EXECUTIVE SUMMARY

The primary raw materials used in the production of paper include pulp fiber, thermal and electrical energy, chemicals, and water. Increased profitability through cost savings can be realized through reductions in these key commodities. This paper describes the process and economic justification for the reuse of machine whitewater through the use of fine-filtration, industry best practices, and new methods.

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For every gallon of water that is reused we can avoid one gallon of fresh water makeup that must be heated and treated and one gallon of waste water that must be treated.

The paper industry obtains their raw process water from a range of sources including ground water from wells, surface water from rivers and lakes, and municipal water systems. The different water sources each have their own unique advantages and disadvantages. Table 0 illustrates these differences.

<table>
<thead>
<tr>
<th>Water Source</th>
<th>Dissolved Solids</th>
<th>Suspended Solids</th>
<th>Organic Load (Vegetation)</th>
<th>Temperature</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground Water (Wells)</td>
<td>Highest due to dissolved minerals collected from the earth’s strata</td>
<td>Lowest turbidity due to filtration by the earth’s strata</td>
<td>Lowest</td>
<td>Most stable (Common average is 55°F worldwide, yet also subject to geographic locations)</td>
<td>Higher pumping cost to lift water from wells and remove some dissolved minerals</td>
</tr>
<tr>
<td>River Water</td>
<td>Lowest mineral / salt content</td>
<td>Highest due to rain events - Stirs up sediment</td>
<td>Highest due to introduction of leaves, vegetation and industrial organic loads</td>
<td>Greater variation due to seasonal fluctuations</td>
<td>Lower cost supply however filtration for rain events can be costly</td>
</tr>
<tr>
<td>Lake Water</td>
<td>Often low mineral content</td>
<td>Generally low determined by location of intake</td>
<td>Second highest due to vegetation and algae plume</td>
<td>Greater variation due to seasonal fluctuations</td>
<td>Lowest cost</td>
</tr>
<tr>
<td>Municipal Water</td>
<td>Must meet EPA drinking water standard with low dissolved solids content</td>
<td>Lowes TSS - Water is usually clarified and filtered</td>
<td>Organic load is controlled to meet drinking water standards</td>
<td>Seasonal fluctuations based on water origin</td>
<td>Highest cost due to public pretreatment infrastructure</td>
</tr>
</tbody>
</table>

Table 0: Common water sources advantages and disadvantages
The most significant parameter concerning the cost for recovery and reuse of water is the heat energy introduced to the water for use at the mill. Of these potential sources, groundwater is the least susceptible to local ambient climate conditions. Worldwide, ground water temperatures average 55°F (13°C). This stable but low temperature requires a significant energy input to raise the water temperature to a useful operating temperature range of 125°F (52°C) to 140°F (60°C). Surface water on the other hand experiences pronounced seasonal fluctuations. These seasonal fluctuations can be strongly influenced by climatic conditions. Additionally, a particular mill's geographic location is often a major contributor to ambient and seasonal water temperature changes.

Regardless of the raw process water source, there is a cost associated with treating this water for introduction to the process. Table 1 illustrates this cost for water treatment. The example considers an operational year of 350 days on a continuous basis at a cost of US$0.30 per 1000 GPM (3785 LPM).

<table>
<thead>
<tr>
<th>Treated Fresh Water GPM (LPM)</th>
<th>Gallons per Day</th>
<th>Cost to Treat</th>
</tr>
</thead>
<tbody>
<tr>
<td>300 (1135)</td>
<td>432,000 (1.635 MLPD)</td>
<td>$45,360</td>
</tr>
<tr>
<td>500 (1893)</td>
<td>720,000 (2.725 MLPD)</td>
<td>$75,600</td>
</tr>
<tr>
<td>1000 (3785)</td>
<td>1,440,000 (5.451 MLPD)</td>
<td>$151,200</td>
</tr>
</tbody>
</table>

*Table 1: Annual cost to treat fresh water prior to process introduction*

Mills that use municipal water supplies can experience significantly higher costs to purchase water. Some of this cost is offset by a reduction in pretreatment costs at the mill. This is due to the cleanliness of the municipal water supply that has a target quality of drinking water. These costs vary widely in different parts of the world. However, there is a general upward trend in the cost of municipal water supplies regardless of location.

