BASIC FILTRATION: AN OILFIELD NECESSITY

Stephen A. Von Phul
Eggelhof Incorporated

ABSTRACT

It is becoming increasingly important for technical personnel in the petroleum industry to have a background in filtration and separation techniques. One of the principal reasons for this need is demonstrated by the number of enhanced oil recovery (EOR) projects currently in operation. Anytime contaminated fluids are introduced into a subsurface formation there is a risk of damage. In the case of water and gas flooding operations where large volumes of fluid are injected, levels of contamination become acute problems.

As an example of a systematic approach to filtration problems, this communication describes the component selection and field operation of a pilot system for the removal of solid and liquid contaminants from waterflood injection water.

INTRODUCTION

Subsurface formations are sensitive to contaminated fluids. (1) The contaminants in the fluid cause formation damage in the form of permeability loss when they become lodged in the formation structure or pore throat. (2, 3) For example, if 50bbls of completion fluid containing 0.5% by volume solids were lost to the formation, 1,235 perforations (10x0.5 inch) could potentially be plugged. (3, 4) Further, if the plugged well were acidized the damage could worsen as a result. (5)

In a single waterflood operation, millions of barrels of water per year are injected into wells to enhance the recovery of up to 50% of the oil remaining in the formation after primary production. (6, 7) The damaging particle sizes differ with the formation permeability, but if 50bbls of fluid can damage a well at 0.5% solids, millions of barrels would not have to be too contaminated to result in the same damage. The contaminating particles have to be removed prior to injection to alleviate potential damage. The easiest and most cost effective method to remove these contaminants is by filtration.

Because of the severity of the problem and the frequency of waterflood operations, oil field technical personnel need to have basic filtration knowledge. This article utilizes a West Texas waterflood pilot study as a model to illustrate some of the basic concepts needed, by oil field personnel, to reduce the time, effort, and mistakes in solving filtration problems encountered in these operations.

Filtration Concepts

Art or science, filtration is a difficult subject to explain sufficiently in an article on equipment, or in a "how to" fashion. So, before delving into the actual concepts, listed below are the steps included in a good problem solving outline. This list is available in the Chemical Engineering Handbook (8), and appears as follows:

1. define the overall problem.
2. establish process conditions.
3. make preliminary selection.
4. take representative samples.
5. make simple tests.
6. modify process conditions if necessary.
7. consult equipment manufacturers.
8. make final selection.

In the article to follow, numbers 3-5 will be the areas of concentration. Presented will be general concepts of method and removal reaction with different contaminants.

The most important point to consider in making the filtration method selection is the contaminant. What is it? How will it react to pressure? Is it shear sensitive? How much of it is there? It is important to know everything possible about the contaminant(s) in the fluid to be filtered.

Contaminants may be categorized as; solids, sand, silt; semi-solids, gels, polymers; or liquids, water, hydrocarbon. Contaminants dissolved in a liquid should be considered ultra-fine solids. Solids are the easiest contaminant to remove with filtration. They are relatively pressure and shear insensitive. Solids settle more readily than other contaminants. Accumulations of solids on a barrier have a greater tendency to be permeable than the other categories.

Semi-solids and liquids have several like tendencies. They are both shear sensitive, liquids being the most sensitive. Both are pressure sensitive. This is to say that when removed from flow by a barrier, they readily deform and migrate under pressure. Semi-solids usually settle more readily than liquids, but this is entirely dependent on operating conditions and specific gravity (mass) differences between the contaminant and the liquid in which it is suspended. When accumulated on or in a barrier, both of these contaminant types are virtually impermeable. Semi-solids and liquid contaminants have to be handled very gently.

As is the case with contaminants, filter methods may be classified generally. Most every filtration device will incorporate one or a combination of the basic filtration methods. The basic filtration methods include: gravity, depth, surface, and chemical. Each method has its own unique advantages and disadvantages, and should be applied to a process accordingly.

Gravity filtration is fairly straight forward. Stoke's law is oftentimes applied to gravity filtration situations as a mathematical model. Physical properties that affect gravity devices include: mass, differences in specific gravity, temperature, viscosity, and particle geometry. Examples of equipment that utilize gravity as a separation method include: settling tanks, corrugated plate separators (oil/water), high volume centrifugal separators, and clarifiers. Regardless of the equipment, the natural separation that occurs due to gravity is the cheapest form of separation. If the specific gravity of a contaminant is significantly less than the suspension medium, it will readily float and can be removed. If the specific gravity of the contaminant is significantly greater than that of the suspension medium it will sink, and can be removed.

