Filtration of aliphatic base oils with VSEP.

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Abstract
This paper is a brief despcription of a practical case of a special membrane filtration technology that uses mechanical action to incude shear and to prevent membrane fouling. The application is the de-ashing of an aliphatic base oil used in oildrilling activities and that is typically present in spent drillling mud. The filtration takes place at high temperature and high solids concentrations with stable fluxes throughout the operational range. The process is operated in a semi-batch mode with concentrations reaching up to 70% vol. in the concentrate.After each batch the membrane is rinsed with permeate which proved sufficient to clean the membrane. So far no chemical cleaning had to be applied.

Introduction
Drilling operations utilising oil-based drilling fluids generate large amounts of oil-contaminated waste. The waste consists of the three major substances: Water, oil and rock/clay. The clays (typically barite and bentonite) are components in the drilling mud and the rock is the cuttings from the drilled hole.
The oils are specially refined low toxic aliphatic oils with the required properties for operation. Thermal desorption is widely used for treatment of drilling waste, because such processes recover the oil phase and produce a solid phase that can be managed as non-hazardous waste.
The company Soilcare AS located at Mongstad, Norway operates a patented thermo-mechanical desorption process named TCC. In this process sufficient heat for complete vaporisation of oils and water is generated by means of mechanical friction. The process has superior properties with regard to HSE standards and quality of recovered components, but has the weakness that very fine clay particles (0,05 – 10 µm) follow the vapourised oil and water out of the processing unit and end up in the recovered oil after condensation of the varours. At the location in Norway an average quantity of 7,5 m^3 oil is produced per day with typical solids content of 6%vol., which corresponds to a about 2% wt. of dry solids. The solids content of 6%vol. is the actual volume that the clay sludge occupies in the sample container after separation in lab-centrifuges.

