Investment and financing programme to exploit the wastewater treatment, water-reuse and resource recovery opportunities for a selected urban local body in Kanpur

Deliverable D7.2

Final version (confidential/public)

Lead beneficiary: Aquafin

Authors: Ivo Boonen (Aquafin)

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CO	Confidential, restricted under conditions set out in Model Grant Agreement	
CI	Classified information as referred to in Commission Decision 2001/844/EC)	
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DEC	Web sites, patent fillings, videos, etc.	
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SUMMARY

The aim of Deliverable 7.2 is to provide recommendations concerning the appropriate investment and financing models to deliver the baseline scenario defined in the "Road map to exploit the wastewater treatment, water reuse and resource recovery opportunities for the Kanpur Nagar Region (Deliverable 7.1). This includes an investigation of the technical feasibility and financial viability of the first steps of the baseline scenario implementation, being:

- Upgrade of the biological treatment of the wastewater; and,
- Energy recovery of the sludge

This is achieved by comparing the technologies investigated in Work Package 5 (ANDICOS the Self Forming Dynamic Membrane Bioreactor (SFD-MBR), and digestion) with a classical upgrade, applied to the existing Jajmau Standard Treatment Plant, in Kanpur. Due to a lack of available recent operational data, the analysis is done based on partial, old measurement results and partial information about the present plant. Also due to a lack of information about the local costs, all analyses are done using European costs.

The present plant complies with the old standards (Environmental Protection Rules 1986) where the main parameter is a BOD concentration of less than 100mg/l. However, due to the publication of Environment (Protection) Amendment Rules 2017, the limit is reduced to 30mg/l since 2022. Also, a court ruling exists that introduces nutrient removal in India. It can thus be assumed that India is in a transition towards stricter effluent standards. Therefore, scenarios for upgrades to include nutrient removal are also assessed.

For the present situation and for each scenario, a biological and cost model is made to size all components and predict the economic and ecological parameters of the treatment plant. Also, the investment and operational costs are estimated. Because not all the tests of the different technologies are finished at the date of this document, preliminary results and estimations are used.

Based on the simulations, it is found that the plant can be upgraded to comply to the standard of 2017 by replacing the aeration equipment. If highly efficient aeration is used, the operational cost can be reduced and the Net Present Value (investment and operational cost) can be reduced, compared to the present situation.

It is also concluded that the scenarios with digestion and dewatering of all the sludge using centrifuges have a positive influence on the NPV. In the case of digestion, the plant can become a net producer of electricity. The main reason for this is that the wastewater contains a high concentration of suspended COD which settles well in the primary clarifiers. A high production of gas can thus be found combined with a low residual load to the biological treatment. By dewatering all the sludge prior to the drying beds, the loading of these beds is reduced. This will increase the dry solids concentration of the sludge and will increase the value of the sludge as energy carrier to be used in power plants or cement ovens.

If nutrient removal is required, the scenario using SFD-MBR has the lower NPV. However, the difference with a conventional upgrade is small and a minor increase in cost of the SFD-MBR units (15%) makes both scenarios equal in NPV. If the cost of the SFD-MBR units can be reduced by producing

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larger units than the present maximum size of these units, SFD-MBR could become a viable process. In case of the Jajmau plant, the ANDICOS scenario has a higher NPV than the other scenarios. The main reason is that the present primary clarifiers have a high efficiency. The membranes thus have a reduced influence on the load towards the biological treatment. The removal rate of the membranes is not enough to justify the investment costs.

We know that the water characteristics of STP Jajmau have in the last two years improved substantially due to the success of stopping the illegal discharges of tannery wastes into the urban sewage network, but the tannery cluster remains in place, surrounding the STP. The new CETP Jajmau being built has insufficient capacity to deal with the tannery cluster effluent, therefore the chances are high that the water quality characteristics, based on the data collated from the period 2009-2021, can return.

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CHAPTER 1 INTRODUCTION

In Deliverable 7.1, a methodology has been proposed and applied to identify the pathways to best valorise wastewater and other resources in the area of the Kanpur Nagar region. The roadmap has been conceived with a 50-year time horizon, looking at a centralized solution for the wastewater treatment services and a wide-scale strategic view into different resource recovery options.

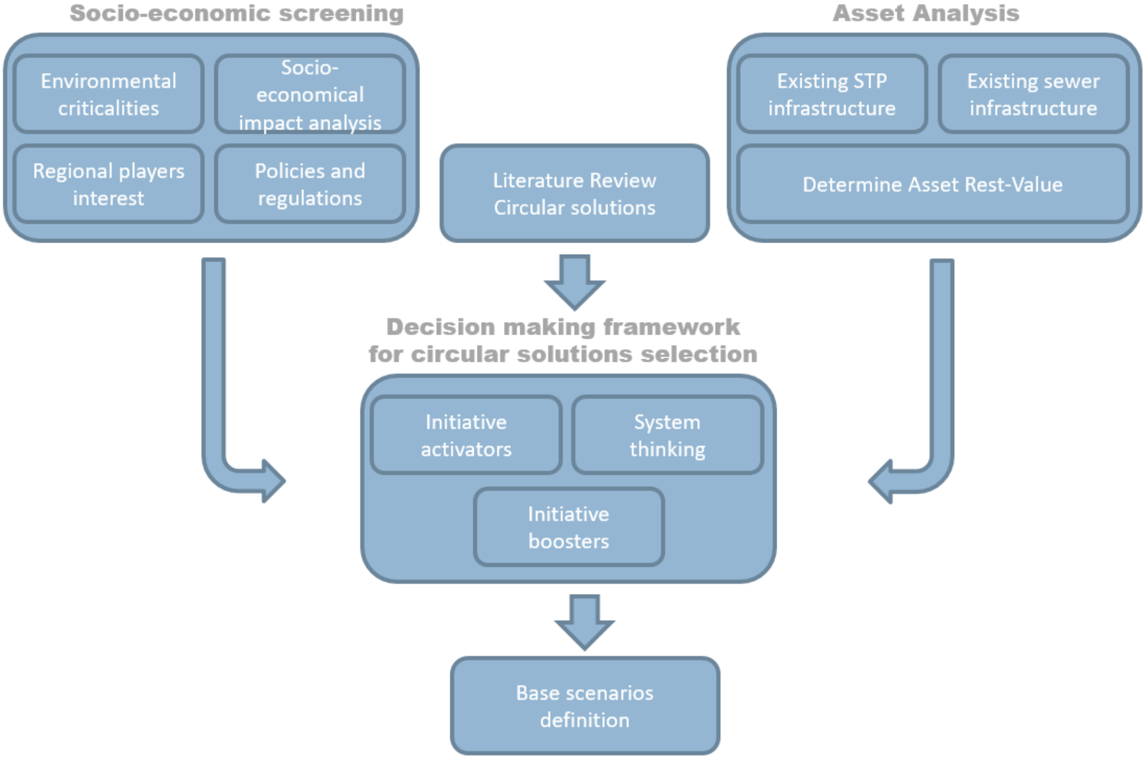

Figure 1: Roadmap scheme

The roadmap has concretely resulted in a proposal for the renovation of the Jajmau WWTP in harmony with a sustainable development of the existing markets and production pathways. The proposed scenario (called the "baseline" scenario) consists of:

- A treatment system that produces ultra-filtered effluent water including removal of metals and recovery of chromium;
- Reuse of the effluent in industry (primarily) and secondarily in agriculture;
- Energy and heat recovery combined with agricultural residues and co-pelletisation with charcoal;
- Integration of septic material and other feasible organic streams for boosting anaerobic digestion at the full-scale site; and,
- Sludge thermal treatment by sun drying.

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Out of the WWTP boundaries, it is suggested that:

- Food-streams would be used for organic fertilizers production and composting; and,
- Phosphorous requirement for the area could be covered by the recovery of the ashes after sludge incineration.

The aim of Deliverable 7.2 is to provide recommendations concerning the appropriate investment and financing models to deliver the baseline scenario defined in the "Road map to exploit the wastewater treatment, water reuse and resource recovery opportunities for the Kanpur Nagar Region (Deliverable 7.1). This includes an investigation of the technical feasibility and financial viability of the first steps of the baseline scenario implementation, being:

- Upgrade of the biological treatment of the wastewater; and,
- Energy recovery of the sludge.

To accomplish this, the existing Jajmau Standard Treatment Plant is used as test case. Several technologies piloted in Pavitra Ganga are compared with a more conventional upgrade of the plant. The investment cost, energy consumption and sludge production are estimated for different scenarios. Due to a lack of information about the construction and operational costs in India, the scenarios are calculated using European costs. The cost level is set at Belgian costs in 2022. Also, economic and ecological benefits are identified to complete the financial and economic analysis.

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CHAPTER 2 PRECONDITIONS

2.1. DESCRIPTION OF THE EXISTING PLANT

2.1.1. INTRODUCTION

On 9/6/2021 the Jajmau Standard Treatment Plant (STP)was visited by a technical group from Aquafin (Belgium). The visit focused on the visual and technical analysis of the present asset, its maintenance state and its functional activity. Further technical data, operational and financial information were requested to the local operational company. Some partial dimensional data was received on 23/8/2021. However, the operator was not allowed to provide specific operational and financial information. The assessment is based on expert judgement and assumptions from other relevant projects.

The present plant consists of 2 parallel lines. The older line (line 1) has a capacity of 130 MLD and the newer line (line 2) has a capacity of 43 MLD. Both lines are conventional activated sludge plants with primary clarifiers, aeration basins and secondary clarifiers. The process flow diagram of the total plant is given in Figure 2.

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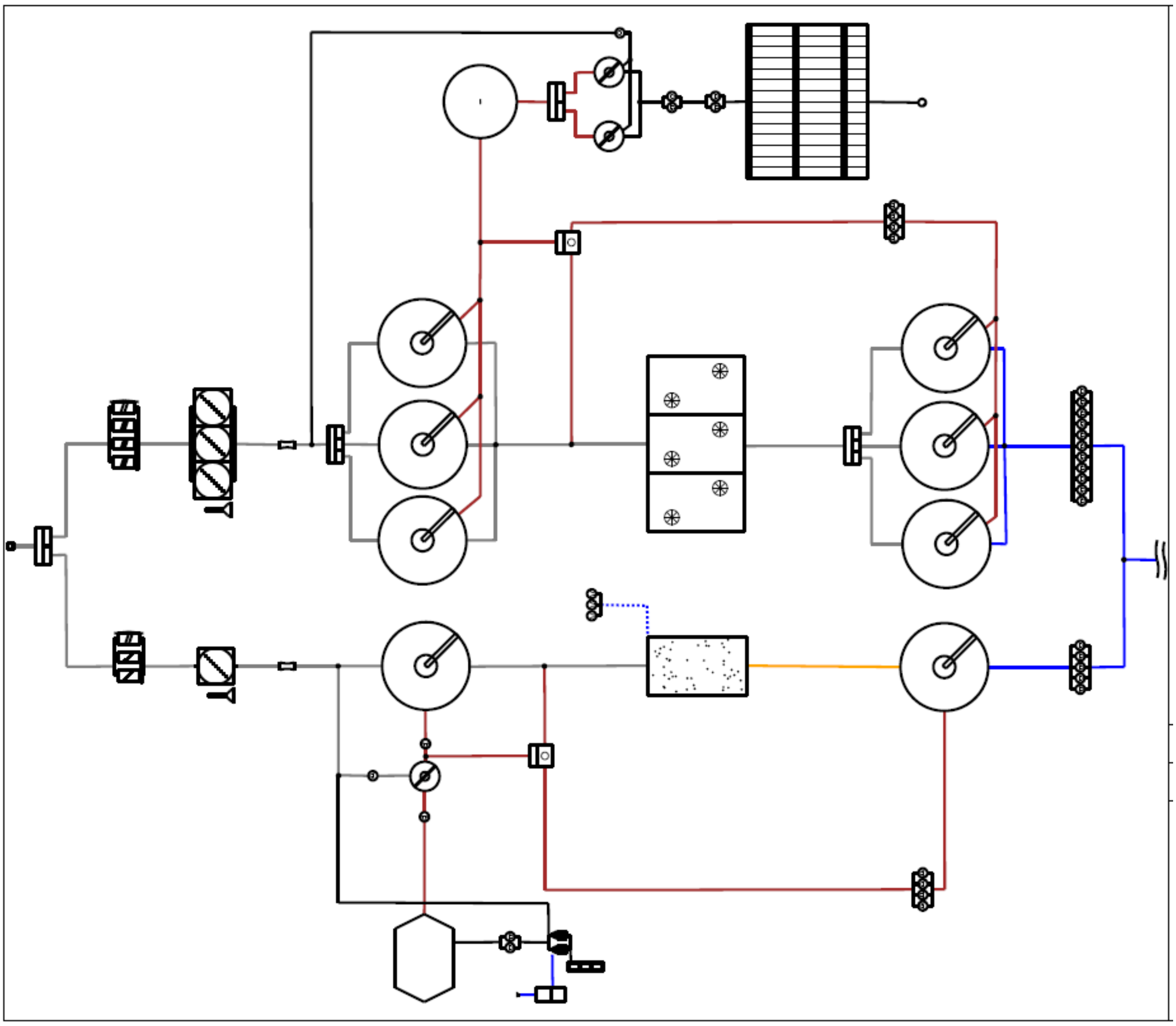

Figure 2: Process flow diagram of the existing installation

The layout of the plant is given in Figure 3.

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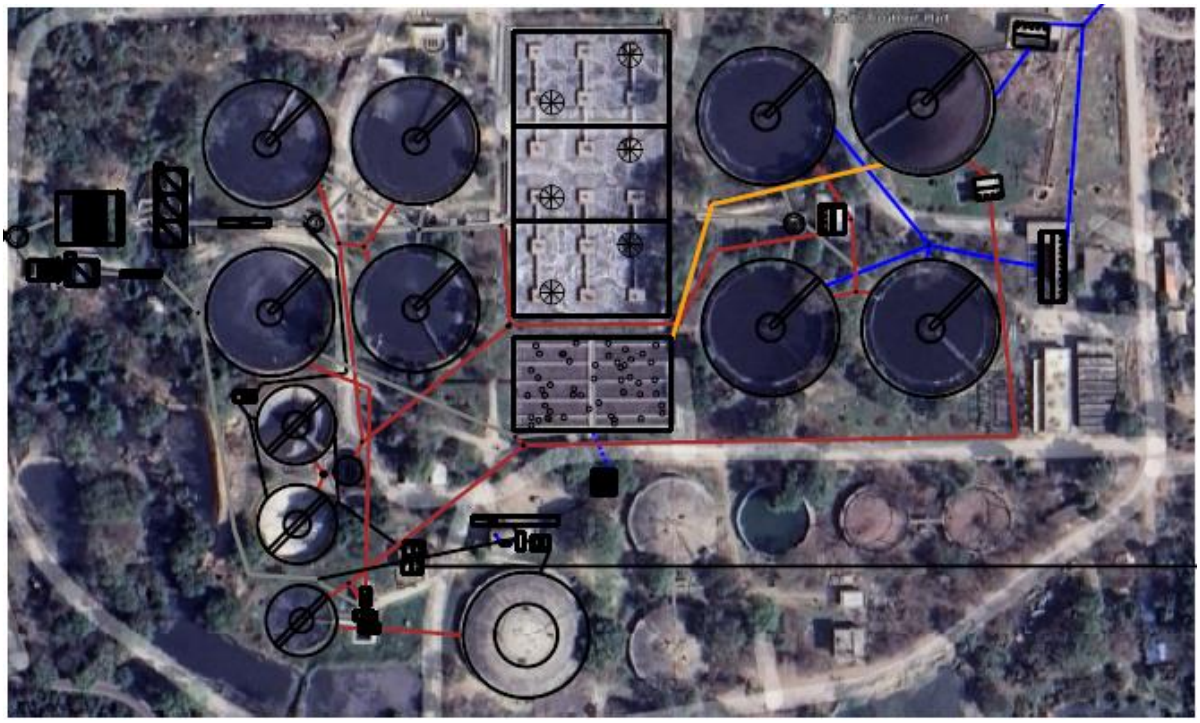

Figure 3: Layout of the existing installation

The wastewater enters the plant by gravity into the reception tank from which it is divided into two Lines.

