Reducing Water Consumption in Industry using VSEP Membrane Technology – Pilot Trials

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ABSTRACT

Australian Hardboards (AHL) own and operate a wet process hardboard manufacturing plant in Queensland, Australia, that generates a significant quantity of process water effluent during the production of Masonite™. AHL management recognised that there were significant opportunities to reduce water and energy usage in the process without adversely affecting product quality. Sinclair Knight Merz (SKM) was commissioned by AHL to examine various technologies for treating and recycling this process water effluent.

SKM and AHL have designed an effluent treatment system based on the latest available membrane technologies to enable almost 100% reuse of 1 ML/d of effluent. The technologies that were assessed included standard cross-flow membranes, the Vibrating Shear Enhancement Process (VSEP), a membrane bioreactor (MBR), evaporation and standard biological systems. Extensive laboratory and pilot plant trials were conducted to assess the VSEP ystem. Economic analysis was conducted to determine the best option. The VSEP system was found to be the treatment option of choice due to cost, footprint and reliability considerations, as well as the ability to produce a high solids concentrate which has positive calorific value and is suitable for boiler fuel or possibly a supplement for animal feedstock.

KEYWORDS
water reuse; membrane technology; VSEP; timber; white water; pulp

INTRODUCTION

Australian Hardboards Ltd (AHL) operates a wet process hardboard plant located in Queensland, Australia that uses mixed eucalyptus species as the principal raw material. The plant produces approximately 1 ML/day of effluent consisting principally of suspended fibre, colloidal and dissolved organic and inorganic materials generated during the pulping and digestion process. The current practice for treating the effluent is to use settling ponds and land irrigation. AHL intend to install a water treatment system to enable the liquid effluent to be recycled and the solid effluent to be used as fuel or composted.

The primary aims of the treatment plant are as follows:

a) cost effective;
b) recover an economically feasible maximum of water suitable for reuse;
c) minimise treatment process complexity and footprint; and
d) minimise solid handling issues.

CURRENT PROCESS

The current thermo-mechanical pulping (TMP) process is largely unchanged from the original, late 1950's design. The effluent flowrate is >1 ML/day and consists of several distinct water sources including:

- Process effluent (ie. from the refiner process; white water overflow; press liquor);
- Clear water (boiler demineralisation, regeneration, cooling water etc.); and
- Miscellaneous sources (wash down water, other manufacturers, storm water).

The average characteristics of the current effluent are summarised in Table 1. The temperature of the effluent is typically, 90^{O}C.

Table 1 Effluent Characteristics

Suspended Solids g/L	Dissolved Solids g/L	Total Solids g/L	TOC mg/L	COD mg/L	pH	Conductivity µ Siemens/cm
2.26	10.75	12.59	7150	4043	3.6	812

As part of the overall project at AHL, investigations were also undertaken to tighten the water circuit to reduce the volume of effluent that will need to be treated. Installation of in-process technologies allow the volume of effluent to be reduced to 35% of the current volume. However, the solid load remains the same resulting in a commensurate increase in solids concentration.

OPTIONS REVIEW

The key technology choices investigated include membrane technology, evaporation and biological systems. The feasibility work involved a literature study of relevant industry practice and an extensive economic analysis to compare each option (including the impact of the process modifications).

Membranes

Conventional cross-flow membranes have been used in conjunction with evaporators in other similar factories in Europe. However, membranes have generally not been considered viable till recently due to the traditional fouling problems, low flux rates and costs.

VSEP Membrane System

Vibratory Shear Enhanced Processing (VSEP) is a relatively recent innovation in membrane separation and is manufactured by New Logic. It uses intense shear waves on the face of the membrane to stop build-up of contaminants and to overcome the separation performance issues associated with conventional cross flow membranes (Figure 1).