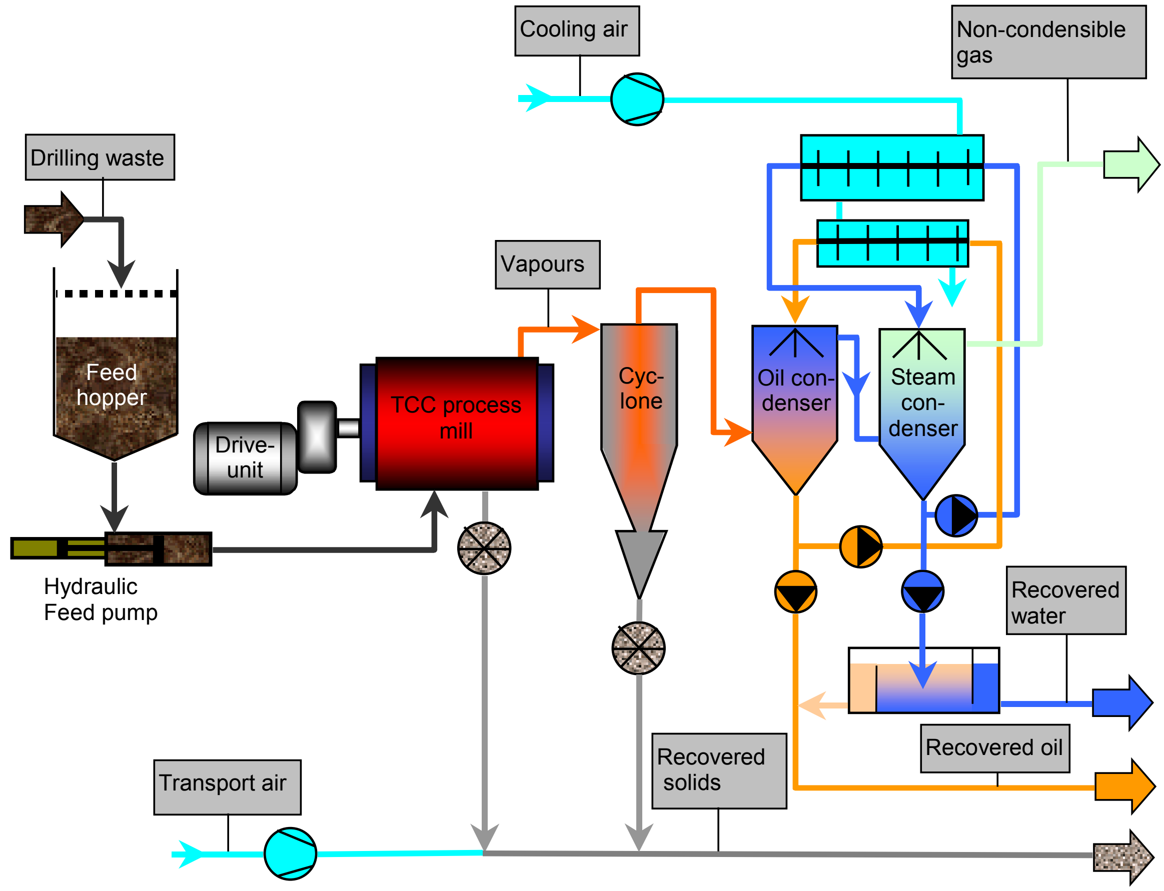


Figure 1: *Process flowsheet for the TCC process.*

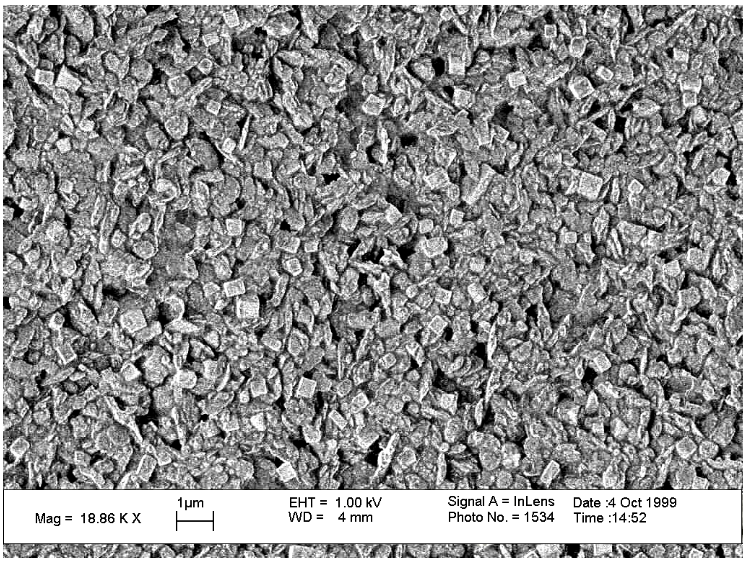


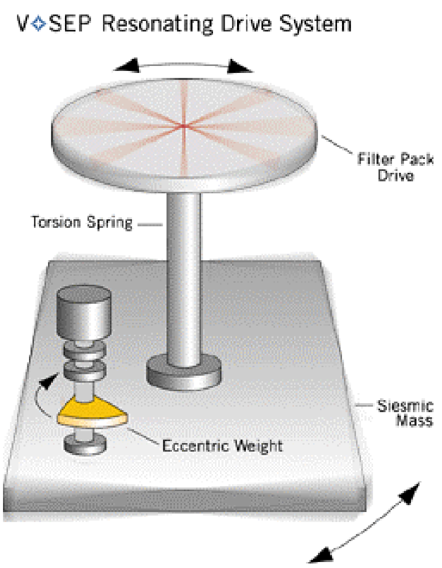
Figure 2: *Picture of the solids in the feed*

Technology selection.

