Paper Machine Water Efficiency

John A. Neun, P.E.
Clean Tech Partners

ABSTRACT

Traditionally, water has been viewed as a virtually free commodity for most paper machines. Changing environmental and economic circumstances have made that view obsolete. Understanding the sources and uses of water can lead to efficiency improvements and not just the conservation of water, but better profitability, most often through energy savings. This paper discusses how water is used, why it is valuable, and how it can be saved.

INTRODUCTION

In our summer, 2016 Paper360 article about climate change and its effects on the pulp and paper industry[1], Jim Atkins, Jan Bottiglieri and I addressed three fundamental resources needed to make paper: fiber, energy, and water. A follow-up article in the winter, 2019 issue was devoted to fiber sustainability, discussing recycling, forest management, and wood fiber alternatives. This article will examine water use on paper machines, why it is important to optimize efficiency of water use, and finally some strategies to do so.

THE IMPORTANCE OF WATER

The 2016 work leads to two broad conclusions: the world is changing and thus so is the supply of resources needed to make paper, and water availability is fundamental to all of those key resources. As the climate becomes more unsettled, unprecedented drought and flooding occur, upsetting normal supply. Paper mills tend to locate at a confluence of resources, especially water. One large corporation even names its mills by the rivers on which they are built. As the world changes, water will become scarce. Or not. Change may be inevitable, but direction is difficult to predict. Prudence demands that in times of uncertainty, prepare for the worst, and the worst requires efficient and minimal use of water. Smart use of water inevitably results in improved energy efficiency, too. Using less water is thus a good way to prepare for the future and save money in the present.

HOW IS WATER USED?

An excellent overview of water sustainability in the paper industry defines three ways to drive to sustainability: reduce, reuse, and recycle. For a paper machine, the first two present fundamental ways for a paper machine to use less water[2]:

- Reduce: tune applications to operate with lower volumes of water
- Reuse: process water mechanically or chemically as necessary to reuse it, replacing fresh water.

Water is the lifeblood of paper machines. A typical headbox can easily flow 30,000 gallons of water per minute (gpm). Most of that water stays on the machine and flows in a loop. How much doesn't, that is, how much is lost, is a fundamental source of inefficiency.

TAPPI TIP 0404-63, "Paper Machine Energy Conservation," indicates water consumption for top performing machines varies by grade. Pulp machines should use about 1000 gallons/ton, brown paper machines about 1,500 gallons/ton, and publication machines about 2,000 gallons/ton[3]. This TIP is currently being revised and all of these numbers will go down. There are a dozen or two mills in North America that actually have zero water discharge. While not typical, these mills represent the possibility of using much less water and overcoming the challenges in doing so.

"Typical" is a dangerous word to use to describe paper machines, because they are all unique. However, to illustrate potential water dispositions, consider a broad, "typical" description. Water can be considered as moving in three large loops, as illustrated in Figure 1. The first is water that leaves the headbox, is drained in the former, and goes back to the headbox as white water. Most of the water that comes to the headbox is white water, that is, water that has been drained from the sheet of paper on the former. Most of the rest comes from the high-density stock chests that supply fiber to the machine. Water can escape from the machine loops in a number of ways, some deliberate and some inadvertent. Water in the paper sheet is lost to evaporation in the dryers by design, but compared to the overall volume of water coming to the machine the volume is almost negligible, usually about 1%.