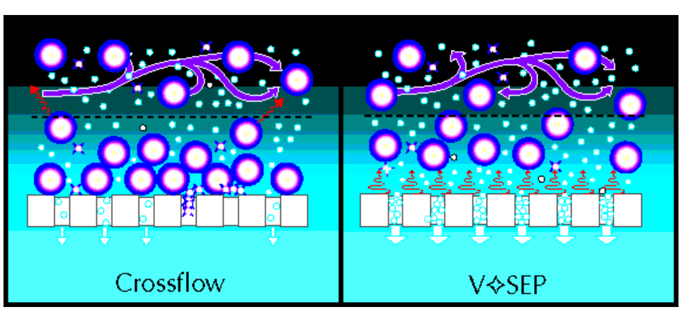

Figure 1 VSEP mechanism compared to Crossflow

The vibration improves fouling resistance and allows for filtration rates up to ten times higher than conventional cross-flow systems. The higher flux results in less membrane area required to treat a certain flow. The improved fouling resistance reduces membrane replacement costs and requires less cleaning and maintenance.

Other Novel Membrane Systems

Other novel membrane systems were investigated in the pre-feasibility studies including:

- Combining powdered activated carbon (PAC) with ultrafiltration (UF) - added complication and cost of handling and purchasing PAC;
- "Airflush" system applied during cleaning - appears to not offer significant gains; and
- Submerged tubular or flat-plate membrane bioreactors – having the key concern that the product solids concentration is around 2% and requires nutrient addition.

Evaporators
Evaporators are a known technology that has been employed in almost all pulp mills and several wet process hardboard factories around the world. Thermal (TVR) and mechanical (MVR) vapour recompression evaporation options were studied and costed and weren't recommended, principally due to high operating costs.

Biological
Biological treatment can provide a cost-effective process for effluent treatment and is used widely in the TMP and pulp and paper industry. A biological system was not selected, mainly due to system complexity, level of robustness, high operating costs from the need to add nutrients and operate aeration devices as well as solids disposal issues.

Relevant VSEP Applications
A VSEP system has been installed in a MDF manufacturing site using nanofiltration (NF) membranes to treat pulp dewatering effluent (Filtration & Separation, Jan 2001) due to the lower operating costs, compared to a conventional system, from the elimination of polymers and other chemicals.

Other relevant installations have included treatment of whitewater and bleach plant effluent as well as concentrating black liquor in the pulp and paper industry. VSEP has also been used in treating oily waters, so demonstrating that it has no problem with handling oils.

Technology Comparison
An economic analysis of the various technology options demonstrated that:
- Capital costs are higher than the installed cost of the VSEP membrane system; and
- Operating costs, even when allowing for waste steam reuse for evaporation are also higher than the VSEP membrane system.

With the favourable economic analysis as well as other key processing advantages, a series of pilot trials of the VSEP system were undertaken.

MEMBRANE TRIALS

The V-SEP process has the potential to be used for treating various process streams at AHL such as whitewater, press squeezings and end-of-pipe. The cleaned permeate water should be suitable for recycling back to the plant or treated further with reverse osmosis (RO) for boiler use. If a high enough reject solids concentrate can be produced, then there is potential to send this to the boiler.

Using the VSEP technology, trials were undertaken to:
1) Screen various membranes for permeate and concentrate quality as well as flux;
2) Determine flux rates and achievable concentration with a range of operating conditions;
3) Determine the cleaning requirements and regime;
4) Determine required membrane area; and
5) Determine the degree of deterioration of membrane performance over time.

Laboratory Tests

Procedure

Testing was conducted off-site using fresh feed supplied by AHL every 2 days. Initial testing focussed on the “end-of-pipe” waste stream. Later tests treated “white water” and “squeezing” streams. All the feed streams were dark in colour and were pre-screened at 45µm before being tested.

Testing was conducted using a Series L/P V-SEP unit, depicted in Figure 2. When operated in L mode, a single membrane is used with a filtration area of approx. 0.5 ft^2 (or 0.046 m^2). Operating pressure can be varied from around 50 to 300 psi (340 to 2070 kPa) depending on the type of membrane used, and the shear rate from 0 to 150,000 sec^{-1}.

