Produced Water Challenges – Lessons Learned from Past and Present

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Abstract and Summary

The disposal of produced water from offshore and onshore operations world wide has become a major challenge over the years. With the increase in the environmental awareness, there is more emphasis in the handling aspect of produced water with the operators concerned, governmental and regional organizations.

In order to establish a better understanding of the produced water management and handling issues and to determine the optimum solution in dealing with increased volume of produced water discharged into the sea, a better approach and tool for evaluating the different options are necessary. Therefore, past experience has demonstrated that although suitable facilities and technologies can be available, the means in utilizing the facilities and the technologies will be the determining factor in achieving optimum treatment efficiency.

In order to resolve produced water issues, a holistic approach should be applied in understanding the different aspects of produced water, namely, the mechanical aspects, fluid chemistry and the operational issues. In terms of produced water management, all options should be considered including the application of produced water re-injection or a hybrid option of both produced water re-injection and treatment. Regardless on which option the project or existing operation will opt for a specific system, it is prudent to determine and assess the long term water production rates, future plan for field development, including the oil recovery strategy of the field and potential changes in the legislation as well as all environmental constraints.

Although the implementation of produced water re-injection strategy can be difficult to adapt in a system if not applied correctly due to risk of system availability, mechanical damage to topside equipment, expensive to retrofit, damage to reservoir injectivity and the risk of reservoir souring; the correct assessment of this option will overcome many of the concerns that have been raised by reservoir engineering management and production teams.

Therefore, using past and current experiences as well as a full understanding of operation limitations of different technologies; the means to troubleshoot and optimize produced water systems and to establish an effective management approach for the long term can be established on the understanding of the holistic approach to produced water management offshore.

The industry has learned that if the correct approach is not applied in resolving the produced water aspects, it will not be productive, as well as expensive at a later stage. Although produced water itself is not revenue generator, indirectly it will have a significant impact on the oil productivity and ultimately the revenue, if not designed correctly.

Introduction

The disposal of produced water from offshore operations in the North Sea as well as the Gulf of Mexico becomes an important and critical issue to the operators concerned, to governmental and regional organizations, as well as to the environment itself. The volume of produced water discharged offshore in the North Sea has increased over the years, both in the British and the Norwegian sectors, as well as the Gulf of Mexico. The deep water production in the Gulf of Mexico is still relativity low in comparison to the North Sea; and the experience and lessons learned from the North Sea should be used for the future changes and increase in produced water in deep water production.

Currently, most of the mature oil fields in North Sea production consist of an average of 80% or more water cut. With current oil prices varying between $55 - $65 per barrel, it is still profitable to carry on production from high water cut reservoirs in order to recover and sweep as much oil as possible. In the coming years, it is not expected to get any better; and oil and gas prices potentially will increase.

During the later stages of production it is not unusual to see that produced water production can account for as much as 98% of the extracted fluids from oil reservoirs. In some older fields, the oil recovery strategy at the late life of the field includes the de-pressurization of the reservoir pressure. This process will create a number of constraints in handling the additional volume of produced water and gas. The de-pressurization process of a field basically will make of a number of suitable produced water treatment facilities redundant on the offshore installations in question and additional upgrades will be required in order to improve the performance of the treatment facilities. What is effective under high pressure operation may well not be as effective in low pressure operation, without suitable system upgrades.

Produced water is a secondary product that oil and gas producers worldwide have to deal with both onshore and offshore. There are equal challenges if not more complicated in dealing with this secondary product onshore as well as offshore.

With new developments over the last decade in water treatment and handling technology, there are basically several options available to the operators in dealing with the produced water. Some of these options are based on well intervention and management together with subsurface treatment including downhole separation; others are based on dealing with water on the surface after extraction, conventionally and unconventionally.

The different options and means that are available to the operators in dealing with produced water in an offshore environment, include discharge of the treated water overboard, disposal of the water treated or untreated into the reservoir, downhole separation as well as subsurface management strategy in terms of water shut off and well completion remedies.

