



**PILOT TESTING**

**OF**

**ENVIRO-CELL**

**INDUCED GAS FLOTATION UNIT**

**LOCATION: Major Oil Operator in Western Africa**

**Contributors:**

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## I. INTRODUCTION

Each year, more than 30 million barrels per day of produced water is treated at a Major Oil Operator in Western Africa's field. The Major Oil Operator is presently using a conventional method of produced water treatment. High maintenance coupled with the excessive cost of spare parts and field labor the Major Oil Operator is considering the replacement of the existing Wemco Flotation cells operating in Western Africa. It has become ever more difficult to stock and maintain a sufficient level of spare and secondly find capable and available technicians from the manufacturer to assist in the maintenance. This is also due in part to the geographic location of the Major Oil Operator in West Africa field. Because of these inherent difficulties with the present equipment the Major Oil Operator has begun a search for a low maintenance compact designed Induced Gas Flotation (IGF) unit which can be maintained easily by its own field operators with minimum training and at the same time maintain equal or superior efficiency to that of the existing Wemco.

The Major Oil Operator's management has given a directive to find the latest and best technology available in the market for secondary produced water treatment. After reviewing different units from several companies, the Major Oil Operator selected the Enviro-cell unit of Enviro-Tech Systems based on its proven performance record and excellent service to the oil industry with more than 100 units working worldwide. The hydraulic style Enviro-cell unit was best suited for the conditions available in the West Africa field. The Enviro-cell unit was noted by the Major Oil Operator personnel to have the following advantages over its competitors in the secondary produced water treatment category,

- Produced water handling capability at design rates with minimum oil effluent discharge.
- Online maintenance without shutting down the process.
- Cylindrical design for best structural integrity and lowering corrosion.
- Less operating and maintenance cost over the life span of the equipment.
- Maintenance can be provided by less skilled personnel.
- High oil and grease removal efficiency of 90-98%.

The Major Oil Operator requested Enviro-Tech Systems do the pilot testing of its latest and advanced Enviro-cell™ unit after analyzing its own produced water treatment requirements. The tests were carried out in the Major Oil Company's West Africa field over a period of two weeks from 09/23/10 to 09/05/10. After the pilot test, final report including test data was submitted.

## II. PRODUCED WATER TREATMENT SYSTEM OF THE MAJOR OIL OPERATOR IN WEST AFRICA

The produced water treatment system is an integral part of dehydration plant at the Major Oil Operator West Africa field. All the produced water generated in onshore and offshore fields is treated at the produced water treatment facility.

The produced water treatment system consists of wash tank, surge vessel, Wemco unit, and skimmer pit. The process flow diagram for produced water treatment system at dehydration plant is shown in **Figure 1**.

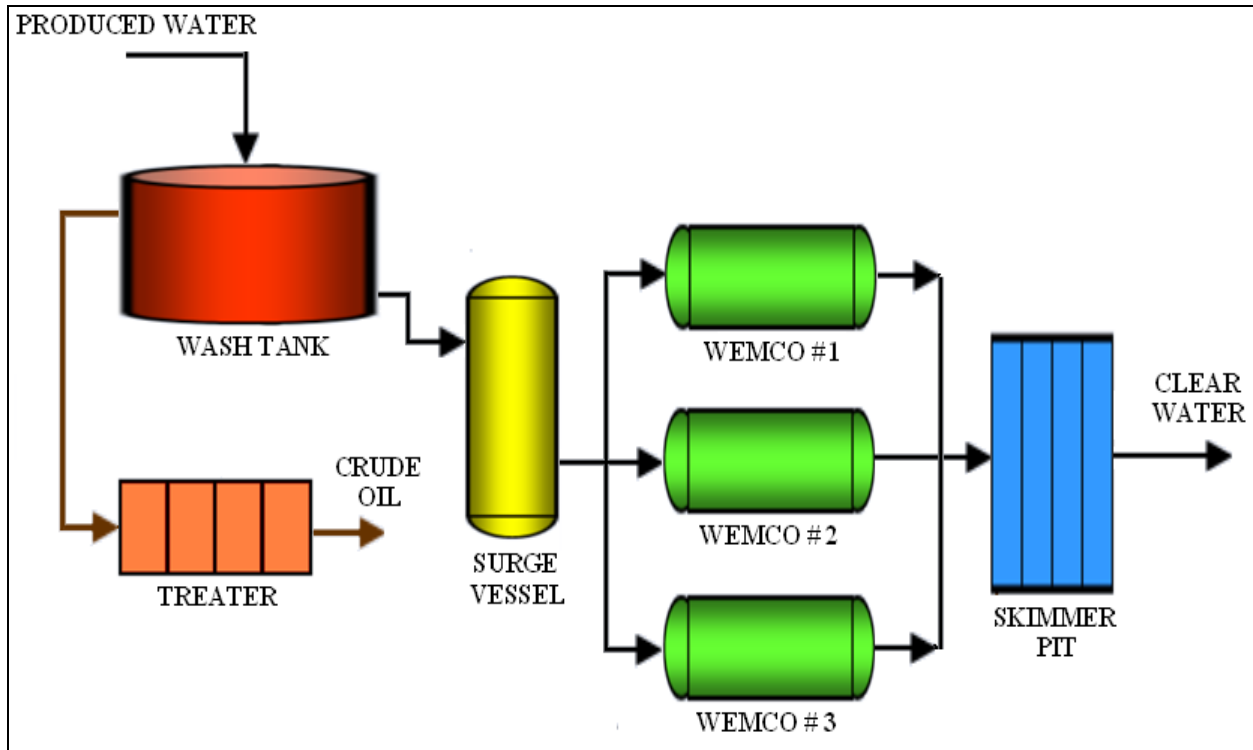


Figure 1: Process Flow Diagram of Produced Water Treatment System.

The produced water from offshore facilities is collected in the wash tank (**Figure 2a**). The separated oil from the wash tank is sent to the treater while the produced water is further treated by the combination of surge vessel, Wemco unit, and the skimmer pit. The clear water from the skimmer pit is then released to a final discharge point (**Figure 2b**).



(a)



(b)

Figure 2: (a) Offshore line to Wash Tank, and (b) Clean Water to Final Discharge Point

The wash tank (**Figure 3**) separates the oil from the produced water by gravity separation technique. The water from the wash tank is then forwarded to the surge vessel. There were two surge vessel of 100,000 BPD capacity each (**Figure 4**).



Figure 3: Wash Tank for Primary Oil Separation and Removal



Figure 4: Surge Vessel before the Enviro-cell Pilot Unit and Wemco Unit for Secondary Oil Separation

The water with low oil concentration from surge tank is further treated by a combination of three Wemco units. Wemco #1 (**Figure 5**) and Wemco #2 had a capacity of 25,000 BPD each, while Wemco #3 had 50,000 BPD capacity. The treated water from Wemco unit is released in the skimmer pit (**Figure 6**). The skimmer pit is a series of ground compartments with separated oil float on the water surface while clear water leaves from bottom of the chamber to the next compartment. The separated oil in the wash tank, surge vessel, Wemco units, and skimmer pit is forwarded back to the treater.





