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Paper machine energy conservation

Scope

The paper machine area is a major energy consumer in most pulp and paper mills. The high cost of energy makes it important to implement energy management and conservation measures. Paper machine energy consumption represents 50-70% of purchased energy for an otherwise efficient integrated mill. If the paper machine is inefficient in its use of energy, the mill will be uncompetitive. Reductions in energy consumption reduce operating costs and increase profitability. Reducing paper machine energy consumption requires attention to details in design, operation, maintenance, and control of nearly all aspects of the papermaking process. This TIP discusses guidelines for monitoring, benchmarking, and optimizing energy-intensive unit operations to reduce paper machine energy consumption.

Safety precautions

Follow normal safety precautions when working around paper machinery, including use of personal protective equipment. Do not allow loose clothing or equipment to contact rotating machinery or ropes. Beware of overhead cranes and thermal and slip hazards around the dryer section. Avoid direct contact with hot surfaces. Use hearing protection in noisy areas. Eye protection should be worn in all production areas. Safety shoes and safety helmets should also be worn where required.

Energy reduction strategy

Efforts to improve paper machine energy efficiency center around five basic principles:

- Minimize the amount of water to evaporate in the dryer section (and pressure of steam used to evaporate it).
- Minimize the amount of steam condensed outside the dryers.
- Maximize condensate return flow and condensate pressure to the powerhouse.
- Minimize electrical consumption for key users.
- Monitor and manage energy consumption and cost.

Mill-wide energy savings require a multi-faceted approach, including purchasing smarter, using less, integrating processes from different parts of the mill, and generating more low-cost electricity. Human factors such as training, publicity, visibility, accountability, benchmarking, and targets can aid in achieving energy conservation goals.

System monitoring

Scottish mathematician and physicist Lord William Thomson Kelvin (1824-1907) said, “If you can’t measure it, you can’t improve it.” A key first step in energy conservation activities is monitoring energy consumption and making sure flowmeters and cost information are accurate. Some mills have developed mill-wide system balances that can be used to check accuracy of individual flowmeters. Assigning a person to be responsible for energy conservation in the mill and/or paper machine area can help increase visibility and accountability of conservation efforts. Steps for an effective monitoring program include:

- Have an energy champion responsible for monitoring and reducing energy consumption on the machines.
- Meter energy flows to each machine.
- Establish key energy parameters.
- Highlight variables that affect energy consumption.
- Include energy parameters in operator rounds and centerlining efforts.
- Provide information to operators, engineers, and managers to encourage continuous improvement.
- Develop trouble, cause, and correction (TCC) procedures to troubleshoot issues contributing to high energy consumption.
- Discuss energy cost and conservation efforts in production meetings.
- Conduct periodic check-ups of key systems.
- Benchmark machine operation with best in class and best achievable for the equipment installed.

Utilities to be monitored include:

- Pressure (kPa or psig), temperature ($^{\circ}\text{C}$ or $^{\circ}\text{F}$), and flow (kg/hr or lb/hr) for each header supplying steam to the machine.
- Electrical consumption for each machine (MW).
- Natural gas (m^3/hr or scfm)
- Water flows and temperatures – mill water, warm or hot water from other areas of the mill, and sewer (L/min or gpm, $^{\circ}\text{C}$ or $^{\circ}\text{F}$).
- Compressed air pressure (kPa or psig) and flow (m^3/hr or scfm).
- Condensate return flow (l/min or gpm, kg/hr or lb/hr) and temperature ($^{\circ}\text{C}$ or $^{\circ}\text{F}$).

