Debottlenecking and CFD Studies of High and Low Pressure Production Separators

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ABSTRACT

Efficient and effective oil/water/gas separation is required for success of many production operations. A major oil producer was experiencing difficulties with the oil/water/gas separation equipment on an offshore platform and improvements were required to meet both present and future production rates. Both HP and LP Separators on a major oil production platform were studied to determine the design limitations for foamy service and BS&W levels. CFD studies were completed to show the volumetric utilization and flow pattern improvements made with the design changes.

Both HP and LP separators showed substantial foam and poor efficiency due to poor inlet device design, plugging and other general vessel design limitations. Debottlenecking efforts determined that while the inlet device was somewhat ineffective, major improvements could be made from changes to perforated plate baffles, fluid level adjustments and weir placement and operations.

CFD calculations performed on both vessels indicated similar problems. The perforated plate baffles with improper design lead to counter current flow through the baffles making them less effective in flow control and distribution. Fluid level settings for the weir height affected the velocity differences between fluid layers and contributed to promotion of recirculation within the vessel, which lead to low volumetric utilization.

With adjustments to vessel internal equipment and changes to fluid phase levels, CFD calculations showed that overall vessel volumetric utilization was improved by 22% for the HP vessel and by 38% for the LP vessel. CFD results also showed the changes to the flow patterns accompanying these improvements.

Vessels with the proposed changes were operating effectively with substantially higher throughputs and meeting the expected BS&W levels for operations of the downstream oil processing equipment. Details about the vessel internals, flow properties and other changes required to accomplish these improvements will be discussed.

1.0 Introduction and Background

Inlet and Low Pressure separators on an offshore platform were not functioning as desired, indicating poor oil/water separation. With oil, water and gas production rates expected to increase and compound the present difficulties, a study was proposed to identify the problems and propose solutions. This project studied the engineering design and evaluation of the inlet and low pressure separators. The main challenge in the inlet separator will be the introduction of a tie-back which will result in significant slugging for a period of two years (2008-1010).

This engineering study considered the liquid level settings, the weir setting, the baffle plate design and the baffle plate position. In addition, the vessel's volumetric utilization was studied by computational fluid dynamics (CFD) to determine the effectiveness of the baffle plate design and position and weir position on the liquid hydraulics.

The objectives of the engineering study were to:

- Evaluate each of the vessel's performance at the production rates expected in 2009.
- Evaluate the effects on the weir height location and the liquid level settings.
- Provide an improved baffle design and location recommendations.

The objectives of the CFD study were to:

- Demonstrate the volumetric utilization and the interfacial flow behavior of the current vessel geometry for both the inlet and low pressure separators at 2007 production rates.
- Demonstrate the volumetric utilization and the interfacial flow behavior of both the Inlet and Low Pressure separator vessels with suggested improved geometry at the higher 2009 production rates.

2.0 PROCESS DESCRIPTION

The process flow is a typical installation with the inlet and low pressure separators both 3-phase vessels. Major dimensions and parameters for the inlet separator are:

- Length 10400mm S/S
- Diameter 4000mm ID
- Operating Pressure 2.790 – 4.52 Barg
- Operating Temperature 38 to 50C
- Design Pressure 13.8 Barg
- Design Temperature 9 – 93C
- Inlet Diameter 32 inch
- Gas Outlet Diameter 26 inch
- Oil outlet Diameter 16 inch
- Water Outlet Diameter 16 inch
- Inlet – Cyclonic Tubes
- Internal Baffles – at 8000mm and 5200mm from end seam
- Gas Outlet – Vane Pack

The input used for the process design for the inlet separator is shown in the following table. The data was based on production rates anticipated in 2009.

