Evaluation of Hydrocyclone Performance for North Sea Produced Water

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Abstract

The performance of liquid-liquid hydrocyclones was evaluated for handling the produced water at Texaco's Tartan "A" Platform in North Sea. These hydrocyclones were handling the effluent water from the high and low pressure separators at the Platform. Microscopic examination was used for measuring the oil droplet size distribution with a specially designed sampling method to retain the original oil droplets in the water samples. With this method, an on-site reliable size measurement was made which was used for determining the performance of hydrocyclones. Corrective measures were made based upon this measurement result.

1. Introduction:

At the Texaco's Tartan "A" Platform, two sets of hydrocyclones were used for removing oil from the produced water in order to meet the discharge standard. The purpose of this work is to use a specially designed method to measure the oil droplet size, so that the performance of the hydrocyclones can be determined.

This specially designed method includes a shear-free sampling device for collecting water samples, and a polymer solution for "capturing" the oil droplets immediately after the on-site sampling. Microscopic examination was used to determine the oil droplet size distributions. These techniques were developed in Texaco with worldwide applications.

2. Background:

The performance of a liquid-liquid hydrocyclone is determined by their ability to remove certain size of particles as guided by Stokes Law. The current application is removing oil from the produced water. A reliable method is required to measure these critical data from Stokes Law, including the oil droplet size distributions.

The production facilities at Tartan "A" Platform consists a high pressure (HP) and a low pressure (LP) systems. The HP and LP produced water systems are shown in Figures 1 and 2, respectively. Both systems utilize horizontal separators to separate water from oil. The water is then polished by hydrocyclones before sending to the last separator and disposal pile for discharge.

Before measuring the oil droplet size distributions, the hydrocyclones were fine-tuned by the engineer of an independent engineering company, IGL, to insure that these hydrocyclones were in the best operations mode.

3. Shear-Free Sampling Device:

When a water sample is collected from a sampling valve, oil droplets have a chance of being sheared by the valve. Depending upon the type and valve opening conditions, these oil droplets could be sheared into smaller sizes. Consequently, an erroneous conclusion could be drawn based upon this measurement.

A shear-free fluid sampling device is shown in Figure 3. This system consists of (1) three snap open type ball valves, A, B and C; (2) a stainless steel sampling cylinder; and (3) a needle valve D. During sampling, valves A and B are opened first to flush the system with produced water. Subsequently valve B is closed, and valves C and D are opened. Valve D is used to control the pressure and flow rate of the water, so that an adequate water sample is allowed to flow through the cylinder and valve D. Since valves A and C are ball type valves, when they are fully opened, there is no shearing action applied to the sampled oil and water. After sampling, valve A is closed and valve B is opened quickly to allow the shear-free water sample flow out at the bottom of the sampling device. This sample can be collected in a bottle with a polymer solution in order to "capture" the oil droplet before it is coalesced each other. With this polymer solution, the oil droplet is suspended for an indefinite time. This solution can be transferred to a laboratory for the particle size measurement.

4. Oil Droplet Size Measurements:

The above shear-free samples were transferred to the on-site laboratory for the oil droplet size measurement.

A high power microscope is used for measuring the oil droplet size distributions down to the micron sizes. The technique used for the particle size counting is similar to the one used in the medical laboratory for counting the blood cells. A counter is generally used to register the oil droplet size and number of oil droplets appeared on the microscope. Usually 200 counts are enough to give an indication of the droplet size distribution. Sometimes, 500 or more counts could be used to increase the precision of the process.

5. Performance of Hydrocyclones:

The oil droplet size distributions in water were measured for the LP and HP hydrocyclones at the Tartan "A" Platform. Results of the measurements are summarized as follows:

(1) The HP Hydrocyclones:

For the HP hydrocyclones, the measured oil droplet size distributions are shown in Table 1 (top section). From this table, the maximum oil droplet size for the inlet water was 25 microns, however, outlet oil droplet sizes were below 12.5 microns.

The above measured oil droplet distributions were converted to the volumetric oil droplet size distributions by utilizing the cubic relationship of the droplet diameters (Table 1, middle section). Once the volumetric oil distribution was obtained, the measured oil content in water was distributed into each size based upon the volumetric percent of oil droplets in that size.

The amount of oil removed at each oil droplet size can be demonstrated by plotting the inlet and outlet oil content distribution on the same graph (Figures 4 and 5). The oil content distributions can be used to evaluate, or even predict the hydrocyclone performance. We can demonstrate this point by observing the following operations data for the HP hydrocyclones:

Run	Water Rate BWPD	Water Rate M^3/hr/cone	Inlet	Outlet	% Removal
(1)	6997	5.79	126	17	86.5
(2)	8000	6.62	57	27	52.6

From the above data, each cone (liner) of the hydrocyclones was operated in the range of 5.79 and 6.63 m^3/hr. According to the manufacturer's separating efficiency curve (Figure 6), this range corresponds to approximately 80% removal of oil droplets for sizes of 10 microns, and 90% removal of oil droplets for sizes of 15 microns. A precise prediction can be generated by using this separating efficiency curve to calculate the expected percentage of oil droplets at each size.