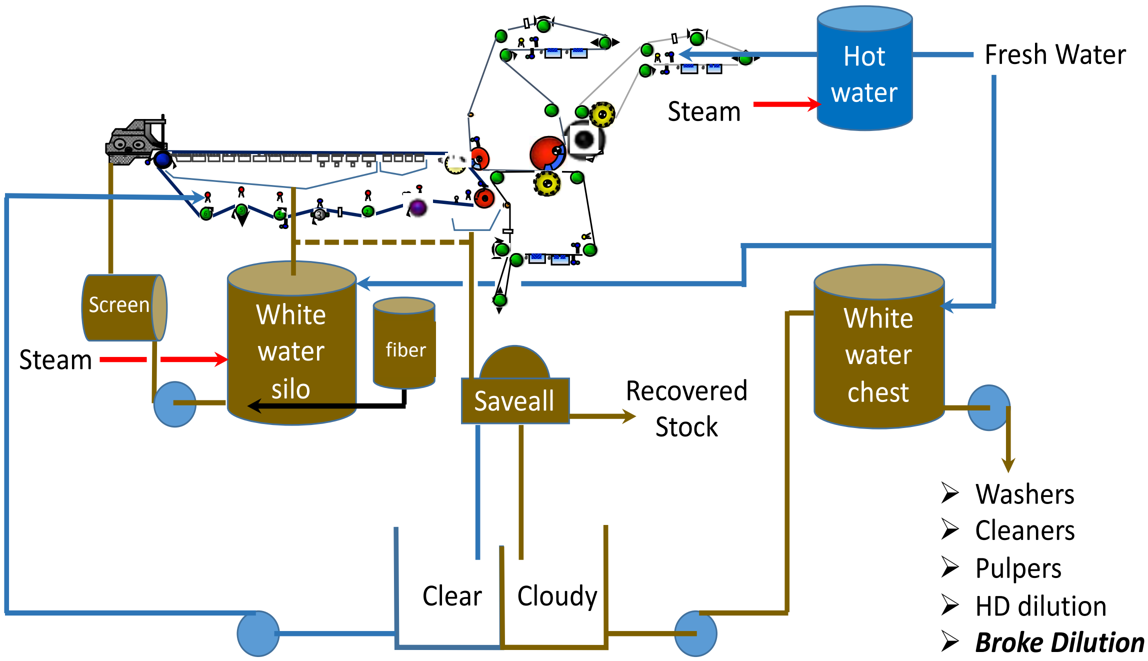

Figure 1: Water Loops on Paper Machines

Consider that first, primary white water loop that supplies water drained from the sheet to the headbox. A 1,000 ton/day machine, if headbox consistency is 0.8%, would have a headbox flow of about 21,000 gpm. If high density stock is supplied at 4% solids, there would be about 4,000 gpm of water coming to the headbox with the stock, so 17,000 gpm of white water would be needed. If sheet consistency leaving the couch roll is 25% solids, there would be about 500 gpm of water in the sheet exiting to the presses, so about 20,500 gpm of white water is created by the former (21,000 gpm - 500 gpm). If only 17,000 gpm is needed, there is a theoretical surplus of 3,500 gpm of white water not needed by the headbox. (In this very simple model, that volume is the high-density water flow minus what goes to the presses.) Either that water becomes effluent and is lost, or it is reused.

The second and third white water loops have two purposes. First, fiber otherwise lost in excess white water is rescued and second, water is captured for reuse in the process. White water is usually processed through some kind of barrier filter system, commonly a save-all, which separates fiber from white water and creates filtered water, often in multiple levels of quality. Usually the clear white water is used for machine showers and other more critical applications in the wet end of the paper machine. That water defines the second loop, where most of the filtered water ends up back in the white water chest. The third loop uses less clear, cloudy white water, pushing it upstream to pulpers, washers, and cleaners, and downstream to pulpers, especially during sheet breaks. In a perfect system, most of that water theoretically ends up back in the white water system, too.

Water usually overflows from one of the white water storage chests. In an ideal world, there would be no overflow, which implies a perfect balance between water entering and exiting the machine, that is, using all of the 3,500 gpm in the example for showering, washers, cleaners, dilution, and other such applications. Given the very large volumes and inherent perturbations of the process, such precision is not even remotely feasible. Since the steady-state process would not be sustainable with too little water entering, there has to be at least some excess, that is, there has to be some overflow. Most machines are designed to overflow the lowest value water, which is the water with the least amount of fiber. In Figure 1, that would be from the clear leg of the save-all. In practice, water often overflows from other, richer white water chests. Reasons can be inadequate save-all performance (very common for machines that are running beyond their design capacities with aging save-alls), low white water demand, or insufficient pumping capacity, to name a few.