Typically, paper mills will control their process water temperature between 105°F (41°C) and 140°F (52°C). Many of these mills will utilize the added benefit of elevated process water temperatures in the Forming and Pressing sections of the paper machine to increase productivity and finished sheet quality. Whenever cold fresh water is introduced to the machine or process, the resultant decrease in system temperature requires increased use of steam energy to return the system to the optimum operating temperature. The relationship between the machine silo temperature and reel speed is illustrated in Figure 1.
When cold fresh water is introduced to the paper machine wet end process the impact is systemic. As system temperatures drop below targeted values, steam usage significantly increases to the machine silo and in many cases also increases in the main dryer section.

This is the result of a decrease in sheet drainage as the system cools and results in a decrease in sheet solids into and out of the machine press section. For every one percent reduction in exiting press section sheet solids, the dryer section steam usage increases four percent.

This scenario is most evident following machine sheet breaks or machine outages when excessive fresh water make up is introduced for chest level control requirements.

The strong correlation (0.82) between silo temperature and the reel speed was measured over 13 hours following a machine outage. The fresh water makeup source was river water with a mean temperature of 34°F (1°C) during this period.

During a Kadant Water and Energy Audit, we examine the client’s associated economic benefit through effective whitewater reuse.
The following parameters are determined by in-mill testing and mill historical data:

- Local ambient temperature of the raw process water by source
- Flow measurements are used to determine the available quantities of whitewater for reuse
- Flow and temperature readings from the prior six months are evaluated

A cost-benefit analysis is conducted based on water and energy savings associated with the reduction of incoming fresh water makeup and reduction of wastewater discharges.

Table 2 depicts the cost to heat 350 GPM – 1325 LPM (approximately 500,000 gallons per day – 1.893 million liters per day) of fresh water to optimum process temperature on a monthly basis. In the following examples, a cost of US$5/MMBTU is used. Raw water source temperatures influenced the cost to bring the water up to usable process temperatures.

<table>
<thead>
<tr>
<th>Month</th>
<th>Raw Process Water Makeup GPM (LPM)</th>
<th>Average Ambient Water Temperature °F (°C)</th>
<th>Optimum Process Temperature °F (°C)</th>
<th>Monthly Cost to Heat Fresh Water to Process Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>350 (1325)</td>
<td>38 (3)</td>
<td>130 (54)</td>
<td>$59,293</td>
</tr>
<tr>
<td>February</td>
<td>350 (1325)</td>
<td>40 (4)</td>
<td>130 (54)</td>
<td>$52,391</td>
</tr>
<tr>
<td>March</td>
<td>350 (1325)</td>
<td>45 (7)</td>
<td>130 (54)</td>
<td>$54,782</td>
</tr>
<tr>
<td>April</td>
<td>350 (1325)</td>
<td>52 (11)</td>
<td>130 (54)</td>
<td>$48,649</td>
</tr>
<tr>
<td>May</td>
<td>350 (1325)</td>
<td>60 (16)</td>
<td>130 (54)</td>
<td>$45,114</td>
</tr>
<tr>
<td>June</td>
<td>350 (1325)</td>
<td>65 (18)</td>
<td>130 (54)</td>
<td>$40,540</td>
</tr>
</tbody>
</table>

Table 2: Monthly cost to heat fresh water to optimum process temperature

The table above illustrates the potential cost of energy savings for whitewater reuse. The table also describes each mill’s specific site conditions strongly influences the associated potential energy savings associated with heat recovery through the reuse of whitewater. In many cases these savings can be accomplished by substituting filtered whitewater where heated fresh water is currently used. Paper machine showers are a primary example of where the recovered water and savings can be realized.

