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Wastewater Treatment Plant Design for Containerboard and Tissue Plants

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Introduction

Managing water usage in the paper making process is challenging, complicated and demanding. Several chemical, physical and biological factors are involved. How you design and operate it will also impact the sustainability parameters of the plant.
Many proven technologies are available and new possibilities also can be applied to minimize water consumption, reduce energy required and chemical usage. A well-designed and installed wastewater treatment plant in combination with dedicated internal and external loops will allow the paper mill to reduce and control operation costs and quality improvements.
In this paper we will be presenting design, experiences and results achieved in a water treatment plant for a containerboard mill making approx. 455,000 MT/year from 100% recycled fibers and a tissue mill plant designed for 45,000 MT/year using 100% virgin pulp and a combination of recycled fibers.
In both cases we have combined aerobic and anaerobic technologies to achieve the desired discharging parameters in combination with tertiary treatment to be able to recover as much water as possible. The target being to reach near zero water consumption.

Design & Critical phases

Let's start with figure 1 below which provides a simple and powerful image of what we are trying to achieve during the design and engineering phases of a Waste Water Treatment Plant. (WWTP). The inlet wastewater is the incoming incognita that we receive from the paper mill. We must design the process units of the plant in such a way as to be able to accept and process it.

Filtered water is the result of a combination of filtration, separation and aerobic and/or anaerobic technologies.

When applying tertiary treatment to filtered water we can expect ultra-filtrated and osmotized water as the best scenario.

Filtered, ultra-filtered and osmotized water can be partially or totally recuperated in the papermaking process.

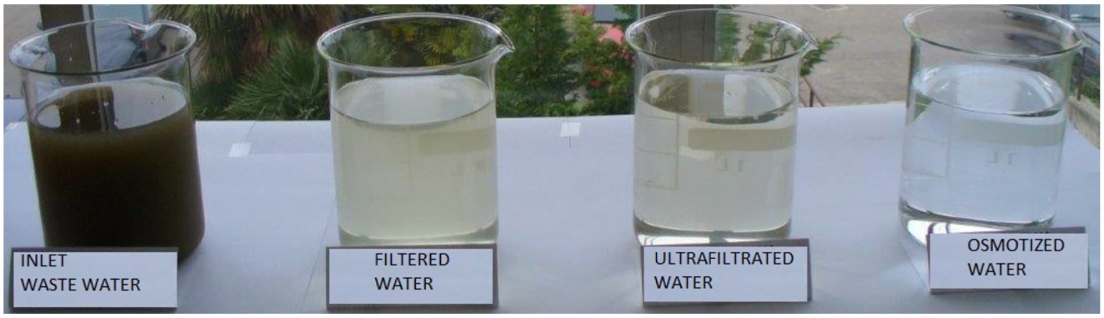


Fig1

Let’s define the critical phases – process units - of a Wastewater Treatment Plant (WWTP) and the relevant equipment. Combination of such process units can be used to treat different qualities of wastewater.

1- *Fine screening*

The screening (fig.2) is an important step in the process - the intent is to remove all coarse debris from the incoming wastewater stream which will eventually affect the efficiency and operation of downstream equipment. Equipment for such tasks have been around for a while. Here is a typical design.

Fig 2

2- *Homogenization tank (fig. 3)*

The main purpose is to homogenize the waste water coming from the fine screening. With the proper sizing and agitation (critical) we can to control the hydraulic and organic load peaks and make the required chemical corrections – for instance the pH.

Fig.3

3- Cooling Tower

A proper cooling tower/s (fig.4) design and position in the WWTP is critical to control and reduce the temperature of the wastewater entering the biological stream. Temperature must be kept aound 35 degrees Celsius.

Fig.4

4- Primary Flotation - DAF

Before entering the biological streams/steps it is critical to remove the suspended solids and fibres present in wastewater. These solids are anticipated to be composed of small fibres from the paper's production process. Fibres tend to float, and dissolved air flotation (DAF) (fig.5) unit *Deltafloat* are installed to complete this task.

