Conservation of energy

A paper machine fingerprint cuts energy usage

CARL-FREDRIK LINDBERG, NAVEEN BHUTHANI, KEVIN STARR, ROBERT HORTON –
Entering the papermaking machine, the raw material that goes into a single A4 sheet of paper would look like a bucket of slightly dirty water. In fact, the stock furnished to a paper machine contains over 99 percent water and less than 1 percent actual paper fiber. Although most of the dewatering in papermaking is performed mechanically, a significant amount is done thermally – resulting in colossal energy usage and making paper production one of the most energy-hungry processes in industry. But where such large consumptions are in play, there also exist opportunities for significant savings. This is why ABB offers a paper machine energy fingerprint. This assessment quantifies energy flows and benchmarks energy use in the paper machine, enabling energy-saving opportunities to be identified.

In principle, papermaking has changed little over the centuries, though the equipment used has evolved dramatically: A slurry, containing more than 99 percent water and less than 1 percent actual paper fiber, is sprayed onto a traveling, endless wire mesh. Much of the water falls, or is sucked, through the mesh and a wet web of fibers continues to the press section of the paper machine, where it is squeezed between heavy rolls to remove even more water → 1. Water removal here is made more efficient by using a steambox to steam-heat the fiber web before the presses. The web then proceeds to the drying section where it passes partly around, in a serpentine manner, a series of steam-heated drying cylinders. This reduces the moisture content to about 6 percent.

Pressing is a far more efficient means of removing water than heating, but only so much water can be pressed out, so heating is unavoidable – and this is when the energy bills start to mount up. However, where large amounts of energy are consumed, there is also scope for significant energy savings.

Title picture
Paper machines use huge amounts of steam to dry paper. How can a critical analysis of the energy flows in the machine deliver substantial savings?

1 A typical paper machine. The "wet end" is in the foreground; the drying section is at the left.

Where large amounts of energy are consumed, there is also scope for significant energy savings.

Energy flows

In the dryer section, energy is transported by steam, condensate, air, water and paper in a complex flow scheme: The paper dries when it is heated on the steam cylinders and the heat from the moisture released is recouped by a heat exchanger and added to the inlet air, which is further heated by a steam-air heat exchanger. The air going into the machine hall is also heated. Steam heats the steam cylinders and some flash steam[1] is recovered by thermocompressors. Remaining flash steam goes to the condenser where it heats up cold water ➔ 2.

The challenge is to identify where energy is wasted in this complex interplay and what savings can be made.

Measuring and improving paper machine energy performance in this way is not a new idea and several approaches have been suggested [1,2]. It has been found that pocket air ventilation, hood balance and dew point have a significant influence on paper machine efficiency [3, 4, 5, 6, 7].

Several aspects can influence energy efficiency:

- The type of equipment (design efficiency and condition)
- Lack of equipment (eg, no heat exchanger, no steambox)
- Plant design (eg, use/waste of flash steam and condensate, heat recovery system)
- Control strategy (eg, no dew point control)
- Operation (manual control, choice of setpoints)
- Maintenance (of heat exchangers, steam traps, valves, sensors, insulation, leaks, tuning control loops, etc.)
- Sensors (calibration, lack of sensors for monitoring and/or control)

Methods

Various methods are used to identify inefficient use of energy.