In addition to reducing heating costs for fresh water, filtered whitewater also offers cost savings from the recovery of fiber for reuse as raw material. In many cases, there are imbalances within the machine...
whitewater system that result in the loss of fiber-rich whitewater. These losses result in an increased load to the wastewater treatment plant. In these instances, thermal energy used to initially heat the whitewater is also lost. Because it is necessary to remove excess heat to avoid thermal pollution, effluent cooling costs are also avoided with the implementation of whitewater recovery.

Numerous additional factors can be identified to illustrate the true economic costs due to a whitewater imbalance, including:

- Water and energy losses (as described above)
- Lost fillers, fiber, and production chemicals
- Excess loads feeding the waste treatment plant
- Additional pumping, aeration, sludge pressing
- Reduction in effluent and raw water treatment chemicals and the associated operational and maintenance costs
- Sludge transportation costs
- Landfill costs (including permits)
- Dredging of the waste treatment ponds
- Reduction of stack emissions resulting from reduced steam heating requirements

Consequently, any reduction in discharges and raw water make-up to the established infrastructure results in cost savings opportunities. The associated reduction in loads to the raw water and wastewater treatment systems yield improvements to existing raw water treatment systems and enhances the effluent discharge quality.

Table 3 illustrates the value of the fiber recovered in a whitewater recovery system. A number of different flows and solids loading are examined. In these examples, US $150 per ton for fiber costs is used and a production year consists of 350 operational days.

<table>
<thead>
<tr>
<th>Flow Rates GPM (LPM)</th>
<th>Consistency 0.02 %</th>
<th>Consistency 0.06 %</th>
<th>Consistency 0.08 %</th>
<th>Consistency 0.10 %</th>
</tr>
</thead>
<tbody>
<tr>
<td>350 (1325)</td>
<td>$22,079</td>
<td>$66,238</td>
<td>$88,317</td>
<td>$110,396</td>
</tr>
<tr>
<td>600 (2271)</td>
<td>$37,850</td>
<td>$113,550</td>
<td>$151,400</td>
<td>$189,250</td>
</tr>
<tr>
<td>1000 (3785)</td>
<td>$63,083</td>
<td>$189,250</td>
<td>$252,333</td>
<td>$315,417</td>
</tr>
</tbody>
</table>

*Table 3: Annual value of recovered fiber at select flows and solids concentrations.*

Table 4 illustrates the annual costs associated with disposing of fiber that is not recovered and is instead lost to the wastewater treatment plant. In these examples, $50 per ton disposal rate is used and the cost assumes 350 operational days per year.
Table 4: Annual cost to dispose of unrecovered fiber at select solids concentrations.

Table 5 illustrates the annual value of the recovered fiber added to the costs associated with the disposal of unrecovered fiber for the potential savings associated with fiber recovery.

Table 5: Annual total fiber purchase and disposal cost at select solids concentrations

Significantly higher savings are realized at mills that discharge their effluent to a municipal waste treatment plant (POTW’s). Many POTW’s levy a surcharge based on the disposal of suspended solids.

Table 6 illustrates the combined cost for steam to heat water from 75°F (24°C) to 120°F (49°C) at US$5/MMBTU, the cost to treat water at US$0.30 per 1000 GPM (3785 LPM), the value of recovering 0.02% fiber at $150.00 per ton and the cost of disposing of 0.02% fiber at US$50.00 per ton annually (350 operational days).

Table 6: Annual total cost for: steam, water treatment, recovered fiber & fiber disposal

There are some additional intangible values to consider, such as:

- Conservation and environmental stewardship.
- Recovered heated water provides a consistent temperature to the process and eliminates seasonal fluctuations in production due to lower raw water temperatures.
Many attempts have been made to filter whitewater for reuse on machine showers and other areas. Most of these attempts have resulted in various levels of success, and the vast majority of machine critical showers are currently supplied by mill reclaimed warm water systems or fresh water sources.