The removal of solids provedto be very important to increase the value of the produced oilphase from waste to product. When the solids are succesfully removed (i.e. the oil is de-ashed, the oil can be reused in drilling operations, or reused as fuel). Several techniques like gas phase dust separators before the TCC's oil condenser, natural settling in large settling

tanks, enhanced settling using special flocculants, and disk stack centrifuges have been extensively tested, but none has proven able to efficiently clean the oil.
Membrane filtration was early identified as a potential solution, but the requirement of a permeate recovery of up to 90% eliminated traditional cross flow processes, due to the corresponding processgoal to achieve high amounts of clay solids in the concentrate of 60% vol. In the VSEP (Vibratory Shear Enhanced Process) high solids concentration and correspondingly high concentrate viscosity do not induce the common problems with membrane fouling. Rather than simply preventing fouling with high cross flow velocity, VSEP reduces fouling by causing shear at the membrane surface through vibrating the membrane surface.

The vibration produces shear waves that propagate sinusoidally from the membrane's surface. As a result of this the stagnant boundary layer is eliminated through creating a high back transport factor, as a result higher feed pressures can subsequently be applied and the filtration rate increases. Industrial VSEP units contain a number of membrane sheets that are arrayed as parallel disks separated by gaskets. The disk stack is contained within a Fiberglass Reinforced Plastic cylinder (F.R.R).



The entire assembly is excited into a torsional oscillation mode by means of a rotating eccentric mass, similar to the agitation of a washing machine.
The resulting shear can reach 150,000 inverse seconds, which is ten times greater than the shear in cross-flow systems. Such great shear rates tend to eliminate or at least significantly reduce the fouling of many materials.

Figure 3: *Vsep resonating drive system*

Shear Rate

The shear rate (γ, s^{-1}) at the membrane surface can be calculated by Eq.1:

$$\gamma = \frac{velocity \quad scale}{length \quad scale} \tag{1}$$

So that the shear rate at the membrane surface set on the VSEP can be calculated by Eq.2

$$\gamma = \frac{4\pi \ f^{1.5}\rho^{0.5}}{\mu^{0.5}} P \tag{2}$$

where f is frequency of vibration (*Hz*), ρ is density of solution (water, units: *kg/m*^{3}), μ is viscosity of solution (water, units: *Pa s*) and P is vibratory amplitude (*m*). Fig. shows a comparison between the shear rate of cross flow filtration and of membrane vibration when using VSEP. It shows that the VSEP generates a shear rate of about 120,000 s^{-1} on the membrane surface at 1 inch vibratory amplitude; this is 20 times greater than the shear rate obtained by cross flow filtration with fluid velocity of 1m/s.

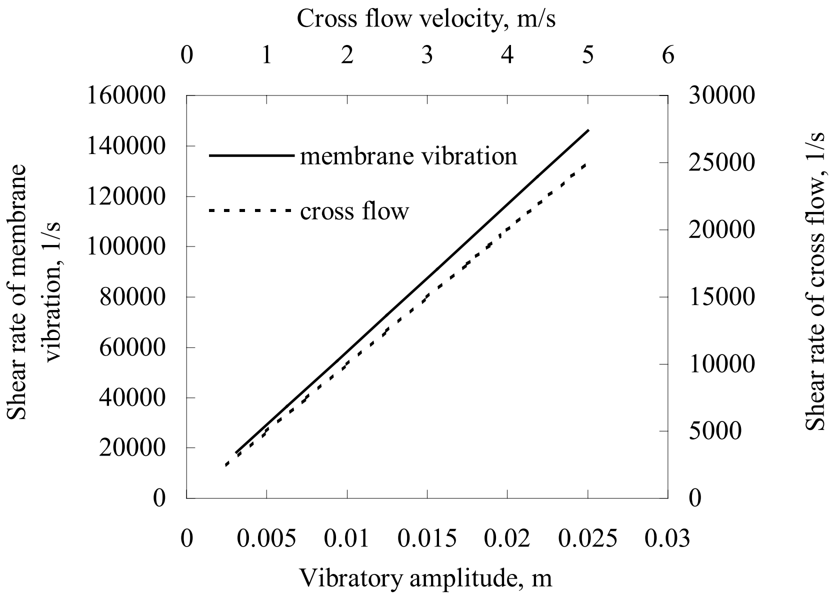


Figure 4: Comparison between shear rate of cross flow filtration and of VSEP membrane filtration

Concentration polarisation and shear rate.