Figure 1 also shows points at which water and steam can be added to the machine. Ideally, cold water is added only during start-ups. If cold water is added during operation, steam must be added too, to maintain process temperature. Water is added for a number of reasons such as insufficient white water volume or inadequate white water quality. For example, if machine showers supplied by filtered white water chronically plug and are switched to clean water, less white water is used (making overflow volumes higher) and fresh water is added to the system. As machines age and production increases above designed capacity, such anomalies become more common.

HOW MUCH IS WATER WORTH?

The value of lost water can be assessed using three parameters:

1. **The value of the water itself**. By today's metrics, water cost is usually the least important factor for overall effluent value. I have had the opportunity to examine many water systems, and in my experience the reported value of water ranges from $0 per million gallons to about $3,000/million gallons. "Free water" is archaic and obviously not realistic; just the cost of power for pumping water to a reasonable storage head is at least $20/million gallons. If municipal water is used, then cost can be thousands of dollars per million gallons. Most typically, mills assess water cost at something like $200/million gallons. Note that 1 million gallons/day corresponds to about 700 gpm.
2. **The value of the fiber in the water**. This number, too, can vary widely depending on the quality of the wasted fiber, fiber retention on the machine, whether paper production is fiber limited, and how expensive it is to get fiber to the machine. If machine fiber retention is poor and overflowed white water is rich, value can be over $600/million gallons. (This assumes 1000 parts/million useable fiber and $150/ton cost.)
3. **The heat in the water**. If process temperature is important to efficiency, and it always is, then every gallon of cold water added to the system to replace a gallon of warm water lost must be heated. If the process temperature is 130^{0}F and entering cold water is 70^{0}F, it would take about 500 million BTU's to heat the replacement water for every million gallons. If steam costs $5/1000 pounds, the heat is worth about $2,500/million gallons. Stated another way, it costs over $1,000/year per gpm to heat water 60^{0}F. Figure 2 is a scatter plot of steam use vs. fresh water use for a large population of paper machines. Even though it varies widely, there is a definite relationship.

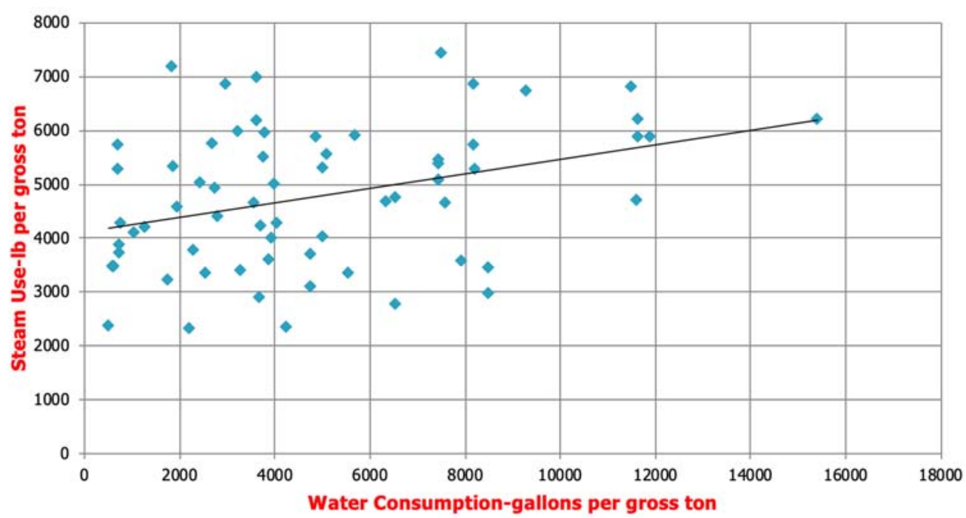

Figure 2: Steam Use vs. Water Use

In an integrated paper mill, the value of water and effluent may not be so straightforward. Kraft pulp mills generate a lot of excess heat. Some mills have systems to use this heat on paper machines, usually as hot water, eliminating or greatly reducing the need for steam heating. If this energy is not used, it ends up in the atmosphere through a cooling tower or some such like at the pulp mill. Thus, from the paper machine perspective, the heat comes at no cost and replacing hot water with recycled white water brings no real energy benefit.

HOW IS WATER WASTED, AND HOW CAN IT BE SAVED?

