SPE 115587

Appplication of Membrane Filtration Technologies to Drilling Wastes

Oluwaseun, Olatubi, SPE, Burnett, David, SPE, Hann Roy Texas A&M University and Rich Haut, HARC.

This paper was prepared for presentation at the 2008 SPE Annual Technical Conference and Exhibition held in Denver, Colorado, USA, 21–24 September 2008.

Abstract

The Environmentally Friendly Drilling (EFD) program is taking a renewed look at dealing with the issue of waste management and re-use particularly with regards to produced water and water based drilling wastes, developing solutions that would possibly reduce the size of reserve pits needed in drilling operations and achieve significant waste volume reduction through the extraction of water from drilling wastes encouraging reuse of the extracted water in drilling operations and the concentration of suspended solids.

The EFD is investigating the use of membrane-filtration technologies in the aforementioned aim of waste volume reduction and water extraction from drilling wastes. The investigation involves processing actual drilling wastes using various membrane types and configurations in developing solutions to challenges facing membranes particularly fouling. We are investigating the ability of these membranes to effectively remove the suspended solids from waste streams and refine the waste to levels where they could be used in drilling operations or sent for further treatment such as desalination. Our aim is to develop a mobile treatment unit made of a suitable membrane system that could be deployed to drilling sites to be used as an onsite option aimed at recycle or re-use of water resources.

We are currently investigating in our laboratories various membrane-filtration technologies with water based oilfield wastes and coupling this with our prior development of field deployed technologies in developing a cost efficient membrane filtration system for field application. We show in this report how membranes have been used in the filtration of actual solids laden field supplied water based muds and a solids simulated laboratory water based mud, highlighting the compatibility of membrane systems with water based muds.

In light of the evolving stringent regulatory standards and in demonstrating good stewardship of the environment, the Oil and Gas industry is expected to be active in reducing the footprint of its various activities on the environment and in showing optimal use of resources. This approach to dealing with drilling wastes confers the two-fold advantage of optimal use of water resources through re-cycle and the reduction of the footprint of drilling operations well within reasonable economic costs by saving significant waste treatment, hauling and freshwater costs.

Introduction

The energy question is increasingly becoming the most important question of this present age, with growing populations especially those of South East Asia and the attendant energy demand of these teeming population the issue of energy has become a pressing issue globally. The search for energy to meet present demands and future forecasts is becoming more intense and more diversified than ever, despite this diversification of sources to meet the energy demand globally, crude oil remains the prime energy source today and probably in the foreseeable future. This increased demand for energy and rising energy prices have renewed interest in unconventional oil resources as unconventional resources are estimated to play a major role in providing energy for the future(1).

Parallel to increasing energy demand is the increasing awareness about environmental issues especially as they pertain to E&P operations. The last decade has witnessed increasing environmental regulation imposed by federal, state and municipal authorities on the industry in other to protect environments where exploration activities occur particularly during drilling. With the projected rise in E&P operations there is an increasing environmental awareness and activism especially as new terrain is expected to be explored for their resources which could culminate into more stringent protective regulations. Emphasis is increasingly placed on reducing the impact or footprint of E&P operations on the environment to minimal levels, issues such as resource conservation, waste minimization (or waste reduction), recycling, re-use are becoming topical issues and metrics in the regulatory toolbox in determining where exploration activities can be carried out in the USA and worldwide. Increasingly environmental concerns are becoming the major determinants to future drilling concessions by the government and landowners.

In the last thirty years drilling technology has gone through significant technological changes resulting in smaller rigs such as Flex rigs and innovations such as horizontal drilling and these changes have resulted in significant reduced surface disturbance during drilling while significantly increasing the subsurface reach (subsurface drillable area) of drilling operations. From Figure 1 (Kansas Geological survey, 2000) we see that rig size has been reduced by 70% in the last thirty years while subsurface drillable area has increased by 6400% in the same period. This shows that the dynamics of impact of drilling operations has shifted considerably in the last thirty years from top to bottom, though surface reduction translates to less surface area or ecosystem disturbance in drilling operations – on the surface, the wider subsurface reach means that there would be an increase in the amount of drilling waste generated subsurface which is usually brought to the surface thereby increasing footprint, thus due to increasing subsurface reach the total impact of drilling operations on the environment is actually increasing despite marked reduction in rig sizes.