In membrane filtration processes, solids are rejected by the membrane and accumulate near the membrane surface. Before reaching a steady state the convective flow of the components to the membrane surface is bigger than that due to diffusion backflow to the bulk solution. This phenomenon is called concentration polarization. It is often a serious problem in membrane operations due to its negative influence on the removal of the components and on the permeate flux. In steady state, the convective components movement to membrane surface is equal to the permeate flow and the diffusive back transport of components into the bulk solution.

$$J\left(C - C_p\right) = -D\frac{dC}{dx} \tag{3}$$

where J is the permeate flux (*m/s*), C is the components concentration in the bulk solution (*mol/m*^{3}), C_p is the concentration in the permeate (*mol/m*^{3}), D is the diffusion coefficient (*m*^{2}*/s*), and x is the distance from the membrane surface (*m*). The diffusion coefficient is assumed to be a constant, so that the following well-known equation can be obtained:

$$J = \frac{D}{\delta} \ln\left(\frac{C_m - C_p}{C_b - C_p}\right) = k \ln\left(\frac{C_m - C_p}{C_b - C_p}\right) \qquad (4)$$

where δ is the thickness of the boundary layer (m), k is the mass transfer coefficient, and C_m and C_b are the concentrations at the membrane surface on the feed side and in the bulk solution, respectively.
Concentration polarization arises because of the convective transport of solute to the membrane surface. It is therefore important to increase the back transport of solute to the bulk solution in order to be able to decrease the accumulation at the membrane surface. This can be achieved by increasing the shear rate. By operating at higher shear rate the concentration polarisation is countered and flux is increased.

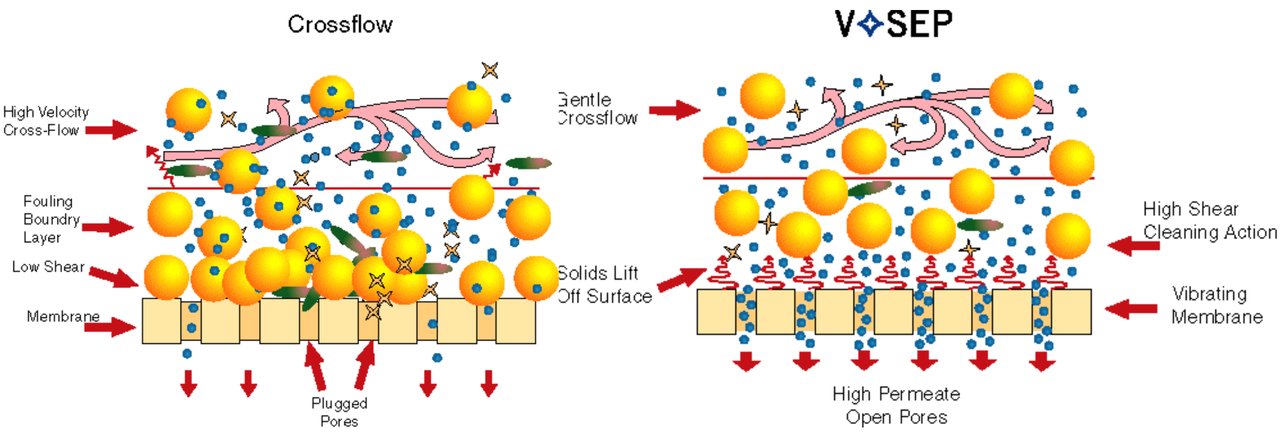


Figure 5: Schematic model of crossflow concentration polarisation and VSEP boundary layer