To enhance flotation there will be a coagulant and polyelectrolyte dosing system. The polyelectrolyte is the flocculants chosen and the dosing system is located at the floatation unit inlet. It is composed of an automatic polyelectrolyte preparation equipment and a dosing pump. Inlet flow to floatation system is controlled by flow meter installed in feeding line. Sludge generated during the treatment flows into a sludge tank from which it will be pumped to the sludge dewatering phase. The resultant sludge consistency will be of 2.5-3.0%, although values are dependent on the solids quantitative in the wastewater. Finally, clarified water will be pumped in the anaerobic reactors. Depending on the layout and space available, circular or square types can be chosen.

Fig.5

5- Anaerobic Reactor

If the wastewater treatment has a high COD load, anaerobic reactors are installed to reduce and remove the organic contaminates and to reduce the COD, BOD5, N, P. This is a common solution when the wastewater is coming from a containerboard paper machine. Along with the reactor, biogas buffers and biogas flares are needed.

Typical reactor (Fig.6) installed is the “Expanded Granular Sludge Bed” (EGSB) technology or IC “Internal Circulation” (IC) technology.

Fig.6

6- Nutrients

The main chemical organic nutrients are N and P; the amount required depends on the quantity of *Converted COD* (CCOD). The relevant dosing of nutrients needs to respect the ratio CCOD: N: P which is 500:5:1 in anaerobic digester with little excess to guarantee the required nutrient content in the further aerobic oxidation reactor. Nutrient dosing pumps are connected automatically to the flow-meter measuring the discharge to the biological treatment and a frequency device, to guarantee the correct dosage of urea and phosphoric acid to the system.

7- Biological Oxidation – Activated Sludge Treatment

To achieve the waste parameters required - as determined by the specifications requested -a stage of biologically activated sludge treatment is needed. The name of the process “with activated sludge” comes from the fact that in the liquid system an “activated” sludge mass is developed. This mass is an agglomerate of heterogeneous microorganisms like Protozoa, Rotifer, Metazoan... besides bacteria themselves. During processes of “natural” aerobic depuration, as the ones in lakes or rivers, the necessary oxygen for the development of biological reactions is taken directly from the atmosphere; in activated sludge plants, instead, given the extremely high concentration of microorganisms, the oxygen coming from the exchanges with the outside is not sufficient at all, so artificial aeration is absolutely necessary. In an environment rich of oxygen complex physical, chemical and, most of all, biological phenomena are established.

Microorganisms, which are present in extremely high concentrations and combine in bacterial colonies to constitute the so-called “biofilm sludge flakes”, agglomerate the settled solids and stop the colloidal solids as an effect of the physical phenomena of adsorption (using attraction powers of superficial type). The microbial high concentrations in aeration tanks are possible thanks to the fact that the air diffusion system allows not only the supply of oxygen but also to mix and to keep in suspension the high quantities of sludge in the tank, avoiding quiet areas that could form phenomena of fermentation and bad smells. The biological process line is composed by a reactor followed by a clarification system.

The air feeding to this reactor is implemented by means of the rotating-plungers blowers system connected in automatic with an oximeter and inverter, so that the correct quantity of oxygen is supplied. The blowers are installed in sound-proofing booths, thus complying with regulations concerning noise. The air supply inside the reactor is mixed with the water to be treated by means of a system of injectors that enhance the internal recirculation and dwell time (fig.7).

Fig.7

Furthermore, there is sludge recirculation from the final sedimentation unit to the biological reactor to keep microorganism concentrations at suitable levels for the process.

In the oxidation tank it is necessary to keep a minimum 1.5 – 2.0 mg/l of oxygen and a good mixing of total suspended solids.