We've discussed in a general way how water is wasted and that some water overflow is inevitable. Here are a few more specific examples.

One of the most baffling indications of paper machine fresh water use is flow while the machine is not operating. Paper machines are large, complicated and often evolved systems with thousands of valves. It is not realistic to expect them all to operate perfectly. The volume of down-time water use, if it is measured, is usually surprising, observed as high as 1,000 gpm. Some of the most common culprits for non-productive water use are

- Agitator and pump seal lubrication
- Oil and hydraulic cooling water
- Hoses
- Vacuum pump seal water.

Shaft packing water is easy to overlook because each shaft requires relatively small volumes of water, typically 3 - 10 gpm. (Larger agitator shafts might need more). This water is almost always left on during shutdowns, which serves no purpose other than to eliminate the possibility that somebody will forget to turn it back on at start-up. Except for new machines, seal and cooling water are usually on individual valves and trying to shut them all is probably not feasible with standard systems. There are a lot of seals, and typical total lubrication volumes are hundreds of gpm. Beyond the cost of the wasted water, there is a thermal penalty, too. Usually the cleanest water available is used for packing lubrication, and that water is most often cold. Typically, about ½ of the water ends up migrating to the process side of the seal during operation, and therefore it is a cooling factor requiring steam heating to compensate. There are some things that should be done to minimize seal water waste, and some more expensive things that can be done to eliminate it. First, packings should be kept in good condition to avoid high clearances. Volumes to each packing should be limited. Water pressure should be regulated and individual flow meters can be used to eliminate excessive flow. Mechanical, dry seals can be used, which are more expensive but pay for themselves in the long run. Finally, recirculating systems are available to recycle lubrication water and eliminate waste. Usually these systems are justifiable only in applications where water is very dear.

The coldest water available is almost always used for oil and especially hydraulic system cooling. It is not hard to understand why, because the price of failure of these systems is very high. The water is heated between 10^0F and 30^0F, which makes it warm but not hot enough to reach process temperatures for most machines. The water usually gets added to the hot water system of the paper machine, which makes sense because it is very clean water, but again, there is a thermal penalty to pay because it must ultimately be heated to process temperature. It would be great to limit the volume of this water through the coolers, thus elevating its temperature. No rational machine operator would do this, however, because the elevated temperature would eat into oil temperature safety margins, and again, the cost of a hydraulic or oil system failure could be devastating. Cooling water typically represents hundreds of gpm. It is often left on during shutdowns, usually for the same reason seal water is left on.

Wash-up hoses are always located all over a paper machine. Even the best-run machines usually have at least one hose that is left on to flush a stray fiber stream or cool something. These hoses should only be used for wash-up.

Liquid ring vacuum pumps are perfectly suited to paper machine applications and can be found on the vast majority of American paper machines. They require a lot of water to maintain the liquid ring used to generate vacuum. A pump's size and vacuum level determine its seal water demand. A very large vacuum system can need as much as 2,500 gpm. For our example 1,000 ton/day machine, demand would probably be closer to 1,000 gpm. The vacuum pump seal water is inexplicably often not turned off during shut-downs.

In theory, vacuum systems do not see any process water. Vacuum flow drawn from the paper machine either passes through separators or comes from suction rolls through which very little water passes (water is transferred from the sheet or fabric to the roll shell and is expelled after the vacuum zone, except for machines that run at very low speeds). In practice, easily 10% of the water in a vacuum system can be process carry-over. The seal water required by liquid ring vacuum pumps is injected at the inlet of the pump and is separated at the pump outlet. Sometimes fresh water used as seal water is passed through the vacuum pumps and dumped into the sewer, but this is increasingly rare. Many paper machines have cooling towers. Seal water is circulated through a strainer to remove process debris, through a cooling tower, and then put back to the pumps. A typical well-running vacuum pump raises seal water temperature about 30^0F, which defines the required performance of the cooling tower. In rare but remarkable cases, vacuum water is diverted back to the process and used usually as white water. In such systems, seal water is often recirculated to the pumps after it is blended with cold water in a proportion that makes the water after the pumps about process temperature. Thus, the pumps are used to heat process water added to the process. The physics of liquid ring pumps dictates that they run better with cold seal water. The cleverest way to implement the blending/recirculation scheme is to put the added cold water to the highest vacuum, most critical pumps, maximizing their performance. Other, less critical pumps can use somewhat hotter water and sacrifice some vacuum in the interest of overall thermal and water efficiency. Another very commendable way to save the heat generated by the vacuum pumps is to use a heat exchanger instead of a cooling tower. Such systems are usually used to pre-heat incoming fresh water. In practice, the heat exchangers are very difficult to keep clean. Most often, they are fouled from contaminants in the seal water from process carry-over. In such systems, the highest possible clearances should be used in the heat exchangers, and a tube-in-shell configuration is best to facilitate cleaning. A compromise in efficiency is well worth maintenance facilitation, because practice shows that even the most fastidious separation cannot guarantee all debris from process carryover can be eliminated.