Laboratory testing on a VSEP pilotplant in Nordcap's test centre showed that several membrane materials gave the required combination of flux and rejection in laborarory tests. The laboratory tests try to simulate the actual operating conditions as close as possible and can be divided in roughly two phases: The first phase is the screening of different membranes in a laboratory scale experiment. The laboratory test takes about a week where different procesexperiments are carried out with varying pressures, flows and temperatures. The most succesfull membranematerial is then used in a pilotscale experiment where the envisioned process circumstances are maintained for several weeks. During this test, information is gathered about the general robustness of the process.
Based on its chemical resistance towards aliphatic hydrocarbons, a polyethersulfone membrane in the upper Ultra Filtration range was selected for this application.

Implementation
A VSEP Series i with a 36 inch membrane stack and a total membrane area of 42 m^2 was installed and started up at Soilcare's facilities early 2001. The VSEP is installed in a semi-batch configuration and operates in cross flow mode with a feed tank in the circulation loop with nominal level 15 m^3. Aside from the storage tanks the filtration process uses a floorspace of 12 m^2, and proved very easy to retrofit into the existing situation. The feed tank is hooked up with large storage tanks for clay contaminated oil on the outside of the production hall.

The objective of the cross flow is to keep all fluid in the circulation loop homogeniously mixed, and not to prevent fouling as in the case of traditional cross flow processes.

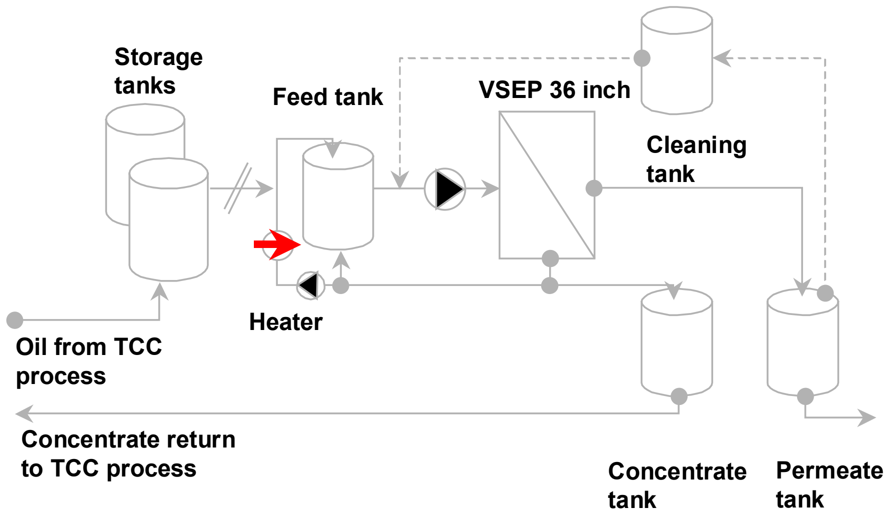


Figure 6: Schematic process flow diagram of the VSEP process

The oil is processed at a temperature of 60-65°C with 1.8 MPa feed pressure, giving a start up flux at 6%vol. solids of more than 20 litres/m^2hr. When the solids level in the feed loop rises to approximately 30%vol., the flux has dropped to 10 litres/m^2hr. The shutdown permeate flux of the installation is set to 4 litres/m^2hr, which corresponds to a solids level in the feed loop of 75%vol. This gives a permeate recovery of 93%.