Energy quantification

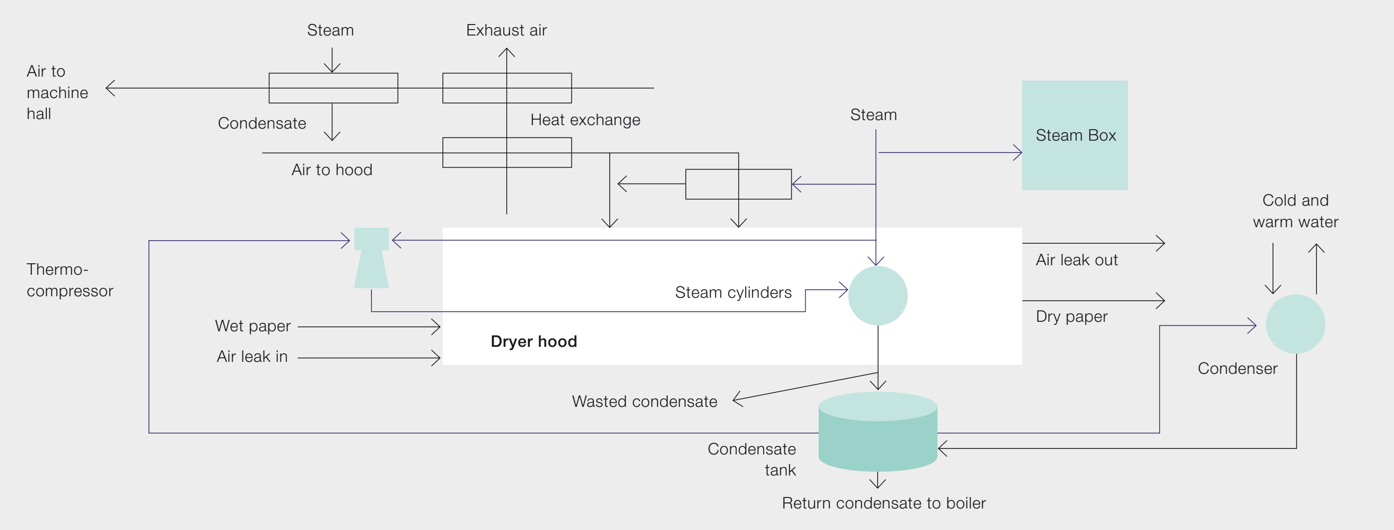
Knowledge of the energy flows inside the paper machine allows waste streams to be identified. Energy flows are more difficult to measure than liquid and gas flows since more measurements are required and very few of the measurements needed for calculating energy are available; steam flow sensors are particularly rare.

The steam flows to the steam groups of a real paper machine were estimated by measuring the rise time in the condensate tanks after switching off the effluent flow from the tanks. The steam consumption in steam-air heat exchangers was, in this case, estimated based on airflow, humidity and temperature measurements. By using energy equations together with measurements, the relative energy consumption was obtained ➔ 3.

Footnote

1 Flash steam is vapor or secondary steam formed from hot condensate discharged into a lower pressure area. It is caused by excessive boiling of the condensate, which contains more heat than it can hold at the lower pressure.

2 Overview of energy flows in a paper machine



The main steam usage is, as expected, in the different steam groups, but, in this paper machine, more than 10 percent of the total steam energy goes to the condenser. An industry-typical value would be under 3 percent, so energy efficiency improvements here are obviously feasible.

Data mining

Historical data can be scanned for operations that influenced the steam consumption per ton of paper ratio. First, data is grouped by paper grade. Then, for each grade group, various signals are plotted against steam consumption per ton of paper. If there is a clear relation between the signal and energy efficiency then a suggestion is given on how to run the paper machine more efficiently. In the future, this search could be automated.

Real data from a paper machine was collected to estimate steam consumption per ton of produced dry paper for some different basis weights. The steam consumption per ton dry paper varied between 1.8 and 2.4 tons ➔ 4. The basis weight has, apparently, a large impact on steam efficiency in this paper machine as heavy basis weights consumed less steam per ton of paper than lighter grades.

Another variable that influenced steam consumption per ton dry paper was machine speed. Generally, the higher this is, the less steam is used ➔ 5. For the lightest basis weights, the velocity relation is weak, perhaps due to condensate rimming in steam cylinders or limited capacity in the press section at higher speeds.

Other parameters that influenced steam efficiency were the differential pressure over steam groups (the lower, the better) and refining (less, if possible).