The use of fresh water or purified reclaimed warm water for critical showers is understandable especially when considering the costs to the mill if the machine clothing is not properly conditioned to protect nozzles from plugging. When a forming fabric or press fabric becomes contaminated in areas where there are plugged shower nozzles, a moisture streak develops and the QCS must make adjustments to the process to compensate for the high moisture variation.

A moisture streak (i.e., variation) can become so severe that the forming fabric or wet felt may need replacement. This can lead to an unscheduled outage to correct the CD profile before returning the process to normal operation. The down time almost always occurs after more than one attempt to chemically clean the affected clothing. Additional downtime can occur if chemical batch washing is also required.

Plugged shower nozzle issues are not isolated to machine clothing. Finely filtered shower water is also critical for forming rolls, press section rolls, lubrication water for roll doctor blades, blind drilled rolls, and grooved rolls. The cost penalty for plugged shower nozzles in these areas can be significant.

The design and implementation of an effective whitewater reuse system for critical showers starts with a detailed process review including real-time measurements of the existing process. Necessary measurements include flows, solids, temperatures, and pressures. This detailed evaluation results in the proper application of technologies that provide the best life cycle costs to the mill.

A proper water and energy audit includes suspended solids monitoring and temperature recording for periods up to 30 days. Ultrasonic or Doppler flow meter and calibrated pressure gauges are also used to document selected flows and pressures.

These measures are necessary to identify process variations. These measurements are time stamped and analyzed in conjunction with mill historical data. It is important to establish correlations between current and historical data. This data is used when designing flexibility and redundancy into an effectively engineered solution.
The water and energy audit should take into consideration all whitewater system inflows and outflows when measuring flow rate, solids, temperatures and pressure. These parameters are identified and collated to establish the system balance.

For example, if a save-all is underperforming or suffers from design deficiencies, these issues must be recognized and accounted for. Allowances should be made and corrective remedies implemented. This is necessary when designing an engineered solution that is adapted to reflect actual mill operating conditions. Accommodations are made for process variations and to facilitate a continued production of quality filtrate with a minimum of process interruptions.

System imbalances that require the addition of fresh water makeup to stabilize chest levels should be recognized. This is important to avoid costly excessive overflow to the sewer or the mill’s wastewater treatment plant. Evaluation of storage capacity is an integral part of an effective solution.

APPLICATION OF TECHNOLOGY

Once a complete understanding of the process is gained, the accurate application of equipment and automation can be considered. Kadant’s audit program has been effective in illuminating system vulnerabilities on a vast majority of machines. Many of the common inline process measurement devices are absent. This limited instrumentation increases the system’s vulnerability to upset conditions often resulting in establishing a narrow operational window before upsets occur.

New and advanced technology developments are available today for flow meters, pressure transmitters, suspended solids analyzers, and variable speed motors for pumps. This technology is readily adaptable to the mill and allows the establishment of the most cost effective solutions with the necessary built-in system flexibility.

When a mill, for example, installs a flow meter, pressure transmitter and suspended solids analyzer in the piping from the save-all clear leg chest to a gravity strainer, identification of process variation is possible and desirable in real time. Once the variations are recognized, controls can be initiated to prevent losses and maximize a return on investment. Likewise, if suspended solids begin to increase on the inlet side of the gravity strainer, a variable speed motor on the strainers cleaning shower can be sequenced to increase speed in proportion to the increasing solids load. If the suspended solids continue to increase, then the cleaning shower pressure is also raised accordingly. These two
actions are known to facilitate a significant positive influence on the capacity of the Gravity Strainer thus avoiding upset conditions.

It is also possible to optimize the open area (mesh count) of the Gravity Strainer screen. When the system includes measurement and control strategies, it is possible to increase the solid reject rate and further improve the accept water quality with the use of a fine screen.

These upgrades to an existing system feature low-cost modifications. These opportunities provide a rapid return on investment while instilling a high degree of system flexibility and reliability. System stabilization and minimization of down time is inherently cost effective. Improvements are easily measured and quantified.

