AADE-14-FTCE-57

High Volume, High Capacity Filtration System for Ultra Deepwater Environments

Edward A. Rapp, TETRA Technologies, Inc.

Abstract

A novel high volume, high capacity filtration system has been developed to meet the challenges and requirements of ultra deepwater environments. The paper presents an overview of the challenges encountered, including flow rate, fluid density, fluid viscosity, contaminant holding capacity, downtime minimization, system footprint, and HSE/ergonomics. It then presents the solutions considered and the solution selected, and compares the new technology with prior art and offers case studies.

Introduction

Diatomaceous Earth Filtration Systems have been used to filter high density brine solutions in completion fluid service for over thirty years[1]. During that period, increases in circulating system volumes, required flow rates and contaminant loading capacities have resulted in an increase in filtration system capacities to the current industry standard 1,500-1,600 ft^2 unit.[2-3]

Today's deep water environment presents a unique set of challenges, such as remote locations, logistical issues, and complex subsea and wellbore conditions. Operators and completion fluids companies are faced with new obstacles such as increased hole and circulating volumes, high rig costs, and hydrate inhibition concerns.

The advanced design Ultra Deepwater (UDW) filtration system has advanced diatomaceous earth (DE) filtration systems technology to keep pace with the challenges presented by the UDW environment. The system is a high flow rate, large capacity plate and frame filtration system with a relatively small foot print. It offers thirty percent (30%) more filter area in roughly the same footprint as an industry standard 1,600 ft^2 filtration system, with design capability to handle twice the flow rate of 30 to 50 bbl/min.

Other design considerations included the following:

- The ability to effectively process Clear Brine Fluids (CBF) of densities ranging from 9.0 to 17.0 lb/gal
- A sustained circulation rate of 20 to 40 bbl/min during the filtration process
- Capacity of filtering ~3,400 bbls of surface volume without interruption of service

Initial Plant Trial

A set of field tests was developed to evaluate the performance of the unit. The primary objectives were to evaluate the pump capacity of the equipment, the ability of the pumps to act in tandem with the mix pit pump, flow losses across the filter press, and flow losses across the entire filter skid.

Test Procedures

Five tests were developed to evaluate system performance:

1. Filter Pump Output Evaluation
2. Gun Line Output Evaluation (Tandem Filter Pump/Mix Tank Pump)
3. Filter Press Flow Throughput Efficiency
4. Filter Package Flow Throughput Efficiency
5. Filter Package Filtration Flow Throughput Efficiency

Test 1: Filter Pump Outlet Evaluation

The Filter Pump Outlet Evaluation test measured the amount of fluid that could be pumped by the filter unit pump from the mix pit to the clean fluid tank through a six-inch flow meter in 10 minutes. It was designed to establish a baseline to correlate unit efficiency and was performed on fresh water and 12.5 lb/gal brine.

Test 2: Gun Line Output Evaluation (Tandem Filter Pump/Mix Tank Pump)

The Gun Line Output Evaluation test measured the amount of fluid that could be pumped by the mix pit pump and the filter unit pump operating in tandem to transfer fluid from the mix pit to the clean fluid tank through a six-inch flow meter in 10 minutes. It was designed to establish a secondary baseline to correlate unit efficiency and was performed on fresh water.

Test 3: Filter Press Flow Throughput Efficiency

The Filter Press Flow Throughput Efficiency test measures the amount of fluid that could be pumped by the mix pit pump and the filter unit pump operating in tandem through the filter press to transfer fluid from the mix pit to the clean fluid tank

through a six-inch flow meter in 10 minutes. It was designed to determine the piping (non-filtration) flow rate through the filter press and was performed on fresh water. The test was performed without filter aid in the press.

Test 4: Filter Package Flow Throughput Efficiency

The Filter Package Flow Throughput Efficiency test measured the amount of fluid that could be pumped by the mix pit pump and the filter unit pump operating in tandem through the entire filter skid to transfer fluid from the mix pit to the clean fluid tank through a six-inch flow meter in 10 minutes. It was designed to determine the piping (non-filtration) flow rate through the entire filter package and was performed on fresh water. The test was performed without filter aid in the press or filter cartridges in the guard filter.