Table 1. Inlet Separator Process Design Data

Process Variables For Inlet Separator	**Units**	**Year 2009**
Oil Flow Rate	BOPD	Max (Year): 104,200 (2009)
Oil Gravity	API	31
Oil Viscosity	cP @ 42 º C	9
Water Flow Rate	BWPD	Max (Year): 17,700 (2009)
Water Specific Gravity		1.1
Water Viscosity	cP @ 42 º C	0.6983
Gas Flow Rate	MMSCFPD	Max (Year): 134.8 (2009)
Gas Molecular Weight	MW	22.3
Gas Viscosity	cP @ 42 º C	0.012
Operating Temperature	º C	42
Operating Pressure	Barg	3.7
Design Temperature	º F	200
Design Pressure	PSIG	200

Major vessel dimensions for low pressure separators are:

- Length 13,500mm S/S
- Diameter 4375mm ID
- Operating Pressure 0.24 – 1.0 Barg
- Operating Temperature 17 – 60°C
- Design Pressure 13.8 Barg
- Design Temperature 5 – 93°C
- Inlet Diameter 30 inch
- Gas Outlet Diameter 12 inch
- Oil outlet Diameter 24 inch
- Water Outlet Diameter 18 inch
- Inlet – Cyclonic Tubes
- Internal Baffles – at 2158mm from end seam
- Gas Outlet – Vane Pack

The input used for the process design for the low pressure separators is shown in the following table.

Table 2. Low Pressure Separators Process Design Data

Process Variables For LP Separators	**Units**	**Year 2009**
Oil Flow Rate	BOPD	Maximum (Year): 223,000 (2009)
Oil Gravity	API	29
Oil Viscosity	cP @ 60 º C	9
Water Flow Rate	BOPD	Maximum (Year): 37,400 (2009)
Water Specific Gravity		1.1
Water Viscosity	cP @ 60 º C	0.6067
Gas Flow Rate(Average)	MMSCFPD	Maximum (Year): 2.1 (2009)
Gas Molecular Weight	MW	43
Gas Viscosity	cP @ 60 º C	0.00899
Operating Temperature	º C	50
Operating Pressure	Barg	1.1
Design Temperature	º F	200
Design Pressure	PSIG	200

Vessel Engineering Study

The major issue necessitating this study is that the separators are not performing. Poor oil/water separation is the major problem, and with production rates expected to increase over the next few years (max year is 2009), these problems could be more severe with the significant slugging expected from some tie-back production. In the present configuration, high pressure fluids from some wells were fed into a high pressure inlet separator. The water from the inlet separator and flow from some other low pressure wells were fed into two low pressure separators.

Inlet Separator

The following conditions were considered for the Inlet Separator.

Inlet Separator (157" X 34')
2007 Conditions
Oil 62,500 BOPD
Oil API 30 (average)
Water 33,000 BWPD
Water SG 1.1
Gas Flow 65 MMSCFD
Gas MW 22
Temp 42°C
Pressure 3.7 Barg

2009 Conditions (max flow rate)
Oil 104,200 BOPD
Oil API 30 (average)
Water 17,700 BWPD
Water SG 1.1
Gas Flow 134.8 MMSCFD
Gas MW 22
Temp 42°C (average)
Pressure 3.7 Barg

NATCO's proprietary modeling program was used to calculate the separator and Revolution™ tube performance for all the conditions. Modeling the inlet separator with the above conditions, calculations indicate that the oil and water phases would have about six minutes residence time for the 2007 conditions and about five minutes for the 2009 conditions. At the 2009 conditions excess gas capacity was minimal and the foam indication was modest, about five inches. Liquids carryover with the gas would not be expected unless the foaming conditions were found to be substantially greater than normal due to some chemical conditions. If liquids were noticed in the gas to the compressor, the liquids levels in the separator would need to be lowered slightly to allow for more gas separation volume. This would reduce the liquids retention times, but the present levels should allow for some reduction and still maintain reasonable oil/water separation.

For the projected large surge volumes (15m^3) expected on this project, the recommended level settings will allow a surge volume between LSH and LSHH settings of about 530ft^3 (15 m^3). This still has a large (740ft^3 / 21m^3) volume from LSHH to liquid full vessel.

Liquid velocities for the oil flowing over the weir will be reduced by the recommended changes. Estimated velocities for the 2009 conditions with the recommended change are about 0.1 m/sec. If the vessels are unchanged, the velocities for the 2009 conditions would be about 0.3 m/sec, which would result in longer oil retention times and less water entrainment in the oil.

