TREATMENT OF LANDFILL LEACHATE WITH TUBULAR REVERSE OSMOSIS SYSTEM

ADVANCED MEMBRANE FILTRATION TECHNOLOGY

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PCI Membranes

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1.Introduction

Several technologies have been developed and implemented over the past years for the treatment of landfill leachate; from biological treatment (aerobic, anaerobic, nitrification and denitrification treatment), chemical treatment (lime precipitation, oxidation or adsorption onto activated carbon), to physical treatment (Evaporation, stripping, combustion or application of membrane technology) or even a combination of any these solutions; such as Membrane Bioreactor (MBR).

Landfill waste can be generated from different sources, this can be from the disposal/collection of industrial effluent and contaminated sludge waste, municipal waste products, digestate from biorefineries, waste from recycling industries: plastic/rubber waste, impregnated wood and so on. Solid waste collected in a landfill will undergo several stages of decomposition, which are biological, chemical and physical stages; the by-products of which are leachate (liquid phase), CO2 & CH4 (gas phase) and the residual solid waste.

Leachate is produced following the percolation of mainly rainwater and sometimes ground or surface water through the landfill waste. The design of a landfill site depends on the type of waste and the location. Sealing the bottom of a landfill site and collecting the leachate has become a conventional technology; this makes it easier to maximize the production of landfill gas, to collect and treat the leachate with a suitable technology. In most cases, the resulting leachate stream is a complex mixture of hazardous pollutants; such as a high concentration of organic matter (both biodegradable and non-biodegradable carbon, or simply biological and chemical oxygen demand: BOD & COD), heavy metals, ammonia-nitrogen, adsorptive organic halogen compounds (AOX), humic acids, chlorinated organic and inorganic salts, colloidal and suspended solids and so on.

Due to the nature and composition of landfill leachate and also, as a result of several stringent environmental legislations, it is becoming more difficult to dispose leachate wastewater into sewer networks; where there is a limitation to the concentration of ammonia-nitrogen, methane and other compounds that can affect the integrity of the sewage pipes and hence, the wastewater treatment plant downstream. To river or water course; where high concentration of BOD, COD, nitrogen, phosphorus and other compounds can lead to the deterioration of aquatic life, surface and ground water quality.

Most industries are now facing the so-called ZERO waste or discharge limit and forced to implement a more efficient method known as 3R – Model (Reduce, recycle and reuse). Produced wastewater should be treated and reused where possible. In the case of leachate wastewater, the treated or purified water can be used as part of other production processes, such as: steam generation for evaporators, cooling tower cooling water or even as a wash water supplement for some production stages.

2. Feed Stream Composition and Type of Leachate

In order to select the most adequate treatment for a landfill leachate, it is important to outline some of the critical factors characterizing a leachate; which are its composition and the volumetric flow. A leachate composition depends on the origin of the waste, biological and chemical activities taking place in the landfill, as well as the design and the age of the landfill. Whilst the volumetric flow of a leachate is mostly influenced by seasonal variation, temperature and the location of the landfill site.

Defining the types of leachate depends on the degradation activities occurring at the landfill site. The initial stage also known as dilute phase is characterised by a short period of time (few days/months) during which an aerobic phenomenon takes place and this phase shows the lowest COD (< 500 mg/l) or contaminant possible, but with high CO2 production. The following stage is the so called acetic/acidic phase, during which the organic substances are degraded into fatty acid, carbon dioxide and hydrogen gas. This occurs in an anaerobic state, between six months to three years and resulting in the highest COD (6000 – 60000 mg/l), BOD and heavy metals production. The subsequent stage is the so-called methanogenic phase, during which the concentration of fatty acids, hydrogen and CO2 decreases as the production of methanogenic gas occurs. The COD concentration in this case is between 500 – 4500 mg/l.

Based on the seasonal variation and composition of the leachate outlined in Table 1 below, this leachate is understood to be in a dilute phase due to the low concentration of COD, solids & salt contents. This article is based on a landfill leachate project completed with one of the feed-stream outlined in Table 1.

Table 1: Composition & Average Seasonal Variation of Leachate.

Components	Unit	Winter 2017	Spring 2018	Summer 2018	Autumn 2018
Cyanide, CN-,	mg/l	0.005	0.005	0.005	0.005
COD_{Cr}	mgO_2/l	120	49.7	55	34.75
Mercury, Hg,	µg/l	0.135	0.1	0.2	0.1
Silver, Ag	mg/l	0.03	0.01	0.01	0.01
Arsenic, As	mg/l	0.011	0.012	0.032	0.013
Barium, Ba	mg/l	0.085	0.12	0.072	0.062
Cadmium, Cd	mg/l	0.001	0.001	0.01	0.001
Cobalt, Co	mg/l	0.004	0.007	0.0015	0.003
Chromium, Cr	mg/l	0.02	0.02	0.0075	0.009
Copper, Cu	mg/l	0.12	0.15	0.125	0.0525
Iron, Fe	mg/l	1.21	1.44	1.055	0.59
Potassium, K	mg/l	186.7	178	175	108
Lithium, Li	mg/l	0.515	0.234	0.21	0.21
Magnesium, Mg	mg/l	4.4	3.26	4.15	5.15
Manganese, Mn	mg/l	0.07	0.07	0.059	0.06
Molybdenum, Mo	mg/l	1.02	0.75	0.74	0.53
Sodium, Na	mg/l	1072	1174	1080	670
Nickel, Ni	mg/l	0.07	0.04	0.04	0.028
Phosphorous, P	mg/l	0.34	0.41	0.19	0.18
Lead Pb	mg/l	0.02	0.03	0.01	0.01
Sulphur, S	mg/l	377	454	440	280
Antimony, Sb	mg/l	0.02	0.02	0.035	0.014
Tin, Sn	mg/l	0.01	0.01	0.01	0.01
Vanadium, V	mg/l	0.01	0.011	0.03	0.01
Zinc, Zn	mg/l	1.03	0.21	0.22	0.043
Fluoride, F^-	mg/l	0.84	0.7	0.86	0.88
Chloride, Cl^-	mg/l	1166.3	1133.1	1105	692
Bromide, Br-	mg/l	9.3	6.4	6.4	4.05
Nitrate, NO_3^-	mg/l	4.7	4.7	4.5	4.5
Phosphate, PO_4^{3-}	mg/l	4	4.5	4.5	4.5
Sulphate, SO_4^{2-}	mg/l	1139.5	1235.2	1285	793
Solids	mg/l	27.95	25.9	18.5	10.4
Ammonium, NH4-N, CFA	mg/l	5.55	2.6	2.8	2.5
Hydrocarbons C10-C40	mg/l				
pH, 25°C		8.9	9.12	8.5	8
Conductivity, 25°C	µS/cm	5775	6404	5905	3950