Test 5: Filter Package Filtration Flow Throughput Efficiency

The Filter Package Filtration Flow Throughput Efficiency test measures the amount of fluid that could be pumped by the mix pit pump and the filter unit pump operating in tandem through the entire filter skid to transfer fluid from the mix pit to the clean fluid tank through a six-inch flow meter in 10 minutes. It was designed to determine the total initial (filtration) flow rate through the filter press, and was performed on 12.5 lb/gal brine. The test was performed with filter aid in the press and 2-micron filter elements in the cartridge housing.

Discussion:

The Pump Output Test (Test #1) demonstrated anticipated flows for both fresh water and 12.5 lb/gal brine. The Gun Line Output Test (Test #2) demonstrated an output increase anticipated by operating the two pumps in tandem, but actual field results were less than anticipated. It is believed that a self-priming filter pump may decrease the back pressure on the mix pump filter, resulting in greater throughput than that experienced with the original filter pump.

The Filter Press Efficiency Test (Test #3) and Filter Package Efficiency Test (Test #4) demonstrated flow rates of 50 bbl/min and 47 bbl/min, which correlated to operating efficiencies of 85% and 80%, respectively.

The Filter Package Filtration Efficiency Test (Test #5) demonstrated a flow rate of 32 bbl/min, which correlated to an operating efficiency of 54%. It is believed that the use of FW-20 filter aid as a body-feed adversely impacts throughput when compared to the use of FW-60 for both pre-coat and body-feed. The cleanliness of the 12.5 lb/gal brine was not defined prior to the start of the test, so it is possible that some of the flow decrease was also due to plugging of the filter media.

Second Plant Trial

Initial testing was conducted in February, 2012. While the preliminary results predicted acceptable field performance, prior to the second trial the pumps were replaced to improve performance. The purpose of the second trial was to repeat the tests conducted in the first trial, along with the incorporation of additional tests to determine the performance of the modified system.

Test Procedures

Ten tests were developed to evaluate system performance:

1. Mix Plant Pump Output
2. Filter Pump Output
3. Gun Line Output (Tandem Filter Pump/Mix Tank Pump)
4. Filter Press Flow Throughput Efficiency
5. Filter Package Flow Throughput Efficiency
6. Filter Package Filtration Flow Throughput Efficiency
7. Filter Package Filtration Flow Throughput Efficiency
8. Filter Package CBF Flow Throughput Efficiency (12.5 lb/gal$CaBr_2$)
9. Filter Package Filtration CBF Flow Throughput Efficiency (13.5 lb/gal$ZnBr_2$)
10. Filter Package Filtration CBF Flow Throughput Efficiency (14.5 lb/gal$ZnBr_2$)

Test 1: Mix Plant Pump Outlet Evaluation

The Mix Plant Pump Outlet Evaluation test measured the amount of fluid that could be pumped by the mix plant pump from the mix pit to the clean fluid tank through a six-inch flow meter in 10 minutes. It was designed to establish a baseline to correlate plant operating efficiency and was performed using fresh water.

Test 2: Filter Pump Outlet Evaluation

The Filter Pump Outlet Evaluation test measured the amount of fluid that could be pumped by the filter unit pump from the mix pit to the clean fluid tank through a six-inch flow meter in 10 minutes. It was designed to establish a baseline to correlate unit efficiency and was performed using fresh water.

Test 3: Gun Line Output Evaluation (Tandem Filter Pump/Mix Tank Pump)

The Gun Line Output Evaluation test measures the amount of fluid that could be pumped by the mix pit pump and the filter unit pump operating in tandem to transfer fluid from the mix pit to the clean fluid tank through a six-inch flow meter in 10 minutes. It was designed to establish a secondary baseline to correlate unit efficiency operating under simulated field conditions and was performed using fresh water.

