The chemical versus energy cost tug of war: A pulp mill perspective

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ABSTRACT: As the cost of energy and processing chemicals changes, the optimal, lowest cost operating conditions within a pulp mill also change. Additionally, the optimal cost operating point within one area of the mill may not result in a total mill low cost operation. Three practical pulp mill examples have been analyzed under varying cost constraints for energy and chemicals to determine the impact of energy and chemical cost changes on the low cost operating point. These examples include changing the digester kappa number target, changing the brownstock washing dilution factor, and the conversion of a continuous digester from one type of cooking process to a lower energy cooking process. Selected mill operating results and laboratory data were employed to tune various process simulation models to obtain cost predictions over a wide range of operating conditions.

Application: The use of an up-to-date process model in conjunction with current chemical and energy prices may be used to minimize the process operating costs of a mill. A full scale mill model will help avoid sub-optimization of specific operating areas.

Many pulp mills tend to operate with production targets that have either been set many years ago or have simply developed as tribal knowledge about how a specific mill runs best. Many of these targets (e.g., kappa number from the digester, amount of extraction flow from the digester extraction screens, amount of applied wash water, conductivity going into the bleach plant, and amount of bleaching chemical applied in various bleaching stages) have a direct impact upon the variable operating cost of the mill. More importantly, it is extremely easy to sub-optimize overall cost performance by optimizing the cost structure in one area of the mill while neglecting other areas. A typical example of sub-optimization would be a mill endeavoring to minimize bleaching cost without accounting for the impact upon woodyard or evaporator costs [1].

For several decades, these types of operating targets have served pulp mills reasonably well because chemical and energy costs tended to change slowly and they also tended to change relative to each other. A few years ago, the trend of slow and relative changes to chemical and energy costs was broken by a rapid escalation in energy costs [2]. Partially, as a result of rapidly escalating and volatile energy costs, many mills focused upon mill wide energy reduction projects during the mid 2000s [3,4]. Recently, chemical prices have also started to experience radical and erratic price escalations. Typically cheap commodity process chemicals have experienced several fold price increases. For instance, sulfuric acid, a traditional, long term low cost commodity, has experienced a several hundred per cent price increase due to its use in fertilizer production [5]. Caustic, another long term, historically inexpensive process chemical, has experienced price escalation of over 100% due to the chlorine-caustic imbalance resulting from the dramatic slowdown in new home construction [6]. Many other chemicals have also substantially increased in price due to changing demand and increased energy costs.

One result of these rapidly fluctuating and increasing prices of energy and commodity chemicals is that traditional process and operating targets may no longer be cost optimal for a mill. During these times of active chemical and energy price movement, accurate material and energy balance process models should be routinely used to determine the most cost effective operating targets for the pulp mill. It is important to consider the overall mill cost balance with these programs and not focus solely on pulp mill costs when determining the optimal variable cost production targets for specific process areas.

As an illustration of the potential impact of changing production costs on the optimal operating targets, three mill based case studies have been examined. These include a determination of the cost optimal dilution factor, determination of the most cost effective digester kappa number, and the impact of a capital modification to change the operation of the continuous digester from Lo-Solids EMCC (Andritz; Graz, Austria) operation to DownFlow (Andritz; Graz, Austria) cooking. Detailed mill and laboratory data were used to tune various process models employed in the current analysis.

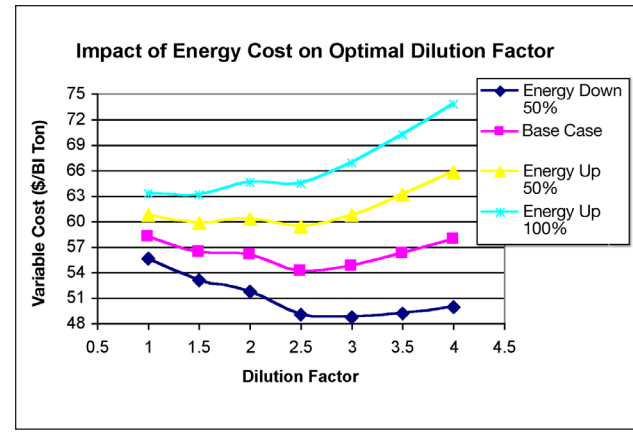
DILUTION FACTOR

In a bleached kraft mill, the operation of brownstock washers has a direct impact upon multiple operating costs [7]. The bleach plant operator wants lots of brownstock washing to minimize the carryover to the bleach plant. The black liquor evaporator operator wants minimal brownstock wash water use to decrease the volume and increase the concentration of