Figure 2 Series L/P V-SEP unit

The test temperature ranged from 28 to 44°C which correlates to a temperature correction base of 34°C. The feed volume was 20 litres of feed effluent and was used in recycle mode (Figure 3). The recycling caused the feed temperature to rise to around 44°C during the tests. No attempt was made to control this but the temperature was measured and recorded, and the final filtration rates corrected during reporting.

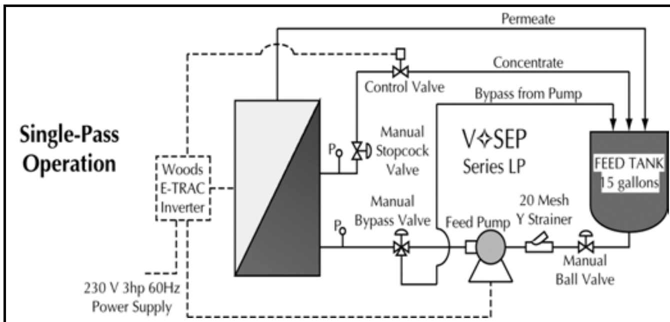

Figure 3 Test flow-sheet configuration used for L mode

Laboratory results

The first experiments were conducted with large pore size membranes in the microfiltration (MF), (Teflon, 2 and 0.1 µm) and UF (G80, 9000 daltons MWCO) range. The feeds used to screen these membranes were mainly the end-of-pipe effluent but 0.1 µm permeate, white water and press squeezings were also tested. The results for the MF and UF membranes showed poor separation of the dissolved materials with the permeate being clear, yet quite dark in colour. This result implied that a great deal of the COD was not being removed. Tighter membranes were tested and an improvement in permeate quality was seen.

From the analysis of the MF and UF permeate, the bulk of the fouling compounds are in the UF pore size range of 9000 daltons and most of the NF fouling compounds are below the UF pore size. Therefore, there would be no benefit in pretreating the feed with MF or UF. Further, the single-step is feasible because the V-SEP process uses high shear vibration which prevents any coarser particles from plugging up the membrane. The NF membranes listed in Table 2 were selected for testing based on the manufacturer’s previous experience with other similar effluents. The testing parameters used for the high temperature membranes are listed in Table 3.

Table 2 NF Membranes tested

Property	A	B	C	D	E	F	G	H
Pore size (daltons)	200-300	8000	≈ 900	≈ 150	~150	2000	2000	600
NaCl rejection (%)	80	nil	10	50	50	96		
Membrane material	Proprietary/ Polyester	Polyimide/ Sulphone	Sulphonated Sulphone	Sulfonated Sulphone	Sulphonated Sulphone	Polyether sulphone	Kynar PVDF	Polyether sulphone
pH tolerance	4-11	2-11.5	2-11	2-11	2-11	2-11	2-11	1-14
Temp tolerance (°C)	50	50	60	60	90	90	90	90
Water GFD			116	26	35	100		
Pressure range (psi)			200-800	200-800	200-800	300-400	300-400	100-250

Table 3 High temperature membrane testing paramaters

Parameter	E	F	G	H
Feed pH	3.5	3.5	3.5	3.5
Feed temperature (°C)	41, 58	58, 73	53, 72	78
Feed pressure (psi)	250-400	250-400	250-400	250-400
Vibration Amplitude (inch)	¾	¾	¾	¾

Many of the membranes were tested and rejected due to the poor quality permeates, limited operating conditions (e.g. temperature, pH, tolerance to solvents), unsuitability to TMP liquids such as irreversible blinding, and poor permeate flow rates as well as salt rejection. Membrane E was found to provide the best flux and separation and is able to tolerate the required operating conditions.

Pilot Trials

Pilot trials were conducted on-site using membrane E with AHL end of pipe (eop) effluent to determine the optimum operating pressure, the flux vs concentration to determine the maximum recovery and a suitable cleaning procedure.

Procedure

Testing was conducted using the same V-SEP™ unit for the L tests but in P mode which uses a small membrane stack with a filtration area of approximately 16.8 ft^2 (1.56 m^2).

