The Autonomous Mill: Optimization Opportunities in the Pulp & Paper Mill

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ABSTRACT

This paper will give an overview of the unit operations and equipment common to pulp and paper mills and conclude with several examples of specific opportunities where control systems optimization through Advanced Process Control (APC) and Model-Based Predictive Control (MPC) can increase production; reduce costs, and autonomously operate the mill of the future.

The pulp and paper mill is often divided into six main “islands” of automation; raw material receiving and preparation (the woodyard), the pulp mill, the powerhouse, the paper mill, converting and finishing, and effluent treatment. Each of these islands presents their own, unique set of unit operations; but, perhaps not surprisingly, you can see similar unit operations in various industries besides pulp and paper. For example, the powerhouse equipment, besides the main difference being that the fuel is “black liquor”, the equipment can be found in any other industrial power plant. In the paper machine “island”, the use of cascaded variable-speed drives to control the paper sheet tension is also seen in the draw line of a steel, textile, or fiber mill. And, as a final example, the effluent treatment facility of the paper mill has many of the same equipment you’ll find in a municipal water/wastewater plant.

Several examples of specific control systems optimization included for each of these “islands” include chemical savings in the lime kiln and causticizing, pulping, screening and refining, washing, and bleaching processes of the pulp mill; energy savings in recovery boiler sootblowing and the lime kiln, pulp stock preparation including cleaning and refining and the paper pressing and drying sections of the paper mill; and the environmental savings involved in effluent treatment and recycling water.

Lessons learned:

1. understand the equipment and the processes in a pulp and paper mill
2. understand the similarities to other industries
3. understand specific areas where control system optimization can decrease costs and/or increase production

INTRODUCTION

Multitudes of careers have been spent understanding and refining the pulp and paper industry and [1,2]textbooks and technical papers too numerous to list have been written about the various processes and equipment in a pulp and paper mill.

This paper is divided into two halves. In the first part the reader will be shown some of the equipment and the processes in a conventional pulp and paper mill. In the second part the reader will be shown some specific areas where control system optimization can decrease costs and/or increase production.

UNIT PROCESSES IN THE PULP AND PAPER MILL

THE WOODYARD (RAW MATERIAL RECEIVING AND PREPARATION)

As the subtitle the woodyard is where the raw material (pulpwood logs or chips) is received and prepared for the pulping processes downstream. Pulpwood logs are sent through debarking drums (see the figure) and chippers and then combined with received wood chips to be classified (sorted) and then stored in either the chip pile or chip bins. The key quality parameters here are uniform chip size, species, and moisture content to yield uniform pulp from the cooking (called digesting) process.

THE PULP MILL

In the pulp mill, the wood chips are mixed with alkaline pulping chemicals (called white liquor, predominately consisting of sodium hydroxide) in either batch or continuous digesters and heated under pressure with process steam from the Powerhouse. The product of the digesters is called “brown stock pulp” in weak (15%) black liquor. The white liquor turns into black liquor because of dark color of the organic compounds and lignin from the wood chips. Lignin can be thought of as the “glue” that holds the wood’s cellulose fibers together.

The basic purpose of the rest of the pulp mill processes downstream of the digesters is to, first, clean by screening, refining, washing, and bleaching the wood pulp to be sent to the paper machine stored in the high-density storage chests and, secondly, recover and concentrate in the evaporators these chemicals in the black liquor and send the strong (65%) black liquor to the powerhouse where it is sprayed with liquor guns into the furnace of the Kraft Recovery Boiler to make steam for the process and make green liquor. This green liquor is sent to the causticizer where it is reacted with lime, either purchased or from lime kiln, creating the white liquor.

At this point, one of the key parameters of wood pulp needs to be defined; and that is the term [3]consistency or the amount of wood fiber in solution (water) in units of percent by weight. Wood pulp stock slurry can really only be pumped at consistencies of 3-5% (3-5 pounds of wood fiber per 100 pounds of slurry solution) but can be stored in the high-density storage chests (in the pulp and paper mill, tanks are called storage chests) at consistencies as high as 15%.