Figure 5: Wemco #1 Unit used during Test A for taking the Samples and Comparing its Performance with Enviro-cell Unit



Figure 6: Skimmer Pit used as a Final Produced Water Treatment Step

### III. REVIEW OF ENVIRO-CELL PILOT UNIT

The Enviro-cell unit is the most effective, efficient next generation induced gas flotation (IGF) unit available for secondary oil/water separation. The Enviro-cell unit of 700 BPD capacity was used during the pilot test (**Figure 7**). It consists of four active cells along with one (1) inlet surge dampening cell and one (1) outlet quiescent cell for multiple stage separation. The Enviro-cell unit uses multiple Eductors for creating minute bubbles incorporating advanced Venturi principles in four active cells. The tank was provided with two pressure relief valves, level controller, gas blanket assembly, oil and water level bridle, centrifugal pump and diaphragm pump for water recirculation and oil discharge respectively. Online maintenance of the pump can also be carried out without shutting down the equipment operation with the help of standby pump. The samples were taken using inlet and outlet Enviro-Tech Retractable Sampler™ provided with the tank. The collected oil was sent to the treater via an oil tank while the water was discharged into the skimmer pit.

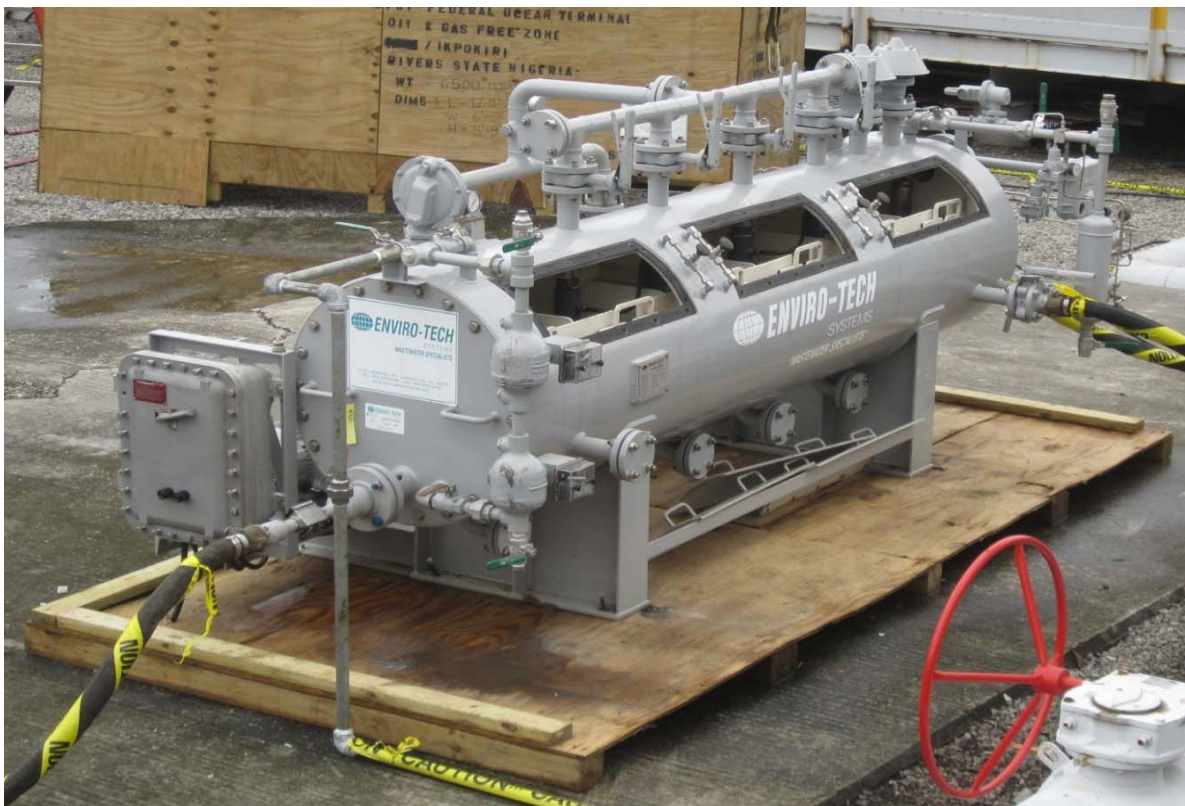


Figure 7: Enviro-cell Unit used during the Pilot Testing in West Africa

The Enviro-cell unit was chosen for pilot testing due to its advanced features and benefits over mechanical style Wemco unit. The benefits of Enviro-cell unit includes

- Cylindrical design for structural stability and minimum corrosion.
- No mechanical moving parts inside the equipment.
- Lower maintenance requirement with hydraulic style Eductor compared to the mechanical style agitators.
- Elimination of wiper system by using innovative v-notch adjustable weir technique.
- Online maintenance without shutting down the equipment compared to Wemco unit.



- Lower cost associated with fewer spare parts required.
- High oil and grease removal efficiency of 90-98% with varying produced water characteristics.
- Operating and maintenance cost associated with Enviro-cell unit compared to Wemco unit is lower over the life span of the equipment.

The compact and fully equipped Enviro-cell pilot unit has been in use for several years with a great success.

#### IV. EQUIPMENT SET-UP AND PILOT TEST OPERATION

After reviewing the process flow diagram of the produced water treatment plant, the possible test scenarios were identified. The Major Oil Operator decided to carry out the pilot test with three (3) different produced water streams with low, moderate, and high oil content. **Table 1** shows three different test protocol of pilot testing operation.

Table 1: Different Tests involved in Pilot Testing of Enviro-cell Unit

TEST	HYDROCARBON CONTENT	INLET WATER STREAM SOURCE	TEST EQUIPEMNT
A	Low	Surge Vessel	Wemco and Enviro-cell Unit
B	Moderate	Wash Tank	Enviro-cell Unit
C	High	Treater + Wash Tank	Enviro-cell Unit

The Enviro-cell unit was installed and connections were made according to the test requirements. **Figure 8** shows the Test A, Test B, and Test C connections and the original process flow diagram (PFD) of produced water treatment system. The separated oil from the Enviro-cell unit is sent to the treater while the clear water from the process was further treated by skimmer pit.