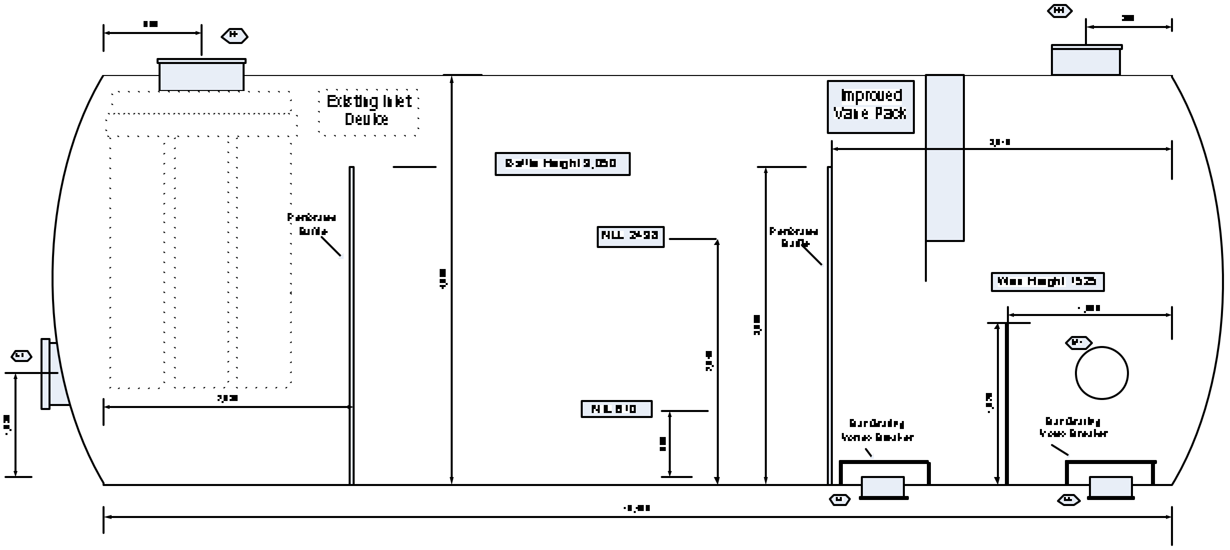
Modeling calculations for BS&W from the inlet separator indicate that under the high flow rate 2009 conditions, the BS&W for the inlet is about 14%, but the outlet should be about half of that value and certainly should remain below 10%.

Based on the anticipated flow rates, the following changes are recommended for the Inlet Separator. A drawing showing these changes is included in Figure 1.

Changes for HP Separator

1. Retain the present cyclonic inlet. The present inlet does not have as large a G force which would enhance the gas/ liquid separation (reduce foam) and does not appear to be breaking the emulsion sufficiently, but the manway is only 24 inch. Installing an upgraded cyclonic inlet designed to meet the increased flow rates was larger than could be installed through a 24 inch opening. Since foaming was not the major concern for the Inlet Separator, it was not viewed as mandatory to change the inlet for this separator.
2. Replace the present baffles at 21% open area with improved designed baffles at about 10% open area. The pressure drop suitable for controlling the flow through the vessel was not obtained with 21% open area. This was validated with CFD studies showing more counter-current flow back through the baffle with 21% open area.
3. Move the baffles to locations two feet downstream from the inlet device and one foot upstream of the water outlet. The inlet baffle was close to the correct position, but the exit baffle was too far in front of the water outlet.
4. The vane pack will need to be changed to NATCO TP Vane pack to have the correct drainage configuration and to enhance the liquid droplet removal from the gas phase. The present demisting pack drains back into the water just down stream of the exit end baffle (likely putting oil back into the water just before the exit.) The NATCO TP Vane pack extends into the liquid layer and will drain the liquid droplets directly into the liquid phase.
5. Move the weir closer to the exit end of the separator. Presently it is 7.6 feet from the seam. It should be moved to 5.3 feet from the exit end seam. This will give longer oil and water retention times.
6. Change the weir height. The designed weir height is 90.67 inches from the vessel bottom operating in spill over mode. A fixed weir at height 60 inches from the vessel bottom was recommended. Even at this lower height, the oil retention time would be about five minutes. (The foam was reportedly not too difficult to break and should break with this retention time.)
7. For the projected large surge volumes expected on this project, the following level settings allowed a surge volume between LSH and LSHH settings of about 530ft^3 (15 m^3). This still had a large (740ft^3 / 21m^3) volume from LSHH to liquid full vessel.

