Induced Gas Flotation (IGF) within an API Skim Tank – A Case Study of Design Approach and Results

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Introduction

Produced water quality has become an increasingly large area of concern for the oil production industry. Production facilities have been re-evaluating their conventional approaches to oil removal from water due to increasing water cuts caused by the maturation of their oil wells, as well as a need for cleaner water for re-injection or disposal purposes. As such, the main concerns for producers are that not only do many facilities require an upgrade to their existing equipment to handle higher capacities, but also that their facilities require a more rigorous, reliable system to maintain their water quality for re-injection or disposal specifications.

Conventional approaches for water de-oiling include the use of equipment such as gravity skim tanks, CPI's, induced gas flotation units, hydrocyclones and filters. GLR Solutions Ltd. has taken particular interest in skim tanks and induced gas flotation units, and has identified them as areas that could be improved upon to meet the goals of oil producers.

API gravity skim tanks have been in use for a number of decades, and rely on a difference between specific gravity values between water and oil for separation. As a result, skim tanks require a substantial retention time for appreciable separation results, and the unit is relatively inefficient for heavy oil or emulsions applications. Recently, there has been a shift within the overall industry to improve the basic skim tank design to improve performance. Most of these modifications have included internal structures or distribution nozzles to encourage the coalescence of oil droplets within the tank. Among those, include tangential nozzle entry to promote swirling and oil droplet coalescence along the sides of the tank, as well as internal baffles or small hydrocyclones within the tank.

Induced Gas Flotation (IGF) and Induced Static Flotation (ISF) units provide a more enhanced approach to oil removal through the addition of gas bubbles to aid in the flotation of oil to the surface. Gas, which is typically induced by sparging tubes or eductors, floats the oil to the surface, which can then be skimmed off. In addition to the gas, a notable benefit to the IGF design is the multistage approach, wherein the vessel is divided into separate chambers. This drastically reduces short-circuiting inside the vessel. Gas is added to each chamber, and only the cleaner portion of the water is transferred to each successive chamber. In this way, the oil can be removed progressively within each stage for better overall performance. Due to the low retention time in the IGF, upsets in upstream processes are difficult to handle and water quality is typically dramatically affected.

It became apparent that a more robust, reliable system was needed. It was GLR Solutions' approach to combine the benefits of both the skim tank and IGF systems for secondary oil removal from produced water. This improved design was thought to greatly improve the performance of a typical API tank or IGF. The result was a multi-chambered API tank, where microbubbles were introduced into all chambers. The benefits to this multi-chamber design included the multiple stages available to remove the oil, elimination of oil short-circuiting, along with an increased retention time, relative to an IGF, which would buffer any upsets in oil concentration produced in upstream operations. As the internal modifications could be performed on an already existing tank, new vessels, and associated foundations, controls and piping would not have to be purchased, thereby lowering capital costs needed to upgrade the facility. In addition, footprint concerns would not be an issue to the upgrade.

GLR Solutions had obtained good results from prior commercial installations using their Microbubble Flotation (MBF™) technology on gravity skim tanks. In this system, microbubbles are generated using one of two devices, either a unique pump or a patented pressure vessel design, and injected to the tank where intimate bubble and oil contact can occur. Due to the small size of bubbles (~30 microns), oil readily adheres to the surface of the bubble, upon which can be floated to the surface and skimmed for collection. Results have been published documenting GLR's use of very small bubbles to aid in oil separation from water using single chambered API tanks (1). This superior oil removal ability of microbubbles over conventional larger bubbles found in IGFs would further improve the performance of the multi-chamber tank design.

ENI Dacion B.V. was the first to explore the multi-chamber API configuration of MBF technology on a commercial scale at its GED-10 Station, Dacion Field, located in the San Tome region of Eastern Venezuela. This novel tank design has since had patent applications filed. This paper outlines the methodology behind the development of the multi-chamber design, and documents the benefits and outcomes of the GLR technology as it applied to the GED-10 Facility.

Case Background

ENI Dacion B.V., a worldwide oil producer and oilfield operator in Venezuela, owns and operates numerous facilities for the treatment of oil and water. One of ENI's smaller facilities is called GED-10 Station in the Dacion field.. The facility is fairly old and when it was originally designed and built, water cuts in the produced oil were typically very low, with flow rates of 5000 – 10,000 bwpd being anticipated. Treated water is disposed of in water disposal wells through high pressure injection pumps. Over the years the field has shown a typical behaviour of producing reservoirs with active aquifers and water cuts have significantly increased. It is predicted that they will continue to do so in the future, and it is currently expected that the facility will now need to handle flows up to 25,000 bwpd. This has meant the majority of the equipment now has insufficient capacity to be used in the way it was originally designed. Currently the facility operates with the following parameters:

- API of the oil = 16
- Flow rate = 6000 BOPD, 15000 BWPD
- Temperature = 105-125 °F

During previous facilities development phases, expensive water treatment systems were installed. These were based on de-sanding and de-oiling hydrocyclones and nutshell filter technology, but were not an ideal solution due to the high capital and operational costs, along with the complexity of operations and maintenance. Based on the poor treatment efficiency observed on these systems, ENI decided to evaluate other technologies for the selection of the most appropriate system in order to meet the treatment capacity and water quality specifications. It was for this reason that ENI approached GLR Solutions for assistance.