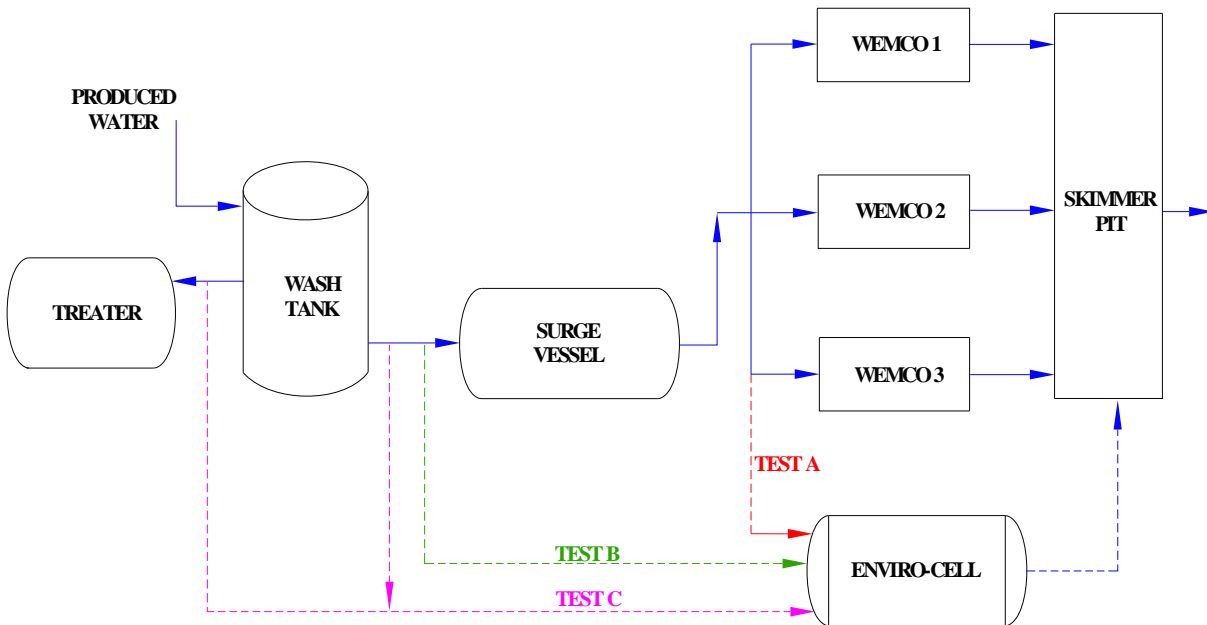


Figure 8: Process Flow Diagram (PFD) for Produced Water Treatment with Three Test Protocols

In Test A, Enviro-cell pilot unit and Wemco #1 unit was connected with the same inlet stream from surge vessel outlet (**Figure 9a**). The inlet flow rate for Enviro-cell unit was 18 to 23 gallon per minute (GPM), while for Wemco unit it was 440 to 525 GPM during Test A. The Wemco unit was operating at a design capacity of 60 to 72 %, and the Enviro-cell unit was operated at 90 to 115% of its designed capacity. The total inlet and outlet oil content was continuously monitored by the Major Oil Operator personnel taking samples from Enviro-cell and Wemco unit.

During Test B, the wash tank outlet was connected to the Enviro-cell unit as shown in **Figure 9b**. In Test B the samples were taken from the Enviro-cell unit and wash tank outlet.

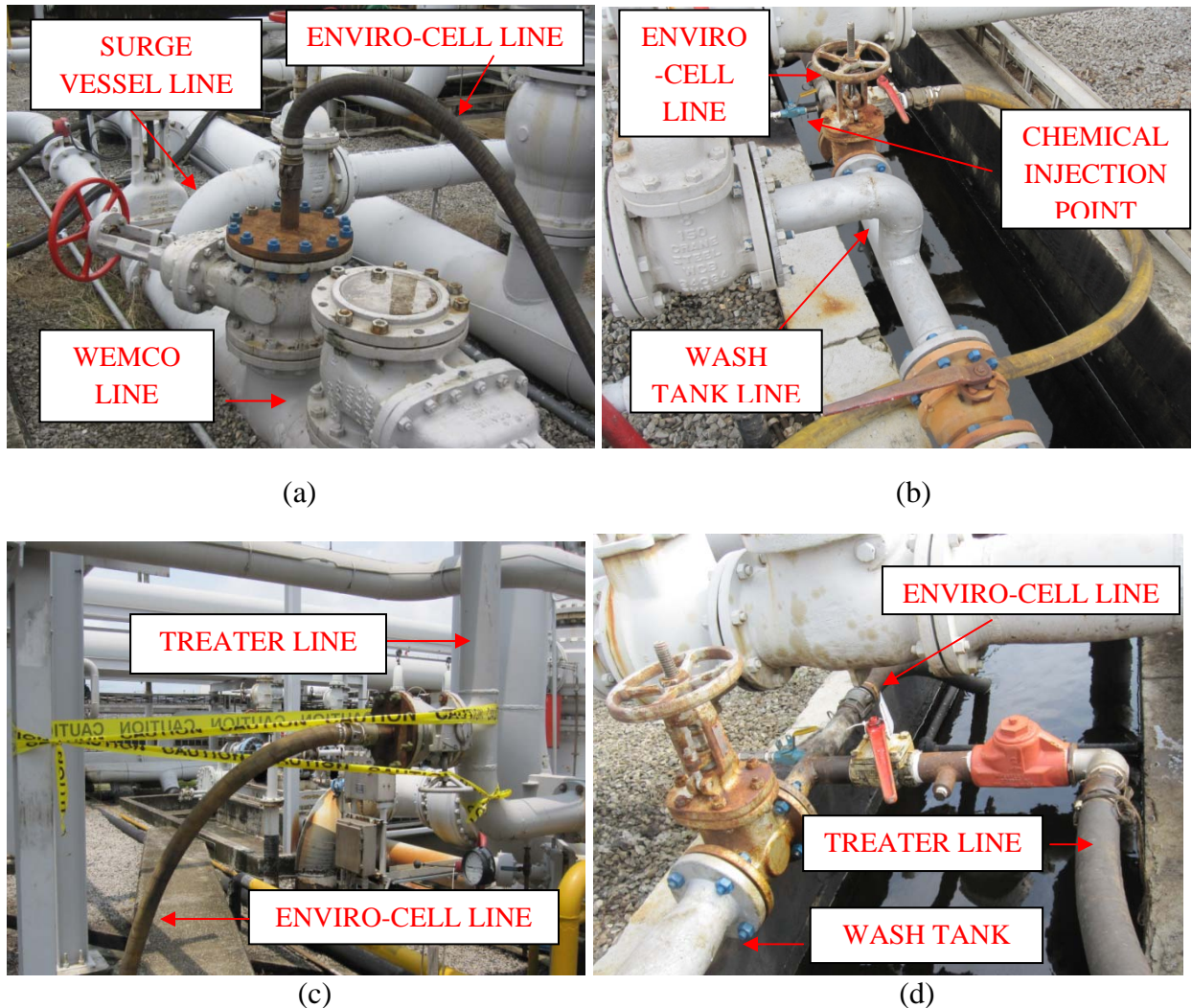


Figure 9: (a) Surge Vessel Line, (b) Wash Tank Line, (c) Treater line, and (d) Treater and Wash Tank Line to the Enviro-cell Unit

In Test C, at first the treater line was connected to the Enviro-cell unit (**Figure 9c**). The treater began discharging pure crude oil into the Enviro-cell unit. Since the wash tank outlet stream does not have higher oil content, it was decided to combine the low pressure crude oil stream of the treater with the high pressure water stream of wash tank (**Figure 9d**). The combining of two different pressure lines was challenging. The low pressure treater line was connected to the wash tank line with the help of diaphragm pump to maintain equal pressure. The water samples were taken from the outlet of treater-wash tank line and Enviro-cell unit.

Chemicals were used for enhanced oil/water separation. A flow rate of 1 to 1.5 gallon per day was maintained during all the tests. The chemicals were injected continuously into the surge vessel outlet, wash tank outlet, and treater-wash tank outlet stream for Test A, Test B, and Test C respectively.

The Enviro-cell unit was operated under a gas blanket during the entire pilot testing operation. The use of gas instead of air improves the oil/water separation efficiency of the flotation unit while minimizing corrosion. An optimum gas pressure of 4 oz/in<sup>2</sup> was maintained during the entire pilot testing.

The operating parameters such as inlet water flow rate, gas blanket pressure, temperature and pH of inlet and outlet water stream, oil and water discharge flow rate were monitored during the tests. A digital turbine meter was also used to measure the inlet flow rate. The water samples were taken on hourly basis during the day, while at night the samples were collected at every 2 hours.