The screening process in the pulp mill is used to remove knots or undercooked pulp fiber from the digester. The screens usually consist of rotating baskets with holes or slots that do not allow the knots or larger fiber bundles to pass. Refiners, which are two rotating plates, are used to cut the wood fibers into a more uniform length that will make better paper.

Following screening and refining, the brown stock pulp goes to the brown stock washers where water washes the black liquor out of the pulp stock. In some mills downstream from the brown stock washers is the bleach plant where bleaching chemicals such as chlorine, chlorine dioxide, hydrogen peroxide, sodium hypochlorite, oxygen, ozone whiten and brighten the pulp stock. The washed and/or bleached pulp is next sent the high-density (15% consistency) storage chests where it awaits the stock preparation for the paper machine

THE POWERHOUSE

Besides the equipment to distribute the fuel, that is, the strong black liquor, the recovered chemicals, specifically green liquor from the bottom of the boiler and the salt cake, Sodium Sulfate, the particulate from the stack gas recovered from the electrostatic precipitator; the Powerhouse of a pulp and paper mill is not much different from any power generating station. The Kraft Recovery Boiler will probably have more steam soot blowers to remove the fly ash from the boiler tubes than a gas or oil furnace; but the main boiler auxiliary equipment, like the feedwater treatment, steam blowdown system, the forced and/or induced draft fans, stack gas analyzers, and steam superheater and makedown systems will be no different than traditional power generating stations.

The strong black liquor comes to fuel the recovery boiler from the evaporators, and is mixed with the saltcake from the electrostatic precipitator and then sprayed into the furnace through the oscillating liquor guns. The liquor guns will hopefully atomize the black liquor so that it at least partially burns before falling to the bottom of the boiler, called the smelt bed. This molten smelt bed is predominantly made up of Sodium Oxide and leaves the boiler via the smelt spouts into the green liquor dissolving tank.

The density of the green liquor in the dissolving tank is controlled for optimum reactivity when it is sent to the causticizer to be reacted with lime to make the white liquor

THE PAPER MILL

The paper mill is where the pulp stock is laid down on the forming wire by the headbox slice at the wet end of the paper machine. As the name “wet end” implies, the other end of the paper machine is called the ‘dry end”. In between the wet and dry ends, the water is first vacuumed from, then pressed from, and finally dried from the paper.

CONVERTING AND FINISHING

Next, the paper is “converted” and/or “finished”, which means that it will be cut to the right size, and the surface is smoothed or a coating can be applied if necessary

EFFLUENT TREATMENT

As with any manufacturing plant, the pulp and paper mill has air and water effluent streams to treat before releasing back to the environment. The odors can be removed from the air by scrubbing. As already mentioned, the particulate is removed from the stack gas by the electrostatic precipitators, and the excess heat in the cooling water is removed by passing through heat exchangers so that the temperature differential doesn’t harm the environment. The water sent to the effluent treatment plant including clarifiers and settling tanks and/or ponds not that much different from any municipal wastewater treatment facility.

OPTIMIZATION OPPORTUNITIES IN THE PULP AND PAPER MILL

There are many opportunities for optimization, either involving energy savings, chemical saving, and/or increases in production rate, of the processes throughout the pulp and paper mill. Several examples will be described in the paragraphs to follow.

RECOVERY BOILER AUTOMATION[4]

The Recovery boiler can be optimized to adjust for the continual variability in Black Liquor BTU value and compensate for changes in boiler load. When the affects of liquor BTU and boiler load variations are eliminated, all parameters associated with the recovery process becomes more stable and the boiler can typically be operated with a higher throughput, better efficiency, improved green liquor reduction, minimized fouling, and reduced emissions. When compared to a traditional control strategy, this system can provide the following benefits to mill recovery operations:

- 5-15% increase in black liquor throughput
- 1-2% increase in thermal efficiency

- Improved reduction efficiency
- Reduced water wash frequency
- Improved environmental compliance
- Reduced variability in all process parameters
- Automatic control virtually at all times
- Consistent boiler operation throughout all shifts

RECOVERY BOILER SOOTBLOWING

As was mentioned in the first section, the Kraft Recovery Boiler utilizes steam sootblowers (usually around fifty per boiler) to blow fly ash in the combustion gases off of the boiler tunes. Without the sootblowers, particulate would build up on the tubes effectively insulating them preventing heat transfer to the water and thereby reducing the steam output from the boiler and lowering the boiler efficiency. To level the steam usage to the boiler the individual sootblowers are scheduled so that they operate in a predefined sequence. Optimization of these sequences can involve using “smart sootblowing” [5] based upon furnace draft pressures and [6] temperatures which would signal when to blow certain regions of the tubes. For example, if the temperature rises in a particular region, that would say that the tubes are becoming covered with soot and it would run the sootblowers in that region.