the weak black liquor being sent to recovery. The brownstock operator tends to want an operation somewhere in the middle. It is preferred to have enough wash water to maintain a reasonably clean, uniform pulp mat but not enough wash water to have difficulties with draining or foaming. Looking at purely brownstock washing costs, minimal washing will reduce the amount of steam required to heat the shower water and result in lower costs. When the bleach plant is included in the economic analysis of the pulp mill system, a substantial increase in the total amount of applied shower water is desirable. Increased wash water results in decreased soda carryover to the bleach plant and is found to be economical due to decreased chemical carryover into the bleach plant, resulting in decreased bleaching costs.

When determining the optimum dilution factor for minimizing variable cost, the impact of chemical carryover on bleach plant costs, the cost of make up process chemical (caustic and NaHS were used as make up chemicals for this analysis), and the cost of evaporating the black liquor to firing solids of 72% needs to be considered. For the current work, a five-effect evaporator with an overall economy of 3.8 was used. An industrially clean five-effect evaporator would have a theoretical economy of no more than 4.0. For some mills, the cost of heating the shower water from ambient temperature to the wash water application temperature also needs to be included in the analysis. Some mills have a significant excess of low pressure process steam or low grade heat, resulting in effectively free hot water available for brownstock shower water application. For the case study examined in this work, laboratory bleaching data, shown in **Table I**, were used to determine the impact of carryover on bleaching chemical demand.

When all of these cost factors are evaluated, it becomes obvious that as the cost of energy increases, it becomes more cost effective to reduce shower water flow and allow a dirtier pulp to enter the bleach plant. **Figure 1** shows the impact of altering energy costs upon the variable cost as a function of dilution factor. For the analysis performed in Fig. 1, all of the bleaching and make up chemical costs were held constant at $350/ton caustic, $700/ton chlorine dioxide, $75/ton sulfuric acid, $850/ton peroxide, and $850/ton sodium hydrosulfide. Base case energy cost was assumed to be $5.50/Meg (1 Meg equals 1 million BTUs.) When energy is relatively inexpensive, the cost of bleaching chemicals and make up chemicals dominate the cost structure associated with brownstock washing, thus moving the optimal amount of washing towards higher dilution factors of 3.0 to 3.5. When the cost of energy significantly increases, the total variable cost increases and the optimal dilution factor shifts towards lower values. In the example evaluated here, the optimal dilution factor shifted from around 3.0 to 3.5 down to 1.5 when energy costs were assumed to double from the base case analysis. The resulting shift in dilution factor produces a far dirtier pulp entering the bleach plant, but significant reductions in steam result from heating less wash water and decrease evaporator loading.