Of the equipment listed that use gravity as a filtration method, high volume centrifugal separators are a bit different. Centrifugal separators should only be used to remove solids that have specific gravities in the 2-3 range GREATER than the suspension liquid. They should settle rapidly upon inspection. Because of the turbulence created inside these units, semi-solids and liquids are usually not removed. Centrifugal separators, as will be shown, can replace bulky tankage and accelerate the gravity separation effect if properly applied.

Depth filtration, as its name implies, is characterized by the thickness of the contaminant removal material (barrier). This material is usually a thick matrix of fiberous or granular materials. Examples of devices that utilize the depth filtration method include: fixed beds, filter aid accumulators, and some cartridge filters. Generally speaking, most contaminated fluids contain heterogeneous mixtures of several different sized contaminants (solids, semi-solids, liquids). In such cases, some of the contaminant would be stopped by the surface of the barrier. The smaller sized particles would migrate into the depth of the medium. In this manner, the depth and the surface are used to hold contaminant material. This is why depth filters have the reputation of holding more contaminant than any other type of barrier filtration method.

Two legitimate trains of thought are included to explain the contaminant removal mechanism in the depth of the matrix. First, the contaminants flow with the fluid until they reach an appropriately arranged spot in the matrix that traps the particle. The second suggestion is that due to the complexity of the flow path and the differences in specific gravities between the fluid and the contaminant, the particle has multiple impactions with the matrix and thereby loses some of its kinetic energy imparted to it from the fluid flow. If the barrier is dense enough, the particle loses sufficient energy to be entrapped in the matrix. This would explain why barrier filtration increases in efficiency with decreased flow rate.

Depth filter devices almost always carry nominal contaminant removal (porosity) ratings. The reason for this is that they are not consistant in the sized particles that are removed. These nominal ratings are placed by the manufacturer of filter devices, and may be perfectly legitimate under their test conditions. Rarely are these ratings applicable to the field. This fact is consistant with all depth filters listed above, and should be considered an approximation or rule of thumb.

Contaminants have a variety of effects on depth type filtration devices. In fixed bed and filter aid (precoat or body feed) devices, semi-solids and liquid contaminants have a tendency to coat the barrier materials. The cartridge depth filter, on the other hand, is made up of a rigid matrix and a more controlled internal structure, and is therefore less sensitive to deformable contaminants. This is not to say that the depth type cartridge filter will not be fouled by deformable contaminants. It is to say, however, that for the amount of flow, the available surface area and the rigid but open internal structure render this type of depth filtration less sensitive. Regardless of the device, depth filtration is basically the same mechanism.

Thin barriers are representative of surface filtration. Examples of devices that utilize surface filtration include: strainers, screens, pleated cartridges, thin fabric devices. Surface filtration devices usually have a more defined surface pore structure and therefore offer more reliable contaminant removal according to size. Because they consist of very little depth, if the contaminant is not stopped on the surface of the barrier, it will not be removed.

These devices are extremely sensitive to semi-solids and liquid contaminants. If the barrier is tight enough in porosity to stop the liquid or semi-solid contaminant, the contaminant reduces the open area for flow increasing the differential pressure causing the particle to deform. As the particle flattens during deformation, even more of the open flow area is restricted, causing the pressure to either build to the point where the contaminant is pushed through the barrier, or the maximum differential pressure is reached. Surface loading filtration devices should be applied with caution when the contaminant is semi-solid or liquid.

In surface filtration, if the contaminant is solid and is stopped on the surface, it will accumulate. The accumulation of solids on the surface is called "cake". If the cake is permeable to flow, it will act as a mini depth filter and continue to remove contaminant from the fluid. However, if the solid contaminants exist as a mixture of particle sizes, the cake is less permeable than the filter barrier (if at all) causing the differential pressure to increase. This mechanism is not unlike the filter aid devices described in depth filtration. The difference is that the filter aids used to build the filter cake are known to be permeable and graded. Contaminants in nature are rarely graded and usually do not form permeable accumulation cakes on surface filtration devices.

Surface filtration devices are usually applied as polishing or quality control steps after gravity and depth filtration devices. These devices should not be exposed to high solid concentrations, deformables, or contaminants greater than their rated pore sizes.

THE PILOT STUDY

The pilot system was to demonstrate the efficiency of the filtration equipment ultimately recommended for use in the full scale system. Of primary interest were the filtration devices chosen by each participant, the filtration efficiencies, and the relevant costs.

Figure 1 and 2 demonstrate why West Texas waterflood projects are one of the best models for a filtration concepts discussion. These figures were supplied by the oil company that requested the study. The initial indication from the data supplied was that the only constant to rely on was that the fluid to be filtered was water. As is usually the case with filtration problems, the variables out numbered the constants 10:1.

