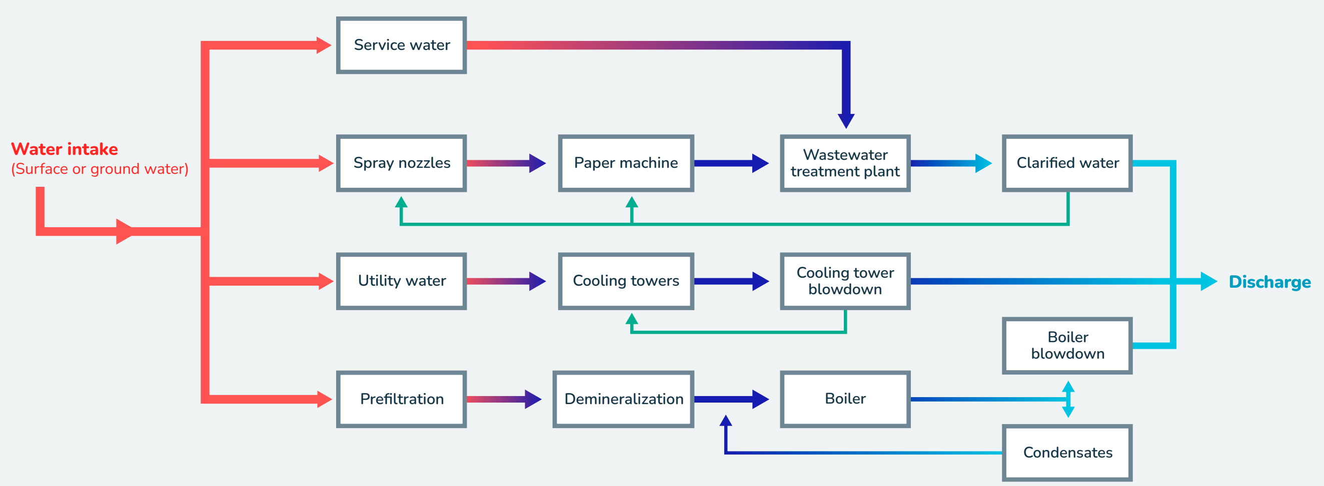
How Hollow-Fiber Membranes Reduce the Water Footprint of the Pulp and Paper Industry

The pulp and paper industry has long been one of the world's largest water consumers. In Europe alone, water volume withdrawal for pulp, paper, and board production in 2012 reached about 3,700 million cubic meters (m^3) annually.[1] More broadly, in 2018, the industry accounted for more than 10% of all consumed freshwater in some nations.[2] The production process is a thirsty one, requiring water at every major step, as shown in Figure 1.

As water scarcity and industry regulations accelerate, the industry reckons with both natural resource stewardship considerations and business risks:

- **Resource consumption:** In addition to depleting resources by taking in vast quantities of water, pulp and paper mills may release environmental contaminants. Contaminants can include short fibers (wasting a valuable resource), organic chemicals that are weakly biodegradable due to hard chemical oxygen demand, chemical residues that may lead to eutrophication, and waterbody temperature pollution, among others.
- **Business risks:** In 2017, the annual global consumption of paper and paperboard products surpassed 400 million metric tons.[3] Overall production continues to grow—driven especially by the appetite of Amazon and other online sellers for cardboard and packaging. However, allowed emission levels in discharge permits remain nearly flat. The level of permitted emissions per ton of product paper has drastically declined as a result, making regulatory compliance an ever-growing challenge. Mills in geographies with limited access to water or land face difficult choices, such as reducing production to comply with discharge limits or risking steep fines from overrunning their discharge permits.

FIGURE 1: **Water usage in the pulp and paper production process**



1 SpotView: Water Efficiency in the Pulp & Paper Industry, 2018-02-8_WorkShop_SpotView-CTP-EL-Vf (aspire2050.eu), slide 4

2 StateOfTheGlobalPaperIndustry2018_FullReport-Final-1.pdf (environmentalpaper.org), page 31

3 The State of the World's Forests 2018 – The Food and Agriculture Organization (FAO), page 51

Looking beyond incremental improvements to conventional treatment processes

The industry has dedicated significant resources to improving conventional treatment processes over the past decade. For example, many mills have increased reuse of water fluxes (i.e., recycling cooling tower blowdown) and now recycle secondary effluents to some degree.