3. The Problem

Due to the nature of the leachate described above and as a result of a more stringent environmental legislation that prohibit the discharge of this wastewater into a sewer network or nearby river/lake, a waste treatment company located in a Scandinavian region has decided to explore the most suitable treatment options available on the market.

Therefore, the reason to opt for a reliable and consistent technology that is able to process a feed flow of 204 m3/day by reducing this volume significantly (concentrating up to a final solid concentration of 20% – 30%), generate good quality water (with minimal COD, salt and heavy metals concentration) which can then be used as part of other production processes. Other factors that were being considered as well are: implementing a technology that is flexible enough to cope with variation in both feed composition and volume (due to the geographical location of the landfill site), the economical aspect: both capital and operational expenditures.

A two-week on-site trial and feasibility study was completed, using one of the PCI's reverse osmosis membranes: AFC99, a polyamide thin film composite membrane and a BRO/BUF pilot testing unit. Then all process and laboratory data collected during the trial were analysed in order to understand if the client requirements were being satisfied, a full-scale plant design and the capital and operational expenditure costs were also calculated.

4. Analysis of the problem and feasibility studies

A brief summary and comparison between the operating cost for treating a landfill leachate with a tubular membrane reverse osmosis system and an evaporation unit is also highlighted in this report.

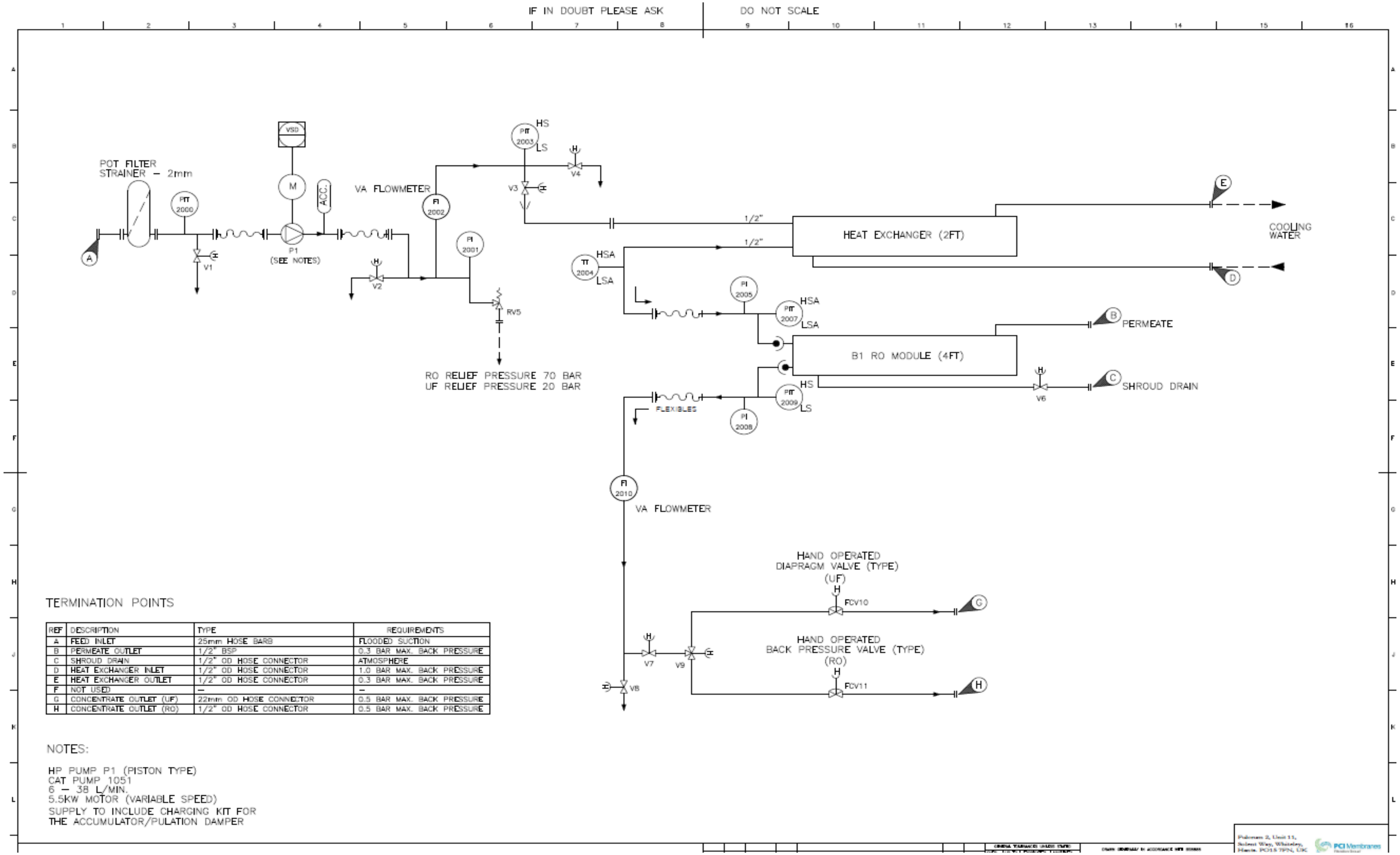
Prior to commencing the process trial on site, approximately a thousand litres of leachate were collected from a landfill pond into an IBC container. The leachate was tested for hydrogen sulphide, which was found to be circa 20 ppm. The IBC was then vented and agitated for 30 minutes prior to testing with the BRO/BUF pilot testing equipment.

