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D3.2

Selected scenario simulation for process and cooling water reuse in the P&P industry

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Deliverable Leader: VTT

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October 2016 – March 2020 (42 month)

1. - Table of Contents

2. - Glossary

adt	Air dry ton
BAT	Best Available Technology
CC	Composite curves
COD	Chemical Oxygen Demand
CR	Cross rotational
DIP	Deinking Plant
HP	High-pressure
PM	Paper Machine
P&P	Pulp and Paper
TSS	Total Suspended Solids
UF	Ultrafiltration
WP	Work Package
WWTP	Waste Water Treatment Plant

3. - Contributions

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4. - Introduction

The objective of this deliverable is to report the work done in Task 3.4 "Sustainable strategies for process water and WWTP effluent reuse in the pulp and paper industry" under the following subtasks:

- T3.4.1. Process water reuse strategy with kidney technology (VTT, VAL, SCA)
- T3.4.3. Process integration and optimization for potential heat loss recovery (PDC, VTT, CTP)

The objective of Task 3.4 was to establish sustainable process water reuse strategies for two types of papermaking processes; packaging and tissue mills. This task was based on process modelling and simulation of process circuits of two industrial sites with specific water challenges. The sites were SAICA EL (former Emin Leydier) packaging mill in Nogent France and Essity's (former SCA) tissue mill in Nokia Finland.

The different process designs and optimized scenario will provide relevant data regarding fresh water saving, waste water reduction, energy requirement, heat recovery as well as process chemical saving and productivity increase. These data will be used to compare the resource efficiency of the different strategies. The new technology designs and information on energy consumption, flows, concentrations and purification yield as well as operation cost will serve for preliminary techno-economical assessment (WP5).

This deliverable reports the results of process water reuse strategies and process integration and optimization for heat loss recovery for Essity's tissue mill in Nokia Finland.

4.1. - Objectives of the work in T3.4.1

Target of VTT's work in T3.4.1 was to evaluate the influence of changes in the arrangement of water circuits and implementation of CR-filter (cross rotational) on water consumption and build-up of dissolved subtances in Essity Nokia mill.

This was accomplished by using steady-state process simulation. Simulation is the imitation of the operation of a real-world process or system over time. Simulation can be used to improve understanding of an existing or new process, investigate complicated, expensive, dangerous, or inconvenient systems, investigate systems in which study in real time would be a problem and show the eventual real effects of alternative conditions and courses of action. Simulation is also an effective tool for guiding lab and pilot test planning and it is often a prerequisite for other analyses such as cost calculation or Pinch Analysis.

VTT has a long history in simulating and modelling of traditional paper and pulp processes using several commercial simulation software. In SpotView project, Balas® -steady-state simulation software was used. It was developed at VTT in the early 80's with emphasis on pulp and paper processes.

In SpotView project also CTP is modelling the Nokia Essity mill (Task 4.3.2). VTT focuses on the mass and energy balances over the entire mill and especially on internal water circulations using steady-state input-output –modelling. CTP, on the other hand, focuses on water balance, detrimental elements and recycling of waste water treatment effluents back to the process. They use steady-state modelling with multiphase chemical equilibrium calculation. CTP's modelling of treated effluent reuse as alternative water source in Essity mill process will be presented in Deliverable 3.7. Figure 1 clarifies the different targets of VTT and CTP modelling.

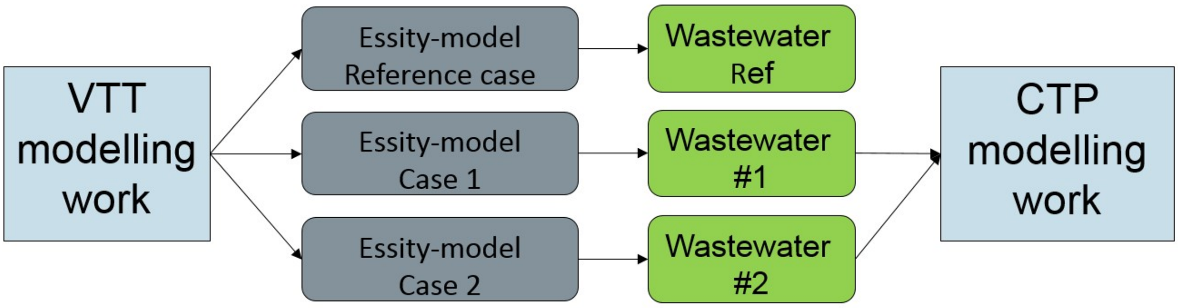


Figure 1. VTT and CTP are modelling different water reuse strategies in Essity Nokia mill in Tasks 3.4.1 and 3.4.2. VTT is focusing on internal water circulations, where as CTP on WWTP effluent reuse strategies.

4.2. - Objectives of the work in T3.4.3

The objective of PDC's work in T3.4.3 is to minimise the energy consumption of the Essity Nokia mill by optimising the heat integration and the potential heat loss recovery.

For the heat integration study PDC used energy pinch analysis software which is embedded in PDC's conceptual process design tool PROSYN.

4.3. - Nokia Essity mill

Essity Finland (former SCA) operates a tissue mill in Nokia, Finland. A deinking plant (DIP) produces about a half of the fibre raw material needed. The other half is purchased virgin pulp. Two paper machines (PM7 and PM9) produce tissue base paper for own converting lines and external customers. Base papers are converted into toilet tissue, kitchen towel, hand towels, hankies and wipers for consumer market and away-from-home customers. There is one deinking line feeding both paper machines. DIP production runs two different DIP pulp qualities, U1 and U3. U1 is brighter and mainly produced using higher recycled paper qualities such as pre-consumer waste paper grades from printing houses and offices. U3 is greyer in brightness and mainly made of household waste paper.

Essity Nokia mill has established a water reduction program, which will reduce the water consumption at first from 45 m^3/t produced paper (2016 average) down to 25 m^3/t produced paper, and finally to 20 m^3/t. Water reduction will be executed gradually. The water reduction actions to reduce water consumption down to 20 m^3/t are listed below (presented in Deliverable D2.5):

1. Increase PM7 white water storage capacity by modifying existing broke chest for white water to enable higher white water usage in pulping and DIP.
2. PM7 & PM9 showers to white water instead of fresh water.
3. PM9 dust removal repair and change to white water instead of fresh water.
4. PM7 dust washers, converting dust washers and converting Nash water to white water instead of fresh water.
5. Collect and utilize fresh and white water in DIP cooling, PM7 dust washers, PM condensate cooling, converting dust washers and Nash pumps.
6. DIP white water system improvements.
7. PM7 control system improvement and update.

8. Wastewater treatment plant (WWTP) modifications to operate with lower waste water amount and stricter discharge limits.
9. Renewal of the fresh water pumping station and fresh water treatment as the current pumping station is outdated. Renewal brings reliability and water quality (i.e. product quality) risks.

The mill has completed the steps 4, 5 and 6 in early 2018. The step 2, change of PM7 and PM9 showers from fresh water to white water is also under work. For the purpose, a Valmet CR-filter was implemented in August 2018 to PM7 to produce ultrafiltered white water to be used in the wire section showers instead of fresh water.

During Spotview project, four measurements campaigns have been conducted in Nokia Essity mill to study the operation of the mill before and after the above listed actions aiming at the water consumption reduction. Three of the measurements campaigns were taken before the actions were made and the fourth after. The analysis results were compared before and after the changes.

4.4. - Valmet CR-filter

During the SpotView project, Valmet has developed a new Valmet CR-filter model for tissue lines. The first customer trials in Essity Nokia started in August 2018. Valmet Ultrafiltration Tissue process produces high quality ultrapure water (permeate) for the paper machine's wire section high-pressure showers to decrease the fresh water consumption. Permeate can also be used for paper machine's other showers on wire and press sections as well as for the dilution of chemical additives.

The permeate produced with Valmet Ultrafiltration technology is

- Free from solid substances
- Free from colloidal material
- Free from turbidity
- Free from bacteria
- Free from secondary and micro sticky and
- It contains 50-70 % less anionic trash

When the permeate is used for replacing the warm fresh water, there are also savings in the energy used for heating the water suitable for PM processes. Removing of trash material from process water helps also maintaining good paper making performance and efficiency. The Valmet Ultrafiltration feed water is normally paper machine white water, e.g. clear filtrate from fibre recovery disc filter. The benefit of Valmet Ultrafilter CR (cross rotational) is the low operating pressure difference and thus there is no clogging of the membrane. This results in high and stable filtrate capacity as well as long membrane lifetime. Valmet's technology uniqueness and comparison vs. state-of-the-art is that Valmet Ultrafiltration Tissue is the first new designed cross rotational ultrafiltration system for tissue mills white water recycling and purification. State of the art nowadays is warm fresh water for the critical consumption points.

With the typical tissue machine (production of 100-300 t/d) the Ultrafiltration process including one or two CR ultrafilters can reach the fresh water reduction of 1-2 m^3/t of produced paper. Using permeate instead of fresh water decreases the overall water consumption in the tissue-making process and creates savings in the energy used for heating the fresh water.

5. - Methods

5.1. - Measurement campaigns

Measurement campaigns were arranged in Essity Nokia mill in order to characterize the chemical and microbial state in different parts of the water circulation. Large number of sampling points were covered in the measurements campaigns. Following properties describing the quality of the sample were measured: total COD (mg/L), soluble COD (mg/L), TSS (mg/L), ash content (mg/L), loss of ignition (mg/L), charge (µekv/kg), temperature (°C), pH, conductivity (mS/m), Redox (mV), turbidity (NTU), consistency (%), chloride (mg/L) and calcium (mg/L). The most important parameters regarding the simulation work of process reuse strategies were TSS and soluble COD. TSS was measured using SFS-EN 872:2005 and soluble COD using ISO 15705:2002.

Altogether four campaigns were arranged. Three of these took place in March, May and September 2017. They represent the situation at the Essity Nokia mill before the first actions to reduce the water consumption were conducted. The fourth measurement campaign was in November 2018. In that time, several re-arrangements in the water circuits both in deinking plant and paper machines were put into action. Also, the CR-filter was operating to clean part of the PM7 white water to be used as high-pressure (HP) shower water.

5.2. - Simulation of process water reuse strategies (T3.4.1)

5.2.1. - Approach of the simulation work

The simulation work was conducted with Balas® simulation software. It is a commercial software created at VTT with emphasis on pulp and paper processes.

Approach for the simulation work was following:

1. Creation of a generic BAT-based model
2. Modification of the generic BAT-based model to Essity-model
3. Defining the reference case of Essity-model
4. Defining the cases to be studied using Essity-model
5. Comparison of different cases with the reference case of Essity-model

Each step is described below in more detail.

5.2.1.1. - Creation of a generic BAT-based model

The generic BAT-based model describes a hypothetical plant. It includes deinking plant, one tissue machine, effluent treatment plant and fresh water production. Raw materials for the tissue machine are kraft pulp and/or recycled fiber. The model is based on BAT-data (best available technology) of deinking plant and tissue machine. The model includes only water, fiber, filler and solid impurites as model components. Soluble components (e.g. COD) are not modelled. The model is parametrized using BAT-data and common available data.

5.2.1.2. - Modification of the generic BAT-based model to Essity-model

The generic BAT-based model is modified to Essity-model. The Essity-model describes the whole Essity Nokia mill including deinking plant, two tissue machines (PM7 and PM9), market pulp pulping, broke handling from converting lines, fresh water production and waste water treatment. The process configuration corresponds to Essity Nokia mill. Raw materials for the tissue machines are kraft pulp and/or recycled fiber. The model includes water, fiber, filler and solid impurities as model components. Also soluble COD is modelled. Trace components like Ca^{2+} and Cl^{-} will not be modelled since their build-up is relevant only in systems where the total fresh water consumption in less than 15 m^3/t. At Essity Nokia mill, the average total fresh water consumption is around 40-45 m^3/t paper. In addition, the presence of CR-filter does not affect the levels of Ca^{2+} and Cl^{-} since ultrafiltration does not remove any dissolved trace components.

5.2.1.3. - Defining the reference case of Essity-model

Since the objective of the modelling and simulation work was to study process water reuse strategies, the reference process to which the new alternative processes are compared, must be first defined. Together with Essity, it was decided that the reference case will be Essity Nokia mill as it was until the end of 2017, thus before any re-arrangements of water circuits or implementation of CR-filter were conducted. The reference case is validated with the measured data of the 3rd measurement campaign. If this is lacking, then data from the 1st or 2nd or average of these two was used.

5.2.1.4. - Defining the cases to be studied using Essity-model

To study the SpotView research change in the process configuration, Essity defined two cases to be studied and compared to the reference case. The selected cases are:

Case 1: actions for water reduction

Case 1 describes the Essity Nokia mill process configuration after January 2018. By that time the following actions (steps 3, 4 and 5 in the water reduction action plan) were conducted:

- PM7 dust washers, converting dust washers and converting Nash water to white water instead of fresh water.
- Collect and utilize fresh and white water in DIP cooling, PM7 dust washers, PM condensate cooling, converting dust washers and Nash pumps.
- DIP white water system improvements
- In addition, the secondary flotation in deinking was taken out of use.

Case 1 is validated with the measured data of the 4th measurement campaign.

Case 2: actions for water reduction + implementation of CR-filter

Case 2 describes the Essity Nokia mill after August 2018. The process configuration is the same as in Case 1 with the addition that a pilot-scale (feed 10 m^3/h) Valmet CR-filter is implemented to PM7. The CR-filter treats about 5% of PM7 white water. Even though it would be possible to treat a greater share of white water, the pilot-scale filter was chosen to be included in the evaluation since it is already implemented in Nokia mill. The clean permeate from the filter is directed to PM7 wire section to replace part of the fresh water used in the high-pressure showers. Permeate from CR-filter may in certain cases be used as press section shower water or as dilution water for chemicals. However, in Case 2, permeate is used only as HP-showers in the wire section because of an existing pipe connection.

Like Case 1, Case 2 is also validated with the 4th measurement campaign data and additional data from the CR-filter pilot tests run by Valmet.

5.2.1.5. - Comparison of different cases with the reference case of Essity-model

To reveal how the re-arrangements in the water circuits in deinking plant and paper machines as well as the implementation of the CR-filter have affected the total fresh water consumption, Cases 1 and 2 are compared to the Reference case.

5.2.2. - Creation of the generic BAT-based tissue mill model

Following input data was used for defining the process:

- Block diagrams of deinking plant and tissue machine and typical process parameters available in BAT reference documents and in literature
- VTT's own knowledge based on many years of modelling work.

The annual capacity of the hypothetical tissue machine was 30,000 tons (uptime 8000 h/a). The generic BAT-based tissue machine was using 20% market pulp and 80% recycled fiber. The model was not validated against any measured data rather than it was parametrized with common BAT-based values.

5.2.3. - Creation of the Essity Nokia tissue mill model

5.2.3.1. - Input data

Following input data was used for defining the process:

- P&I diagrams from deinking plant, PM7 and PM9
- Print screens of the process control system
- Block diagrams of the mill done by CTP in the beginning of SpotView project
- Discussions with mill staff
- Previous measurement results and reports related to water consumption
- Measurements conducted by CTP at the mill in the beginning of SpotView project
- Results from the four measurement campaigns conducted during SpotView project

P&I diagrams, print screens of the process control system and block diagrams were used for drawing the process configuration (stream connections and process units). For setting the consistencies, yields, shower water consumptions, fresh water consumptions, effluent flows, etc to average values, discussions with mill staff and measurement results and reports conducted before and during SpotView project were used.

5.2.3.2. - Capacity and recipe

Average capacities (adt/d) for both paper machines were used in the simulation model. The capasities will not be presented here for confidentiallity reasons.

In Nokia mill, several recipes are used in both paper machines and they may vary daily several times. Both paper machines use recycled fiber (two grades U1 and U3), market pulp and broke from the onsite converting lines in different ratios. Ideally all four measurement campaigns should have been scheduled so that the same recipe would have always been in use on both paper machines. However, due to the fluctuation, this was impossible. As a result, the recipe during the 3rd and 4th measurement campaign was not same. The difference was taken into account in the model by different raw material feed. The recipes will not be presented here for confidentiallity reasons.

5.2.3.3. - Validation of the simulation model

The four main variables that were modelled and validated to show good agreement between the measured and simulated data were:

- Total fresh water consumption
- Total effluent flow to WWTP
- Total suspended solids (TSS) and
- Soluble COD.

Total fresh water consumption

For calculating the total fresh water consumption in the mill, fresh water consumptions in both paper machines (PM7 and PM9) were fixed to their hourly average values (m^3/h) based on long-term averages. Since PM7 and PM9 white waters are used in deinking for carrier water, the simulation model calculates the fresh water consumption in DIP as the difference ”water needed in DIP minus PMs white water feed to DIP”. Based on measured data (presented in Deliverable D2.5 in Table 1), also the fresh water used for sealing water and chemical preparation was fixed. Fresh water consumption in market pulp pulping and converting broke pulping were fixed. Their amounts were estimated with the help of mill staff. As a result, the simulation model calculates total fresh water consumption as the sum of all above mentioned fresh fresh water usages.

Total effluent flow to WWTP

For calculating the total effluent flow to waste water treatment plant, effluent flows from both paper machines (PM7 and PM9) were fixed to their hourly average (m^3/h) values based on long-term averages. The effluent flow from DIP to WWTP was calculated by the model. The total effluent flow to WWTP was calculated by the model as the sum of DIP, PM7 and PM9 effluents.

TSS and sluble COD

During the four measurement campaigns, around forty samples were collected and analyzed to define the chemical and microbial state of Nokia mill. Table 1 lists the thirty measurement points that were used to validate the TSS and soluble COD levels the simulation models.

Table 1. List of analysis sample points that were used to validate the TSS and soluble COD level in the simulation models.

#1	DIP PULPER DILUTION WATER
#2	SCREW PRESS 1 FILTRATE
#6	DIP DAF FEED
#7	DIP DAF FILTRATE
#8	DIP WHITE WATER TOWER
#3	DRUM WASHER FILTRATE
#4	SCREW PRESS 2 FILTRATE
#5	FROM DIP STORAGE TOWER
#18	DIP PMS WATER TOWER
#19	3rd: DAF2 FEED, 4th DIP SLUDGE DEWATERING FILTRATE
#20	2ND DAF FILTRATE
#9	PM7 HEADBOX
#11	PM7 WIRE WATER
# 31	PM7 PRESS WATERS
#12	PM7 CLEAR FROM DISC
#30	PM7 WHITE WATER
#28	PM9 MACHINE CHEST
#13	PM9 HEAD BOX
#14	PM9 WIRE WATER
#15	PM9 DAF FEED
#16	PM9 DAF FILTRATE
#17	PM9 WHITE WATER
#29	PM9 WHITE WATER TOWER
#21	PM7 EFFLUENT
#22	PM9 EFFLUENT
#23	INLET WWTP
#24	INLET AEROBIC
#25	OUTLET WWTP
#27	BROKE CHEST8
#10	CONVERTING BROKE CHEST

The simulated value of the total suspended solid (TSS) at the thirty measurement points listed in Table 1 was validated to correspond the measured value by adjusting the equipment performance parameters. These included for example retentions, reject ratios, accept ratios, solid losses, consistencies etc. The simulated and measured TSS-levels for the thirty points were plotted for comparison.

The simulated value of soluble COD at the thirty measurement points listed in Table 1 was validated to correspond the measured values by modelling the solubilization of COD from fiber in different points of the process. It was also assumed that some COD-load comes in with the chemicals. The simulated and measured soluble COD-levels for the thirty points were plotted for comparison.

5.3. - Process integration and heat loss recovery (T3.4.3)

5.3.1. - Approach of the heat integration study

For studying the energy optimization opportunities of the Essity Nokia mill, the following approach was used:

1. Localization of hot and cold streams
2. Data extraction
3. Identification of improvement options
4. Conversion of targeting results to actual process modifications
5. Determine saving potential

5.3.1.1. - Localization of hot and cold streams

The streams which are of interest for a pinch analysis are the so called 'hot' and 'cold' streams, which can be defined as follows :

Hot stream is a stream that needs to be cooled down (by a process stream or a cold utility like cooling water).

Cold stream is a stream that needs to be heated (by a process stream or a hot utility like steam)

Most often these hot and cold streams are associated with a heat exchanger so localization of all heat exchangers within the process forms an essential part of a thorough heat integration study. Furthermore the waste heat streams that can be used as potential heat source must be tracked down. To facilitate the localization of the heat exchangers, a questionnaire was prepared for Essity in which simplified flowsheets of the process units were presented and in which the position of the exisiting heat exchangers can be indicated.

5.3.1.2. - Data extraction

During the data extraction phase the relevant pinch data are traced for all hot and cold streams. The essential data needed for a pinch analysis are the so called 'start temperature' (TS), the 'target temperature' (TT) and the duty. The data extraction was also performed via the questionnaire. For streams for which certain data were not available, PDC made a first estimation.

As result from the data extraction, a so called 'stream table' was prepared which was used as input file for the pinch analysis software. This stream table will not be presented here for confidentiallity reasons.