These efforts have improved water quality and consumption—but only to a point. Conventional treatment methods have inherent limitations:

- These methods cannot adapt to variations in raw water quality. Left untreated, high turbidity, presence of organic matter, and other factors would degrade downstream water quality, and the treatment required to restore downstream water quality uses more water.
- Increasing production creates a higher pollution load and can drive water flow rates beyond what a given wastewater plant can handle. As a result, the plant may overrun the limits of its discharge permit. Additionally, standard water recycling goals become harder to achieve, as the plant must first restore the polluted effluent to the quality of the inlet water.

Pulp and paper industry leaders are looking beyond incremental improvements. New corporate policies have shifted to align with objectives of global stewardship, such as those in the 2015 Paris Agreement and other international treaties. As a result, mills are seeking to drastically reduce their carbon footprint and rethink their water use. Corporate policies of the key players (SCA, Essity, Ahlstrom Munksjö, and others) now include sustainability initiatives centered on awareness of water scarcity and a commitment to reasonable use of resources.

Hollow-fiber membrane technology: A compelling alternative to conventional processes

Opportunities to further improve conventional water treatment processes are limited. However, technology using hollow-fiber membranes to improve ion exchange (IX) or reverse osmosis (RO)-based treatment provides a compelling alternative.

Hollow-fiber membrane technology has amassed a solid track record. The technology has been in use overall for more than two decades. The pulp and paper industry began using it more than a decade ago. In recent years, mills have increasingly adopted RO systems (protected and supported by hollow-fiber membranes) to drive large-scale treatment process improvements over conventional methods.

Hollow-fiber membranes enable benefits such as:

- Adapting to wide variations in water quality caused by turbidity, organic contents, etc.
- Cutting back the water usage required for backwashes and cleaning
- Significantly reducing operating costs by lowering system maintenance requirements
- Reducing the water footprint by some five to six times based on the high capacity of hollow-fiber membranes
- Decreasing overall plant emissions as a result of these improved processes

The sections that follow will detail how hollow-fiber membranes deliver on these benefits across the treatment cycle—from source water to boiler water, to reuse and recycling of cooling water and wastewater.

Treatment considerations for source water

Challenges

To ensure proper operation, paper mills need a consistent and abundant source of water. Mills require up to 54 m^3 of water per metric ton of finished product. A large share of this volume comes from natural water sources—wells or surface water resources such as lakes or rivers. In recent years, these natural water sources have been mixed with reused water from secondary effluent from the site's wastewater treatment plant.

Characteristics of source water fluctuate throughout the year, with episodes of high turbidity and organic content load. To manage these variations, mills often use traditional methods that include screening to remove the largest debris, clarifiers with coagulation and flocculation, and media filtration to lower the concentration of suspended solids and allow a proper pretreatment before entering the process.

Conventional water clarification methods can remove solids and particles down to an outside diameter of 15 to 20 microns (µm), especially when sand filters used as polishing are included at the end of the filtration cycle.

While water at the 15 to 20µm rating is generally suitable for the manufacturing process, it is less suited for feeding a complex demineralization unit, especially one based on RO.

However, these methods have drawbacks.

Drawback: Clarifiers are highly sensitive to variations in turbidity and suspended solids concentration. Changes in these parameters will require chemical dosing adjustments.

- Insufficient dosage leads to carryover of suspended solids in the clarified water, meaning pressure filters clog faster and backwashes are needed more frequently.
- Overdosage leads to self-coagulation of the clarification aids and has the exact same effect.

Furthermore, even if a lamellar configuration reduces the footprint of the clarifier, pressure filters are still required to work at a filtration speed between 8 and 12 meters per hour (m/h) for simple-layer media (sand filter) and up to 18 m/h for a dual-layer filter (anthracite plus sand). The two-dimensional surface area makes hitting their upper performance limit easy, thus limiting the capacity to expand production. Because this type of unit's footprint is extensive, upgrading an existing installation with the same technology can be difficult, as existing buildings are typically not extensible.