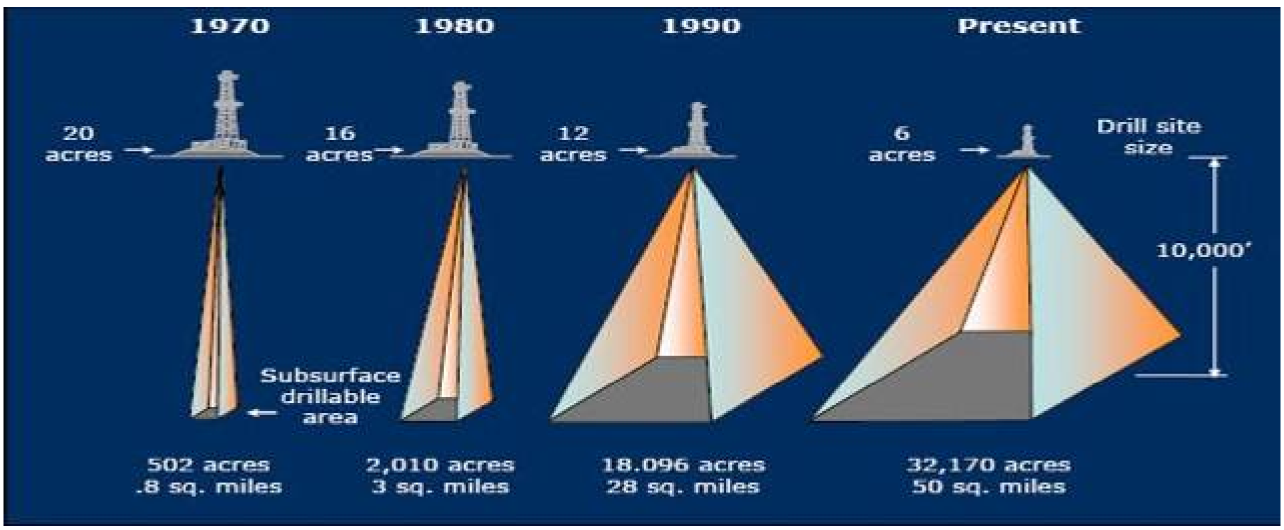

Figure 1: Rig size and subsurface drillable area in the last thirty years.

Freshwater sourcing could easily become a limitation factor in the exploration and production of oil and gas as operators are increasingly putting pressure on freshwater sources to meet increased E&P needs especially in the exploitation of unconventional resources. Copious volumes of produced water and water based wastes are disposed without re-use and recycle, from the last industry published study on fates of waste about 4 billion barrels of produced water per year is disposed into disposal wells and over 70% of water based drilling wastes are not recycled or re-used (2). Although the agricultural industry consumes the largest portion of freshwater resources present, industry disposal practices presents unsustainable disposal of scarce water resources especially produced water and water based drilling wastes. An early look into increasing re-use would be of benefit to all stakeholders and society as a whole.

The Environmentally Friendly Drilling (EFD) program is taking a renewed look at dealing with the issue of waste management and re-use particularly with regards to produced water and water based drilling wastes. The EFD is investigating the use of membrane filtration systems for removing suspended solids from water based drilling wastes to achieve the dual purpose of extracting water from these wastes and reducing or concentrating the volume of these wastes with the belief that this would help in reducing the footprint of drilling operations and conserve scarce water resources.

Theory

The objective of our investigation is to develop a treatment option that deals with reducing the impact or footprint of drilling operations specifically by looking into ways of minimizing wastes associated with increasing subsurface reach which we have identified as the largest contributor of footprint. In tackling the issue of these wastes, the perspective has been to critically look into the constituents of these wastes to determine what the "useable" constituents of the waste are and what constituents are "non-useable and if a separation could be made of the waste based on this delineation. If such delineation can be made and executed this would fortuitously help at achieving volume reduction while the useable constituents could be re-used.

Volume reduction of drilling wastes portends a veritable tool to reducing the overall footprint; if the waste volume could be reduced to a factor of the whole this would then augment rig size reduction in reducing the total impact or footprint of drilling operations. Volume reduction would also expand the choice of treatment options available to deal with wastes, current audits show that increasing waste volumes due to higher subsurface reach are making uneconomical preferred waste treatment and or disposal options, even options deemed environmentally friendly. Re-use and recycle have always been envisioned on a larger scale such as desalination of brine as a source of freshwater for agriculture or potable use, such expectations of recycle and re-use sometimes fall short of expectations due to extraneous issues such as public perception of recycled waste or market for the recycled waste. The EFD aim is first localized to encourage recycle and re-use in drilling operations to optimize the use of water resources, this gives room for more flexibility in waste recycling as the burden of greater polishing of the waste is reduced and the lessons from such localized recycling can be used as fodder for more ambitious re-use programs.

Produced water and drilling wastes are the major contributors to drilling wastes. For water based drilling wastes the presence of suspended solids hinders most attempts at recycle and re-use amongst other contending issues, while in the desalination of produced water periodic fouling of reverse osmosis membranes due to suspended particles has also been a major hindrance raising the costs of desalination, the problem associated with suspended solids could be indentified in various wastes such as wastes from fracturing operations like the frac fluid backflow. Any successful approach at reclaiming these wastes for re-use or recycle must deal with removal of suspended solids in these wastes before other issues such as toxicity, salinity and other secondary issues are treated.

In this study we set out to show the removal of suspended solids and water from water based drilling wastes which are solids laden is possible and that with proper engineering and maintenance field deployable equipment could be created to achieve this first step in the reclamation of water based drilling wastes. We set about this objective by investigating the use of membrane filtration technologies for solids removal from these wastes making the case for membrane filtration technologies over traditional suspended solids removal equipment such as centrifuges and hydrocyclones because we believe the particle size removal limits of these traditional solids removing equipments are well above the limit needed to make re-use or recycle possible.

Traditional solids removal equipments have particle size limitation on what they can separate and are far from the separation efficiencies of membranes which can range from separation of bacteria to atoms (3, 4). The separation range of the membrane filtration technologies we investigate make it possible for total removal of all suspended solids thereby changing significantly the wastes making re-use or recycle possible either in its solids free state or in preparation for secondary treatment such as desalination. The major challenge in the adaptation of membranes is fouling (5), we investigate but not report extensively (as our investigation is ongoing) the positive effect fouling mitigation techniques have on reducing the impact of fouling and how these could be incorporated into field deployable systems.