Test 4: Filter Press Flow Throughput Efficiency

The Filter Press Flow Throughput Efficiency test measures the amount of fluid that could be pumped by the mix pit pump and the filter unit pump operating in tandem through the filter press to transfer fluid from the mix pit to the clean fluid tank through a six-inch flow meter in 10 minutes. It was designed to determine the piping (non-filtration) flow rate through the filter press, and was performed using fresh water. The test was performed without filter aid in the press.

Test 5: Filter Package Flow Throughput Efficiency

The Filter Package Flow Throughput Efficiency test measures the amount of fluid that could be pumped by the mix pit pump and the filter unit pump operating in tandem through the entire filter skid to transfer fluid from the mix pit to the clean fluid tank through a six-inch flow meter in 10 minutes. It was designed to determine the piping (non-filtration) flow rate through the entire filter package, and was performed using fresh water. The test was conducted without filter aid in the press or filter cartridges in the guard filter.

Test 6: Filter Package Filtration Flow Throughput Efficiency

The Filter Package Flow Throughput Efficiency test measures the amount of fluid that could be pumped by the mix pit pump and the filter unit pump operating in tandem through the entire filter skid to transfer fluid from the mix pit to the clean fluid tank through a six-inch flow meter in 10 minutes. It was designed to determine the simplified clean filtration flow rate through the entire filter package, and was performed using fresh water. The test was conducted with FW-60 DE filter aid in the press and 2-micron filter cartridges in the guard filter.

Test 7: Filter Package Filtration Flow Throughput Efficiency

The Filter Package Flow Throughput Efficiency test measures the amount of fluid that could be pumped by the mix pit pump and the filter unit pump operating in tandem through the entire filter skid to transfer fluid from the mix pit to the clean fluid tank through a six-inch flow meter in 10 minutes. It was designed to determine the clean filtration flow rate through the entire filter package, and was performed using fresh water. The test was performed with a FW-60 DE filter aid pre-coat and FW-20 DE body-feed in the press and 2-micron filter cartridges in the guard filter.

Test 8: Filter Package CBF Flow Throughput Efficiency

This test repeats Test #7 using 12.5 lb/gal$CaBr_2$ and measures the amount of fluid that could be pumped by the mix pit pump and the filter unit pump operating in tandem through the entire filter skid to transfer fluid from the mix pit to the clean fluid tank through a six-inch flow meter in 10 minutes. It was designed to correlate the piping (non-filtration) flow rate of fresh water through the entire filter package to that of 12.5 lb/gal$CaBr_2$ brine. The test was performed with a FW-60 DE filter aid pre-coat and FW-20 DE body-feed in the press and 2-micron filter cartridges in the guard filter.

Test 9: Filter Package CBF Flow Throughput Efficiency

This test repeats Test #7 using 13.5 lb/gal$CaBr_2$ and measures the amount of fluid that could be pumped by the mix pit pump and the filter unit pump operating in tandem through the entire filter skid to transfer fluid from the mix pit to the clean fluid tank through a six-inch flow meter in 10 minutes. It was designed to correlate the piping (non-filtration) flow rate of fresh water through the entire filter package to that of 13.5 lb/gal$CaBr_2$ brine. The test was performed with a FW-60 DE filter aid pre-coat and FW-20 DE body-feed in the press and 2-micron filter cartridges in the guard filter.

Test 10: Filter Package CBF Flow Throughput Efficiency

This test repeats Test #7 using 14.5 lb/gal$CaBr_2$ and measures the amount of fluid that could be pumped by the mix pit pump and the filter unit pump operating in tandem through the entire filter skid to transfer fluid from the mix pit to the clean fluid tank through a six-inch flow meter in 10 minutes. It was designed to correlate the piping (non-filtration) flow rate of fresh water through the entire filter package to that of 13.5 lb/gal$CaBr_2$ brine. The test was performed with a FW-60 DE filter aid pre-coat and FW-20 DE body-feed in the press and 2-micron filter cartridges in the guard filter.