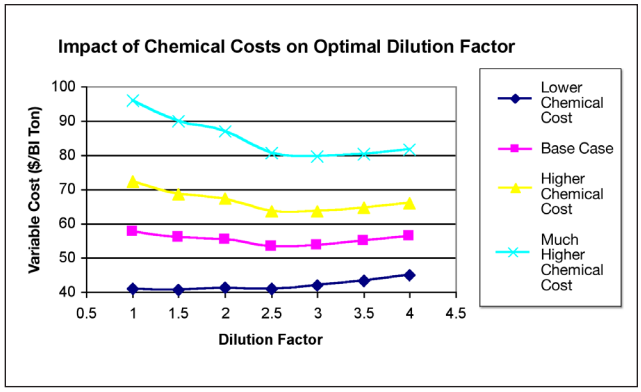


1. Impact of energy cost on dilution factor with constant chemical costs.

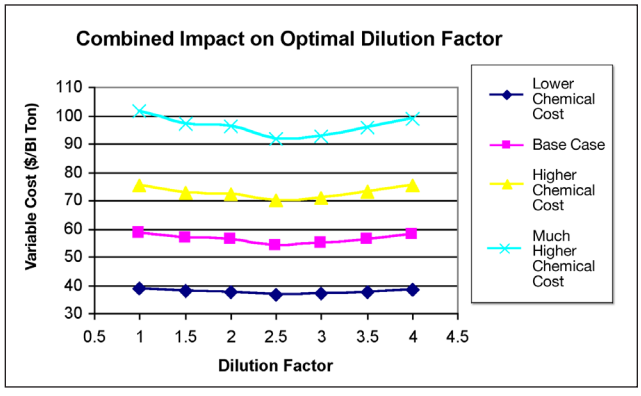
When the cost of energy is held constant and only chemical costs are allowed to fluctuate, the situation is reversed. **Figure 2** clearly shows that when chemical costs are low, the amount of washing required to obtain optimal costs is not really important until the dilution factor gets over roughly 2.5. Once the dilution factor exceeds 2.5, the total cost of energy starts to dominate the variable cost, resulting in higher cost operation. As the cost of chemicals increases, poor washing

DF	Soda Loss # Na_2O/ Bleached Ton	# ClO_2/ Bleached Ton	# NaOH/ Bleached Ton	# H_2SO_4/ Bleached Ton	# H_2O_2/ Bleached Ton
1.00	46.720	89	60.2	25	12
1.50	35.990	87	59	17	12
2.00	29.860	86	57.9	12	12
2.50	19.010	85	57	3	12
3.00	15.240	84	56.3	0.7	12
3.50	13.360	84	56.3	0	12
4.00	12.410	84	56.3	0	12

I. Impact of dilution factor on carryover to and chemical demand in the bleach plant to obtain an 88%GE brightness pulp. Chemical demand determined from laboratory studies.



2. Impact of chemical costs on the optimal dilution factor with fixed energy costs.



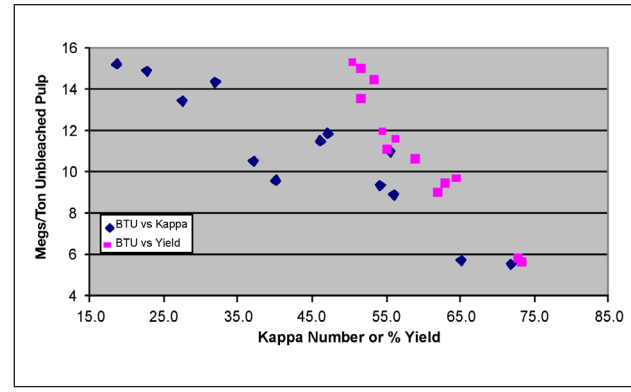
3. Impact of relatively changing chemical and energy costs on the optimal dilution factor for minimum variable cost operation.

from lower dilution factor operation dominates the variable cost curves and moves the optimal, lowest cost operation point towards a dilution factor of 3.5.

When the cost of energy is high, the optimal cost is obtained with a lower dilution factor. When chemical costs are high, better washing resulting from a higher dilution factor becomes the cost optimum operating condition. As these two items result in the optimal dilution factor shifting in opposite directions, when both chemicals and energy increase or decrease uniformly in cost, the optimal dilution factor does not really change appreciably. **Figure 3** details the impact upon variable cost for uniform changes in both chemical and energy costs. Because the cost optimal dilution factor does not change substantially, the use of long term, well established operating targets is justified. It is only when energy costs alone change or chemical costs alone change dramatically that new operating targets need to be evaluated to obtain a minimal operating cost associated with the brownstock washing system.

OPTIMAL KAPPA NUMBER TARGET

Another potential operating target for the pulp mill is the determination of the optimum kappa number from the digester. The choice of kappa number target impacts the amount of bleaching chemical required in the bleach plant, the total amount of wood required from the woodyard, the total amount



4. Laboratory data detailing the total heat value from black liquor solids per ton of pulp as a function of kappa number or pulp yield.

of black liquor solids produced, and the amount of heat available from the recovery boiler. White liquor requirements and lime kiln fuel demand are also impacted by changing kappa number targets. The amount of energy required in the digester is also partially dependent upon the target kappa number.