Technology selection criterion was established by ENI to rank various technologies options according to the:

- Ease of operation & maintenance
- Cost of operation & maintenance
- Capital Cost
- Performance
- Flexibility (i.e. be able to handle a large range of inlet flow fluctuations, both in total flow and oil & solids content)

After internal evaluations within ENI the multi-chamber API tank configuration of MBF was selected. The reason ENI chose GED-10 as their first site to use MBF was due to the relatively low flow rates at the facility in comparison to other facilities in the area, and the fact that there were not major operational issues with the site. This project was viewed within ENI as a commercial scale trial of GLR's technology, with potential application at the larger facilities depending on performance.

The original process setup consisted of two 1,500 barrel tanks that received water from a Heater Treater and a Free Water Knock Out (FWKO). A de-emulsifier was injected just before the flow entered the 2 tanks. Total retention time across the skim tanks was 3 hours. Figure 1 shows the process flow.

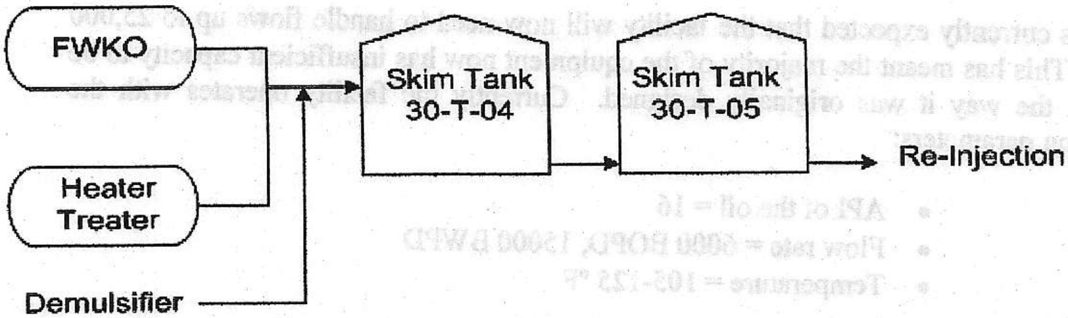


Figure 1: Original Process Flow (Water Treatment)

The two tanks were gravity fed, both single chamber design. The connection between the two tanks was done in a rather unconventional manner. The main transfer of water from T-04 to T-05 flowed out a nozzle located near the base of the tank. In addition to this, an overflow near the top connected both tanks. As a result, in the event of high levels within the first tank, the oiliest water was transferred to the second tank. Finally, an additional nozzle was located near the base of tank 30-T-05 in which water from surrounding fields would be trucked in. This water of varying quality would be immediately sent for re-injection When GLR became involved high outlet oil concentrations of approximately 300 mg/l were consistently being observed. Figure 2 shows the setup of the two tanks side by side.

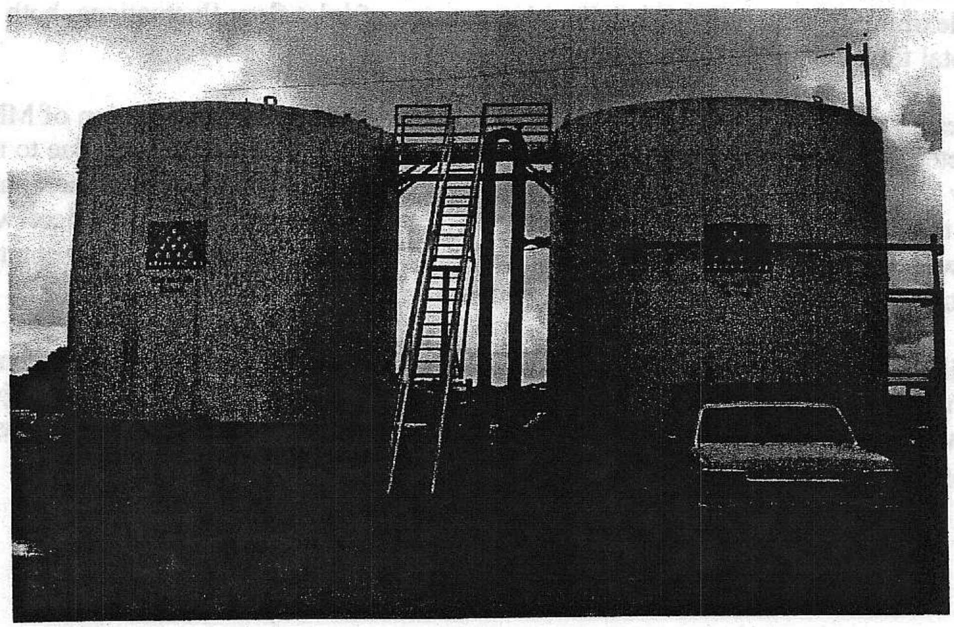


Figure 2: Skim Tanks T-04 and T-05

Design Approach

To minimize the probability of design failure, a systematic approach was used to bring the novel, multi-chambered API tank to fruition. As with all of GLR Solutions' tank designs, a number of steps were involved in the approach used for GED-10, as follows:

1. Ideas are drawn from successful designs of prior units, designed both by GLR Solutions and others. For existing tanks such as GED-10 considerations regarding feasibility and cost of retrofit as well as optimal use of existing nozzles and piping are weighed.
2. A conceptual design is determined and drafted
3. Pilot units of the design or components of the design are built and tested.
4. The full scale design is simulated using Computational Fluid Dynamics (CFD) modelling.
5. The commercial unit is constructed and operated
6. Results obtained onsite and analysed
7. Modifications are made, either structurally or with regards to operating philosophy as necessary.