Discussion:

The Pump Output Test (Test #2) demonstrated anticipated flow rates. The Gun Line Output Test (Test #3) demonstrated the output increase anticipated by operating the two pumps in tandem. The Filter Press Efficiency Test (Test #4) and Filter Package Efficiency Test (Test #5) demonstrated observed flow rates of 47 bbl/min and 41 bbl/min, which correlated to operating efficiencies of 99% and 86%, respectively. The Filter Package Efficiency Test conducted on 12.5 lb/gal brine demonstrated a flow rate of 39 bbl/min, which resulted in an anticipated flow decrease of 5% when compared to fresh water under the same conditions.

The Filter Package Filtration Efficiency Test utilizing FW-60 DE (Test #6) demonstrated a flow rate of 41 bbl/min, correlating to an operating efficiency of 84%, while the Filter Package Filtration Efficiency Test utilizing a FW-60 DE pre-coat and FW-20 body-feed (Test #7) demonstrated a flow rate of 40 bbl/min, which correlated to an operating efficiency of 81% . It is believed that the use of (0.6µ) FW-20 filter aid as a body-feed adversely impacts throughput when compared to the use of (1.8µ) FW-60 for both pre-coat and body-feed.

As anticipated, Filter Package Filtration Efficiency Test performance decreased with increasing density, with flow rates of 37 bbl/min observed for the 13.5 lb/gal brine and 33 bbl/min observed for the 14.5 lb/gal fluid.

Initial Field Trial

Testing was conducted on the job-site using a two-salt $CaBr_2/ZnBr_2$ fluid with densities ranging between 14.8 and 14.9 ppg.

Three systems were evaluated:

1. 1500 ft^2 with a 4" diesel-drive pump
2. UDW filter unit with a 6" electric-drive pump
3. UDW filter unit with a 6" diesel-drive pump

Each system was tested under a broad range of field conditions dictated by project needs. Results were segregated into high turbidity (>500 NTU) and low turbidity (<500 NTU) conditions in order to quantify performance under both extremes.

Influent turbidity ranged from 121 NTU to 1000 NTU, corresponding to solids percentages from <0.2 to 0.3%. Maximum flow rates ranged from 8 to 22 bbl/min.

Discussion:

The trial consisted of twelve filtration cycles using two different-sized filter units and three different pumps. The 1500 ft^2 filter press was coupled with a 4" diesel-drive pump and the UDW filter unit was paired with a 6" diesel-drive pump and a 6" electric-drive pump.

Performance of each filter/pump combination in both high turbidity (>500 NTU) and low turbidity (<500 NTU) conditions met design expectations with respect to throughput, flow rate, effluent quality, and solids retention.

The UDW filter unit coupled with either the 6" electric- or diesel-drive pump offered demonstrable flow rates ranging from 18 to 22 bpm, which represented a 120-125% improvement over the 1,500 ft^2 coupled with the 4" diesel-drive pump. As expected, flow rates under high turbidity conditions were less than those under low turbidity conditions, ranging from 20% less for the 1,500 ft^2 unit down to 14% less for the UDW filter unit equipped with the 6" diesel-drive pump. UDW filter unit flow rates were, for the most part, limited by the fluid availability provided by the rig pump.

Conclusions

Plant testing of the UDW filter unit has confirmed both the design calculations and lab-scale performance testing and indicates that the unit offers significant performance improvement over other SafeDEflo® filtration systems.

Testing of the UDW filter unit under actual field conditions has confirmed full-scale performance testing and indicates that the unit offers significant performance improvement over a 1,500 ft^2 filtration system.

Filtration of a low turbidity (<500 NTU) two-salt $CaBr_2/ZnBr_2$ fluid with densities ranging between 14.8 and 14.9 lb/gal yielded a sustained circulation rate of 21 to 22 barrels per minute (bbl /min) during the filtration process, which is within the 20 to 50 (bbl /min) design specification, and over 120% greater than that offered by the ,1500 ft^2 unit. These flow rates were, for the most part, limited by the rig pump fluid availability and do not represent the maximum potential of the unit.

Performance data from future UDW filtration projects will be used to build a comprehensive performance database.