Procedure and Equipment

There are four common membrane filtration modules or configurations common to membrane systems; they are tubular, plate and frame, spiral and hollow fibre membrane modules. Our investigation was carried using the tubular and hollow fibre configurations, the plate and frame and spiral wound modules were not investigated due to practical issues with adopting them to drilling wastes and or actual drilling operations. Two water based drilling mud types were used in our investigation; a field supplied lignosulphite based mud supplied from actual field operations in East Texas by an operator (was taken from the mud pit) and salt type mud that was made in the lab using mud software and simulated cuttings were introduced into the lab prepared mud. Each mud type was run using both membrane filtration modules.

For the tubular configuration experiments, a simple in-house built filtration unit (schematic in Figure 2, appendix) fitted with a titania honeycomb ceramic membrane with mean pore size of 0.005 microns was used, the membrane length was 305 mm and had a surface area of 0.13 metres square. The transmembrane pressure (TMP) was controlled by an adjustable valve, the fluid velocity was measured by a flow meter and tests were run in the recycle mode i.e. the filtrate from the membrane was passed back to the feed reservoir. The ZW-10 Zenon® hollow fibre demonstration unit was used for the hollow fibre configuration tests (Figure 3, appendix), it has a nominal surface area of 0.93 metres square, and a nominal pore size of 0.04

microns. The Zenon unit has an air blower that continuously scours the surface on the membrane and also mixes the feed. The system had micro pumps which are set to automatically backwash at periodic intervals using permeate from a backpulse tank, suction was also controlled automatically. A typical run in the ZW-10 consists of a period of suction for a set interval followed by a brief period of backwash using greater pressure; this helped to unclog the pores of the membranes. Both units (tubular and ceramic) carry out filtration in the ultrafiltration range with the ceramic module having finer pores. Before and after each run membranes were cleaned as prescribed by the manufacturers and RO water flux was recorded at the start and end of all experiments and clean-up.

The lignosulphite based mud from the field had a mud weight of 10 pounds per gallon, 10.20 % solids by volume ratio, funnel viscosity of 37 sec/quart and had 92% water by volume. For the lab made mud the recipe is shown in Table 1, mud weight was 9.4 pounds per gallons, solids ranging from 0.762- 3.81 mm (762 -3810 microns) were simulated and added to the mud to make 5 % solids by volume ratio, this particle size distribution represents the larger spectrum of particles in most muds. All tests were run for four hours, the tubular ceramic module was run using a flow of 61 liters per minute corresponding to a crossflow velocity of 3.6 m/s, transmembrane pressure of between 52-72 kPA and 25-30 C was maintained. The hollow fibre pressure was maintained at 55 kPA, a 20% dilution of the sample had to be made because each test required a minimum of 90 gallons per run. Permeate volume for both modules was measured manually using a graduated cylinder and a stop watch, the average of three readings was used as the final measurement. The turbidity of the sample was read using a Hach-2100P turbidity meter and particle size distribution was read using the Microtrac S3000® particle size analyzer. Parameters of importance that were measured include flux over time, the pressure, the solids concentration and temperature during filtration. Variations to the system were carried out in order to optimize filtration such as changing pore size of membranes, varying system parameters and varying the rheological characteristics of samples, this represent part of our on-going investigation and results of these variation are not extensively reported here as results reported in this paper are confined to showing the possibility of membranes filtration of drilling wastes.

Results

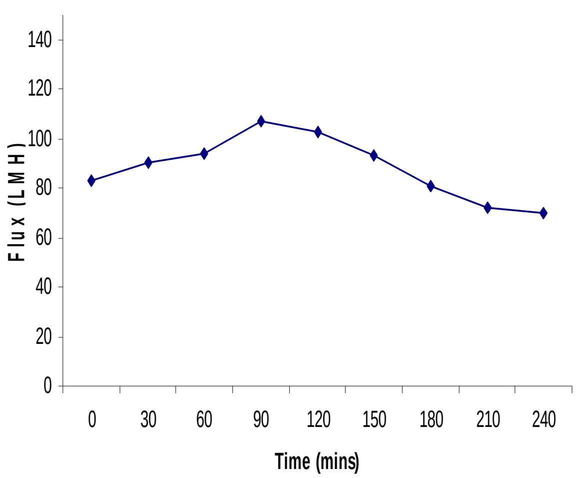

Figure 4: Flux over time of ceramic membrane filtration of field supplied lignosulphite WBM
(Density 10 ppg, solids content: 10.2 % by volume)

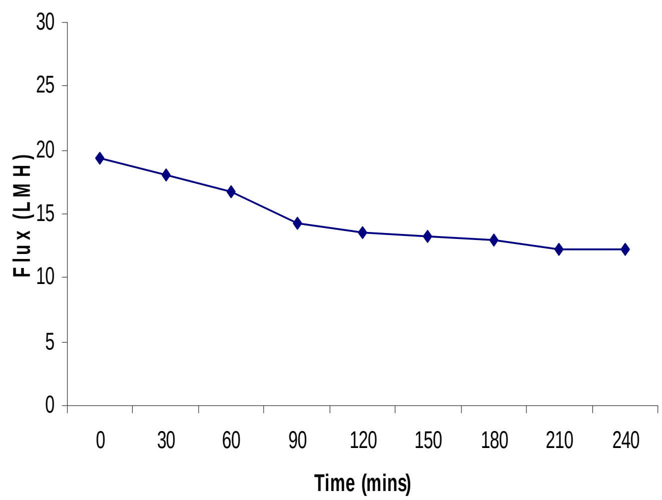

Figure 5: Flux over time of hollow fibre membrane filtration of field supplied lignosulphite WBM
(Density 10 ppg, solids content: 10.2 % by volume)