5.3.1.3. - Identification of improvement options

With pinch analysis the minimum energy usage of a process can be determined. For this process, called 'targetting', composite curves are generated with the pinch software. A distinction can be made in a 'hot composite' and a 'cold composite'. With the hot composite curve all the hot streams in the process can be represented as one combined line in a Q – T diagram (Q = Duty, T = Temperature), as is schematically shown in the Figure 2.

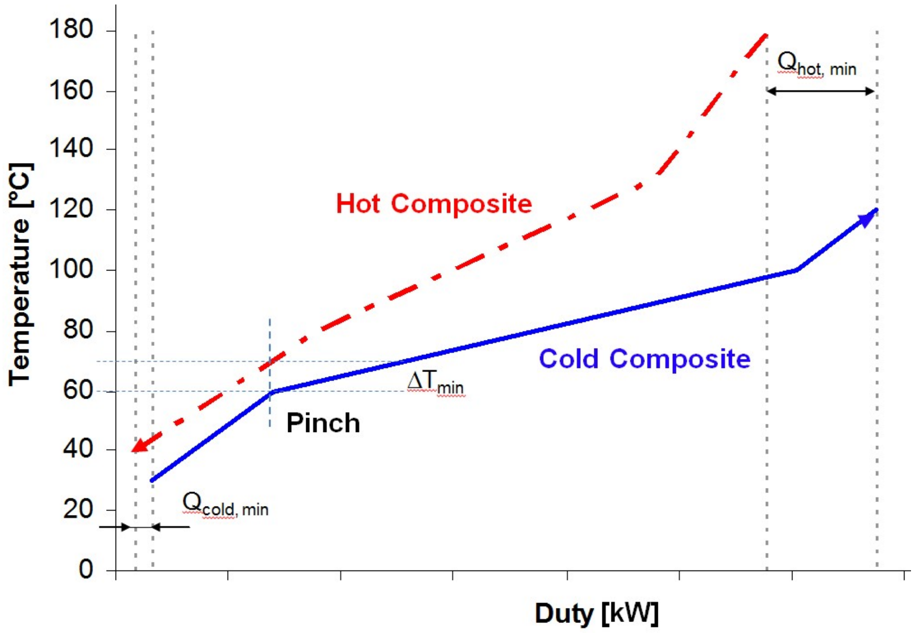


Figure 2. The basic principle of pinch analysis.

The point where the hot and cold composite curves approaches each other most close is called the pinch point. Here the temperature difference ΔT is at its minimum position.

The minimum amount of cold utility ($Q_{cold\ min}$) and hot utility ($Q_{hot,\ min}$) needed to drive the process can be deduced from the composite curves (represented by the parts on the left and right side of the curves, where there is no overlap between the hot and cold composite). These values are the main results of a targeting excercise.

Experience is needed to interpret the composite curves (CC) and to identify potential improvements options by making modifications to the CC, especially when many streams are involved. PDC identified 4 improvement options for the reference process of the Nokia mill to reduce the energy consumption. These options will be discussed in more detail in Chapter 6.3.

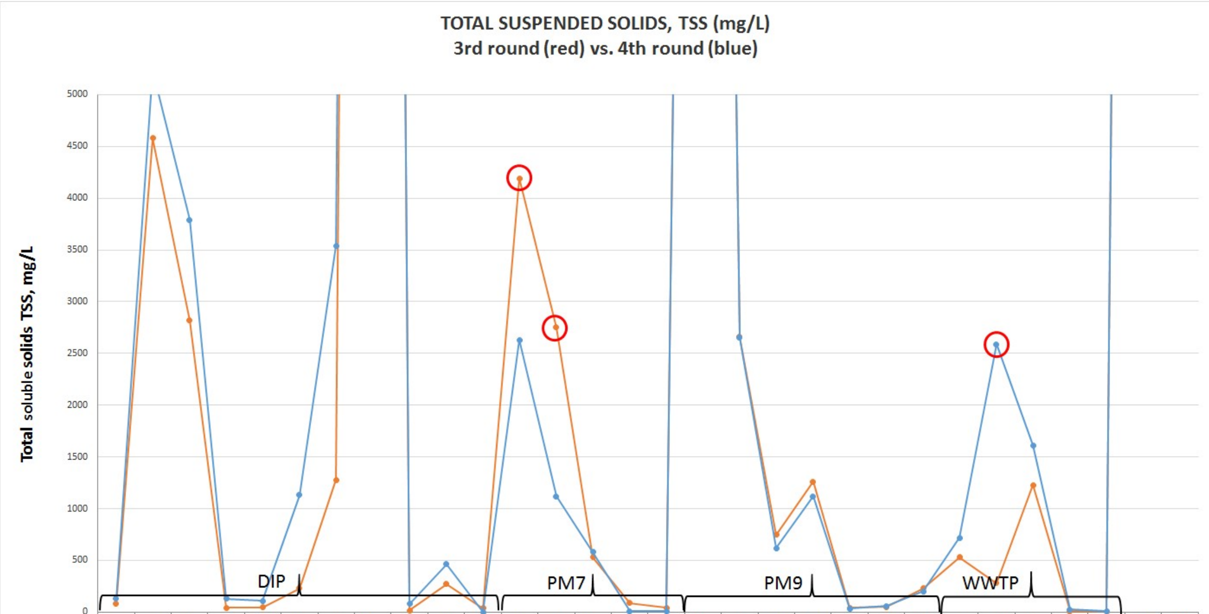
5.3.1.4. - Conversion of targeting results

In a next step the targetting results of the identified options are converted into real process modifications, to make clear what the differences are between the existing process and the modified option, followed by an estimation of the savings potential on basis of the actual utility prices.

6. - Results

6.1. - Measurement campaigns – comparison

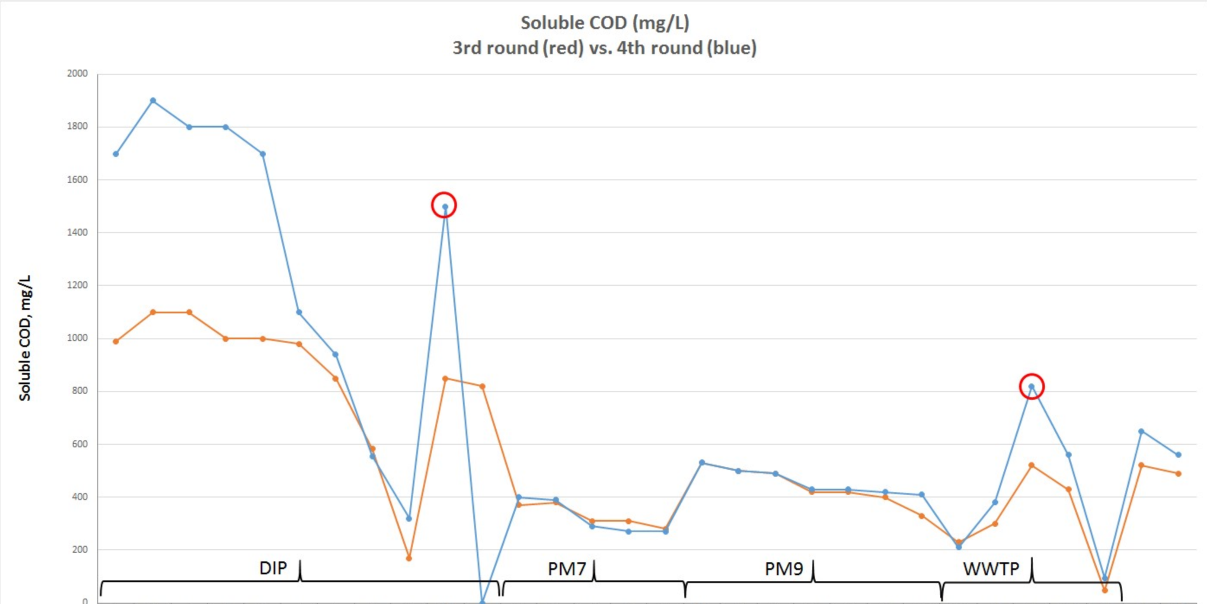
Figure 3 and Figure 4 show the analysis results for the 3rd and 4th measurement campaigns for TSS and soluble COD in the thirty measurement points listed in Table 1 that were used to validate the simulation models. The 3rd round, depicted in red in the figures, shows the state of the mill in September 2017 before any of the actions to reduce water consumption were conducted. The 4th round, depicted in blue in the figures, shows the state of the mill in November 2018 when the first actions to reduce water consumptions were conducted. As can be seen from Figure 3, the first actions to reduce the fresh water consumption have had an increasing effect on the total suspended solids level especially in the deinking plant. The TSS of DAF1 filtrate (#7), DIP white water tower water (#8), drum washer filtrate (#3), screw press 2 filtrate (#4) and PMs carrier water tower water (#18) are 2 to 5 times higher after the improvements in DIP white water system have been executed. In PM7 the analysis results for head box (#9) and wire water (#11) in the 3rd measurement campaign are unrealistic high. Values of 4rd campaign represent more realistic ones. In PM9, a such a high difference in the TSS level isn't seen. However, there must be some error in the sampling of PM9 effluent (#22) during the 4rd campaign. It is almost 10 times higher than the value of 3rd campaign.



	1	2	6	7	8	3	4	5	18	19	20	9	11	31	12	30	28	13	14	15	16	17	29	21	22	23	24	25	27	10
3rd round	81	4580	2820	41	45	230	1280	45000	19	270	38	4190	2750	530	89	44	27300	2660	750	1260	41	50	230	530	280	1230	11	9.4	37600	28500
4th round	130	5240	3790	130	110	1130	3540	45000	82	465	0	2630	1120	580	7.4	7.6	27300	2650	620	1120	36	60	200	720	2590	1610	25	9	37600	28500

Figure 3. Total suspended solids (TSS) levels before (red line) and after (blue line) the first actions to reduce water consumption in Essity Nokia tissue mill were conducted.

As can be seen from Figure 4 the improvements in DIP white water system have increased the soluble COD level in the beginning of deinking plant from 1000 mg/L to 1800 mg/L. The soluble COD in both paper machines, however, have stayed at the same level. The increased soluble COD level in the WWTP inlet (#23) during the 4rd campaign can be explained with the higher COD load coming in with DIP effluents.



	1	2	6	7	8	3	4	5	18	19	20	9	11	31	12	30	28	13	14	15	16	17	29	21	22	23	24	25	27	10
3rd round	990	1100	1100	1000	1000	980	850	582.5	170	850	820	370	380	310	310	280	530	500	490	420	420	400	330	230	300	520	430	46	520	490
4th round	1700	1900	1800	1800	1700	1100	940	555	320	1500	0	400	390	290	270	270	530	500	490	430	430	420	410	210	380	820	560	94	650	560

Figure 4. Soluble COD levels before (red line) and after (blue line) the first actions to reduce water consumption in Essity Nokia tissue mill were conducted.

6.2. - Simulation of process water reuse strategies (T3.4.1)

6.2.1. - Generic BAT-based tissue mill model

The simulation work was started by creating the generic BAT-based tissue mill model. It depicts a hypothetical tissue mill using best available technology. The model is hierarchical; it contains four submodel under the main flowsheet (see Figure 5). The generic tissue mill model was created to offer a model that can be later modified to describe any real tissue mill. It can also be used for reflecting the results of SpotView project to other tissue mills.

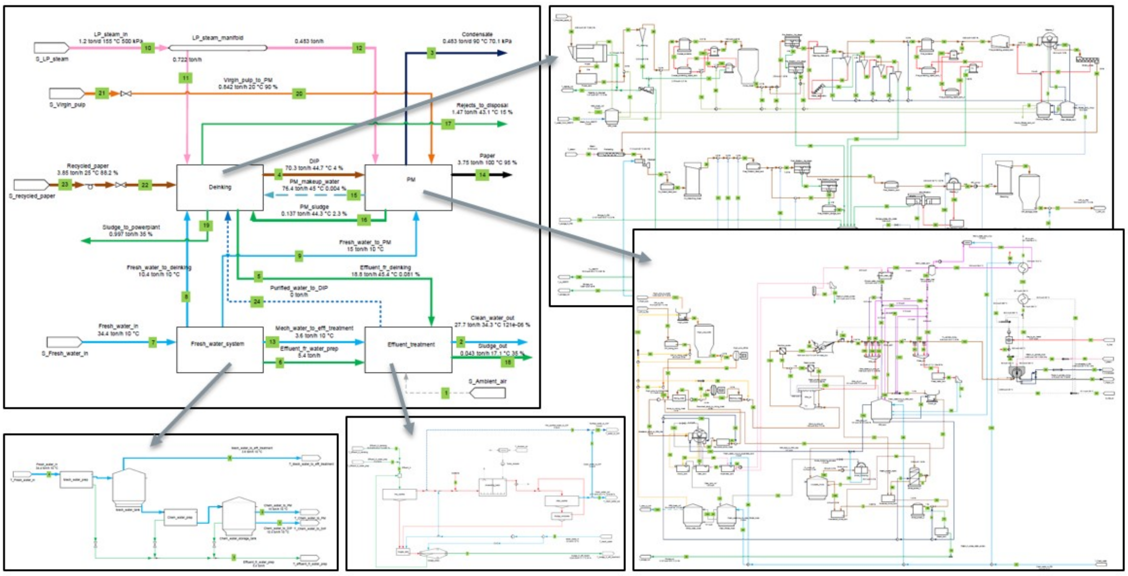


Figure 5. Flowsheet of the generic BAT-based tissue mill model.

6.2.2. - Essity Nokia tissue mill model

6.2.2.1. - Model flowsheet

The genereic BAT-based tissue mill model was modified to Essity Nokia model. The model flowsheets for all three evaluated cases are presented in Appendix 1. The sample points listed in Table 1 are presented in the flowsheet with orange numbered boxes. The simulation model is hierarchical; it includes the following seven submodels under the main flowsheet:

1. Deinking plant (DIP)
2. Paper machine 7 (PM7)
3. Paper machine 9 (PM9)
4. Fresh water production
5. Waste water treatment plant (WWTP)
6. Market pulp pulping
7. Converting broke pulping

Process configurations for deinking plant and both paper machines differ in Reference case, Case 1 and Case 2 due to the re-arrangament of water circuits. Process configurations in all rest four submodels are identical in all three evaluated cases.

Figure 6 shows the arrangements of water circuits in DIP before the step 6 in water reduction action plan has been executed. Thus, it depicts the Reference case. Figure 7, instead, shows the arrangements of water circuits in DIP after DIP white water system improvements (step 6) have been executed. Thus, it depicts Cases 1 and 2. Main differencies after the changes are:

- Flotation dilutions with drum washer filtrate instead of PMs water and DAF1 filtrate
- Part of drum washer filtrate is recycled to DNT-washer feed instead of directly to DAF1 feed
- There is a circulation between drum washer filtrate tank and screw press 2 filtrate tank
- DAF2 is out of use. Part (10%) of DIP sludge press filtrate is recycled back to DAF1 feed, rest is discharged to WWTP.

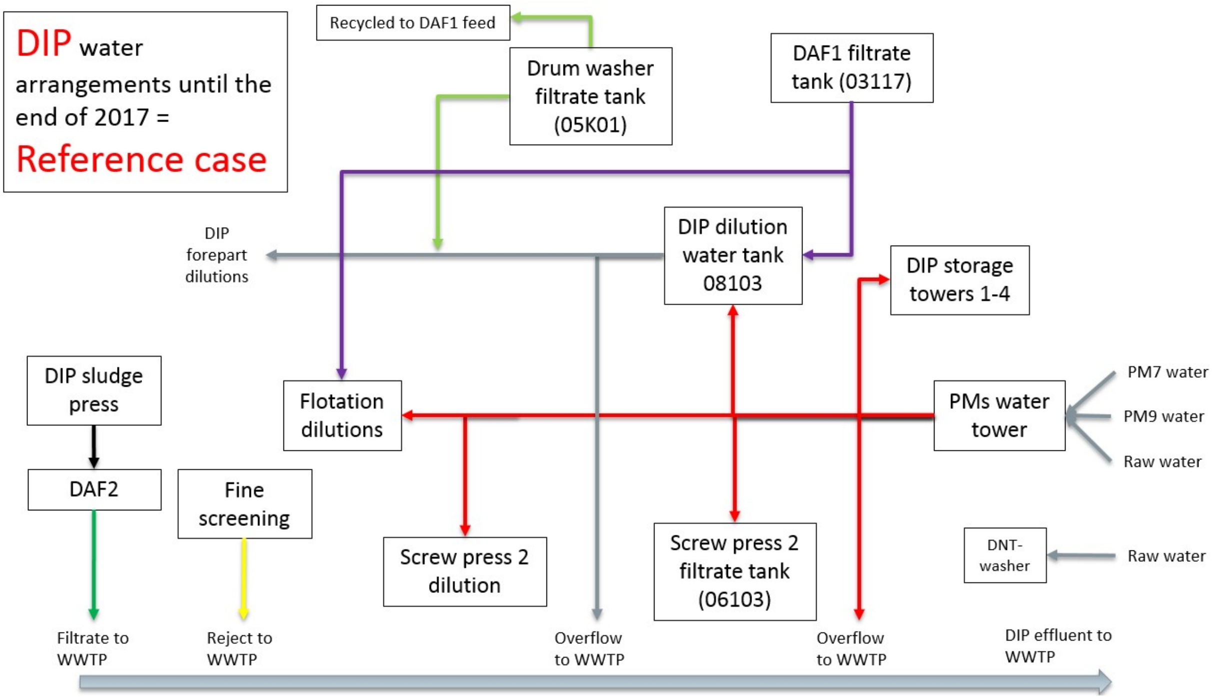


Figure 6. Water circuit arrangements in deinking plant until the end of 2017 before any DIP water system improvements have been executed (Reference case).

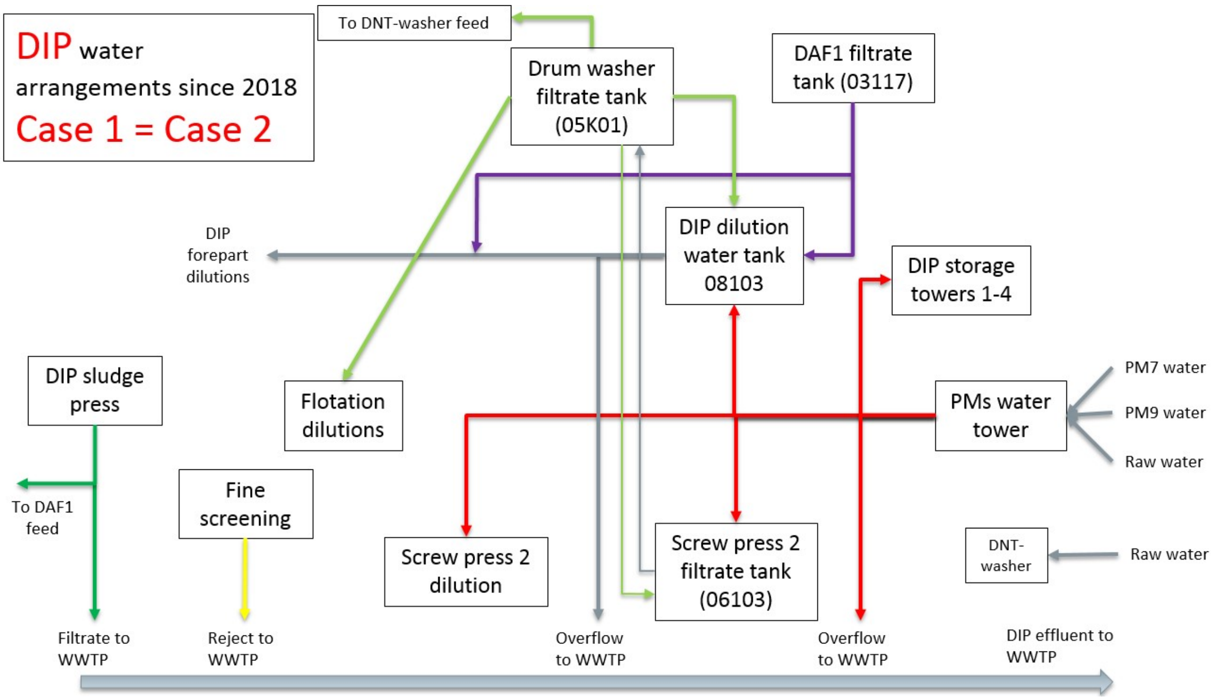


Figure 7. DIP white water system improvements (step 6 in water reduction action plan). Water circuit arrangements in deinking plant in Case 1 and Case 2.

Figure 8 shows the water circuit arrangements in PM7 in all three evaluated cases. Before 2018 (Reference case) waters from PM7 dust removal were directed to waste water canal. After executing the steps 4 and 5 in the water reduction action plan in early 2018, waters from PM7 dust removal were collected and recycled to PM7 couch pit.

Valmet's CR-filter was implemeted to Essity Nokia mill in August 2018. It treats part of PM7's white water from disc and produces clear permeate which is used in wire section high-pressure showers to substitute part of fresh water. The capacity of the CR-filter is 10 m^3/h. The permeate flow is 9 m^3/h. Reductions for TSS is 100% and for soluble COD 20%. The capacities and reductions are based on pilot trials conducted in Nokia mill.