A major factor which aided in the determination of an optimal tank design was Computational Fluid Dynamics (CFD) modelling. CFD modelling is an advanced software tool which allows fluids of a variety of compositions to be simulated as they flow through three dimensional structures. GLR Solutions has developed unique code to model complex multiphase flows of water, oil, gas and solid particles. Results from CFD modelling are qualitative only, and include graphic views of fluid flow patterns, velocity trajectories, and particle tracing throughout the system. An example of a fluid flow pattern past the weir structure in the first chamber of T-04 can be seen in Figure 3.

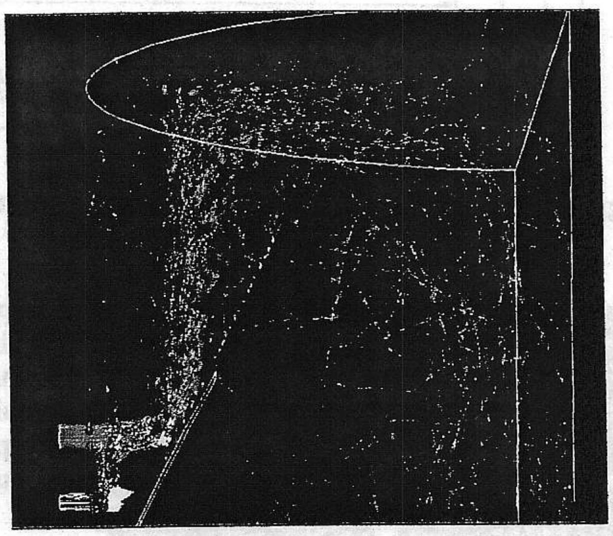


Figure 3: Gas and Oil Trajectories

Approximately one year prior, a single chambered tank design had been implemented with successful results. The design had incorporated a single water weir, where water flow patterns allowed for continuous skimming to the oil weir, located on the opposing side of the tank (figure 4). Due to the favourable results, similar weir structures were incorporated in the multi-chamber design.