## V. RESULTS AND DISCUSSION

The pilot test was carried out in three phases. Test A involved comparing the performance of Enviro-cell unit with Wemco unit at low oil content in produced water. In Test B, the Enviro-cell was tested under moderate oil concentration from wash tank. While in Test C, the performance of Enviro-cell unit was evaluated against high hydrocarbon content from treater and wash tank combined. Each test was carried out over a period of 24 hours.

The inlet and outlet samples were collected by the Major Oil Operator personnel and tested in the Major Oil Operator laboratory for data recording (**Figure 10**). A Photometry (API-RP 45) method using HACH DR 2000 Spectrophotometer was used for water sample analysis in the Major Oil Operator in West Africa laboratory.



Figure 10: Laboratory Testing of Produced Water Sample at the Major Oil Operator Environmental Lab Facility

The samples were also checked periodically by a portable Enviro-Tech Systems TD 500 oil-in-water analyzer. **Figure 11** shows the inlet and outlet water samples from the Enviro-cell unit with oil content of 200 and 7 ppm respectively. The sample readings from TD 500 analyzer were consistent with the readings from the the Major Oil Operator laboratory during the pilot test.

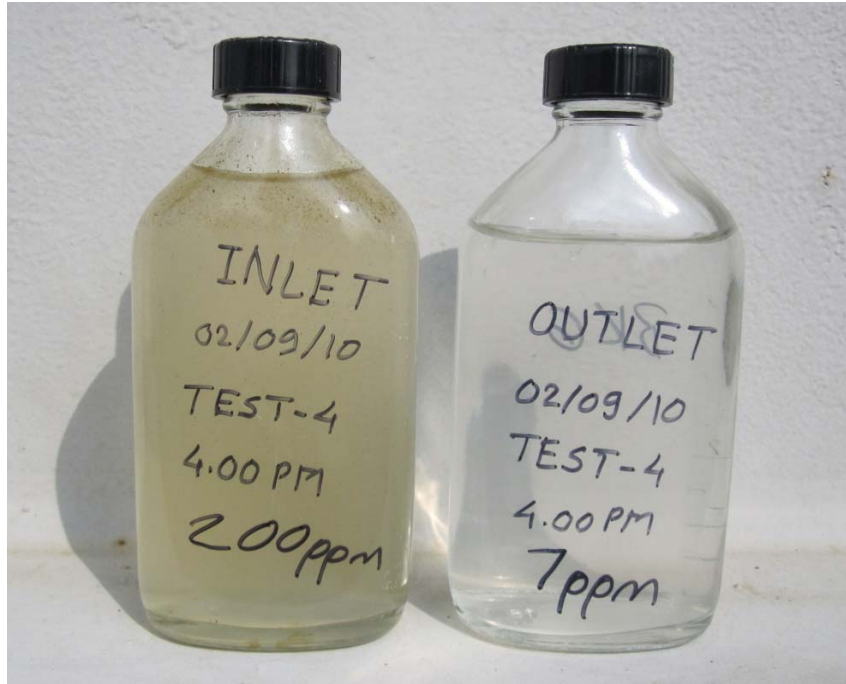


Figure 11: Inlet and Outlet Water Sample from Enviro-cell Unit

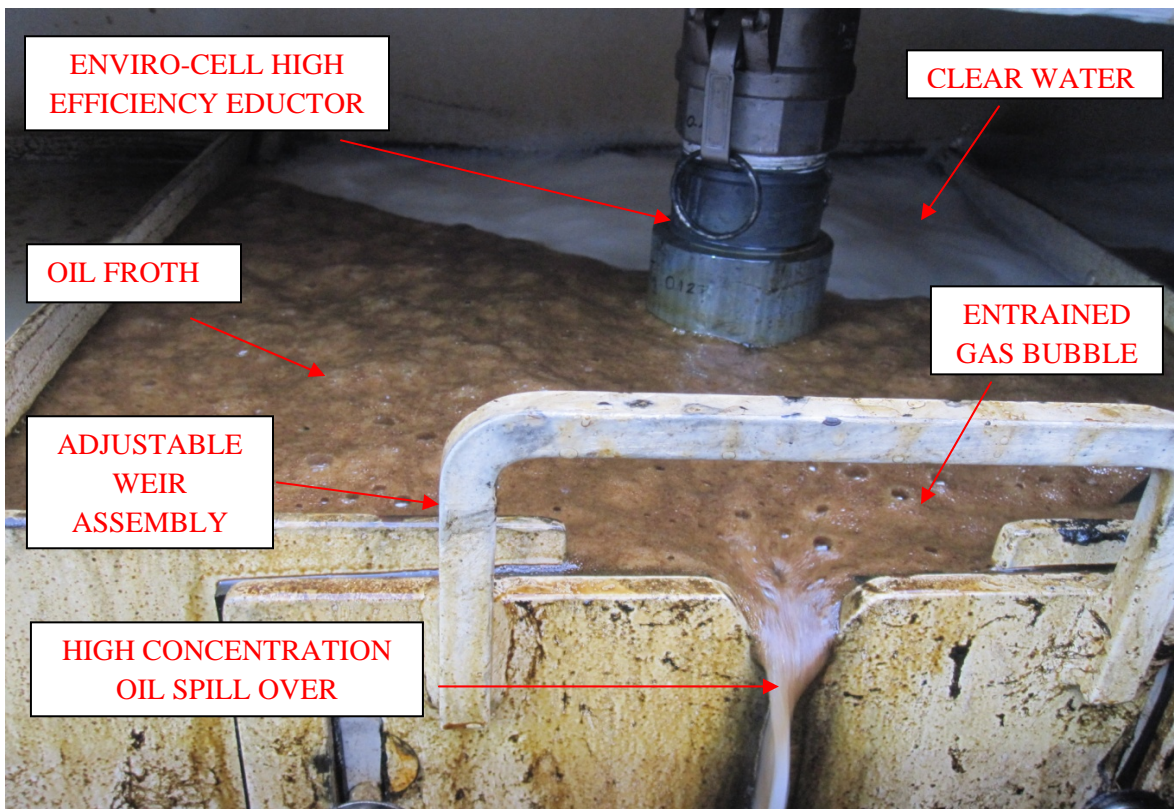


Figure 12: Interior View of Enviro-cell Unit Compartment showing Oily Froth Build-up and Removal

**Figure 12** shows the oil spill over in the oil bucket inside the flotation tank assisted by v-notch weir. The Eductor at the center of the compartment is designed for gasification creating very small bubbles. The attachment of the gas bubble to the oil droplet encourages the oil droplets to rise faster at the surface coupled with the internal process roll over. The pushing of oil creates a pad of oil on the water surface near the weir assembly. The dark brown oil froth with entrained gas bubbles can be seen in the **Figure 12**. This was a common picture in all the tests.

The Enviro-cell pilot unit was tested from low to high hydrocarbon content in produced water. In Test A, the outlet from the surge vessel was used as a common inlet for Wemco and Enviro-cell unit. **Table 2** shows the low inlet and outlet oil content of Wemco #1 unit and Enviro-cell unit.

Table 2: Total Oil Concentration in Outlet Stream of Wemco #1 Unit and Enviro-cell Unit during Test A.