Figure 1. High Pressure Separator Drawing for Recommended Internal Modifications



Low Pressure Separator

The following conditions were considered for the LP Separator:

LP Separator (172” X 44’)

2007 Conditions

- Oil 148,000 BOPD
- Oil API 29 (average)
- Water 27,000 BWPD
- Water SG 1.1
- Gas Flow <0.5 MMSCFD
- Gas MW 43.1
- Temp 50°C
- Pressure 1.1 Barg

2009 Conditions (max flow rate)

- Oil 238,700 BOPD
- Oil API 29 (average)
- Water 33,100 BWPD
- Water SG 1.1
- Gas Flow 1.0 MMSCFD
- Gas MW 43.1
- Temp 50°C
- Pressure 1.1 Barg

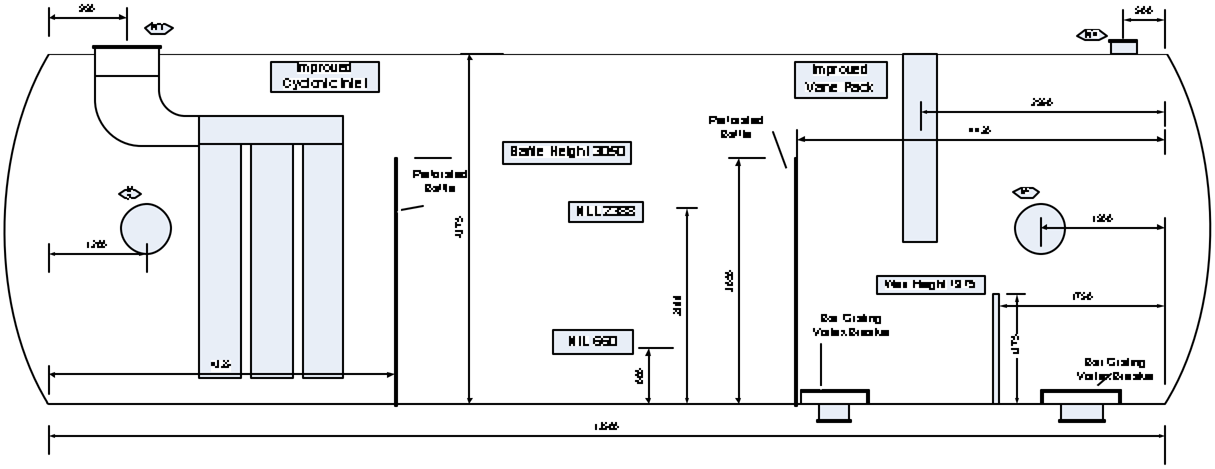
Modeling the LP Separator with the above conditions show that the oil and water phases would have about 4.5 minutes residence time for the 2007 conditions and about 3.7 minutes for the 2009 conditions. Generally the liquid and interface levels are designed to have similar oil and water retention times. This helps insure that the liquid velocities of each phase would also be similar and resulted in less turbulent flow at the liquids interface. For these conditions the water residence times were a little larger than the oil times because of the very low water level. At the 2009 conditions the foam calculated to have a level of about ten inches. This was sufficiently high to require the liquids levels in the vessel to remain in the range of 60% full vessel. Liquids levels higher than this would reduce the gas volume available for gas/liquid separation and increase the risk of having liquid carried with the gas phase. Liquids carryover with the gas would not be expected unless the foaming conditions were found to be substantially greater than normal due to some chemical conditions. If liquids were noticed in the gas to the compressor, the liquids levels in the separator would need to be lowered slightly to allow for more gas separation volume. This would reduce the liquids retention times, but the present levels should allow for some reduction and still maintain reasonable oil/water separation. However, if no liquid was noticed in the gas phase out of the vessels, this would indicate that the foaming may not be as severe and the liquids levels might be increased. There was sufficient time from the LSHH level to full vessel for raising the liquids level, if foaming was not observed. This could give substantially longer retention times of both oil and water phases and improved separation. The weir location showed 5.7 feet in the modeling calculations, but the location of the manway required that the weir be moved to 6.3 feet from the vessel end seam to be located slightly in front of the manway. Liquid velocities for the oil flowing over the weir will be reduced by the recommended changes. Estimated velocities for the 2009 conditions with the recommended change are about 0.1 m/sec. If the vessels are unchanged, the velocities for the 2009 conditions would be about 0.3 m/sec, which would result in longer oil retention times and less water entrainment in the oil.