As highlighted in Table 1, all feed streams tested during this trial had a pH ranging between 8 – 9. To prevent the precipitation of fouling and scaling material from the leachate unto the membrane layers, the pH was adjusted and maintained below 7 by adding up to 0.5ml/l of hydrochloric acid to the batch tank.

4.1. Membrane type and pilot unit set up

A PCI's reverse osmosis tubular membrane was selected for the process trial; AFC99 a polyamide thin film composite membrane which has a minimum sodium chloride rejection of 99%, and a maximum pressure and temperature rating of 64 bar & 80oC respectively and limited by the pilot plant unit.

A BRO/BUF pilot unit was used and as per the process & instrumentation diagram in figure 1 below, it comprises of a 4 ft B1 module (containing 18 perforated stainless-steel tubes in the form of a shell and tube arrangement. All 18 tubes are connected in series with a specially designed series flow end cap, with a membrane area of 0.9 m2), 2 ft shell and tube heat exchanger, a high-pressure positive displacement CAT 1051 pump (with a maximum flow of 38 L/min), 2 magnetic GMTX variable area flowmeters (one on the feed line and the other on the retentate line), a pulsation damper and pressure relief valve set at 40 bar and 70 bar respectively and a 2 mm filter strainer. An external feed tank of circa 220 litres was used with the unit.



TERMINATION POINTS

REF	DESCRIPTION	TYPE	REQUIREMENTS
A	FEED INLET	25mm HOSE BARB	FLOODED SUCTION
B	PERMEATE OUTLET	1/2" BSP	0.3 BAR MAX. BACK PRESSURE
C	SHROUD DRAIN	1/2" OD HOSE CONNECTOR	ATMOSPHERE
D	HEAT EXCHANGER INLET	1/2" OD HOSE CONNECTOR	1.0 BAR MAX. BACK PRESSURE
E	HEAT EXCHANGER OUTLET	1/2" OD HOSE CONNECTOR	0.3 BAR MAX. BACK PRESSURE
F	NOT USED	–	–
G	CONCENTRATE OUTLET (UF)	22mm OD HOSE CONNECTOR	0.5 BAR MAX. BACK PRESSURE
H	CONCENTRATE OUTLET (RO)	1/2" OD HOSE CONNECTOR	0.5 BAR MAX. BACK PRESSURE

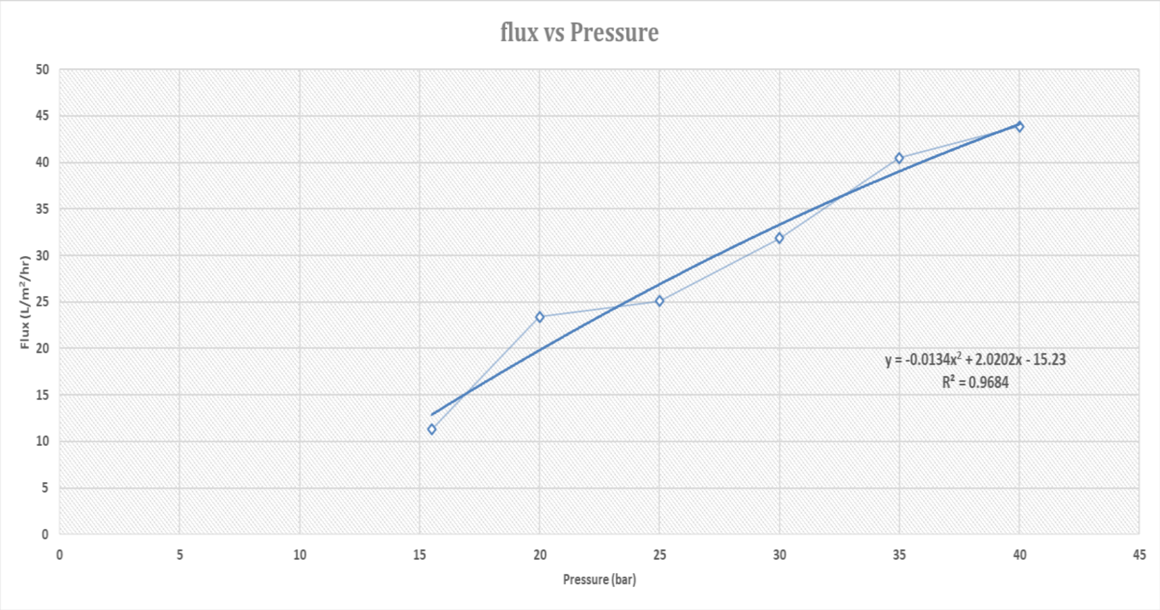
NOTES:

HP PUMP P1 (PISTON TYPE)
CAT PUMP 1051
6 – 38 L/MIN.
5.5KW MOTOR (VARIABLE SPEED)
SUPPLY TO INCLUDE CHARGING KIT FOR
THE ACCUMULATOR/PULATION DAMPER

Figure 1: BRO/BUF Pilot Unit Process & Instrumentation Diagram.

4.2. Operating conditions and procedure

A pressure scan was performed at the beginning of the trial in total recycle mode (with both concentrate and permeate returned to the feed tank) in order to determine the optimal operating pressure for the system. An initial pressure of 15.5 bar was chosen and then process data like permeate flow, temperature & time were recorded. This was then followed by collecting similar process data within a 15 minutes time interval for a pressure increase up to 40 bar.