Drawback: Using sand filtration to polish the clarification of surface waters has proven to be efficient over the last 50 years. But improper backwash, bacterial contamination, or even scale can impair performance. To ensure nominal performance, mills must conduct a regular checkup of the differential pressure setting that triggers the backwashes, the level of media in the pressure tank, and the flow rates during production and cleaning.

Media filtration is also highly sensitive to raw water quality. Backwashes are more frequent when the quality of the inlet water is degraded. This can also happen when coagulant and flocculent are used improperly through overdosing. As a result, incremental volumes of water are required for backwashes, which ultimately negate the site's water consumption savings. In fact, the backwash of a sand filter can consume up to 3.3 m^3 per square meter of filtration surface.

Maintenance needs are another complicating factor for traditional sand filtration. Manufacturers typically recommend reviewing the inside of the pressure filter annually. To avoid downtime, many sites neglect this process, but it is essential for detecting any preferential passage through the filtering layer that could lead to improper performance; any media surface irregularity that could indicate a breakage in a floor nozzle; or a loss of filtering media, which is evidence of suboptimal backwash settings.

As a best practice, the treatment process should avoid creating a preferential throughput. Lack of maintenance in an industrial pressure / sand filter can cause water to distribute unevenly across the filtration surface, resulting in the creation of sand blocks.

Drawback: Maintenance neglect is not the only problem that causes sand blocks. Sand may build up during pretreatment processes, such as coagulation, flocculation, and clarification, which remove particles and color from the water. If an overdose of chemicals occurs, the excess chemicals go straight into the media, leading sand grains to stick together and form sand blocks.

TABLE 1: **Common Media Filtration Maintenance Challenges**

Media filters require ongoing attention and maintenance.

ISSUE	POTENTIAL CAUSES	CONSEQUENCES
Improper filtered water quality	Preferential throughputs	Downstream process contamination • Particle contaminants • Microbial contaminants
Frequent backwashes	Deep clogging of filtration media	• Higher water consumption • Potential water shortage
Loss of filtration media	Aging of filtration media	Decreased filtration performance

How hollow-fiber membrane technologies help

Membrane technologies replace the need for clarification and filtration steps by providing a physical barrier to solids to protect downstream equipment. Membranes are positioned into modules, regrouping several hundreds of fibers, each able to treat a fraction of the flow. The wall of fiber acts as a filter, stopping particles and microbial contamination.

Different kinds of membranes are available to meet various operating conditions. Membrane-based pretreatment can remove particles from the water down to typically 0.1µm. This pore size sufficiently removes most biological contamination, protecting downstream assets including RO systems from microbial contamination that could potentially impair performance.

- Adaptive to the most stringent water conditions, microfiltration and ultrafiltration membranes can handle turbidity above 500 NTU and suspended solids concentrations up to 250 parts per million.
- With automated operation that makes them self-adaptive, these systems limit the need for manpower to occasional clean-in-place (CIP) operations.
- An extensive filtration area (typically 50 to 60 m^2 per element) means that membrane technologies offer a low footprint and can be containerized to limit civil work requirements.

Membrane-based technologies are designed to minimize water loss for backwash. If also triggered on a threshold relating to the difference in pressure from one side of the membrane to the other, the quantity of water used for the backwash is minimal—in the range of 70 to 80 liters per backwash per module.

- Membrane operation is fully automated, and parameters are adjusted in real time to achieve the best performance of the asset independently from the raw water quality.
- Two types of hollow-fiber membrane technologies are available on the market: "in to out" and "out to in." While both technologies offer some benefits in comparison to conventional cleaning methods, the "out to in" has several advantages, as described in Table 2.

TABLE 2: **Hollow-Fiber Membrane Technologies**

Two types of hollow-fiber membrane technologies are available in the market.