After running the field supplied lignosulphite water based mud in both the tubular ceramic membrane and the hollow fibre membrane the flux over time is reported in figure 4 and figure 5 respectively. Tubular membranes have the lowest surface area to volume ratio when compared to other module configurations and this would explain the difference in the flux of the ceramic tubular membrane to the hollow fibre membrane. The conditions at which both tests were run was the least optimized conditions as the aim of the tests was to see the waste handling capacity of both modules when handling such solids laden waste, thus this is our baseline filtration. Filtration of the mud by the tubular ceramic membrane reached peak filtration after about 90 minutes, this unique gradual build up of flux is suspected to be caused by the interference of the mud solids plugging pores spaces and the inherent ability of muds to form a filter cake on the surface of the membrane. After reaching its peak, flux did not decline beyond 22% over the next two hour period. The Zenon unit has a high surface area to volume ratio, but primarily the test unit (figure 3) was not intended for our purpose but designed for wastewater filtration, thus there were some design issues that hindered its performance, for example a system with more fibre bundles than was in the test unit system would have improved filtration considerably, still this design issues did not hinder the objective of assessing how hollow fibre membranes would handle solid laden wastes. The solids in the mud settled at the bottom of the unit as water was removed from the system and the waste concentrated, flux decline by 37% was observed before steady state filtration which seemed to occur between 90-120 minutes and after steady state there was a less than 5% decline in flux.

The solids content of the lignosulphite water based mud and the filtrates after filtration were measured using a mud retort, the solid content of the feed was 10.20 % by volume and the permeate samples from both modules were determined not to have any solids in them using the mud retort. A particle size analyzer, the Microtrac S300, was used to analyze the particle size distribution of the samples (feed, permeate and retentate), figure 6 and 7 show the particle size analysis of the feed and permeate of the lignosulphite mud (permeate particle size distribution was similar in both modules; figure 7 represents permeate from both modules). The particle size distribution of the feed show a diverse range of particle sizes with the majority of particles falling within the 1-10 micron range and the about 30% within the 11-100 micron range, after the feed was run through the membranes the particle size distribution as shown in figure x shows most particles in the ultrafiltration range to be non-existence giving basically a solids laden free permeate.

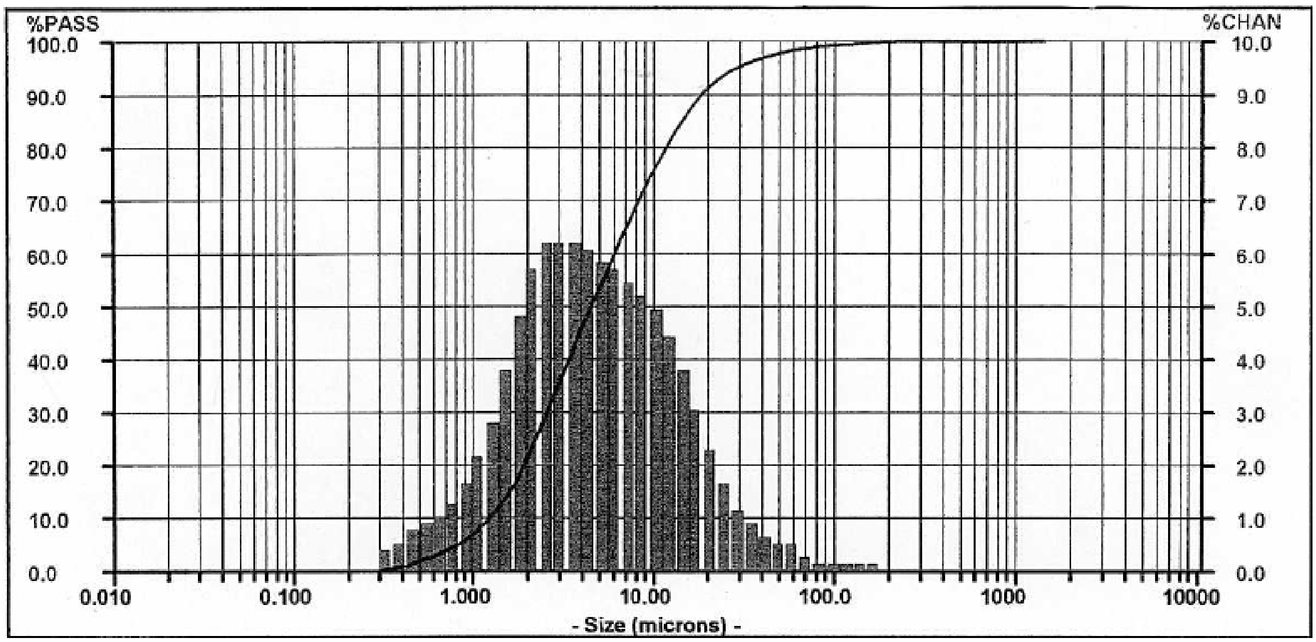

Figure 6. Particle size distriubution of the lignosulphite water based mud (feed)