Since most of the oil droplets above 10 microns could be removed by the HP hydrocycones, we may use this size as a cut-off point as an alternative method to predict the outlet oil content in water. For instance, based upon the inlet oil droplet size distribution, the cumulative oil content distributions were calculated and shown at the bottom Tables 1. If the HP hydrocyclone could remove all oil droplets above 10 microns, the oil content in the outlet would be 20 and 26 ppm for the above data (Table 1, inlet data). This prediction compared favorably with the actual measured oil content of 17 and 27 ppm, respectively.

(2) For LP Hydrocyclones:

The inlet oil droplet sizes of the LP hydrocyclones were consistently below 20 microns (Table 2) and this makes it difficult for hydrocycones to show good oil removal efficiencies. However it appears that the hydrocyclones removed most of the oil droplets larger than 12.5 to 15 microns (Figures 8-11). The flow rates, oil removal efficiencies and water flow rate per cone (liner) are summarized as follows:

Run	Water Rate BWPD	Water Rate gpm/cone	Inlet	Outlet	% Removal
(1)	12,832	37.0	250	155	38.0
(2)	12,756	41.4	161	144	10.6
(3)	10,500	38.5	294	163	44.6
(4)	12,881	37.4	530	360	32.1
(5)	18,628	41.9	83*	59.5*	28.3
Average:			264	176	

Note: * A deoiler chemical was injected at 2 ppm

The above data indicated that without the deloiler chemical, the LP hydrocyclones could only remove oil down to the level of 176 ppm. From theoretical calculations based upon the inlet oil droplet size distributions, the outlet oil content could reach approximately 196 ppm if the LP hydrocyclones performed ideally and removed all oil droplet above 15 microns (Table 2, average of the accumulated oil content at 15 microns). This value is approximately 11% above the actual average value.

The water flow rates were ranging from 37 to 42 gpm per cone. This range was well within the optimum range of 32-45 gpm per cone specified by the manufacturer. In this flow range, the removal efficiency would be approximately 50% for oil droplet size of 10 microns and 80% for sizes of 15 microns (Figure 7). These removal efficiencies were confirmed by the actual data (most oil droplets larger than 12.5 microns to 15 microns were removed.

The data at item (5) of the above table was collected approximately 2 hours after a deoiler chemical was injected upstream of the V-20 separator. It showed that the inlet oil content was significantly reduced to 83 ppm and the outlet was down to 59.5 ppm. This data indicated that the use of deoiler chemical could significantly reduce the oil content of the system. In fact the deoiler chemical trial was conducted and confirmed its effectiveness. It has been used since to correct the deficiency of the relatively small oil droplet sizes in this water.

6. Conclusion:

An effective method has been developed for collecting, capturing and measuring the oil droplet size distribution of the produced water. This method was used for evaluating the performance of the HP and LP hydrocyclones for handling the oil removal of the produced water. It was found that relatively high removal efficiency was obtained for the HP hydrocyclones due to the presence of relatively large oil droplets. However, poor oil removal efficiency was obtained for the LP hydrocyclones due to the presence of smaller oil droplet size distributions. The above method could also be used as a tool for predicting the performance of the hydrocyclones in the new fields. Deoiler chemicals were found effective for dealing the water with small oil droplet sizes.

Figure 1 HP Produced Water System for Tartan Platform "A"