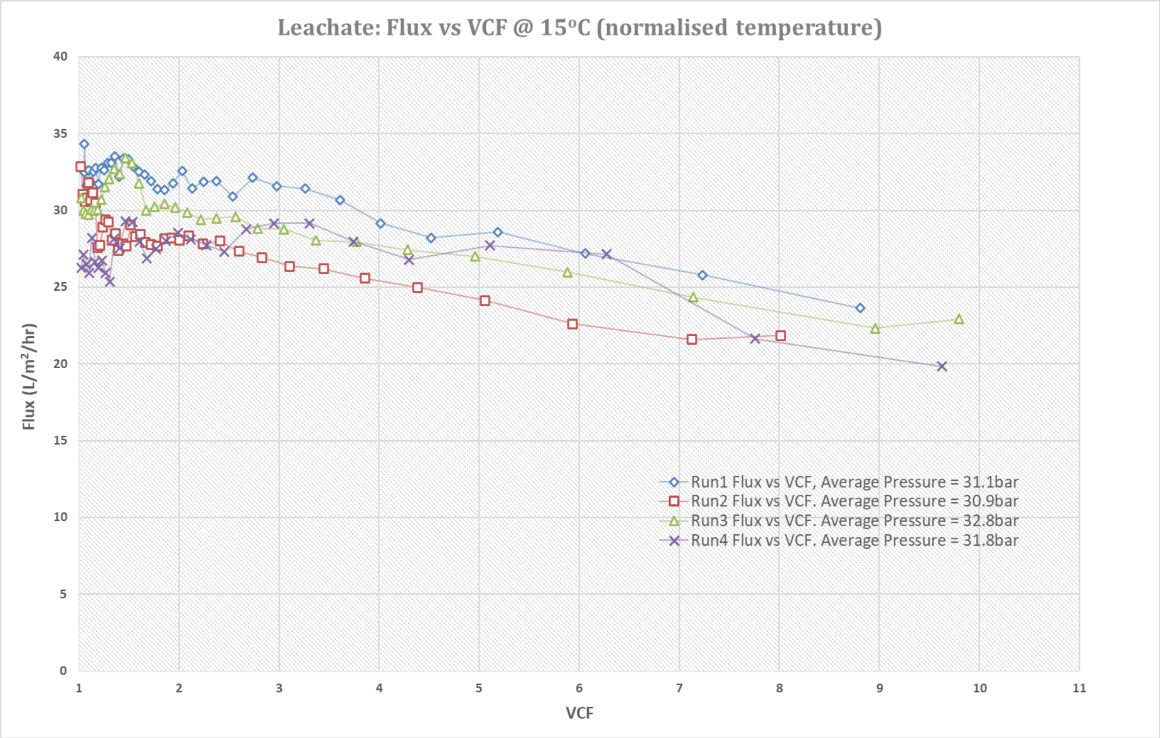


Graph 1: Pressure Scan: Flux (L/m^2/hr) vs Pressure (bar)

As per the graph above, the optimal operating pressure for the leachate used during the trial is between 30 – 35 bar. The gain in flux (ratio of the permeate flow (l/hr) to membrane area: 0.9 m2) with pressure above 35 bar resulted to be lower when compared to the increase in flux with pressure between 30 – 35 bar. Hence, a further increase in pressure does not result in a significant gain of flux, but can result in higher energy consumption, increased fouling or concentration polarisation phenomenon. An increase in the operating pressure would have to be considered in the event that the leachate concentration is higher than that of the process trial.

Once the range of optimal operating pressure has been selected, the following stage of the trial was the concentration scan which was completed mostly in batch mode: with the concentrate/retentate line returned to the feed tank, whilst the permeate was being collected in separate tank. Process data such as flows, temperature, pressure and conductivity were also recorded during all experiments. A summary of the concentration scan data is reported in the graph below, showing the variation of flux against the volumetric concentration factor (VCF). All process runs were completed on average within six hours of operation, after which the system was flushed with dechlorinated water, cleaned chemically (by using either alkaline chemicals:

Ultrasil 110 & caustic or acidic clean: Ultrasil 75) and a clean water flux test performed.



Graph 2: Concentration Scan: Flux vs Volumetric Concentration Factor (VCF)

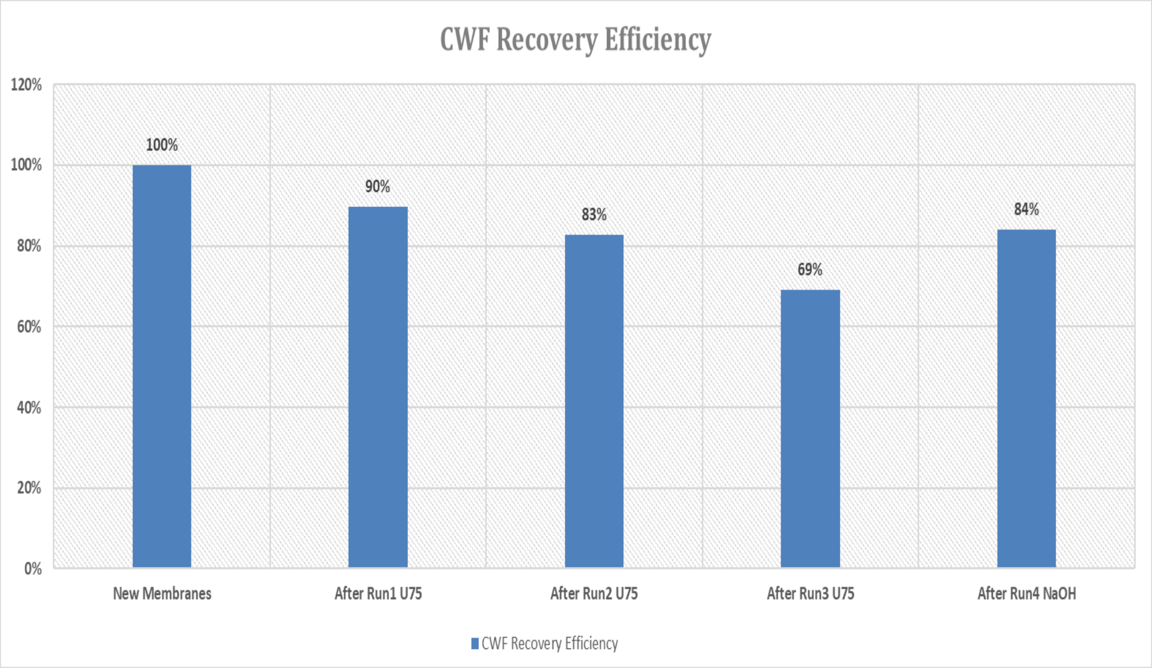
All four experimental process runs are highlighted in graph 2 above. Flux data has been normalised to a temperature of 15oC, however these trial runs were performed with process temperature ranging between 20.5oC to 41oC at an average pressure drop of 2.8 bar across the 4ft B1 module. The initial instability of the flux with VCF is possibly due to a membrane conditioning phase; lower initial process temperature and fluctuation in pressure, as this stabilised as the process progresses.