Steambox optimization

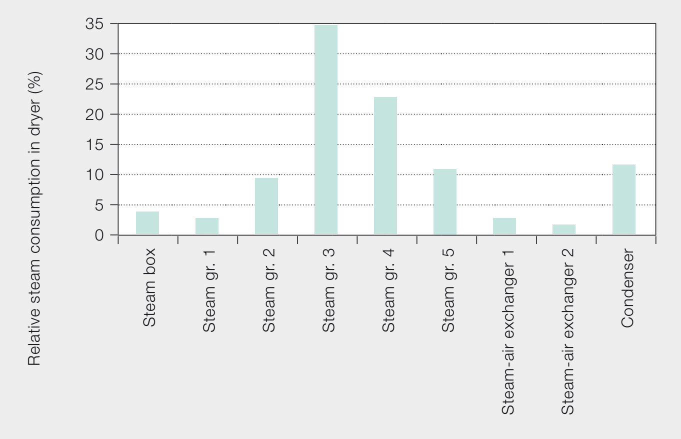
Steam-heating the paper web reduces total steam consumption because hot paper is more easily dewatered in the press section, and the dryer section consequently needs less steam to drive out the remaining moisture. However, feeding too much steam to the steambox does not improve dewatering. Setting the steambox flow to the optimal pressure minimizes total steam flow. It should be noted that the steambox is also used for flattening the moisture profile across the web and dewatering measures should not interfere with this.

An experiment was performed on a steambox ➔ 6. First, the steambox pressure was reduced, then all actuators were set to 80 percent open and the steambox pressure was ramped up slowly and then partly down. The total steam consumption in the paper machine (top curve) reached a minimum after 80 minutes, when it was around one ton per hour (about 2.5 percent) less than in normal operation. The reel velocity was constant during the experiment and the total lower steam consumption at 80 minutes is not a result of higher moisture.

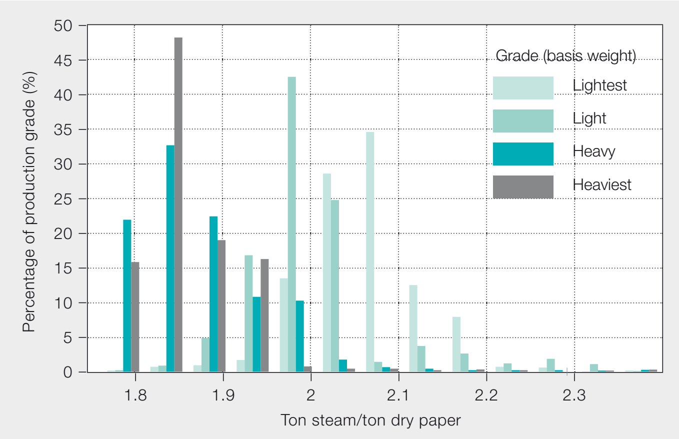
The moisture profile across the sheet (not shown) deteriorated, as expected, with high moisture at the edges when all the actuators were opened. It remains to be seen what steam consumption savings can be achieved when automatic moisture profile control is running.

The challenge is to identify where energy is wasted in this complex interplay and what savings can be made.

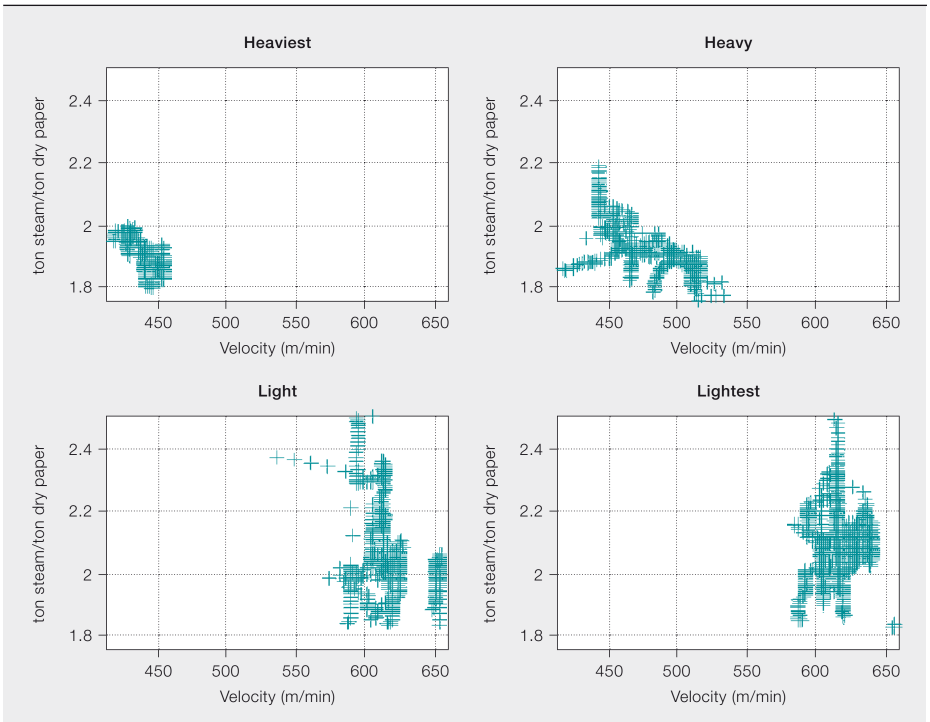
3 Relative steam consumption in the dryer section of a real paper machine



