10. MACSbleach Solution Overview

Final Brightness variability is also reduced via MACS bleach, allowing a shift up or down (depending on the mill's goals) within the existing range of operation. Typical chemical savings of 2-5$/T and final pulp variability reduction of 25-50% are very common.

**Recovery Boiler:**

Size, physical configuration, steam pressure, and many other factors vary widely among recovery boilers across the Kraft pulp industry. However, one thing they all have in common is the need for good control of the air/fuel ratio, which is most often determined by measuring the excess oxygen content of the flue gas leaving the furnace. Since boiler efficiency is directly related to excess oxygen, wide variations in excess oxygen lead to wasted energy, lost production, and other operational challenges.

The benchmarking plot for recovery boiler excess oxygen standard deviation is shown below. Since excess oxygen targets should be similar for most boilers, there is no need to normalize this variability statistic.

Based on the plot in Figure 11, boilers with oxygen standard deviation below 0.5% are world leaders, while those with standard deviation greater than 1.0% likely have a significant opportunity for improvement.

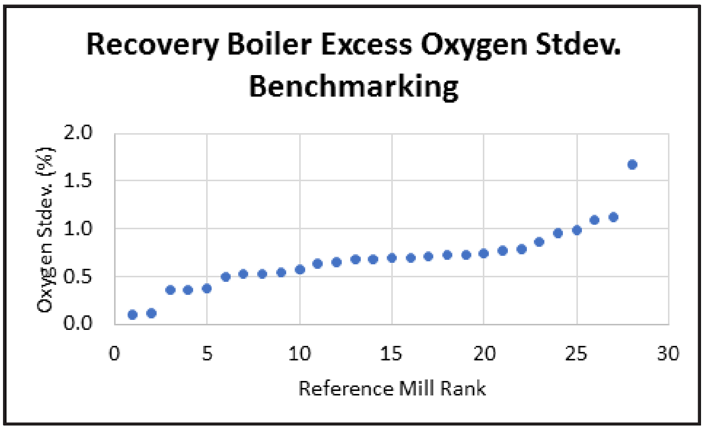



Figure 11: Recovery boiler excess oxygen standard deviation benchmarking

MACS recovery provides a solution for variability reduction, efficiency, and productivity improvement for recovery boilers. Figure 12 displays an example of a typical recovery boiler installation, the manipulated variables are shown in blue, controlled variables are shown in yellow, and feed for ward variables are shown in green.

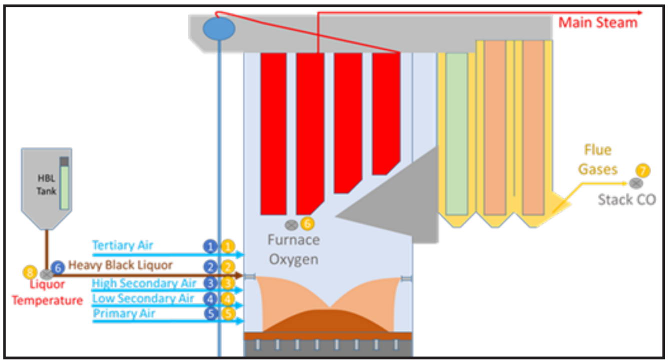



Figure 12. MACSrecovery Solution Overview

**Lime Kiln:**

Energy is the primary cost input for re-calcining lime in a Kraft mill and is considered to be the third biggest variable cost in pulp making after wood and chemicals. Benchmarking the specific energy usage (GJ/ton) for a large set of mills is helpful to determine a mill's overall efficiency compared to others around the globe.

Only one Indian lime kiln is included in the current benchmarking set, but its specific energy ranks near the lowest.

Improving lime kiln energy efficiency requires coordinated control and optimization of mud, air and fuel flows, while maintaining the correct temperature profile and excess oxygen target. Environmental emission constraints must also be respected at all times. MACS kiln is a proven