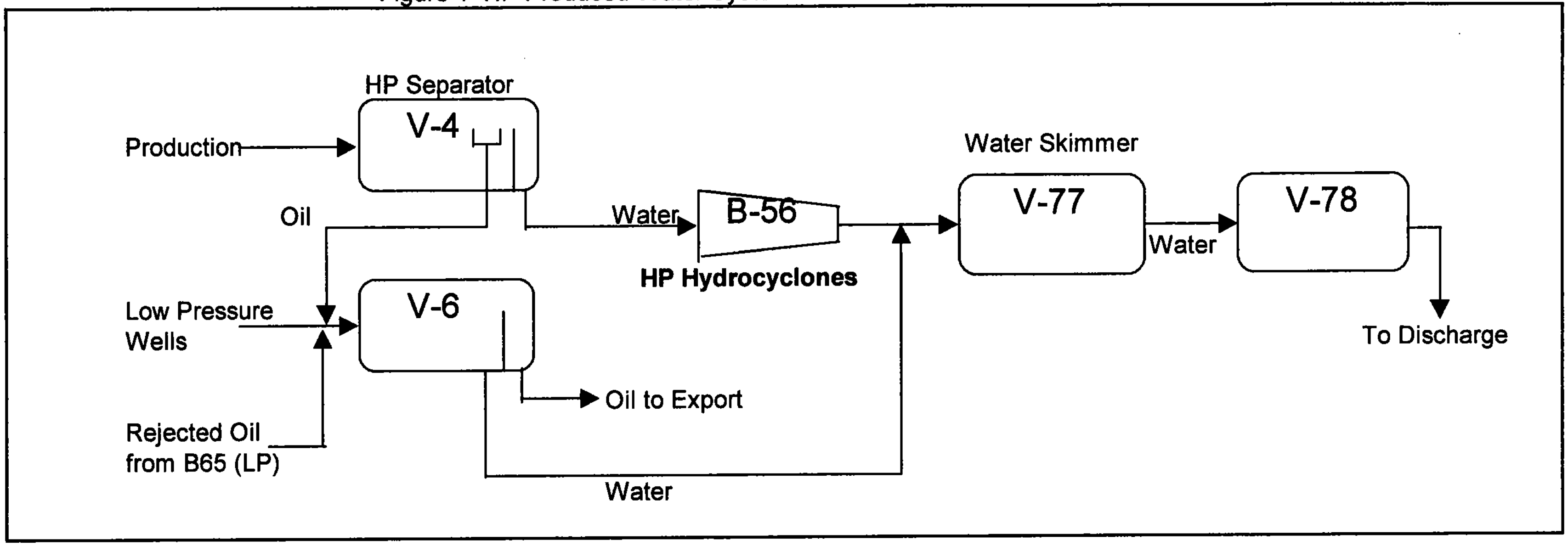


Figure 2 LP Produced Water System for Tartan Platform "A"