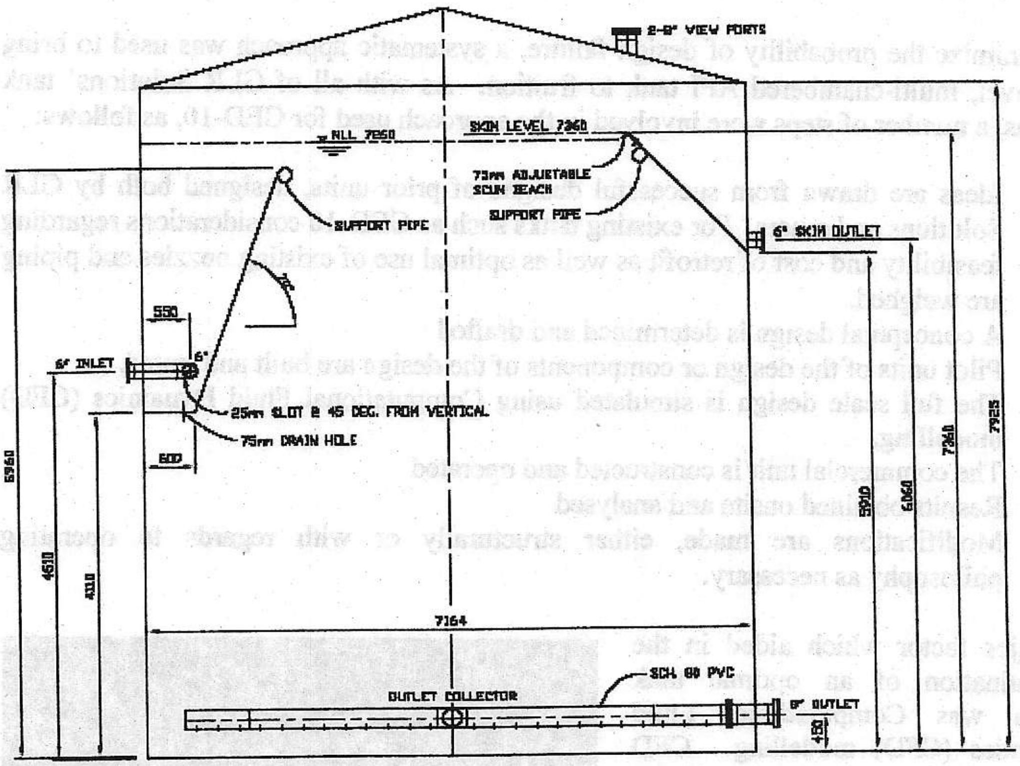


Figure 4. Single Chamber Tank Design with Opposing Weir Structures

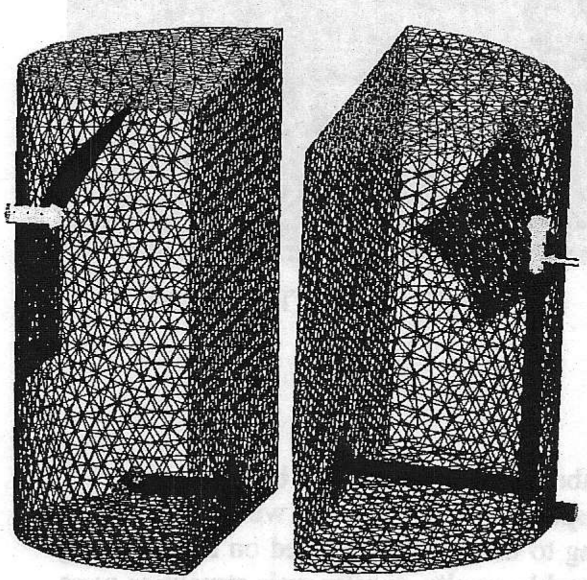


Figure 5: Two Chamber Design with Meshes

An optimal design, as determined by GLR Solutions, had to include a number of attributes. First, tank usage had to be optimized. As the design was to be incorporated into an existing tank at GED-10 Station, and it was known that flow rates would be increasing, it was important to make use of the available volume of the tank. In cases of heavy oil as found at GED-10, contact between an oil droplet and a micro-bubble is integral to floating it to the surface, and for its subsequent removal. As flow patterns can be tracked through CFD modelling, it could be determined whether fluid patterns ran throughout the volume of the tank, and sufficient mixing between microbubble and produced water streams occurred. From the mixing patterns obtained, GLR Solutions was confident that microbubble and oil contact would occur readily in most areas of the tank, and present a path for oil to exit at the tank surface, thus producing in high oil removal efficiencies. It was not desirable to have micro-bubbles passing through to the outlet of the tank as this can cause problems for downstream processes.

Using this technology, GLR Solutions was able to test a variety of designs and ideas, and was in turn able to suggest an optimal design to ENI, as shown in Figure 5. This design incorporated two chambers, a water inlet weir in each, and one common oil trough running diametrically along the top portion of the tank. Produced water enters high in chamber 1 (left chamber in Figure 4), flows over the water weir, and then flows through a large interconnecting pipe to enter high in chamber 2. From here it flows over a second water weir. Microbubble flow is generated in a slipstream of clean water that exits the second tank and passes through a GLR vessel that sits on a separate skid (Figure 6), and is then re-injected to two points in the skim tank. The first stream is mixed directly with the inlet water to enter the first chamber. The second is injected into the large interconnecting piping to mix with water transferring between chamber 1 and 2. Oil floats to the surface is skimmed off by hydraulic flow patterns into the central trough, which was sloped to encourage flow to one outlet oil nozzle.

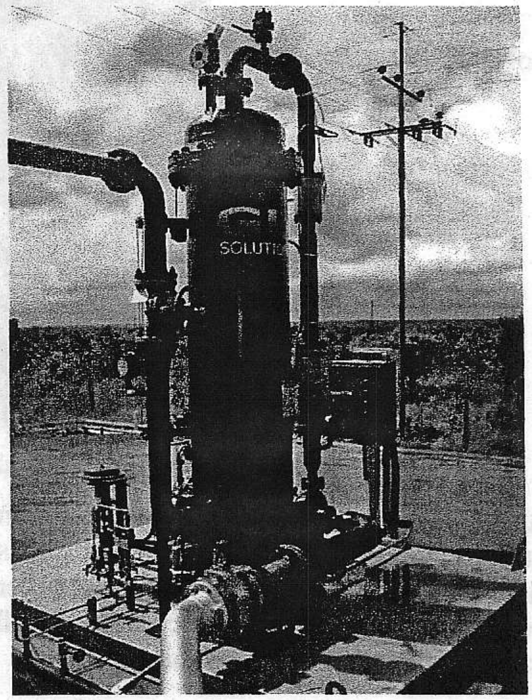


Figure 6: The GLR Vessel & Skid

Second, flow patterns within the tank were closely examined for additional benefits within the system. As GED-10 had identified a major concern with solids in their water treatment system, it was important to incorporate internal modifications that would not only prevent solids from hindering performance, but might also aid in the removal of solids from outlet water. In response, GLR incorporated a solids dropout area within the water weir of the first chamber Figure 7. CFD modelling was able to predict that upon entry of the produced water to the weir, the majority of the water would flow over the weir into the chamber, while a smaller volume of water containing the heavier solids would drop out and be directed to the bottom of the tank.