The filtration system had to be designed to handle solids in the form of sand and silt, liquids in the form of oil, and a shear sensitive contaminant that behaves much like a semi-solid that has not been discussed as yet, i.e. precipitates.

The particle distributions were given for only two of the four samples, but they indicated a high concentration of particulates in the lower micrometer ranges. This meant that the filters had to be tight and have a high contaminant loading capacity. The consistency of high concentrations of solids in the upper size ranges made the decision on the level of prefiltration difficult. The most efficient level of prefiltration had to be found that would distribute the contaminant load to each filtration step.

Common practice for correlating Total Suspended Solids (TSS) and particle distribution is done by adding the total number of particles in each category, dividing each category by the total, and multiplying by 100. This number is the percentage of particles present in each category with respect to the total number of particles. The next step is to multiply the TSS number by each category percentage to arrive at the amount of mass for each particle size category.

The previously described method for TSS correlation was considered inadequate because it does not allow for a mass difference between particle sizes. It assumes that a 10 micron particle has the mass of a 1 micron particle. A new method was developed that appears to more accurately demonstrate masses in each size category. The Relative Mass Distribution method begins by assigning a relative mass number to each category in the size distribution. This RM number is actually the average of the high and low size number in each category. For example the 0-1 micron range would have a RM number of 0.5. This means that all of the particles in the 0-1 range would have a theoretical mass of 0.5 Relative Mass Units. After the RMU's are determined for each category, they are multiplied by the actual particles present per volume (COUNTS/LITER). The term RMU/L was chosen because most TSS data is reported in MG/L. The RMU/L column is added to give a total RMU for the distribution. The TSS (MG/L) for the sample is divided by the RMU/L for the sample to arrive at the actual correlation MG/RMU for the sample. To convert the particle categories from RMU to real mass numbers, the RMU/L column is multiplied by the MG/RMU number to yield the new category mass. This method is demonstrated in figure 4.

From the relative mass calculations, it became apparent that the bulk of the contaminant load appeared in the 10-20 and 2-5 micron ranges. These were the most likely ranges for the prefilters to protest the lower contaminant holding capacity final filter. To complicate the matter further, the presence of liquid hydrocarbon made the possibility of oil wetted solids high. The prefilters had to be selected on the likely presence of these combination contaminants. Oil wetted solids act somewhat like oil and somewhat like solids. They are much more pressure stable than the liquid oil contaminant and much more deformable than the solid contaminant. They have a tendency to stick to the surface of even depth filtration devices, partially deform plugging flow channels, and causing premature rises in differential pressure. Further, centrifugal separators are often ineffective at removing these contaminants because the oil reduces the apparent specific gravity of the solids alone.

Equipment Selection

The first stage of the filtration system had to handle the bulk of the 20 micron and greater particle removal that were not reported. It had to be insensitive to liquid hydrocarbon contamination, and be as maintenance free as possible. It was decided to use a high volume centrifugal separator. The separator had a 98% efficiency rating for sand and silt down to the 44 micron level, and was insensitive to deformables. Further, it was suggested that because of the efficiency, oil wetted solids would possibly be removed to a large extent.

It was decided to use 10-25 micrometer nominal disposable cartridge filters for the second stage of prefiltration. The relative mass distribution showed that at least a 10 micron prefilter was needed to protect the next step in filtration. The contaminant load was going to be high and possibly oil wetted. The depth style disposable filter cartridge is, as previously discussed, capable of handling high contaminant loads, is capable of removing oil wetted solids if handled gently, are easily handled in the field, and are relatively inexpensive.

The third filtration stage had to handle high contaminant loads, remove contaminants in the 1-5 micron range, and possibly be insensitive to moderate hydrocarbon levels. It was decided to use a 1 micrometer nominal disposable depth filter cartridge. This element was very similar to the 10-25 used in the step previously.

The polishing filter should only have to handle 1-2 micrometer sized particles. The hydrocarbon should have been removed by this stage, but if not, should be stopped. Because of the possible contaminant load and the possibility of hydrocarbon, it was decided to use a medium depth disposable filter cartridge. This filter was to perform much like a surface filter in efficiency, but have only slightly less contaminant holding capability of the purely depth type filter. This element was charge modified for enhanced particle removal. The charge modification was positive because most contaminants occur in nature as negatively charged materials. The filter had a 1 micrometer nominal particle removal rating.