8- Sludge separation with final sedimentation

After the biological reactors, the mixed water goes to the final sedimentation (fig.8) units since this kind of sludge is better separated by these means. Thanks to this clarification system, the resulting sludge achieves a consistency of 1.0-1.3%.

Sludge is drawn out from the centre of the sedimentation tank and discharged by gravity into the sludge recirculation tank. Sludge recirculation at the biological reactor will be carried out by means of the same pumps, with time-controlled operations, used both for recirculation and for sludge treatment.

Sludge recirculation to the oxidation tank is very important to keep microorganism concentrations at suitable levels because they are responsible for the polluting substances degradation.

Fig.8

9- Primary and biological dewatering

Excess sludge coming from the biological system and primary sludge coming from the DAF units are periodically sent to the sludge storage tank. Centrifuge decanters or gravity and sludge presses (fig.9) are installed at this stage. This allows for 18-22% of dryness, using a suitable dosage of polyelectrolytes. Water separated at the centrifuge decanters will be sent by gravity to the homogenization/pre-acidification tank in order to flow again into the treatment.

Fig.9

Case study A - Containerboard Plant

Design parameters:

Inlet:

Parameters	Values
Short Peak Flow	440 m3/d
Max flow (after homogenization tank)	350 m3/h
Average daily flow rate	5.600 m3/d
pH	6-8
Total BOD_5	24.600 kg/d
Total COD	63.650 kg/d
TSS max	< 1000 mg/l
Total Hardness	< 2050 mg/l $CaCO_3$
Calcium Hardness	< 1800 mg/l $CaCO_3$
Calcium	< 720 mg/l
Temperature	< 42 C

Outlet:

Parameters	Values
COD	< 250 mg/l
BOD_5	< 100 mg/l
TSS	< 150 mg/l*
TSS after tertiary filtration (back to paper mill)	< 50 mg/l*

(*) This parameter refers to filtered samples with paper filter "Black Ribbon filter paper" like WHATMAN #41 with mesh of 20 microns, mesuremen at mixing sample (24h).

The chosen process units sequence and equipment are:

DAF – Primary clarification

After coarse screening the DAF area - primary clarification stage has a design capacity of 440 m3/h and TSS estimated at 1000 mg/lt with an outlet parameter of 100 ppm of SS. Estimated sludge consistency would be 2.5-3.0%

Cooling Towers

To control the temperature of the wastewater a cooling tower of 350 m3/h is required.

Homogenization/Pre-acidification tanks

Volume of the tank about 2000 m3 to manage the both hydraulic and organic peaks. Three submerged agitators are required to keep the wastewater mixed and avoid solid sedimentation.

Anaerobic ICC Reactor

The anaerobic system is an ICC model with internal recirculation and an external recirculation system. The system has a riser/downer configuration, and a degassing tank and an influent mixing chamber.

Special feature is the heavy sludge removal system at the bottom of the reactor. This enables the possibility to discharge equally sludge from the bottom. ICC-Reactor is equipped with two settling stages and, accordingly, two compartments. In the lower compartment, the fluidized bed turns COD/BOD into biogas and therewith reduces the concentration.

The minimum requirement of dealing with biogas is flaring. Furthermore, the anaerobic system operates optimally under a stable pressure. Therefore, a biogas buffer is included in order to stabilize the pressure. The buffer is explicitly not used as storage, but only for pressure stabilization. Biogas flare 900 Nm^3/h for continuous use. Biogas buffer for 15 minutes retention time on MAX flow.

The biogas is assumed to contain about 124 kgS/d. As this is both a safety-risk and harmful to the biogas utilization equipment, desulphurization is installed.

Nutrient dosing

To ensure the life of bacteria in the aeration tank some nutrients will be dosed (urea and tri-polyphosphate). In order to guarantee the correct supply of N and P the ideal ratio to be respected is COD:N:P=350:5:1.

Conventional activated sludge treatment

Two concrete tanks with total volume of about 8.000 m3. Equipped with air/water injector aeration system.