Acknowledgments

The author thanks the management of TETRA Technologies, Inc. for its support and permission to publish this work. Special thanks go to the TETRA Technology Center and to Operations Personnel at TETRA's Houma and Fourchon facilities for their efforts in supporting this research.

Nomenclature

HSE = *Health, Safety & Environmental*
UDW = *Ultra Deepwater*
DE = *Diatomaceous Earth*
CBF = *Clear Brine Fluids*
NTU = *Nephelometric Turbidity Unit*

References

1. Baron, W.C, Young, J.A. and Munson, R.E. "New Concept – High Density Brine Filtration Utilizing a Diatomaceous Earth Filtration System" SPE 10648, Society of Petroleum Engineers of AIME, 1982
2. MI Swaco "Completion Fluids Filtration" Product Literature 2007
3. TETRA Technologies, Inc. "1,500 ft^2 Filtration System" Product Literature 2013

Data

Table 1 - Initial Plant Trial Test Data

Fluid Type	Start BBL Amount	Ending BBL Amount	Start Time	Stop Time	Duration Minuets	Total BBL	BBL Min	Observed Flow Rate	% Efficiency
Test #1 - Pump Output									
Fresh Water	145	500	6:34	6:44	10	355	35.5	35-40	
12.5 ppg Brine								30	
Test #2 - Gun Line Output					1808rpm				
Fresh Water	10	480	5:45	5:53	8	470	59	59	
Test #3 - Filter Press Efficiency									
Fresh Water								50	**85%**
Test #4 - Filter Package Efficiency									
Fresh Water								47	**80%**
Test #5 - Filter Package Filtration Efficiency									
12.5 ppg Brine	10	510	3:42	3:59	17	500	29.4	32	**54%**

Table 2 - Second Plant Trial Test Data

Test #	Fluid Type	Start BBL Amount	Ending BBL Amount	Duration Minutes	Total BBL	BBL/ Min	Observed Flow Rate	% Efficiency	Pressure Press Inlet (psig)	Pressure Pod Inlet (psi)
1	Fresh Water	490	115	10	375	37.5	39	N/A	N/A	N/A
2	Fresh Water	487	214	10	273	27.3	31	N/A	N/A	N/A
3	Fresh Water	500	41	10	459	45.9	49	N/A	N/A	N/A
4	Fresh Water	465	12	10	453	45.3	47	99%	N/A	40
5	Fresh Water	493	99	10	394	39.4	41	86%	N/A	53
6	Fresh Water	484	98	10	386	38.6	41	84%	30	50
7	Fresh Water	465	94	10	371	37.1	40	81%	35	51
8	12.5 ppg Brine	462	85	10	377	37.7	39	82%	N/A	80
9	13.5 ppg Brine	305	0	9	305	33.9	37	74%	37	69
10	14.5 ppg Brine	975	0	32	975	30.5	33	66%	45	72

Table 3 - Initial Field Trial Test Data

Unit	Turbidity Range	Volume (BBL)	Cycle (Min)	AVG Flow (BPM)	Max Flow (BPM)	Turbidity (NTU)		Solids (%)	
						Suction	Discharge	Suction	Discharge
1500 4" Diesel	>500	80	10	8.0	8	665	15	0.2	<0.001
1500 4" Diesel	<500	500	55	9.1	10	127	8	<0.2	<0.001
UDW 6" Diesel	>500	410	25	16.4	18	802	15	0.3	<0.001
UDW 6" Diesel	<500	2675	135	19.8	21	121	15	<0.2	<0.001
UDW 6" Electric	>500	180	10	18.0	18	1000	14	0.3	<0.001
UDW 6" Electric	<500	907	55	16.5	22	258	14	0.2	<0.001