Based on these measurements and paper machine production rates, specific energy indices can be calculated and tracked:

- Steam consumption (kg/tonne or lb steam/ton paper)
- Electrical consumption (kWh/tonne or kWh/ton)
- Natural gas consumption (m^3/tonne or kscf/ton)
- Total energy consumption (kWh/tonne or MMBtu/ton)
- Water consumption (m^3/tonne or gal/ton)
- Compressed air consumption (m^3/tonne or kscf/ton)
- Condensate return (%)
- Total energy cost (\$/ton)

Determination of energy unit costs typically requires assistance from mill accounting and powerhouse personnel. Understanding the relative cost of different energy sources can help papermakers minimize total energy costs. Note that the cost of various energy sources will change based on relative cost of corresponding raw materials. Cost components that should be included in evaluation of total costs include:

- Net cost of steam to each paper mill supply header (\$/kg or \$/klb). One method is to determine fuel cost for high-pressure steam minus the value of electricity generated by turbines. Marginal cost of steam (cost of the last steam generated) should be used to measure the value of steam savings. Marginal cost is usually higher than average cost since powerhouses use more expensive fuel to top off demand. Note that this method of calculation may be an over-simplification if pressure and flow in a low-pressure steam header are maintained by high-pressure make-up steam supplied from a pressure-reducing valve in the powerhouse.
- Net cost of natural gas cost (typically expressed in \$/kcal, \$/therm or \$/MMBtu)
- Electrical cost (\$/MWh). Calculating \$/kWh or \$/hp-hr can assist in calculating electrical energy savings.
- Water and sewer costs (\$/M liter or \$/MMgal). Both supply and sewer water treatment costs should be included to determine true value of water conservation projects.
- The value of condensate returned to the powerhouse. This should include associated energy, water treatment costs, wastewater treatment costs, and raw water pumping costs to get it to the water treatment plant. Cost should be adjusted downward for condensate polishing costs.

The combination of production rates, energy consumption, and cost information can be used to determine energy cost per ton of product. It is also important to understand energy contracts. Generally managing energy savings downward is the correct move; however, with some peak energy contracts unless you are able to save off of peak there are no apparent savings and conversely if you can save off of peak there is an immediate benefit.

Additional specific energy flows can also be useful, including dryer section steam, if it is metered separately from total steam to the machine. There are three areas that are typically poorly monitored that can help a mill identify steam waste; the steam flow to the wire pit or silo, the steam flow used to heat shower water, and the energy loss to the dryer vacuum condenser (water flow, temp in, temp out). Looking at valve position is one way of tracking these energy flows but does not tell the entire story. Most mills have no idea how much energy they are using in the silo or for shower water heating. The normal response from papermakers is "not much" but in reality it can be a significant use. Dryer drainage system vacuum condenser tracking is also recommended. It is a sure way to assess and maintain the health of the dryer drainage system. The percent energy loss can be tracked and trended. This identifies bad vent valves, open vent valves, high wet end dryer losses, air leaks, high water flow, etc. The vacuum condenser is often a piece of equipment that is poorly controlled. Poor control often results in high water flow that dilutes and upsets the fresh water system.

Performance indices

Performance indices can be used to benchmark energy consumption and identify opportunities for improvement. TAPPI TIP 0404-47 "Paper machine performance guidelines" (1) provides a broad range of indices for different grades of paper. Target values for key indices applicable to energy consumption are shown in Table 1 for various grades.

Key factors

Each machine typically has several key factors that influence energy consumption on the machine. Green/yellow/red indicators can be used for key process conditions that affect energy consumption to show whether values are in desired ranges. DCS and/or data historian trending can be used to track trends of key parameters.

Sheet consistency out of the press section is often the primary variable affecting paper machine energy consumption. Regular grab samples (TAPPI TIP 0404-01 "Determination of water removal by wet presses" discusses the proper procedure) or the use of portable or fixed sheet moisture gauges specifically designed for use in the press section are recommended to track solids. Press solids can also be calculated based on press section and/or dryer section water balances. Typical additional key factors include:

- Venting from dryer section thermocompressor or cascade sections
- Condenser water valve output/condensate flow
- Differential pressure (especially for lead dryers)
- Wire pit steam water heating steam valve positions
- Mill water make-up into whitewater or warm water systems.
- Basis weight versus standard
- Press section weir flows
- Size press starch solids and pick-up
- Pocket ventilation temperature
- Temperatures through hood exhaust heat recovery systems
- Warm water flow, pressure, and temperature from pulp mill
- Winter/summer operating strategy for machine room ventilation
- Any additional steam venting

Centerlining

Centerlining is often a tool used to help ensure consistent paper machine operation and quality. The tool can also be used to help monitor and control energy consumption. Centerlining of energy parameters can often be divided into two categories: process setpoints and factors reflective of system health.