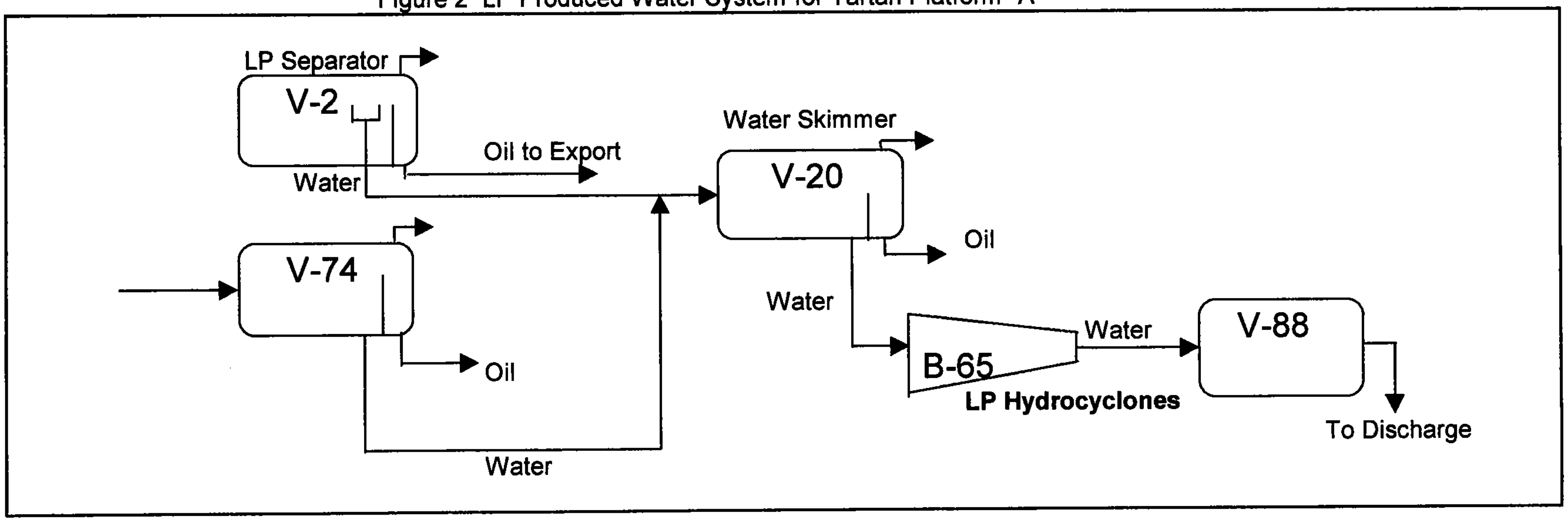


Figure 3
Shear-Free Sampling Device

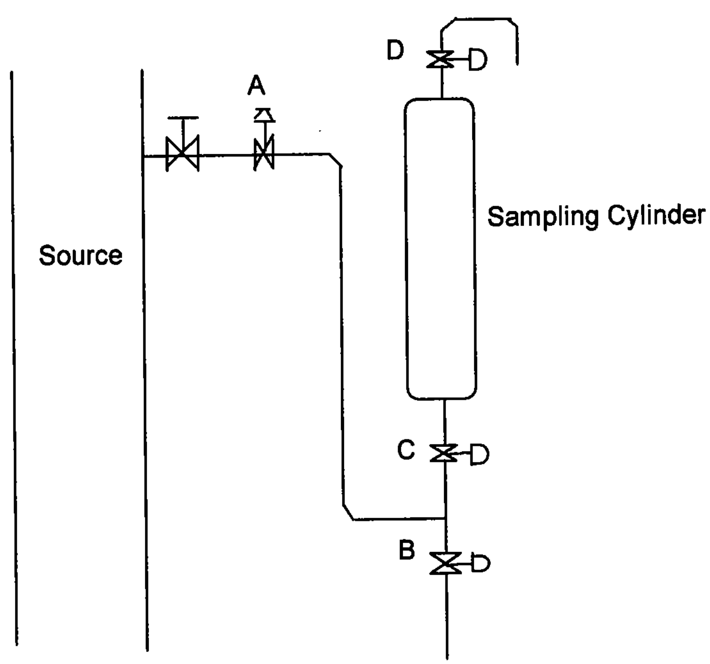


Figure 4
HP Hydrocyclone Performance
September 27, 4:00 PM

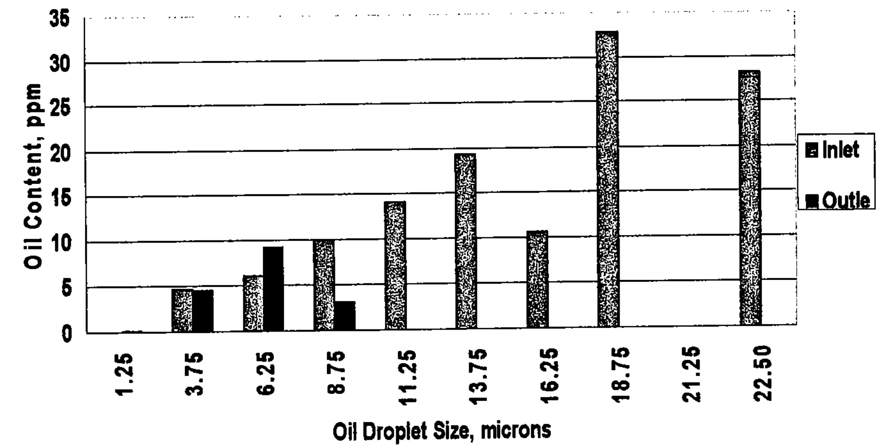