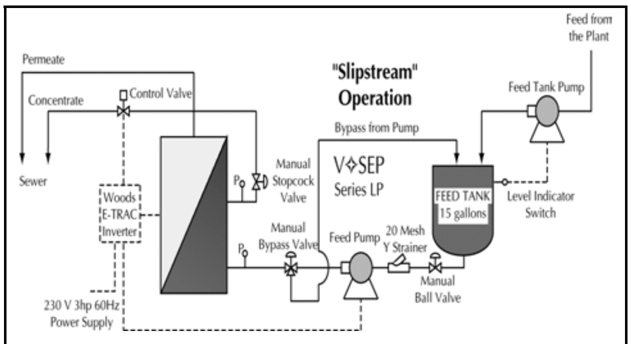

Figure 4 Flowsheet used for automated concentration/recovery study

A pressure study was conducted to select the 'Optimum Pressure' for use throughout the rest of the pilot-trial. After the unit was run on water to confirm system integrity the feed tank was prepared with the eop effluent (feed suspended solids were 1.5%) and the system configured in "Recirculation Mode" (Figure 3). All of the feed was prefiltered at 250 μm to remove fibres and other large particles. A 2 to 4 hour "Line Out Study" was conducted to bring the membranes close to equilibrium. Then, the pressure was incrementally increased and the permeate flow rate recorded. The results were graphed and the "Optimum Pressure" determined.

For the flux-recovery studies, the unit was set at the optimum conditions and run in "Slip Stream" or "Recirculation" mode (Figure 4). Approximately 37 gallons (140 litres) of feed was collected and used for these trials. Permeate was withdrawn continuously and its cumulative volume measured. Samples of concentrate were also taken periodically for solids analysis. Flux measurements were made at 250 psi (1725 kPa) and 350 psi (2410 kPa) feed pressures.

Pilot Results & Discussion

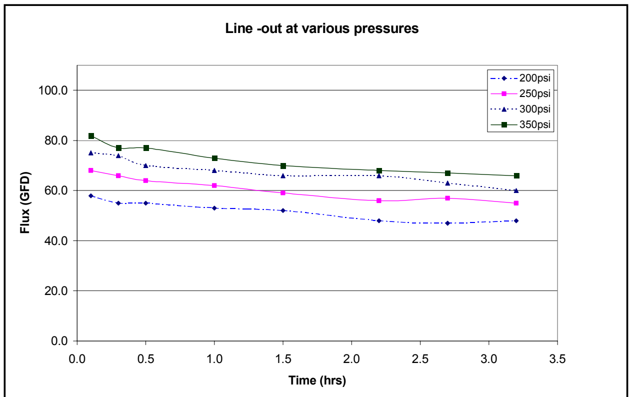

Figure 5 Line-out at various pressures

The graph in Figure 5 shows the performance of the membrane at various pressures during the “Line Out Study”. The flux rate increased steadily as the feed pressure was increased. The relative decline in flux (i.e. starting flux – ending flux) appeared to be similar at all the feed pressures tested. The pilot-plant trials were conducted with a feed pressure of 250psi (1725 kPa) – due to feed pump constraints.

During the flux-recovery studies, the flux rates were corrected up to 50°C using the viscosity-temperature correction factors for water. The correction factor was found to correlate well for two membranes (Membrane E and G). The feed solids were measured during this trial. The average solids in the stack were actually slightly higher and were determined by correcting for the permeate that was removed during the time period. The feed concentrate reached around 37% solids when the testing was terminated. The temperature of the concentrate was relatively low at around 34°C. It is likely that a higher solids concentration will be achieved at higher temperatures. Viscosity data determined for the concentrate support this hypothesis.