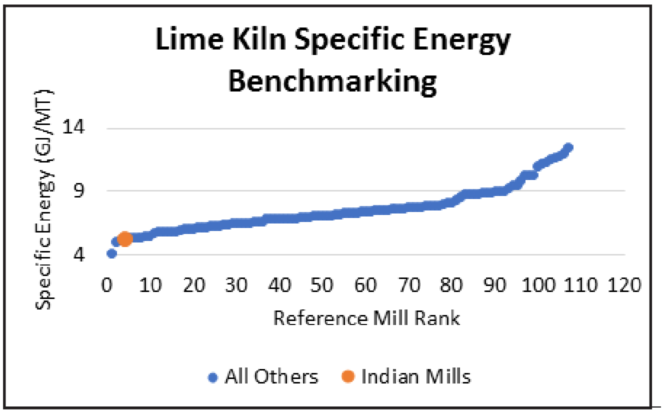



Figure 13: Lime kiln specific energy benchmarking

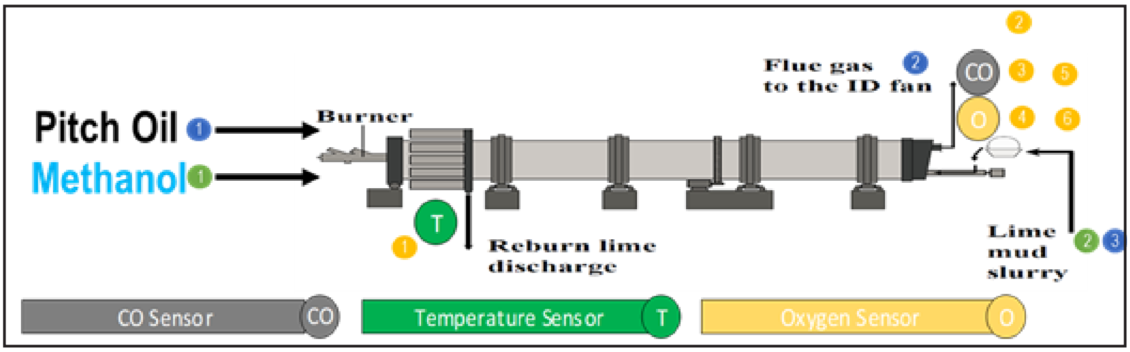



Figure 14. MACS kiln Solution Overview

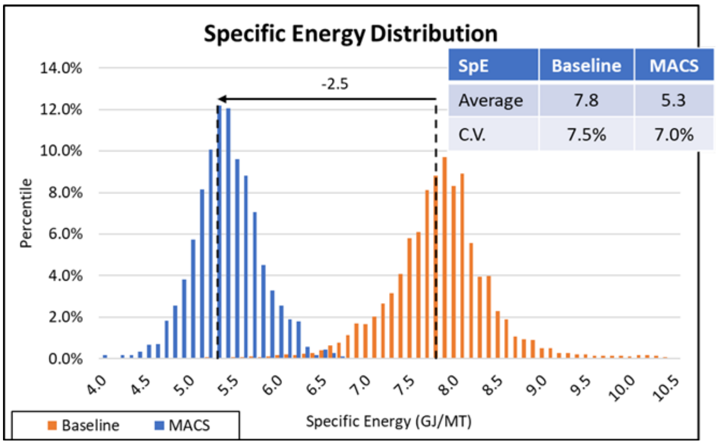



*Figure 15: MACSkiln specific energy reduction example*

strategy for improving efficiency while reducing lime quality variability. Figure 14 displays an example of a typical lime kiln installation, the manipulated variables are shown in blue, controlled variables are shown in yellow, and feed for ward variables are shown in green.

The plot in Figure 15 above shows actual results of MACS kiln implementation – this mill was able to make a significant move down the specific energy benchmarking curve, yielding substantial energy cost savings.

**Recausticizing:**

Two primary parameters that are critical in the recausticizing process are Total Titratable Alkali (TTA) and Causticizing Efficiency (%CE). TTA indicates the total concentration of sodium compounds capable of participating in the causticizing reaction. %CE refers to the degree of reaction achieved in the Slaker and Causticizers – higher %CE drives the reaction closer to its theoretical equilibrium limit. Goodwin's Curve is a plot showing the equilibrium curves at various sulfidity levels, with TTA on the x-axis and %CE on the y-axis as shown in Figure 16. When we plot a benchmarking data set alongside Goodwin's Curve, we can judge how much opportunity a mill may have to increase TTA, %CE, or both.

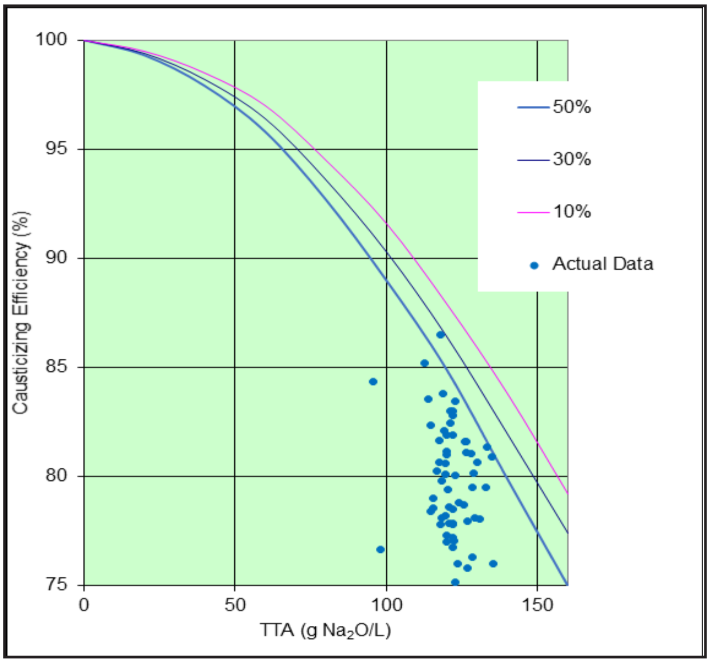



*Figure 16: White Liquor benchmarking alongside Goodwin's Curve*

Mills whose operating point is far from the equilibrium curve compared to others likely have an opportunity to shift to a higher TTA or %CE target.