Solids Dropout Area

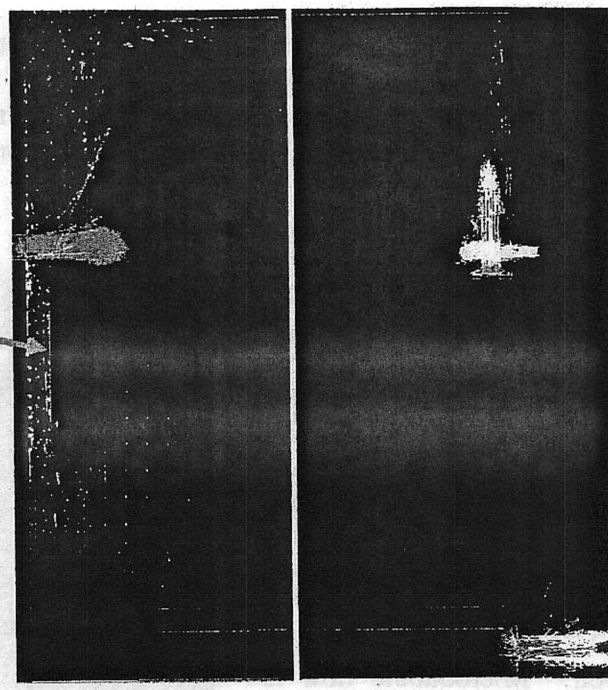


Figure 7: Tank showing the solids dropout zone.

An additional benefit that was incorporated into the multi-chamber design was positioning and sizing of nozzles and weir shapes and sizes to allow for easy hydraulic skimming of oil into the oil trough. As seen by the CFD graphics (Figure 8), hydraulic patterns at the surface are such that oil collected on the surface readily flows into the trough, from all areas of the chamber.

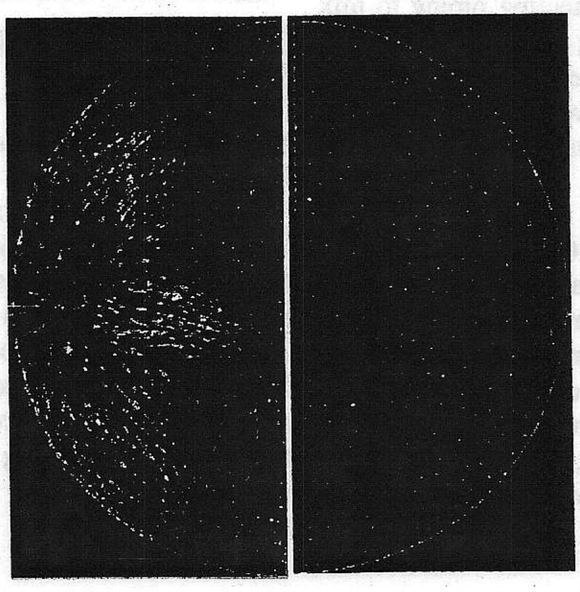


Figure 8: Flow Patterns on the surface

Operations and Results

Modifications of the existing tank 30-T-04 began in mid February of 2005. After cleaning and preparing the tank, nozzles were added and internals were welded as designed by GLR Solutions. The microbubble system was started up in May 2005, and favourable results for water quality were observed within days of start-up. The modified process flow is shown on Figure 9.

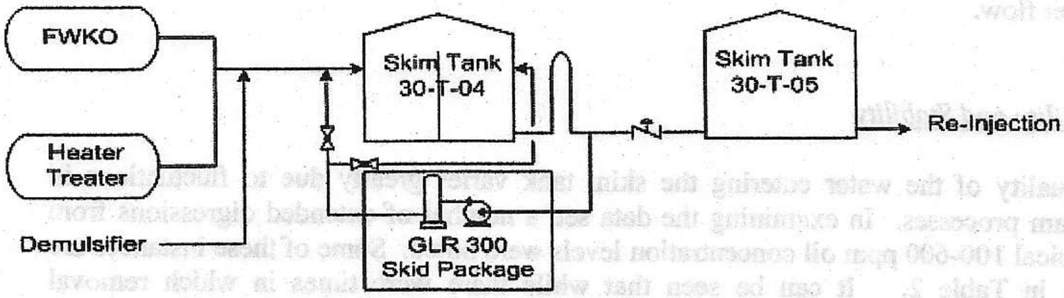


Figure 9: Modified Process Flow

Oil Removal

During normal operations over the spring/summer of 2005 the skim tank (30-T-04) receives approximately 15,000 bpd of produced water at oil concentrations ranging from 100-600 ppm as measured by Xylene extraction and IR quantification. The quality of the clean water exiting the tank is consistently within 2-21 ppm during normal operations (Table 1). Periodically high inlet oil concentrations would occur in which concentrations of oil would spike to 1,000-2,000 ppm and in rare cases much higher. During these upsets it was found that oil removal efficiencies would remain above 90% with outlet oil in water concentrations less than 40 ppm.

Table 1. Oil in Water Concentrations (normal operations)

Date	Skim Tank Inlet (ppm)	Skim Tank Outlet (ppm)	Water to Re-injection (ppm)	Skim Tank Removal Efficiency (%)	Overall System Efficiency (%)
21/09/2005 11:00	240	20	15	92	94
22/09/2005 14:00	100	2	7	98	93
23/09/2005 02:00	64	2	2	97	97
26/09/2005 0:00	149	17	17	89	89
27/09/2005 0:00	411	37	21	91	95
28/09/2005 0:00	321	19	10	94	97
29/09/2005 0:00	420	25	18	94	96
30/09/2005 0:00	109	23	3	79	97
03/10/2005 0:00	130	18	9	86	93

Skimming Rates

The system was initially configured for a continuous skimming operation, where the skim flow rate was determined to be 5-8% of the inlet flow. In order to reduce this volume the skimming operation was switched to an intermittent one, where the control valve on the clean water outlet line was periodically shut in to raise the level of the tank to allow for oil flow over the oil weirs. With this setup, skim rates are currently reduced to < 3% of the inlet flow.