4 Histogram for ton of steam consumption per ton of dry paper produced over 19 days for different basis weights.



5 Ton steam consumption per ton dry paper vs. paper velocity for different basis weights. Higher velocity is more energy efficient for the heavier grades.



Infrared thermography

Heat leaks and associated equipment problems reduce energy efficiency. Such issues can be located using thermal imaging. Dryer cylinders, the dryer hood, the thermocompressor, steam and condensate traps, etc. have been studied using this technique.

For example, a thermogram of a section of the hood showed a hot air leak heating the hood on the outside (hot air itself cannot be detected by thermal imaging) ➔ 7. Sealing the leak would save energy and reduce the humidity in the machine hall. This also reduces the amount of moisture to be removed by the ventilation, which, in turn, saves yet more steam by reduced steam heating of outside air.

A thermogram of a thermocompressor was used to detect inefficiency ➔ 8. In the lower part of the figure, cooler flash steam enters at 124.6 °C. High-pressure motive steam enters from the right at 149.9 °C. The mixed flow is at 147.5 °C, which is close to the motive steam temperature, hence very little flash steam is recycled. Energy could be saved by recovering more flash steam and reducing the flow to the condenser.

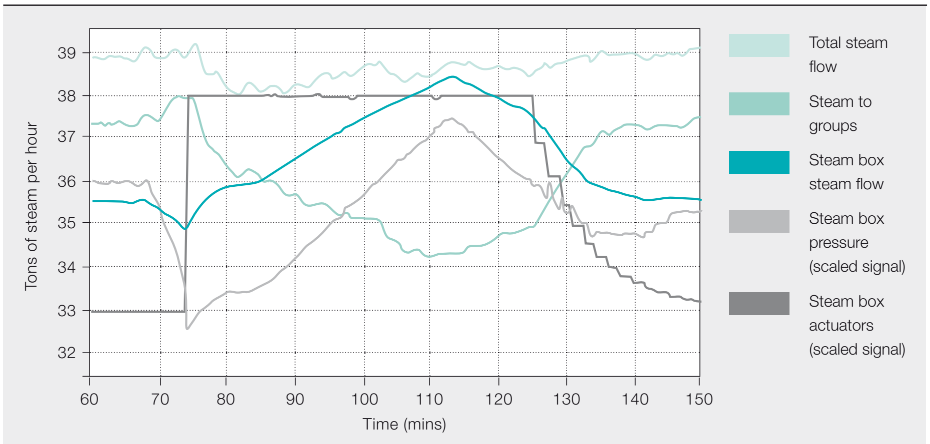
Another way to check the thermocompressor is to study total steam consumption or condenser load when it is switched off. When this was done, no change was observed on total steam consumption or condenser load.

Energy benchmarking

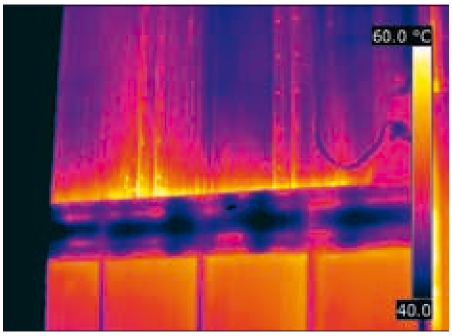
Various benchmarks have been calculated to determine the energy efficiency of the mill, eg:

- Ton steam/ton dry paper
- Steam energy in Joules/evaporated kilogram water
- Electricity kWh/ton paper
- Condensate return ratio to power house
- Dew point in hood (exhaust air)

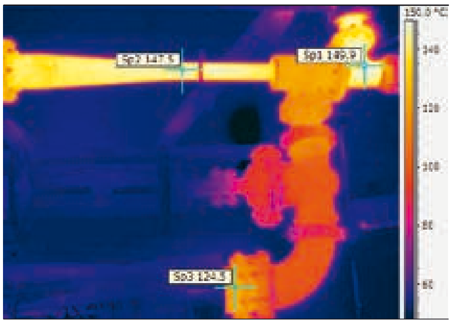
6 Steambox experiment. Note lower total steam consumption (top curve) at t=80.