Numerous technology developments have been made in the area of laser cut screening. A more robust approach to filtering save-all clear leg whitewater features a pressure screen with hole diameters as fine as 60 micron. These technology advancements in manufacturing have resulted in application flexibility of pressure screen baskets. These improvements provide new opportunities for whitewater filtration applications.

The save-all performance and the first stage of whitewater filtration is a critical area of a whitewater filtration system. If a failure occurs in this section, there is a high probability that rich whitewater will feed forward to the next stage and foul or plug the subsequent filtration step. Ultimately, the fines and contaminants can arrive at the machine shower nozzles or other services and plug these sensitive areas of the machine.

The filtration equipment that follows either a gravity strainer or a pressure screen will depend on the end use of the filtered whitewater. For example, forming fabric flooded nip shower may only require a pressure filter for protection. If the end use is forming and press section critical showers, then additional fine-filtration equipment may be required.

Fine-filtration equipment has been developed that will provide filtrate quality suitable for use in feeding a 0.040” (1 mm) shower nozzle orifice. These shower orifices are most commonly found in high-pressure shower applications. With the exception of trim squirts, these nozzles are typically the smallest orifice sizes found in machine shower applications.

The accepted engineering practice recommends filtration media capable of removing contaminants at 1/6 of the diameter of the smallest shower nozzle orifice. Historically, in the case of 0.040” (1 mm) shower nozzle orifices, the filtration media would be selected to remove particles 25 micron or greater with accepts at a concentration of 20-40 ppm.

Recent technology advancements require removing particles 10 micron or greater with accepts 20 ppm or less. These fine-filtration systems can
be more complex and capital intensive to implement. The return on investment must be established on an individual mill basis with a payback period less than two years.

Once the whitewater has passed through the fine-filtration stage, pressure filters and polishing filters are recommend as final protection against contaminants that may pass through the fine-filtration stage. The best practice is to equip the multi-barrel pressure filters with automatic backwash capability normally actuated by an increase in differential pressure.

Polishing filters are primarily configured in a duplex arrangement to allow for uninterrupted supply to the associated shower. The duplex configuration allows for cleaning of the filter media on one bank while sustaining flow on the in-service bank of filters. This arrangement maintains one polishing filter online while the second is isolated. When cleaning is required, the isolated filter is brought online and the previously online filter is isolated and the filter element removed for cleaning or cleaned automatically.

The end use of the filtered water is typically machine showers. Advancements in shower design feature:

- Oscillators with enhanced reliability and expanded capabilities
- Cleaning brushes that are located internally to the shower pipes
- Automatic rotation equipment for the internal shower brushes
- Vacuum augmented contaminant removal systems

Vacuum augmented contaminant removal system is a new a concept that provides another degree of confidence in shower system recovery following a significant process upset. High vacuum used in combination with internal shower pipe rotating brushes can often eliminate shower nozzle plugging in difficult applications.

Figure 2 illustrates an example of an automated design for a vacuum augmented contaminant removal system for selected machine showers. This design utilizes an automatic 3-way valve arrangement that includes a manual override feature. In some instances, the valves are cycled on a predetermined time sequence to maintain cleanliness.
Figure 3 illustrates an automated internal brush rotator and the internal brush. The automatic brush rotator can be set to rotate on a timed basis or initiated when cleaning is necessary.

Figure 2: Machine shower vacuum augmented contaminant removal system.

Figure 3: Machine shower automated internal brush rotator.
CLOSING THE WHITEWATER LOOP

The effective removal of larger particles and fine suspended solids from the whitewater loop is of prime importance. However, the fine-filtration method must effectively prepare the water for critical reuse applications.

A properly designed fine-filtration stage should operate to remove suspended solids and also effectively produce water quality that is as close to fresh water quality as possible.

This level of filtration will include additional treatment technologies that facilitate the removal of unwanted residuals and often results in a significant chemical additive cost savings for the mill.

It is essential to complete a detailed whitewater and energy audit with a focus on the processes and economics prior to initiating equipment trials. Only after the completion of these target assessments can an effective whitewater reuse strategy be optimized.