SOME APPROACHES TO WATER EFFICIENCY

Most paper machines in the United States are not new. Most have run for decades, and most are run at high production rates undreamed of when they were built. Our traditional paradigm for water is that it is free and limitless, and there is little incentive to use less of it. If that paradigm is no longer valid, how can we change our approaches to water use? “Reduce and reuse” provides a new, timely paradigm.

Reduce

We’ve already discussed ways to reduce demand by being clever about vacuum pump seal water, packing lubrication, and clean-up hoses. Most of the water that goes to the paper machine in the second white water loop we’ve discussed goes to showers. Our example 1,000 tpd machine would probably use about 1,000 gpm or more of shower water. It could get by with about half of that amount. TAPPI TIP 0404-61 provides some reference standards for paper machine showers[4].

The highest volume shower on most machines is the flooded nip knockoff shower. If used continuously, it can easily consume half of the shower water on the machine. Modern forming fabrics make flooded nip showers very attractive for reliable sheet knock-off during sheet breaks. There are a few proven schemes to reduce flooded nip shower volume.

1. Reduce shower pressure during operation. High volumes are needed only to knock off the sheet. The flooded nip is also a superb fabric cleaning device, but knock-off volumes are not needed for good cleaning. It’s a good idea to have the shower running continuously for instant sheet knock-off when required, but if the shower is run at low pressure for cleaning and knock-off stand by, a booster pump can be added for high volume sheet knock-off instantly. Such a scheme has been used reliably on many machines, and can reduce the steady-state water demand of the knock-off shower by over half.
2. Wash rolls, if properly lubricated and doctored, are proven knock-off devices that work at much lower water volumes than flooded nip showers, usually less than 20%. If the couch pit is configured to accept the sheet after the wash roll, it can be used to eliminate a flooded nip shower. Ideal wash roll configuration is shown in Figure 3.

The next-highest shower water users are lubrication showers, mostly on wire return rolls in the former. These showers lubricate doctors and keep return rolls wet to prevent build-up. The shower standard (reference 4) defines their required volume as .15 gpm/inch-width. Because they are usually located in the wettest section of the paper machine, this volume is often excessive, and it is rare that they cannot run successfully at ½ of that volume.

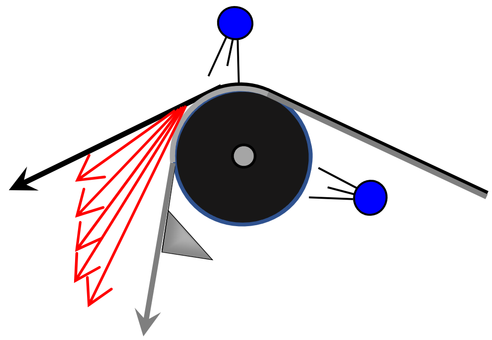

Figure 3: Wash Roll Shower

The most critical cleaning showers on the machine are the high-pressure needle showers. These typically use about ½ as much water as the lubrication showers. There are two effective ways to reduce their required water volume.

1. Use smaller nozzles at higher pressure. Standard high-pressure nozzles use 0.040 inch diameter orifices. Replacing them with 0.028 inch orifices and running them at higher pressures to produce equivalent cleaning energy could save about 40% of the water used by the shower with no sacrifice in cleaning efficacy[5,6].
2. Single-jet scanning showers can apply equivalent cleaning power to full-width showers and reduce required shower flow by over 90%. They can be expensive, though, and not as simple as full-width showers.