7 Thermogram of a part of the hood where hot, humid air leaks (above the gap)



8 Thermogram of a thermocompressor



Cooler flash steam enters at 124.6 °C. High pressure motive steam enters from the right at 149.9 °C, giving a 147.5 °C mix, which is close to the motive steam temperature, hence very little flash steam is recycled.

- Sheet consistency after press section
- Availability (uptime/total time)
- Performance (actual speed/maximum for that grade)
- Quality (good tons/total)
- Overall equipment effectiveness

These and other performance indices can be compared with other paper machines producing the same type of paper. Where a benchmark is found to be poor, there exists an opportunity for energy saving.

Other experiments

The discussion above is not exhaustive – there are other experiments that could be performed to identify areas to save steam:
- Increase the wire tension to improve heat transfer rate and reduce steam consumption.
- Reduce over-superheated steam to make the steam cylinders more energy efficient.

Savings all round

Paper machines consume large amounts of energy, but, in most cases, large savings can be also be made. By quantifying steam supply and steam use, inefficiency can be measured, poor energy users can be identified and solutions can be applied.

An audit of a paper machine has identified the following potential steam savings:
- 2.5 percent steam savings by increased reel velocity
- 2.5 percent steam savings by optimization of steambox pressure
- 2 to 8 percent “condenser” savings by repairing and/or improving the operation of thermocompressors, reducing differential pressures over steam groups and improving pressure control in general.
- Plus some more percent steam savings by sealing leaks from hood and ventilation systems, less refining (if possible), increased wire tension, increasing hood dew point, reduced steam superheating, etc.

By simply optimizing control setpoints, steam consumption can be reduced by 5 percent. With limited investments, steam savings of around 10 percent would be possible.

Carl-Fredrik Lindberg
ABB Corporate Research
Västerås, Sweden
carl-fredrik.lindberg@se.abb.com

Naveen Bhuthani
ABB Corporate Research
Bangalore, India
Naveen.bhuthani@in.abb.com

Kevin Starr
ABB Process Automation Services
Westerville, OH, United States
kevin.starr@us.abb.com

Robert Horton
ABB Optimization Service
Atlanta, GA, United States
robert.horton@us.abb.com

References

1] Kuvalekar D. (2007). *Reducing Specific Steam Consumption through Automation in Steam Systems.* Proceedings of Paperex 2007, New Delhi, India, December 7–9, 2007.

[2] Reese D. (2009). *Measuring Paper Machine Energy Performance.* Proceedings of PaperCon ‘09, May 31 – June 3, St. Louis, MO, USA. 2009.

[3] Ghosh A. K. (2009). *A Systematic Approach to Optimise Dryer Performance and Energy Savings – Case Studies.* Proceedings of PaperCon ‘09, May 31 – June 3, St. Louis, MO, USA, 2009.

[4] Ghosh A. K. (2005). *Optimization of Paper Machine Dryer Section*. Proceedings of 7th International Conference on Pulp, Paper and Conversion Industry, PAPEREX 2005, New Delhi, 2005.

[5] Kilponen L. (2002). *Improvement of Heat Recovery in Existing Paper Machines.* Licentiate thesis, Department of Mechanical Engineering, Espoo, Helsinki University of Technology, 2002.

[6] Lindell K. and Stenström S. (2004). *Assessment of Different Paper Drying Processes to Reduce the Total Energy Costs from a Mill Perspective.* Drying 2004 – Proceedings of the 14th International Drying Symposium, São Paulo, Brazil, 22-25 August 2004, vol. B, 1233-1240.

[7] Sivill L. and Ahtila P. (2009). *Energy efficiency improvement of dryer section heat recovery systems in paper machines – A case study.* Applied Thermal Engineering, 29 (17–18), 3663-3668, December 2009.