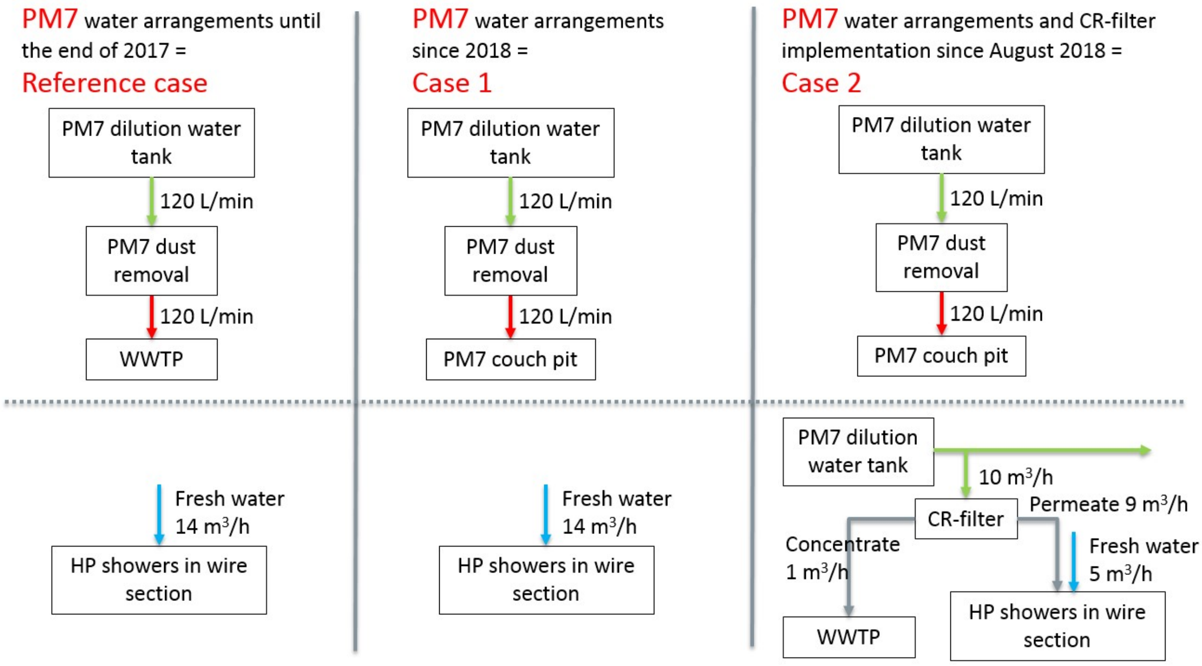


Figure 8. Actions to reduce water consumption in PM7 (steps 4 and 5 in the water reduction action plan): i) reuse of PM7 dust removal waters instead of directing to WWTP and ii) implementation of Valmet's CR-filter to produce clear permeate from white water to be used as HP-shower water in wire section.

Figure 9 shows the water circuit arrangements in PM9 in all three evaluated cases. Before 2018 (Reference case) the dustwashers in converting lines 2, 3 and 4 used fresh water and discharged to waste water canal. After executing the steps 4 and 5 in the water reduction action plan in early 2018, dushwashers in converting lines 2 and 4 were changed from fresh water to PM9 white water. Waters from dustwashers in converting lines 2 and 3 were collected and recycled to PM9 carrier water tank.

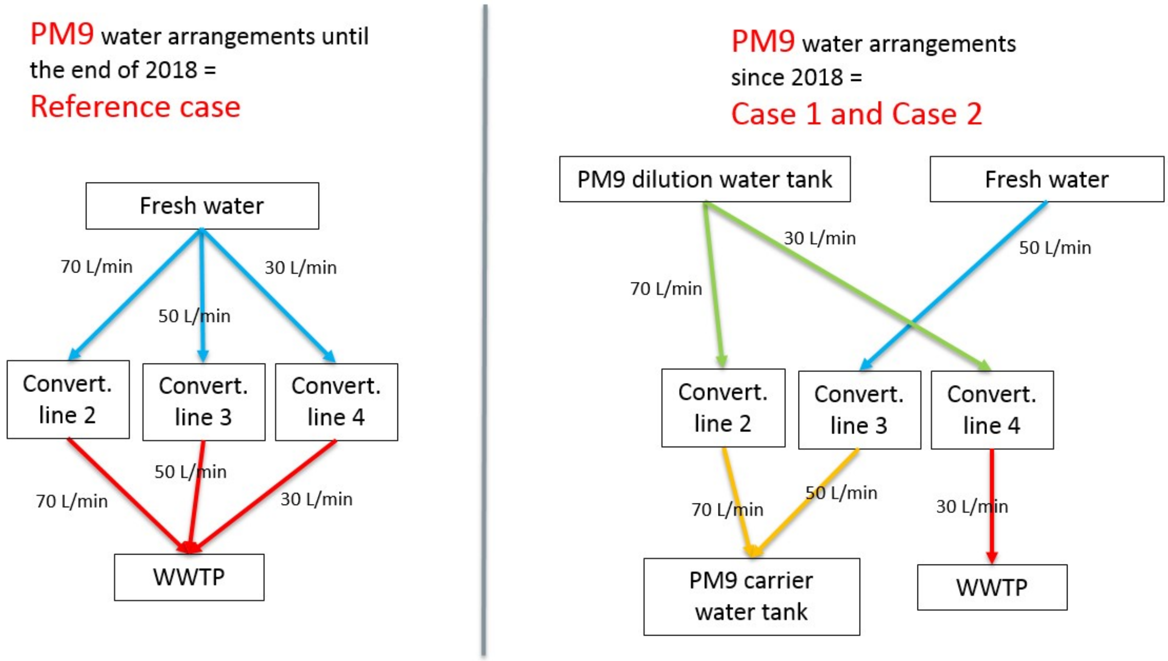


Figure 9. Actions to reduce water consumption in PM9 (steps 4 and 5 in the water reduction action plan): i) dustwashers in converting lines 2 and 4 changed from fresh water to PM9 white water and ii) reuse of dustwasher waters from converting lines 2 and 3 instead of directing to WWTP.

6.2.2.2. - Fresh water flows and effluent

<u>Reference case</u>

Following fresh water consumptions were fixed in Reference case:

- PM7 fresh water: 85 m^3/h
  - Market pulp pulping: 5 m^3/h
  - HP-showers: 27 m^3/h
  - Warm water showers: 39 m^3/h
  - Additional water: 14 m^3/h
- PM9 fresh water: 110 m^3/h
  - Market pulp pulping: 10 m^3/h
  - HP-showers: 17.4 m^3/h
  - Warm water showers: 54 m^3/h
  - Dustwashers in converting lines: 9 m^3/h
  - Additional water: 19.6 m^3/h
- Sealing water: 2 m^3/h
- Chemical preparation: 78 m^3/h (divided equally to DIP, PM7 and PM9)
- Converting broke pulping: 10 m^3/h

Following effluent flows were fixed in Reference case:

- PM7 effluent: 70 m^3/h
- PM9 effluent: 100 m^3/h
- Other effluent: 2 m^3/h

As a result of the simulation, following fresh water consumptions and effluent flows were achieved for Reference case:

- Deinking plant
  - Fresh water consumption: 90 m^3/h
    - DNT-washer: 12 m^3/h
    - PMs carrier water tank: 78 m^3/h
  - Effluent flow: 189 m^3/h
- Total fresh water consumption: 375 m^3/h
- Total effluent flow to WWTP: 361 m^3/h

Figure 10 depicts the total water balance of Essity Nokia mill until the end of 2017 when no actions to reduce fresh water consumption have been yeat conducted.

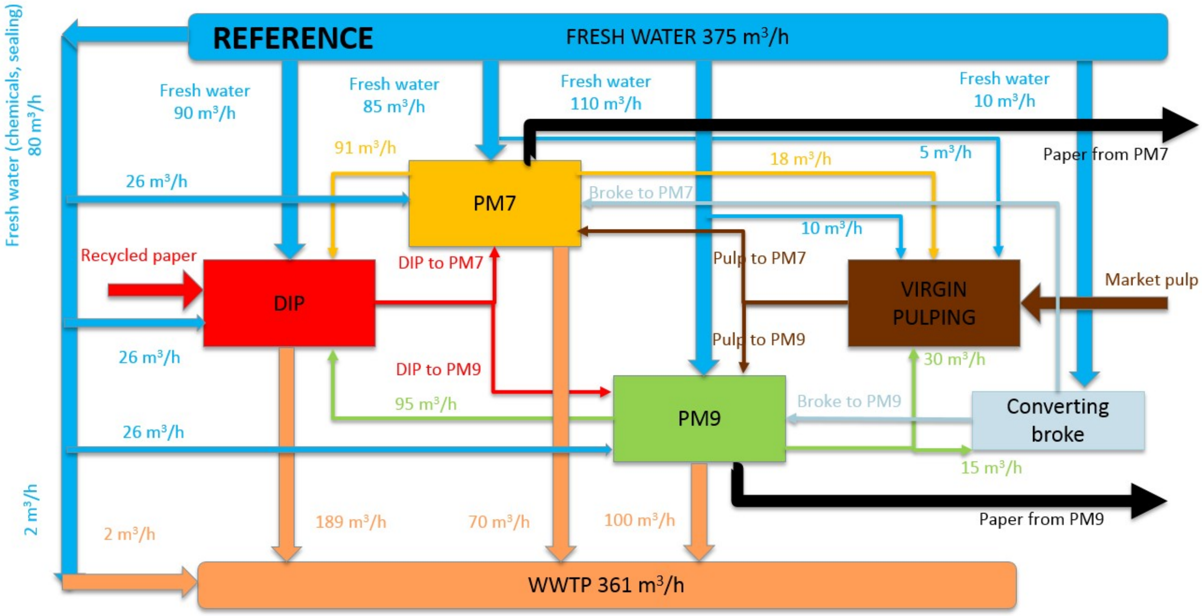


Figure 10. Reference case: Water balance in Essity Nokia mill until the end of 2017 when no actions to reduce the fresh water consumption have been executed.

<u>Case 1: changes in water circuits</u>

The effects of the re-arrangements of water circuits aiming at lower fresh water consumption (explained in 6.2.1. -) were covered in the simulation model as follows:

- **Deinking**: new arrangements of water circuits were updated to the model and DAF2 was taken out of use

  → DIP fresh water consumption and effluent flow will be automatically updated as a result of the simulation
- **PM7**: Water from PM7 dust removal directed to couch pit instead of waste water canal

  → PM7 effluent decreased in the model by 7.2 m^3/h from 70 to 62.8 m^3/h
- **PM9**: Fresh water in converting lines 2 and 4 replaced by PM9 dilution water tank water

  → PM9 fresh water decreased in the model by 6 m^3/h from 110 to 104 m^3/h
- **PM9**: Water from converting lines 2 and 3 directed to PM9 carrier water tank instead of waste water canal

  → PM9 effluent decreased in the model by 7.2 m^3/h from 100 to 92.8 m^3/h

The following decreased values of PM7 and PM9 fresh water consumptions and effluents were set to the simulation model:

- PM7 fresh water: 85 m^3/h
  - Market pulp pulping: 5 m^3/h
  - HP-showers: 27 m^3/h
  - Warm water showers: 39 m^3/h
  - Additional water: 14 m^3/h
- PM9 fresh water: 104 m^3/h
  - Market pulp pulping: 10 m^3/h
  - HP-showers: 17.4 m^3/h
  - Warm water showers: 54 m^3/h
  - Dustwashers in converting lines: 3 m^3/h
  - Additional water: 19.6 m^3/h
- Sealing water: 2 m^3/h
- Chemical preparation: 78 m^3/h (divided equally to DIP, PM7 and PM9)
- Converting broke pulping: 10 m^3/h
- PM7 effluent: 62.8 m^3/h
- PM9 effluent: 92.8 m^3/h
- Other effluent: 2 m^3/h

As a result of the simulation, following fresh water consumptions and effluent flows were achieved for Case 1:

- Deinking plant
  - Fresh water consumption: 13 m^3/h
    - DNT-washer: 12 m^3/h
    - PMs carrier water tank: 1 m^3/h
  - Effluent flow: 118 m^3/h
- Total fresh water consumption: 292 m^3/h
- Total effluent flow to WWTP: 276 m^3/h

Figure 11 depicts the total water balance of Essity Nokia since early 2018 when the first actions to reduce fresh water consumption have been conducted.

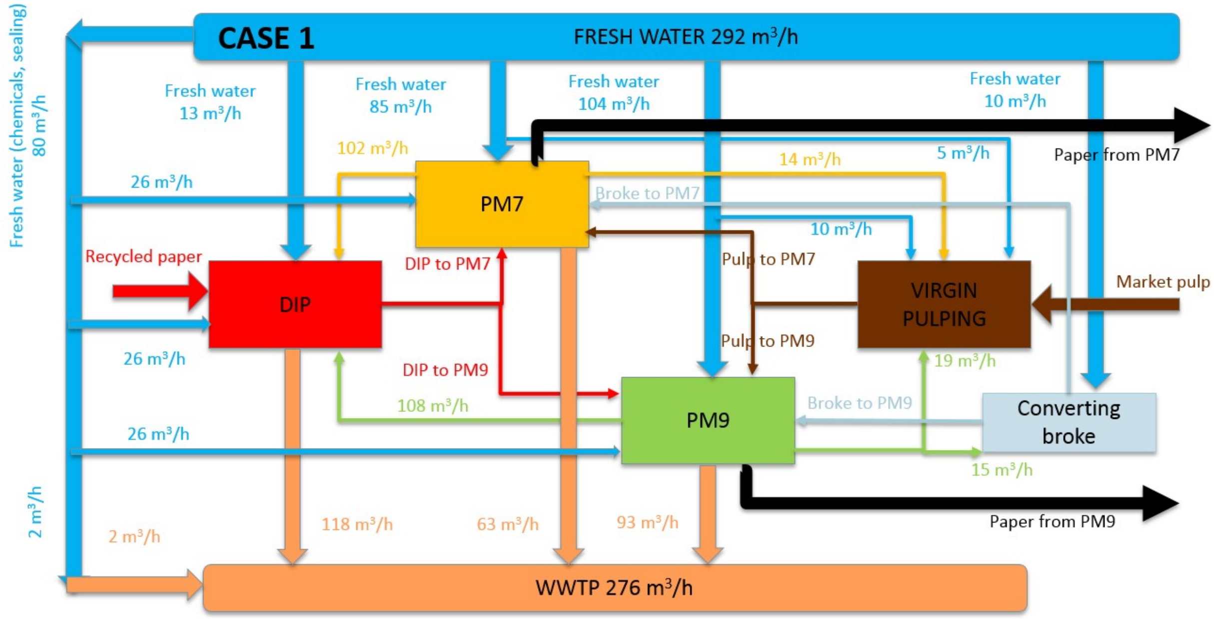


Figure 11. Case 1: Water balance in Essity Nokia mill since 2018 when first actions to reduce the fresh water consumption have been executed.

<u>Case 2: changes in water circuits + implementation of CR-filter</u>

The effects of the re-arrangements of water circuits aiming at lower fresh water consumption (explained in 6.2.1. -) were covered in the simulation model same way as in Case 1. In addition, the pilot-scale CR-filter was implemented to PM7:

- **PM7**: PM7 white water feed from disc to CR-filter 10 m^3/h. CR-permeate, 9 m^3/h, substitutes fresh HP-shower water in PM7 wire section. CR-concentrate, 1m^3/h, discharged to WWTP.

  → PM7 fresh water decreased in the model by 9 m^3/h from 85 to 76 m^3/h

  → PM7 effluent decreased in the model by 9 m^3/h from 62.8 to 53.8 m^3/h

The following decreased values of PM7 and PM9 fresh water consumptions and effluents were set to the simulation model:

- PM7 fresh water: 76 m^3/h
  - Market pulp pulping: 5 m^3/h
  - HP-showers: 18 m^3/h
  - Warm water showers: 39 m^3/h
  - Additional water: 14 m^3/h
- PM9 fresh water: 104 m^3/h
  - Market pulp pulping: 10 m^3/h
  - HP-showers: 17.4 m^3/h
  - Warm water showers: 54 m^3/h
  - Dustwashers in converting lines: 3 m^3/h
  - Additional water: 19.6 m^3/h
- Sealing water: 2 m^3/h
- Chemical preparation: 78 m^3/h (divided equally to DIP, PM7 and PM9)
- Converting broke pulping: 10 m^3/h

- PM7 effluent: 53.8 m^3/h
- PM9 effluent: 92.8 m^3/h
- Other effluent: 2 m^3/h

As a result of the simulation, following fresh water consumptions and effluent flows were achieved for Case 2:

- Deinking plant
  - Fresh water consumption: 13 m^3/h
    - DNT-washer: 12 m^3/h
    - PMs carrier water tank: 1 m^3/h
  - Effluent flow: 118 m^3/h
- Total fresh water consumption: 283 m^3/h
- Total effluent flow to WWTP: 267 m^3/h

Figure 12 depicts the total water balance of Essity Nokia since early 2018 when the first actions to reduce fresh water consumption have been conducted and the pilot-scale Valmet CR-filter inplemeted to PM7 to purify part of PM7 white water.

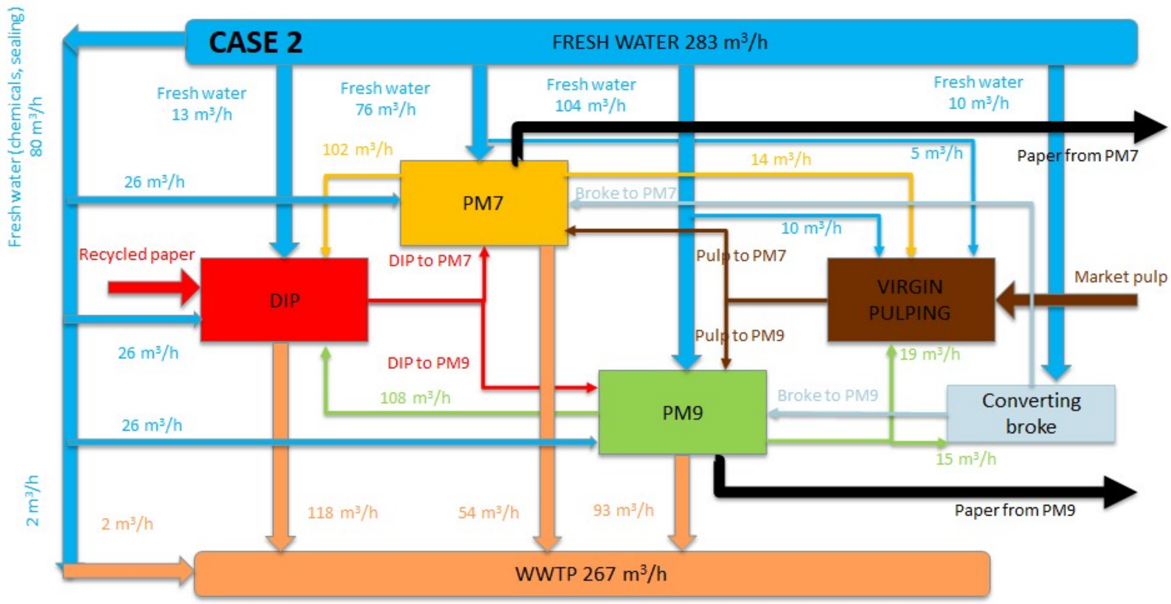


Figure 12. Case 2: Water balance in Essity Nokia mill since 2018 when first actions to reduce the fresh water consumption have been executed and Valmet's CR-filter implemented to PM7 to produce clear permeate from disc filtrate.

Table 2 compiles the total fresh water consumption and effluent flow to WTTP as well as the fresh water consumptions and effluent flows separately for deinking, PM7 and PM9 for all three evaluated cases. For deinking, also the white water flows from both paper machines to deinking are shown. Table 2 contains also the comparison of Case 1 vs. Reference, Case 2 vs. Reference and Case 2 vs. Case 1.

Table 2. Comparison of water balances in all three evaluated cases.