System Construction

The system was constructed of five filtration vessels piped together with 1" schedule 40 PVC pipe and appropriate fittings. The entire unit was secured to an oil field like wooden skid. Pressure gauges used on this system were Weksler 0-60 and 0-120psi range gauges. The filtration vessels used were: two Lakos 3/4" centrifugal separators, four AMF Cuno 5RP3 filter housings, and one AMF Cuno PTP-1 ZetaPlus filter housing. The system was successfully hydrotested at 80psi H_2O. An Arad totalizing flow meter was also utilized.

Filter Elements

The filter elements used during this study were:

Prefilter #1 - G78F8-3 AMF Cuno industrial depth filter, porosity 25um
- G78C8-3 AMF Cuno industrial depth filter, porosity 10um

Prefilter #2 - G78Y4-3 AMF Cuno industrial depth filter, porosity lum

Polishing Filter - 45115-01-30S AMF Cuno microfiltration ZetaPlus filter, porosity 2um
- 45115-01-50C AMF Cuno microfiltration ZetaPlus filter, porosity lum.

Flow Rates & Samples

The flow rate data was collected at the time of water sampling. These data were measured with a stop watch and the totalizing flow meter. This meter was calibrated to show 0.lgpm at its smallest increment. The samples were taken from petcocks placed in line prior to and after each system component. The petcocks were opened and allowed to run for approximately 30 seconds before samples were taken. The samples were collected in wrap bags and screw top glass or plastic containers. The samples were then placed in ice until delivered to the laboratory for analysis.

System Operation

The tank water return and feed pumps were connected to the system and then actuated. The inlet pump delivered 18-20 gpm at up to 40psi pressure. The outlet or return pump pulled water out of a 55 gallon drum and back into the storage tank. This arrangement was decided upon because of a return pump starvation concern.

The inlet feed pump was activated and subsequently self-primed by the tank pressure. At the time of start up, there was approximately 5 feet of water in the tank. The vent plugs were placed in the top of the filter housing after filled with water. The housings were checked for air by removing the plugs again approximately 10 minutes later. System readings were taken after 280 gallons had passed through the unit.

After each day of operation, the system was shut down. The pumps were turned off and the inlet valves closed. The plugs were removed from the filter housings allowing them to drain, and the outlet valves closed. The separators were purged (collected as a sample) and then closed. The pumps and hoses were also drained before shut down.

RESULTS

Figures

1. Figure 4 demonstrates the total suspended solids utilizing the system, the level coming out of the prefilter (Y4) and the polishing ZetaPlus element.

2. Figure 5 shows the level of hydrocarbon in the water after each respective filtration step. Because oil/water coalescing is usually a function of flow rate, the system flow rate fluctuations during the operation are shown.

3. Figure 6 demonstrates the differential pressures across the various system components throughout the operation of the unit. The line labeled "normal filter changeout pressure" was included to show how the system components were operating relative to the changeout pressure.

4. Figure 7 shows the particle counts between 0 and 10 micrometers seen with the ZetaPlus filter elements through the life of the test.

System Performance

High points that will be mentioned in this communication include: oil in water reduction, filter system life from component and system standpoints, particle removal levels compared to total suspended solids, and finally suggestions for system improvement. These topics are, by no means, a total review of the data submitted in this report, but rather highlights and trend conclusions.

As the system flow was initiated, the total suspended solids (TSS) levels began to drop as expected (See Fig. 4). Because the skid had recently been constructed, the TSS level seen with the prefilters was not a surprise. These contaminants were picked up by the next filter in each case until the system was totally clean or flushed out.

The graphic results (See Fig. 4) showed a curious upturn in solids that supposedly passed through the ZetaPlus polishing element after approximately 33,000 gallons. Also, the raw and polishing line slopes were compared and found to be almost identical between 5,000-17,000 and 30,000-52,000 gallons. This indicated that the prefilter was removing more of the contaminant than was passing through, as the concentration increased in the raw water. The prefilter can be seen to have reacted almost exactly the same as the polishing element.

The area under the polishing filter curve, between 33,000 and 140,000 gallons, represents a contaminant that passed through both the prefilter and polishing elements and was increasing steadily in concentration in the raw water. Even though the TSS levels were reduced by a significant level constantly, it was a curiousity to discover what this mysterious contaminant could have been.

Figure 6 and 7 were examined to see what the differential pressure and particle counts leaving the ZetaPlus were at this point. Interestingly, the particle counts were extremely low and the differential pressure increased slowly and steadily. This slow and steady differential pressure increase proved that there was no pressure surges, and that the elements were capturing particles. The system was performing consistently and efficiently.