*Figure 17: White Liquor TTA C.V. benchmarking curve*

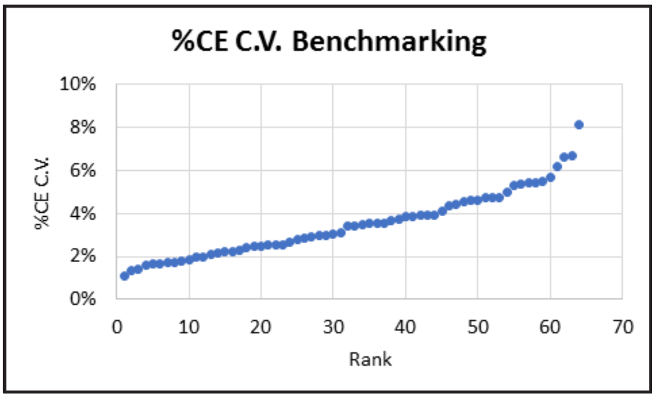


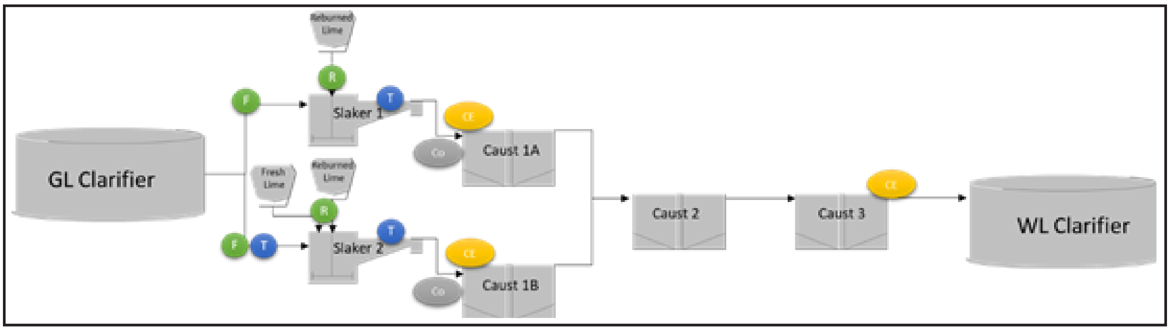

*Figure 18: White Liquor %CE C.V. benchmarking curve*

This can save significant energy and chemical makeup costs, but in many cases variability reduction is required to achieve the desired target shift without over-liming at times.

We can also plot the TTA and %CE variability benchmarking data to help gauge a mill's overall control performance.

Automation of the recausticizing process with a tool such as MACSrecaust can drive variability lower, allowing a mill to shift its average TTA and %CE closer to Goodwin's Curve equilibrium. Figure 19 displays an example

*Figure 19. MACS recaust Solution*



of a typical re-causticizing plant installation, the manipulated variables are shown in blue, controlled variables are shown in yellow, and feedforward variables are shown in green.

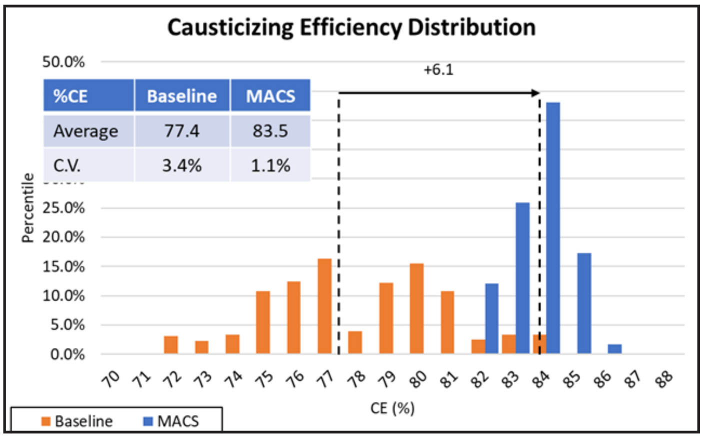



*Figure 20: White Liquor %CE variability improvement via MACS*

An example result is shown below.

## CONCLUSION

Benchmarking variability and efficiency KPIs is a useful tool for evaluating a mill's performance. However, few resources are available which compile a large set of data from across the globe. BTG's data analysis efforts have facilitated development of very comprehensive benchmarking datasets for a variety of Kraft mill KPIs. These data can be used to generate benchmarking plots so mills can compare their results to the industry at large.

For mills who desire to improve their position on the benchmarking curves, advanced process control solutions such as BTG online analysis instruments and MACS advanced control can provide rapid return on investment. Improved control reduces variability, allowing target-shifts to more economically optimum operating conditions without exceeding process constraints.