At the high flow rate 2009 conditions and with the vessel modifications recommended in this study, the BS&W for the inlet is about 14% with the anticipated flow split between the two vessels. The oil outlet BS&W calculates to be about half of that value and certainly should remain below 10%.

Modeling the separated crude oil BS&W from the LP separator during the equipment upgrades (June-07) with a higher flow processed through only one of these vessels showed a higher BS&W in the oil outlet. With the higher flow through only one vessel, the calculated BS&W decreased from only 18% to 14%. This was close to the field measured result of outlet oil BS&W of 16%. This result indicates that the modeling program gives reasonable results and the predicted results of less than 10% BS&W should be obtained with the recommended vessel modifications when both vessels are returned to service.

Based on the anticipated 2009 flow rates, the following changes are recommended for the LP separator. A drawing showing these changes is included in Figure 2.

Figure 2. LP Separator Drawing for Recommended Internal Modifications



Theoretical residence time (TRT) is calculated by simply dividing the total oil and water volume present in the vessel by the corresponding oil and water volumetric flow rates entering into the vessel. This is the ideal residence time that will allow the best possible separation, since the fluids should move in a plug flow manner. These ART and TRT data are then used to evaluate the volumetric utilization of the liquid phase. Separation efficiency is expected to be higher with larger residence time and volumetric utilization. In this study, volumetric utilization was calculated by simply dividing the ART by the TRT. For consistent comparison, overall volumetric utilization of the combined oil and water phases (present in the whole tank) was considered. Overall volumetric utilization is defined as:

$$OVU\,(\%) = \frac{(Oil\ \ flowrate\ \times oil\ \ ART + water\ \ flowrate\ \times\ water\ \ ART)\times 100}{Total\ \ Liquid\ \ Volume\ \ (oil + water)}$$

The volumetric utilizations of all four cases are shown in Table 3 and plotted in Figures 3-4. Results for the HP Separator (Figure 3) show a 68% overall volumetric utilization for the original design and 83% for the recommended design. The water phase of the original design shows 55% utilization compared to 75% utilization for the recommended design.

The data for the LP separator are presented in Figure 4. The overall volumetric utilization of the original design shows 68% utilization compared to a 94% for the recommended design. The original case shows significantly lower water phase utilization (52%) compared to 95% utilization for the recommended design. The oil phase shows an 87% volumetric utilization for the original design, but the recommended design shows 94% utilization. These data were further analyzed by reviewing the flow path lines from CFD calculations, as shown in Figures 5-8.

Table 3: Volumetric utilization of the two designs

	Volumetric Utilization (%) of the Liquid phases		
	Overall Liquid Phase	Water Phase	Oil Phase
HP original	68	55	82
HP recommended	83	75	84
LP original	68	52	87
LP recommended	94	95	94

Figure 3: Volumetric utilization for the HP separator of the two designs: original design using 2007 conditions and recommended design with changes using 2009 conditions.