	REF	CASE 1		CASE 2		
TOTAL	m³/h	m³/h	Vs.Ref	m³/h	Vs.Ref	Vs.Case1
Fresh water	375	292	**-22%**	283	**-25%**	**-3.1%**
Effluent	361	276	-24%	267	-26%	-3.3%
DIP	m³/h	m³/h	Vs.Ref	m³/h	Vs.Ref	Vs.Case1
Fresh water	90	13	**-86%**	13	**-86%**	**0%**
PM7 water	91	102	+12%	102	+12%	0%
PM9 water	95	108	+14%	108	+14%	0%
Effluent	189	118	-37%	118	-37%	0%
PM7	m³/h	m³/h	Vs.Ref	m³/h	Vs.Ref	Vs.Case1
Fresh water	85	85	**0%**	76	**-11%**	**-11%**
Effluent	70	63	-10%	54	-23%	-14%
PM9	m³/h	m³/h	Vs.Ref	m³/h	Vs.Ref	Vs.Case1
Fresh water	110	104	**-5.5%**	104	**-5.5%**	**0%**
Effluent	100	93	-7.2%	93	-7.2%	0%

In Case 1 the following steps in the water reduction action plan were implemented to Essity Nokia mill:

3. PM7 dust washers, converting dust washers and converting Nash water to white water instead of fresh water.
4. Collect and utilize fresh and white water in DIP cooling, PM7 dust washers, PM condensate cooling, converting dust washers and Nash pumps.
5. DIP white water system improvements

As a result, following theoretical reductions in fresh water consumption compared to the Reference case were reached:

- -22% total fresh water
- -86% fresh water to DIP
- 0% fresh water to PM7
- -5.5% fresh water to PM9

Due to the re-arrangements in water circuits both in deinking and paper machines, in Case 1 the total water consumption (fresh water + PMs water) in deinking has decreased by 20%. In the same time more carrier water from PM7 (+12%) and PM9 (+14%) is available for deinking's use. This results that the total fresh water consumption in deinking has decreased by 86%. For realizing the principle of counter-current washing, the best solution is to take the fresh water in in paper machines rather than in deinking. This guarantees that the paper machines stay cleaner. Thus, to minimise the fresh water intake in deinking, major part of

PMs water should be directed to deinking rather than discharged to WWTP resulting that deinking would be the major source of mill effluents.

In Case 2, same water reduction steps as in Case 1 were conducted. In addition Valmet CR-filter was implemented to PM7 to decrease fresh water usage in PM7 HP-showers. As a result, following theoretical reductions in fresh water consumption compared to the Reference case were reached:

- -25% total fresh water
- -86% fresh water to DIP
- -11% fresh water to PM7
- -5.5% fresh water to PM9

Due to the re-arrangements in water circuits both in deinking and paper machines, in Case 2 the total water consumption (fresh water + PMs water) in deinking has decreased by 20% like in Case 1. Like in Case 1, the carrier water amount from PM9 available for deinking's use stayed unchanged (+14% compared to Reference). Due to the implementation of CR-filter in Case 2, some PM7 white water was used as HP-showers instead of as deinking carrier water as in Case 1. To guarantee the same amount of PM7 carrier water for deinking's use as in Case 1 and to follow the counter-current washing idea (minimize the fresh water intake to DIP by maximizing the PMs water usage in DIP), the effluent amount from PM7 was decreased in Case 2. This resulted that the PM7 and PM9 carrier water consumptions and fresh water consumptions in deinking were the same in Cases 1 and 2. However, in the same time, the total fresh water consumption in PM7 decreased by 11% due to the usage of CR-permeate instead of fresh water in HP-showers. This resulted that the total fresh water consumption of the mill in Case 2 has decreased by 25% compared to Reference and by 3% compared to Case 1.

The gap between fresh water intake and effluent disposal is in Reference case 14 m^3/h and in Case 1 and Case 2 16 m^3/h. The difference can be explained with the water that leaves the system with DIP sludge that is directed via conveyor to power plant for combustion. In Cases 1 and 2, the share of recycled fiber in the recipe is greater than in Reference case. This results a greater amount of water leaving the system with the DIP sludge.

6.2.2.3. - TSS and soluble COD

To depict the chemical state of Essity Nokia mill, the total suspended solid (TSS) and soluble COD levels were adjusted in the simulation models to correspond the measured ones.

The simulated value of the total suspended solid (TSS) at the thirty measurement points was validated to correspond the measured value by adjusting the equipment performance parameters. These included for example retentions, reject ratios, accept ratios, solid losses, consistencies, etc.

The simulated value of soluble COD at the thirty measurement points was validated to correspond the measured values by modelling the solubilization of COD from fiber in different points of the process. Alltogether nine points were identified. These were six pulpers (recycled paper, PM7 broke, PM9 broke, converting broke, PM7 market pulp, PM9 market pulp), bleaching tower in DIP and refiners in both PMs. It was also assumed that some COD-load comes in with the chemicals. Following points for COD-load incoming with chemicals were identified: defoamer feed to DNT-washer and drumwasher in DIP, wet strenght resin feed to PM9 mixing chest and defoamer feed to PM9 couch pit.

The validation was started with the Reference case. Equipment performance parameters were modified, COD-formation in nine points across the process were taken into consideration and COD-load coming in with chemicals in four points were added to reach the measured values obtained from the 3rd measurement campaign. The comparison of measured and simulated TSS and soluble COD levels for Reference case are presented in Appendix 2 in Figure 35 and Figure 36. As can be seen from Figure 35, the measured and simulated values for TSS in the thirty points showed quite good agreement apart from the two measurement outliers (#9 PM7 headbox and #11 PM7 wire water) that were known to be incorrect and thus not targeted to reach with the simulation model. There were also two points in the model that did not agree with the measured value; PM9 DAF feed (#15) and total effluent feed to WWTP (#23). The deviation of the simulated TSS of total effluent feed to WWTP from its measured value is questionable since the simulated TSS levels for DIP effluent (#20), PM7 effluent (#21), and PM9 effluent (#22) agreeded well with their measured values. Reasoning for the deviation of PM9 DAF feed was not found. Figure 36 shows the comparison of simulated and measured values for soluble COD in the thirty points. The correspondence was not quite as good as it was for TSS. There was some validation mismatch in the area of WWTP inlet (#23 and #24).

Since Case 1 and Case 2 represent the process after the water reduction actions were conducted, the chemical state of the process has changed and the simulated values must be compared to the new measured values from the 4th measurement campaign. TSS and soluble COD levels have changed especially in deinking (see Figure 3 and Figure 4). After updating the stream connections in the Reference model to correspond to the new process configuration of Case 1 and Case 2, some modifications mainly in DIP equipment performances were done to reach the new TSS level of Cases 1 and 2. Same modifications were valid for both new cases. During the 4th measurement campaign, twelve additional analysis points were included. These points gave additional data that was not available when parametrizating the equipments for Reference case. For achieving a good agreement of measured and simulated soluble COD level, COD solubilization in five points were adjusted. The comparison of measured and simulated TSS and soluble COD levels are presented in Appendix 2 in Figure 37 and Figure 38 for Case 1 and in Figure 39 and Figure 40 for Case 2. For Case 1 and Case 2, the correspondence of simulated and measured TSS levels show the same trends as observed for Reference case; the points that did not agree with the measured value were again PM9 DAF feed (#15) and total effluent feed to WWTP (#23). There was also most likely one measurement outlier (#22, PM9 effleunt) that was not targeted to reach with the simulation model. For Case 1 and Case 2, the agreement of simulated and measured soluble COD levels was extremely good, much better than for Reference case.

6.3. - Process integration and heat loss recovery (T3.4.3)

To facilitate the data extraction, a questionnaire was prepared for Essity in which the location of the existing heat exchangers as well as the relevant pinch data can be filled in. In the case of missing data, these were complemented by an estimation of PDC.

6.3.1. - Data extraction DIP and Stock preparation section

The location of the existing heat exchangers (HE's) in the DIP section are indicated in Figure 13. This figure, which consists of a simplified block diagram of the DIP unit operations with the relevant water flows, is a modification of the flow scheme that was prepared by CTP for the measurement campaign in 2017.

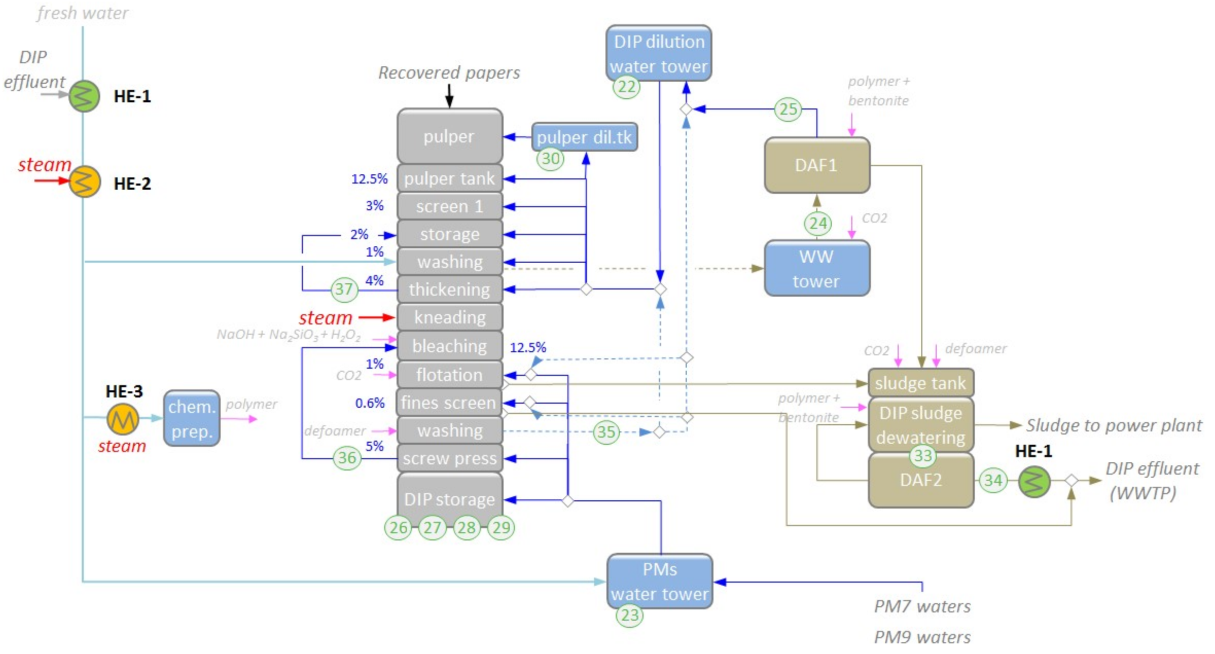


Figure 13. Simplified block diagram of DIP section in Reference case with locations of existing HE's.

In the DIP section three heat exchangers are present. The first heat exchanger (HE-1) preheats fresh water by using DIP effluent. Because the preheating is done with waste heat from an other process stream (i.e. DIP effluent) this heat exchanger is already heat integrated.

The 2nd heat exchanger (HE-2) preheats the fresh water further by using LP steam. Also HE-3, which preheats fresh water for chemical preparation purpose (polymer dilution), is heated with steam. To distinguish the heat exchangers that are already heat integrated with the heat exchangers that are not (i.e. heated with a hot utility), the heat exchangers of the first category are indicated with a green color and the second category with an orange color.

In Figure 13 also the locations of the sampling points for the measurement campaign are indicated (grey circles with green numbers). The corresponding temperature data for the three sampling campaigns are given in Table 3.

Table 3. Temperature data for the three sampling campaigns (March, May and September 2017).

DIP No	Temperature, °C 27,09	15,05	08.03	Description	avg
	water streams				
22	39	40	35	DIP dilution water tower	38
30	38	38	36	DIP dilut2	38
37	38	41	38	screw press filtrate tank	39
35	38	41	39	Drum wash filtrate	39
36	37	39	37	screw press filtrate tank	38
23	28	32	32	PMs water tower	31
	water purification				
24	39	40	37	DAF1in	39
25	39	41	38	DAF1out	39
33	x	28	25	DAF2 in	26
34	35	30	24	DAF2 out	30
	feed/product				
26	x	32	31	DIP storage1	31
27	x	x	35	DIP storage2	35
28	28	22	x	DIP storage3	25
29	x	22	26	DIP storage4	24

6.3.2. - Data extraction paper machines (PM7 and PM9)

A schematical representation of PM7 and PM9 is given in Figure 14 and in Figure 15. In principle the same set-up is used for the heat exchanging system.

Five process heat exchangers are present in the PM section. All these heat exchangers are already heat integrated (in Figure 14 and Figure 15 the heat integration is represented by the dotted lines).

- The fresh water to the press section is first preheated by exhaust air in HE-10 and then further preheated by flash steam (HE-12) and condensate (HE11) from the Yankee condensate system.
- In HE-13 the heating of fresh water for chemical preparation is also done by heat from the Yankee condensate system.
- Fresh air is first preheated with exhaust air in HE-14 and then further heated by natural gas before entering the Yankee dryer.

Two other heat exchangers (i.e. not regarded as process heat exchangers) are installed before and after HE-10 and used for building heat (mainly in winter time).

External heat is added to the process by natural gas and steam for the purpose of water evaporation in the Yankee dryer.

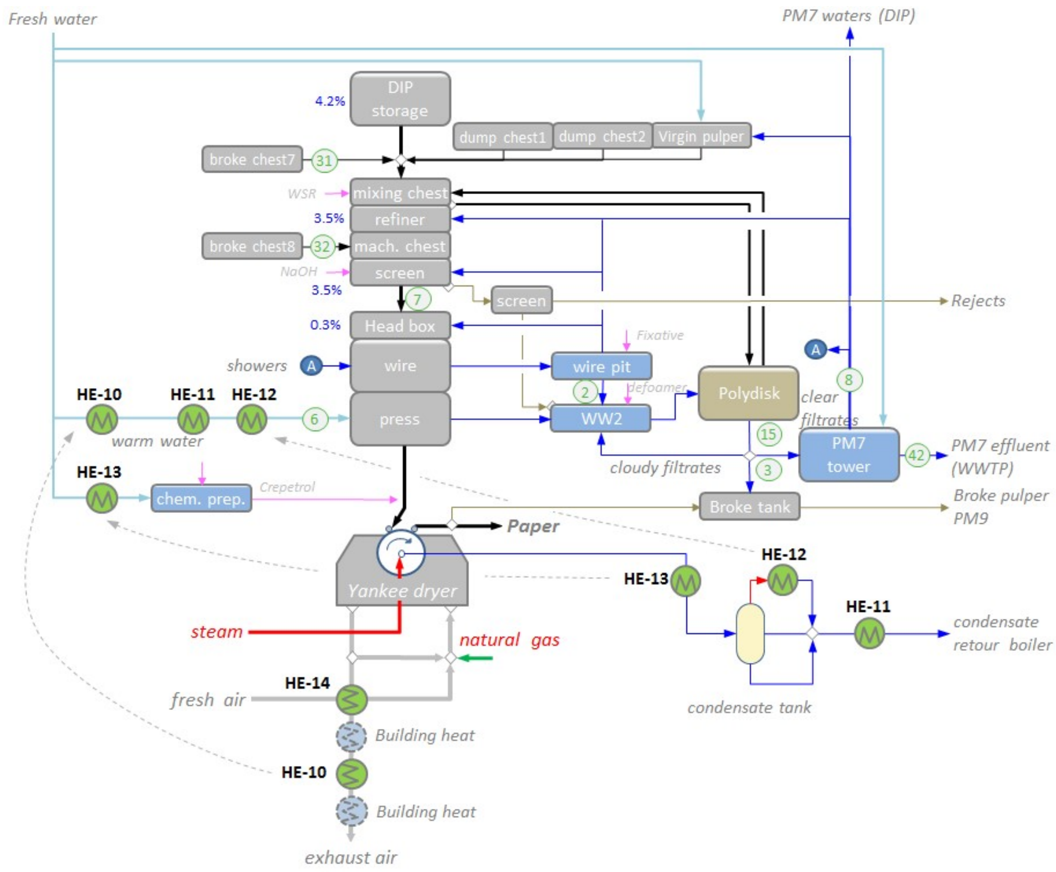


Figure 14. Simplified block diagram of PM7 in Reference case with locations of existing HE's.

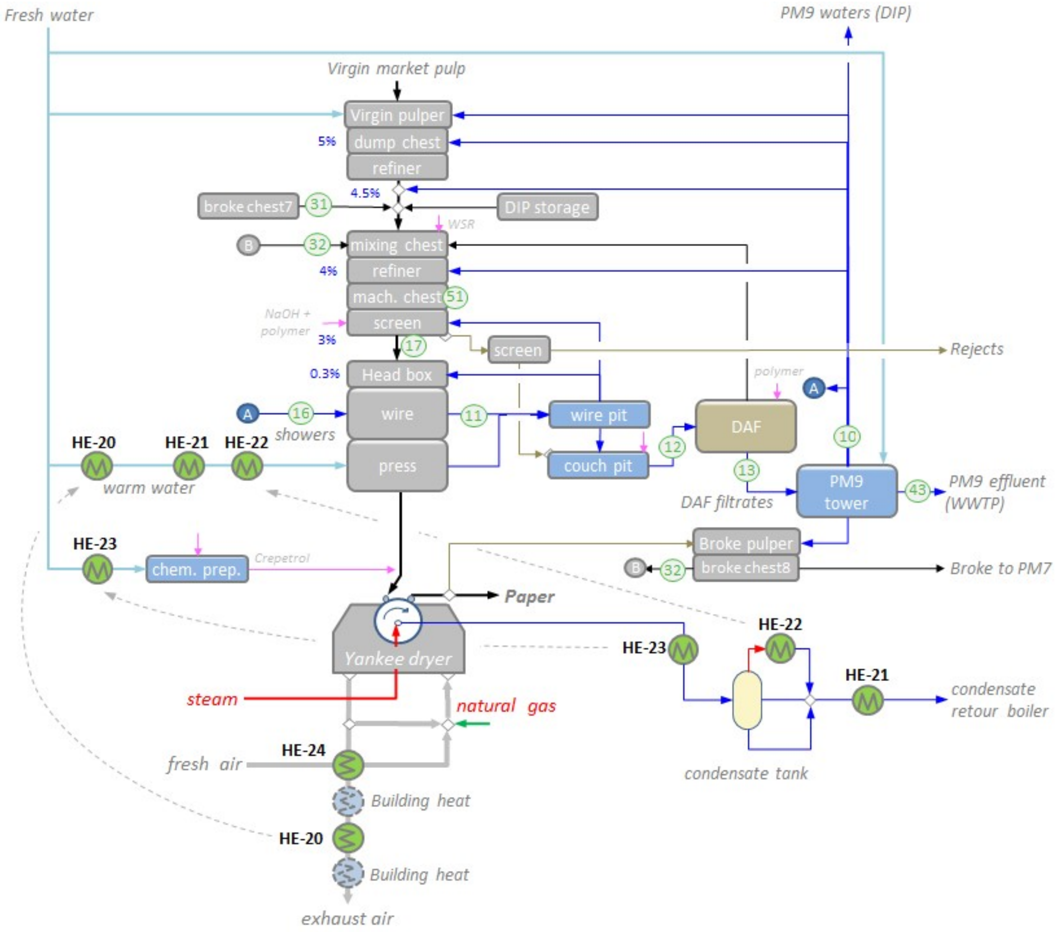


Figure 15. Simplified block diagram of PM9 in Reference case with locations of existing HE's.

6.3.3. - Targeting existing heat exchange system

The data extraction from 6.3.1 and 6.3.2 resulted in a stream table with the start and target temperatures and duties for all hot and cold streams in the DIP, PM7 and PM9 sections (for the WWTP no hot or cold streams were identified). Targeting performed with the stream table for the existing heat exchange system, resulted in the composite curves for the Reference case presented in Figure 16. The overlap area of the hot and cold composites, indicated in the figure with the green shaded area, represents the actual amount of heat integration.

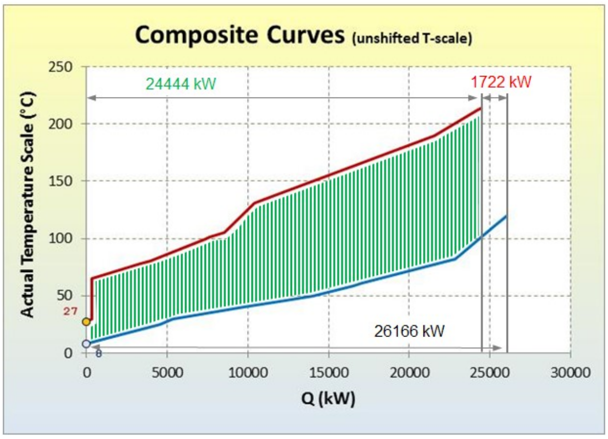


Figure 16. Composite curves for the Reference case of the Nokia mill.

From Figure 16 it can be seen that the paper tissue manufacturing process of Essity's Nokia mill is already heat integrated to a large extend. Nearly all of the heat demand from cold composite curve appears to be covered by the hot composite curve, resulting in an actual heat integration amount of 24.44 MW.

There only remains an amount of 1.72 MW which has to be covered by using external hot utility (i.e. 5 barg LP steam). Furthermore it can be seen that no cold utilities are needed to cool down excess hot streams.

6.3.4. - Identification of improvement options

When the existing heat integration (mainly located around the Yankee dryers in PM7 and PM9) is kept as it is, the associate streams can be taken out of the initial stream table. Renewed targeting with the reduced stream table results in a simplified CC (Figure 17).