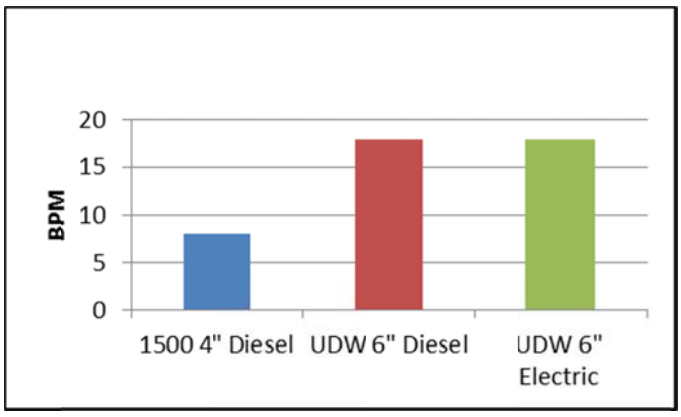

Figure 1 – Field Trial - High Turbidity Maximum Flow Rates

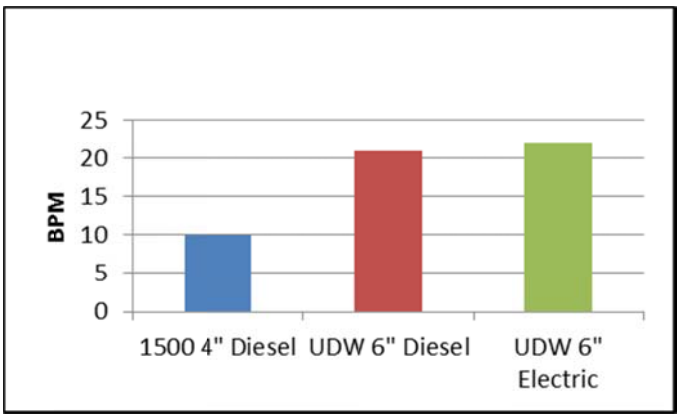

Figure 2 – Field Trial - Low Turbidity Maximum Flow Rates

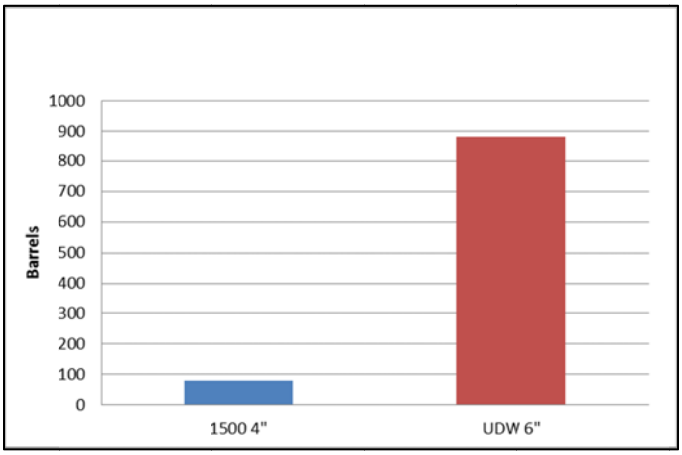

Figure 3 – Field Trial - High Turbidity Cycle Length

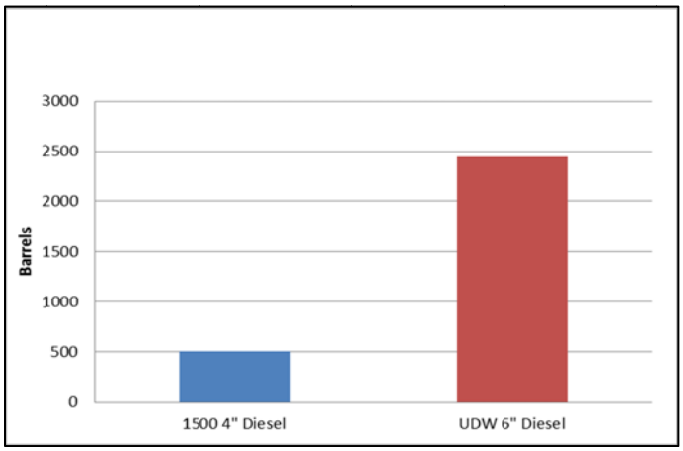

Figure 4 – Field Trial - Low Turbidity Cycle Length