Although the disposal of produced water downhole into a well from offshore operations becomes an important and critical option to the operators due to the environmental concerns and constraints, there are a number of issues that still cause concern to use the well disposal option in the long term. These reasons include the risk of plugging the wells and reservoir souring, which among others are considered as potential problems with re-injection of produced water, as well as the additional cost of providing dedicated wells for disposal only in an offshore environment.

The process of selecting one or more options to handle and dispose of the produced water can be based on economical, operational, reservoir management as well as

environmental reasons. In general terms most fields will choose at least 2 options or more in dealing with produced water and will generally involve at least one sub-surface strategy/option and one topside strategy and solution.

In gas and condensate reservoirs, water production is relatively low and does not cause a major problem in disposal from the volumetric point of view. However, for such wells, the overall suspended hydrocarbons in the water discharged are on average slightly higher than that for water discharged from oil production facilities. In addition, it is has been known that the soluble hydrocarbons in produced water from gas and condensate reservoirs may contain higher concentrations of the BTEX's (Benzene, Toluene, Ethylbenzene and Xylene) and PAH's (polycyclic aromatic hydrocarbons). These additives are harmful to the environment.

Handling and treating produced water should be dealt with from the source of the problem. Therefore a holistic approach is needed in order to address the problem more effectively.

The Holistic Approach

From operation experience, it has been established, an effective approach in dealing with the produced water problem should include all relevant upstream facilities, including design of the process system and separators, method of operating the plant and the configuration and routing of the different fluid streams. Different parts of the process equipment can play a major part in either improving or reducing the overall efficiency of produced water treatment facilities.

In addition, understanding the characteristic of both the produced fluid chemistry and all other production chemistry aspects of the system will be a critical part in achieving an effective produced water management.

Therefore it is fundamental to the whole process of produced water management to have an integrated approach to deal with the undesirable water. This approach should include from the early stage of development as well as later production, design aspects, selection of equipment and instrumentation as well as a clear understanding of all produced fluid issues.

In addition, with the increased volume of produced water handled in the North Sea, the environmental issues are becoming a major concern in the industry, especially with the prospect of reduction in the oil content allowed in the discharged water from 2006 as well as reducing the average ppm oil in water from 2006. Therefore assessing all the options available to handle produced water is becoming more critical in order to ensure long term sustainability in the operation of the different facilities offshore and maintaining the productivity at the same time. This should include the possibility of produced water re-injection, with the flexibility of maintaining production during the loss of the injection facilities.

Typical produced water treatment facilities in oil and gas condensate production facilities

Produced water treatment facilities will normally consist of a core vessel or vessels that will be used for removing oil from the water and associated vessels and other equipment that are an integrated part of the system. Associated equipment will include degassing vessels that will be used for flashing off the dissolved gas in the produced prior to disposal or discharge, oily recovery vessel, filters and pumps. Core equipment for cleaning the produced water can be flotation and coalescing type vessels or hydrocyclone units. Sand production can significantly reduce the efficiency of any of the produced water treatment facilities regardless of their nature.

Centrifuge and filter units have been used for treating and cleaning produced water but for limited applications, due to both pressure operating limitations and the handling of these type of treatment facilities that has been proven to be very challenging, mainly in the offshore environment. These types of facilities are even more susceptible to solid production.

In the last 5 years, different, modified and new technologies in handling produced water have been evolved in both US and Europe market. Some of the new technologies are very specific for certain applications and some are more universal. However, based on experience gained from the technologies available, it is believed that the industry can still absorb more unique innovations in handling produced water. Nevertheless the oil industry should be prepared to assess these new technologies in order to prepare for the new future challenges in handling produced water.

Also, it is very critical that new as well as old technologies are configured correctly in the system in order to optimize their operation. Potentially any core unit or device for removing oil in the water will have a number of operation problems that will reduce the efficiency of the overall produced water facilities, unless an effective holistic design will be implemented. These operation problems will be associated to different issues and very often is caused by either the facilities upstream of the unit, control issues of the whole system, design issues or production chemistry issues. The holistic trouble solving approach to oily water problem is not dissimilar in principle, but in some cases it can be system specifics.