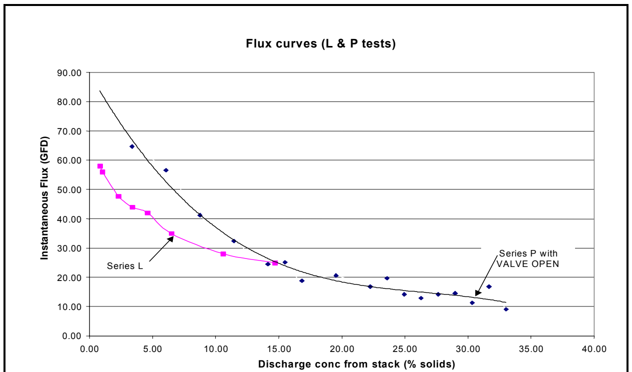

Figure 6 Instantaneous flux curves (L and P)

The P flux curve was slightly higher than the L curve at low concentrations but lower at high concentrations. Flux declined from around 70 GFD (120.7 l/m^2/h) at the feed concentration to around 10 GFD (17.2 l/m^2/h) at 33% solids (Figure 6).

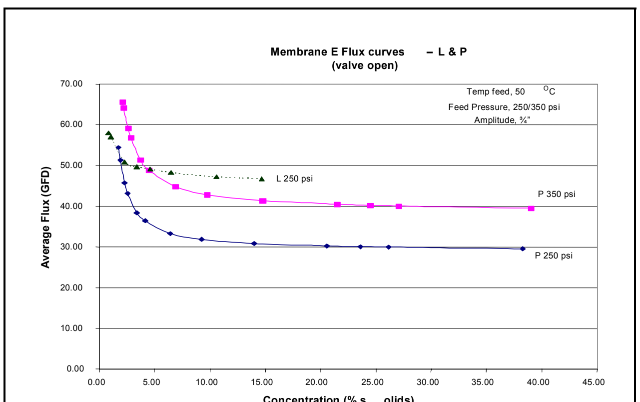

Figure 7 Average GFD flux curves at 250 and 350 psi

The average flux to concentrate from 1.4% to 39% was around 30 GFD at 250 psi (51.7 l/m^2/h, 1700 kPa) and around 40 GFD at 350 psi (68.9 l/m^2/h, 2410 kPa) (Figure 7). This concentration relates to a recovery of over 96%. Both feed pressure and temperature were found to have a significant impact on flux.

Concentrate Properties

In AHL’s case, the VSEP technology has demonstrated that it can produce a highly concentrated stream in a single pass that could be combined with other solid waste streams for use as a fuel or on its own for animal feed. The properties of the concentrate were determined to be as follows:

- Calorific value (CV) of 22 MJ/od.kg; and
- A highly viscous fluid at room temperature and hence, must be stored hot (>50^{o}C) to be pumpable;

Permeate Properties

The permeate properties are dependent on the membrane type and the effluent characteristics. Membrane E removed 98% of the organics, but only removed approximately 50% of the inorganic salts. The reduction in TDS (total dissolved solids) was substantial (>92%) as was the decrease in calcium, magnesium, chloride and iron (between 80 and 90%). Only small reductions in sodium (>35%) and some of the other smaller ions, were experienced.

Since inorganic dissolved materials were not completely removed, recycling this water would build-up the salt concentration within the process water circuits. The end result would be an increase in scaling and other quality problems. A system to manage these salts is therefore required.

Membrane Cleaning

The pilot membrane stack was cleaned at various intervals during the pilot test program. There appeared to be little or no degradation in the cleaned membrane water flux rate over the 4 week test period. It appears that a simple cleaning procedure based around the use of warm, high pH solution (pH approx 12 using NaOH at 55°C) is sufficient to clean a fouled membrane. Most of the flux recovery occurred within a few minutes of cleaning.

Reverse Osmosis Trials

Further treatment of the NF permeate could consist of using RO with the permeate being used for boiler makeup. This system will increase the boiler feed water temperature from ambient to about 60°C resulting in energy savings. Trials were conducted using permeate from the NF pilot trials to test various membranes and measure the permeate quality and conduct line-out testing to determine if the flux rates were stable.

Procedure

The feed was freshly prepared by filtering the AHL eop effluent through membrane E. The characteristics of the tested RO membranes are listed in Table 5. These membranes were tested in L mode (Figure 3). Line-out testing of up to 3 hours was carried out. The membranes were tested close to their temperature limits (i.e X at 42°C, Y at 55°C and Z at 65°C). The conductivity and pH of all the RO permeates was measured. The pH was raised to 7 for all the membranes to determine the effect on separation performance.