After 90,000 gallons, the system TSS levels were reducing less rapidly than the raw levels until 125,000 gallons. Both the pre and polishing elements reacted to the terrific increase in raw TSS, and the mystery contaminant began to be completely removed. The graph on Figure 5 proves, almost without a doubt, that the mystery contaminant was oil.

The elements were reducing the particle levels to 0ppm, and were also reducing the oil level from 5 to 1.8ppm at the same time. This would also account for the observation, at 113,000 gallons, that the raw input oil level was lower than either of the three filters. (See Fig. 5). The elements were bleeding accumulated oil at the given flow rate and differential pressure; 16gpm and 17psi. At 139,000-149,000 gallons, the oil levels in the filtrate dropped to 0ppm with a 16.5-6.5ppm input concentration.

As the filters loaded with oil, the flow rate dropped to 13gpm with a 27psi differential pressure. This would indicate that the filters were retaining the oil which restricted the flow through the ZetaPlus. There is no way, at this time, to predict how long the filters would have lasted under these conditions.

It is suspected that the oil was not plugging the element, but rather impeding the flow and raising the differential pressure accordingly. This suspicion is based on the observation that oil level reduction was taking place between 50,000-110,000 gallons with only a gradual increase in differential pressure. When the oil was allowed to accumulate and was totally being removed at a 16.5ppm input level, the differential pressure increased accordingly with the flow rate and added contaminant.

When the TSS level reduction (See Fig. 4), the differential pressure drop (See Fig. 6), and the oil level fluctuation (See Fig. 5) are compared after the filter and water change at 154,000 gallons, a realistic view of how new filters, with a reduced flow rate and differential pressure, would react if a slug of oil and contaminants were to be encountered with the system.

The filters allowed a certain amount of oil to pass at the given flow rate and subsequent differential pressure, because of the nature of the oil particle nature; i.e. deformable. At lower flow rates the pressure against the oil particle would allow them to coalesce and accumulate on the filter. As the surface coated with oil, the removal capability would increase because of the oil-oil surface cohesion. After an unknown amount was allowed to accumulate, it is suspected that the flow rate and differential pressure would be increased without bleeding too much of the accumulated oil. The coalesced oil at the top of the filter housing could be bled off at the top air vent.

Although not central in importance, the oil removal data are considered worthy of such report space. This also shows that if removal of the oil is not desired, it would not affect the particulate removal capability of the system.

Figure 6 demonstrates system component differential pressure. As is shown at 136,000 gallons, when the flow rate decreased the separators became less efficient. The lowest flow rate suggested for this pilot system super separator was 10gpm. The flow rate, at 135,000 was approximately 13gpm, consequently a reduction in efficiency that showed up at the polishing filter level. At higher flow rates, the separators had actually reduced the particle loads below the prefilter level to a certain degree; thereby increasing prefilter life.

The prefilters and polishing filters were changed out on a differential pressure basis, i.e.: 35psi as indicated at the top of Fig. 6. The prefilters were not developing any significant differential pressure. The housings in the larger system were oversized for increased filter life and the same applied to the pilot system for data accuracy. The life of the prefilters, even though their particle removal levels were excellent, cannot be determined on a 200,000 gallon throughput basis. Previous studies performed by the office have lead to the hypothesis that efficiently applied prefilters reduction of solids would flatten the normally logarithmic filter load up curves, in the literature. This data tend to suggest that the prefilters were removing particulates efficiently with long life, the gradual increase in differential pressure seen with the polishing element flattened and assumed a linear configuration. As it stands, by linear regression, the life of the polishing filter can be predicted to have been in the 460,000 gallon range to 35psi. This would equate to 4.6×10^6 gallon for the full size system, or 21 days maintenance free life. At that point, only the polishing elements in the system would be changed. As the prefilters began to load, through time, their efficiency would increase and the subsequent polishing filter changes would decrease in frequency.

Figure 7 shows a terrific increase in particles present, in all ranges, at the 20,000-55,000 gallon and 120,000-155,000 levels. This raises two critical questions:

1. How can a filter stop lum particles and not stop 10um particles after being efficient for 20,000 gallons, and then go back to being lum efficient?

2. How can the TSS level be virtually 0ppm at the point of highest particle counts in the samples?

The obvious conclusion was that those particulates had to have been on the slide examined for particle distribution before the sample was examined or solids introduced to the samples in the laboratory after the particles distribution was performed. It is possible that most of the TSS was oil floating on the top of the sample, but not according to the hydrocarbon data. The floating oil would have been seen as TSS (mass) but not as particulates. In any case, it is unlikely that a sample could contain the level of particulates shown at 35,000 gallons and have a lppm TSS unless the particles did not have as much mass as the others shown on previous samples with more TSS and less particles. The points that deviate from the trend are therefore considered erroneous.