For the current economic analysis, the pine kappa number was allowed to vary between 20 and 30 for practical reasons. Below kappa no. 20, pulp strength tends to be damaged. Above kappa no. 30, process rejects tend to rapidly increase and bleaching costs rapidly escalate. The amount of wash water applied in the brownstock washing area was maintained at a constant level for each of the kappa numbers investigated. The five-effect evaporators were assumed to have an overall economy of 3.8. An industrial clean five-effect evaporator set would have a theoretical economy of no more than 4.0, so an average economy of 3.8 over the entire cycle between washes is reasonable.

As the kappa number increases, the unbleached pulp yield increases, resulting in a decrease in wood and a decrease in the absolute amount of white liquor required in the digester. The fuel demand in the lime kiln changes. The total amount of black liquor solids decreases, but the heating value of each pound of black liquor solids increases. The total amount of heat in the black liquor solids per ton of pulp produced does decrease. **Figure 4** shows the total amount of heat available in the black liquor as a function of the kappa number and yield of the cook. Laboratory cooks were performed to determine the kappa number, yield relationship, and the changes in heating value of the resulting black liquor solids. **Table II** shows the details of changes in the economically important parameters. For the current analysis, the base case costs employed were $5.50/Meg for energy, $30/green ton for wood, $350/ton for caustic, $700/ton for chlorine dioxide, $75/ton for sulfuric acid, $850/ton for peroxide, and $850/ton for sodium hydrosulfide. These costs were all assumed for the current study. Actual mill costs would have to be used for this type of analysis for a specific mill.

Energy was allowed to increase up to 100% from the base case. The chemical costs were varied in 10% increments from

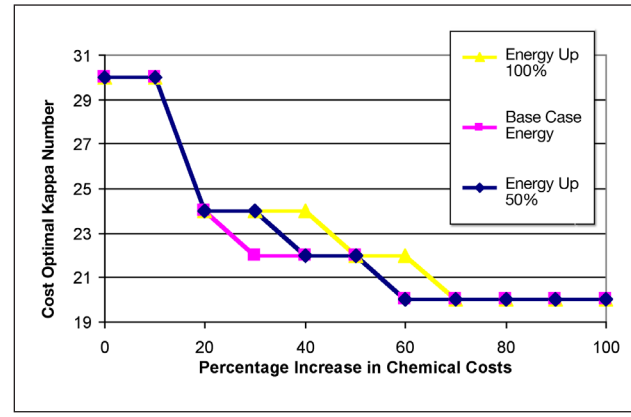
Woodyard, Digester and Washing Items								
Pine Kappa #	Brown Yield %, o.d. Wood	EA,% on Wood	H Factor	K # Steam/ Bleached Ton	Ton Green Wood/ Bleached Ton	Ton Brown/ Ton Bleached	BLS #/ Ton Bleached Pulp	Wk BLS %
20	42.134	17	1744.3	6.0	5.05	1.063	3778.1	0.191
22	43.041	17	1595.4	5.5	4.96	1.066	3665.2	0.186
24	43.948	17	1470.6	5.0	4.87	1.070	3556.7	0.180
26	44.854	17	1364.4	4.7	4.79	1.073	3452.4	0.175
28	45.761	17	1273.0	4.4	4.71	1.077	3352.0	0.170
30	46.668	17	1193.4	4.1	4.63	1.080	3255.4	0.165

Bleach Plant and Recovery Items								
Pine Kappa #	HHV BTU/#BLS	DF	# H_2O Evaporator to 72% Solids	Evaporator Steam Meg/ Bleached Ton	# ClO_2/ Bleached Ton	# NaOH/ Bleached Ton	# H_2SO_4/ Ton	# H_2O_2/ Ton
20	4287.4	3.14	14497	3.815	58	41.2	2.2	12
22	4283.2	3.11	14654	3.856	62	46.5	1.8	12
24	4287.2	3.08	14804	3.896	68	48.1	1.6	12
26	4299.1	3.06	14949	3.934	73	54.7	1.1	12
28	4318.5	3.03	15088	3.971	79	55.8	0.5	12
30	4344.9	3.00	15222	4.006	84	56.3	0	12