Final sedimentation unit and sludge recirculation/excess

Final sedimentation unit (circular concrete tank diam. 34 m), since this kind of sludge is better separated by these means. The clarified water is discharged by gravity to the treated water tank from where it is pumped to the tertiary treatment. Thanks to this clarification system the resulting sludge achieve a consistency of 1.0-1.3%.

Microfiltration

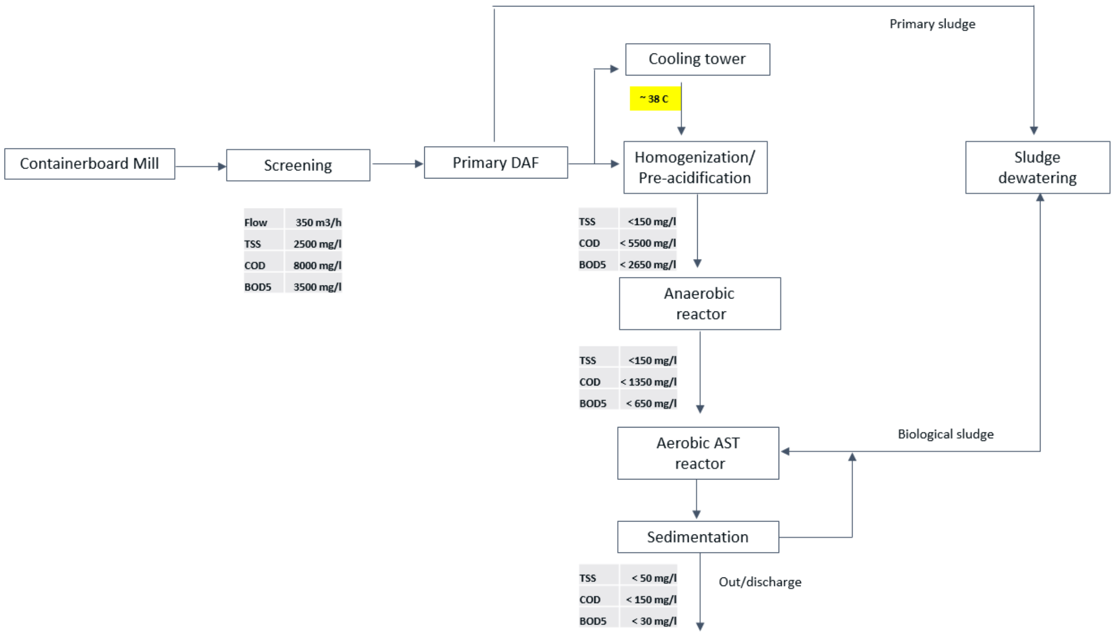
A final stage of microfiltration will allow recovery up to 50% of the final water back to the plant. A disc filter with a simple and modular design is used for this application. It consists of a drum equipped with filtering elements that are easy to replace, so that maintenance operations are very fast.

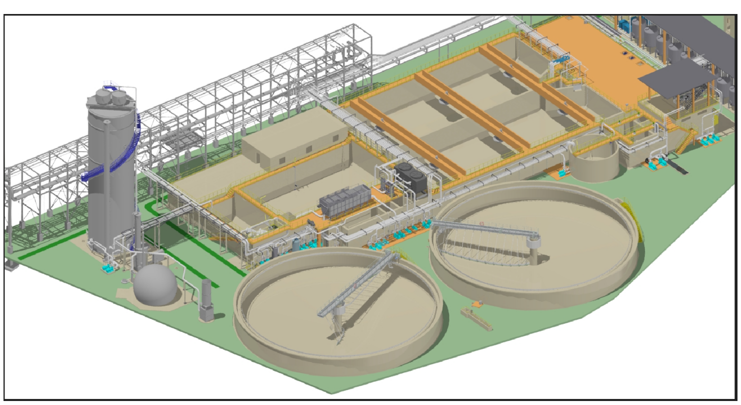
Sludge dewatering station

Excess sludge coming from the mixed sludge tank (about 25-30 m3/h, considering both sludge from primary flotation unit and biological sludge) is sent to dewatering system with centrifuge decanter. This allows for 20-25% of dryness, using a suitable dosage of polyelectrolyte. This dewatered sludge will be discharged into a sludge container, ready for transport and disposal.