The preliminary conclusions of this study are as follows:

1. The filtration system will produce lum quality water at 5,000bpd.

2. It is capable of oil removal, at the sacrifice of a small amount of flow rate, if desired.

3. The prefilter had excellent particle removal efficiency with an undetermined life. (Suggest no longer than 120-200 days).

4. Extrapolation indicates the system will perform, as is, to 460,000 gallons (pilot) or 21 days (under the given conditions). Only polishing elements would require changeout at this time.

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SPECIFICATIONS AND PLANS

Millipore Filter Analysis	Sample #1	Sample #2	Sample #3	Sample #4
Suspended Solids (mg)	15.7	199.9	94.2	121.9
Volume Throughout (ml)	7.41	0.66	0.98	0.97
Total Suspended Solids (mg/l)	2.12	302.9	96.1	125.7
(1) Hydrocarbon Solubles (mg/l)	0.17	2.19	15.85	53.02
(2) Carbonates (mg/l)	0.20	1.59	39.35	43.64
(3) Iron Compounds (mg/l)	1.49	88.96	33.92	5.49
(4) Acid Insolubles (mg/l)	0.25	107.15	7.02	19.75

(1) Refers to oil-in-water contamination
(2) Carbonate scaling products
(3) Byproducts of corrosion
(4) Sand, Dirt, Silt

Particle size Distribution (particles/ml)	Sample #1	Sample #2	Sample #3	Sample #4
0-1 u	11,994	X	$1.4\text{x}10^6$	X
2-5 u	15,554	X	$2.4\text{x}10^6$	X
5-10 u	626	X	$6.15\text{x}10^4$	X
10-20 u	1,792	X	$1.35\text{x}10^5$	X

Figure 1

SPECIFICATIONS AND PLANS

Water Analysis	Sample #1	Sample #2	Sample #3	Sample #4
Carbonate (mg/l)	0	0	0	0
Bicarbonate (mg/l)	549	1386	1135	910
Barium (mg/l)	0	0.5	0.6	1.8
Chloride (mg/l)	1595	45,912	21,626	63,993
Calcium (mg/l)	48	337	296	1323
Magnesium (mg/l)	7.3	265	100	1556
Iron (mg/l) **	1.5	1	2.1	1
Sodium (mg/l)	1800	30,850	13,900	39,680
Sulfate (mg/l)	566	588	468	429
Sulfide (mg/l)	0	0	0	0
Oil-in-water (mg/l)	-	33.9	3.5	-
Temperature (°F)	76	74	96	88
ph	7.6	7.7	7.95	7.0
Oxygen (ppm)	0	1	.4	0
Hydrogen Sulfide (ppb)	0	trace	trace	trace
Resistivity (ohm-cm)	160	14	24	12.5
Density (g/ml)	1.0	1.049	1.024	1.069
Total Disolved Solids	4567	79,338	37,527	107,893

**Total Iron

Water Additives:
1) Ammonium Bisulfite for 0_2 removal
2) 15-50 ppm gluteraldehyde isothiazolone for biocide
3) Corrosion inhibitor

Figure 2

RANGE	RMU X	COUNT =	RMU/L X	MG/RMU =	NEW MASS DIST	NEW %

Total Suspended Solids = __________MG/L

$\frac{TSS/L}{RMU/L}$ = __________MG/RMU

TSS = 2.12

OLD METHHOD			NEW METHOD		
COUNTS	%	MASS	COUNTS	%	MASS
11994	40.0	0.85	11994	6.6	0.14
15554	51.9	1.1	15554	61.3	1.35
626	2.1	0.05	626	5.2	0.11
1792	5.9	0.13	1792	29.3	0.62
29966	99.9	2.13	29966	102.4	2.22