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Figure 4: Inlet reception tank

Both Lines are described in separate sections below.

2.1.2. LINE 1

Mechanical treatment

The first step of the mechanical treatment consists of 3 automatic fine screens with a manual screen in bypass. The automatic screens have a slot width of 6mm.

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Figure 5: Inlet screens line 1

Works are in progress to increase the reliability of the screens and solve some safety issues. However, during our visit, we measured elevated levels of H_2S. This indicates that the sewage entering the plant is anaerobic and highly concentrated. The necessary individual protection means are to be correctly used to avoid serious safety hazards. Above all, a gas meter is supposed to be carried at any access.

In a second step sand and grit is removed in 3 Dorr-type degritters with each a surface of 9.3x9.3m. This gives a surface loading at maximum flow of about 25m/h. This is sufficient to remove the relevant fraction of the sand and grit.

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Figure 6: Degritters Line 1

After the degritters, the flow is measured in a venturi flume.

Primary clarifiers

The flow is divided over 3 primary clarifiers with each a diameter of 44m, resulting in as surface loading of 1.2m/h. The clarifiers have a side wall depth of 4.1m and a cone depth of 5.8m, resulting in an average depth of 4.7m. The total volume of each tank is thus 7,150m³ giving a retention time of 4h. The capacity of the primary clarifiers is thus certainly high enough assuming normal design parameters:

- a surface loading of 1.5-2.5m/h
- a retention time of 1.5-2h.

The high retention time alreadygives a problem at high temperatures because the sludge in the tank starts to digest, increasing the fatty acids in the effluent of the tank. This can also be detected by the gas bubbles on the surface of the clarifier. This could be decreased by adjusting the sludge pumps to decrease the sludge retention time in the PSTs.

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Figure 7: Primary clarifiers Line 1

A programme is in progress to renovate the clarifiers.

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Figure 8: Renovation works in progress on primary clarifiers Line 1

Aeration tanks

After the primary clarification, the pre-treated wastewater is combined with the return sludge and split over three aeration tanks, each with a volume of 7,700m³ and a depth of 4.3m. Each tank is equipped with six turbine surface aerators, each with a capacity of 37kW. However, some of the aerators are missing or not operational. The operational surface aerators are working at full speed without any control.

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Figure 9: Aeration tank Line 1

Visually it can already be seen that the aeration system is a limiting factor because the aeration tank is in an anaerobic state (black smelling sludge). It can also be seen that the sludge concentration is very low. These issues are further discussed in the modelling section.

Secondary clarifiers

After the aeration tanks, the flow is divided into three clarifiers with a diameter of 48m and a sidewall depth of 3.8m. This results in a surface loading of 1m/h. For a high loaded treatment plant such as this, a surface loading of 1m/h is fairly high and results in the fact that only a low sludge concentration can be maintained in the aeration tank. The secondary clarifiers are also in a renovation program.

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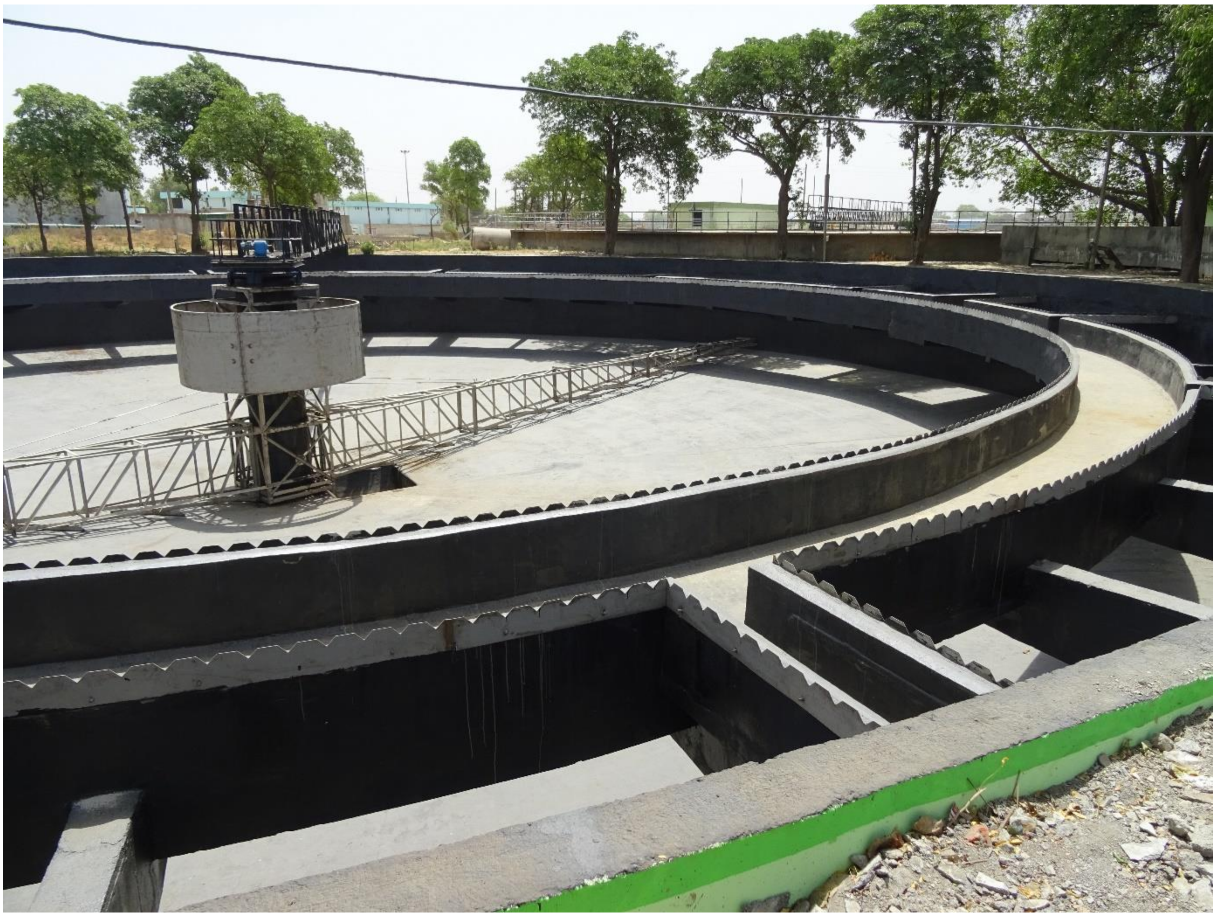

Figure 10: Renovation in progress on the secondary clarifiers of Line 1

The settled sludge is returned with four centrifugal pumps with a capacity of 1,535m³/h each in a (2+2) configuration.

Effluent pumping station

The effluent is pumped to the irrigation channel using eleven centrifugal pumps with a capacity of 1,800m³/h each in a 3+8 configuration.

Sludge treatment

The primary sludge flows by gravity to a blending tank where it is mixed with the secondary sludge. This tank has a volume of 520m³.

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Figure 11: Sludge blending tank Line 1

From this tank, the sludge is divided into two renovated sludge thickeners with a diameter of 28m each and a sidewall depth of 3.5m.

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Figure 12: Sludge thickeners Line 1

The digestors are not in use and the sludge is now pumped directly to the sludge drying beds using two pumping stations in series. Based on a visual inspection we assume that the existing digesters cannot be safely used in future upgrades. No information about the sludge production and disposal was given by the operator.

2.1.3. LINE 2

Mechanical treatment

The first step of the mechanical treatment consists of two automatic fine screens with a manual screen in bypass. The automatic screens have a slot width of 6mm.

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Figure 13: Inlet screens Line 2

In a second step sand and grit is removed in 1 Dorr-type degritter with a surface of 9.3x9.3m. This gives a surface loading at maximum flow of about 25m/h. This is sufficient to remove the relevant fraction of the sand and grit.

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Figure 14: Degritters Line 2

After the degritters, the flow is measured in a venturi flume.

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Figure 15: Inflow flume line 2

Primary clarifiers

The wastewater goes to one primary clarifier with a diameter of 44m, resulting in as surface loading of 1.2m/h. The clarifier has a side wall depth of 4.1m and a cone depth of 1.8m, resulting in an average depth of 4.7m. The total volume of the tank is thus 7,150m³ giving a retention time of 4h. The capacity of the primary clarifiers is thus certainly high enough assuming normal design parameters:

- A surface loading of 1.5-2.5m/h; and,
- a retention time of 1.5-2h.

The high retention time already gives a problem at high temperatures because the sludge in the tank starts to digest, increasing the fatty acids in the effluent of the tank. This can also be detected by the gas bubbles on the surface of the clarifier.

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Figure 16: Primary clarifiers line 2

Aeration tanks

After pre-treatment, the wastewater flows to an aeration tank. This aeration tank is equipped with fine bubble aeration. The tank is divided into four compartments from which the first compartment is a sort of selector tank in which the return sludge is mixed with the wastewater. From this tank, the mixture flows to other tanks. From a process point of view, we can treat this tank as one completely stirred reactor. The exact volume of the tank is not known to us, but, because the horizontal dimensions are about the same as the tanks in Line 1, it is assumed that the depth is also the same. This gives a volume of 7,700m³.

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Figure 17: Aeration tank Line 2

The air is provided by (2+1) blowers of 132kW. The exact configuration of the air distribution system and the number and type of the aeration disks were not provided.

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Figure 18: Blowers Line 2

In this aeration tank, we see the same problem as in the other aeration tank, there is a very black anaerobic sludge present, and the sludge concentration is also very low. This indicates that the oxygenation capacity of the aeration is not enough for the load entering the plant.

Secondary clarifiers

After the aeration tanks, the flow goes to one clarifier. The exact dimensions of this tank were not provided, but based on aerial photos, we see that the tank is slightly bigger than the other clarifiers. A diameter of 50m is therefore considered for further calculations. The depth of the tank could not be estimated.

The settled sludge is returned by four centrifugal pumps.

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Effluent pumping station

The effluent is pumped to the irrigation channel using five centrifugal pumps. The capacity and the configuration was not provided.

Figure 19: Effluent pumping station Line 2

Sludge treatment

The primary sludge is pumped to a thickener where it is mixed with the secondary sludge. The exact dimensions of the thickener are not provided, but, based on aerial photos, the diameter is estimated at 25m. From this thickener, the sludge is pumped to a digester that is currently used as storage tank.

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The exact dimensions of this tank are not provided. Based on aerial photos, the diameter is estimated at 45m. Assuming a depth of 9m, this gives a volume of about 14,000m³. This gives a high retention time of the sludge in this tank. We thus can assume that, depending on the temperature but certainly during summer, some sludge digestion takes place with methane production and subsequent methane release to the air.

Figure 20: Sludge storage tank Line 2

After storage, the sludge is pumped to two centrifuges with a rated capacity of $13m^3/h$ each.

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Figure 21: Sludge dewatering Line 2

2.2. Wastewater composition

2.2.1. Long term data

The operator of the plant was not allowed to provide any recent measurement data (influent nor effluent). This makes an in-depth analysis of the plant difficult. The results of this study can thus not be directly used as basis of a design. In other work packages of the project, some measurements have been carried out. These are used to carry out the analysis. This gives some information about the functioning of the present plant and the projections of the technologies for possible future operations.

2.2.2. Historical data period 2009-2013

In Figure 22 is an overview of the water quality characteristics for the Jajmau STP (Deliverable 5.1).

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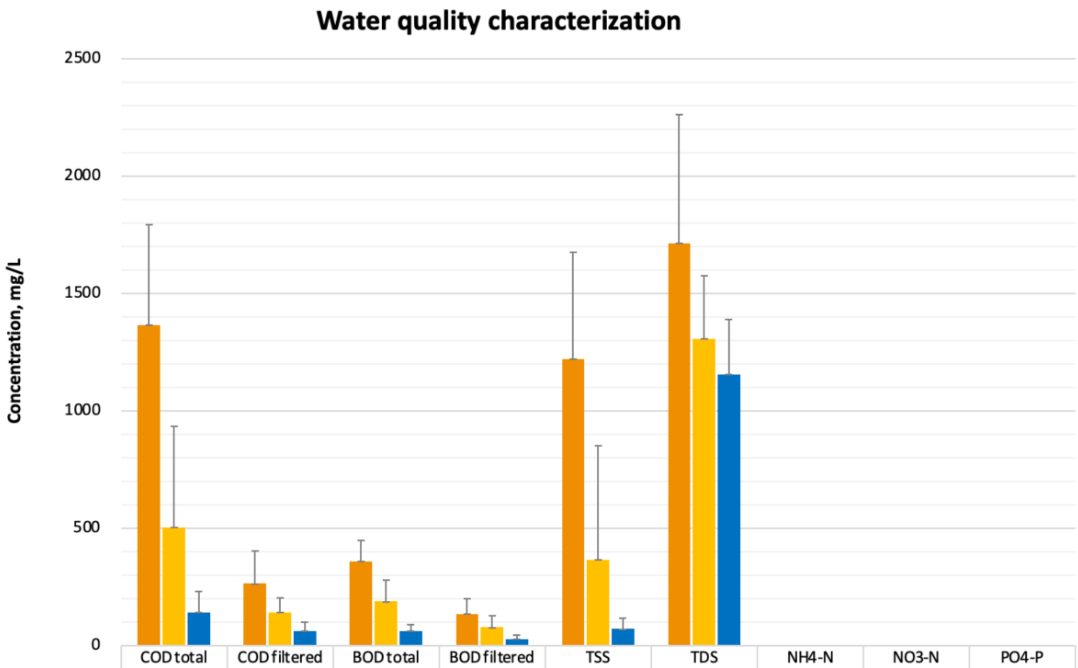

	COD total	COD filtered	BOD total	BOD filtered	TSS	TDS	NH4-N	NO3-N	PO4-P
STP: Influent	1366	265	360	134	1223	1716	N/A	N/A	N/A
STP: Primary effluent	504	141	188	78	365	1308	N/A	N/A	N/A
STP: Secondary effluent	143	64	63	29	72	1156	N/A	N/A	N/A

Figure 22: Water quality data of Jajmau STP (2009 to 2013)

This data is interesting because it gives an indication of the fractionation of the COD into soluble and suspended parts. Based on the BOD, we can also find an indication of the biodegradability of the COD. As basis of the fractionation of the COD we use the method derived for IWA ASM3 (activated sludge model 3).

Firstly, we can see that ((1366-265)/1366) = 80% of the COD is suspended. If we assume that 1mg of BOD corresponds with 1.5mg of biodegradable COD, we find a biodegradable fraction of the soluble COD of (134*1.5/265) = 75%. The biodegradable fraction of the suspended COD is calculated as ((360-134)*1.5/(1366-265)) = 31%. The results are summarized in Figure 23.