A crossflow velocity of 2.5 m/s (18.5 L/min) was used during all process runs and a maximum volumetric concentration factor of 9.8 was achieved during the trial. Although, most of the process runs were completed at circa 10 VCF due to time limitation, minimal fouling effects were notice and a reasonable flux was also seen at this point. Extrapolating both process runs 3 and 4 data with the following 4th order polynomial equations, show that the maximum achievable concentration factor for this process fluid is around 12 VCF.

R3: Flux (l/m2/hr) = -0.0436*X4 + 1.0639*X3 – 9.245*X2 + 32.859*X + 12.743 Eq. (1)
R4: Flux (l/m2/hr) = -0.0279*X4 + 0.7322*X3 – 7.278*X2 + 30.399*X + 8.422 Eq. (2)

With X = volumetric concentration factor (VCF).

Chemical cleans with either Ultrasil 75 (acidic medium) or sodium hydroxide were carried out following each process runs. This was needed to evaluate membrane performance in terms of flux recovery efficiency), fouling characteristic and the effectiveness of the chemical clean.



Graph 3: Clean Water Flux (CWF) Recovery Efficiency

A clean water flux recovery efficiency is reported in graph 3 and as highlighted, the cleaning of the membranes with both Ultrasil 75 (0.25 – 0.3% v/v) and a caustic solution (0.1 – 0.25% w/w) has proven quite efficient, indicating a very low fouling phenomenon as the average clean water flux recovery across all processes was within an acceptable range 81%.

4.3 Process and laboratory data analysis

A brief summary of the process efficiency from using PCI's reverse osmosis AFC99 membrane for the treatment of the landfill leachate is highlighted in Table 2; resulting in a very low permeate conductivity throughout all process runs, with a maximum of 0.2% solute passage recorded for Run1, which equates to 99.8% retention of the feed components.

Table 2: Feed & Permeate Conductivity, Solute Passage and VCF

Process Run	Feed Conductivity mS/cm	Final Concentrate Conductivity mS/cm	Average Permeate Conductivity µS/cm	Solute Passage	Volumetric Concentration Factor (VCF)
1	3.54	22.3	43	0.2%	8.81
2	3.45	20.7	35	0.17%	8.01
3	3.46	25.3	37	0.15%	9.8
4	3.46	24.8	32	0.13%	9.63

Table 3: Permeate, Raw & Concentrated Leachate Analysis and % Reduction

Components	Unit	Raw water RO	Concentrate RO	Permeate RO	% Reduction
Cyanide, CN-,	mg/l	<0,006	0.0087	<0.006	
COD	mgO_2/l	71	650	15	78.9%
Phenol, CFA	mg/l	<0,050	<0.05	<0.05	
Mercury, Hg, FIMS	µg/l	<0,10	<1	<1	
Silver, Ag	mg/l	<0,013	<0.013	<0.013	
Aluminium, Al	mg/l	0.54	3	0.1	81.5%
Arsenium, As	mg/l	0.013	0.11	<0.005	
Barium, Ba	mg/l	0.083	0.67	0.01	88.0%
Calcium, Ca	mg/l	210	1800	0.22	99.9%
Cadmium, Cd	mg/l	<0,0013	0.0035	<0.0013	
Cobalt, Co	mg/l	0.013	0.083	0.0063	51.5%
Chromium, Cr	mg/l	0.014	0.067	0.0063	55.0%
Copper, Cu	mg/l	0.11	0.6	0.0063	94.3%
Iron, Fe	mg/l	1.2	6.8	0.013	98.9%
Potassium, K	mg/l	120	910	3.8	96.8%
Lithium, Li	mg/l	0.52	6	<1.3	
Magnesium, Mg	mg/l	9.4	80	0.013	99.9%
Manganese, Mn	mg/l	0.29	2.3	0.013	95.5%
Molybdeeni, Mo	mg/l	0.38	2.3	0.013	96.6%
Sodium, Na	mg/l	510	3800	7.1	98.6%
Nickel, Ni	mg/l	0.029	0.22	0.0063	78.3%
Phosphorus, P	mg/l	0.19	3.8	0.063	66.8%
Lead, Pb	mg/l	<0,013	0.056	<0.013	
Sulphur, S	mg/l	290	2200	1.3	99.6%
Antimony, Sb	mg/l	<0,05	0.085	<0.063	
Tin, Sn	mg/l	<0,013	0.013	<0.013	
Vanadium, V	mg/l	<0,013	0.014	<0.013	
Zinc, Zn	mg/l	0.14	0.79	0.0063	95.5%
Fluoride, F-	mg/l	0.95	6.6	0.1	89.5%
Chloride, Cl-	mg/l	597	4370	7.1	98.8%
Bromide, Br-	mg/l	3.4	24.2	0.2	94.1%
Sulphate, SO_4^{2}-	mg/l	802	6310	0.5	99.9%
Solids	mg/l	14	420	0.8	94.3%
Ammonium, NH4-N, CFA	mg/l	3.7	28	0.6	83.8%
Hydrocarbon C10-C40	mg/l	0.11	0.77	0.11	0.0%
pH, 25°C		6.8	7.6	8.2	
Conductivity, 25°C	µS/cm	3720	20900	42.7	98.9%
Total Organic Carbon	mg/l	19.1	204	10	47.6%
Volatile Orgnaic Compound	mg/l	<0,10	0.1	<0.1	

An overview of the laboratory analysis of one of the process runs completed during the trial is reported in Table 3; a percentile reduction of each components in the permeate sample is also highlighted.