Most of current oil and gas treatment process facilities will comprise of produced water facilities based on current technology of using oily water hydrocyclones. In addition, with potential sand production, the facilities will possibly also include sand removal hydrocyclones, most commonly in the produced water streams. Polishing produced water treatment facilities to complement the efficiency of the main oil removal equipment are becoming more common to have in order to reduce the oil in water content for discharge.

Typical conventional produced water treatment facilities in high pressure system will be based on dedicated hydrocyclone unit or units for treating the water out of the individual stages of separation, with the low pressure process stabilization stage water recycled back to the high pressure system using suitable pumps. However with the low pressure oil production systems the produced water is normally treated through one stage hydrocyclones unit or units with all the water from the low pressure systems being pumped back to the high pressure stage.

Figures 1, 2 and 3 show typical designs of treating produced water in high, medium and low pressure systems. In order to reduce costs, the trend in the industry is to utilize one stage hydrocyclone unit or units for the whole requirement whenever possible and most likely for systems with 1st stage operating pressure of 20 Bar or less.

It is also important to establish a full understanding of the differences in the treatment of produced water system in oil production facilities and gas condensate production facilities. Although in most gas condensate production facilities the operating pressure is higher, certain core devices will not be as efficient in treating produced water out of gas condensate system. Consequently alternative equipment should be selected. These aspects should be determined as part of the total system evaluation prior to the selection of the optimum treatment facilities. **Figures 4, 5 and 6** show other typical produced water treatment facilities that will require similar holistic approach in the design and operation. Both flotation and coalescing produced

water treatment systems, as shown in **Figure 4**, were widely used offshore in the past, but few operators utilize such system offshore currently. The filtration devices, as shown in **Figure 5**, that are used for produced water system are considered effective but have limited applications for full scale treatment offshore under existing technology, unless improved filtration and recovery system will be developed. The produce water system with centrifuge treatment facilities, as shown in **Figure 6,** potentially can be an effective system for gas condensate water treatment facilities but not used widely.

Issues concerning produced water

In order to have a full understanding of produced water problems offshore, different aspects of produced water and related fluids should be addressed in any design or troubleshooting scenario. Although not limited to following points, the listed items are considered the critical factors in assessing the design of the produced water system:

1. The full characterization of the oil and gas condensate that will be produced, including composition, physical and chemical properties.
2. The chemical nature of the produced water including the salinity level of the water.
3. The physical nature of the water including the specific gravity and viscosity of the water.
4. The range of operating temperatures in the system that will be designed or assessed for water handling.
5. The different operating pressures the system will be operated at and the different stages of stabilizations.
6. Full understanding of all flow assurance issues including the strategy in controlling hydrates if applicable as well as any produced water related problems.
7. The different production chemicals that will be utilized in the system.
8. Potential production of sand should be assessed.

In most field developments, the above data and information are gathered but not necessarily fully utilized or assessed as one integrated part of the design of the system. In a typical scenario, the process design engineers will carry out a full design study of the process system on the basis of oil stabilization and gas processing. In association to the design of the oil and gas processing facilities, a basic water handling system and relevant facilities will be designed, albeit with suitable equipment but without the full understanding of the fundamental produced water issues. Consequently the produced water facilities will have gaps, weaknesses and not effective in meeting the required operation criteria. Normally the deficiency of the facilities will be determined after the commissioning of the system, after the start up of produced water, with limited flexibility in carrying out and implementing the necessary modifications.

In order to address these aspects of the design and understand the importance of carrying out a full holistic design approach to the produced water facilities, the nature and the type of the water should be fully integrated in the design concept.

Produced water with potential production chemistry issues may result in the addition of a number of chemicals in the produced fluid that will have a direct impact on both

oil water separation as well as treating the produced water. Low salinity water and/or viscosity of water close to the oil viscosity will prove to be more difficult to separate the water from the oil in a conventional approach. Certain type of oils will have additives in the oil that will cause numerous oily water problems in a conventional produced water handling system and will not effectively treat the water. Typical example of such an issue is the heavy oil or the oil with high total acid number crude (TAN).