Table 1. Energy performance indices

Index	Grade									
	Fine	Bleached board	Liner	Corrugated medium	Market pulp	Fluff pulp	Recycled paper-board	News-print	LWC	Kraft paper
Uptime, %	95	93	94	94	95	95	93	93	93	94
First quality, %	93	90	97	97	99	97	93	98	85	97
Overall machine Efficiency, %	89	84	91	91	94	92	86.5	92	79	91
Total steam consumption										
lb/ton	4,000	4,000	2,800	2,750	2,000	2,500	2,800	2,800	3,000	5,000
kg/ton	2,000	2,000	1,400	1,400	1,000	1,250	1,400	1,400	1,500	2,500
Electrical consumption										
kWh/ton	350	350	300	300	150	150	300	300	400	400
kWh/tonne	385	385	330	330	165	165	330	330	440	440
Total energy cons.										
MMBtu/ton	6.0	7.0	5.0	5.0	4.0	4.5	6.0	5.0	5.5	6.0
GJ/tonne	7.0	8.1	5.8	5.8	4.6	5.2	7.0	5.8	6.4	7.0
Water consumption										
gal/ton	2,000	2,000	1,500	1,500	1,000	1,000	<1,000	2000	2000	1500
m ³ /ton	7.6	7.6	5.7	5.7	3.8	3.8	<3.8	7.6	7.6	5.7
Couch solids, %	22	25	27	27	28	28	NA	21/18	22/18	20/19
Press solids, %	42/45	42	42/50	42/50	50	45	48	43/48	43/49	42/46
Size press moisture, %	3.0	3.0	NA	NA	NA	NA	NA	NA	NA	NA
Reel moisture, %	5.0	5.0	7.5	10.5	10.0	7.5	>7.5	7.5	5.0	7.5
Drying steam										
lb steam / lb water evaporated	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
PV supply temperature										
°F	<180	<180	<180	<180	NA	NA	<180	<180	<180	<180
°C	<80	<80	<80	<80	NA	NA	<80	<80	<80	<80
Condensate return	75-80	75-80	75-80	75-80	75-80	75-80	75-80	75-80	75-80	75-80

Examples of process setpoints that can be used in Centerlining include:

- Wire pit and other water heating temperatures
- Pocket ventilation, blow box, and other air heating temperatures
- Dryer section differential pressures (or blowthrough flows)
- Press loads
- Sheet moisture at the reel
- Refining kW, freeness, hpd/t and/or kWh/t

Examples of factors reflective of system health include:

- Overall consumption indices such as ton steam/ton paper, kWh/ton, and energy cost/ton
- Dryer section ton steam/ton
- Warm water flow and temperature from the pulp mill
- Mill water flow
- Silo and process heat exchanger valve positions
- Warm water make-up valve positions
- Mill water make-up valve positions into the white water or warm water systems
- Venting from dryer sections (dp or blowthrough vent valve positions)
- Pulper pump and agitator amps
- Press section weir flows

Operator rounds

Operator rounds should be utilized to manage systems that are not visible in DCS or data historians. Examples of areas where operator round may be required include:

- Roof or mezzanine rounds to check for leaking vent or safety-relief valves.
- Roof supply and machine room ventilation temperatures.
- Hydraulic cooling/heating systems.
- Condenser systems.
- Steam leaks.
- No dumping of condensate.

Some mills utilize an infrared temperature gun to check stock and water system temperatures and detect cold-water infiltration. Note that flat black spray paint should be used to mark areas on piping where infrared measurements are used to ensure uniform emissivity.

Energy surveys

Energy audits can provide useful first steps to identify and prioritize opportunities to reduce paper machine energy consumption.

Data can be collected from direct observation; data historians; discussions with mill operating; maintenance, and engineering personnel; and previous reports conducted on subsystems of the paper machine. A computer simulation of the papermaking process can help validate data and determine potential benefits from process changes.