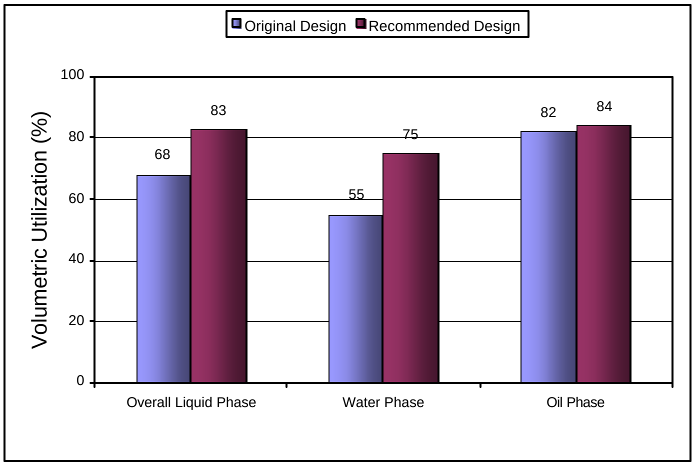
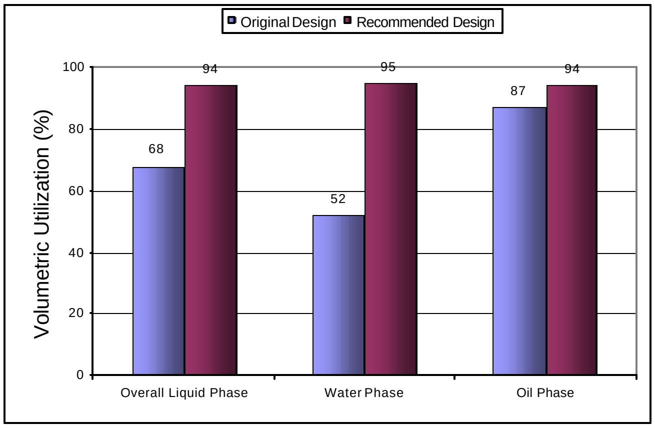


Figure 4: Volumetric utilization for the LP separator of the two designs: original design using 2007 conditions and recommended design with changes using 2009 conditions.



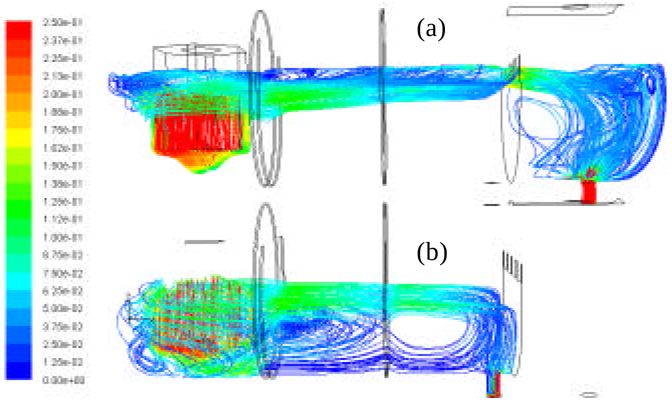
Flow Pattern Analysis:

Flow pathlines scaled to the velocity magnitude from the CFD calculations are presented in Figures 5-8 to qualitatively illustrate the dynamics of liquid (oil and water) volume utilization inside the vessel. Pathlines are the trajectories of the fluid particles moving through the flow field. Separation efficiency is higher when the fluid particles uniformly travel through the flow domain of each phase without much recirculatory motion. The presence of recirculation zones prohibits the volume from being utilized efficiently. Recirculation zones divert the fluid particles from plug flow and some fluid particles travel backward in counter-current directions, due to the development of the rotational fluid motion. As a result, the residence times of the fluid particles increases but poor separation is expected. Pathlines from CFD calculations can clearly show the presence of recirculation zones in the flow domain. Note that it may not be possible to prevent the recirculatory motions that create the short circuit zones completely from the flow domain, but their presence can be minimized by using different flow conditions and/or properly designed vessel internals.