The overall reduction in COD, salts, metals, solids and conductivity is exceptional. As expected, the concentration of volatile organic and hydrocarbon compounds in both permeate and concentrate are very low; resulting in lower reduction of total organic carbon.

This further demonstrates that the leachate wastewater could be treated with PCI reverse osmosis system, not only to give a significant reduction of feed stream volume, but also to generate a high quality permeate (equivalent to a recovery of approximately 90 - 92% of the feed flow) which could be used as part of other production processes on site.

5. Engineering solution to the problem

Upon completing the trial on site, both process and laboratory data were analysed, process performance was evaluated with emphasis placed on factors like: leachate volumetric flow and seasonal variation; which have an impact on process fluid temperature and composition. With all these in mind, a process design was completed and an engineering solution was presented to the end user based on the use of PCI's reverse osmosis system for the treatment of the landfill leachate (this is currently being evaluated by the client in terms of capital and operating expenditures, lead time with regards to site construction and the delivery of the reverse osmosis system by PCI Membranes).

5.1Full scale plant design

With a feed flow of 204 m3/day, a PCI's RO unit would be installed; based on a volumetric concentration factor of 12 VCF: circa 92% recovery of the initial feed flow, by using a polyamide thin film composite membrane (AFC99, with 99% minimum sodium chloride rejection). All membranes are installed in a 12 ft (3.6m) long B1 module. Each module comprises of 18 perforated stainless-steel tubes (housing each membrane tube) in the form of a shell and tube arrangement. The shell side is also fabricated in stainless-steel and has outlets fitted for permeate collection. Each module has a membrane area of 2.6 m2.

The design has been completed for a system with a feed flow available at 25oC, an initial feed conductivity of 3.5 mS/cm and operating at 35 Bar. As both feed composition/conductivity and temperature could vary during the year; the plant has been designed to operate up to 50 Bar when this occur and a plate and frame heat exchanger would be used prior to the reverse osmosis unit during winter time, a tube and shell type B1 heat exchanger (tube-side comprises of 18 non-perforated stainless-steel tube) will also be used to maintain the system temperature at 25 - 30oC.

A summary of the plant design is reported in Table 4:

Table 4: Plant Design Summary

Feed (m^3/day)	**204**
Operation time (hr)	20
Feed (m^3/hr)	10.20
Membrane Type	AFC 99
Temperature ◦C	25
VCF	12
Flux production (L/m^2/hr)	25.0
Feed path Flow (L/min)	18.5
Retentate [L/h]	850
Permeate [L/h]	9350
Membranes Area calc [m^2]	374
Number of modules calc	143.8
Number of modules taken for design	156
Number of stacks	1.95
Number of Heat Exchanger on each stack	2
Membranes Area for design [m^2]	405.6
Number of modules in series	2
Number of modules on each stack	78
Stack Size @ 8 wide, 10 high (modules + HE)	80
Feed Pump size [m^3/h]	10.2
Recirculation Pump per stack (m^3/h) @ 12 bar	44.4
Feed pressure [bar]	35
Drop Pressure max [bar] per module	6
Total pressure drop across 2 modules	12
Total refrigerant flow: 25 L/min/module	100
Type of modules	B1
Type of endcaps	SF
Type of Design	MSR
Available time (hr) CIP/day	4

For a feed flow of 10.2 m3/hr and a design flux of 25 L/m2/hr, the calculated number of modules comes to circa 144. By taking into account a risk factor of circa 8% and a balanced module/stack distribution, the final design is based on 156 B1 modules (with 405.6 m2 membrane area) plus 4 B1 heat exchangers. Which equates to 2 stacks with 78 B1 modules and 2 heat exchanger per stack.

Feed path flow or crossflow velocity of 2.51 m/s (18.5 L/min) would be required for each module. With an average pressure drop of 2.8 Bar on a 4 ft B1 module, a 6 Bar pressure drop per 12 ft B1 module is calculated; hence, it is possible to reduce the size of the recirculation pump to 44.4 m3/hr per stack by connecting two 12 ft B1 modules in series.

With 80 modules: B1 plus heat exchanger on each stack and 2 modules in series, there are 40 pathways per stack and a feed path flow of 18.5 L/min; 40 * 18.5 = 740 L/min = 44.4 m3/hr recirculation pump size per stack, equating to 12 Bar total pressure drop across the 2 modules in series when operating at 35 Bar feed pressure. The feed pump is sized as a function of the available feed flow per hour.

A total of 4 B1 type heat exchangers will be installed across the 2 stacks; this is calculated based on an assumption that the process temperature is to be maintained at 25oC, whilst the amount of heat energy generated across each stack (feed and recirculation pump, both at 50% efficiency and a 1.2 safety factor considered) is circa 47 KW. Based on PCI's internal heat removal efficiency graph per heat exchanger, we have concluded that each 12 ft B1 heat exchanger will remove approximately 22 – 23 KW of heat; hence a total of 2 heat exchanger per stack. The required cooling fluid is to be supplied at a feed flow of 25 L/min/module, up to a maximum of 2 bar pressure.

Each module is equipped with a series flow end cap configuration; which allows all 18 tubes in the module to be connected in series and giving a hydraulic flow length of 83 metres per 12 ft B1 module. The plant is designed based on a multi stage with recirculation loop configuration, with 20 hrs/day process operation and cleaning to be completed within the 4 hrs time frame.