Production facilities that will be exposed to sand production and accumulation in the process system should be assessed and designed accordingly. Included in the design is the flexibility of cleaning the sand from all produced water facilities online with redundancy for maintenance. Conventional treatment system for low temperature process facilities will not be effective in treating the produced water. Hence additional facilities will be required.

Design and selection and operation issues

Based on field experience gathered over the last 25 years, it appears that the offshore oil and gas industry has recognized the type of equipment that will be needed for dealing with oily water treatment. The utilization and application of old technology has gradually disappeared from the offshore environment, although it is still widely used onshore and some offshore locations. In most cases the use of hydrocyclone units of different designs has proven to be effective and suitable for treating produced water.

Nevertheless, the oil water separation facilities upstream of the produced water system and the operating conditions are just as important as the produced water treatment facilities in ensuring the optimum water quality. In many cases it has been proven that the culprit in not getting the optimum water quality is either the separation system or the operating conditions. This may include bit not limited to, low operating temperature, not the optimum routing of the recycle streams in the process system, the use of the wrong chemicals or the use of excessive amount of chemicals.

Therefore it is prudent in the design of the process system is to ensure that the facilities are correctly assessed, selected, the operating conditions carefully determined and to ensure that the system will be less dependent on chemicals. By applying these principles in the system design and selection, it will be more likely to have a more stable system in delivering a good water quality for discharge in the long term and potentially can meet all environmental constraints.

The design and the sizing of the separator are critical to the efficiency of the produced water system. In this case, all aspects of internals of the separator should be fully included and assessed.

In general terms these issues are fully addressed in the design stage, but it is common to get some aspects wrong due to the lack of understanding of the produced water issues. Therefore it is not unusual to select the wrong internal that are not necessarily the most effective in producing clean water. Consequently the oil content out of the separators is too high and the produced water treatment facilities can not cope with the load.

This can be caused by poor fluid distribution inside the separator, sand accumulation that will reduce the separation efficiency as well as the retention time in the separators.

As a result of poor level measurements, wrong positioning of measurement devices

and the control loop associated with instrumentation used, poor separation can cause serious produced water problem. This has been experienced in the past and very often it is overlooked in the early stages with issues related to the produced water problems.

In addition, in multiphase flow operating conditions, both slugging and preferential flow to one separator than another can cause both separation problems and control problems. Although these aspects are not directly associated or related to the design of produced water treatment facilities, these issues are very often the source of the produced water problems. Consequently the optimization of the produced water system cannot be achieved effectively without the holistic understanding of the whole system.

Produced Water Re-injection

Although currently the bulk of produced water produced offshore is discharged into the Sea and is meeting the regulatory limits, the question still remains whether the discharge into the sea is the most effective environmental option and whether new guidelines in the future can be met by the operators. This is more true with the mature fields where there is a significant increase in the water production over the recent years. Hence a hybrid solution of produced water re-injection and treatment can be the answer or total produced water re-injection will be the optimum solution.

(PWRI) in oil producing installation can be put under four different categories, depending on the nature and the purpose of the re-injection.

A general document describing the guidelines for produced water re-injection was issued in the past by various groups in the oil industry. The different documents addressed all relevant issues concerning PWRI in terms of reservoir issues and criteria for the re-injection, in terms of, well design, operational issues, process monitoring, containment and confinement. Although these documents are generic in nature, they are useful to use for assessing the PWRI from reservoir and operational aspects. However, for the purpose of this paper, the different categories of re-injection will be addressed from the operational sustainability and the HS&E impact of the individual categories. These categories are:

1. PWRI into a dedicated disposal well that is not part of the reservoir pressure maintenance management.
2. PWRI into a dedicated injection well that it is part of the reservoir pressure maintenance management, with full filtration criteria.
3. PWRI into a dedicated injection well that it is part of the reservoir pressure maintenance management, with minimum filtration criteria.
4. Produced water commingled with seawater and injected into a well that it is part of the reservoir pressure maintenance management, with full filtration criteria.
5. Produced water commingled with seawater and injected into a well that it is part of the reservoir pressure maintenance management, with minimum filtration criteria.
6. Produced water Re-injection (PWRI) in Gas producing installation that is based on injection into a dedicated well for disposal. Generally speaking water injection is not utilized widely in gas reservoir for pressure maintenance.