HP Separator – Original and Recommended Design

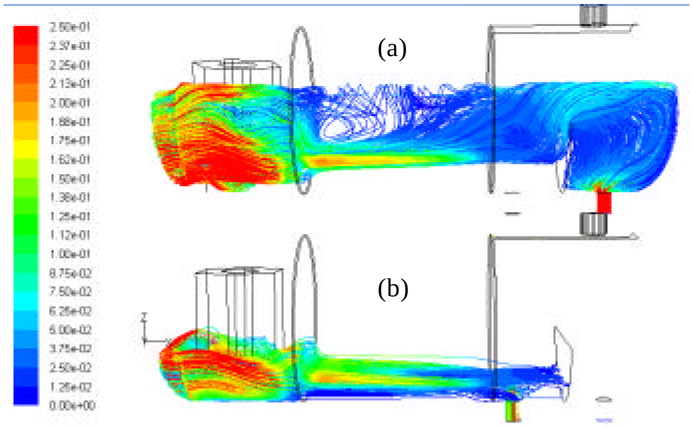
Figures 5(a-b) show the flow pathlines for the original design of the HP separator for both oil and water phases. Oil pathlines (Figure 5(a)) show a very small recirculation zone immediately after the inlet baffle. This recirculation region emerged when the fluid particles with high velocity crossed the inlet baffle near the oil and water interface. Fluid particles then traveled further downstream in axial and diagonal directions due to the influence of multiple parameters including velocity, gravity, baffles and weir. A second oil phase recirculation zone appeared as the oil traveled over the weir, generating a recirculation region in between the weir and the oil outlet nozzle. CFD calculations showed 82% oil phase volumetric utilization. The water phase (Figure 5(b)) shows two very large recirculation zones caused by the difference in high oil/water flow velocity near the oil and water interface. As the high velocity oil/water mixture traveled over the low velocity water body, first recirculation zones developed in between the two baffles. Similarly, the second recirculation zone developed between the exit baffle and the weir due to the same reason. Hence, the water phase showed poor volumetric utilization, 55%. Overall, the liquid phase was only 68% utilized.

Figure 5: Pathlines colored by Velocity magnitude (m/sec) for HP separator original case showing overall flow pattern of the (a) oil phase (b) water phase. Overall volumetric utilization was 67.9%.



Figures 6(a-b) show oil and water flow pathlines for the recommended design of the HP separator. Oil pathlines (Figure 6(a)) again show that a recirculation developed right after the inlet baffle. This recirculation zone is larger than the one observed in the original design, caused primarily due to use of low oil-water interface level. However, this recirculation zone appears to be very week in nature since very few pathlines travel back in counter-current direction forming recirculation loops. Hence this weak recirculation may be less detrimental to the oil phase volumetric utilization. However, the weir location was also moved downstream by 725 mm (closer to the oil outlet) for the recommended design, and this provided more time for oil/water separation before the oil crossed over the weir. Hence, the effect of the weak oil phase recirculation zone near the inlet baffle might be counter balanced by the extended length of the oil phase. Unlike the original design, the recommended design does not show any prominent oil phase recirculation after the weir due to higher oil level and lower weir height. CFD calculation showed 84% volumetric utilization (oil phase), showing somewhat better volumetric utilization compared to the original design (~3%). Water phase pathlines (Figure 6(b)) show a single but less prominent (narrow) recirculation zone developed right after the inlet baffle, unlike two large recirculation zones observed in the original design. Hence, the water phase shows 75% utilization and the overall liquid phase shows 83% utilization.

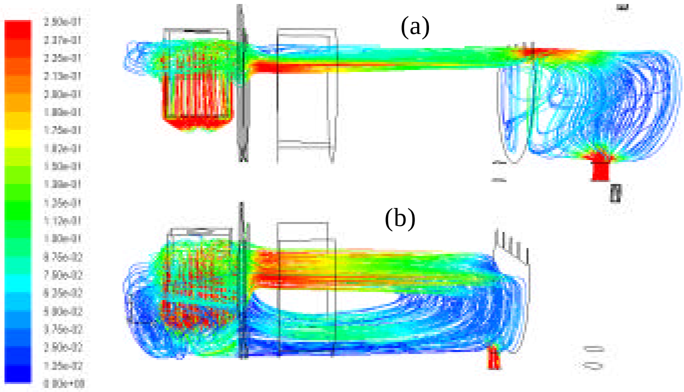
Figure 6: Pathlines colored by Velocity magnitude (m/sec) for HP separator recommended design showing overall flow pattern of the (a) oil phase (b) water phase. Overall volumetric utilization was 83%.