Table 5 RO Membranes

Membrane	Type	NaCl rejection, %	Temp °C	pH range	Pressure psi
X	Thin film composite	99.5	45	3-10	450-600
Y	Polyamideurea	99	60	4-11	450-600
Z	Thin film composite	96	70	2-11	400-600

Results & Discussion

Raising the pH improved the dissolved solids rejection by the RO which resulted in a permeate suitable for boiler feed. Flux results (Figure 8) demonstrate that membrane Z gave the highest flux rates, even at relatively low feed pressure (330 psi, 2275 kPa). The RO concentrate may be used for ash cooling water, garden irrigation and low grade process water. Current tests are determining the recovery of water that will be achieved with the RO in the VSEP system. The manufacturer expects a recovery of 85% in 1 stage.

PROPOSED TREATMENT PROCESS

The effluent system has been split into three trains (Figure 9) to ensure one train remains free of chemicals such as resins and to increase the redundancy of the system. The concentrate from the main effluent train will essentially be “clean” and, therefore, is a potentially valuable by-product that may be sold as wood molasses suitable for animal

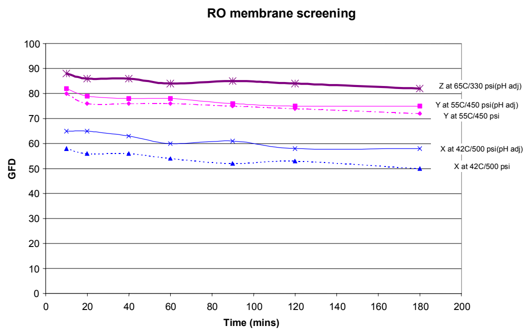

Figure 8 Flux results for RO membranes at constant feed concentration

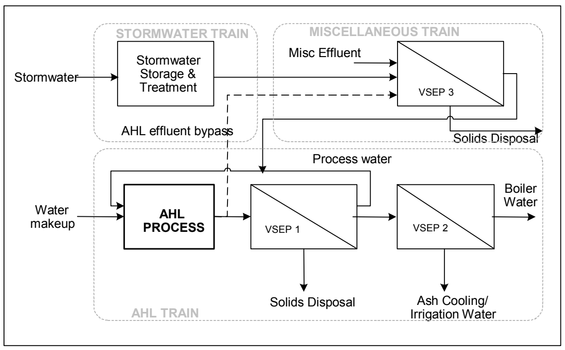

Figure 9 Simplified process flow diagram of the effluent treatment system

feed, or alternatively used as an auxillary fuel for the boilers to supplement coal requirements.

The advantage of segregating miscellaneous effluent sources is that it:

- Reduces risk of contamination of the AHL main process train membranes;
- Ensures the main AHL train remains a "clean" stream and the concentrate also remains "clean";
- Provides flexibility and redundancy;
- Increases the flux rates through the AHL train over what combined streams would achieve due to less foulants and higher temperatures; and
- Allows additional types of effluent to be treated by the system (eg paint waste).

CONCLUSION

The results have shown that an acceptable permeate quality at high filtration rates can be achieved using a 250 µm filter followed by a tight NF membrane in the VSEP system. The average flux achieved with a NF membrane was 70 l/m^2/h (at 1700 kPa, 50^{o}C). The final concentration was 39% and recovery was over 96%. The flux was stable and could be recovered with a short caustic wash. The permeate was successfully treated to boiler feed water quality using RO in the VSEP system which is expected to achieve 85% recovery in 1 stage. It will also increase the boiler feed water temperature from ambient to about 60^{o}C resulting in energy savings.

This treatment scheme is a great advance compared to conventional treatment systems as it significantly reduces the capital outlay, operating costs, process complexity and footprint. It also compares favourably with standard crossflow membranes due to the ability to produce high recoveries and concentrations in one stage, without significant loss in flux.

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