Reliability and Stability

The quality of the water entering the skim tank varies greatly due to fluctuations in upstream processes. In examining the data set, a number of extended digressions from the typical 100-600 ppm oil concentration levels were noted. Some of these instances are shown in Table 2. It can be seen that while there were times in which removal efficiencies dropped, for the most part, the MBF modified skim tank is able to retain outlet concentrations at less than 40 ppm. This is a substantial benefit of the system as the water quality remains to the specifications needed for downstream processes which was previously not possible with the conventional gravity configuration.

Table 2. High Inlet Oil in Water Concentrations

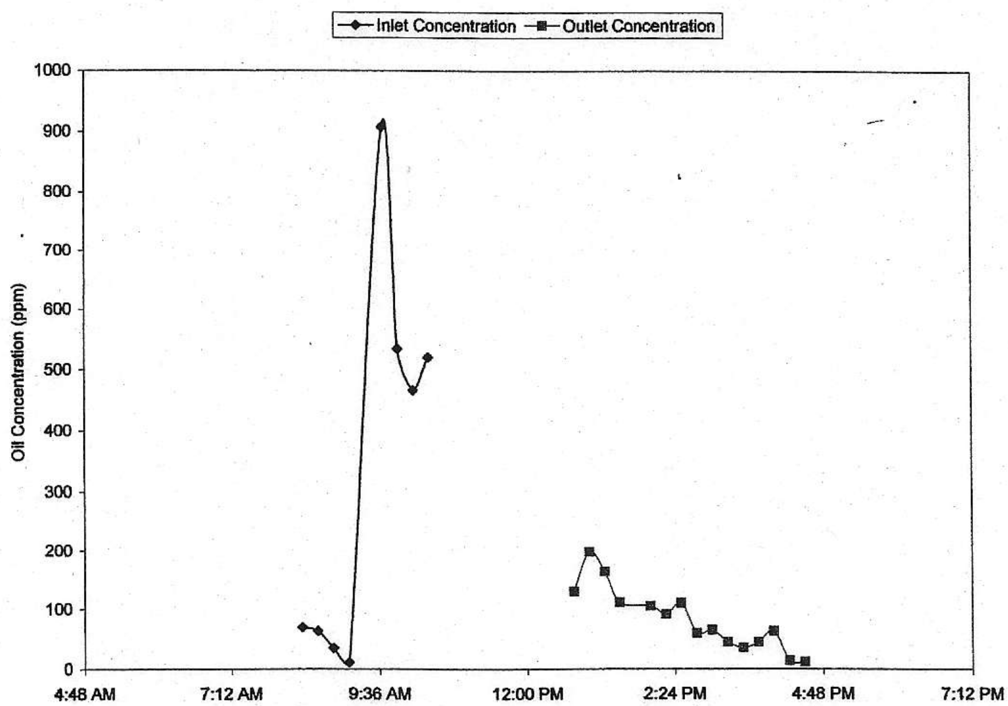
Date	Skim Tank Inlet (ppm)	Skim Tank Outlet (ppm)	Water to Re-injection (ppm)	Skim Tank Removal Efficiency (%)	Overall System Efficiency (%)
26/05/2005 08:00	819	58	12	93	98
05/06/2005 09:00	455	31	21	93	95
07/06/2005 16:00	574	29	27	95	95
13/06/2005 14:00	1978	51	32	97	98
14/06/2005 17:00	581	43	40	93	93
20/06/2005 10:00	1643	45	25	97	98
23/06/2005 16:00	1276	99	14	92	99
16/07/2005 09:00	655	84	56	87	91
06/08/2005 10:50	872	25	12	97	99
09/08/2005 14:30	1274	15	19	99	98

The robust quality of the two chamber skim tank was very apparent early on during its operation. At one point, oil accumulated at the surface of the tank had not been skimmed for a period longer than 1 week. As a result, the 24 ft height tank was found to be filled with 8-10 feet of oil. In addition to this, during this period difficulties in controlling the interface level of the FWKO were causing spikes in oil entering the skim tanks. Despite all this, the oil concentrations exiting the tank remained around 50 ppm. While this concentration did not meet the specifications required, it is indicative of high performance despite extreme circumstances.

Buffering Capacity

A planned upset condition was performed in Sept 2006. GLR Solutions commissioned Clean H2O Services to test and study some problems that ENI was experiencing with their produced water at the facility. Testing was completed with a Jorin ViPA™ analyser, which can monitor oil and solids concentrations and particle sizes online. The ViPA was used to first measure oil and solids concentrations of the stream entering the skim tank. As the current skim tank has a retention time of two hours, the outlet of the skim tank was measured two hours after the upset occurred. The spike in oil concentration to the skim tank was easily attained by dropping the interface level within the Heater Treater. The results can be seen in Figure 10, where oil concentrations increased from less than 50 ppm to 900 ppm in less than a half hour period and above 10% oil as measured by IR during peak oil ingress (prior to ViPA analysis). Approximately two hours later the ViPA was moved to read oil and solids concentrations exiting the tank. Levels were found to be slightly elevated at 200 ppm, however within four hours, levels were found to return back to oil concentrations of <10 ppm.