Water separated at the centrifuge decanter will be sent by gravity to the homogenization tank in order to flow again into the treatment.

Flow diagram of the plant, process parameters and layout.





Case study B – Tissue Paper Plant

Design parameters:

Inlet:

Parameters	**Values**
Max flow (after homogenization tank)	130 m3/h
Total COD	1.600 mg/l
COD tot/d	7.030 kg/d
BOD_5	800 mg/l
BOD_5/d	3.520 kg/d
TSS avg.	2.500 mg/l
TSS/d	10.980 kg/d
Temperature	< 35 °C
Calcium	< 300 mg/l

Outlet:

Parameters	**Values**
COD	150 mg/l
BOD_5	< 35 mg/l
TSS	< 50 mg/l
pH	6.5-8.0

50% max 60% of total flow can be reused in paper mill.

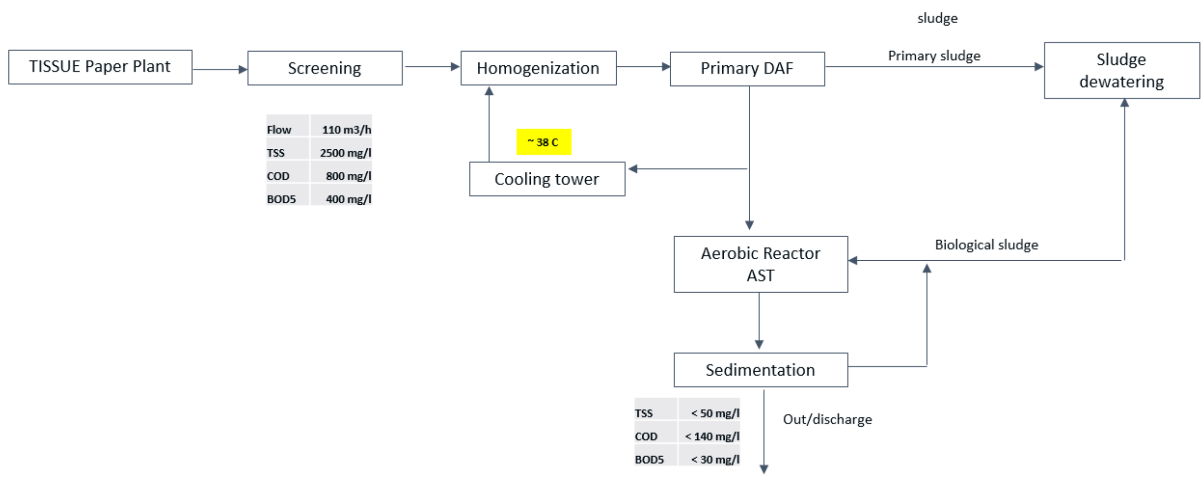