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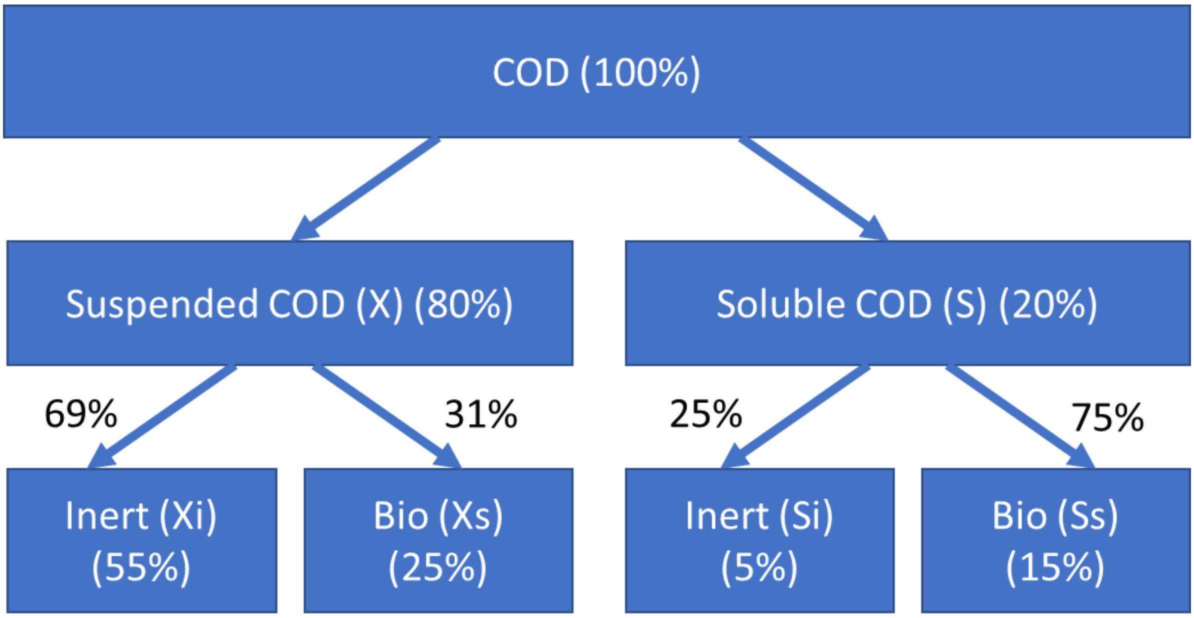

Figure 23: COD fractionation based on data from Jajmau STP water characteristics

This gives a very different fingerprint compared to a typical composition in Belgium, being presented in the next drawing.

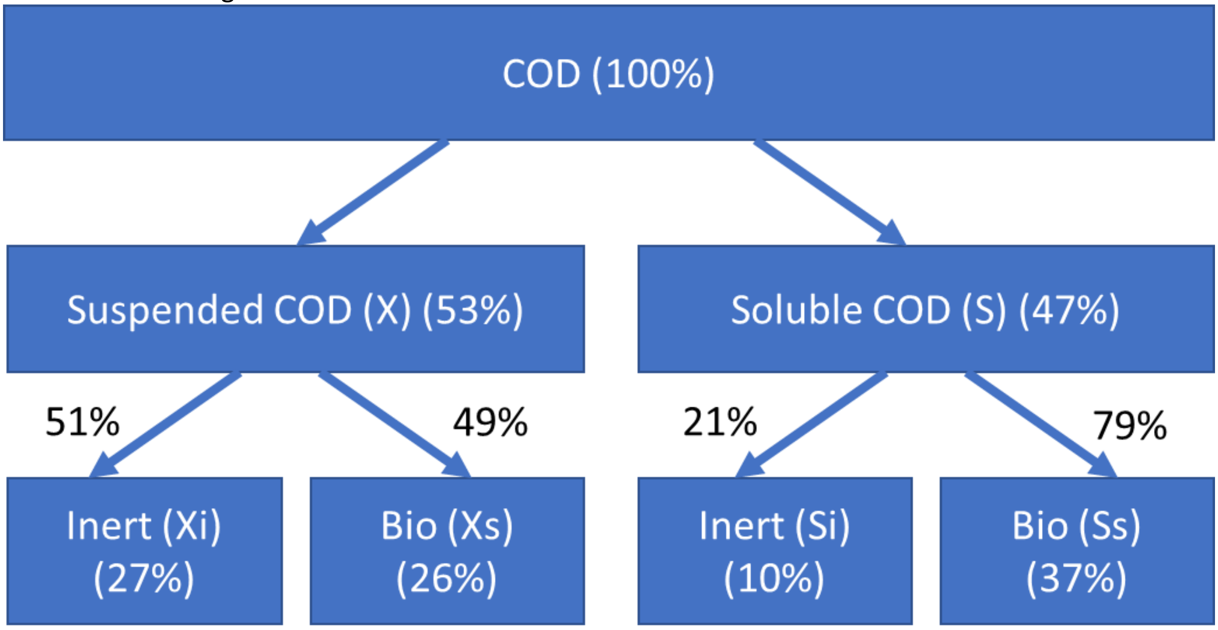

Figure 24: Typical COD fractionation in Belgium

The wastewater in Jajmau thus contains much more suspended inert fractions than a typical domestic wastewater in Europe. Reasons for this could be:

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- Biological reactions in the sewer network that convert organic matter into inert matter;
- Industrial discharges; and,
- Different eating habits.

If we assume that 1mg of organic suspended solids contain 1.5mg of COD, the organic fraction of the suspended solids is ((1366-265)/1.5/1223) = 60%. The inorganic fraction of the suspended solids (Gi) is thus 40%. In a typical Belgian domestic wastewater, this is about 30%.

Based on Figure 22we can also see that the primary clarifier has a removal rate of ((1223-365)/1223) = 70% of the suspended solids. This is high compared to normal removal rates (<50%). If we apply this to the above fractionation, we get the results in Table 1.

Fraction	Fraction of COD	Removal of fraction	Removal of COD
Xi	55%	70%	38.5%
Xs	25%	70%	17.5%
Si	5%	0%	0%
Ss	15%	0%	0%
Total	100%		56%

Table 1: Removal rate of the primary clarifiers

Based on the data, the removal rate of COD is ((1366-504)/1366) = 63%. Taking into account the unknown source of the data, this is a fairly good relation between the data. Based on this data, we can also make an estimation of the fractionation of the wastewater after the primary clarifier. This is given in Table 2.

Fraction	Fraction of CODin	Not removed	Remaining	Fraction after PST
Xi	55%	30%	16.5%	37.5%
Xs	25%	30%	7.5%	17%
Si	5%	100%	5%	11.5%
Ss	15%	100%	15%	34%
Total	100%		44%	100%

Table 2: Estimated fractionation of the COD based water characteristics of Jajmau STP

According to the provided data, the average flow to the 130 MLD plant was 64 MLD in this period. This therefore means that the hydraulic loading of the plant is about 50% of the design flow. Extrapolated to the total plant (Line 1 and Line 2) this gives a flow of ((130+43)*0.5) = 87MLD. During our visit on 9/6/22 around noon, the influent flow was 4,900m³/h to Line 1 and 1,900m³/h to Line 2. This corresponds to a loading of ((4900+1900)*24/1000) = 163MLD. This shows that the peak loading of the plant is certainly about the design capacity.

2.2.3. DATA 2019-2021

In the period between 2019 and 2021, several samples were taken after the PST (table 2 of the report of 31/1/22 in work package 5.3). The average COD was 890mg/l. This is higher than measured in the

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period 2009-2013 (504mg/l). Also, the measured BOD (374mg/l) is higher than in the period 2009-2013 (188mg/l). Because the data of 2009-2013 is based on a larger dataset, it is assumed that this data is more reliable.

In these samples also the nutrients were measured. This resulted in an average total nitrogen concentration of 22mg/l and a total phosphorous concentration of 5.4mg/l. However, there seems to be a problem with this data. Normally, wastewater contains nutrients that are bound to the organic fractions. In Table 3, the normal fractions are given.

Fraction	Fraction of COD after PST	N-org (mgN/mgCOD)	P-org (mgP/mgCOD)
Xi	37.5%	0.02	0.01
Xs	17%	0.04	0.015
Si	11.5%	0.02	0
Ss	34%	0.03	0
Total	100%	0.0268	0.0063

Table 3: Nitrogen fraction bound to the COD

With a COD of 890mg/l, this gives an organically bound N of (890x0.0268=) 23.8mg/l and P of (890x0.0063=) 5.6mg/l. It thus seems that not the total nitrogen and phosphorous is measured, but the organic part of the nutrients. In normal wastewater there is also a fraction of not bound nutrients (ammonium and ortho-phosphate). For future designs towards nutrient removal, this is a very important issue. For example, with a total nitrogen concentration of 22mg/l it will be very easy to reach an effluent concentration of 10mg/l (EU-legislation). However, if the nitrogen concentration is 62mg/l (estimating an ammonium concentration of 40mg/l) a full nitrogen removal process is needed. In the further analysis an ammonia concentration of 40mg/l and an ortho-phosphate concentration of 5mg/l is assumed.

2.2.4. Summary

Taking into account the above analysis, we assume the following influent.

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Parameter	Average	Maximum
Flow	87MLD	173MLD
COD	119,000kg/d	138,000kg/d
Xi (inert suspended)	65,000kg/d	130,000kg/d
Xs (bio suspended)	30,000kg/d	60,000kg/d
Si (inert soluble)	6,000kg/d	12,000kg/d
Ss (bio soluble)	18,000kg/d	36,000kg/d
SS	106,000kg/d	212,000kg/d
Gi (inorganic solids)	43,000kg/d	86,000kg/d
TN	6,660kg/d	13,320kg/d
Xnd (suspended org N)	2,500kg/d	5,000kg/d
Snd (soluble org N)	660kg/d	1,320kg/d
Snh (ammonia)	3,500kg/d	7,000kg/d
TP	2,100kg/d	4,200kg/d
Xp (suspended org P)	470kg/d	940kg/d
Sp (ortho P)	435kg/d	870kg/d

Table 4: Composed design influent

2.3. Effluent

We did not receive any recent long-term data from the operator. The only data that is available are the data from 2009-2013. In Table 5, the average concentrations are given.

Parameter	Concentration (mg/l)
BOD	63
COD	143
SS	72

Table 5: Present effluent quality

It is assumed that present effluent standards of the plant are based on the Environmental Protection Rules 1986 and National River Conservation Directorate Guidelines for Faecal Coliforms. Following these standards, the effluent standards are given in Table 6.

Parameter	Standard	Unit
BOD	100	mg/l
SS	200	mg/l
Oil and Grease	10	mg/l
Faecal Coliform (desirable)	1,000	MPN/100ml

Table 6: Effluent standards Environmental Protection Rules 1986

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However, according to the Environment (Protection) Amendment Rules 2017, the standards are set stricter. These standards apply to new plants build after 1/6/2019 and to old plants after 13/10/2022 (5 years after the publication date of 13/10/2017).

Parameter	Standard	Unit
pH	6.5-9.0	S
BOD	30	mg/l
SS	100	mg/l
Faecal Coliforms	<1000	MPN/100ml

Table 7: Effluent standards Environment (Protection) Amendment Rules 2017

Also, court rulings exist (Green Tribunal Principal Bench, New Delhi Original Application No 1069/2018, 30/04/2019) to also include nutrient removal, resulting in the standards given in Table 8 for Class I cities.

Parameters	Standard	Unit
pH	5.5-9.0	S
BOD	20	mg/l
SS	30	mg/l
COD	100	mg/l
TN	15	mg/l
TP (discharge in ponds, lakes)	1.0	mg/l
Faecal Coliforms (Desirable)	230	MPN/100ml
Faecal Coliforms (Permissible	1000	MPN/100ml

Table 8: Effluent standards Green Tribunal Principal Bench, New Delhi

From the above, it is clear that India is in a transitional phase concerning the effluent standards and that standards are becoming increasingly strict. The present plant was compliant to the old standards of 1986 but does not comply with the present and probable future standards.

The effect of cleaner effluent will not be considered a financial benefit in this study. However, it will be seen as an economic benefit because it is assumed that the effluent will be reused. Although at the moment the effluent is reused in agriculture, it is assumed that in the future the effluent will be used as process water for the industry. In this study, we only consider the biological treatment without any post treatment steps (disinfection, filtering, RO, …), because this will depend on the exact reuse route.

2.4. SLUDGE DISPOSAL

At present, the produced sludge is dried on sludge drying beds. The ultimate disposal route of the sludge is not clear to us. Probably it is reused in agriculture or disposed on a landfill. None of these disposal routes are seen as sustainable. One of the conclusions of the roadmap of Deliverable 7.1 is to promote resource recovery of the sludge. The main components in this recovery are energy and

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phosphorous. Ideally, the sludge should be incinerated in a mono-incinerator with energy recovery and recovery of the phosphorous from the ashes. However, in shorter term, this will probably not be economically viable.

Figure 25: Existing sludge drying beds

In the scenario analysis, it is assumed that the sludge is dried on the plant using the existing sludge drying field (with or without digestion) with an estimated surface of 40,000m² and then transported to an incinerator with heat recovery (power plant or cement oven). The recovered energy is seen as an economic benefit. The financial cost is assumed to be the transport cost of the sludge. Using European costs (0.2EUR/Ton/km) and assuming a transport distance of 50km to a nearby incinerator, the cost is estimated at 10EUR/Ton.

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2.5. Electricity cost

For consistency reasons, also here European cost are used. Due to high fluctuations in the electricity costs, it is difficult to put a long-term cost on electricity today. A cost of 280EUR/MWh is used in this study. This is the same cost as Aquafin is using in Belgium for long-term analyses.

2.6. Simulation of the present situation

2.6.1. Model setup

Based on the above analysis, a model is built in the CIS software (proprietary software of Aquafin). This software is based on the IWA ASM-3 model joint with other models for different types of processes. The PFD of this model is given here below.

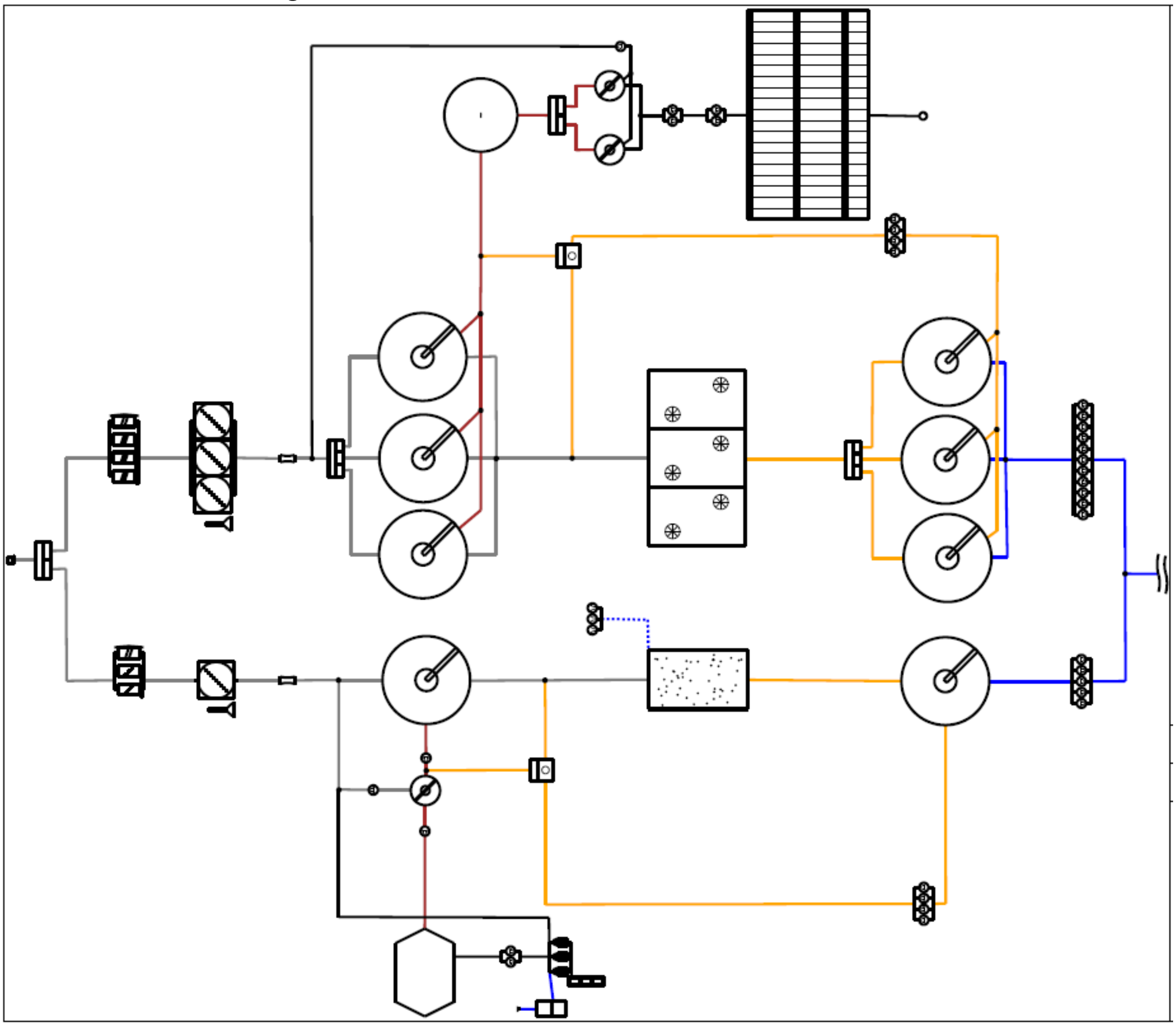

Figure 26: PFD of the existing plant

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The layout of the model is given in the next figure.