This consists of the following two cold streams:

- freshwater to the DIP (must be heated from 11 → 25°C)
- fresh water for DIP polymer dilution (must be heated from 11 → 40°C)

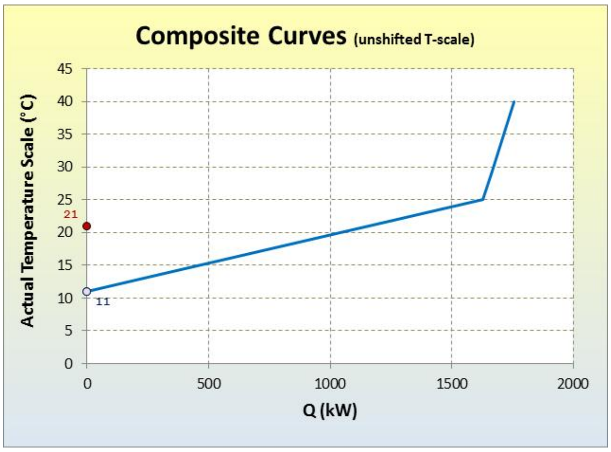


Figure 17. Composite curves without existing heat integration.

On basis of the pinch analysis and targeting results, the following options for Reference case were identified to

1. **Use clarified water from DAF-1 in DIP to preheat the fresh water to the DIP**
2. **Use exhaust air PM7 / PM9 to preheat the fresh water to the DIP**

In case additional heat is needed (e.g. for chemcials preparation, building heating):

3. ***Use clarified DAF-1 water as 'waste heat' source for a heat pump system that generates hot water at higher temperature level.***
4. ***Make further use of available heat in Yankee condensate***

Above mentioned options for Reference case are further elaborated in the next paragraphs.

6.3.4.1. - Improvement option-1 for Reference case

The clarified DAF-1 effluent, with an average temperature of about 39°C according to the measurement campaign data (see Table 3), migth be used as heat source for heating the fresh water to the DIP. If the total flow of clarified waters is used, the temperature drop is relative small, as can be seen in Figure 18: when heating the fresh water to the DIP from 11 to 25°C, the temperature of the clarified waters drops from 39 to 37.6°C.

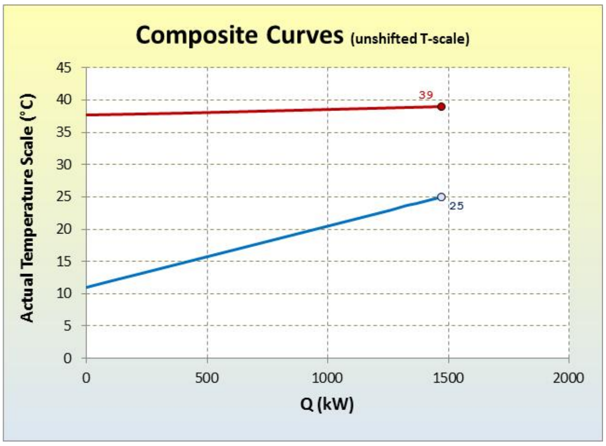


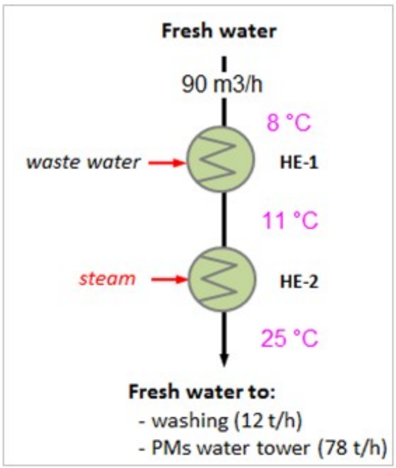
*Figure 18. Using clarified DAF-1 waters for preheat fresh water DIP (**option 1**).*

In Figure 19 the existing situation as well as the proposed modification in the DIP section is given. As can be seen, in this option 1472 kW of heat in the clarified water stream is used as heating source, resulting in an equivalent saving on LP steam (1472 kW). Besides the saving on steam, some additional electricity is needed to drive a water circulation pump.

The total annual savings potential for this option, including additional electricity for pumping, is calculated by PDC to be **285 k€/yr**.

Remark-1:

An alternative option is to use the DIP effluent as heat source instead of the clarified DAF-1 waters. The benefits of this option is that the temperature in the DIP section remains unchanged and that the piping of the streams are more close to each other in a certain part of the DIP unit (about 10 m distance according the plant visit begin February 2019). The disadvantage however is that the temperature of the DIP effluent is lower than that of the clarified DAF waters (which results in an increased cost for the heat exchanger area). During winter time the DIP effluent temperature might even drop to about 20°C (or lower) so that the freshwater heating to 20°C is not attainable any more (without using steam as an extra heating source).



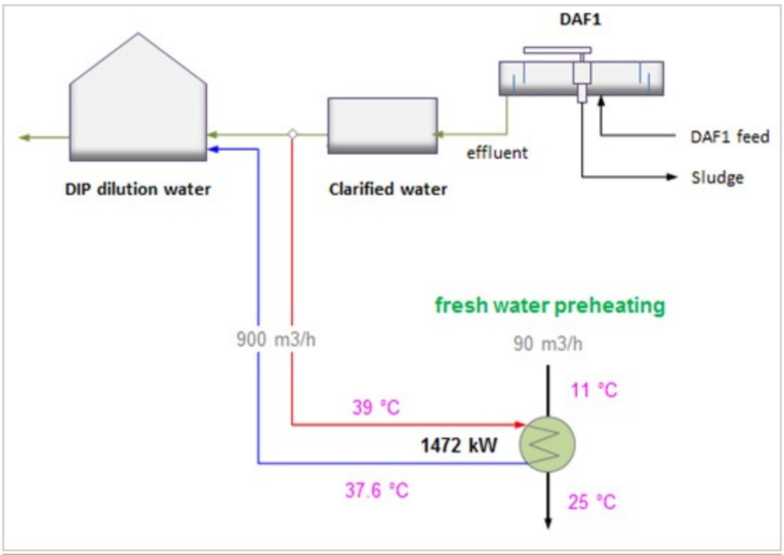


Figure 19. Existing situation DIP (left) and proposed modification (right) for **option-1.**

Remark-2:

During the plant-visit in February 2019 it appeared that the fresh water flow is not constant through out the year and that there might be periods that this flow reduces. If this is indeed the case, the savings will become proportionally lower. When there is actual interest to implement this energy improvement option, it is recommended to investigate the flow fluctuations in more detail.

6.3.4.2. - Improvement option-2 for Reference case

In this option exhaust air from PM7/PM9 is used as heating source to preheat the fresh water to the DIP. This option can be regarded as an alternative option for option-1. Assuming an exhaust temperature of 65°C, the exhaust air can in principle be used for heating both cold fresh water streams in the DIP section (see Figure 20).

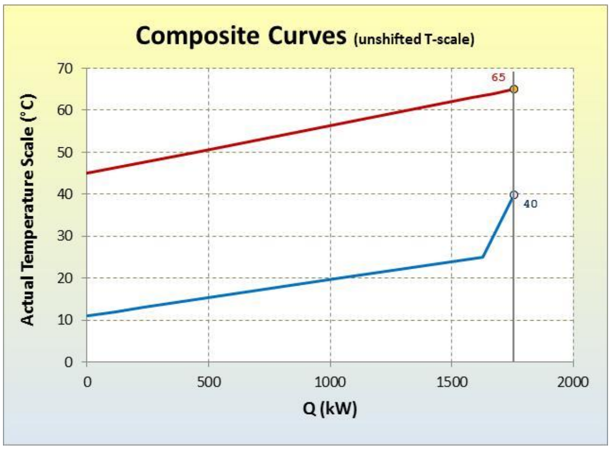


*Figure 20. Using PM exhaust air for preheat fresh water DIP (**option 2**).*

In Figure 21 the existing situation as well as the proposed modification is given. The maximum achievable saving for this option is 1472 kW (equivalent to option-1). As was found out during the plant visit in February 2019, there are already two additional heat exchangers placed in the exhaust stream besides the two process heat exchangers HE-14 and HE-10.

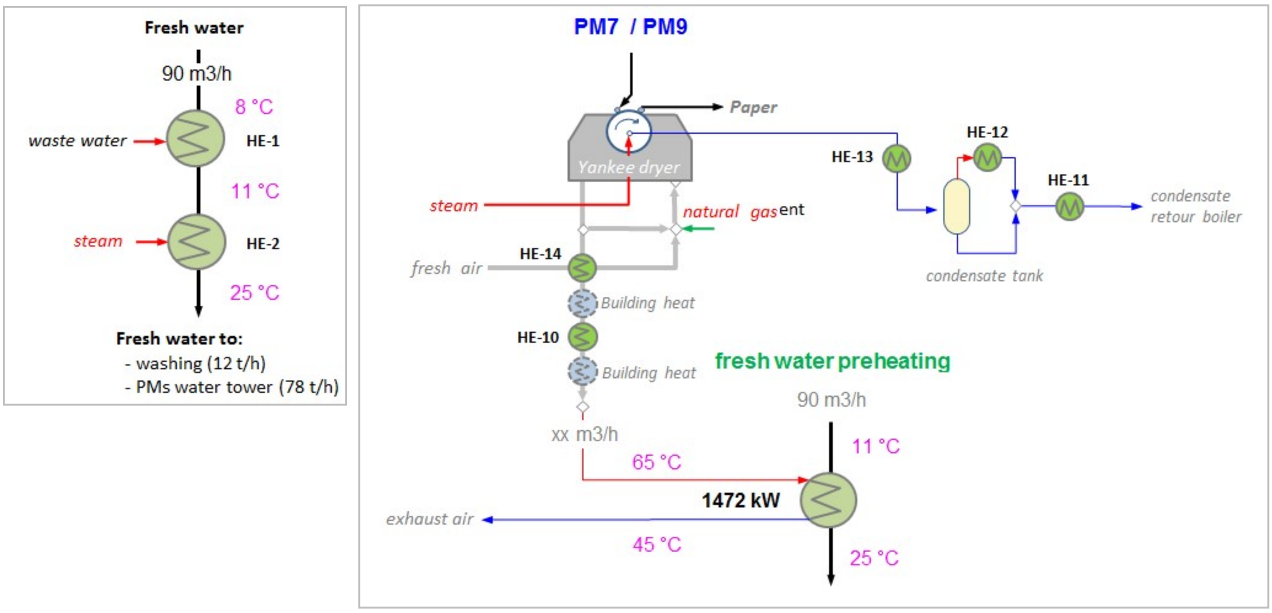


Figure 21. Existing situation DIP (left) and proposed modification (right) for ***option-2.***

These heat exchangers are mainly operational in colder periods (winter time). When they are in operation the temperature of the exhaust air may drop to 40 - 50°C, which will reduce the available ΔT for heat transfer further. This and the fact that we deal with relative large air streams (and thus big heat exchangers) makes this option far less attractive then option-1.

The maximum annual savings potential for this option, will be lower than calculated for option-1 (285 k€/yr), especially when higher building heat capacity is desired in case of colder winters.

6.3.4.3. - Improvement option-3 for Reference case

If additional heat is needed for process heating (e.g. for chemicals preparation, air pre-heat) or building heating, it might be interesting to implement a hot water system which is heated by 'waste heat' from the DIP section via a conventional or chemical heat pump system.

In Figure 22 is, as an example, a concept given which is based on a conventional heat pump system (e.g. with ammonia as working medium). Waste heat from the DIP plant at a temperature level of about 39°C is upgraded by the heat pump to a temperature level of about 73°C (after the compressor). This temperature is sufficient to heat a hot water circuit to about 70°C. The design capacity of the given example is 3000 kW, which means that 3 MW of heating is made available at a higher temperature level for process heat and/or building heat.

If this hot water system can be used to replace LP steam consumption, the savings will be substantial. However, the compressor of the heat pump system also uses a substantial amount of electricity to drive the heat pump cycle. The total annual savings potential for this option, including additional electricity for the compressor, is calculated to be about **400 k€/yr** (based on an assumed 3 MW heating demand).

Remark:

The building heating system falls out-side the scope of the SpotView project. Because nearly all of the remaining process heat demand can already be fulfilled with option-1, the full potential of this option is not further explored (e.g. investigation of building heat system and capacities).

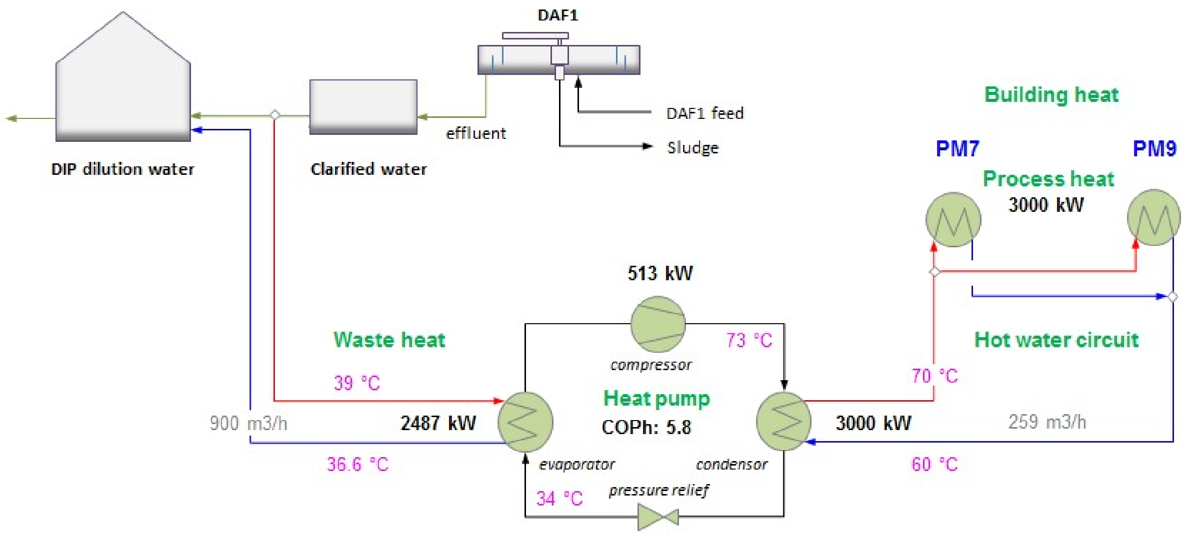


Figure 22. Hot water generation with a heat pump by using 'waste heat' from the DIP.

6.3.4.4. - Improvement option-4 for Reference case

The condensate from the Yankee dryers in PM7 and PM9 is not directly returned to the boiler, but first used to generate warm water of about 50°C for the press section of the paper machines (see Figure 14 and Figure 15). The return temperature to the boiler should preferably be about 90°C (to prevent excessive venting at the deaerator). During the plant-visit in February 2019 it appeared however that the actual condensate return temperature is a bit higher (about 100°C). The exact reason for this is not fully clear to Essity.

If the condensate retour temperature is indeed (on average) about 100°C during the whole year, it might be an option to install an additional heat exchanger in the condensate system to preheat the polymer dilution water in the DIP section. This stream is now preheated with LP steam to a temperature level of 40°C. The savings potential for this option is **250 kW**.

A disadvantage of this option is that (because of historical reasons) the DIP section and the PMs are located far apart from each other, which complicates the feasibility of this option.

6.3.5. - Energy effect for Case 1 and Case 2

From the previous chapter it can be concluded that for the Reference case improvement option-1 looks most promising (savings potential = 285 **k€/yr**).

The attainable saving is associated with the heating of the fresh water (90 m^3/h) to the DIP. For Case 1 and Case 2 the water balances however have changed and therefore the savings potential for these cases will change accordingly. In Table 4 the energy data for the three cases are given, with in the 3rd column from the right giving an estimation of the savings potential when improvement option 1 is implemented. From this column it is clear that by the reduction of the fresh water consumption of the DIP for Case 1 and Case 2 the energy savings potential for the proposed heat integration reduces drastically, from 285 k€/yr (Reference) to 41 k€/yr for Case 1 and Case 2.

Due to increased PM water recycling to the DIP in Cases 1 and 2, the water balances have changed resulting in a saving of 86% of freshwater to the DIP section compared to the Reference case (Table 2). This results also in a saving on steam consumption, because less fresh water has to be heated in the DIP section. The corresponding annual savings, which are thus not directly due to heat integration but are a resultant of the various waterlines rearrangements, are represented in Table 4 in the 2nd column from the right. The savings on steam due to these waterlines changes are 262 k€/yr for both cases.

Table 4. Energy data for the three cases.

Case	Description	Flow	T-in	T-out	Duty	option-1 Saving	waterline changes Saving	total Saving
		t/h	°C	°C	kW	k€/yr	k€/yr	k€/yr
Reference	fresh water DIP	90.1	11	25	1,472	285	0	285
case-1	fresh water DIP	12.9	11	25	211	41	262	302
case-2	fresh water DIP	13.0	11	25	212	41	262	303

In the most right column of Table 4, the total of both types of savings are given. From this it can be concluded that the overall energy savings for all three cases are more or less the same (saving about 300 k€/yr). The saving for the Reference case is a little less, because here somewhat more electricity is involved (pumping energy) in the heat integration option.

The effect on improvement option-2 will not be discussed here, because this option is regarded as less interesting.

Improvement option-3 concerns a hot water system driven by a heat pump on waste heat from the DIP section. The hot water system might be used as a heating utility for cases were now LP steam is used (e.g. building heat, heating for chemical preparation or eventually air preheating). For the Reference case, assuming that option-1 is implemented (involving about 1.5 MW of heat from the DIP section), it is estimated that there is still room to extract about 3-4 MW of heat from the clarified DAF-1 waters for hot water generation purposes.

For Case 1 and Case 2, the energy involvement for improvement option-1 is less (only 211 kW), liberating additional capacity for hot water generation (about 5 MW total).

7. - Conclusions

Essity Nokia mill has established a water reduction program, which will reduce the water consumption at first from 45 m^3/t produced paper (2016 average) down to 25 m^3/t produced paper, and finally to 20 m^3/t. Water reduction will be executed gradually. First actions to reduce fresh water consumption was conducted in early 2018 and latest in August 2018.

VTT's target was to study the effect of these water reuse strategies on fresh water consumption and mill water balance using process simulation. Three cases were evaluated:

1. Reference case: mill until the end of 2017 before any actions to reduce fresh water consumption were carried out
2. Case 1: mill since early 2018 when first steps in the water reduction action plan were carried out. These were i) PM7 dust washers, converting dust washers and converting Nash water to white water instead of fresh water, ii) Collect and utilize fresh and white water in DIP cooling, PM7 dust washers, PM condensate cooling, converting dust washers and Nash pumps and iii) DIP white water system improvements.
3. Case 2: mill since August 2018. Same water reduction steps as in Case 1 were carried out and Valmet CR-filter was implemented to PM7 to treat part of PM7 white water to be used as shower water in the wire section.

Main conclusions of the VTT's simulation work were:

- A total fresh water reduction of 22% was achieved by carrying out the first steps for water reduction (Case 1). The total water consumption (fresh water + PMs water) in deinking decreased by 20%. In the same time, more carrier water from PM7 (+12%) and PM9 (+14%) was available for deinking's use. This resulted that the total fresh water consumption in deinking decreased by 86%. The fresh water consumption in PM9 reduced 6%. In PM7, no reduction was achieved.
- A total fresh water reduction of 25% was achieved by carrying out the first steps for water reduction and by implementing Valmet CR-filter to PM7 (Case 2). Compared to the case without the CR-filter (Case 1), an extra saving of 3.1% in total fresh water consumption was achieved. With CR-filter, the total fresh water consumption in DIP, the amounts of PM7 and PM9 carrier water available for deinking's use and the fresh water consumption in PM9 were the same as without CR-filter. However, due to the implementation of CR-filter, the total fresh water consumption in PM7 was decreased by 11%. Using permeate instead of fresh water in showers creates additional savings in the energy used for heating the fresh water.
- It must be noted that the presented reductions of fresh water are based on theoretical calculations and are valid only when the mill is running non-stop. All planned and/or unplanned shutdowns cause unwanted extra consumption of fresh water used in washing.
- For realizing the principle of counter-current washing, the best solution is to take the fresh water in in paper machines rather than in deinking. This guarantees that the paper machines stay cleaner. Thus, to minimise the fresh water intake in deinking, major part of PMs water should be directed to deinking rather than discharged to WWTP. This results that deinking will be the major source of mill effluents.
- The created simulation model predicts well the TSS and soluble COD levels of Nokia mill.
- The model can be later used for new water reduction studies at Essity Nokia mill. The generic BAT-based tissue mill model created in the beginning of SpotView project can be modified to present any other tissue mill.