Figure 3 - Theoretical mass distribution worksheet

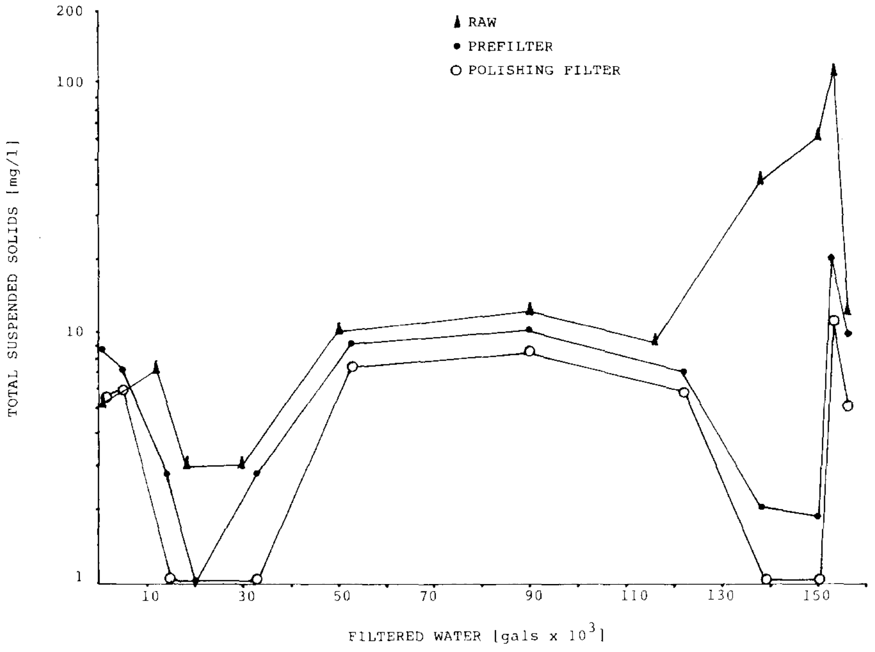

Figure 4 - Total suspended solids

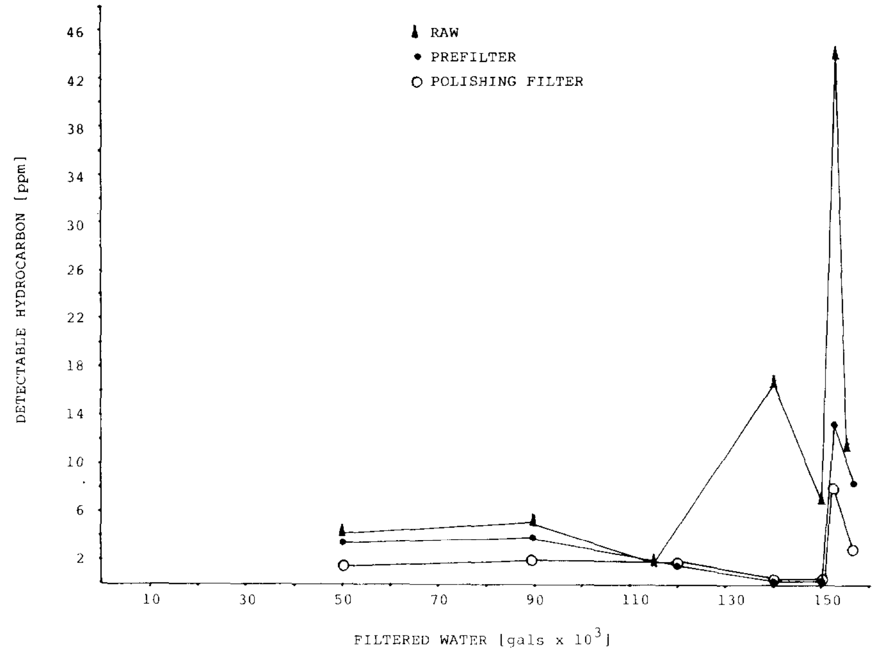

Figure 5 - Hydrocarbon levels

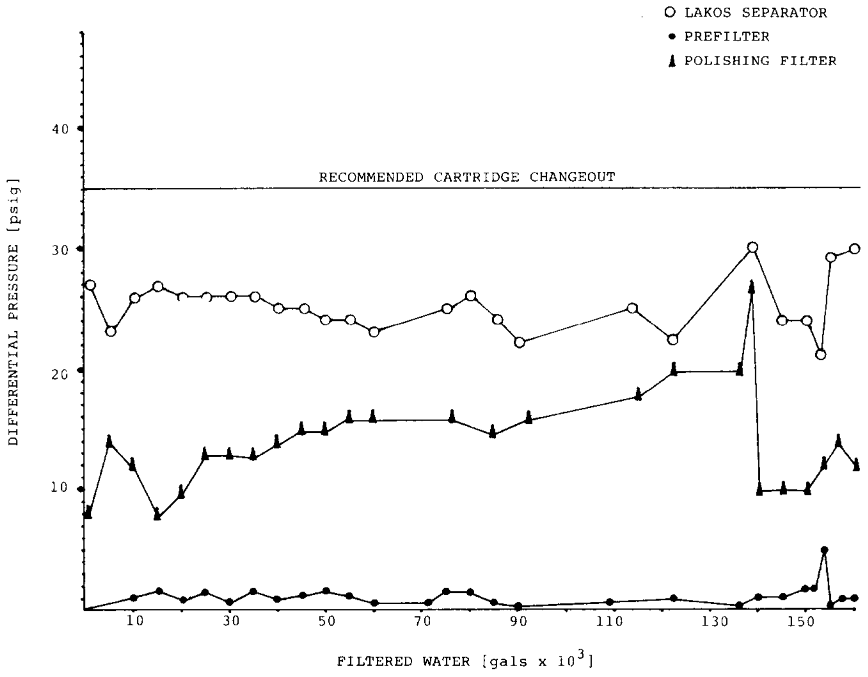

Figure 6 - Component differential pressure

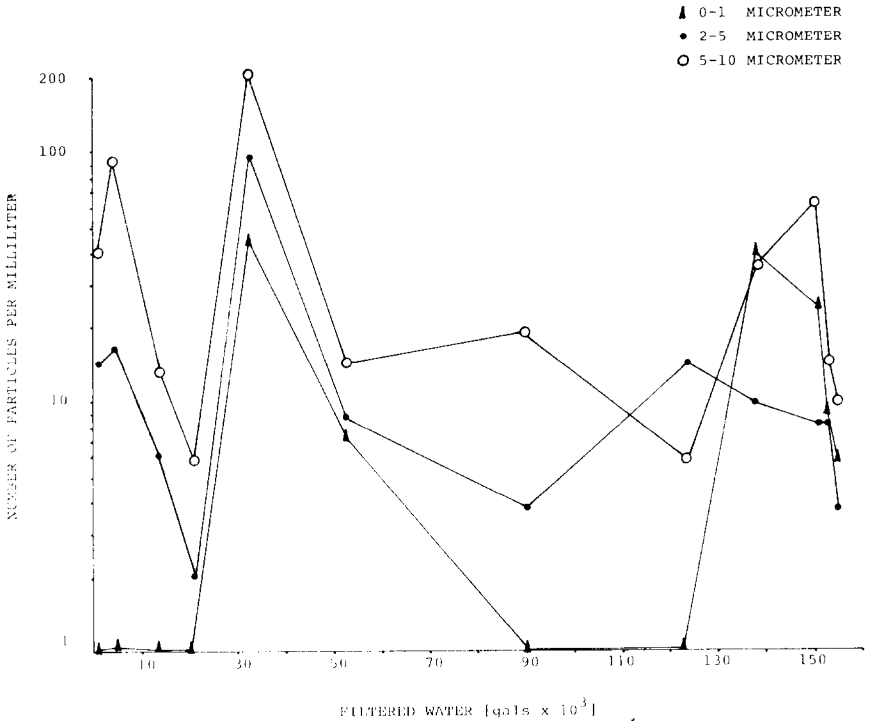

Figure 7 - Effluent particle counts

Fluid - water

Flow rate - 5,000bpd

Degree of filtration - 1 micron

Temperature - (-10) - 112°F

Pressure - 30psig filter outlet

Control lights - normal operation
pump on/off
filter backwash