Figure 27: Layout of the existing plant

At first instance, standard parameters for all constructions are used, with the exception of:

- The removal rate of the primary clarifiers is set at 70% as proven by the measurement data.
- The efficiency of the turbine aerators is set at 1.2kgO2/kWh instead of the standard 1.5kgO2/kWh because the turbines are of an older less efficient type. Also, the alpha factor is set at 0.6 instead of the normal 0.8 because due to the very high loading of the biological treatment, lots of surface-active substances will be present in the aeration tank.
- The transfer efficiency of the fine bubble aeration is set at 4%/m (6%/m is the standard) because visually, we can see that the bubbles are larger than normal. Also, the alpha factor is set at 0.3 instead of the normal 0.8 because of the high concentration of surface-active substances.
- The SVI (sludge volume index) is set at 150ml/g because the anaerobic nature of the sludge will create a badly settling sludge.
- No data has been provided, but it is assumed that the sludge concentration in the aeration tanks is 2g/l.
- During our visit, 4,900m³/h was going to line 1 and 1,900m³/h to line 2. Thus 70% of the load is going to line 1 and 30% to line 2. It is assumed that this is the normal condition.

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2.6.2. SIMULATION

Based on the above assumptions, the model predicts that the BOD should be removed almost completely if enough oxygen is provided in the aeration tanks. However, in reality this is not the case. The reason for this is that the aeration capacity is not enough. Taking into account the above assumptions, the needed aeration capacity in Line 1 is estimated at 800kW in average conditions and 1,500kW at peak loadings. The installed aeration capacity is 18x37kW=666kW. During our visit, 4 aerators were not in working conditions, reducing the aeration capacity to 14x37=518kW.
In the aeration tank of Line 2, the needed average aeration capacity is estimated at 300kW with a peak capacity of 575kW. The installed aeration capacity is 2x132kW=264kW. So, in Line 2, the aeration deficiency is probably lower. However, fine bubble aeration systems are more influenced by higher concentrations of surface-active substances. Because, at peak conditions the aeration capacity is much too low, an aeration tank with fine bubble aeration can spiral into a state where the aeration efficiency is reduced dramatically.

Simulating an activated sludge plant which is limited by oxygen input is difficult because it influences all the processes within the bacteria. One of the methods to take this into account is to reduce the "active" part of the sludge. By using this method, it is found that the real "active" sludge concentration is below 1g/l. At these concentrations, the oxygen uptake is as installed and also the BOD-concentration in the effluent increases towards the real concentration. Taking into account that in reality during the peak loading of the plant is even worse, it can be stated that the model predicts the reality.

At these low sludge concentrations, the sludge age in the plant reduces to values of about 0.5days. This means that the plant is run more like an aerated lagoon than an activated sludge plant. The limited aeration capacity also means that it can only remove a certain amount of organic load. If the load increases during the peak event, there is no reserve and the additional load goes directly towards the effluent. This results in a very unstable situation. The only thing that is making the plant stable is that the primary clarifiers have a high efficiency resulting in a BOD concentration of about 188mg/l of which only 144mg/l is soluble BOD.

The sludge production is estimated in Table 9.

	Sludge production (kgDS/d)	Sludge production (m^3/d)
Line 1	77,200	2,570
Line 2	27,300	87
Total	104,500	2,657

Table 9: Sludge production present situation

According to our simulations, the centrifuges of Line 2 are overloaded, resulting in a lower dry solids concentration of the dewatered sludge and/or worse separation efficiency.

In Table 10 , the average rainfall and evaporation rate in Kanpur is given.

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	Rainfall	Evaporation rate	
Jan	13	60	mm/month
Fed	13	80	mm/month
Mar	5	150	mm/month
Apr	5	250	mm/month
May	15	300	mm/month
Jun	79	300	mm/month
Jul	199	200	mm/month
Aug	185	200	mm/month
Sep	137	130	mm/month
Oct	36	100	mm/month
Nov	5	80	mm/month
Dec	8	60	mm/month
Year	700	1,910	mm/year

Table 10: Rainfall and evaporation in Kanpur

On average, a good sludge drying can be obtained with the existing sludge drying beds (+/-50%DS) resulting in a total sludge production of 73,000T/year. However, from the rainfall and evaporation data, it can be seen that in July, August and September a very poor result is achieved with very little or no net evaporation obtained. Temporary storage is required.

In Table 11, the main operational costs drivers are summarised. This is not the total operational cost and does not include:

- Labour cost
- Maintenance cost
- Lab costs
- Management costs

The same methodology is used for the different scenarios. The values thus only can be used for comparing the scenarios, assuming the above costs are the same for all scenarios.

	Quantity	Unit cost	Cost (kEUR)
Aeration	6,850 MWh/y	280	1,918
Centrifuges	550 MWh/y	280	154
Other consumers	2,190 MWh/y	280	613
Sludge production	71,700T/y	10	717
PE for dewatering	152T/y	1,200	182
Total			3,584

Table 11: Operational cost drivers present situation

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CHAPTER 3 CONVENTIONAL UPGRADES

3.1. INTRODUCTION

In this chapter some scenarios are made using conventional technologies. These scenarios are used as reference for the evaluation of the scenarios using new technologies. Two reference scenarios are made. In one scenario, we assume that the plant has to be upgraded to a full BOD removing plant (present Indian standards and comparable to the EU standard for basic quality). In the second scenario we assume that also nitrogen removal is needed (possible future Indian standards, comparable to the EU standard for fish water quality).

3.2. UPGRADE TO FULL BOD REMOVAL

3.2.1. CONFIGURATION

In this chapter the possibility of upgrading the existing plant to full BOD-removal, using classical technology, is investigated. Full BOD-removal in this case means compliance to the present Indian standard of 30mg/l. However, by upgrading the plant, an effluent BOD-concentrations of less than 10mg/l can be achieved.

As stated before, the main bottle neck of the existing plant is the installed aeration capacity. Based on the simulation of the existing plant, it is found that the aeration capacity has to be increased. Especially in Line 1, this will not be possible using the existing mechanical aeration system because there is not enough space to place these aerators. It is proposed to convert the aeration in line 1 to a fine bubble system. Also, the aeration in Line 2 will have to be updated to increase the capacity. Because the aeration energy is one of the largest operational costs, it is proposed to install a highly efficient aeration system with low loaded aeration disks and highly efficient centrifugal blowers. To increase the flexibility and the operational safety, it is proposed to build a central blower station that feeds both lines. This gives the configuration as drawn in Figure 28. It is also assumed that the flow division over the 2 lines is set at 75%/25% according to the existing aeration volumes.

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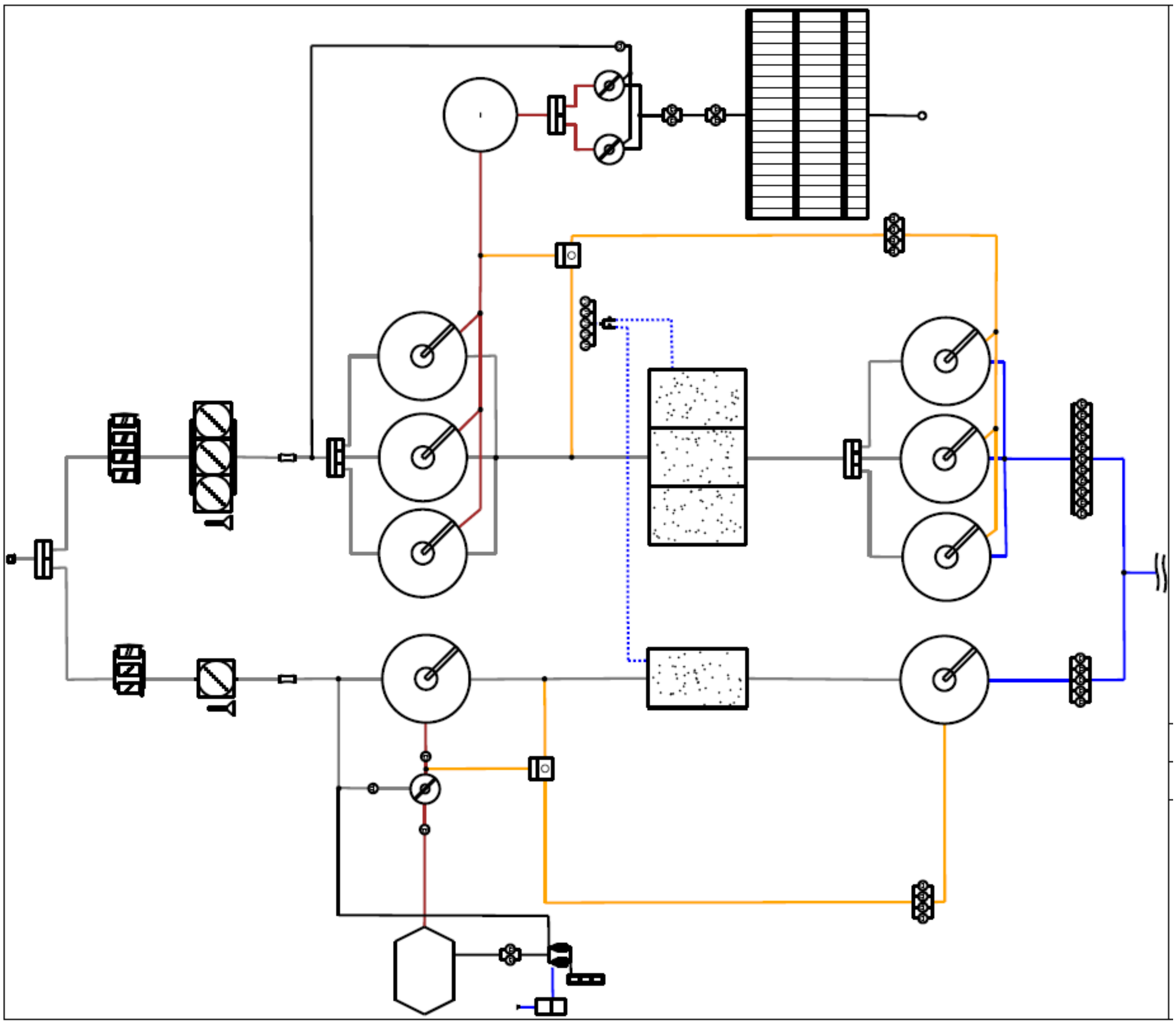

Figure 28: PFD of a full BOD removal plant using conventional technology

3.2.2. SIMULATION RESULTS

Based on the model, it is calculated that the blowers need to have a total installed capacity of 800kW with an average consumption of about 400kW. Compared to the present consumption of (14x37+2x132=) 782kW, the total installed capacity does not have to be increased by much when highly efficient aeration is used. This will result in the total average energy consumption being halved.

Based on the model it is also found that care has to be given to the sludge concentration in the aeration tank. The size of the secondary clarifiers allows to have a sludge concentration of about 3g/l before sludge washouts are expected. However, at higher sludge concentrations it is predicted that a partial nitrification can occur. A partial nitrification at temperatures reached in India can result in high concentrations of nitrite (NO_2). Nitrite is poisonous for man and environment and thus has to be avoided. This can be done by decreasing the sludge concentration. At a water temperature of 25°C, a

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maximum sludge concentration of about 2g/l is found. To avoid further problems with nitrite, it is proposed to provide the possibility of an intermittent aeration system in the aeration tank to introduce a partial denitrification when nitrite is detected.

3.2.3. COST ESTIMATE

Based on European prices, a high-efficient aeration system has an investment cost of 8MEUR. Details are given in Table 12.

Item	Cost estimate (kEUR)
Blower configuration	2,400
Aeration tank 1 EM	4,000
Aeration tank 2 EM	1,300
Electrical works	300
Total	8,000

Table 12: Investment cost estimate of a conventional upgrade to full BOD removal

The operation cost drivers are summarised in Table 13.

	Quantity	Unit cost	Cost (kEUR)
Aeration	3,500 MWh/y	280	980
Centrifuges	445 MWh/y	280	125
Other consumers	2,190 MWh/y	280	613
Sludge production	74,9000T/y	10	749
PE for dewatering	123T/y	1,200	148
Total			2,615

Table 13: Operation cost drivers of a conventional upgrade to full BOD removal

The operational cost thus can be reduced with (3,584-2,615=) 969kEUR, resulting in a return period of (8000/969=) 8years. So, financially, it is not a very interesting investment. However, the investment will result in a much better effluent quality, and this has an economical return for reuse. A big

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uncertainty in this investment is the phasing of the project. To install a fine bubble aeration system, the aeration has to be emptied. It is not certain that the 3 aeration tanks in Line 1 can be emptied separately (for example, can the dividing wall support the pressure of a different water level?). If they can not be emptied separately, the whole of Line 1 has to be put out of operations during the retrofit.

3.3. Upgrade to nitrogen removal

3.3.1. Configuration

If nitrogen removal is needed, the sludge age of the plant must be increased. This means that the volume of the aeration tanks needs to increase. The existing aeration tanks will not be big enough. In this scenario we assume that the new aeration tanks will be constructed towards minimisation of the energy consumption, meaning a highly efficient fine bubble aeration system with a deep tank. The two separate lanes are kept, however a central blower station using centrifugal blowers is assumed. In this scenario, the rest of the plant will be kept as it is. In the next drawing, the PFD of this scenario is given.