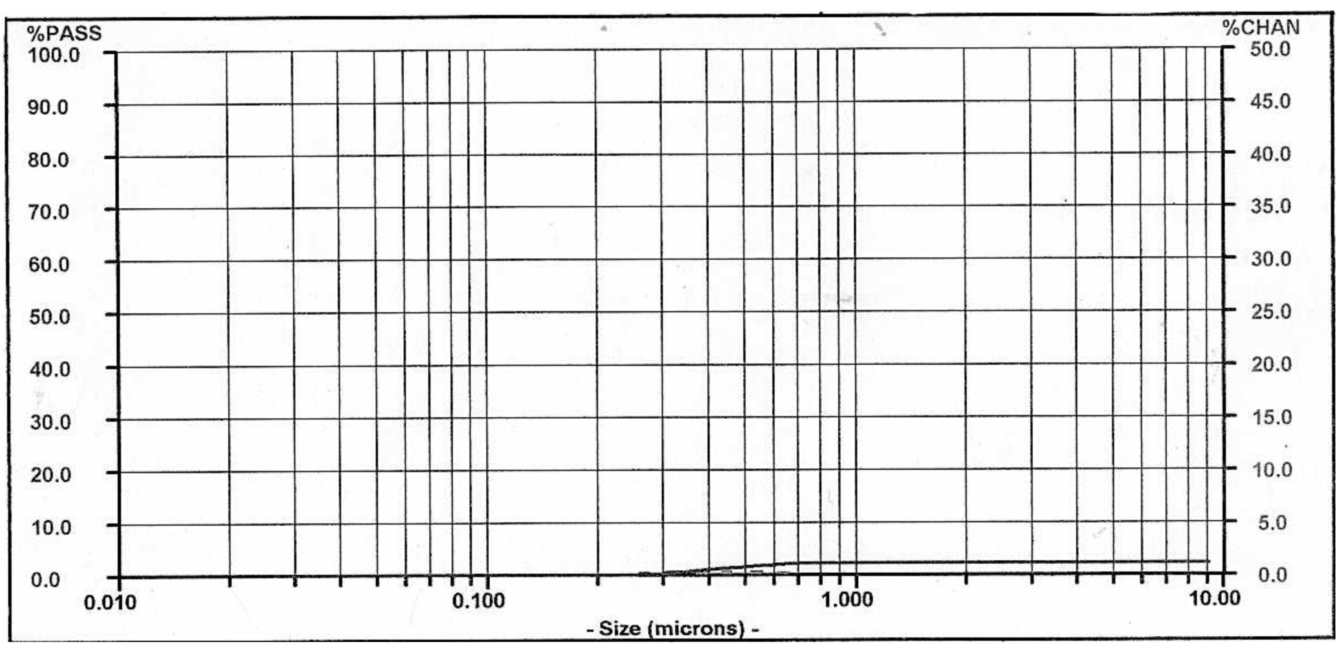

Figure 7. Partcle size distribution of permeate of the lignosulphite water based mud after filtration through membranes.

Turbidity measurements were made of the samples also, the lignosulphite mud feed sample had 55200 NTU, the permeate from the ceramic tubular membrane had a measured turbidity of 6.86 NTU and permeate from the hollow fibre membrane had 7.44 NTU after membrane filtration. Surprisingly the turbidity of both permeate samples were close despite a 10 fold difference in their pore sizes. The dissolved character of the mud largely remained the same as ultrafiltration of the samples does not seem to affect the dissolved properties of the sample. Pictures of the feed and permeate from both modules are shown in figure 8 (appendix).

The laboratory prepared mud was also filtered using the ceramic membrane and the hollow fibre membrane as described larger micron size particles were simulated and added to the mud. The particle size range were significantly greater than the pore sizes of both membranes and the role of attrition causing smaller particles did not seem to affect filtration at least directly as flux rates were higher (figures 9 and 10) when compared to the lignosulphite mud filtration. With the tubular ceramic membrane a prescreen was needed as it was not practical to have the solids go through the membrane so a 10 micron prefilter was used but with the hollow fibre design the large particles easily settled to the bottom of the tank. Flux reduction in the hollow fibre membrane for the four hour period was less than 4% and for the ceramic tubular membrane it was about 7.5% after the initial hump, there was no recorded pressure rise in the hollow fibre membrane while the pressure rise in the ceramic tubular membrane was minimal. Turbidity measurement of the feed sample and permeate were made, the feed sample had a turbidity of 1670 NTU and permeate samples had a turbidity of 1.67 NTU, figure 11 (appendix) shows the picture of the feed sample and the permeate sample. It can be adduced that due to the absence of solids in the lower micron range (10-100 microns) filtration was easier and could be responsible for the higher fluxes. The particle size distribution of the permeate sample (not shown) was similar to figure 7 and the particle size distribution of the feed was more to the right of the particle size scale.