5.2 Plant description; operating condition and limitations

The plant design is based on a multi stage with recycle loop configuration (MSR), with 2 stages or stack system, each having 78 off 12ft B1 modules and 2 off 12ft B1 heat exchangers. The current design is supplied with the opportunity of having a future expansion of an extra 10% per stack; taking the overall module and heat exchanger to 88 per stack.

The 10.2 m3/hr feed is supplied to the system through the use of a high-pressure positive displacement diaphragm pump from Wanner, as this can generate an operating pressure up to 50 bar when the process fluid is supplied at a higher concentration. The recirculation pumps on each stage are centrifugal pumps by Fristam and are designed to boost the fluid flow and pressure (40 – 44 m3/hr flow and compensating the pressure lost that results from the 2 modules in series: 12 bar), which is recycled through the stages until the required concentration is attained.

Due to a possible seasonal variation of the process fluid initial temperature, a plate and frame heat exchanger from Alfa Laval will be installed prior to the reverse osmosis unit. Based on an assumption that the leachate is available at a temperature of 1oC and the heating fluid supplied at 60oC, a total of 28 plates in 316 stainless steel material and an area of 3.6 m2 will be used to heat the leachate to a temperature of 25oC prior to PCI reverse osmosis unit.

A process and instrumentation flow diagram of the plant is shown in figure 2 below:

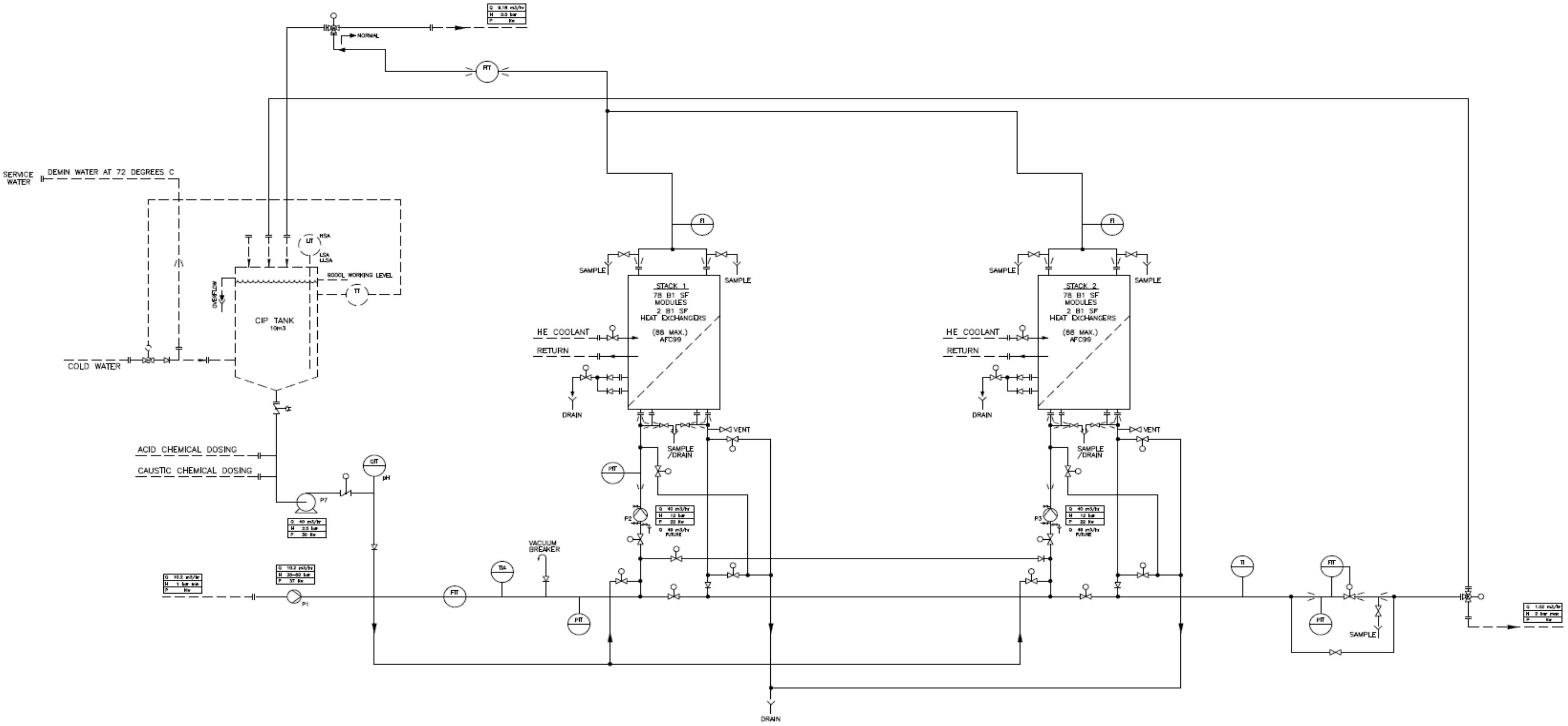


Figure 2: Process & Instrumentation Diagram of the reverse osmosis plant for leachate treatment.

As the plant will be processing 10.2 m3/hr of leachate across 20 hours operation time, it is recommended to at least flush the whole system with demineralised water (50 – 60oC) daily. The routine chemical cleans using a caustic solution (Ultrasil 11 or 50% sodium hydroxide) and an acid solution (Ultrasil 75 or 70% nitric acid) within a week is needed.

The plant is to be operated in a fully automated mode, hence a CIP (cleaning in place) system has also been incorporated to the designed. The CIP tank volume is approximately 10 m3 and it is designed with respect to the whole system holdup volume. A CIP transfer pump has also been included; this will be used together with the recirculation pump during the cleaning phase.

6. Conclusion

The use of membrane technology for the treatment of a landfill leachate has been proven to be effective over the years. However, depending on the quality of the leachate or permeate quality required, different membrane and modules combinations can be implemented.