Keys to successful implementation of recommendations from an energy audit include:

- Obtaining buy-in from all parties involved
- Focusing on optimal measures, but not forgetting incremental gains
- Understanding the costs, risks, and benefits of potential projects
- Considering life cycle costs in project evaluation
- Thoroughly planning implementation
- Training

- Documenting results
- Optimizing the system after the project

Additional surveys

A detailed review of various paper machine systems can ensure that systems and equipment are operating efficiently. Some of these recommended surveys and suggested frequency are listed below.

- Steam trap surveys (annual)
- Compressed air system surveys (annual)
- Refining optimization (on-going) and mechanical surveys (annual)
- Saveall audit to check capacity and filtrate quality (annual)
- Showering surveys (every 2 years)
- Press section optimization (on-going)
- Press section nip surveys (every 2-3 years)
- Vacuum pump boroscopes or orifice plate testing (annual)
- Vacuum system surveys/optimization (every 3 years)
- Thermography to check for leaks and hot spots (annual)
- Steambox surveys (annual)
- Dryer steam and condensate system surveys (annual)
- Hood air system surveys (annual)
- Machine room ventilation studies (every 5 years)
- Pulp dryer maintenance/capacity reviews (annual)
- Tissue machine hood balances/inspections (annual)

System optimization

Key process areas to consider when in a program to reduce paper machine energy consumption are discussed below.

Reducing the amount of water to evaporate

Drying steam represents the majority of energy consumption on a paper machine. A step in minimizing energy consumption is reducing the amount of water to evaporate in the dryers. Opportunities to do this include:

- Increase press dryness (high-load, shoe presses)
- Optimize press fabrics and roll cover designs (venting and hardness, nip dewatering vs. Uhle box dewatering)
- Reduce basis weight (while meeting the product specifications)
- Trim the sheet at the wet end rather than at the dry end
- Improve cross-machine moisture profile uniformity
- Increase starch solids used in size press (metering size press)
- Minimize water added to the sheet through rewet showers
- Increase moisture content of the sheet at the reel (when sheet properties and profiles allow).

Machine efficiency

Increasing overall machine efficiency has a direct effect on specific energy consumption since it takes as much or more energy to produce a ton of broke as it does to make a ton of first-quality paper. Some steps to increase machine efficiency include:

- Reduce sheet break and grade change times.
- Shorten open press-to-dryer draws, provide direct sheet support.
- Minimize trim losses with good edge control and coordination with business logistics.
- Full machine threading - including features that minimize break recovery and thread times.
- Optimize performance of trim squirts.

- Utilize camera systems to identify and characterize breaks.
- Optimize quality control system (QCS) performance to ensure good machine-direction (MD) and cross-machine direction (CD) profiles.
- Control sheet in open draws in the dryer section.
- Utilize capability of distributive control systems (DCS) and data historians to impact efficiency and troubleshooting.
- Optimize process chemistry for runnability and maximizing ash content - closed loop control of retention, charge, etc.
- Manage broke to maintain stability.
- Optimize whitewater saveall to maximize overall retention, to stabilize wet end during break conditions, and to increase clear filtrate quality and quantity for replacement of mill water in showers.

Agitation

Chest agitation is a significant contributor to paper machine electrical consumption. Opportunities to reduce energy consumption with design and operation of agitation include:

- Do not overestimate consistency when designing systems
- Design chests for the optimum dimensional ratios (cube is best)
- Do not underestimate temperature
- Allow for a larger manhole to install a larger impeller at low speed
- Keep flow impediments [ladders, etc] out of chest design
- Only operate the number of pulper agitators necessary
- Consider variable-speed or two-speed agitator motors
- Utilize zone agitation where complete mixing is not required.
- Consider top-entry instead of side-entry agitators
- Do not put pump suction behind the impeller
- Slow down an agitator and reduce horsepower if operating consistency has dropped substantially from design.
- Make sure there is not excessive motion when you look in a chest.
- Work with a supplier that understands the mixing process intimately

Pump and motor systems

U.S. Department of Energy (DOE) information indicates that average motor energy cost/mill/year is \$1.7 MM for pulp mills, \$4.6 MM for paper mills, and \$3.0 MM for board mills. Average available motor savings opportunities per year are estimated to be \$483,000 for pulp mills, \$679,000 for paper mills, and \$492,000 for board mills. The U.S. DOE Office of Industrial Technologies web site (3) includes information on pump and motor systems, compressed air systems, steam, and other opportunities to conserve energy.