PRODUCTION OF SLUDGE

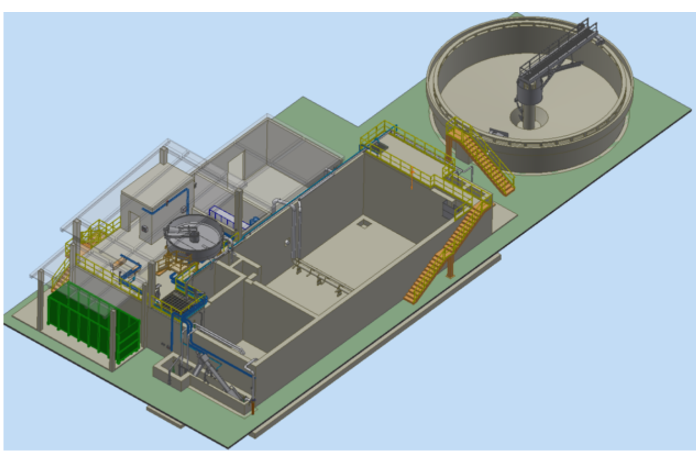
Parameters	**Values**
Avg. Primary Sludge production	10-12 m3/h (@3.0-3.5% dryness)
Avg. Biological sludge production	4-6 m3/h (@1.5-2.0% dryness)

To treat wastewater coming from a tissue plant (*Pulp and Recycled* combined) we have two possible configurations.

The first one – using *Activated Sludge Treatment* **–** where a final sedimentation will be use to separate solids form the clarified water.

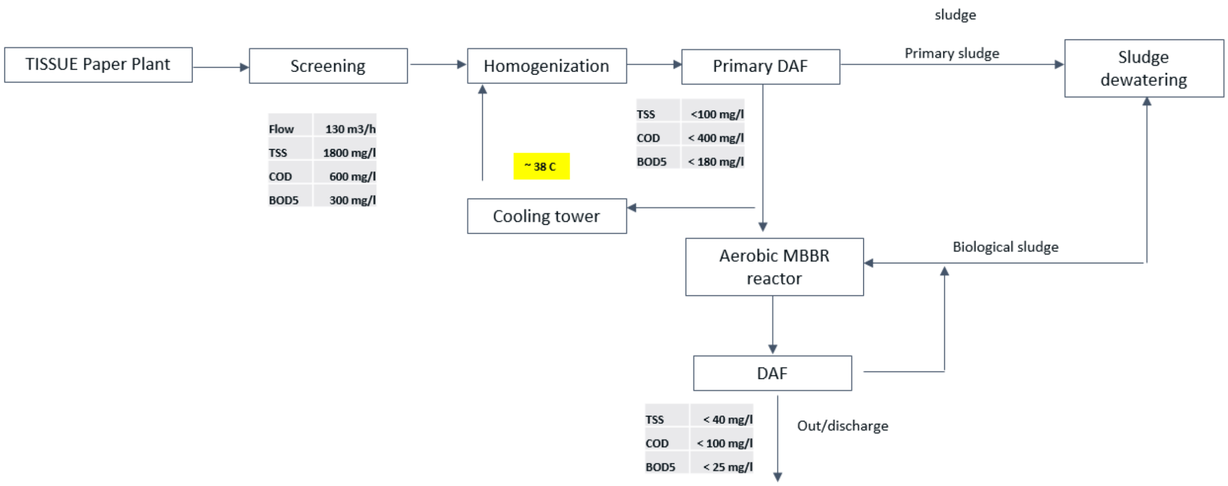
The flow diagram, process parameters and typical plant layout are shown here below. This solution is the most flexible and can take handle peaks of COD load and hydraulic flow.