Main conlusions of PDC's heat integration work were:

- The heat integration study performed on the Nokia mill showed that the mill is already integrated to a large extend.
- For PM7 and PM9 no improvement options were found, because all available hot and cold streams are already integrated to the maximum extend.
- Some energy improvement however is achievable in the DIP section. The most promising improvement option identified for the Reference case is to use the clarified water from DAF-1 as heat source for heating the fresh water to the DIP. This option has a savings potential of 285 k€/yr.
- When the same improvement option is applied for Case 1 and 2, the heat integration savings potential reduces to 41 k€/yr for both cases.
- However, due to increased PM water recycling to the DIP for Case 1 and 2, the freshwater consumption of the DIP is reduced by 86% (compared to the Reference case), resulting in 262 k€/yr additional savings on steam consumption for fresh water heating for each of the two cases. When both savings (from heat integration and decreased freshwater consumption DIP) are taken into consideration, it can be concluded that the overall energy savings for all three cases are more or less the same (about 300 k€/yr).
- Improvement option-2, in which exhaust air is used as heat source for preheating the DIP fresh water, is regarded as a difficult and hardly feasible option, because interference with the building heat exchangers will occur and the temperature of the exhaust air might become too low (< 45°C, especially in winter time) to be effective as heating source.
- Further energy improvement is possible by utilizing available 'waste heat' from the DIP section by using a heat pump system for hot water generation at a higher temperature level. The hot water system might be used as a heating utility for cases were now LP steam is used (e.g. building heat). The building heating system is however out-side the scope of the SpotView project, so it isn't elaborated in further detail. Assuming that option-1 will be implemented, there is for the Reference case capacity available for a hot water system of about 3-4 MW. For Case 1 and Case 2 this capacity can be increased to about 5 MW, because the heat requirement for option-1 is less.

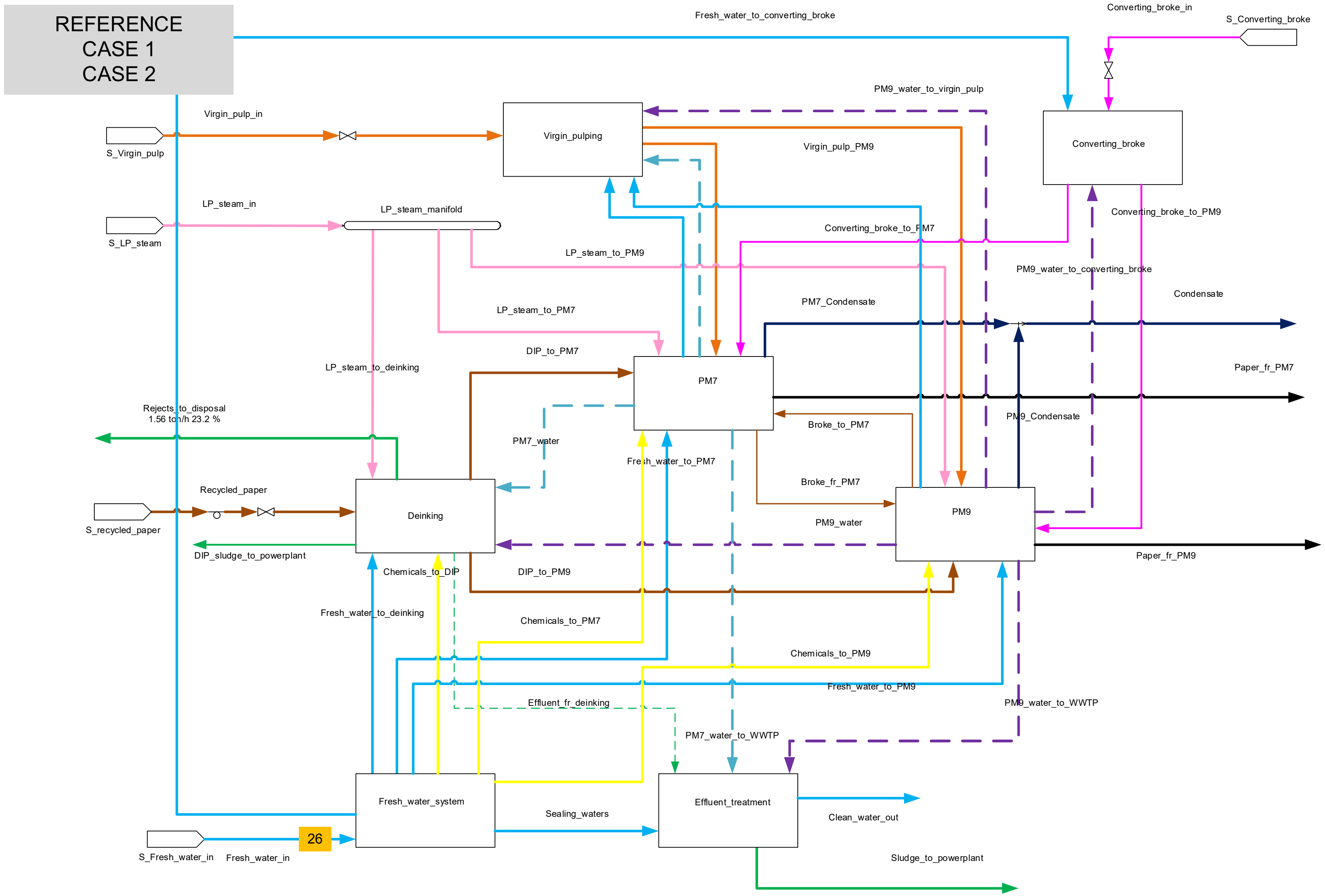


Figure 23. Essity Nokia tissue mill - Main flowsheet for Reference case, Case 1 and Case 2.

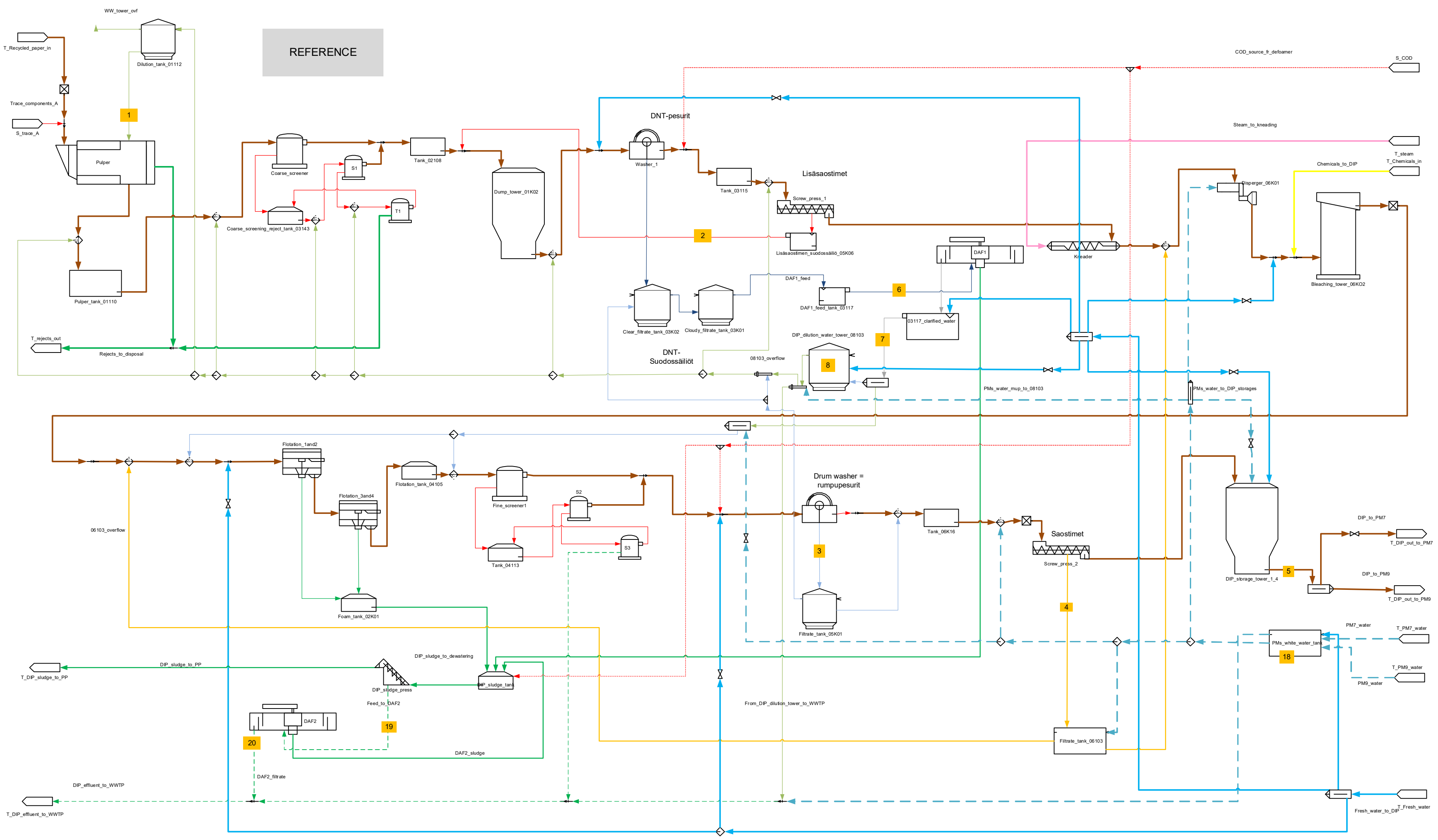


Figure 24. Essity Nokia tissue mill – Deinking plant for Reference case.

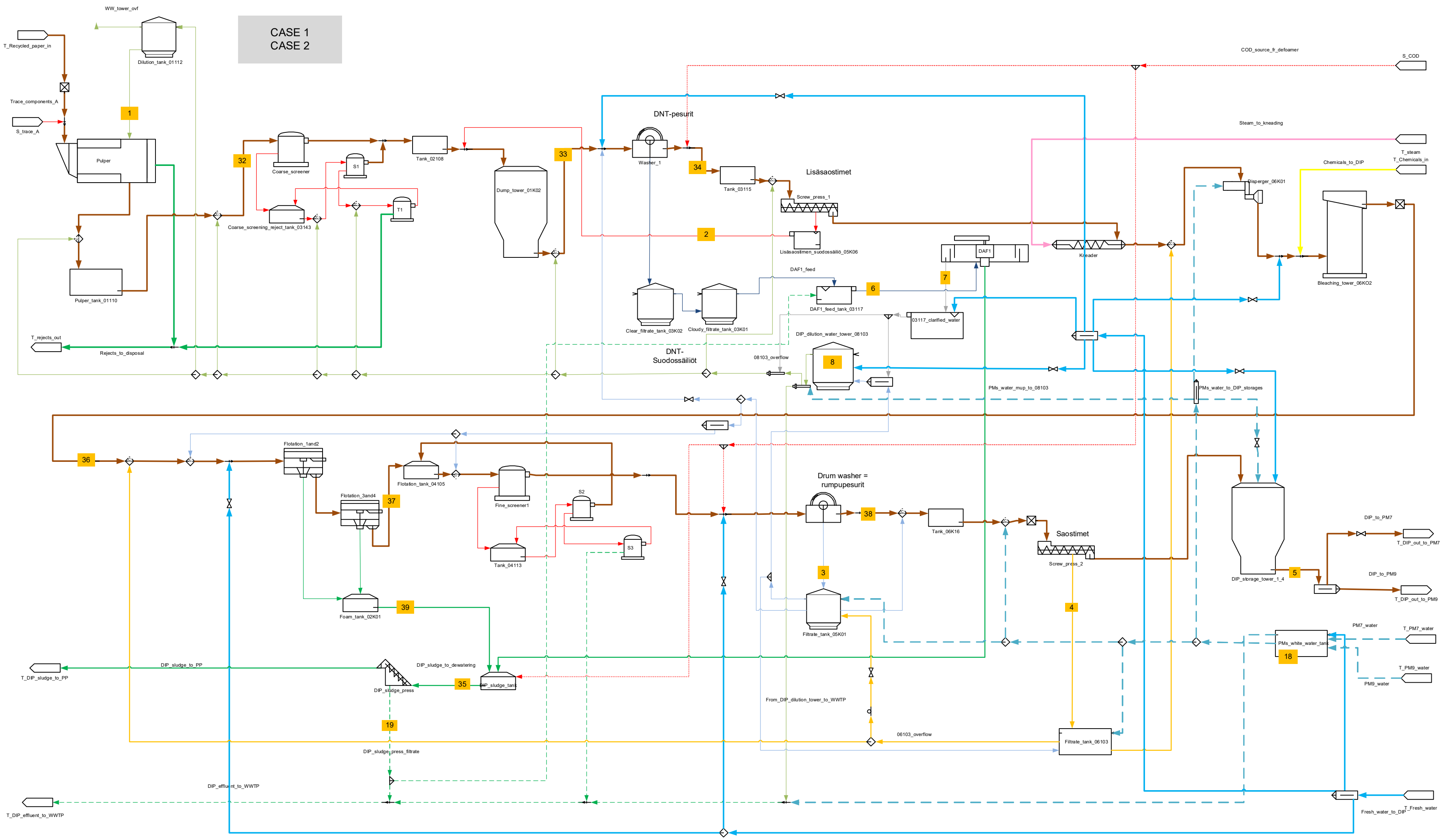


Figure 25. Essity Nokia tissue mill – Deinking plant for Case 1 and Case 2.

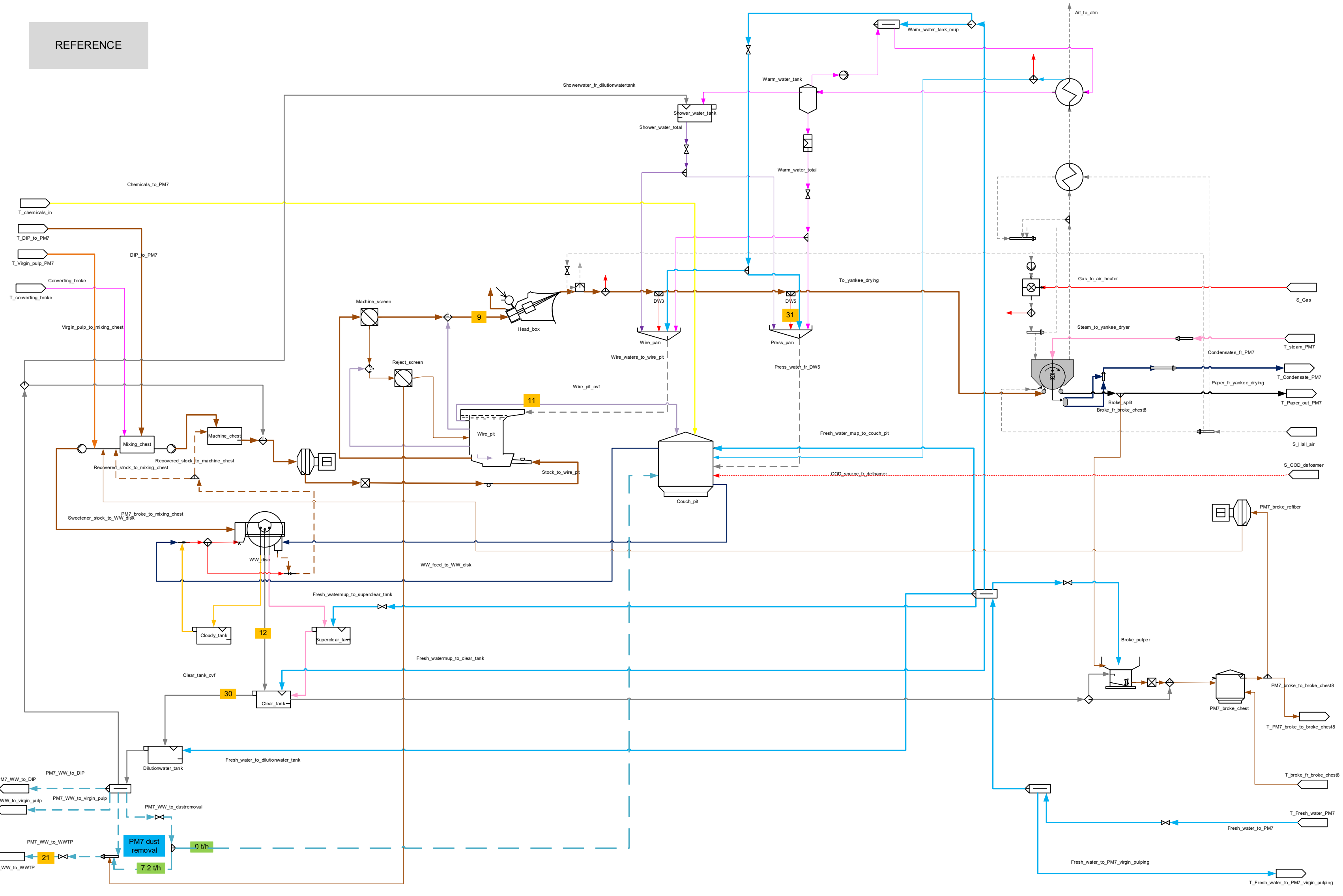


Figure 26. Essity Nokia tissue mill – Paper machine 7 for Reference case.

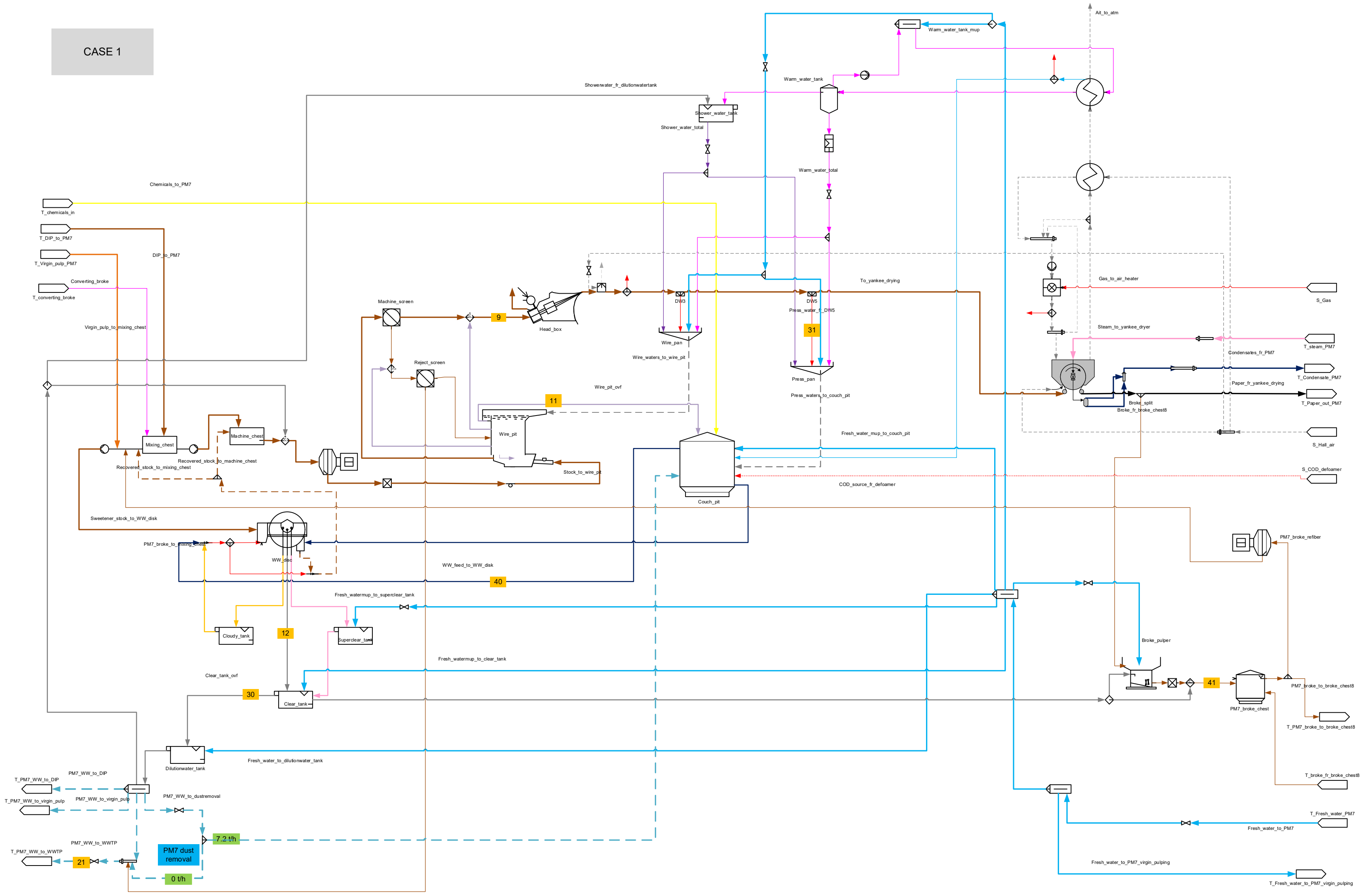


Figure 27. Essity Nokia tissue mill – Paper machine 7 for Case 1.