HOLLOW-FIBER TYPE	DESCRIPTION
"In to out" technology	• Basic technology in which water flow is filtered from the inside to the outside of the fiber. • Dirt remains in the fiber. • Improper backwash execution can cause rapid deposit and pore clogging. • Inefficient CIP decreases mid-term transmembrane flow rate.
"Out to in" technology	• Advanced technology filters water flow from the outside of the fiber to the inside. • Membrane is cleaned tangentially, including an air rumbling sequence in addition to normal water using backwash. • Fibers are then intensively stirred, and eventual deposits are removed from the water surface.

Treatment considerations for boiler water

Paper mills increasingly have converted to using cogeneration as they focus on responsible consumption. As far back as 2014, nearly all electricity generated at U.S. paper and pulp mills involved cogeneration.[4]

Challenges

As part of this conversion, these mills now use high-pressure boilers that are key to producing steam and electricity. Unlike low- or mid-pressure boilers, high-pressure boilers have a state-of-the art turboalternator that is highly sensitive to impurity and requires a constant feed of ultrapure water. This level of water purity can be hard to achieve through conventional treatment methods, as previously discussed.

How hollow-fiber membrane technologies help

To achieve the necessary water quality, mills are also adopting RO or IX systems, along with hollow-fiber microfiltration membranes. Hollow-fiber membranes guarantee the pretreatment of the demineralization process and protect the systems from contamination.

4 For paper mills and cogeneration, everything old is new again | Energy News Network, June 2014

Treatment considerations for cooling water reuse and recycling

Challenges

Challenges of using conventional treatment methods for cooling water reuse and recycling are much like those in other pretreatment processes. Especially in the case of cooling water reuse, any issues will be tightly tied to the quality of the raw water. Ensuring consistently high-quality inlet water is an important best practice for cooling water reuse and recycling.[5]

The inability to adapt to variations in raw water conditions accounts for the most significant issue. Variable water quality can cause fouling that impairs a cooling system's capacity to optimize the cooling tower's concentration cycles—depleting the heat exchange. Related challenges include the need to maintain and adjust the systems, as well as high water consumption for backwashes of side-stream filtration, cleaning, and sludge disposal.

How hollow-fiber membrane technologies help

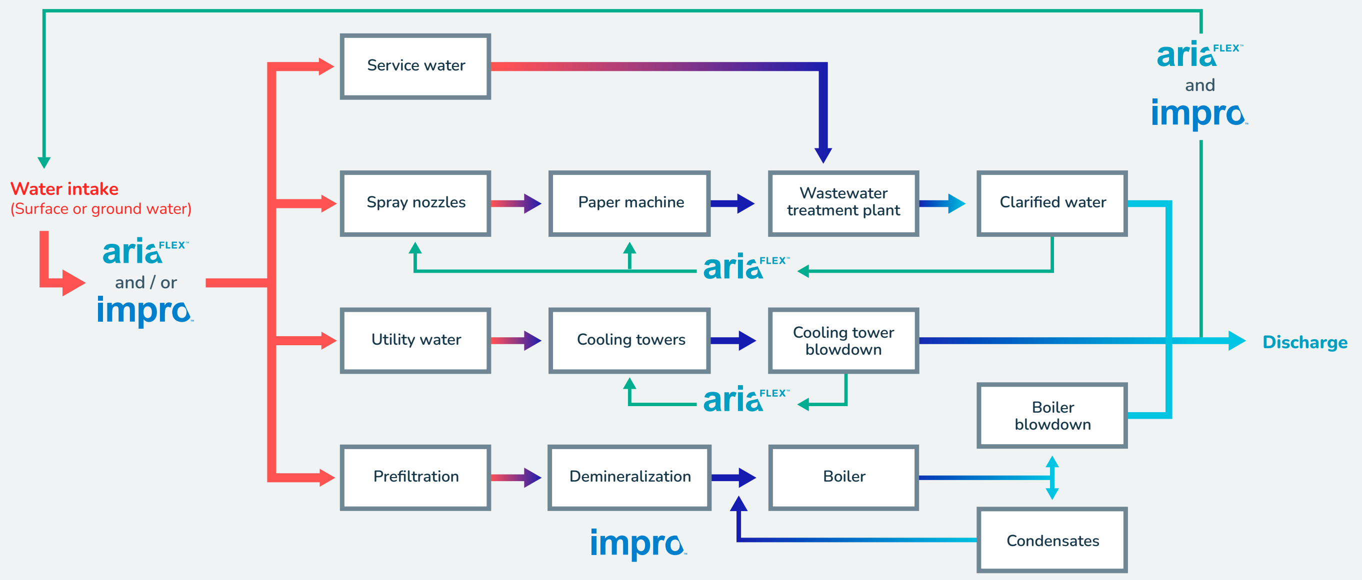
Hollow-fiber membranes can improve inlet water quality by concentrating the water, decreasing water consumption requirements, and decreasing the blowdown from the cooling tower.