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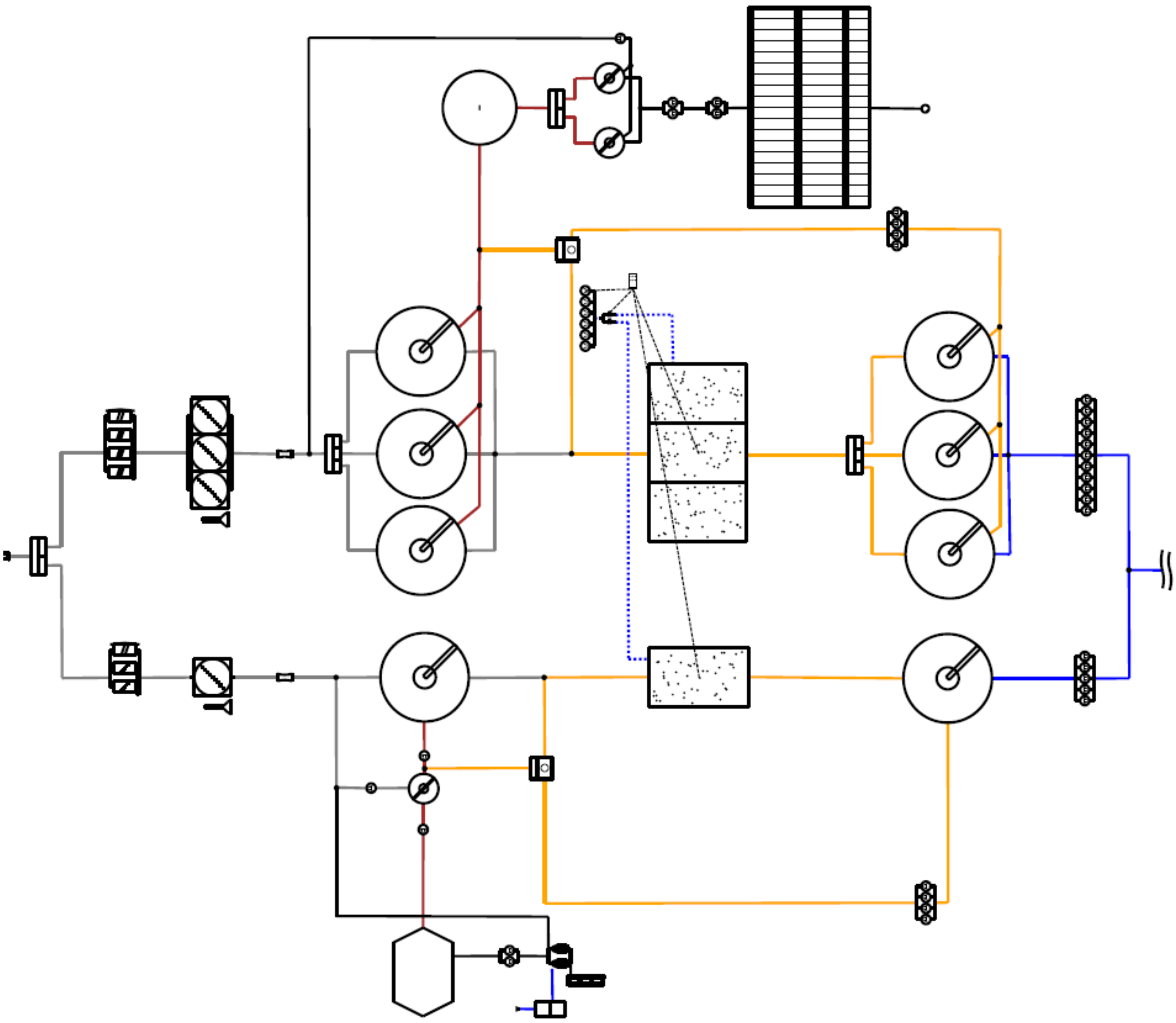

Figure 29: PFD of a N removal plant using conventional technology

3.3.2. SIMULATION RESULTS

If nitrogen removal is needed, the sludge age of the plant must be increased. This means that the existing aeration volumes are not enough, and an extension of the civil structures are needed. Taking into account a maximum nitrogen concentration of 10mg/l in the effluent, it is modelled that a total aeration volume of 150,000m³ is needed compared to the present (4x7,700) = 30,800m³. This already indicates that a major reconstruction of the plant would be needed. In the figure here below, the needed aeration tanks are drawn on the existing layout of the plant, taking into account a depth of 7m of the aeration tank. One aeration tank could be constructed on the footprint of the existing aeration tanks, the 3 further aeration tanks could be built on the footprint of the, not in use, existing digestion tanks. By building these 3 tanks first, the plant can be kept in full operations during the retrofit. The blower station consists of 5+1 centrifugal blowers of 300kW each. The average power consumption is estimated at 700kW.

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Due to the higher sludge age of the plant, the sludge production is decreased. This results in a lower loading of the sludge drying fields.

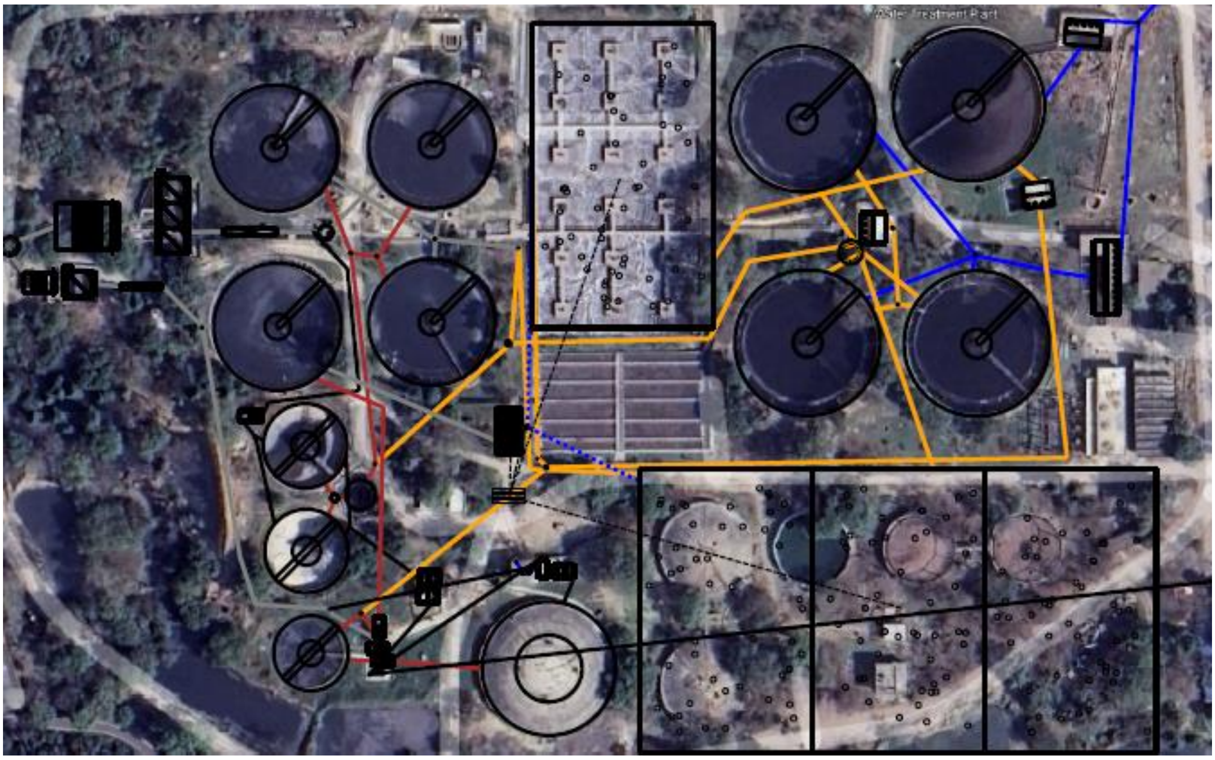

Figure 30: Layout of a conventional upgrade for nitrogen removal

3.3.3. Cost estimation

This will involve a major investment. Based on European prices, the investment is estimated in Table 14.

Item	Cost estimate (kEUR)
Aeration tank 1 civil	16,500
Aeration tank 1 EM	6,000
Aeration tank 2 civil	6,200
Aeration tank 2 EM	2,200
Blower station	3,500
Electrical works	2,000
Piping and others	3,000
Total	39,400

Table 14: Investment cost estimation of a conventional upgrade for nitrogen removal

The operation cost drivers are summarised in Table 15.

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	Quantity	Unit cost	Cost (kEUR)
Aeration	6,000 MWh/y	280	1,680
Centrifuges	422 MWh/y	280	118
Other consumers	2,190 MWh/y	280	613
Sludge production	71,500T/y	10	715
PE for dewatering	120T/y	1,200	144
Total			3,270

Table 15: Operation cost drivers of a conventional upgrade for nitrogen removal

3.4. UPGRADE TO NITROGEN REMOVAL WITH DIGESTION

3.4.1. CONFIGURATION

Based on the influent composition, it is found that a large part of the organics in the influent consist of suspended solids. Because the existing primary clarifiers have a high efficiency (70% removal of suspended solids) this results in a high load of organics in the primary sludge. It is thereby logical to try to digest this sludge to produce energy.

Based on preliminary simulations, it is found that large amounts of gas can be produced if full digestion can be achieved. Even if highly efficient gas motors are used, the amount of heat in the cooling water of these gas motors is enough to heat the digesters to high temperatures. On the other hand, there is a problem with the stability of the digestion because a large part of the sludge is primary sludge that is rapidly converted to fatty acids. This means that there is a possibility that the digesters will acidify and thus will not produce methane. A solution to this problem is found by operating the digesters as thermophilic reactors (temperature > 45°) and not as mesophilic reactors (temperature around 37°). This will increase the reaction rate of the methane forming bacteria, avoiding problems with acidification. By operating them as thermophilic reactors, the retention time can also be reduced from 20days to 15days. Based on the preliminary simulations, it is also found that there will be enough heat so that the sludge concentration in the digestors does not has to be high. This has as result that normal gravity thickeners can be used to thicken the secondary sludge. This results in the following process flow.

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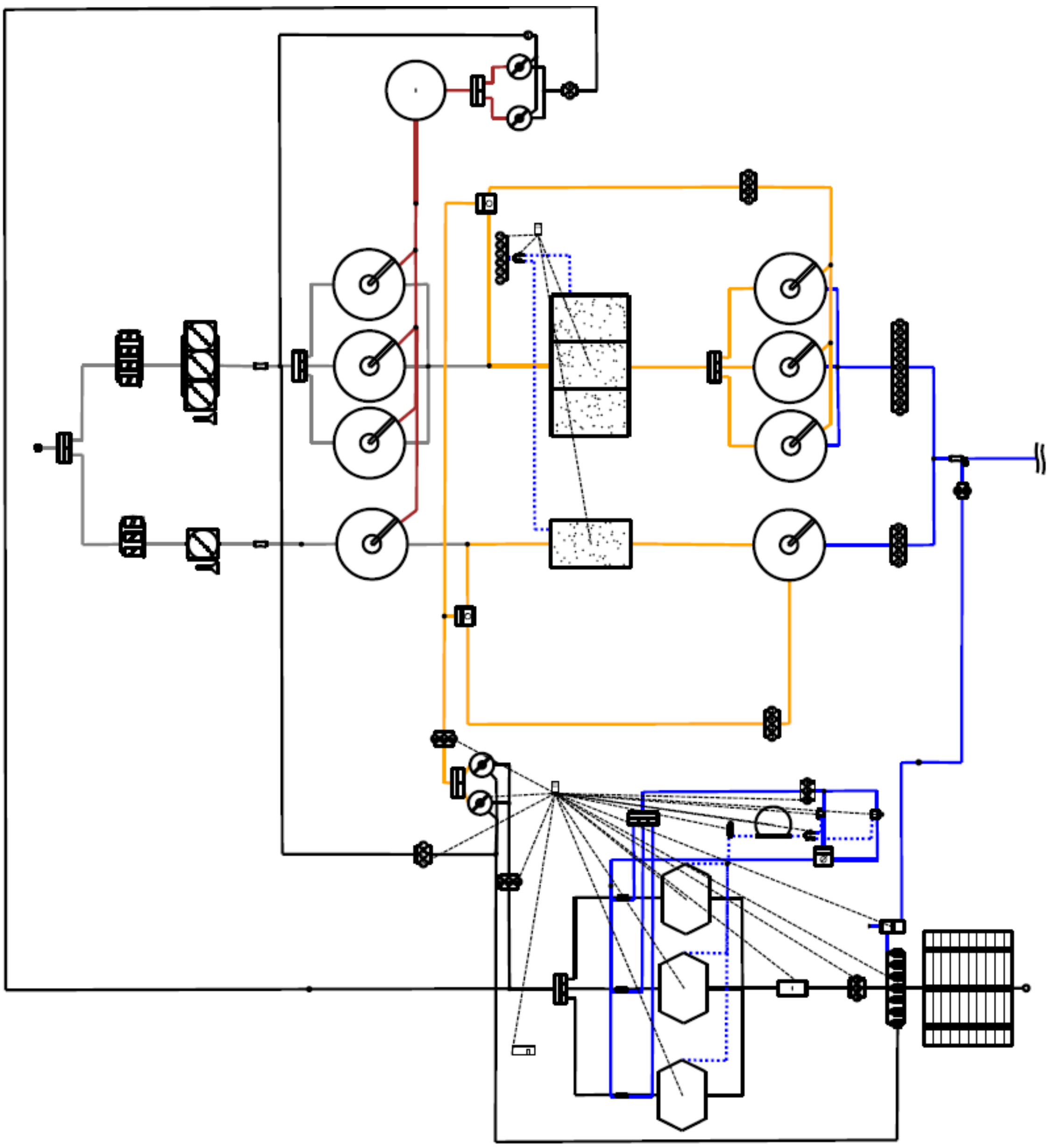

Figure 31: PFD of a conventional upgrade for nutrient removal and digestion

The primary sludge is thickened using the existing gravity thickeners. The secondary sludge is thickened with new gravity thickeners because the existing thickeners are not big enough to reach a high sludge concentration. After thickening, the sludge is heated and digested in three thermophilic digesters. After digestion, the sludge is stored and dewatered using centrifuges. The dewatered sludge is dried in the existing sludge during beds. The produced gas is stored and then primarily used to produce electricity in gas motors.

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3.4.2. Simulation results

The secondary sludge is thickened using two gravity thickeners that are operated at a surface load of 20kgDS/m²/d. This results in two thickeners with a diameter of 32m. It is assumed that a dry solids concentration of 3%DS can be obtained with these thickeners. After mixing with the thickened primary sludge, a dry solids concentration of 4.5%DS is assumed.

The thermophilic digesters are operated at a temperature of +/-45°C. With a retention time of 15days, a volume of 3x12,500m³ is calculated. It is simulated that about 20% of the sludge can be converted into gas, resulting in a heat content of the produced gas of 4.9MW. Using a gas motor, this can be converted to 2.1MW of electricity and 2.1MW of heat. The heat can be used to heat up the digesters. After digesting, a sludge production of 85TDS/d is found. This sludge is dewatered using 6+1 centrifuges with a capacity of 25m³/h each. Dewatering all the sludge reduces the amount of sludge that has to be stored during the wet season. It is estimated that during the 3month period, about 25,000m³ of sludge will accumulate. Because all the sludge is dewatered, the hydraulic loading of the sludge drying beds is decreased. This will result in a higher dry solids concentration of the dried sludge. It is simulated that a concentration of 80%DS can be reached. This increases the caloric value of the sludge, increasing its value as energy carrier.

The sludge liquors are returned back to the main process. This increases the load to the plant, resulting in a slightly larger aeration volume (160,000m³) and higher aeration energy consumption (723kW).

Figure 32: Layout of a conventional upgrade for nutrient removal and digestion

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3.4.3. COST ESTIMATION

Based on European prices, the investment is estimated in Table 18.

Item	Cost estimate (kEUR)
Aeration tank 1 civil	18,000
Aeration tank 1 EM	6,500
Aeration tank 2 civil	6,400
Aeration tank 2 EM	2,400
Blower station	3,600
Gravity thickeners and pumps	2,000
Digesters and gas circuit	21,000
Dewatering	3,000
Electrical works	4,000
Piping and others	5,000
Total	71,900

Table 16: Investment cost estimation of conventional upgrade for nitrogen removal and digestion

The operation cost drivers are summarised in Table 17.

	Quantity	Unit cost	Cost (kEUR)
Aeration	6,300 MWh/y	280	1,764
Centrifuges	2,008 MWh/y	280	562
Other consumers	2,190 MWh/y	280	613
Energy production (own consumption	10,498 MWh/y	-280	-2,939
Energy production (export)	7,639 MWh/y	-140	-1,069
Sludge production	37,200T/y	10	372
PE for dewatering	466T/y	1,200	559
Total			-138

Table 17: Operation cost drivers of a conventional upgrade for nitrogen removal and digestion

The plant will thus be a net electricity producer of about 7,6GWh/y.

Compared to the present situation, the operational cost is reduced with (3584+138=) 3,722kEUR/y. This results in a return period of (71900/3722=) 19years. This is financially not an interesting project. However, a much better effluent quality is generated, resulting in economic and ecological benefits by increasing the reuse potential. Also, sludge with an estimated dry solids concentration of 80%DS is generated. This has a higher caloric value as in the present situation, increasing the reuse potential as an energy source.

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CHAPTER 4 UPGRADES USING ANDICOS

4.1. INTRODUCTION

At the moment of making this document, not many relevant results of the pilot plant are available. In the following analysis, we assume the following:

- The IPC membranes remove all the suspended solids and suspended COD fractions from the wastewater;
- The IPC membranes can be operated at a flux of 25l/m²/h;
- The retentate of the IPC membranes can reach a concentration of 5000mg/l in the reactor;
- The retentate can be thickened to 1.2%DS (12,000mg/l) of suspended solids without adding a relevant amount of chemicals;
- The design is done using IPC80 multimode membrane stacks in a tank with a depth of 5m, a width of 3m and a length of 1m per stack. The stacks are arranged into different lanes depending on the capacity; and,
- It is assumed that the biological reaction within the membrane compartment can be neglected.