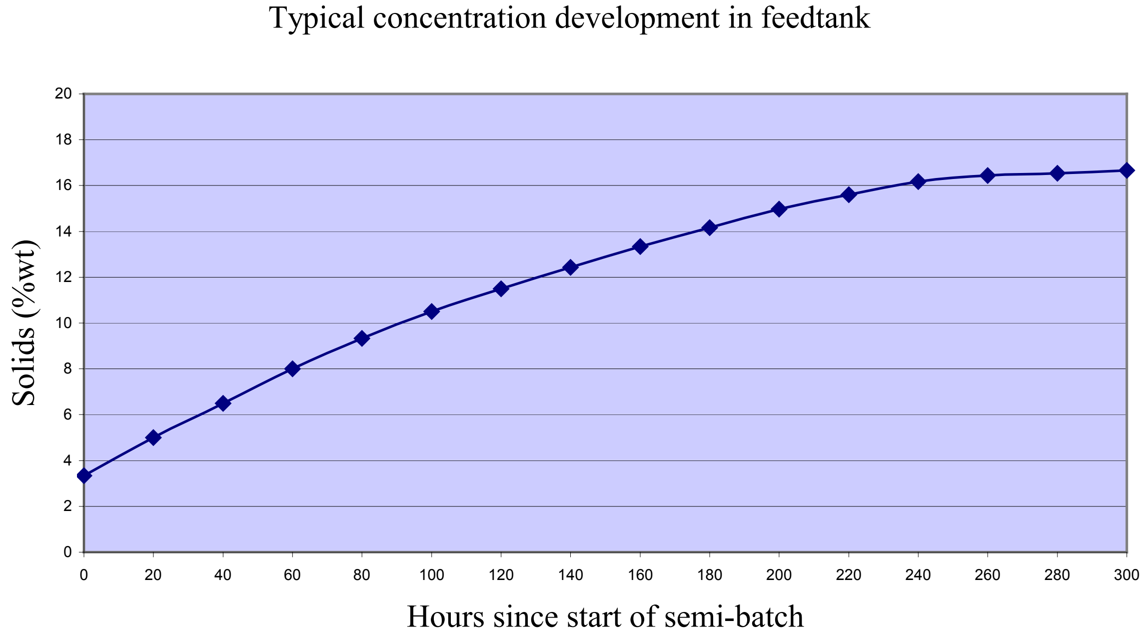


Figure 7: Diagram of development of solids concentration during batch proces

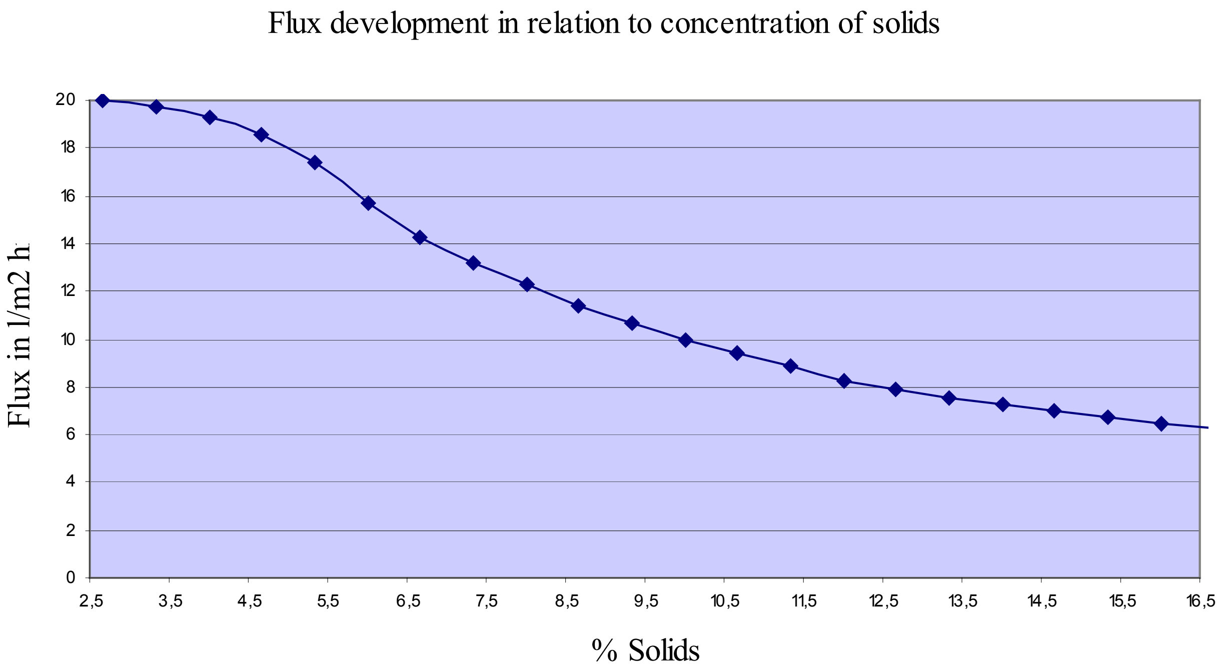


Figure 8: *Diagram of flux development during batch process*

The process is also engineered to operate in a single pass mode. In this mode the unit runs in a dead end filtration mode by closing the concentrate valve (effectively stopping the crossflow) and opening this concentrate valve only when the desired conctration factor is reached. Feed flow to the membrane process is than governed by the amount of permeate that is removed. This is an option that can be used for production of extremely thick slurries, which are too viscous to pass the feed pump in the cross flow mode.
The results with running in a slip stream mode are so good however that there is no need for this special single pass mode that the installation has been prepared for.. The typical batch size processed continuously without stack flushing and discharge of concentrate from the feed tank is about 200 m^3. A comprehensive PLC program is able to handle all normal disturbaces in this mode, and the operation can be regarded as fully automatic. The 200 m^3 batch requires a processing time of about 18 days giving an average flux of 11 litres/m^2hr. The 15 m^3 of concetrate from the feed loop is pumped over to the feed containers for the TCC process and reprocessed mixed with the drilling waste.
There have been no signs of permanent fouling or membrane degradation and the full flux is recovered simply by flushing the membrane stack using permeate. The membrane stacks are not constructed to be backflushed, therefore only a normal rinse can be applied.
The total production shut down for concentrate discharge, membrane cleaning and required preparations for a new batch is less than 24 hours, which gives a very fair total operator requirement for the operation.
The actual operational costs are still under investigation however indications are between 5-7 Euro/m^3 produced permeate. Whereas the value increase of permeate through the operation is covering the operational and capital cost in a year of operation.

Cleaning of recovered base oil from drilling waste using VSEP:

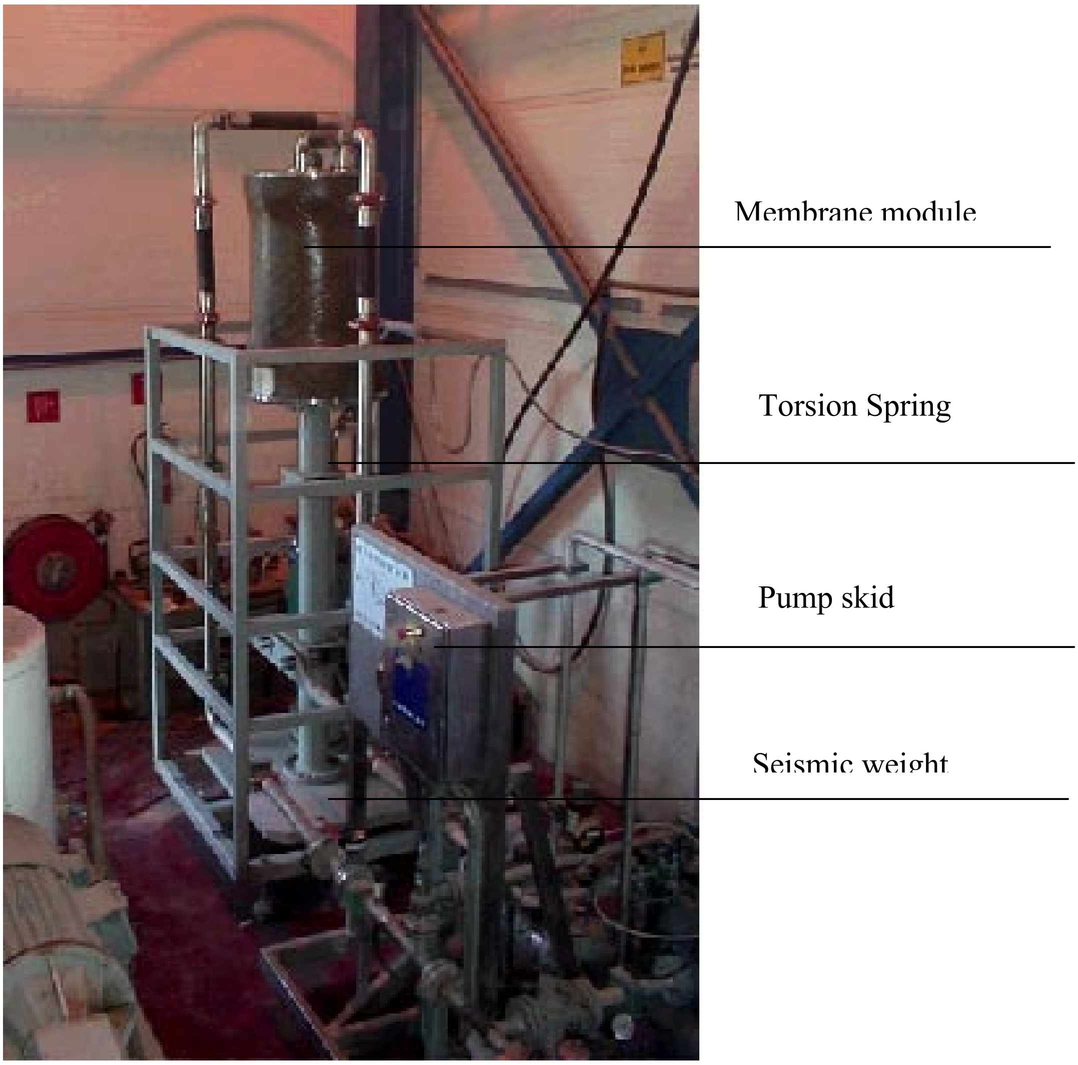
Operational record	
• Experience • Mode of operation:	• Produced 1400 m^3 of permeate since January • Semi batch with continuous cross flow
Operational	
• Vibration frequency: • Cross flow rate: • Feed pressure: • Feed temperature: • Overall recovery of base oil: • Final concentration: • Processing time of batch: • Batch volume • Cleaning procedure: • Chemical cleaning: • Mean operator demand:	• 49.6 Hz • ~5 m^3/hour • 17-19 bar • 67-70 ºC • 95% • 70%vol sludge in spin test (~25%wt solids) • 300 hours • 200 m^3 • Flush with permeate between production batches • Has not yet been necessary • 4 hours/day incl. maintenance
Composition data	
Analysis of raw feed Analysis of permeate Particle size analysis: Solids composition Average density of solids	6-10%vol sludge in spin test (~3.5%wt solids) <0.005% ash and 240 ppm water 0.01-10 µm – mean at 2 µm Bentonite/Calcite/Silicates/Carbon fines 2.5 g/cm^3

Table 1: Overview of operational data

Conclusion

The VSEP is an effective solution to a separation problem that requires a membrane separation as well as operation at high solids concentration. The vibratory shear used in process is very effective in preventing fouling and increasing fluxes under difficult circumstances where conventional technology, centrifuges, cyclones and cross flow membrane filtration have proven to be ineffective.

Figure 7: *Vibrating Shear Enhanced Proces (VSEP) membrane module in operation*



Figrure 8: *VSEP installation overview*