LP Separator – Original and Recommended Design

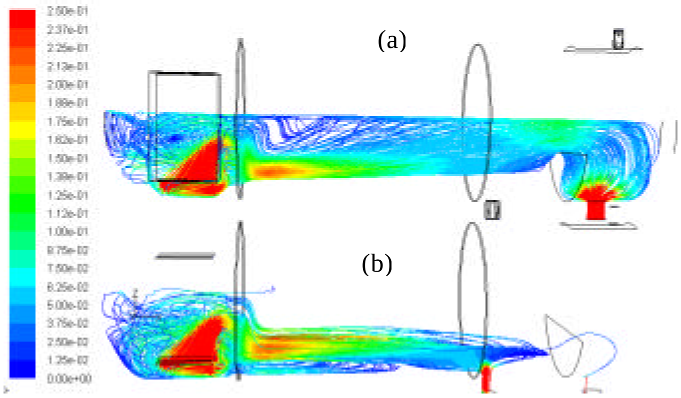
Figures 7(a-b) show the flow pathlines for the original design of the LP separator for both oil and water system. Oil pathlines (Figure 7(a)) show very small recirculation zone right after the inlet baffle. This occurred when the faster moving fluid particles crossed the inlet baffle near the oil and water interface, which tended to result in a faster moving oil layer on top but a slower moving oil layer on bottom being slowed by the slow moving water layer. The oil phase also shows one large recirculation zone present after the weir because of the high oil flow rate crossing over the weir slots. However, CFD calculations showed 87% oil volumetric utilization. For the water phase (Figure 7(b)), pathlines show one very large recirculation zone caused by the high axial velocity fluid crossing the baffle near the oil and water interface. Only one baffle was used for the LP separator and therefore only one recirculation zone formed. As a result, a large section of the water phase was not well utilized and CFD calculations showed a poor volumetric utilization of 52%. As a result, overall liquid phase was only 68% utilized.

Figure 7: Pathlines colored by Velocity magnitude (m/sec) for LP separator original design showing overall flow pattern of (a) oil phase (b) water phase. Overall volumetric utilization was 68%.



Figures 8(a-b) show the flow pathlines for the recommended design of the LP separator. Oil pathlines (Figure 8(a)) again show a weak recirculation zone developed right after the inlet baffle. This recirculation zone is larger than the one present in the original design, caused by low oil-water interface considered in this design. As indicated earlier, this recirculation zone is very weak in nature, since the pathlines do not show strong reverse flow characteristics (not many pathlines returning to form a closed loop). However, the weir location was moved downstream (closer to the oil outlet) by 1695 mm, which provided an additional length for the oil phase. As a result, oil phase gained more residence time for better separation and the detrimental effect of the oil phase recirculation near the inlet baffle might be partially compensated by the extended oil region. Oil phase pathlines shows no obvious recirculation flow patterns as the flow moves over the weir. Therefore, CFD calculations for the recommended design showed a 94% volumetric utilization compared to 87% for the original design. Water phase pathlines (Figure 8(b)) show a less prominent recirculation zone developed right after the inlet baffle, unlike one large recirculation zone observed in the original design. Note that two baffles were used for the recommended design (instead of one baffle used in the original design) and this also helped control the recirculation zones. Hence, water phase showed a 95% utilization compared to 52% utilization for the original design. The overall liquid phase utilization was 94%.

Figure 8: Pathlines colored by Velocity magnitude (m/sec) for LP separator recommended design showing overall flow pattern of (a) oil phase (b) water phase. Overall volumetric utilization was 94%.



4.0 CONCLUSIONS

1. Performance from both the Inlet and LP separators can be improved with changes to the inlet, baffles, weir and demisting devices.
2. Retain the inlet device for the Inlet separator. For the LP separators where foaming is more of a problem, change the inlet to an improved inlet device.
3. Change the perforated plate baffles to reflect an open area that will properly control the fluid flow.
4. Move the perforated plate baffles to improved locations.
5. Change the weir height to operate in spillover mode and change the position to better utilize the separator volume.
6. Change the demister to drain back into the oil layer slightly in front of the weir.
7. Adjust the liquid levels so the oil and water phases have similar velocities through the separator.