4.2. UPGRADE TO BOD-REMOVAL WITHOUT DIGESTION

4.2.1. CONFIGURATION

In this first scenario, the IPC membranes are placed downstream of the existing PSTs without any biological treatment. The goal is to achieve partial BOD-removal to comply with the old standard of 100mgBOD/l. The PFD of this scenario is given in the next drawing.

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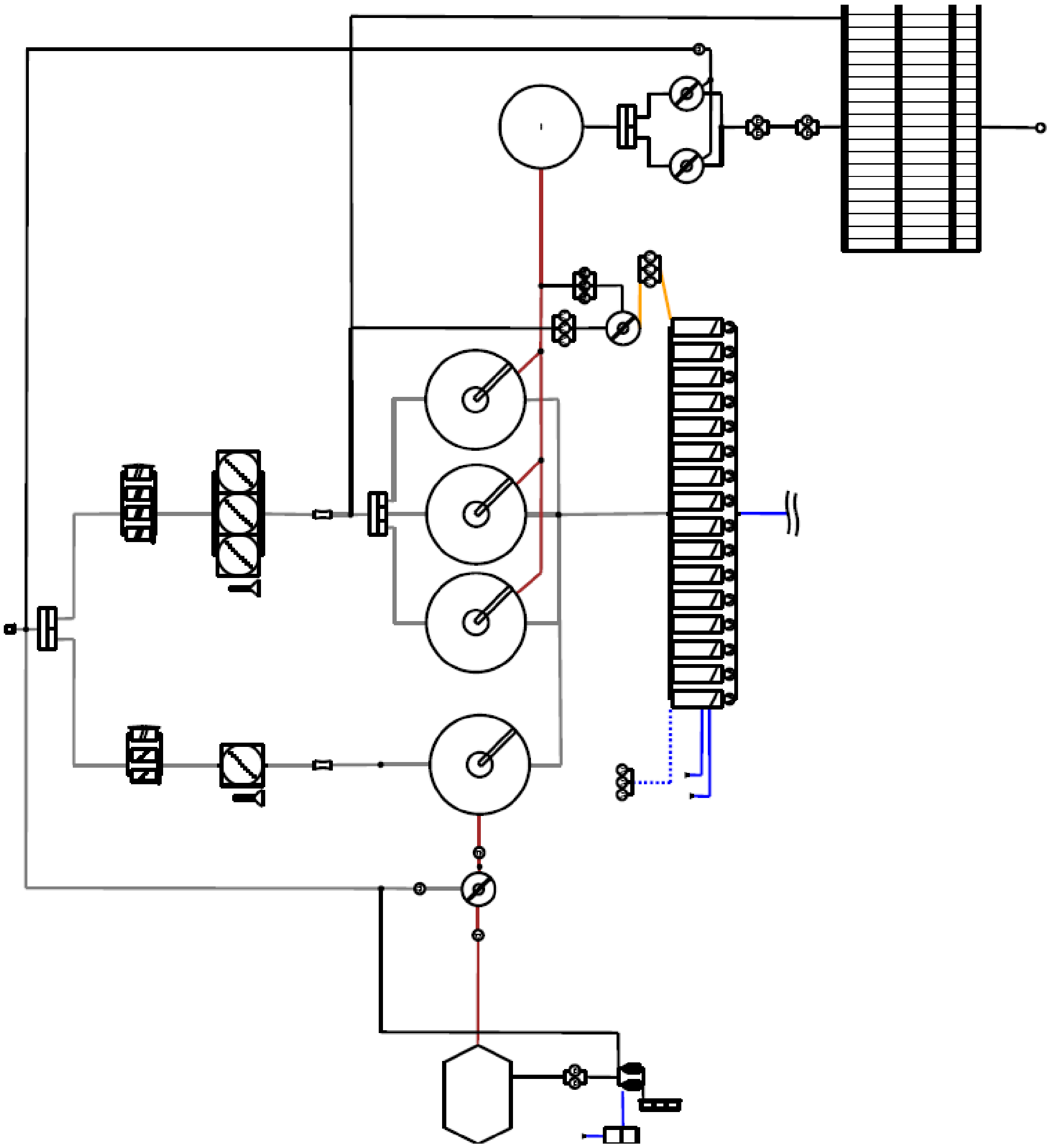

Figure 33: PFD of Andicos for BOD-removal

The membrane tank has about the same dimensions as one of the aeration tanks. However, it needs to have a depth of 5m and needs many internal structures. A new tank thus will need to be constructed at the location of one of the existing aeration tanks. The retentate of the membranes will have to be thickened before it can be processed in the sludge treatment. One of the existing clarifiers could be used for this purpose. The membranes need to have a complex system of pumps for filtrate extraction and backwash. This can be combined with the function of effluent lifting station. The existing effluent lifting station will not be used in this scenario.

A possible layout of this scenario is given in the next drawing.

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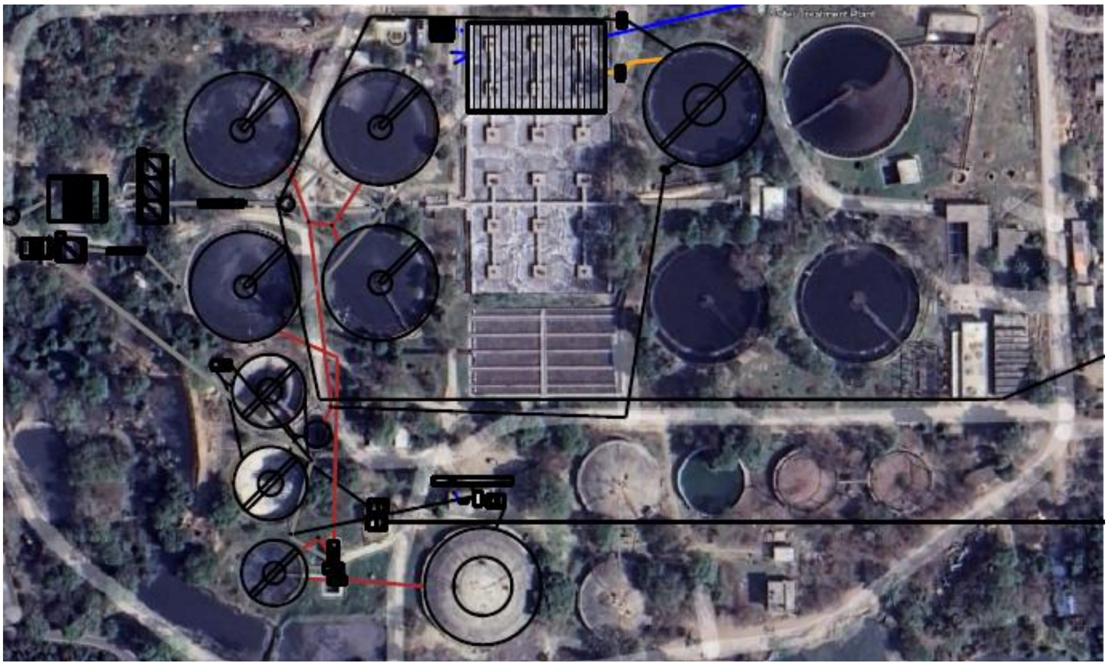

Figure 34: Layout of Andicos for BOD-removal

4.2.2. SIMULATION RESULTS

Based on the assumed influent composition, it is found that the soluble biodegradable COD (Ss) concentration in the influent is (18000/87=)207mg/l. Taking into account a ratio of 1.5 between the BOD and Ss, the soluble BOD concentration in the influent is estimated at 138mg/l. This already indicates that, in this scenario, the plant will not comply to the effluent standard because there is no process that removes the soluble BOD. Taking into account that there are also some anaerobic processes in the sludge treatment, the effluent BOD will even be higher than the influent soluble concentration. Based on the model, an effluent BOD concentration of 155mg/l is estimated.

4.2.3. COST ESTIMATION

Although this scenario doesn't comply to the effluent standards, the costs are estimated.
In the next table, the investment cost of the scenario is estimated.

Item	Cost estimate (kEUR)
Membranes	19,000
Membrane tank, pumps and piping	7,500
Blower station	1,000
Electrical works	2,000
Piping and others	3,000
Total	32,500

Table 18: Investment cost estimation of Andicos to BOD removal

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The investment cost is thus higher than a conventional upgrade to full BOD-removal (8MEUR). The needed energy for membrane cleaning (blowers) is estimated at about 400kW. This is the same as for the conventional upgrade. This scenario is thus not economically viable and does not comply to the present standards.

4.3. Upgrade to N removal without digestion

4.3.1. Configuration

Based on the previous scenario, it is concluded that a further treatment step, downstream of the Andicos membranes, is needed. On the scale of the Jajmau plant, it is not possible to use an extensive system (reed beds, lagoons,….). A full activated sludge plant will be needed.

Assuming that ANDICOS removes all suspended COD and taking into account the existing aeration volumes, the sludge age increases a lot. This results in the fact that the existing aeration volume is big enough to fully nitrify and denitrify. In principle, the aeration volume could be decreased to only get BOD-removal. However, the retention time in the aeration would be that low, that the whole system becomes unstable. A scenario with Andicos and only full BOD-removal is thus not possible.
To simplify the nitrification/denitrification process, the 4 aeration tanks will be joined into one process. The PFD of this process is given in Figure 35.

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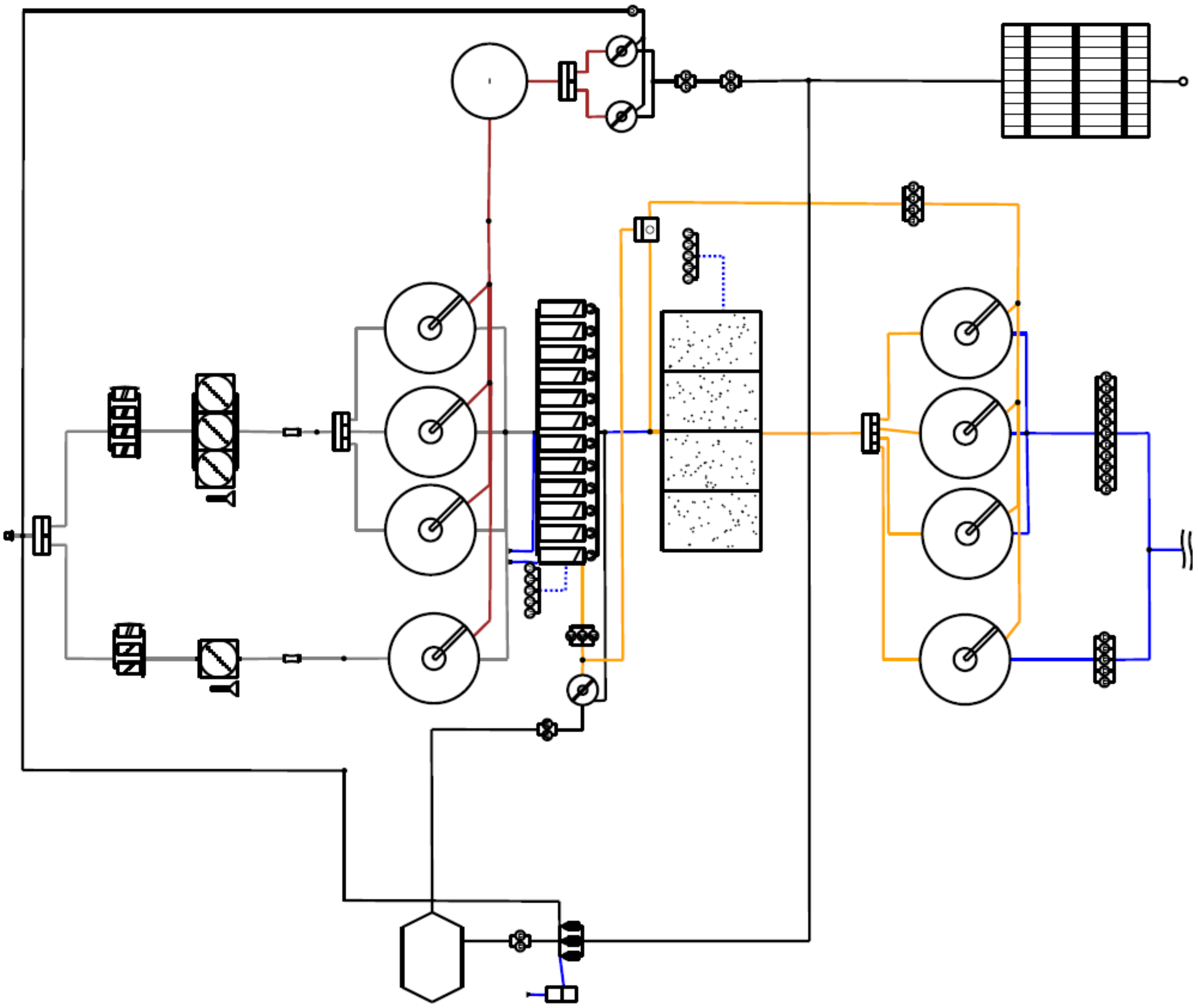

Figure 35: PDF of ANDICOS for nitrogen removal

The IPC membrane units are placed downstream of the existing primary clarifiers. The retentate of the membranes is pumped to a gravity thickener in which the sludge is thickened together with the secondary sludge to 3.5%DS and further dewatered with centrifuges. The existing gravity thickener on line 2 is not reused because it is too small.

The filtrate of the ANDICOS, combined with the top water of the new gravity thickener flows to the existing aeration tanks which are equipped with a new aeration system. From the aeration tanks the water/sludge mixture flows to the 4 existing clarifiers. The sludge is returned back to the aeration tanks. A possible layout is given in Figure 36.

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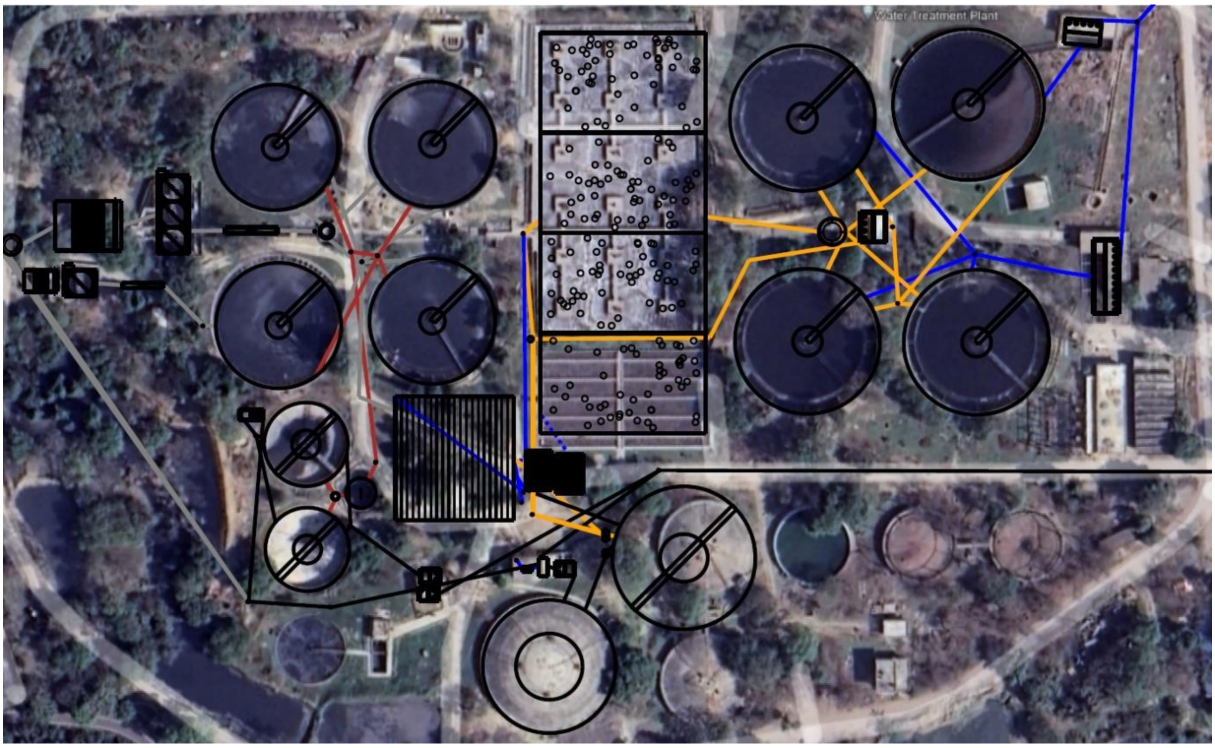

Figure 36: Layout of Andicos for nitrogen removal

4.3.2. Simulation results

It is simulated that a total nitrogen standard of less than 10mg/l can be reached with a sludge concentration of about 2.5g/l. It is also calculated that a denitrification percentage of about 70% is needed. In the present configuration of the aeration tanks, that will be difficult (especially in line 2 with only 1 aeration tank). The control of the system would be less complicated if it is seen as one system with 4 aeration tanks in parallel or in some kind of alternating configuration. Also, the sludge recirculation system can be simplified because the existing recirculation pumping stations are too big.