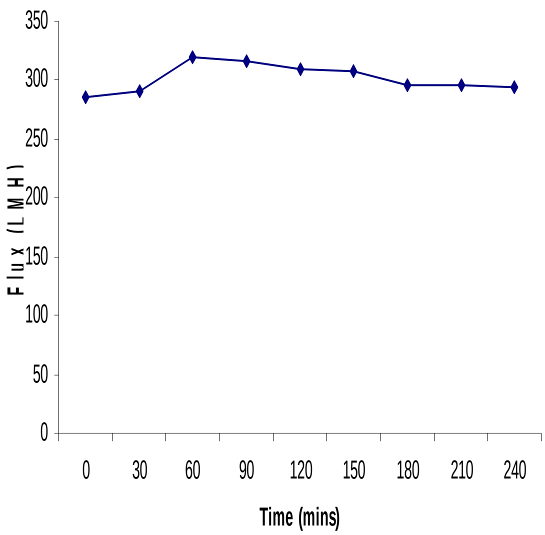

Figure 9: Flux over time of ceramic membrane filtration of lab made WBM
(Density 9.4 ppg, solids content: 5 % by volume)

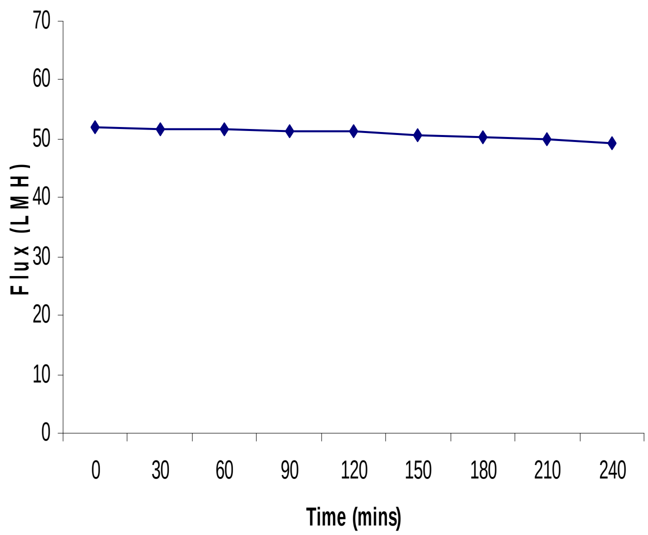

Figure 10: Flux over time of hollow fibre membrane filtration of lab made WBM
(Density 9.4 ppg, solids content: 5 % by volume)

Using the volume of the retentate, volume of permeate and volume of mud after filtration we calculated the percent volume of reduction. In the filtration of the lignosulphite mud using the tubular ceramic membrane we achieved a 61% volume reduction i.e. we reduced the volume of the mud by 61% leaving a concentrated retentate that was 39% of the initial mud volume and the rest was extracted water while in the hollow fibre module we achieved about 52% volume reduction of the lignosulphite mud. Higher volume reduction was achieved in the filtration of the lab based mud when compared to the lignosulphite based mud; the ceramic module achieved about 78% volume reduction while the hollow fibre unit achieved about 63% volume reduction.

As stated earlier we are investigating modifications that would help maintain filtration flux by lowering the propensity of fouling. One of such early investigation was to look at the effect of backflushing on the membrane flux. Backflushing usually entails forcing a fluid either permeate or air in the reverse direction of flow at pressure higher than the normal filtration pressure for a short period, this helps to unclog blocked pore spaces thereby reducing resistance to flux. For backflushing to be effective the fouling has to be physical in nature, fouling due to chemical interaction between the membrane and the feed sample would require chemical cleaning of the membrane, for these investigation we expect that flux decline would be mostly due to fouling of a physical nature (solids plugging the pores) than chemical interaction between the mud and the membrane at lest in the initial stages of filtration.

Backflushing in the traditional sense is mostly confined to ceramic membrane use but as explained in the operation of the Zenon Zeeweed unit above backflushing is incorporated in its system. We investigated the effect of backflushing on flux using the ceramic tubular membrane in the filtration of the lignosulphite mud, all conditions were maintained as previous experiments and all we did to backflush was to reverse flow at 90 kPA for 15 seconds. We chose the 120th minute and 180th minute time interval because in the previous runs flux decline was noticed at about those time intervals, figure 13 shows the result of backflushing. As we can see from the graph the decline was slowed down after backflushing and after the 180th minute backflush the flux rose similar to the previous flux, this shows that possible modifications in a design system can slow down flux decrease if such system is properly designed. Figure 4 and figure 13 compare the filtration with backflushing (right) and without (left).

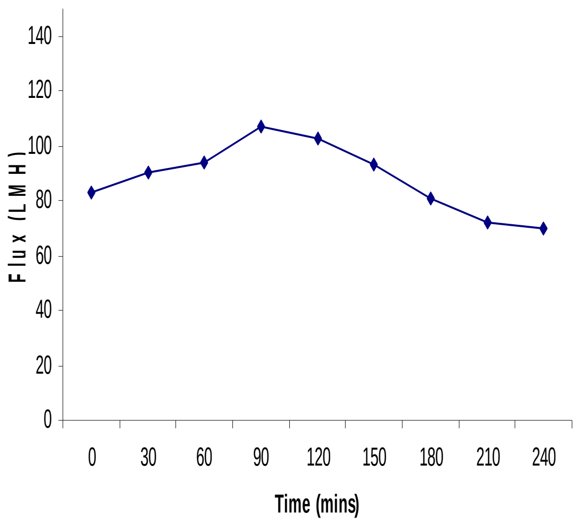

Figure 4: Flux over time of ceramic membrane filtration of field supplied lignosulphite WBM (no backflush) (Density 10 ppg, solids content: 10.2 % by volume)