Technologies such as spiral-wound, hollow fibre, plate-and-frame and tubular membranes are mostly used for membrane separation. All of these technologies present their own advantages and disadvantages. Spiral-wound, hollow fibre and plate-and-frame membrane types are known to possess a higher ratio of membrane surface area to system volume (which is beneficial for the system capital expenditure cost), however, for these technologies; concentration polarization and severe membrane fouling are a major issue when treating a process fluid with high concentration of suspended solids, whilst a prefiltration is also likely to be required up front. Tubular systems on the other hand, have a lower ratio of membrane surface area to system volume, offers a significant advantage in terms of controlling the concentration polarization and membrane fouling when processing a fluid with high concentration of suspended solids in the feed solution.

To minimise the fouling potential in a membrane system and increase the quality of the permeate generated, a combination of these technologies is sometime used: from using either a microfiltration/ultrafiltration system together with a reverse osmosis system, all in a tubular module format, to using a tubular reverse osmosis then followed by a spiral-wound reverse osmosis or by implementing a membrane bioreactor system (biological pre-treatment followed by a membrane system). With all these in mind, the current system is designed to be operated based on a one stage tubular reverse osmosis system, as a trial has been completed; with process data and laboratory analysis proven that the landfill leachate can be treated successfully when using a PCI Membrane's AFC99 membrane.

The average solute passage across all 4 process trials completed was 0.16%, this is also supported by a significant reduction of other parameters or components: chemical oxygen demand, conductivity and inorganic compound in the permeate side. Although, the reduction of hydrocarbon, total and volatile organic carbon in the permeate stream isn't massively great, the overall performance of the system can be defined satisfactory.

The solution proposed is based on a 2 stacks system configuration, distributed across a multi stage system with recirculation loop. Initially, each stack would be accommodating 80 modules (78 off 12ft B1 module and a 2 off 12ft heat exchanger). However, this can be expanded to 88 modules per stack in the future, in the event that leachate production capacity increases. The plant is also designed to be operated up to a pressure of 50 bar (to allow for any variation in leachate composition with time) and the cross-flow velocity can also be taken up to 20 L/min (to help minimise any fouling or concentration polarization phenomenon).

An overview of the plant annual operating cost is outlined in Table 5 below. The dominating cost for the process operation resulted from the system electricity demand: this has been calculated to be in the region of 14.1 KWh/m3; based on 204 m3/day feed flow supply, 22 hours operation per day (process and CIP), 250 days/year, at a rate of 0.067 €/KWh. The other major cost to be considered is the membrane replacement cost; in Table 5, this is spread across 3 years as a function of the predicted membrane lifetime. To prevent the precipitation of both fouling and scaling components from the leachate, acid addition would be needed. Hence, a sulphuric acid cost per year has been included. Further cost includes the CIP and preservation chemicals; for this case, a cleaning prediction based on a daily alkaline clean within a week of operation, an acid clean per week and the system preservation over a weekend period with sodium metabisulphite.

Table 5: Annual operating costs of the system.

Operating Costs	Cost per year
Membrane replacement (based on 3 year's life)	€ 28,340.00
Electricity @ 0.067 €/KWh	€ 48,125.63
Chemical - pH adjustment (50% H_2SO_4 @ 0.45€/L)	€ 11,475.00
Cleaning (5 caustic/week & 1 acid/week) & Preservation	€ 8,381.70
Total Operating Cost/year	€ 96,322.33

As with most countries, the disposal cost for an industrial wastewater depends on different parameters; this is often calculated as a function of the ratio between COD/BOD, nitrogen, phosphorus, fat & oil content and other contaminants. For this particular case, leachate disposal cost has been estimated to be in the region of 5 €/m3, whilst the wastewater generated from CIP and system flushing disposal cost is estimated to be 2.5 €/m3. The price for purchasing a fresh water is estimated to be around 1 €/m3.

One of the main reasons for treating the leachate wastewater was to implement the zero waste and 3R-Model (reduce, recycle and reuse). As with the current solution provided when using a tubular reverse osmosis system, the leachate daily volumetric flow has been reduced from 204 m3/day to 17 m3/day, which equates to circa 91.7% recovery rate. The final concentrated volume can either be recycle back into the landfill (this means that the landfill design has to be properly sealed or in a closed system to utilize the anaerobic degradation of the organic substances) or it can be disposed of for further treatment.

The permeate water generated from the plant is of high quality, hence; this could be reused either for CIP/system flushing or it could be used to replace/supplement the water requirement for other processes within the site.

Table 6: Payback calculation

1	**Volume to be treated (m^3/day)**	**204**
2	Capital cost of the system	€ 723,581.80
3	Recovery rate (%)	91.70%
4	Final volume of the waste (m^3/day)	17
5	Leachate disposal savings per year @ 5€/m^3	€ 233,750.00
6	Annual operating costs	€ 96,322.33
7	Savings on fresh water (permeate) per year	€ 42,197.50
8	CIP & Flushing waste water disposal cost per year @ 2.5€/m^3	€ 11,381.25
9	Net annual savings (5) - (6) + (7) - (8)	€ 168,243.92
10	Capital cost allowance (i.e. 10% /year over 10 years write-off)	€ 72,358.18
11	Taxable savings (9) - (10)	€ 95,885.74
12	Corporate income tax payable @ 20%	€ 19,177.15
13	Savings after tax (9) - (12)	€ 149,066.77
14	Payback period after tax (year)	4.9

The plant payback time is highlighted in Table 6 and this is calculated to be in the region of 4.9 years, which is reasonable when considering the size and the nature of the plant. Also, the capital and operating cost of a tubular reverse osmosis system is significantly lower when compared to other alternative solutions out there; to treat a similar process fluid under the same conditions with an evaporator; the capital cost of the system is estimated to be around 1.2 million Euro, whilst both operating and maintenance costs are even higher (higher energy demand and a more frequent scaling issues on the heat exchanger surfaces).

7. References:

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