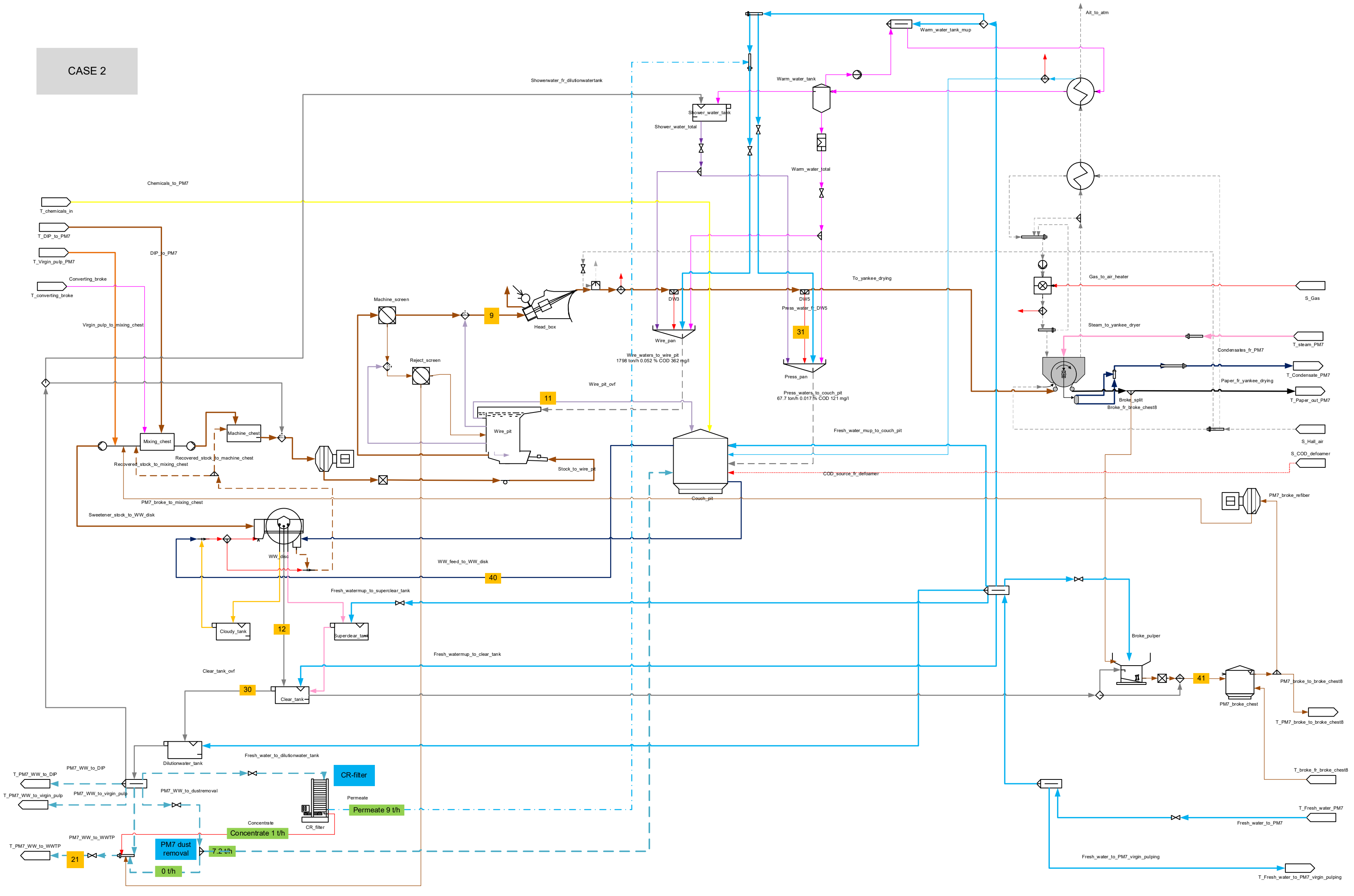


Figure 28. Essity Nokia tissue mill – Paper machine 7 for Case 2.

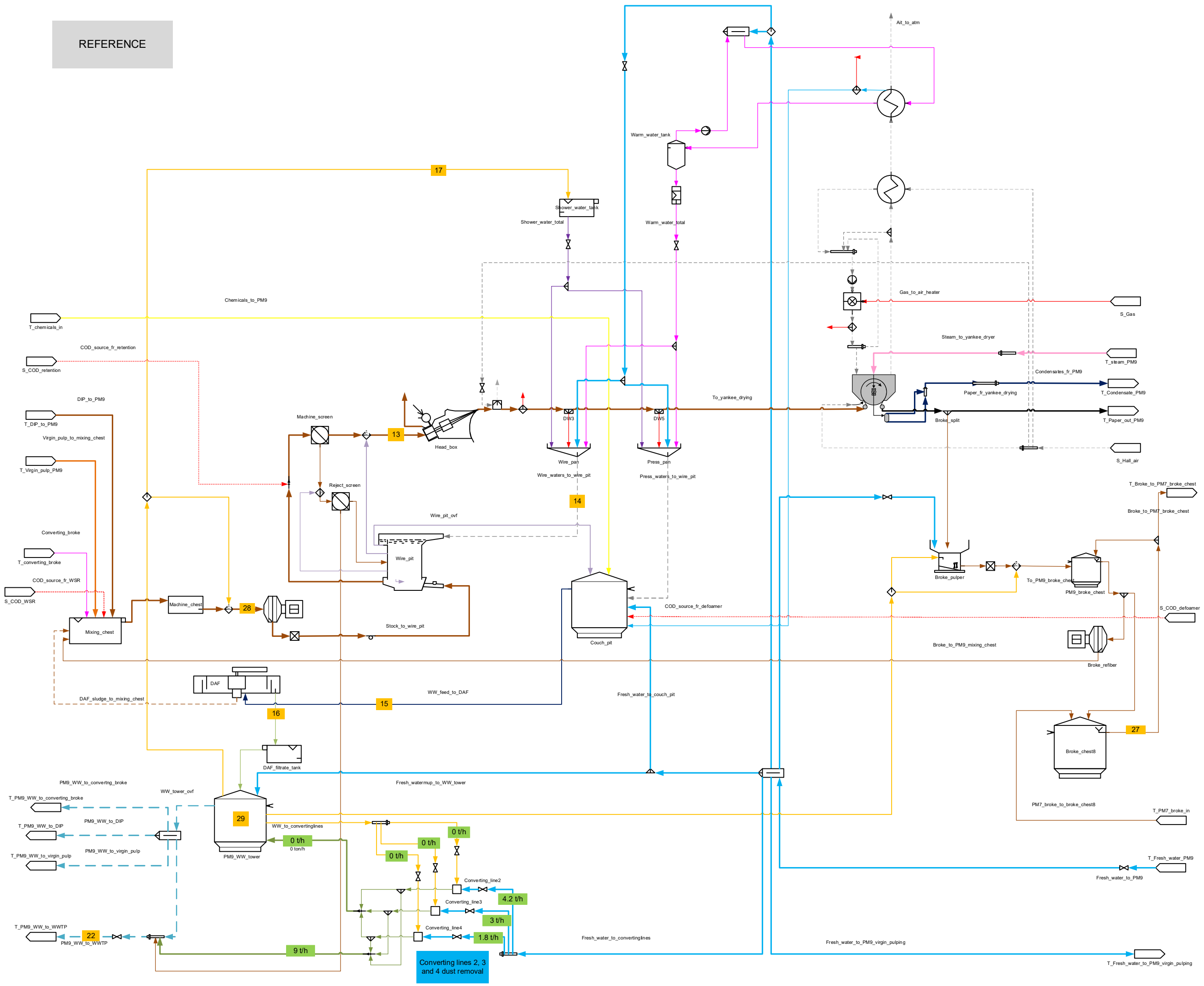


Figure 29. Essity Nokia tissue mill – Paper machine 9 for Reference case.

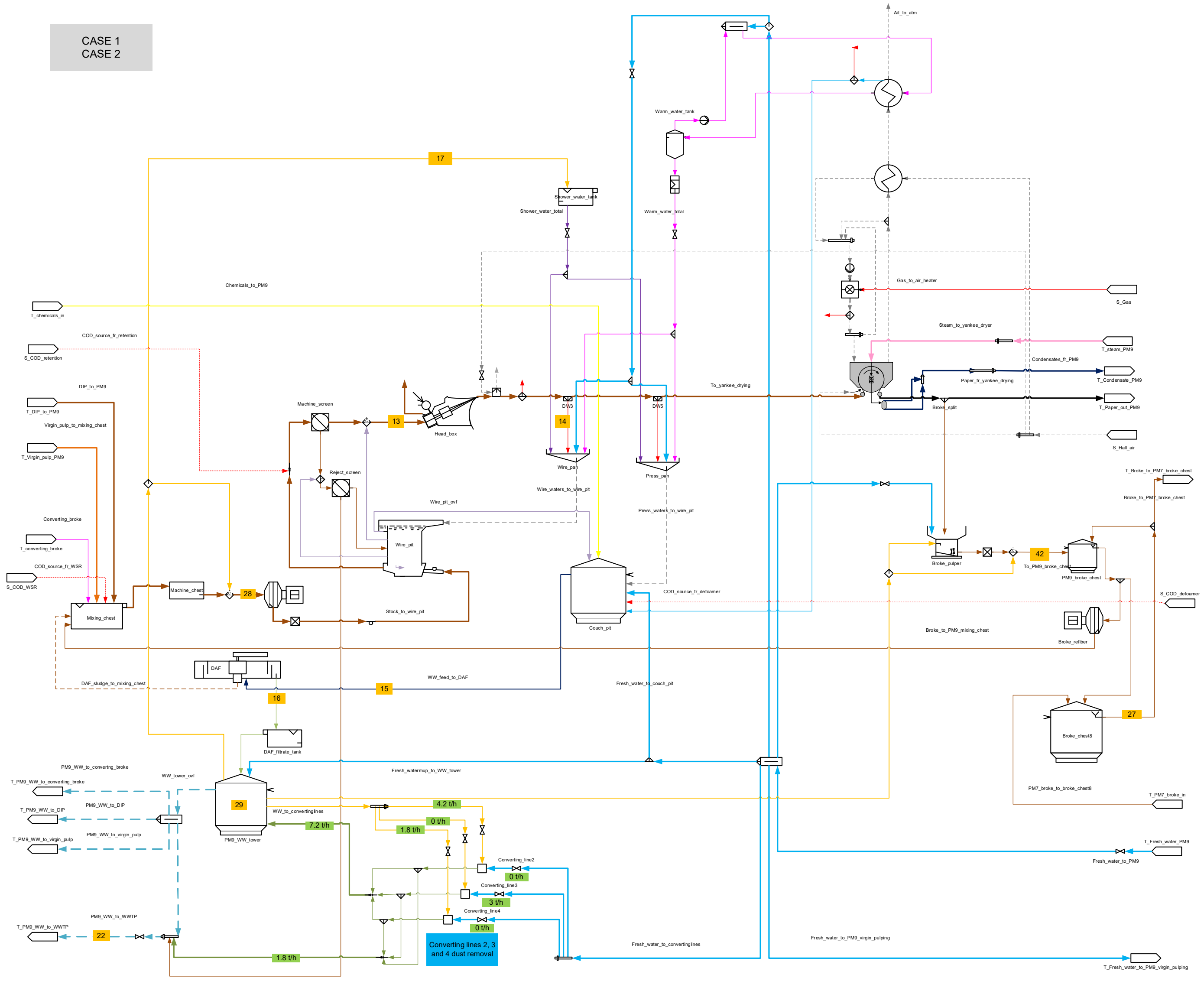


Figure 30. Essity Nokia tissue mill – Paper machine 9 for Case 1 and Case 2.

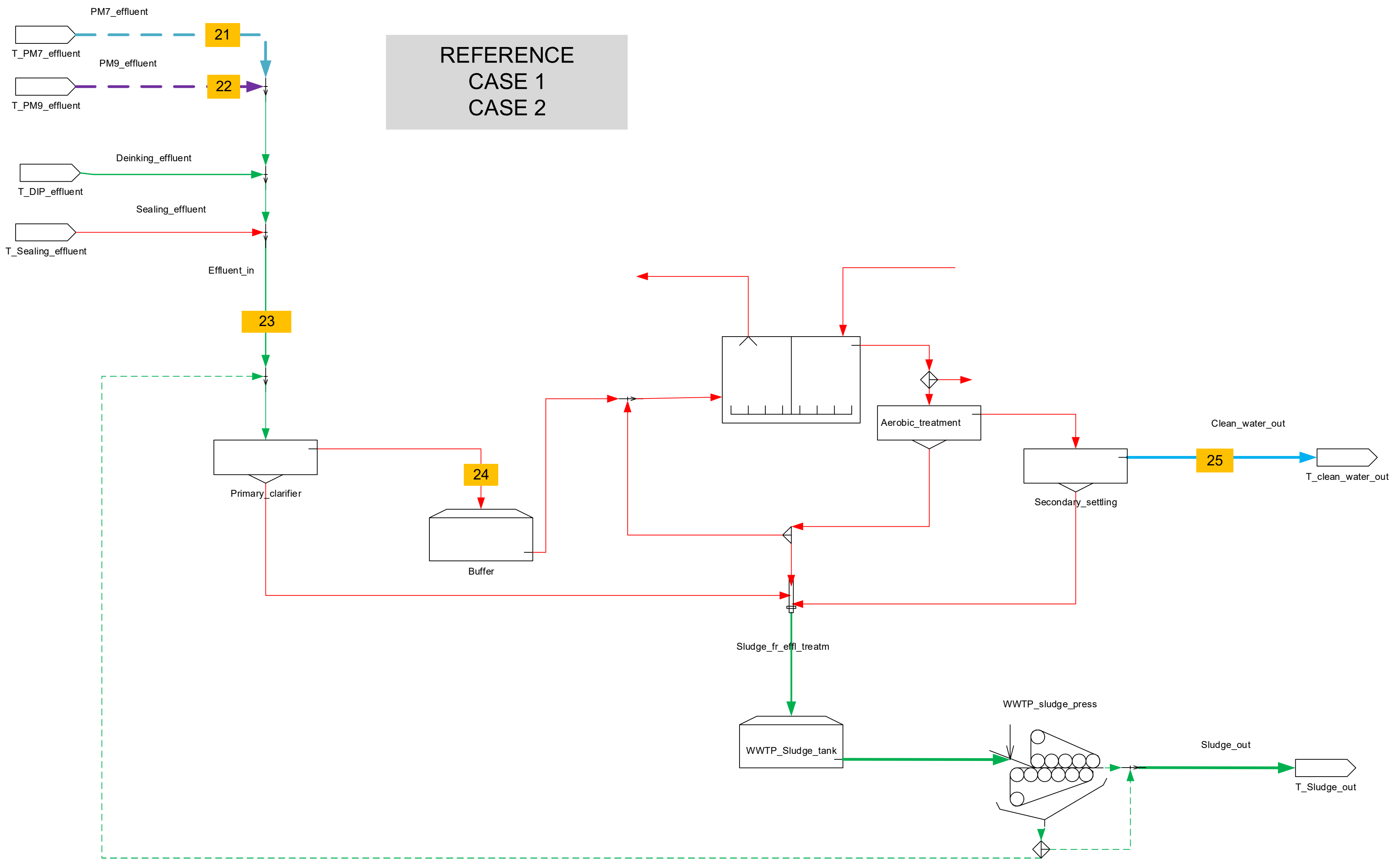


Figure 31. Essity Nokia tissue mill – Waste water treatment plant for Reference case, Case 1 and Case 2.

REFERENCE
CASE 1
CASE 2

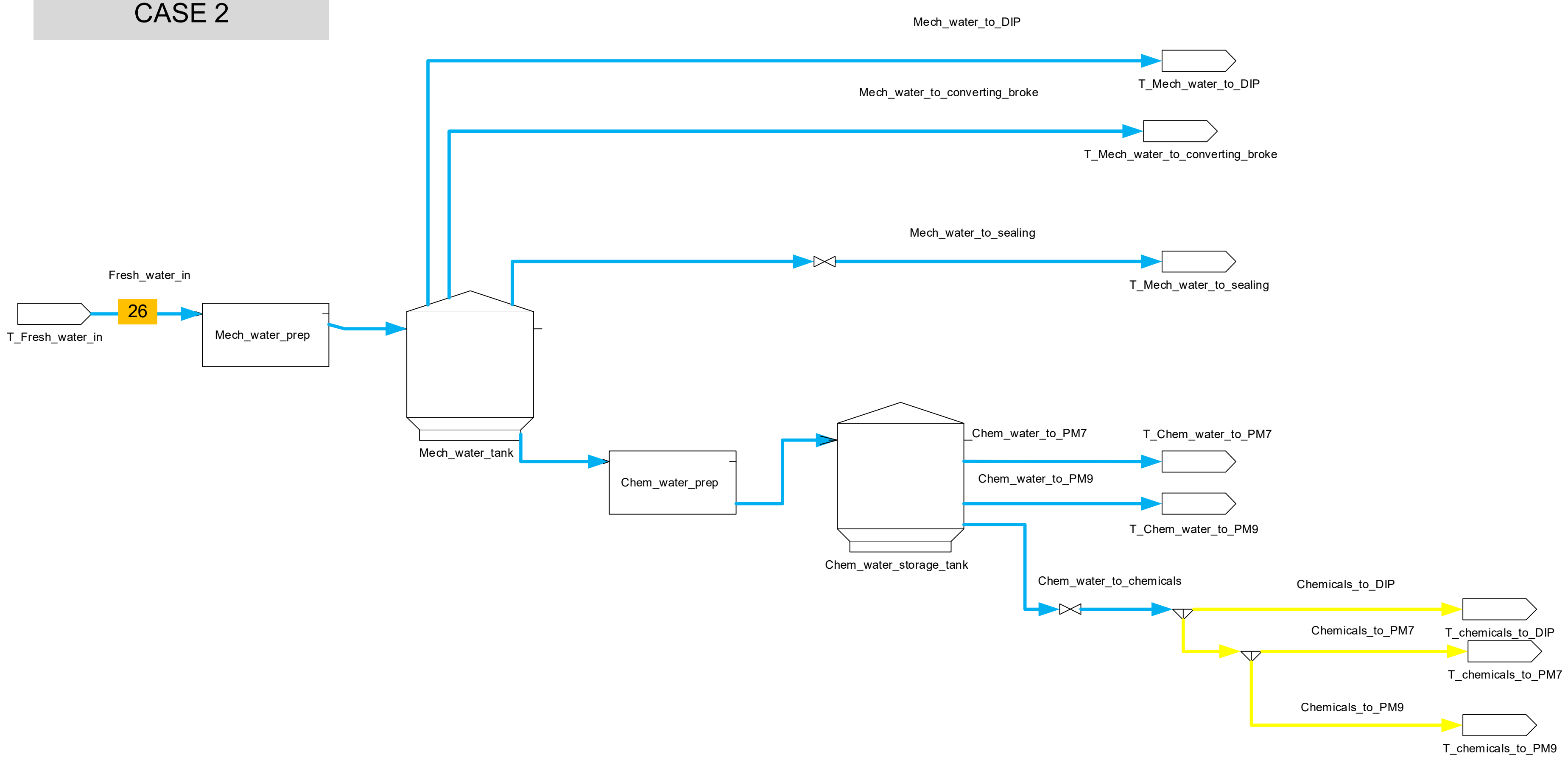


Figure 32. Essity Nokia tissue mill – Fresh water production for Reference case, Case 1 and Case 2.

REFERENCE
CASE 1
CASE 2

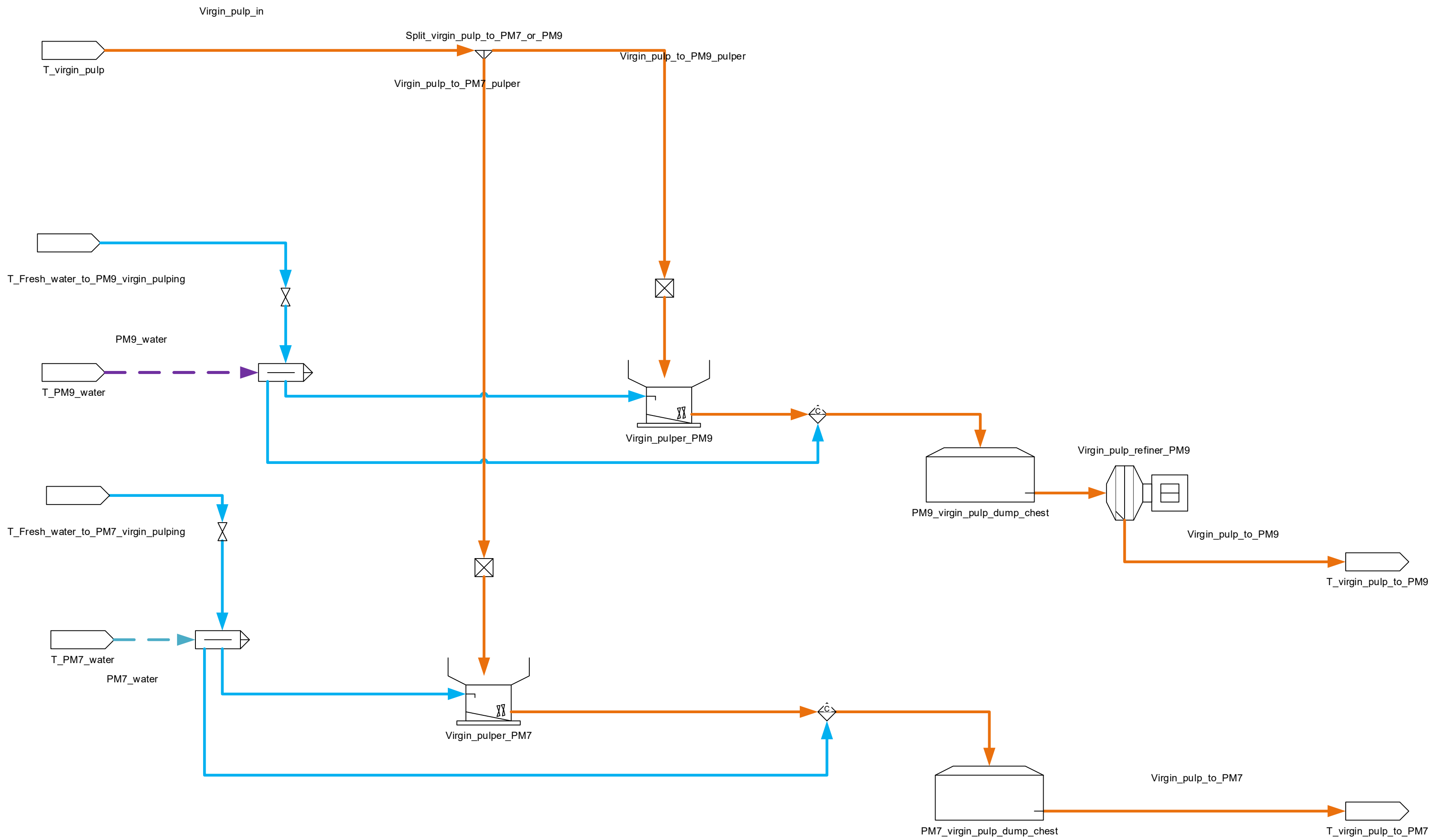


Figure 33. Essity Nokia tissue mill – Market pulp pulping for Reference case, Case 1 and Case 2.