Date	Time	Surge Vessel Outlet (ppm)	Wemco Outlet (ppm)	Enviro-Cell Outlet (ppm)
08/29/10	1000	6	0	1
08/29/10	1100	9	2	2
08/29/10	1200	7	1	1
08/29/10	1300	8	2	2
08/29/10	1400	9	1	2
08/29/10	1500	7	2	2
08/29/10	1600	7	1	1
08/29/10	1700	7	3	2
08/29/10	1800	9	3	2
08/29/10	1900	6	1	2
08/29/10	2000	7	1	2
08/29/10	2100	10	1	2
08/29/10	2300	12	1	2
08/30/10	0100	8	1	1
08/30/10	0300	10	1	2
08/30/10	0500	10	1	2

Both the units were tested under the same operating conditions and inlet hydrocarbon content. **Figure 13** shows the graph of total oil content in the outlet stream of surge vessel, Wemco unit and Enviro-cell unit. The removal of low hydrocarbon from produced water with the help of flotation technology was a challenging job. But Enviro-cell and Wemco unit brought down the oil content in outlet stream from 6-12 ppm to 1-3 ppm as shown in **Figure 13**. The effluent oil concentration from the Enviro-cell unit was in the range of 1 to 2ppm.

In situations where the inlet oil content is very low (<20ppm), it is very difficult to achieve the standard oil removal efficiency. The Enviro-cell unit achieved 78 to 88% oil removal efficiency with low inlet hydrocarbon content in this case.

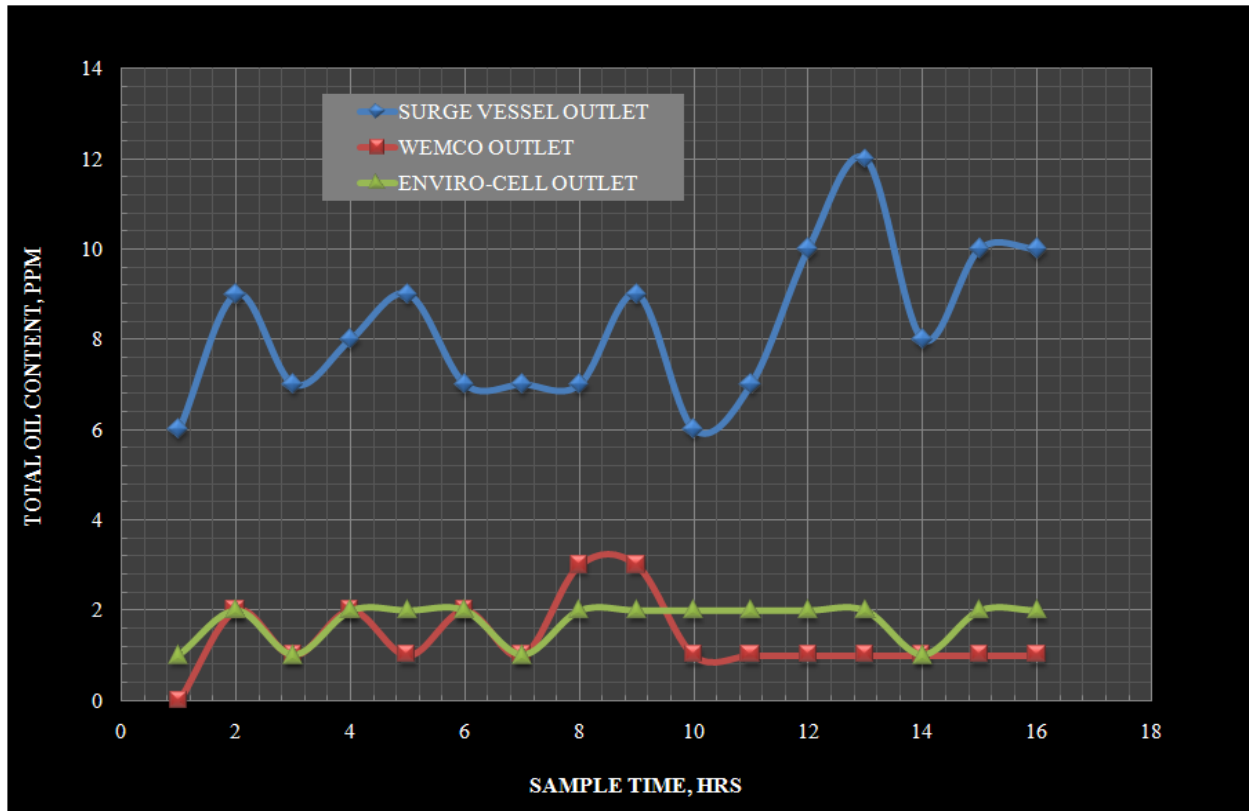


Figure 13: Performance of Enviro-cell and Wemco Unit at Low Inlet Oil Concentration

The Enviro-cell unit was designed with a capacity of 700 BPD, and the Wemco #1 test unit has a design capacity of 25,000 BPD. During Test A, the Wemco #1 was operated at a flow rate of 150 to 180 gallon per minute with an operating capacity of 60 to 72%. And the Enviro-cell unit was operated with a flow rate of 10 to 23 GPM with an operating capacity at 49 to 112%. The Enviro-cell unit was operated at lower as well as at higher designed capacity in order to analyze the effect of increased produced water surge on the oil effluent concentration. The Enviro-cell unit effluent oil concentration was recorded at 1-2 ppm, while the hydrocarbon content in the outlet stream of Wemco #1 was 1-3 ppm during Test A.

**Figure 14** compares the operating capacity of Enviro-cell and Wemco unit with different inlet flow rate conditions. Also, the total oil content in the outlet stream of Enviro-cell and Wemco unit was observed to within the specified discharge limit.