DF= dilution factor; BLS = black liquor solids; Meg = 1 million BTUs; HHV= higher heating value

II. Important physical data for changing kappa number targets.

the base case to 100% more than the base case. For all energy costs evaluated, an increase in chemical costs of 20% results in a significant decrease in the optimal kappa number target from 30 to 24. As the cost of chemicals increases more, the optimal kappa number decreases to 22 and then to 20. Increased energy costs delay the decrease towards lower kappa numbers. **Figure 5** details the change in optimal kappa number as a function of percent increase in chemical and energy costs for all of the examined cases.

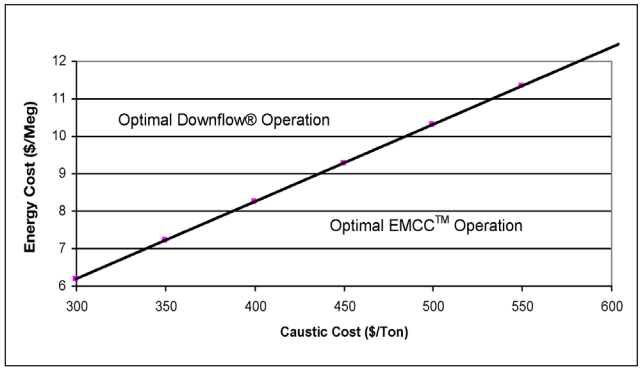


5. Optimal kappa number target for increasing chemical and energy costs.

CONTINUOUS DIGESTER OPERATION

Several years ago when the cost of energy dramatically increased independently from the cost of commodity process chemicals, several mills evaluated the potential of performing capital expenditures to alter the operation of their continuous digesters from up flow - down flow operation to strict DownFlow operation. Changing to DownFlow operation allows mills to extend the cooking zone and substantially reduce the cooking temperature in the digester.

One mill examined in this work converted the digester from EMCC operation to DownFlow operation. An 11 week analysis of digester operation showed a decrease in total energy of roughly 0.255 Meg/bleached ton of pulp. Unfortunately, when a full pulp mill analysis was performed, it was determined that in addition to decreasing the heat requirements, DownFlow operation increased the amount of black liquor carryover to the bleach plant by 10.48 lb of NaOH/bleached ton of pulp. The increased carryover resulted from the sub-



6. Delineation of cost optimal conditions for DownFlow and EMCC cooking.

stantial decrease in the digester high heat washing zone residence time and elimination of up flow within the digester. When the conversion from EMCC operation to DownFlow operation was originally performed, the cost of make up caustic was relatively low, resulting in a lower cost of operation due to the energy savings. As a result of recent substantial increases in caustic costs, DownFlow operation has actually resulted in an increase in overall operating costs. As long as the cost of energy, in dollars per Meg, and the cost of make up caustic in dollars per ton are known, it is possible to determine which mode of operation results in lower cost operation. **Figure 6** shows the regions of preferred operation for a variety of caustic and energy prices.

EXPERIMENTAL

Pulp yield and black liquor properties were obtained from laboratory cooks at various kappa numbers performed with mill chips and mill liquors in an M/K digester (M/K Systems; Peabody, MA, USA). Sodium carryover to the bleach plant tests were performed with an inductively-coupled plasma (ICP) on squeezed liquor samples and on nitric acid solublized pulp. The impact of brownstock washing carryover on acid and bleach plant chemical demand was determined by spiking an extremely well washed pulp with various levels of final stage washer effluent and bleaching to a constant brightness. Several of the evaluated conditions, kappa nos. 20, 26, and 28, were performed with data collected from an operating mill. Mill data were also obtained from washing studies performed at 3.0 and 3.5 dilution factors. For the digester operation portion of this work, mill data were collected for two sequential 11 week operating periods. During the first 11 weeks, the digester was being operated in DownFlow conditions. EMCC operating conditions were employed during the second 11 week period.