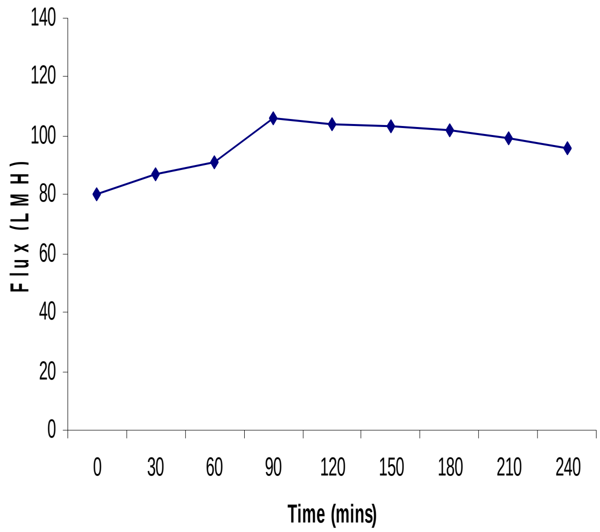

Figure 13: Flux over time of hollow fibre membrane filtration of field supplied lignosulphite WBM (with backflush) (Density 10 ppg, solids content: 10.2 % by volume)

Conclusion

We have demonstrated on a laboratory scale the filtration capability of membranes in processing drilling wastes. We have shown that there are possibilities in the engineering design of membrane systems to alleviate traditional challenges that face membranes in the filtration of solids laden wastes. Of importance is the realization that re-use and recycle of these water based wastes is dependent to a large extent on the concentration of suspended solids in these wastes, large concentrations of suspended solids (in the limit range of most traditional solids removal equipment) reduce the propensity of re-use. A qualitative comparison could be made of water based drilling wastes treated with traditional solids removal equipment versus membranes as shown in our study and it becomes clear that the limits of solids removal go a long way in determining the suitability of waste to re-use.

As shown from our results we had about 60% reduction in waste volume, this confers numerous advantages apart from the re-use of the extracted water from these wastes, an example of such an advantage would be the possible reduction in the footprint of drilling operations this portends. Excavations such as the reserve pits contribute largely to the footprint of drilling operations, with membrane filtration of wastes as a possibility during drilling operations, pits sizes could be designed to be remarkably smaller during planning stages due to the expected concentration of the waste, this would go along way in the reduction of the overall footprint of drilling operations complementing the reduction made over years in rig size. Also if wastes are to be hauled away, a reduction in the concentration reduces the volume to be hauled away, this reduced traffic reduces footprint as well as cost. Savings from concentrating wastes add up in reduced costs of hauling, reduced cost of purchasing fresh water and most importantly when the waste size is smaller it increases the viability of treatment options available to treat the wastes. With an estimated 30% of one’s waste size previous treatment options, even environmentally friendly options deemed unrealistic due to the initial waste volume becomes realistic in the face of waste volume reduction.

A rational first step towards building sustainable re-use of water resources would be encouraging “in-house” reuse during drilling operations, membrane filtration extracted water can find a lot of use in drilling operations such as in the mixing of muds (some dissolved constituents still in the extracted water might be a plus), rig wash and various operations where water quality in not necessary of essence or importance. Huge pre-treatment costs hinder presently desalination of produced water and other brines, Reverse Osmosis (RO) membranes used in desalination are very effective at desalination but extremely sensitive to solids, membrane systems such as the types described here would offer relatively inexpensive pre-treatment options for desalination aside from the other purpose of concentrating waste. The need for water resource recycle and re-use can not be overstated in the light of water concerns by stakeholders as stakeholders are requesting more water tracking from operators during their operations.

In conclusion, membranes have been around for a long period and are very effective at removal of solids, they find wide use in various industries and have reliably performed their operation in a cost effective manner when managed properly. Membrane systems are cost effective and the initial investments in them are moderate in relation to costs associated with drilling operations. The challenge is in the design and development of a system that can be seamlessly incorporated into drilling operations without much disruption of operation, the EFD is continuing or investigation looking into the effects of operational parameters and how compositional and rheological effect affect filtration. In the same vein we are looking into practical design issues aimed at ensuring durability of the system, easy operation and cost effectiveness amongst other practical issues.

Reference

1) Stark, P.H, Chew, K and Fryklund, B (2007). The Role of Unconventional Hydrocarbon Resources in Shaping the Energy Future**.** IPTC 11806. International Petroleum Technology Conference 11806, 4-6 December 2007, Dubai, U.A.E.

2) Petrusak R.L., Freeman B.D., Smith G.E, (2000). Baseline Characterization of U.S. Exploration and Production Waste and Waste Management. SPE 63097, presented at the SPE Annual Technical Conference and Exhibition held in Dallas, Texas, October 2000.

3) Cheryan, M (1998). Ultrafiltration and Microfiltration Handbook. Technomic Publishing Company Inc. Lancaster, UK.

4) Cheremisinoff, N. (1998). Liquid Filtration (Second Edition). Butterworth-Heinemann, USA.

5) Noble, R.D. and Stern, S.A. (1995). Membrane Separations Technology: Principles and applications, Elsevier, Amsterdam.

Products	Concentration (Ib/bbl)
Xanthum Gum	0.46
Salt Gel	11.1
Caustic Soda	0.46
Carboxymethylcellulose salt	0.96
Salt	52.5
Bentonite	4.62
Water	298

Table 1: Laboratory prepared mud recipe.