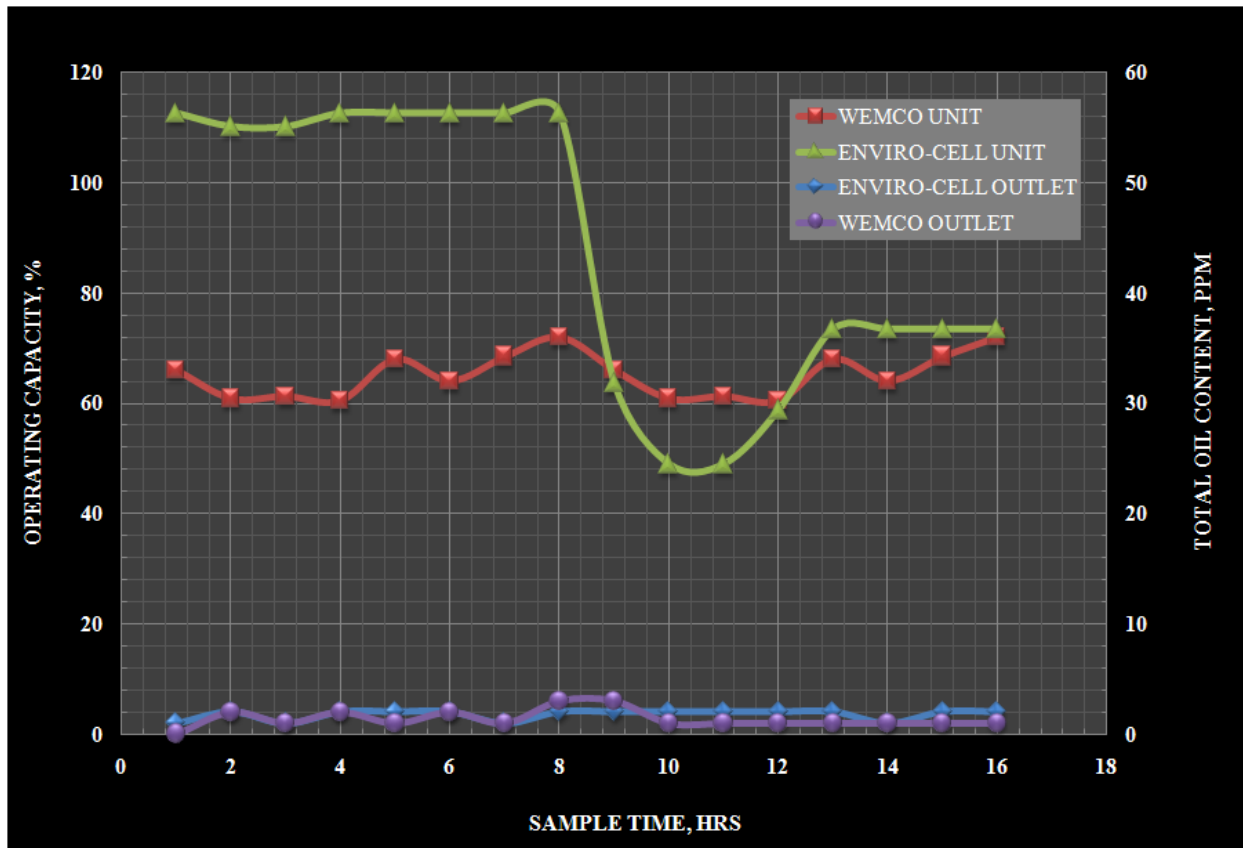


Figure 14: Performance of Enviro-cell Pilot Unit with Low and High Operating Capacity compared to the Wemco Unit.

In Test B, the wash tank outlet stream with moderate oil content was used as an inlet stream for Enviro-cell unit. A connection was made from wash tank directly to the Enviro-cell unit by passing the surge vessel for testing purpose. In test B, samples were taken only from the Enviro-cell and wash tank outlet. **Table 3** shows the inlet and outlet oil concentration of Enviro-cell pilot unit during Test B.

Table 3: Total Oil Concentration in Outlet Stream of Wash Tank and Enviro-cell Unit during Test B.

Date	Time	Wash Tank Outlet (ppm)	Enviro-cell Outlet (ppm)
08/30/10	1700	9	3
08/30/10	1800	14	4
08/30/10	1900	10	4
08/30/10	2000	9	2
08/30/10	2100	11	3
08/30/10	2200	11	3
08/30/10	2400	9	2
08/31/10	0200	11	2
08/31/10	0400	12	2
08/31/10	0600	12	3

08/31/10	0800	14	4
08/31/10	1000	13	4
08/31/10	1200	15	4
08/31/10	1400	11	4
08/31/10	1600	10	4
08/31/10	1800	15	4
08/31/10	2000	13	4
08/31/10	2200	9	4
08/31/10	2400	11	4
09/01/10	0200	17	4
09/01/10	0400	12	1

**Figure 15** shows the total oil content in the wash tank outlet and Enviro-cell outlet. The oil content in the outlet stream of wash tank was in the range of 9 to 17 ppm during the test. The Enviro-cell worked well by reducing the oil concentration in the effluent to 1-4 ppm as shown in **Figure 15**. The oil removal efficiency of Enviro-cell unit with moderate hydrocarbon content was found to be 72 to 92 %. The performance of Enviro-cell unit was excellent compared to Wemco unit and surge vessel combined.

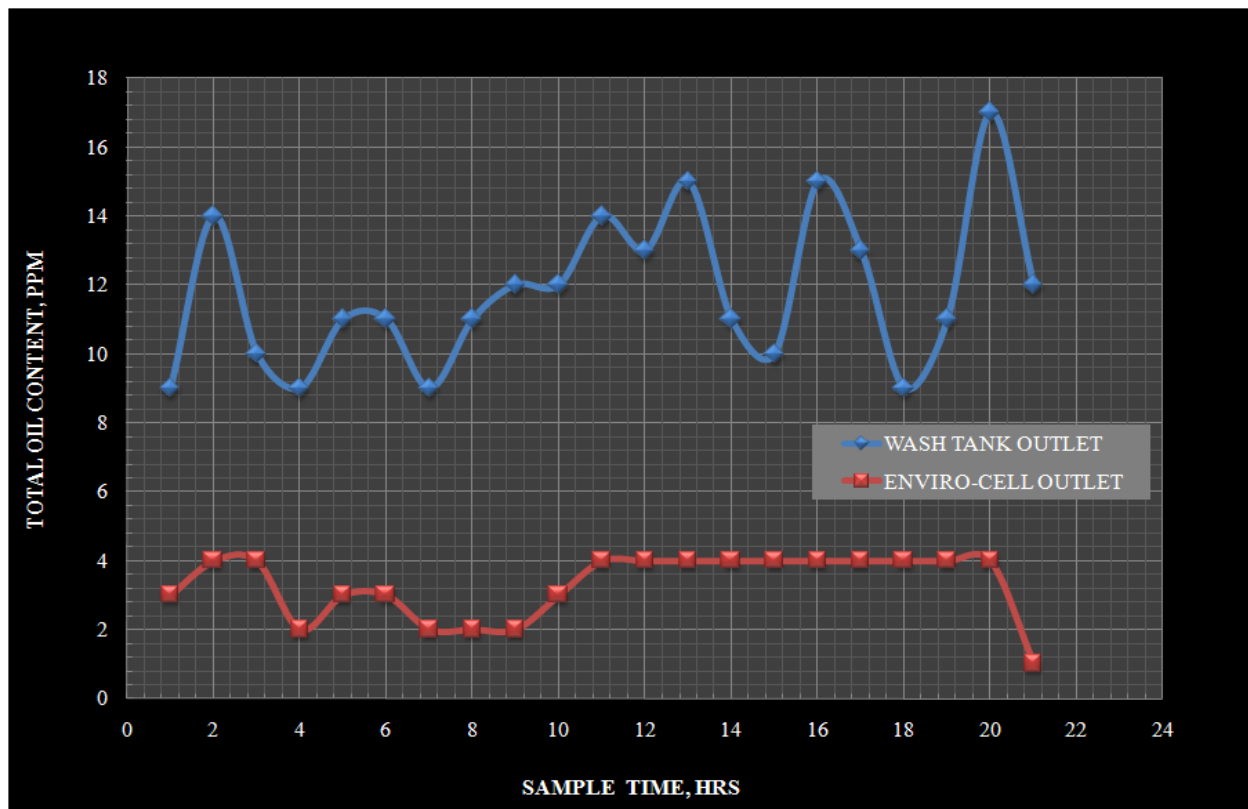


Figure 15: Performance of Enviro-cell Pilot Unit at Moderate Inlet Oil Concentration

After conducting Test A and Test B; connections were made between the treater-wash tank and Enviro-cell unit for higher hydrocarbon content in the produced water. The combination of high pressure wash tank line with low pressure treater line created some pressure difference allowing greater oil concentration to enter the pilot unit. The oil content in the combined stream varied from 11 to 16500 ppm as shown in **Table 4**. The effluent oil ppm from the Enviro-cell unit was found to be in the range of 3 to 80 ppm.

**Table 4** shows the total oil removal efficiency of Enviro-cell unit which was found to be 86-99% depending on the inlet oil content in the produced water.