BLACK LIQUOR EVAPORATORS

The purpose of the black liquor evaporators is to concentrate the weak black liquor from the pulp washing process at around 15% solids to around 60% solids that will burn effectively in the recovery boiler. The evaporators can be either a packed single-column or multi-effect (up to seven). To decrease the evaporation temperature, the multi-effect units operate at a vacuum. The process can be optimized by using pressure and temperature differential to signal tube fouling that would cause a decreased heat transfer rate and a lower vacuum and automatically start a boilout of the evaporators to clean the fouling.

CAUSTICIZING

In causticizing area of the pulp mill green liquor is reacted with lime to form the white liquor used in the wood chip digesting (cooking) process. Traditionally, conductivity was used a variable to measure the reaction completeness. With new nuclear instruments the exact chemical constitutes in the white liquor can be determined to better gauge the reaction completeness. Since the causticizing process is by nature a process with a long lag time and not a good candidate for traditional PID control; a new optimization technique involving using [7] Model-Based Predictive Control (MPC), can tune the process more tightly which would yield a more consistent white liquor product.

BATCH AND CONTINUOUS DIGESTERS

The pulp digesting (cooking) process uses either/or [8] batch or continuous digesters. Either way, the principle is the same; the wood chips and the cooking chemicals are added to the digester and under pressure and at an elevated temperature from the steam addition, the wood chips are cooked (really “exploded”) for sixty to ninety minutes. The pulp stock slurry exits the digester at a consistency of 6% and the resulting pulp fibers are close to the state they need to be in to make the paper. The optimization here can involve energy savings by increasing throughput and scheduling the batches so that steam consumption is leveled so that spikes cause fluctuations in the boiler demand. Also, online freeness (a measure of the cooking completeness) analyzers can close the control loop to more accurately determine when the cook is complete.

SCREENING AND REFINING

Screening and refining is used to get a more uniform pulp stock. The screen, which is a piece of equipment with a rotating, cylindrical basket with either slots or holes, lets the optimally-sized pulp fibers pass through but centrifugally removes knots, uncooked or undercooked fiber bundles that can be recycled back to the digester for additional cooking. The refiner, which is a piece of equipment with two rotating, rough-surfaced plates, is used to cut or defibrillate the wood fibers giving more uniform pulp stock.

WASHING

The digested, screened, and perhaps refined pulp stock, although uniform in fiber size, is still very dirty with all of the by organic and inorganic byproducts from the digesting process, known as weak black liquor at around 15% solids. The dark color comes primarily from the lignin which is the “glue” that binds the wood fibers and gives the wood its strength and rigidity. There are also a lot of residual cooking inorganic chemicals that can be reused in the digesting process. [9] The brown stock washers usually consistent of multiple (three), countercurrent (which means pulp tock comes one direction and clean wash water comes from the opposite direction) stages. Fresh make-up wash water is added on the cleanest pulp at the latter stages to wash the pulp stock, but the recycled weak liquor wash water is added on the dirtiest pulp at the earlier stages. A common optimization technique is to use Dilution Factor Washing based on pounds of wash water to pounds of wood fiber (the optimal ratio is about 1.0) to minimize overwashing that would use more water that would subsequently need to be evaporated to get the black liquor to the magic number of 65% for burning in the recovery boiler.