The cooling process for a boiler is a good example of how hollow-fiber membranes improve recycling and water reuse:

- In a boiler, high-pressure steam goes to the turbine that creates the electricity. The cooling system then cools down the steam, generating condensates and making it water once again. That water is then reheated at a certain pressure, and the whole process repeats as a virtuous cycle.
- If poor water quality hinders this cooling process, fouling on the cold-water side of the condenser may form and impair the efficiency of the heat transfer, resulting in decreased production of electricity, and ultimately, of paper.

Using hollow fibers eliminates the need to adjust treatment chemical doses to ensure quality of the raw water. With less time spent on process adjustment, fewer manpower hours are needed, which in turn reduces operating expenses.

FIGURE 2: **Aria Filtra™ membrane water treatment solutions help pulp and paper mills increase process efficiency from water intake through discharge.**



5 Pulp and Paper revised BREF from European Commission (2015): https://eippcb.jrc.ec.europa.eu/sites/default/files/2019-11/PP_revised_BREF_2015.pdf

Treatment considerations for wastewater reuse

Challenges

Traditional treatment methods pose slightly different challenges when processing wastewater, which involves polishing the second effluent for reuse through the combination of ultrafiltration / microfiltration and RO. Here, the quality of the recycled water must comply with process specifications. Traditional treatment methods in the wastewater plant involve coagulation, flocculation, clarification, and filtration—which are not adaptive to changes in effluent quality.

How hollow-fiber membrane technologies help

To properly recycle wastewater back into the production process, the water must also be restored to similar (or better) quality as it was at the beginning of the production process.

Hollow-fiber membranes improve the recyclability of this wastewater. They enable the plant to handle extreme variations in water pollution load. Unlike traditional methods, membrane technologies will deliver the needed water quality for recycled wastewater, whether turbidity levels are at 20 NTU or 400 NTU.

Aria Filtra provides integrated membrane solutions to treat challenging waters

Aria Filtra's integrated membrane solutions help pulp and paper customers move beyond the limitations of traditional water treatment processes. Aria Filtra's hollow-fiber membrane system uses superior "out to in" filtration to address temporary and permanent removal of physical impurities. Aria Filtra systems based on RO remove dissolved solids and further contaminants.

From water intake through discharge, these solutions together provide pulp and paper mills with benefits such as:

- Consistently high-quality feedwater and continuous operation across challenging water variations
- Wastewater recovery rates of 90% or greater
- Direct feed to downstream equipment, with low cross-contamination risk
- High membrane integrity, with no fiber breakage
- Filtration performance down to 0.1µm, with low transmembrane pressure
- Upstream water pretreatment, with no chemical injection required

Aria Filtra offers permanent and temporary membrane-based filtration systems to help pulp and paper mills solve their toughest water treatment challenges.

- **Aria FIT™**– Standardized and skid-mounted membrane systems for flow rates up to 300 m^3/h that can be configured to fit any footprint
- **Aria FLEX™** – Completely customizable, modular membrane-based systems that are ideal for new plants or facility upgrades
- **Aria FAST™** – Temporary and semipermanent containerized membrane and RO solutions for added capacity and emergency relief
- **IMPRO™** – Easy-to-operate high-recovery RO systems that are available in mobile units and skid-mounted packages

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