Table 4: Total Oil Concentration in Outlet Stream of Treater-Wash Tank and Enviro-cell Unit during Test C.

Date	Time	Treater + Wash Tank Outlet (ppm)	Enviro-cell Outlet (ppm)	Total Oil removal Efficiency (%)
02/09/2010	1600	305	6	98.03
02/09/2010	1700	8000	80	99.00
02/09/2010	1800	16500	59	99.64
02/09/2010	1900	490	14	97.14
02/09/2010	2000	76	11	85.53
02/09/2010	2100	1100	11	99.99
02/09/2010	2300	1025	25	97.56
02/09/2010	0100	860	13	98.49
02/09/2010	0300	560	14	97.50
02/09/2010	0500	30	4	86.67
02/09/2010	0700	1150	25	97.83
02/09/2010	0900	285	11	96.14
02/09/2010	1100	22	4	81.82
02/09/2010	1300	20	5	75.00
02/09/2010	1500	11	3	72.73
02/09/2010	1600	205	20	90.24

**Figure 16** shows that the oil concentration in Enviro-cell effluent was within the specified discharge limit. The Enviro-cell was perfectly suited for this type of situation where the inlet oil concentration changes frequently. Overall the effluent oil content was well below 25 ppm in Test C. The oil concentration in treater-wash tank outlet stream changed considerably from low level to a higher level perhaps due to the uneven pressure. The oil removal efficiency of Enviro-cell unit was found to increase with higher inlet hydrocarbon content in the produced water.

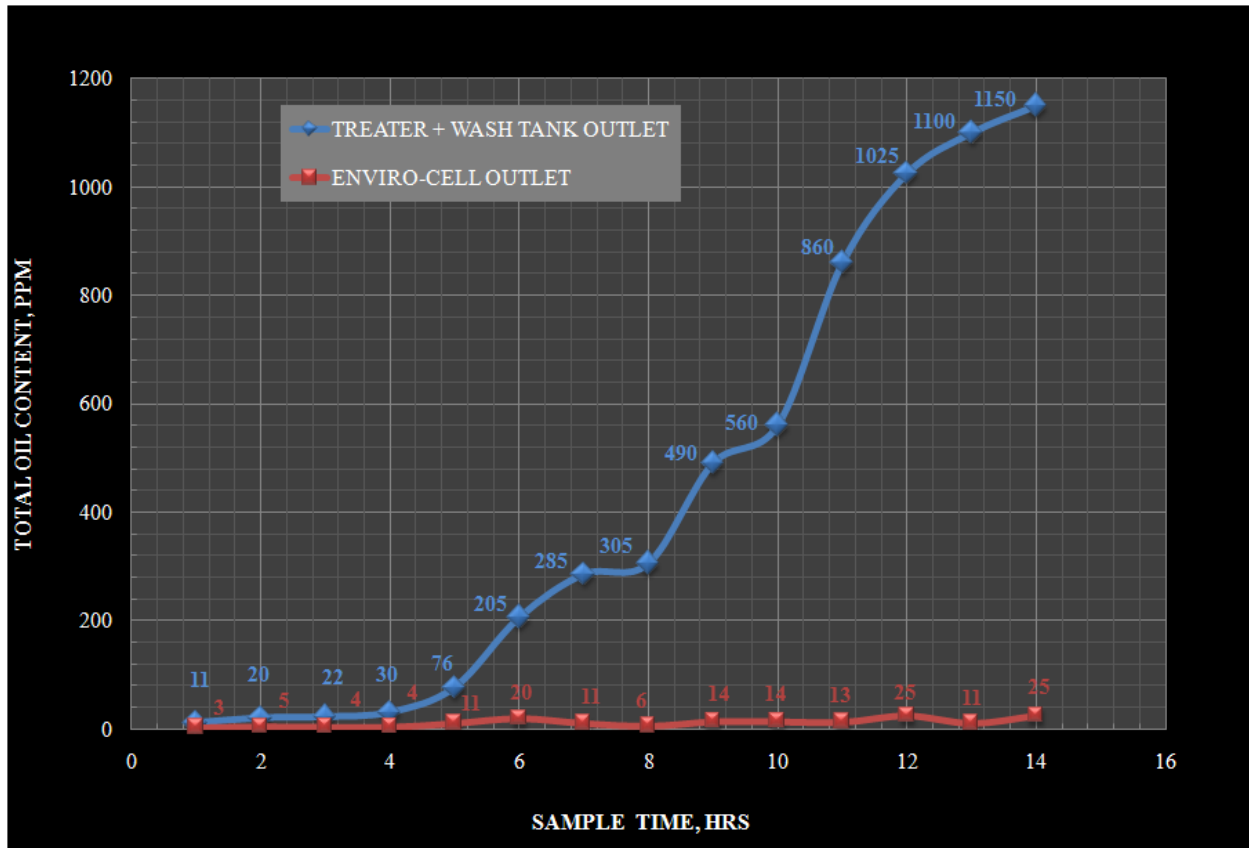


Figure 16: Performance of Enviro-cell with varying Inlet Oil Concentration

**Figure 17** shows the brown dark color inlet sample and clear water outlet sample taken from the Enviro-cell unit during Test C. The oil removal efficiency for this sample was more than 98% during Test C. Overall the oil removal efficiency of Enviro-cell unit was found to be more than 95% with the inlet oil content of 210 ppm and higher as shown in **Figure 18**. While in case of inlet oil content lower than 210 ppm, the efficiency was in between 85 to 95%.





Figure 17: Inlet and Outlet Water Sample from Enviro-cell Unit with Higher Hydrocarbon Content in Produced Water.