Sometimes reducing flow is just a matter of finding open valves that should be closed or at least not fully open. In a paper mill in Wisconsin, we discovered a condenser cooling valve stuck fully open. The subsequent "over cooling" of the condensate cost the equivalent of 2200 lb/hr of steam to make up for the lost heat.

Reuse

There are two critical factors that often block the use of white water, and consequently cause its waste. These are

1. Insufficient capacity for filtration of white water to save fiber and create cleaner white water for paper machine use.
2. Insufficient quality of processed white water for paper machine use, causing substitution of fresh water.

Both of these factors are often immediately attributable to a poorly functioning or simply too small save-all. Save-alls are wonderful devices, but they are expensive. Often, inadequate save-all operation can be alleviated by adding simpler mechanical filtration devices to both save fiber and create better water for machine use. These strainers can be used in parallel with save-alls, as shown in Figure 4, or downstream of clear or cloudy save-all legs to make more clear or ultra-clear water for use in machine showers. Such approaches have been successful in enough mills to make them state of the art. They are very valuable to economically make up for papermaking systems that have simply outrun their save-alls, or for save-alls that are far past their most efficient years.

We found a great example of potential for reuse in a Wisconsin mill. White water was passed over a gravity strainer, where recovered fiber was dropped into the broke chest for reuse, and water was used for showers. Unfortunately, the strainer was dysfunctional, so very little water was recovered and white water flowed straight to the broke chest over-diluting it and causing fresh, cold water to be used for machine showers. In this case, the annual cost to heat the 450 gpm of cold water used for showering was about $450,000/year. Replacing the obsolete screen would save this steam cost, and reduce excess white water overflow.

CONCLUSION

It makes sense to save water, not just because water is a critical and diminishing resource, but because saving water saves money. There are two or three extreme examples of very low water volume users in the US, and these mills provide a standard toward which every paper machine can work. Just wanting to save water can yield results, for example by turning off water when the paper machine is shut down. Other techniques can be used to reduce a typical paper machine's water consumption considerably and by up to ½. These techniques range from simple to somewhat expensive, and they will be increasingly important to many mills that face shortages of water in the foreseeable future.

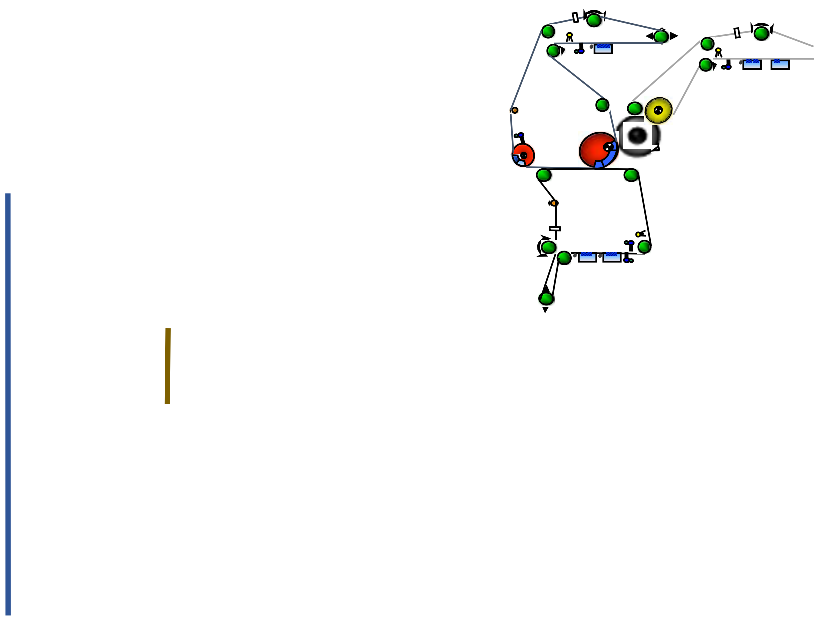

Figure 4: Strainer to Augment Save-all

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