Figure 5
HP Hydrocyclone Performance
October 2, 10:00 AM

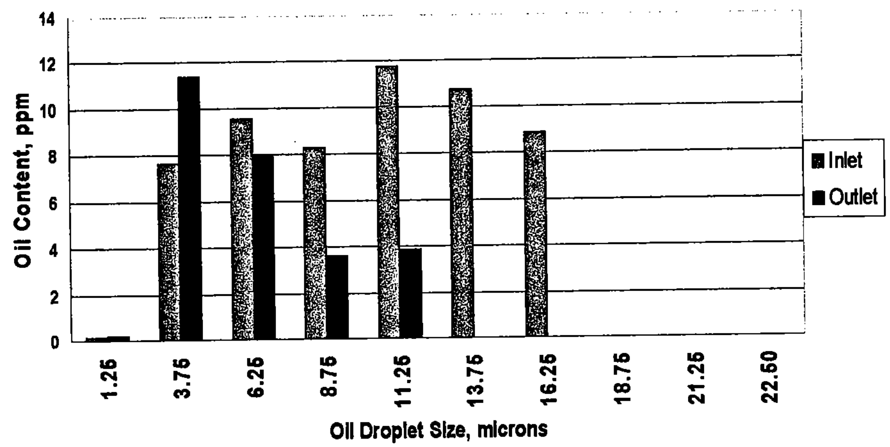


Figure 6

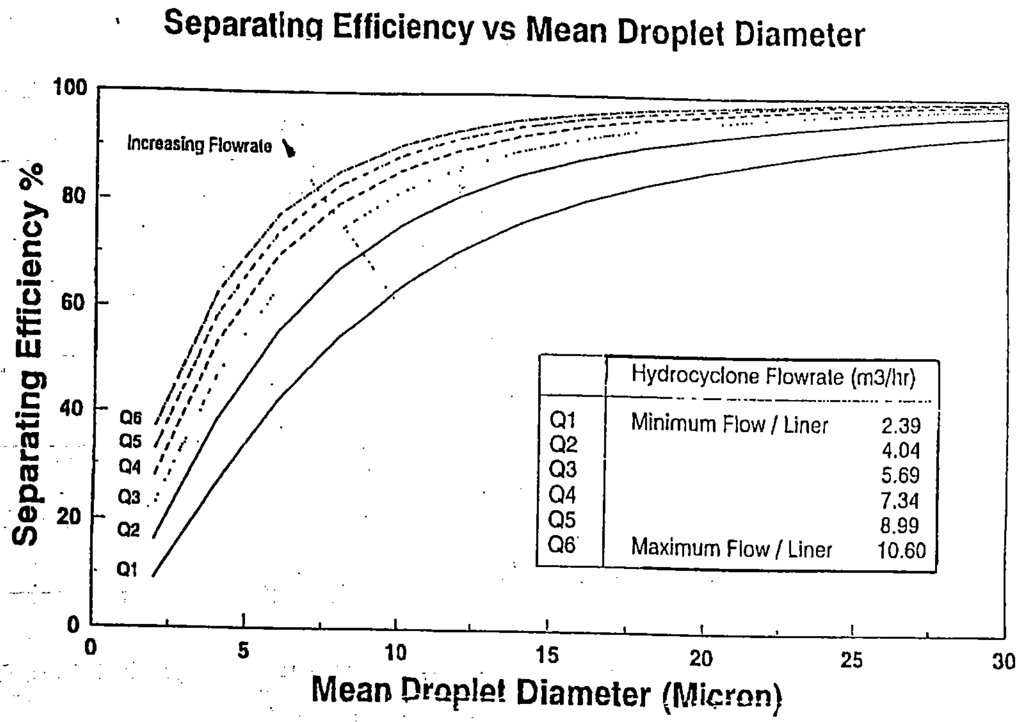
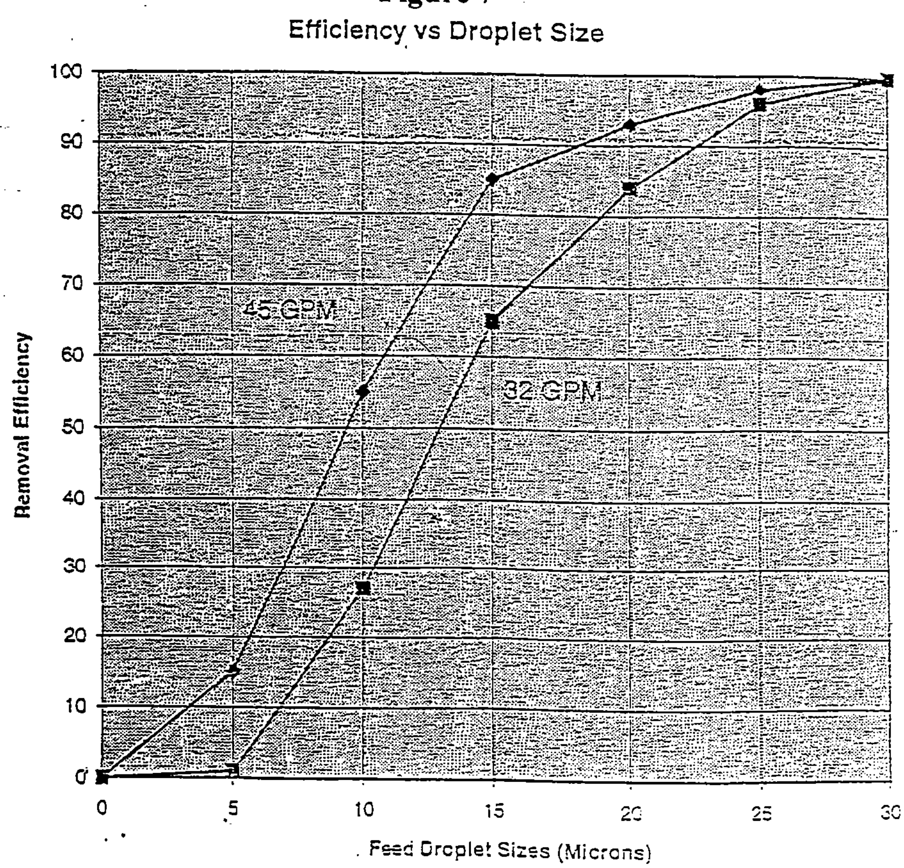