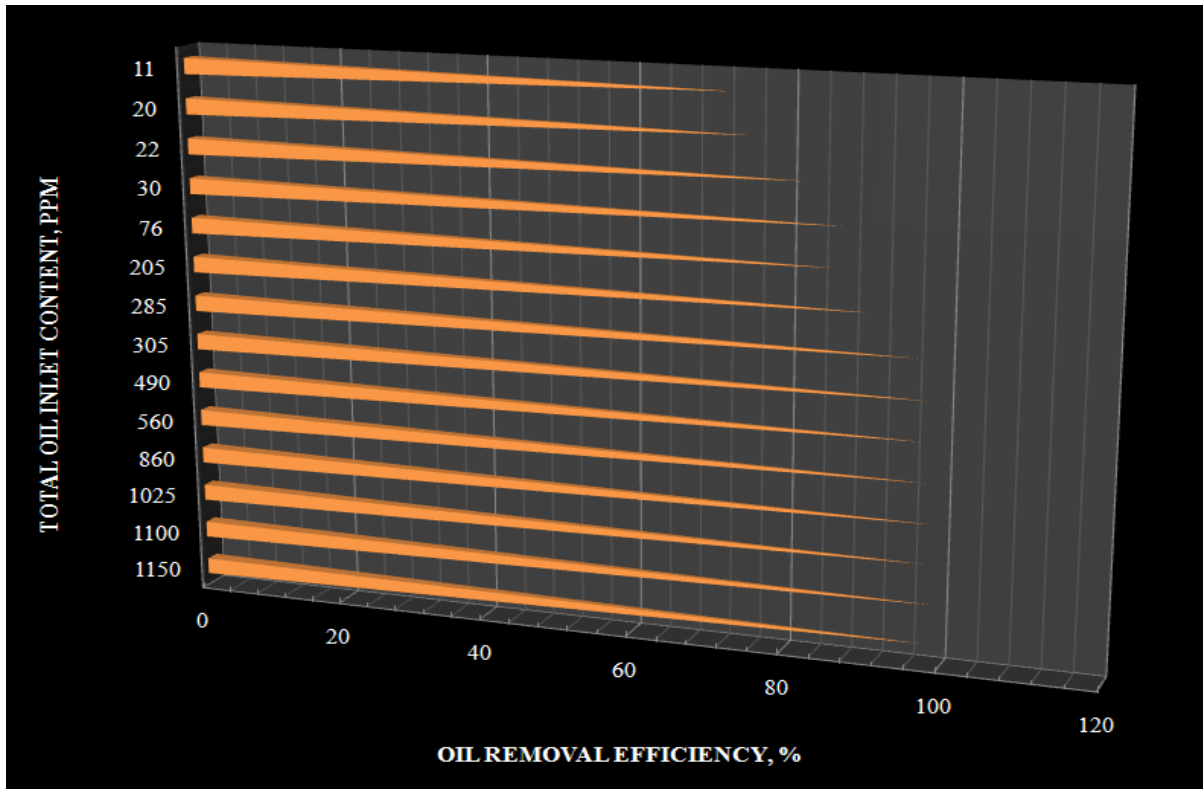


Figure 18: Oil Removal Efficiency of Enviro-cell Unit with varying Inlet Oil Content

The effluent oil concentration was within the specified discharge limit during Test A, Test B and Test C. While in two cases during Test C, the effluent oil concentration from Enviro-cell unit was 80 and 59 ppm for inlet oil concentration of 8000 and 16500 ppm respectively (**Figure 19**). This was due to combination of uneven pressure line of treater and wash tank and excessive inlet oil concentration. Even though the outlet oil concentration was above the specified limit of 29 ppm, the oil removal efficiency of Enviro-cell unit for both cases was more than 99%.

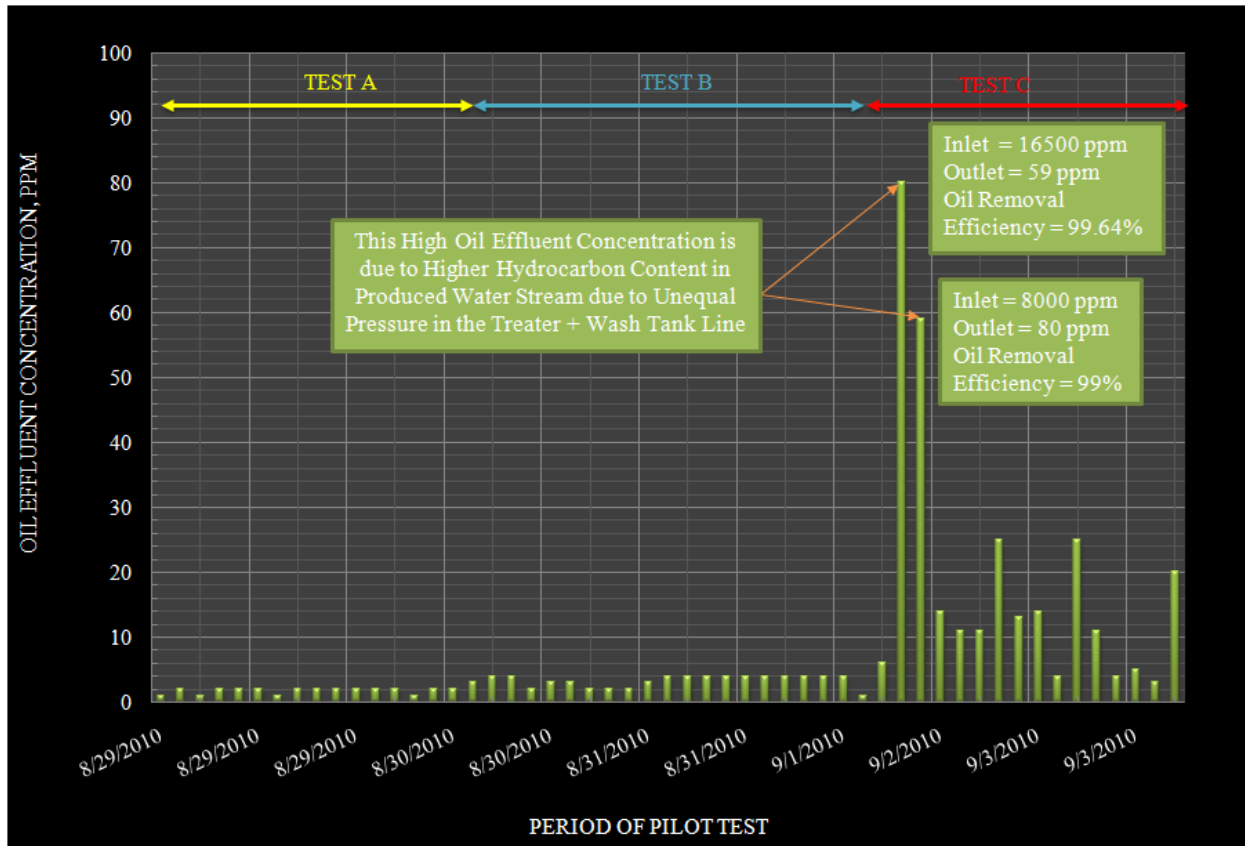


Figure 19: Oil Effluent Concentration from Enviro-cell Unit during 6 day Period of Pilot Test Operation

Overall **Figure 19** shows lower oil effluent concentration for Enviro-cell unit under different produced water characteristics present in the West Africa field during the entire pilot testing operation. The samples were also tested periodically with the Enviro-cell portable oil-in-water analyzer during all the tests. After the test the data was analyzed, studies and discussed with the Major Oil Operator.

## VI. CONCLUSIONS

Based on our results, we may conclude that

- The Wemco unit was operating at 60 to 72% of its capacity, while Enviro-cell unit was operated at 90 to 115% designed capacity. The effluent oil concentration from Enviro-cell unit was 1-2 ppm compared to the Wemco outlet oil concentration of 1-3 ppm during Test A. The performance of Enviro-cell unit was found to be superior over the Wemco unit in terms of effluent oil concentration and operating capacity load.
- The oil and grease removal efficiency of Enviro-cell unit at lower (<20 ppm) and moderate (< 210 ppm) inlet oil concentration was found to be 78-92% and 85-95% respectively.
- The performance of Enviro-cell unit was superior in comparison to the Wemco and surge vessel combined with the same operating conditions in Test B. The outlet oil concentration of Enviro-cell unit was in the range of 1 to 4 ppm.
- The Enviro-cell unit performed best with higher inlet hydrocarbon content (210 to 16500 ppm) by achieving more than 95% efficiency during Test C. This indicated that the Enviro-cell can handle incoming surges and upset process conditions more effectively than Wemco.
- It was noted by the Major Oil Operator personnel that the Enviro-Cell had user friendly attributes when compared to the mechanical style Wemco. Also noted was the Enviro-Cell had less moving parts and therefore less overall maintenance.
- The pilot test was completed in a record period of 6 days. (excluding the equipment arrival and set-up, plant crew change, monsoon weather conditions, and time required for getting approval for electricity, gas, and water connection)