It is found that the capacity of the existing centrifuges is not enough, and an additional centrifuge is needed.

4.3.3. Cost estimation

In this scenario, the investment will be:

- Installing the ANDICOS membranes with thickening;
- Install a new aeration system in the existing aeration tanks;
- Install a new centrifuge; and,
- Some minor changes in the piping.

The investment is estimated in Table 19.

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Item	Cost estimate (kEUR)
Membranes	19,000
Membrane tank, pumps and piping	7,500
Blower station membranes	1,000
Blower station aeration	3,000
Aeration system	9,000
Thickener	1,500
Centrifuge	500
Electrical works	3,000
Piping and others	3,000
Total	47,500

Table 19: Cost estimation of ANDICOS for nitrogen removal

The operation cost drivers are summarised in Table 17.

	Quantity	Unit cost	Cost (kEUR)
Aeration	4,800 MWh/y	280	1,344
Andicos	3,900 MWh/y	280	1,092
Centrifuges	777 MWh/y	280	218
Other consumers	2,190 MWh/y	280	613
Sludge production	45,300T/y	10	453
PE for dewatering	158T/y	1,200	190
Total			3,910

Table 20: Operation cost drivers of ANDICOS for nitrogen removal

4.4. Upgrade to N removal with digestion

4.4.1. Configuration

Based on the results of the simulation of digestion combined with a classical upgrade, it is found the digestion can have good results. In an ANDICOS system, the production of "primary" sludge is even increased compared to the classical upgrade because the membranes are removing 100% of the suspended solids. Compared to the scenario with a classical upgrade, the problem with acidification even increases because the part of primary sludge increases further. As in the classical upgrade, operating the digesters as thermophilic digesters can solve the problem of acidification. As in the previous digestion scenario, it is assumed that the sludge is dewatered using centrifuges.
Based on the above issues, the PFD in Figure 37 is made.

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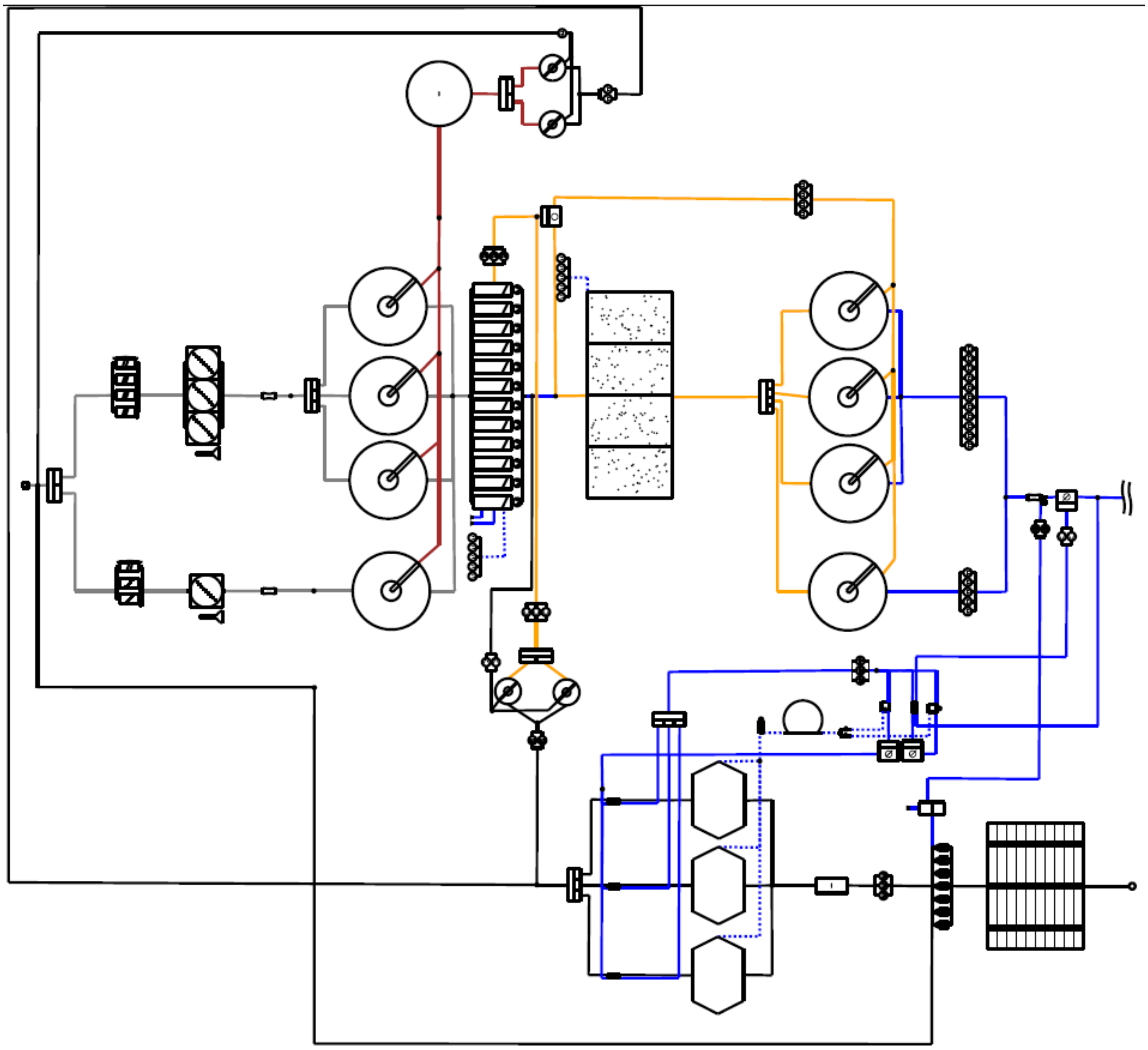

Figure 37: PFD of ANDICOS for nitrogen removal and digestion

4.4.2. SIMULATION RESULTS

Due to the digestion, nitrogen in the sludge is released and send back to the main treatment. It is simulated that the existing aeration tanks have enough volume to fully nitrify and denitrify the wastewater if the sludge concentration in the tank can be kept at 3g/l. This should be possible with the existing secondary clarifiers. A possible layout is given in Figure 38.

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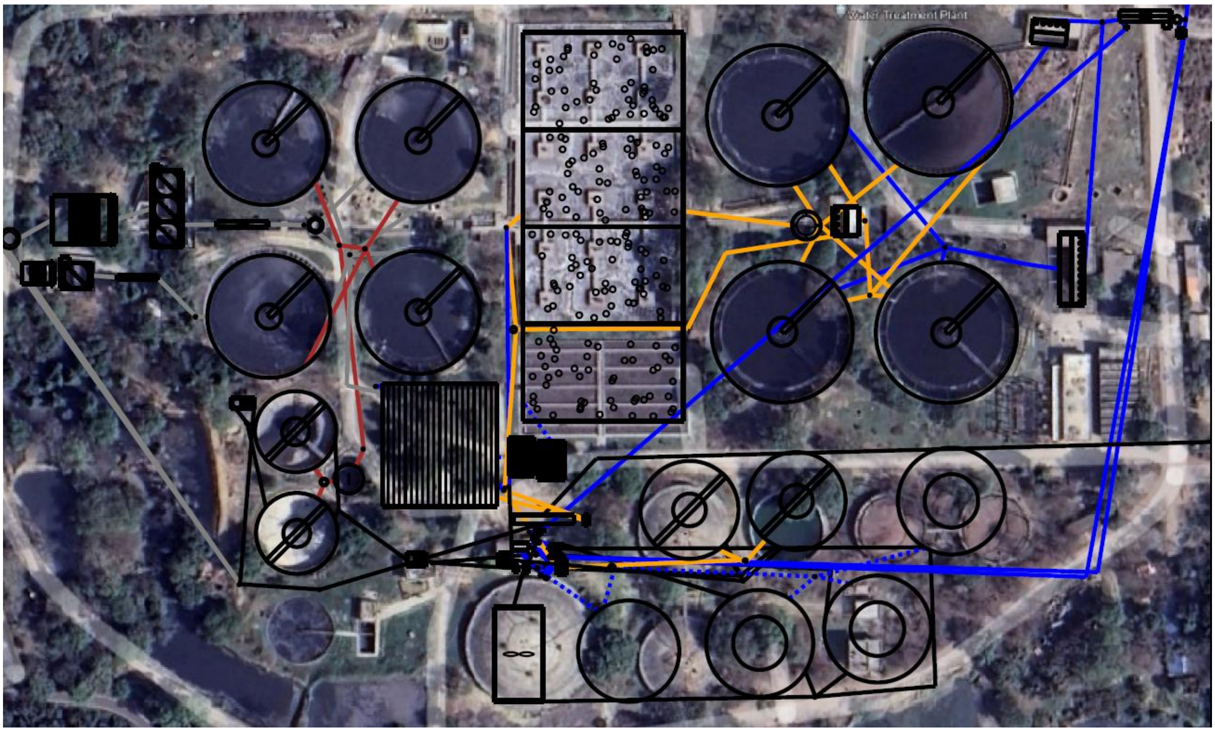

Figure 38: Layout of ANDICOS for nitrogen removal and digestion

It is simulated that the digesters can reduce the amount of sludge with 22%, producing gas with a heat content of 6MW. This can be converted to 2.5MW electrical power and 2.6MW of heat in the cooling water. The electricity consumption of the aeration is estimated at 600kW and the 450kW for the aeration of the IPC membranes.

4.4.3. COST ESTIMATION

In this scenario, the investment will be:

- Installing the Andicos membranes with thickening;
- Install a new aeration system in the existing aeration tanks;
- Construction of new digesters;
- Construction of new dewatering centrifuges; and,
- Some minor changes in the piping

The investment is estimated in Table 21.

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Item	Cost estimate (kEUR)
Membranes	19,000
Membrane tank, pumps and piping	7,500
Blower station membranes	1,000
Blower station aeration	3,000
Gravity thickeners and pumps	2,500
Digesters and gas circuit	22,000
Dewatering	3,000
Aeration system	9,000
Electrical works	3,000
Piping and others	3,000
Total	73,000

Table 21: Cost estimation of ANDICOS for nitrogen removal and digestion

The operation cost drivers are summarised in Table 22.

	Quantity	Unit cost	Cost (kEUR)
Aeration	5,300 MWh/y	280	1,484
Andicos	3,900 MWh/y	280	1,092
Centrifuges	1,984 MWh/y	280	556
Other consumers	2,190 MWh/y	280	613
Energy production (own consumption)	13,374 MWh/y	-280	-3,745
Energy production (export)	8,719 MWh/y	-140	-1,221
Sludge production	36,900T/y	10	369
PE for dewatering	462T/y	1,200	554
Total			-298

Table 22: Operation cost drivers of ANDICOS for nitrogen removal and digestion

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CHAPTER 5 UPGRADE WITH SFD MBR

5.1. INTRODUCTION

From previous simulations, it is clear that a scenario using SFD-MBRs is not applicable in the case only BOD-removal is required because the existing aeration tanks are large enough to achieve full BOD-removal using the existing secondary clarifiers if enough aeration is installed. In the case of the Jajmau plant, the SFD-MBRs could be useful in the case nitrogen removal is required because the sludge concentration in the aeration tanks can be increased and nitrogen removal could be achieved without having to increase the aeration volume, thus avoiding large civil works.

At the moment of making this document, not many relevant results of the pilot plant are available. In the following analysis, we assume the following:

- The standard Xylem model 2212, with 12 disks and 39m² membrane surface is used.
- Although, until now, the pilot plant is only operated at a flux of 500l/m²/h, the producer Xylem is proposing a flux of 1,500l/m²/h. In this study, the calculations are done using a flux of 1,500l/m²/h.
- One unit has a construction width of 5x2.4x2.6m.
- The energy consumption of the membrane unit is 0.07kWh/m³.
- Each unit needs 125m³/h of air at a pressure of 180mBar.
- It is possible to reach a sludge concentration of 10g/l in the membrane reactor.
- The producer, Xylem, indicates a budget cost of 115,000EUR/unit.

5.2. UPGRADE TO NITROGEN REMOVAL

5.2.1. INTRODUCTION

In this scenario, it is assumed that the four existing aeration tanks are converted to SFD-MBRs. This is done by placing the membranes in the existing aeration tanks. The aeration tanks are converted to fine bubble aeration systems because the existing aeration is not enough to reach nitrogen removal. The existing mechanical aeration can also not be extended to reach the needed capacity. The primary sludge of all clarifiers is sent to the existing gravity thickeners of Line 1. The capacity of the gravity thickeners is not enough to thicken the secondary sludge. Because the secondary clarifiers are not needed in a SFD-MBR process, one of these clarifiers can be used as thickener for the secondary sludge.

This gives the following PFD.