Figure 7



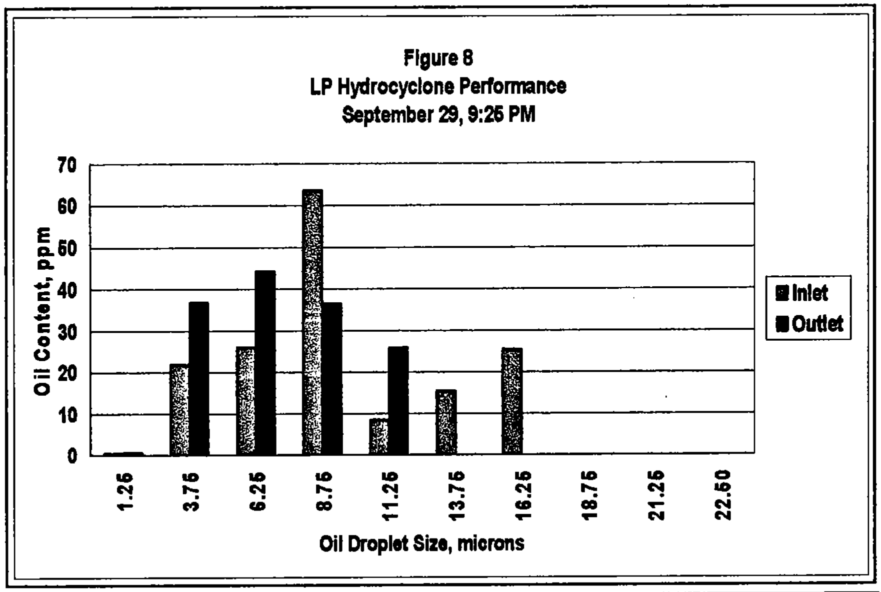


Figure 8
LP Hydrocyclone Performance
September 29, 9:25 PM
Oil Content, ppm
70
60
50
40
30
20
10
0
1.25
3.75
6.25
8.75
11.25
13.75
16.25
18.75
21.25
22.50
Oil Droplet Size, microns
Inlet
Outlet

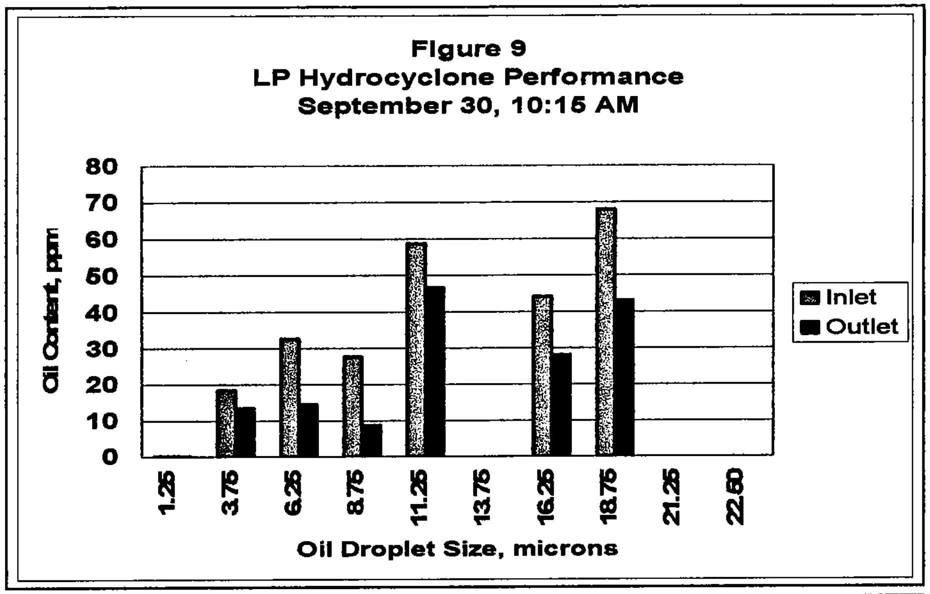


Figure 9
LP Hydrocyclone Performance
September 30, 10:15 AM
Oil Content, ppm
80
70
60
50
40
30
20
10
0
1.25
3.75
6.25
8.75
11.25
13.75
16.25
18.75
21.25
22.50
Oil Droplet Size, microns
Inlet
Outlet

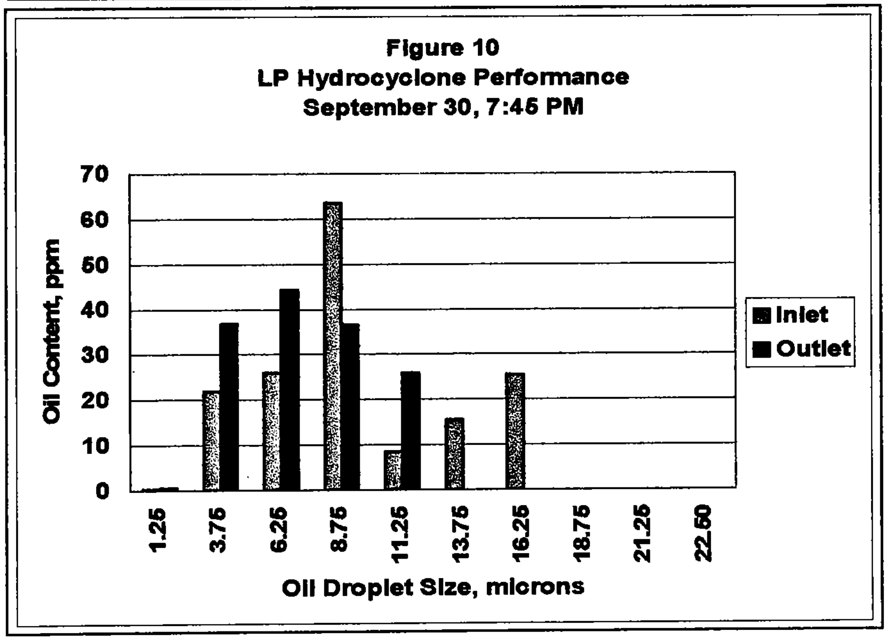


Figure 10
LP Hydrocyclone Performance
September 30, 7:45 PM
Oil Content, ppm
70
60
50
40
30
20
10
0
1.25
3.75
6.25
8.75
11.25
13.75
16.25
18.75
21.25
22.50
Oil Droplet Size, microns
Inlet
Outlet