Figure 10: Monitored Performance During a Planned Upset



Operability

A major concern with the technology to be implemented was its ease of operations, as it was a novel technology. It was imperative that the MBF system and control philosophy surrounding the tank be user-friendly, such that operators onsite would not take issue with its use. While a continuous skim situation would have been similar to the operations of other skim tanks, the new intermittent skim system required some operator management. A variety of level control methods were explored, however an automated approach was determined to be most effective. Skimming is still performed manually, however ENI has planned to install an automated skimming operation based on a timed cycle, where a timer would cause the control valve on the outlet line to shut in, in order to raise the level within the tank. The frequency of skim cycles and duration of each cycle would be pre-determined to meet oil skim volumes and concentrations stipulated by operations. This automated skimming would allow for minimal supervision of the tank and, in turn, better acceptance of the technology within operations. It also ensures that oil within the tank is maintained at an adequate level so as to prevent oil on the surface to transfer out of the clean water line.

Future Directions

With the positive results obtained from the two chamber system, and the observation that water quality seemed to continue to improve in the second tank (30-T-05), most subsequent designs have incorporated a four chamber design, specifically in situations where a more robust oil removal capability is required. As shown in Figure 11, an extra wall is added within the tank, however water weir and oil weir structures remain similar to those found in the two chamber design. This system should provide improved oil removal capability and improved buffering capacity. Because of the increased number of stages, short circuiting of oil is further eliminated, and the majority of solids should be confined to the earliest few chambers. At the time of this paper being prepared a number of commercial projects are currently under construction using this design.

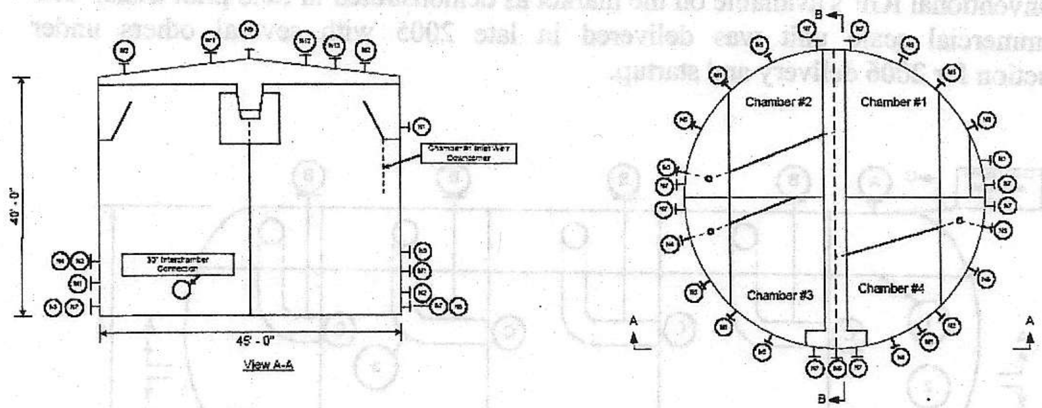


Figure 11. Typical Four Chamber API Tank Design

CFD modelling has proven to be a continuously useful tool in the development of current tank designs. A pertinent issue that was not a factor in the GED-10 site is that of bubble carryover to the re-injection pumps. While there is no evidence of microbubbles exiting out of the MBF modified skim tank (30-T-04) at GED-10, the microbubbles, if transferred through, would be able to settle out in the second surge tank (30-T-05). The majority of facilities do not have a tank downstream of the skim tank, but rather feed directly to re-injection pumps. As customers take issue with possible cavitation of the re-injection pumps if the bubbles were to exit the tank, CFD modelling allows for the tracking of bubble particles through the tank. It can therefore be predicted whether bubbles travel to the lower portions of the tank, and if so, be prevented. Current chambered API tank designs have been modelled and it has been confirmed that bubbles will not exit the last chamber with the clean water.

Many on-going projects are being designed through the use of CFD modelling by GLR Solutions. As solids is a concern for many oil producers, solids will be tracked through CFD models and a design will be determined in order to better handle water with high solids concentrations. Another substantial issue that GLR Solutions is exploring further is the modifications to the CFD software itself. There has been an extensive push for the ability to model bubble and oil coalescence, as this is an obvious occurrence within the system. To date, the modelling of this coalescing activity has yet to be developed. GLR Solutions will be taking on this challenge to develop the necessary code.

In some instances, due to space and facility limitations, an IGF vessel is preferable over an API tank. From these results, it was apparent that the hydraulics of this system was critical in obtaining the desired skimming action, good usage of the volume available and prevention of bubble carryover. GLR Solutions thought it advantageous to incorporate the knowledge gained from their multi-chambered API tank design to the more conventional IGF unit. As a result, GLR Solutions have since developed their own IGF unit called the Revolift™, in both horizontal and vertical configurations (Figures 12, 13). While these units do not have the long retention times that were available in the API tanks, their hydraulics along with the MBF technology has resulted in better performance than conventional IGF's available on the market as demonstrated in field pilot trials. The 1st Commercial scale unit was delivered in late 2005 with several others under construction for 2006 delivery and startup.