These data, both laboratory and mill, were used to tune various process models to cover the entire operating ranges evaluated in this work. Some of the process models were based on customized spreadsheets. Other data were obtained from parametric studies conducted with WinGEMS models (Metso; Helsinki, Finland) tuned with the mill and laboratory data.The base case chemical costs were arbitrarily chosen to be relatively representative of actual costs within a generic pulp mill operating during the 2005-2007 timeframe. No actual mill costs were obtained for this work.

CONCLUSIONS

Determination of the optimal operating targets to obtain the lowest cost operation within other physical process parameters is a relatively complex process that requires an active knowledge of costs associated with areas of the mill outside of the pulp mill. Woodyard, evaporators, recovery boilers, recausticization, and bleach plant costs may all be impacted by process decisions made in the pulp mill. Detailed material and energy balance process models that have been tuned to the actual process with data in conjunction with actual mill chemical and energy costs are helpful in determining the optimal cost operation

For the current work, three distinct process examples were examined. The first, determination of the optimal dilution factor for the brownstock washing area, was found to have direct process impacts upon the amount of bleaching chemical, make up caustic, and evaporator steam requirements. The detailed economic analysis showed that increasing energy costs tended to lower the optimal dilution factor while increased bleaching and make up chemical costs tended to increase the optimal dilution factor. As chemical and energy costs frequently increase relative to each other, standard rules of thumb for an optimal dilution factor may be successfully employed and the optimal dilution factor will not change much. However, when only chemical costs or only energy costs change significantly, a reevaluation of the optimal dilution factor could reduce the overall mill operating cost.

The second process example determined the optimal kappa number target for digester operation. The bleachable grade pine kappa number target was allowed to vary between 20 and 30 due to physical process limitations on pulp strength and shive generation. For all energy costs evaluated, low chemical costs resulted in an optimal kappa target of 30. As the cost of process chemicals increased, the optimal kappa number rapidly decreased to 20 for all energy costs evaluated. The current analysis assumed that all of the chemical costs increased in the same percentage for the analysis. Under true mill operating conditions, it may be possible for specific chemicals to increase much more rapidly than others. Mill specific data would be required to determine the optimal kappa target for a specific mill situation.

The final process example evaluated the potential of physically altering the operating conditions of a continuous digester between DownFlow and EMCC operation. Mill data on energy savings and changes in carryover to the bleach plant were used to determine the optimal operating ranges for a series of make up caustic and energy costs. When energy prices rapidly escalate, DownFlow operation is more economical than EMCC operation. As the cost of chemical make up increases, EMCC operation may be more economical. **TJ**

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ABOUT THE AUTHORS

Within the last few years, process chemicals and energy costs have fluctuated wildly and in many cases, independently of each other. As a result, long term optimized operational targets within the mill may no longer be cost optimal. General rules of thumb may no longer apply. The current work attempts to tie operational set points with chemical and energy costs to provide real time, cost optimal set points for major operational conditions.

Past research in this area has assumed either static chemical and energy costs or chemical and energy costs that escalate relative towards each other. The current work attempts to separate chemical and energy costs and tie the cost data into operating data in order to obtain real time cost optimized set points.

The most difficult aspect of this work was to avoid sub-optimized solutions. When performing optimal set point analyses, it is important to evaluate the impact of set point changes on the entire pulp mill, recovery, and recaust system instead of focusing on just the subsystem of immediate interest (e.g., digester yield or washer soda loss). System wide process models were developed to help avoid set point sub-optimization.



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It was surprising to see how many changes in chemical and energy costs impacted established, long term operational set points. In some cases, the optimal set point changed from one extreme of operating condition to another extreme. In other cases, the operational set point was only moderately impacted.

Understanding which set points are most impacted by energy and chemical costs will allow the mill to focus on those areas while paying less attention to the areas that are only marginally impacted by large swings in chemical or energy costs. The next step would be to take this information and combine it with monthly cost data to actually adjust mill operational set points on a weekly or monthly basis in an effort to cost optimize the mill.

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