BLEACHING

The decision whether to bleach the pulp is based on the final product of the paper mill. If the product is cardboard or paper sacks, bleaching is probably unnecessary. But if the product is writing paper, paper towels, tissue, diapers, etc. then the pulp will need to be bleached. [10]The bleach plant usually consists of multiple (three to five) stage washers interspersed between bleach towers. Typically bleaching chemicals are liquid or gaseous chlorine, chlorine dioxide, sodium hydroxide, sodium hypochlorite, hydrogen peroxide, liquid or gaseous oxygen, and liquid or gaseous ozone. These bleaching towers allow the resident time (usually one to three hours per tower) for the bleaching chemicals to brighten and whiten the pulp.

The predominant area for savings in the bleach plant is to optimize the chemical usage by utilizing techniques something like KAPPA Factor bleaching and stock tracking throughout the bleaching stages to apply bleaching chemical based on a precise ratio of pounds of effective chlorine to the pounds of fiber.

As with the causticizer, the bleaching process is by nature a process with a long lag time and not a good candidate for traditional PID control; a new optimization technique involving using Model-Based Predictive Control (MPC), can tune the process more tightly which would yield a more consistently bleached pulp.

LIME KILN

The lime kiln is a large (15 ft diameter by 200 ft long), rotating cylinder used to calcinate the byproduct of the causticizing process, the lime mud, to convert it back to the lime that can be added in the causticizer.

The predominant area for savings is the energy (gas burned in the lime kiln) savings by optimizing the lime mud moisture content and the temperature of the calcined lime exiting the kiln.

As with the causticizer and bleach plant, the Lime kiln process is by nature a process with a long lag time and not a good candidate for traditional PID control; a new optimization technique involving using [11]Model-

Based Predictive Control (MPC), can tune the process more tightly which would yield a more efficient combustion process.

PULP STOCK PREPARATION, CLEANING, REFINING, AND BLENDING

This is the area where the pulping ends and the papermaking begins. The "art of papermaking" is in the final cleaning to remove any remaining contaminants, in the "tickle" refining to "brush" the fibers to optimize fiber bonding in the paper sheet, in the blending of different pulp species (hardwood and softwood), filler, additives, to achieve the optimum paper optical, physiochemical, strength, structural, and surface properties.

PAPER PAPERMAKING, PRESSING AND DRYING SECTIONS OF THE PAPER MILL

After all of the preparation of the pulp it is stored in the machine chest. From there, the fan pump pumps the pulp stock to the headbox from which the pulp stock slurry is "laid down" on the fourdrinier wire along the entire width (sometimes over 300 inches wide) of the machine via the "slice" out of the headbox. The primary control variables in papermaking are the [12]basis weight, moisture, and [13]caliper (or thickness). A typical paper machine can be as long as a football field. As in the pulp mill where the majority of the processes remove the pulping byproducts; the majority of the paper machine removes the water from the paper in first the forming section, followed by the [14]press section, and, finally, the dryer section. The main area for savings are again those of energy savings in the dryer where steam is used to heat the "dryer cans" to heat the paper sheet as it passes over them on its way down to the "dry end" of the paper machine

Recently, the use of video cameras placed at strategic points along the paper machine has been very effectively used to alert the operators of events that can cause a paper sheet break. [15] With this information, the operator can avoid an actual sheet significantly decreasing production downtime.

Use of cascaded and coupled, variable frequency drives controlling the various rollers in the fourdrinier wire, press, and dryer sections can more tightly regulate the tension (rush and drag) of the paper sheet mitigating undue stresses that could cause a paper sheet break.

CONCLUSIONS

This paper is merely an overview of the unit operations and equipment common to a pulp and paper mill; innumerable books and careers have been spent describing and learning these aspects of the control of these processes that I have endeavored to tell you about in these pages. Hopefully, you now can find your way around the six main "islands" of automation of any pulp and paper mill:

- raw material receiving and preparation (the woodyard)
- the pulp mill
- the powerhouse
- the paper mill
- converting and finishing
- effluent treatment.

Use of [16]Production Rate control will enable the Autonomous Mill to achieve optimal performance.

After reading this paper you now have a better understanding of the equipment and the processes in a pulp and paper mill, you can see the similarities to other industries, and you have an idea of several specific areas where control system optimization, Advanced Process Control (APC), and Model-Based Predictive Control (MPC) can increase production, decrease costs, and autonomously operate the mill of the future.

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