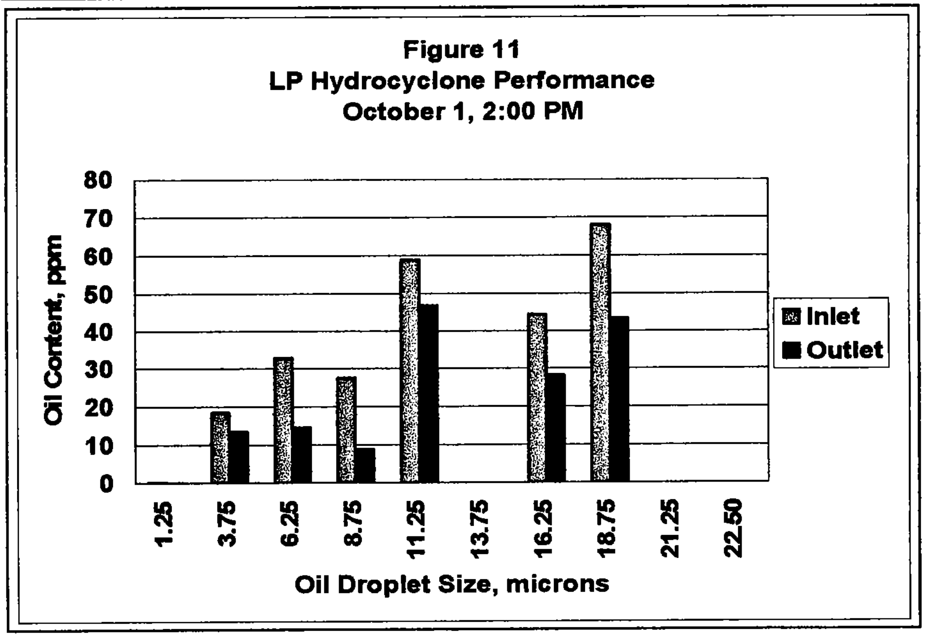


Figure 11
LP Hydrocyclone Performance
October 1, 2:00 PM
Oil Content, ppm
80
70
60
50
40
30
20
10
0
1.25
3.75
6.25
8.75
11.25
13.75
16.25
18.75
21.25
22.50
Oil Droplet Size, microns
Inlet
Outlet

Table 1

Oil Droplet Size Measurement for HP Hydrocyclone Water

Oil Droplet Size (microns)	Average Size (microns)	% Frequency			
		Inlet, September 27, 4:00 PM	Outlet, September 27, 4:00 PM	Inlet, October 2, 10:00 AM	Outlet, October 2, 10:00 AM
0-2.5	1.25	37.0	45.0	49.0	52.5
2.5-5.0	3.75	36.0	37.0	35.0	40.0
5.0-7.5	6.25	10.0	16.0	9.5	6.0
7.5-10.0	8.75	6.0	2.0	3.0	1.0
10-12.5	11.25	4.0	0.0	2.0	0.5
12.5-15.0	13.75	3.0	0.0	1.0	0.0
15.0-17.5	16.25	1.0	0.0	0.5	0.0
17.5-20.0	18.75	2.0	0.0	0.0	0.0
20.0-22.5	21.25	0.0	0.0	0.0	0.0
22.5-25.0	23.75	1.0	0.0	0.0	0.0
Total		100.0	100.0	100.0	100.0
		Oil Content, ppm			
0-2.5	1.25	0.06	0.07	0.13	0.19
2.5-5.0	3.75	4.53	4.59	7.62	11.41
5.0-7.5	6.25	5.83	9.19	9.58	7.93
7.5-10.0	8.75	9.60	3.15	8.30	3.62
10-12.5	11.25	13.60	0.00	11.76	3.85
12.5-15.0	13.75	18.63	0.00	10.74	0.00
15.0-17.5	16.25	10.25	0.00	8.86	0.00
17.5-20.0	18.75	31.49	0.00	0.00	0.00
20.0-22.5	21.25	0.00	0.00	0.00	0.00
22.5-25.0	23.75	32.00	0.00	0.00	0.00
Total		126.00	17.00	57.00	27.00
		Cumulative Oil Content, ppm			
0-2.5	1.25	0.06	0.07	0.13	0.19
2.5-5.0	3.75	4.59	4.86	7.76	11.60
5.0-7.5	6.25	10.42	13.85	17.34	19.52
7.5-10.0	8.75	20.03	17.00	25.64	23.15
10-12.5	11.25	33.63	17.00	37.40	27.00
12.5-15.0	13.75	52.26	17.00	48.14	27.00
15.0-17.5	16.25	62.51	17.00	57.00	27.00
17.5-20.0	18.75	94.00	17.00	57.00	27.00
20.0-22.5	21.25	94.00	17.00	57.00	27.00
22.5-25.0	23.75	126.00	17.00	57.00	27.00