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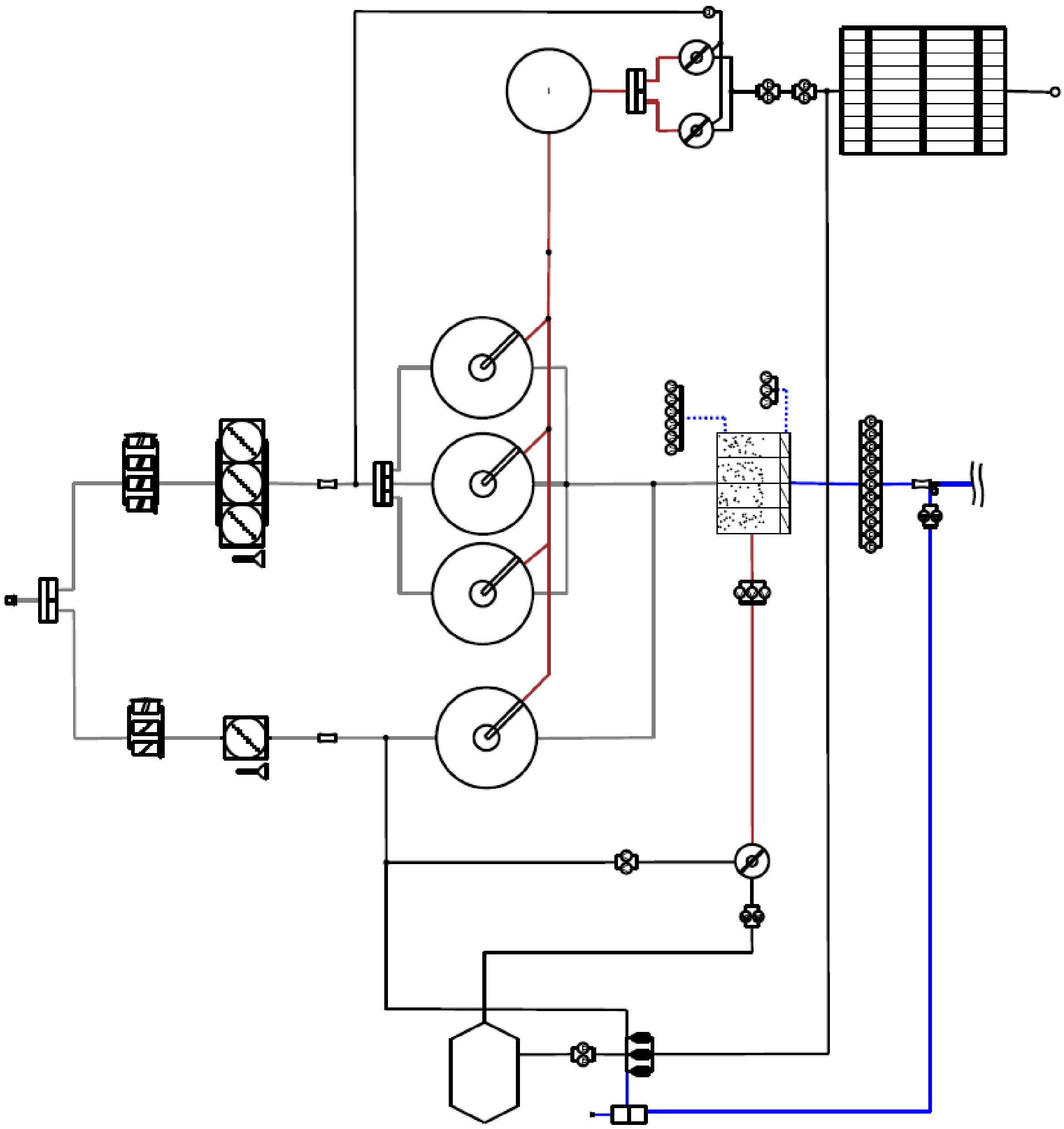

Figure 39: PFD of upgrade using SFD-MBRs for nitrogen removal

By placing the membranes in the aeration tanks, civil costs can be avoided.

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Figure 40: Layout of upgrade using SFD-MBRs for nitrogen removal

5.2.2. Simulation results

It is simulated that it is needed to operate the aeration tank at a sludge concentration of 10g/l to achieve full nitrogen removal (TN<10mg/l). It is also simulated that a part of the nitrogen removal follows the nitrite path. This means that the nitrogen is only nitrified to nitrite (NO2) and then denitrified. This has as advantage that the needed aeration energy is reduced (average of 550kW compared to 700kW for a classical upgrade). However, there is also the disadvantage that some nitrite will be in the effluent. This could jeopardous the reuse of the effluent because nitrite is poisonous.

To reach a maximum flow of 173,000m³/d, 128 SFD-MBR filters are needed. This corresponds to thirty-two filters per aeration tank. If this technology will become more mature, the product gamma will probably be extended to larger units, reducing the number of units and probably also the cost. To become viable for this range of capacity, the surface per unit should be about 8 times the present capacity, resulting in a submerged surface of about 300m²/unit.

5.2.3. Cost estimation

The investment cost of this scenario is given in Table 23.

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Item	Cost estimate (kEUR)
SFD membranes	14,720
Civil works in the aeration tanks	2,000
EM works in the aeration tanks	8,500
Blower station aeration	3,500
Blower station membranes	200
Centrifuge	500
Electrical works	2,000
Piping and others	1,000
Total	32,920

Table 23: Investment cost estimation of SFD-MBRs for nitrogen removal

The operation cost drivers are summarised in Table 17.

	Quantity	Unit cost	Cost (kEUR)
Aeration	4,700 MWh/y	280	1,316
SDF	2,300 MWh/y	280	644
Centrifuges	827 MWh/y	280	232
Other consumers	2,190 MWh/y	280	613
Sludge production	44,900T/y	10	449
PE for dewatering	153T/y	1,200	184
Total			3,438

Table 24: Operational cost drivers of SFD-MBRs for nitrogen removal

5.3. Upgrade to nitrogen removal and digestion

5.3.1. Introduction

In this scenario, it is assumed that the four existing aeration tanks are converted to SFD-MBR. This is done by placing the SFD-MBRs in the existing aeration tanks. The aeration tanks are converted to fine bubble aeration systems because the existing aeration is not enough to reach nitrogen removal. The existing mechanical aeration can also not be extended to reach the needed capacity. The primary sludge of all clarifiers is sent to the existing gravity thickeners of Line 1. It is assumed that a gravity thickener on sludge of a SFD-MBR cannot reach high sludge concentrations because the sludge is not selected on settling. To achieve a higher concentration to allow digestion, mechanical gravity table thickeners are installed to thicken the sludge to 5-6%DS. The thickened sludge is digested in three new digesters. The digested sludge is dewatered using centrifuges. The dewatered sludge is dried on the existing sludge drying beds.

This gives the following PFD.

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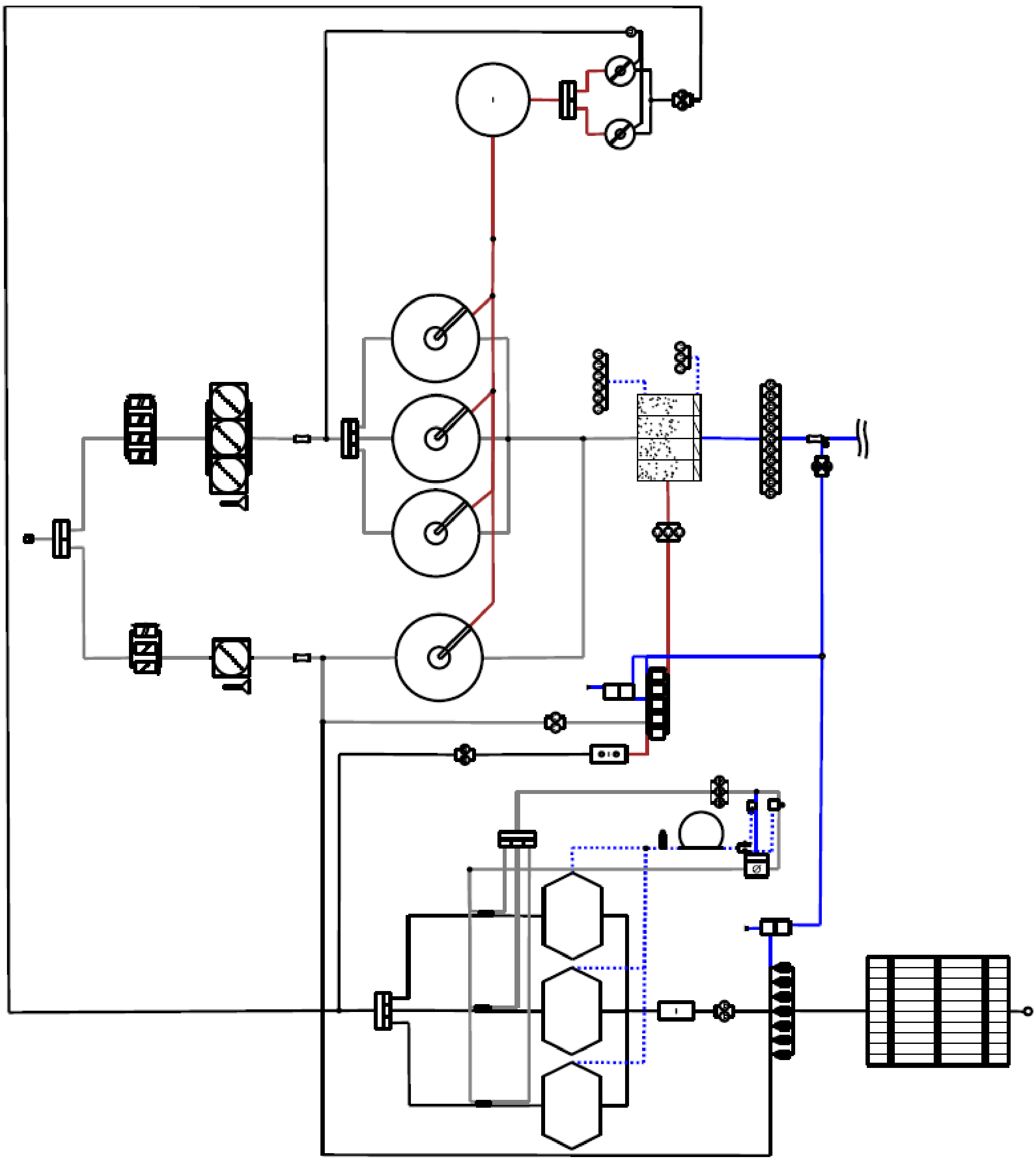

Figure 41: PFD of upgrade using SFD-MBRs for nitrogen removal and digestion

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Figure 42:Layout of upgrade using SFD-MBRs for nitrogen removal and digestion

5.3.2. SIMULATION RESULTS

It is simulated that it is needed to operate the aeration tank at a sludge concentration of 10g/l to achieve full nitrogen removal (TN<10mg/l). The energy consumption of the aeration is slightly higher (560kW) than in the previous scenario due to the increased load of the sludge liquors.

It is simulated that the digesters can reduce the amount of sludge with 21% with a retention time of 18d, producing gas with a heat content of 5.3MW. This can be converted to 2MW electrical power and 2.3MW of heat in the cooling water.

5.3.3. COST ESTIMATION

The investment cost of this scenario is given in Table 25.

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Item	Cost estimate (kEUR)
SFD membranes	14,720
Civil works in the aeration tanks	2,000
EM works in the aeration tanks	8,500
Blower station aeration	3,600
Blower station membranes	200
Mechanical thickeners	1,500
Digesters incl. gas circuit	21,000
Centrifuge	3,000
Electrical works	3,000
Piping and others	3,000
Total	60,520

Table 25: Investment cost estimation of SFD-MBRs for nitrogen removal and digestion

The operation cost drivers are summarised in Table 26.

	Quantity	Unit cost	Cost (kEUR)
Aeration	4,900 MWh/y	280	1,372
SDF	2,300 MWh/y	280	644
Centrifuges	1,740 MWh/y	280	487
Other consumers	2,190 MWh/y	280	613
Energy production (own consumption	11,130 MWh/y	-280	-3,116
Energy production (export)	8,560 MWh/y	-140	-1,198
Sludge production	36,900T/y	10	369
PE for dewatering	527T/y	1,200	632
Total			-197

Table 26: Operational cost drivers of SFD-MBRs for nitrogen removal and digestion

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CHAPTER 6 CONCLUSIONS

Several different scenarios using conventional, Andicos and SFD-MBR technologies have been generated and applied to the case of the Jajmau Kanpur plant. Also, scenarios with and without digestion are generated. Due to a lack of local information, the scenarios are generated using the following assumptions:

- All costs are calculated using European prices;
- It is assumed that the historical water quality data from the period 2009-2013 are still valid.

We know that the water characteristics of STP Jajmau have in the last two years improved substantially due to the success of stopping the illegal discharges of tannery wastes into the urban sewage network, but the tannery cluster remains in place, surrounding the STP. The new CETP Jajmau being built has insufficient capacity to deal with the tannery cluster effluent, therefore the chances are high that the water quality characteristics, based on the data collated from the period 2009-2021, can return.

For the Andicos scenarios, it is assumed that:

- The IPC membranes remove all the suspended solids and suspended COD fractions from the wastewater;
- The IPC membranes can be operated at a flux of 25l/m²/h;
- The retentate of the IPC membranes can reach a concentration of 5000mg/l in the reactor;
- The retentate can be thickened to 1.2%DS (12,000mg/l) of suspended solids without adding a relevant amount of chemicals;
- The design is done using IPC80 multimode membrane stacks in a tank with a depth of 5m, a width of 3m and a length of 1m per stack, with the stacks are arranged into different lanes depending on the capacity; and,
- The biological reaction within the membrane compartment can be neglected.

For the SFD-MBR scenarios, it is assumed that:

- The standard Xylem model 2212, with 12 disks and 160m² membrane surface is used;
- The flux is 1,500l/m²/h;
- One unit has a construction width of 5x2.4x2.6m;
- The energy consumption of the membrane unit is 0.07kWh/m³;
- It is possible to reach a sludge concentration of 10g/l in the SFD-MBR; and,
- A cost of 115,000EUR/unit is used.

For the digestion, it is assumed that:

- There is no inhibition of the digestion due to heavy metals and a standard model can be used;
- Due to the high proportion of primary sludge a thermophilic digestion is needed.
- The total gas production is used to produce electricity; and,
- After digestion, the sludge is dewatered using centrifuges and dried on existing sludge drying beds.

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In Table 27, the financial results of the scenario analysis are summarised. The Net Present Value is calculated using a financing cost of 3% above inflation over a period of 30 years with a reinvestment of the equipment and management costs (EM) after 15 years.

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Scenario	Investment cost (kEUR)			Operational cost (kEUR/y)	NPV (kEUR)
	EM	Civil	Total		
Present situation	0	0	0	3,584	68,202
Full BOD removal with classical technology (upgraded aeration)	8,000	0	8,000	2,615	62,369
Full nitrogen removal with classical technology	13,700	25,700	39,400	3,270	108,768
Full nitrogen removal with digestion and classical technology	30,500	41,400	71,900	-138	85,633
ANDICOS with BOD-removal	Non-compliant				
ANDICOS without digestion to full nitrogen removal	35,500	12,000	47,500	2,818	121,220
ANDICOS with digestion to full nitrogen removal	49,000	24,000	73,000	-298	94,849
SFD MBR in the existing aeration tanks	29,420	3,500	32,920	3,438	115,184
SFD MBR in the existing aeration tanks and digestion	45,520	15,000	60,520	-197	82,549

Table 27: Financial results of the scenarios

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In Table 28 , the economic and ecological parameters of the different scenarios are given.

Scenario	Energy (MWh/y)			Sludge		Effluent quality
	Consumption	Production	Net consumption	Production (T/y)	%DS	
Present situation	9,590	0	9,590	71,700	52	BOD<100
Full BOD removal with classical technology (upgraded aeration)	6,135	0	6,135	74,900	50	BOD<10
Full nitrogen removal with classical technology	8,612	0	8,612	71,500	50	BOD<10 TN<10
Full nitrogen removal with digestion and classical technology	10,498	18,137	-7,639	37,200	80	BOD<10 TN<10
ANDICOS with BOD-removal	Non-compliant					
ANDICOS without digestion to full nitrogen removal	7,767	0	7,767	45,300	80	BOD<10 TN<10
ANDICOS with digestion to full nitrogen removal	9,474	22,093	-12,619	36,900	80	BOD<10 TN<10
SFD MBR in the existing aeration tanks	7,717	0	7,717	44,900	80	BOD<10 TN<10
SFD MBR in the existing aeration tanks and digestion	8,830	19,690	-10,860	36,900	80	BOD<10 TN<10

Table 28: Economic and ecological parameters of the scenarios

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From the above, we can conclude that an investment in an efficient aeration system has a positive financial impact (lower NPV as present situation). It also has a positive economic and ecological impact by using less energy and producing effluent with a better quality (BOD<10). The sludge production increases slightly because more secondary sludge is produced.

We can also conclude that sludge digestion has a positive financial impact. These scenarios all result in a net production of electricity, reducing the operational cost. In these scenarios we also assumed that the sludge will be dewatered with centrifuges after the digestion. This reduces the loading of the sludge drying beds, resulting in a higher dry solids concentration of the sludge after the beds. This increases the viability of reusing the sludge as energy carrier.

Although the present standards only require BOD removal, it is clear that India is in transition towards nutrient removal. It is found that from the scenarios with nutrient removal, the scenario with SFD-MBR has the lowest NPV. However, the difference with the classical upgrade is minor. If we assume that the cost of the SFD-MBR modules increases with 15%, the NPV of both scenarios is equal. The actual cost of the modules is thus a very important parameter for the viability of this technology. If the cost can be further decreased by constructing larger modules, the SFD-MBR technology can become a very promising technology.

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