REFERENCE
CASE 1
CASE 2

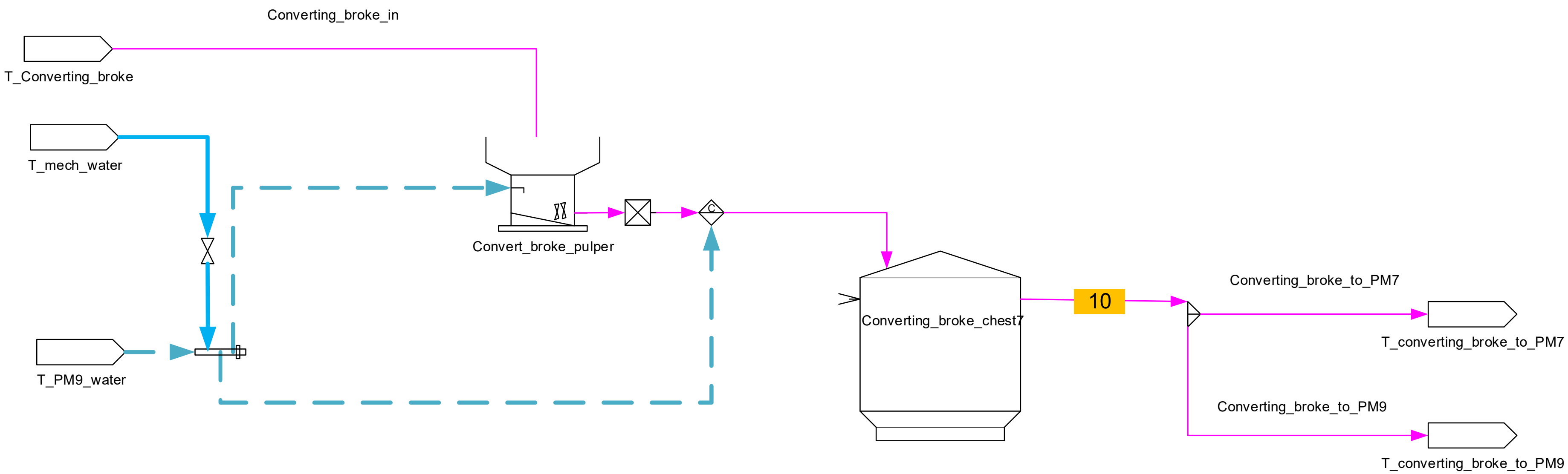


Figure 34. Essity Nokia tissue mill – Converting broke pulping for Reference case, Case 1 and Case 2.

APPENDIX 2

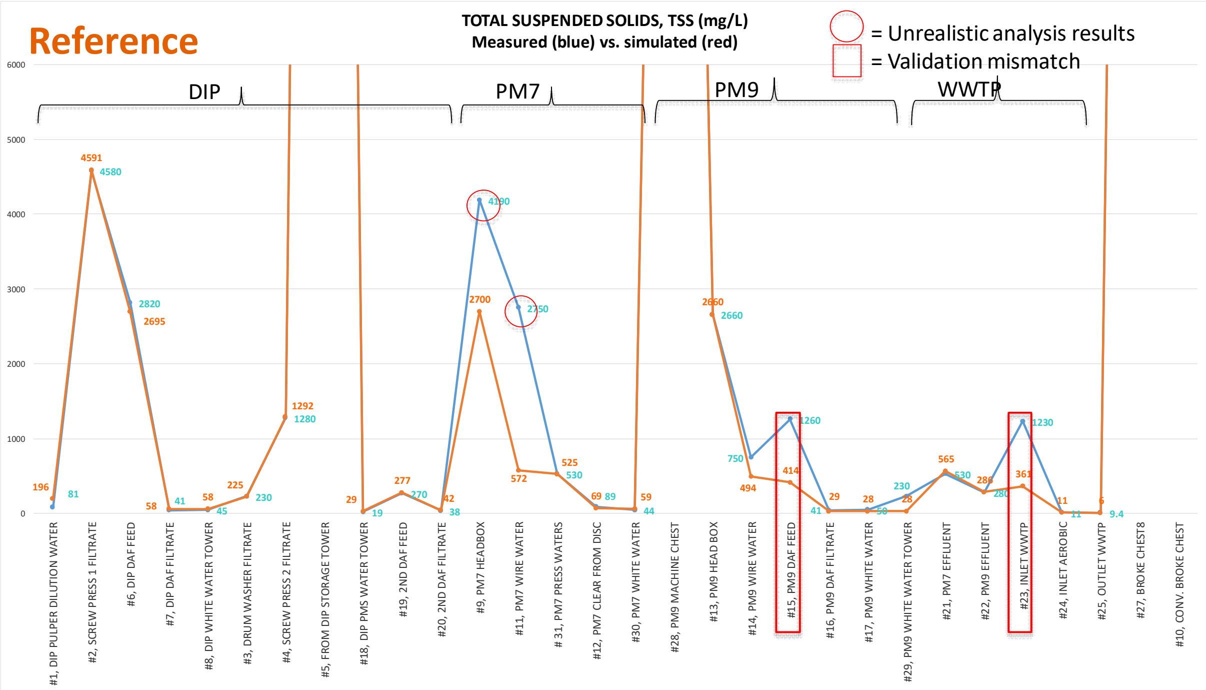


Figure 35. Reference case: Comparison of measured (blue line) and simulated (red line) total suspended solids values in thirty points across the Essity Nokia mill.

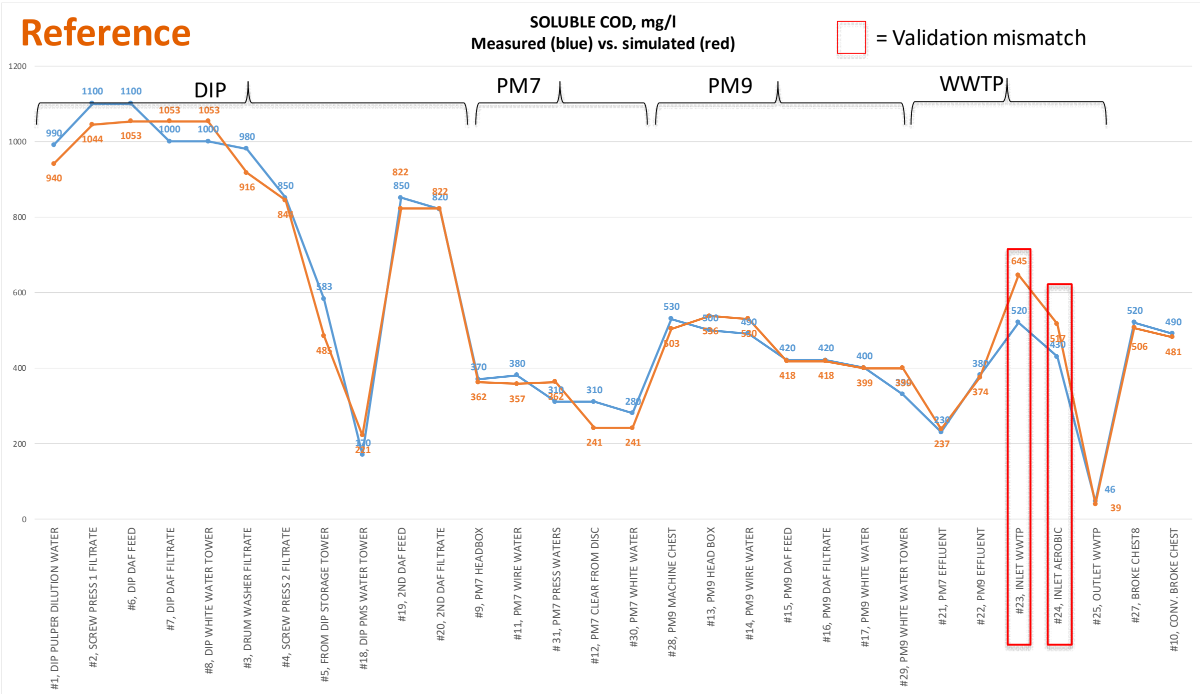


Figure 36. Reference case: Comparison of measured (blue line) and simulated (red line) soluble COD values in thirty points across the Essity Nokia mill.

APPENDIX 2

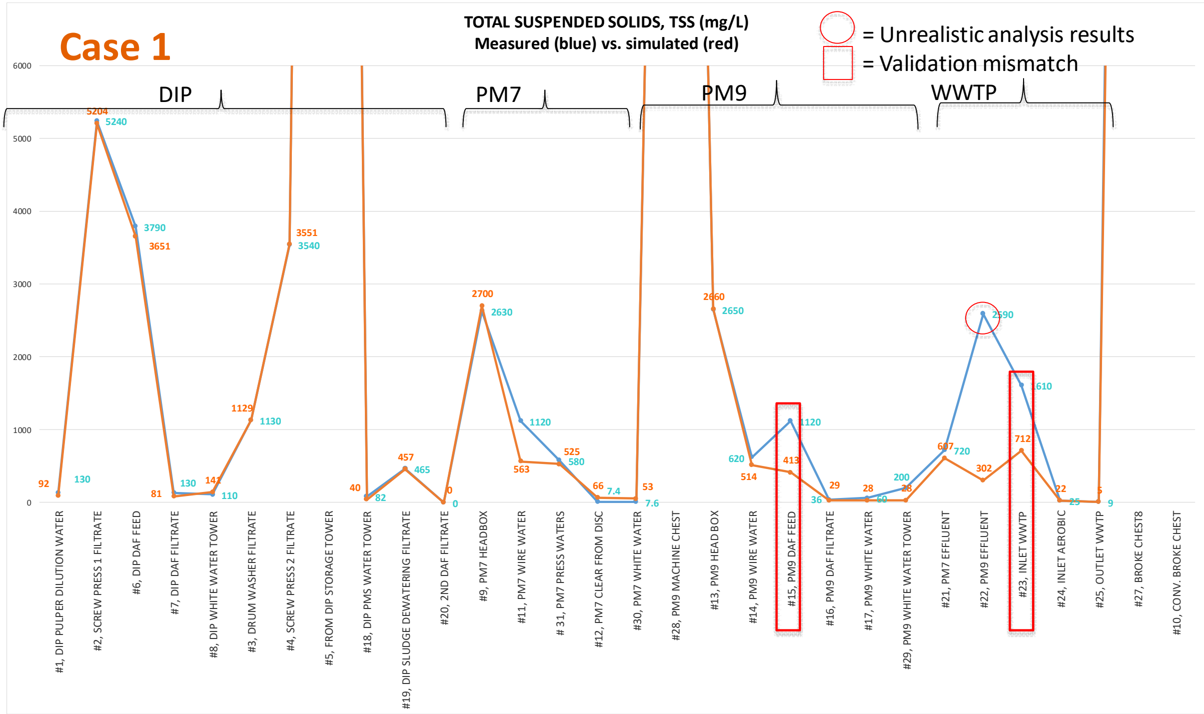


Figure 37. Case 1: Comparison of measured (blue line) and simulated (red line) total suspended solids values in thirty points across the Essity Nokia mill.

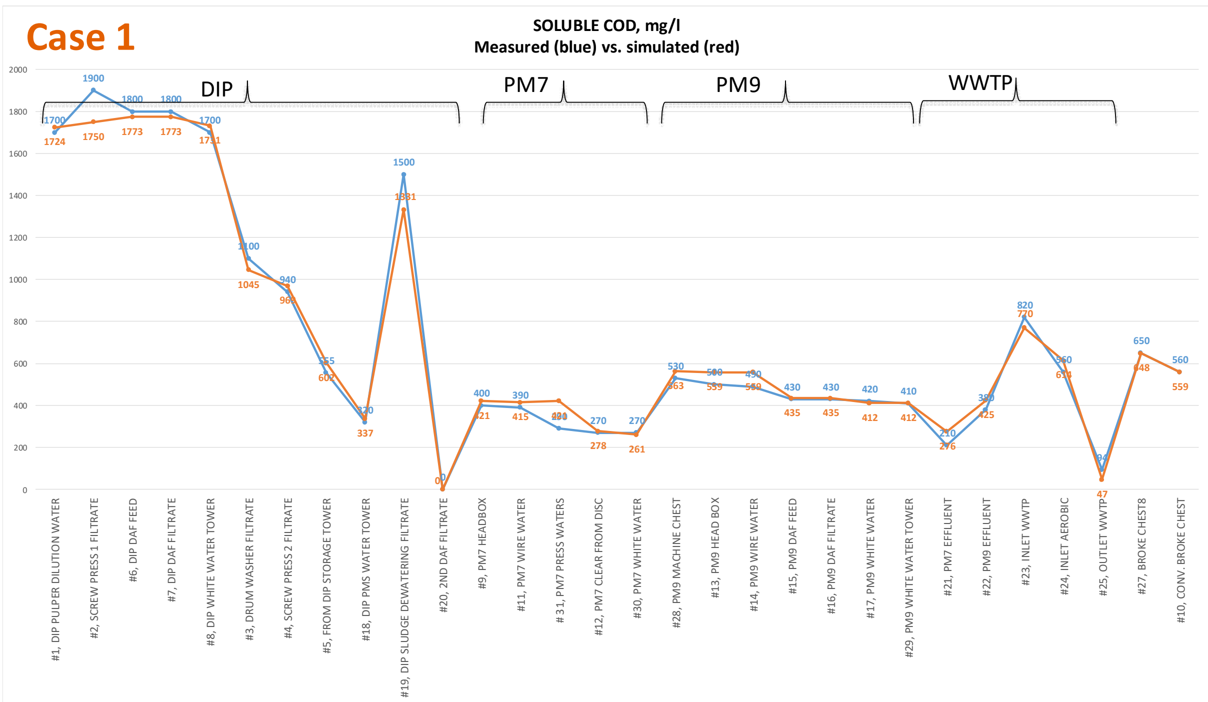


Figure 38. Case 1: Comparison of measured (blue line) and simulated (red line) soluble COD values in thirty points across the Essity Nokia mill.

APPENDIX 2

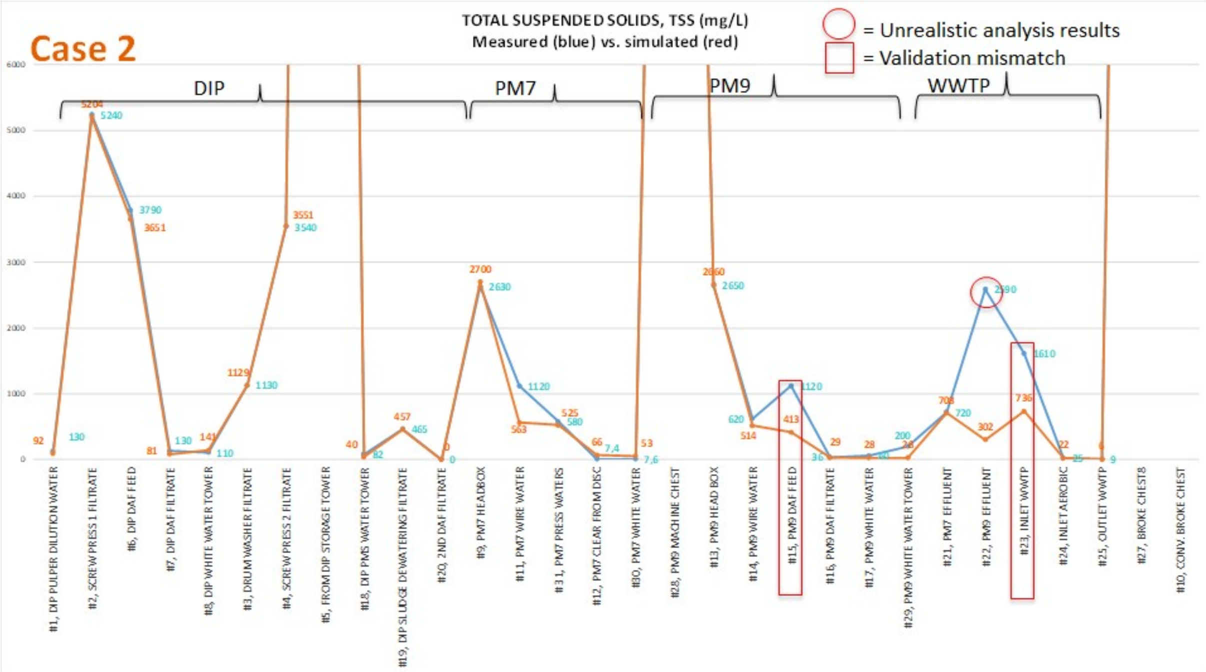


Figure 39. Case 2: Comparison of measured (blue line) and simulated (red line) total suspended solids values in thirty points across the Essity Nokia mill.

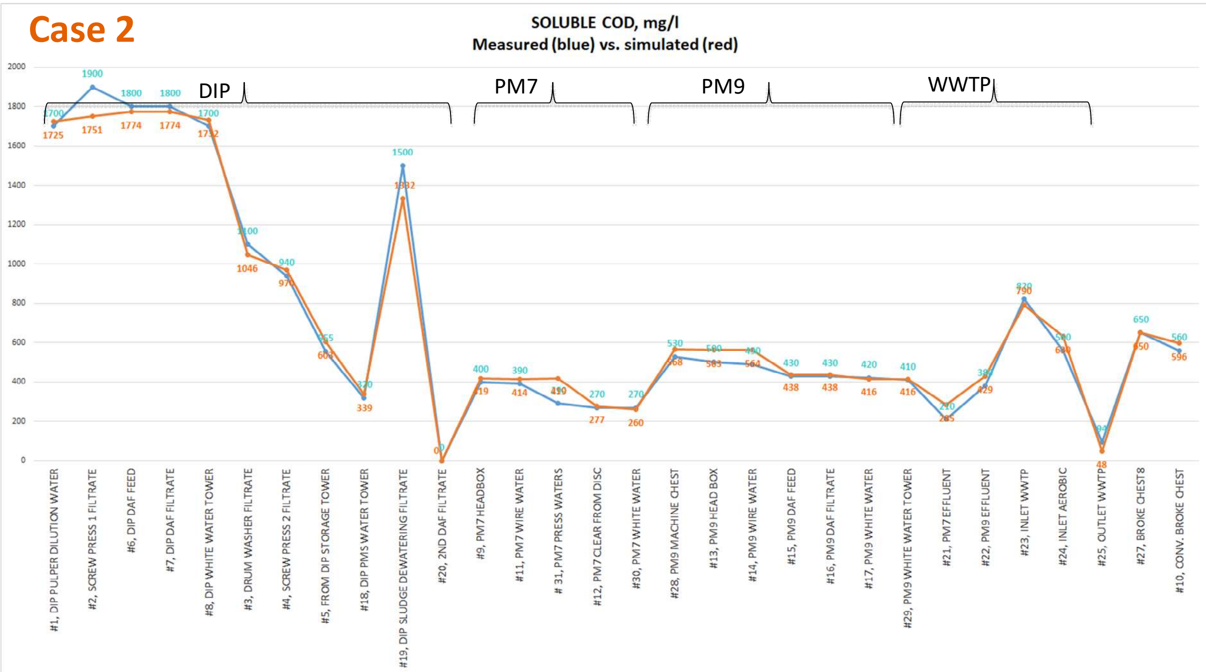


Figure 40. Case 2: Comparison of measured (blue line) and simulated (red line) soluble COD values in thirty points across the Essity Nokia mill.