Table 2

Oil Droplet Size Measurement for LP Hydrocyclone Water

Oil Droplet Size, microns	Average Size microns	Inlet, Sept.29 1:30 PM	Outlet, Sept.29 1:30 PM	Inlet, Sept.29 9:25 PM	Outlet, Sept.29 9:25 PM	Inlet, Sept.30 10:15 AM	Outlet, Sept.30 10:15 AM	Inlet, Sept.30 7:45 PM	Outlet, Sept.30 7:45 PM	Inlet, Oct.1 2:00 PM	Outlet, Oct.1 2:00 PM
		% Frequency									
0-2.5	1.25	43.0	43.0	46.5	47.5	39.5	47.0	41.0	35.5	43.0	36.0
2.5-5.0	3.75	34.0	39.0	35.0	38.5	38.5	42.0	30.5	38.5	37.0	44.0
5.0-7.5	6.25	13.0	9.0	9.0	10.0	12.5	7.0	14.5	14.0	9.5	13.0
7.5-10.0	8.75	4.0	2.0	8.0	3.0	4.0	2.0	7.5	8.5	5.5	4.0
10-12.5	11.25	4.0	5.0	0.5	1.0	2.0	1.5	3.0	1.5	2.0	2.0
12.5-15.0	13.75	0.0	0.0	0.5	0.0	2.0	0.5	2.5	1.0	1.5	1.0
15.0-17.5	16.25	1.0	1.0	0.5	0.0	1.5	0.0	1.0	0.5	1.5	0.0
17.5-20.0	18.75	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0
20.0-22.5	21.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22.5-25.0	23.75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total		100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		% Oil Content									
0-2.5	1.25	0.29	0.18	0.36	0.56	0.34	0.57	0.56	0.4	0.11	0.10
2.5-5.0	3.75	18.48	13.49	21.87	36.84	26.80	41.35	33.75	34.3	7.65	10.12
5.0-7.5	6.25	32.72	14.42	26.03	44.30	40.29	31.91	74.27	57.7	9.09	13.84
7.5-10.0	8.75	27.62	8.79	63.49	36.47	35.37	25.02	105.42	96.1	14.45	11.69
10-12.5	11.25	58.71	46.71	8.43	25.83	37.59	39.88	89.62	36.0	11.17	12.42
12.5-15.0	13.75	0.00	0.00	15.40	0.00	68.64	24.27	136.35	43.9	15.29	11.34
15.0-17.5	16.25	44.23	28.15	25.42	0.00	84.97	0.00	90.03	36.2	25.24	0.00
17.5-20.0	18.75	87.95	43.25	0.00	0.00	0.00	0.00	0.00	55.6	0.00	0.00
20.0-22.5	21.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.00	0.00
22.5-25.0	23.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.00	0.00
Total		250.0	155.0	161.0	144.0	294.0	163.0	530.0	360.0	83.00	59.50
		Cumulative Oil Content									
0-2.5	1.25	0.29	0.18	0.36	0.56	0.34	0.57	0.58	0.39	0.11	0.10
2.5-5.0	3.75	18.77	13.68	22.23	37.40	27.14	41.93	34.31	34.64	7.76	10.22
5.0-7.5	6.25	51.49	28.10	48.26	81.70	67.43	73.84	108.58	92.29	16.86	24.06
7.5-10.0	8.75	79.11	36.89	111.75	118.17	102.80	98.85	214.00	188.34	31.30	35.75
10-12.5	11.25	137.82	83.60	120.18	144.00	140.40	138.73	303.62	224.37	42.47	48.16
12.5-15.0	13.75	137.82	83.60	135.58	144.00	209.03	163.00	439.97	268.22	57.76	59.50
15.0-17.5	16.25	182.05	111.75	161.00	144.00	294.00	163.00	530.00	304.41	83.00	59.50
17.5-20.0	18.75	250.00	155.00	161.00	144.00	294.00	163.00	530.00	360.00	83.00	59.50
20.0-22.5	21.25	250.00	155.00	161.00	144.00	294.00	163.00	530.00	360.00	83.00	59.50
22.5-25.0	23.75	250.00	155.00	161.00	144.00	294.00	163.00	530.00	360.00	83.00	59.50