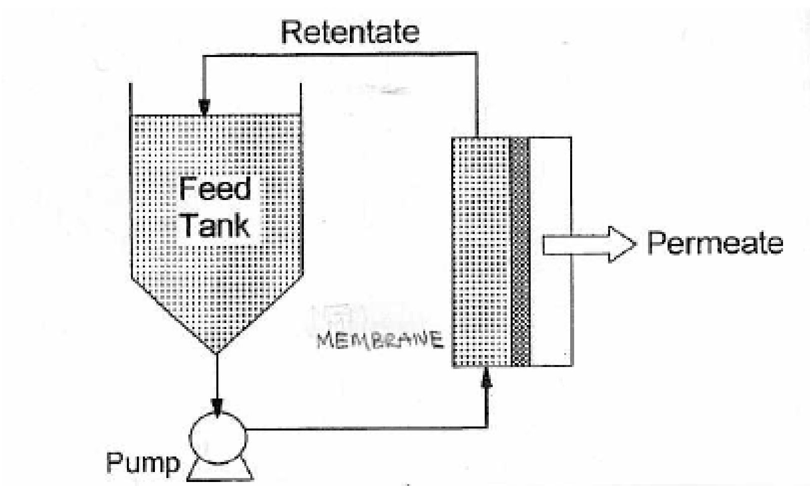

Figure 2. Schematic of Ceramic membrane filtration

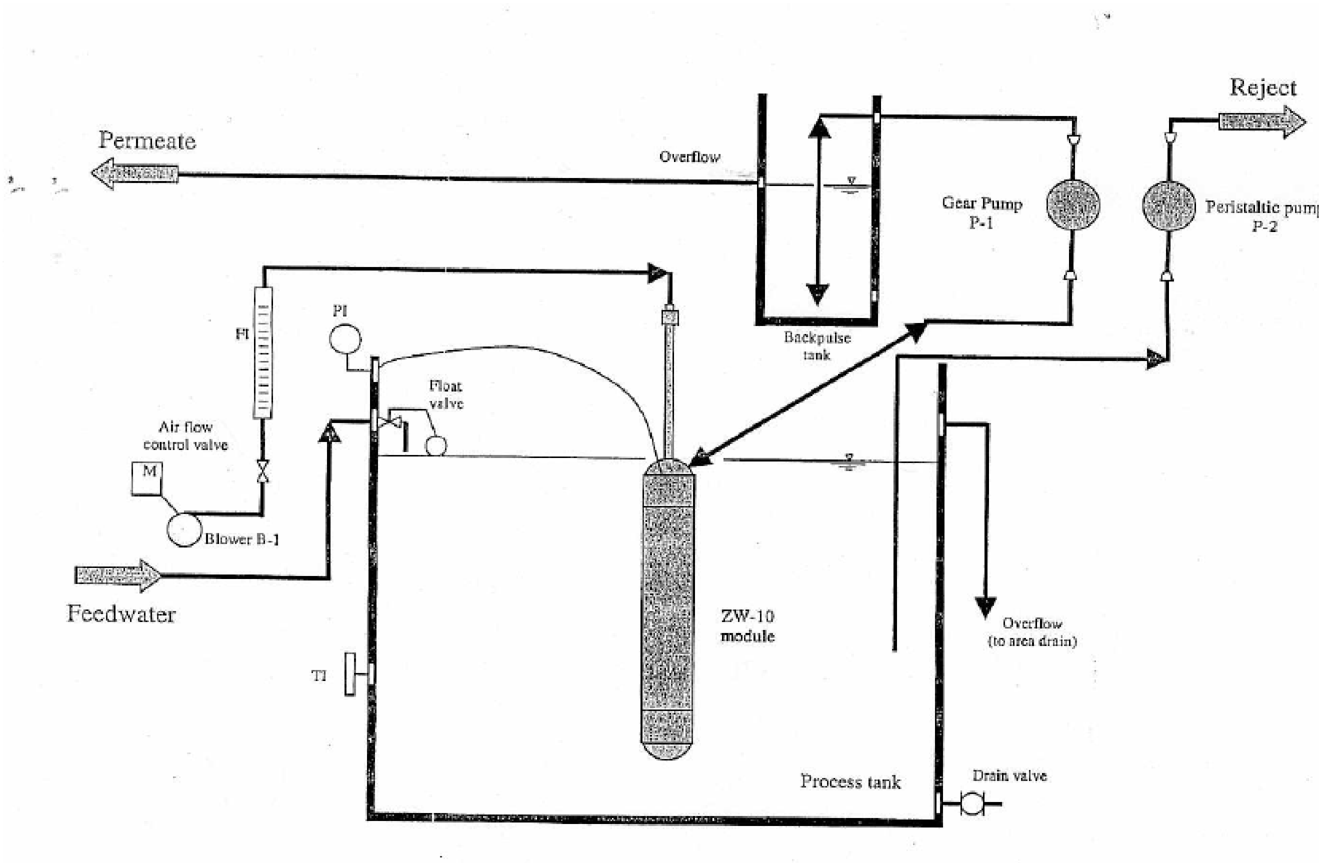

Figure 3. Schematic of hollow fibre membrane filtration courtesy of Zenon

Figure 8. Feed sample (left) and permeate samples, ceramic tubular membrane, 0.005 micron (middle), hollow fibre membrane 0.04 micron (right) of field supplied lignosulphite WBM.

Figure 11. Feed sample (left) and permeate samples (right) of ceramic tubular membrane, 0.005 micron and hollow fibre membrane 0.04 micron of lab prepared mud.