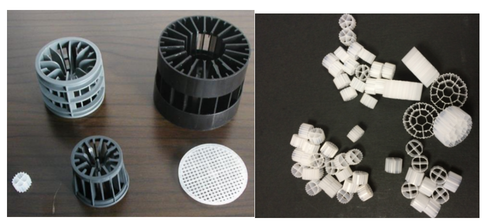


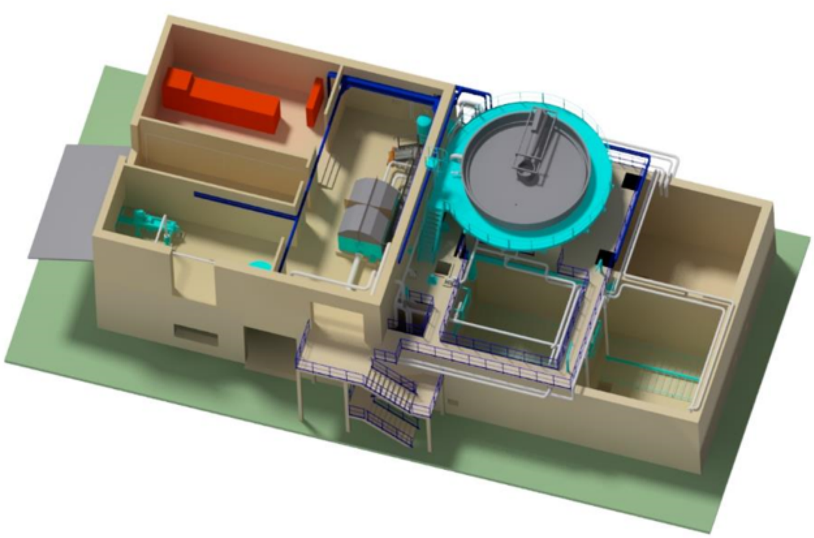



The second option if space is limited and COD loads are quite low, is using *MBBR technology (Moving Bed Biofilm Reactor)*

The flow diagram, process parameters and typical layout/plant are shown here below.


sludge
TISSUE Paper Plant
Screening
Homogenization
Primary DAF
Primary sludge
Sludge dewatering
Flow 130 m3/h
TSS 1800 mg/l
COD 600 mg/l
BOD5 300 mg/l
~ 38 C
TSS <100 mg/l
COD < 400 mg/l
BOD5 < 180 mg/l
Cooling tower
Aerobic MBBR reactor
Biological sludge
DAF
TSS < 40 mg/l
COD < 100 mg/l
BOD5 < 25 mg/l
Out/discharge



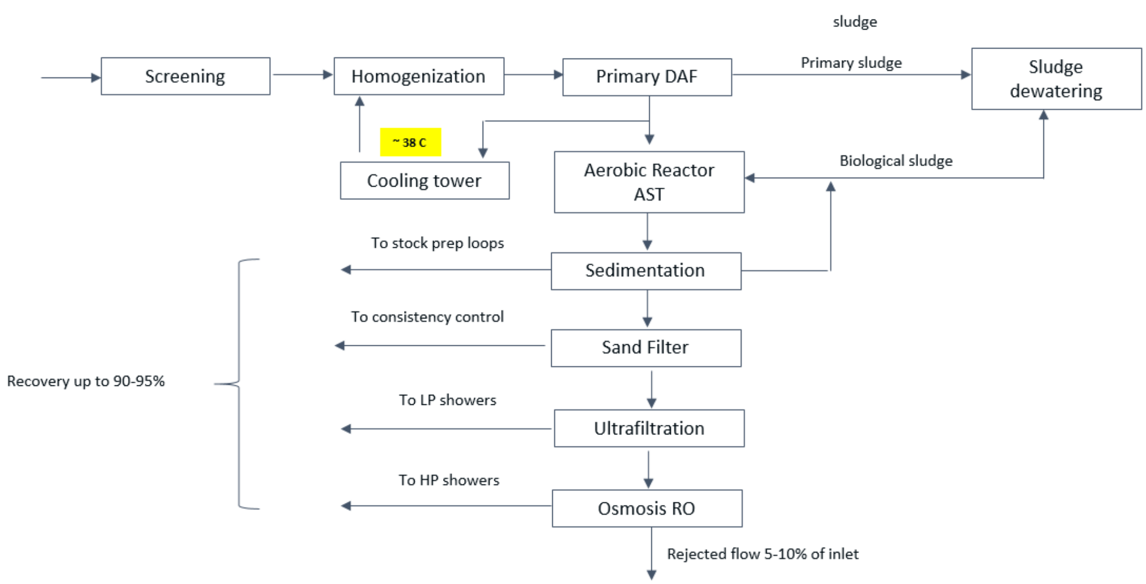


Tertiary system – challenges and opportunities

Let's take a look at some more process units. We call them tertiary system and the aim is to further treat the water coming from an aerobic or anaerobic process and send it back to the papermaking process to minimize the discharge stream.