Approximately 30% of paper mill electrical energy consumption is by pumps, 20% by fans, 5% by compressors, and 45% by drive motors and other electrical equipment. Potential electrical energy savings opportunities are available through pumps and fans (53%), motor efficiency upgrades (23%), air compressors (6%), rewind improvements (6%), motor downsizing (6%), and other systems (6%). Pump-based systems represent the largest single group of energy-consuming equipment and offer greatest potential savings.

DOE indicates that 80% of electrical consumption is by 10% of the motor population (motors greater than 50 hp). 200-500 hp motors typically have the largest percentage of savings opportunities.

The primary reasons pumps waste energy are over-design, change in process conditions, or degradation. Over-design can be the result of overestimating design conditions, contingencies, safety factors, catch-up capability, "room to grow," or design for a wide range of process conditions.

Energy is wasted when a pump system is changed; resulting in a lower flow rate or lower head pressure requirements, but the pump, motor, and/or piping are not downsized to meet the change. Energy is also wasted when

a larger pump than required is used for the purpose of commonality of spares. This also highlights the need to build to what will be required instead of building to some future incremental capacity.

Pumps that operate in caustic or solids applications tend to experience impeller and wear ring degradation, causing a loss in pump efficiency. Routine inspection of pumps in these applications is recommended. Parts should be maintained and/or replaced as necessary.

DOE promotes identifying motors with the greatest saving potential for further investigation. The greatest savings potential is typically centrifugal loads with a high duty cycle. These motors are referred to as the “vital few.” The following steps can identify them:

1. Categorize motors by size times operating time. Establish a threshold for more detailed consideration. (Should be a one-day effort in most plants – a plant-wide motor inventory is not necessary).
2. Segregate by load type (focus on centrifugal loads)
3. Look for symptoms in pumping systems that indicate potential opportunity:
 - Systems controlled by throttling valves
 - Recirculation line normally open
 - Systems with multiple parallel pumps with the same number of pumps always operating
 - Constant pump operation in a batch environment or frequent cycle batch operation in a continuous process.
 - Cavitation noise (at pump or elsewhere in the system)
 - High system maintenance
 - Systems that have undergone a change in function.
4. Establish policies to replace seldom-used, small-load, and large, non-centrifugal systems with high-efficiency motors.

The Pumping System Assessment Tool (PSAT) (3) can be used to quantify energy consumption and cost savings potential from a pump. The assessment requires flow rate, pressure, and motor current or power data.

Note that cost to buy a pumping system is usually much less than its operating cost. Life cycle cost should be used for evaluating pumps.

Opportunities to reduce energy consumption by pumps and motor systems include:

- Replace throttling valves with speed controls where appropriate
- Reduce speed for fixed-load pumps
- Install parallel system for highly variable loads
- Equalize flows using surge vessels
- Replace motors and/or pumps with more efficient models
- Avoid recirculation control
- Avoid incompatible duties on common pumps
- Do not operate in startup configurations permanently
- Design systems with proper line sizes
- Avoid tanks where feasible
- Optimize process configuration, consistency and pressure setpoints
- Determine what can be shut off or bypassed during slow backs.

Refining

Refiners must be in good mechanical condition to minimize energy consumption and optimize fiber development. Effective life of refiners between rebuilds is typically 10-15 years. Mechanical condition can be estimated by checking no-load horsepower by backing off refiners while stock is running through them. Higher than normal no-load power indicates mechanical problems such as bad bearings, sticking quill, improperly greased slide coupling, etc. Lower than normal no-load horsepower indicates worn refiner plates. Poor mechanical condition can increase no-load horsepower by over 10%. Refiners should be inspected annually to check mechanical condition.