max. diff. pressure
auto shut down
large overhead light for changeout alarm
master lock out switch

Unit to be self contained and skid mounted with pump.

Unit to be final tested for a period of 168 hours.

Unit will operate for an additional 24 consecutive hours.

At the end of the above time, samples will be taken for water analysis:

a) particle size distribution
b) Millipore filter analysis
c) bacterial results

Figure 8 - System requirements

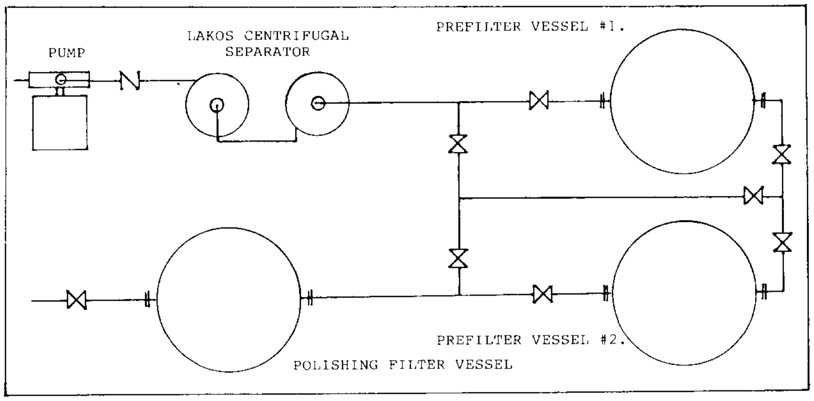

Figure 9 - Proposed waterflood filtration skid
(controls and panel not included)