The flow diagram below summarized the concept. After sedimentation (separation of solids form clear water) we can apply three different filtration processes in sequence. Sand filters follow by *Ultrafiltration* to finish with osmosis.

However, to achieve such level of loop closure is quite complicated. Even though some experiences / plants are running under such configurations, still more improvements are required to have full stable systems able to perform close to zero water discharge.



Pressure sand filters

From the clarified water tank, water is pumped to the pressure sand filters (fig.10) where the residual suspended solids are removed; the backwashing will be done with filtrated water + air.

Fig.10

Activated carbon filters

Filtrated water from the sand filter is finally pumped to carbon filters (fig.11) in order to remove the residual fraction of COD and BOD5 mainly due to the not-biodegradable colloidal substances.

Fig.11

Ultrafiltration station

Ultrafiltration removes the residual fraction of COD mainly due to the not-biodegradable colloidal substances.

The ultrafiltration unit consists of modules, (fig.12) hydraulically interconnected with PVC pipes and linked to an AISI 304 stainless steel structure. Each module is equipped with hollow fibre membranes in the vessel. Water to be treated is pumped with moderate pressure, of approximately 0.1-0.8 bar, enough to overcome the transmembrane pressure, the water is passed through them, retaining suspended, fine and colloidal substances, algae, bacteria, viruses, faecal coliforms and streptococci, coli, salmonella and elements that increase the turbidity of water.

Fig.12

Reverse Osmosis

RO membranes (fig.13) act as a barrier to all dissolved salts and inorganic molecules, as well as organic molecules with a molecular weight greater than 100.

The system uses high pressure pumps to increase the head to a value above the specific osmotic pressure of the water in the feed (which depends on the value of the dissolved salts and on the temperature).

The result of this process is the separation of the feed flow into two different flows: what has passed through the osmotic membrane is called *Permeate,* which has a high purity and a very low quantity of dissolved elements; and what cannot be used and needs to be discharged, called *Concentrate,* which has a high concentration of mineral salts that is the part retained by the membranes. The *Permeate* of the reverse osmosis is sent back to the paper making process, while the *Concentrate* is sent to the discharge.

Fig.13

Conclusions and future

We have tried to show some practical applications of wastewater treatment plants designed to minimize water discharge. The first one is a combination of aerobic and anaerobic systems designed to handle high loads of flow and COD in a linerboard mill. What is critical here is to maintain the proper balance between the reactions happening in the anaerobic reactor and the air mixing conditions and dwell time in the aeration / aerobic phase and sedimentation. It becomes important to control the dosing of nutrients and the amount of biogas generated into the process.

We have also shown the application and comparison of AST (Activated Sludge Treatment) and the MBBR (Moving Bed Biofilm Reactor) on paper tissue plants using pulp and deinked fibres.   The AST system requires more space but can handle significantly high loads of COD and flow/peaks variations. The MBBR is more suitable for plants with moderate COD loads and limited space. MBBR is quite commonly recommended for tissue plants using mainly pulp, and during the rebuilding of existing plants.

We then approach the most interesting and timely topic: How to design and implement tertiary systems which allow for the re-use of most of the treated water back into the plant. Technologies like ultrafiltration and reverse osmosis, if properly designed, could allow paper mills to re-use up to 95% of the water coming from production. Most of water treated in the tertiary systems can be re-used, such as mechanical sealing, low and high pressure showers and in some cases also for chemicals preparation.

The goal is to think, design and implement equipment and technology that can help existing pulp and paper mills to reduce the intake water from rivers and lakes or wells to minimize impact on the watersheds and respect the stewardship of water and lands.

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