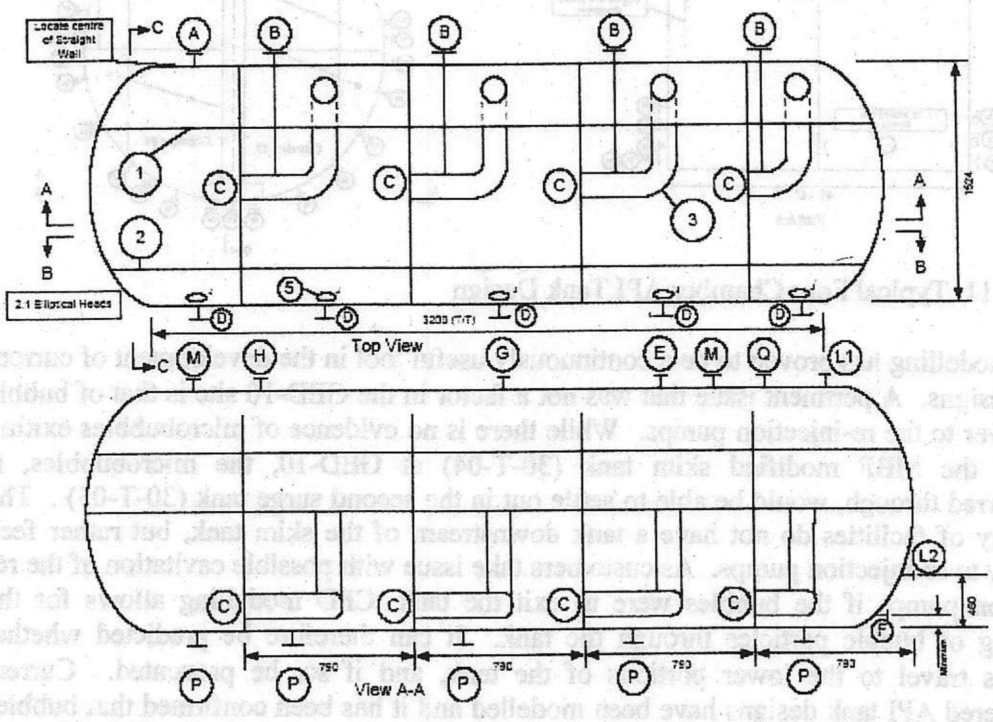


Figure 12. Typical Horizontal Revolift IGF Design

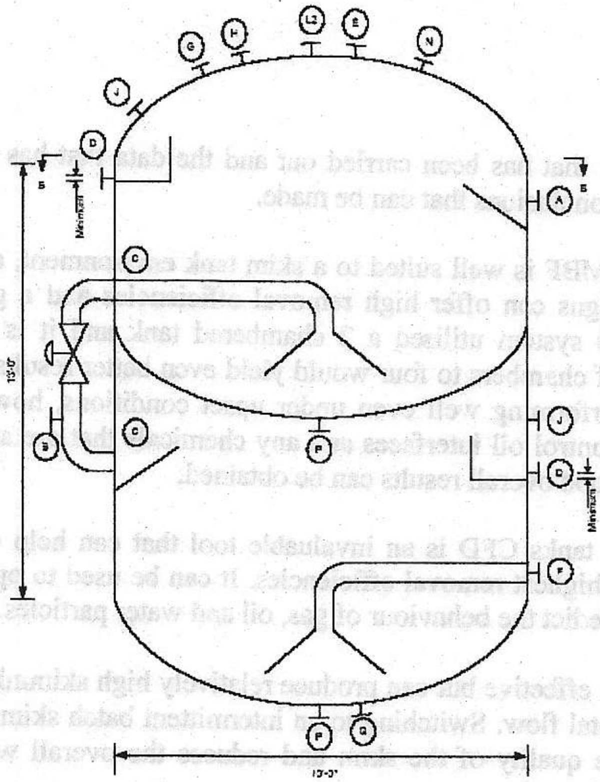


Figure 13. Typical Vertical Revolift IGF Design

Conclusion

From all of the research that has been carried out and the data that has been obtained there are several major conclusions that can be made.

It has been proven that MBF is well suited to a skim tank environment, and that multi-chamber skim tank designs can offer high removal efficiencies and a good buffering capability. The GED-10 system utilised a 2 chambered tank and it is predicted that increasing the number of chambers to four would yield even better results. The GED-10 system is capable of performing well even under upset conditions, however it is still important to carefully control oil interfaces and any chemicals that are added upstream so that in combination good overall results can be obtained.

In designing such skim tanks CFD is an invaluable tool that can help obtain the best possible results and the highest removal efficiencies. It can be used to optimise internal design and accurately predict the behaviour of gas, oil and water particles.

Continuous skimming is effective but can produce relatively high skimming percentages as a proportion of the total flow. Switching to an intermittent batch skimming operation can greatly improve the quality of the skim and reduces the overall water cut and is therefore a more desirable option.

Overall ENI Dacion B.V. is very satisfied with the modifications that have been carried out and the MBF system that has been installed at their facility at GED-10 Station in Dacion Field. They have since contracted GLR Solutions for MBF systems integrated to 4-chambered API tanks, which they intend to install at two of their much larger facilities. The flow rates of these are approximately 100,000 & 150,000 bwpd.