Although there is a concern among many reservoir engineering with the produced water re-injection option due to a number of reasons, mainly plugging of injection wells and reservoir souring, it feasible to apply the principle of Produced water re-injection without any major problems if the system is correctly assessed and designed, as well as learning from past experience.

Conclusions

The oil and gas industry has learned from past experience on how to deal with produced water. Many successes have been achieved as well as failures have taken place. Unfortunately, lesson has not been learned from the bad and poor performance cases of the facilities and the design.

In some cases, the configuration of produced water treatment handling facilities is still designed poorly with and without suitable technologies. More engineering and hands on operating experiences should be put into new design, projects and upgrades, in order to avoid the mistake the industry have been applying; as well as the high cost.

By doing so, the handling of produced water will be much easier to deal with than many engineers, environmentalists and asset mangers realize.

Figure 1: Typical Produced water treatment facilities for High pressure system using hydrocyclone units

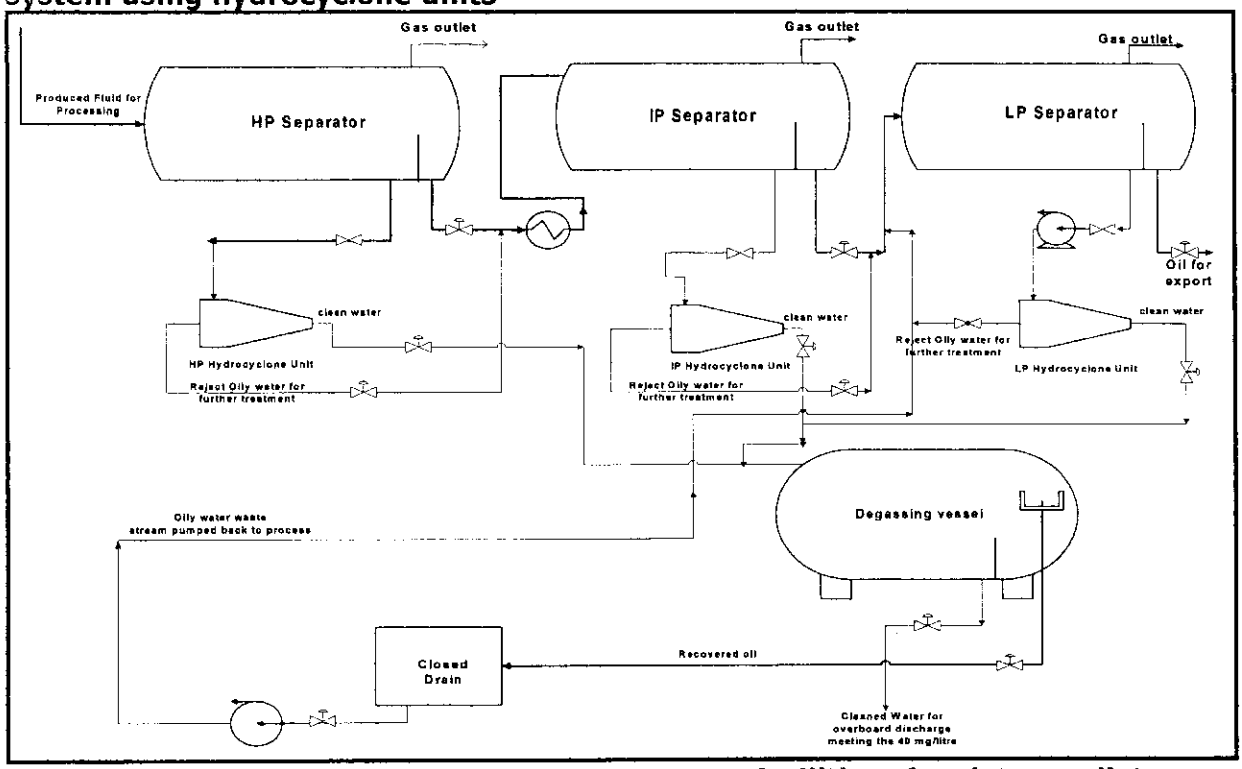

Figure 2: Typical Produced water treatment facilities for intermediate pressure system using hydrocyclone units

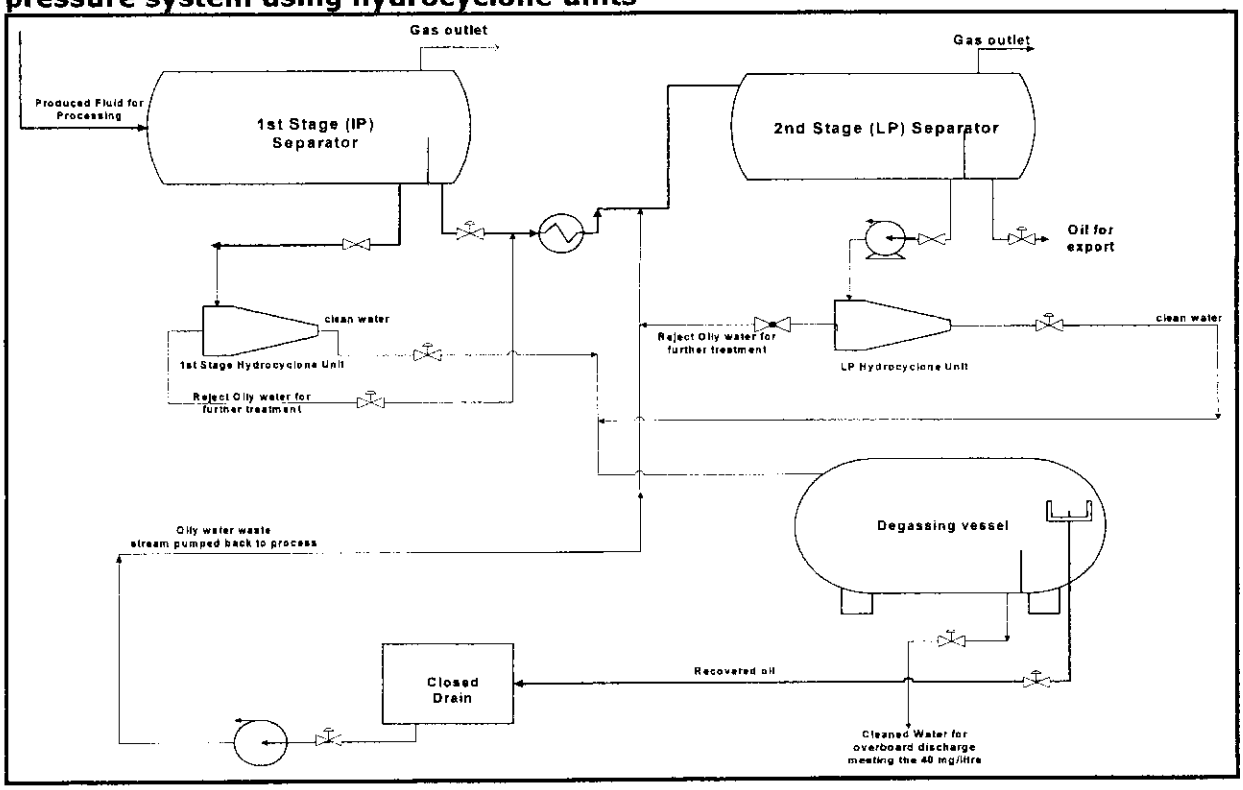

Figure 3: Typical Produced water treatment facilities for low pressure system using hydrocyclone units

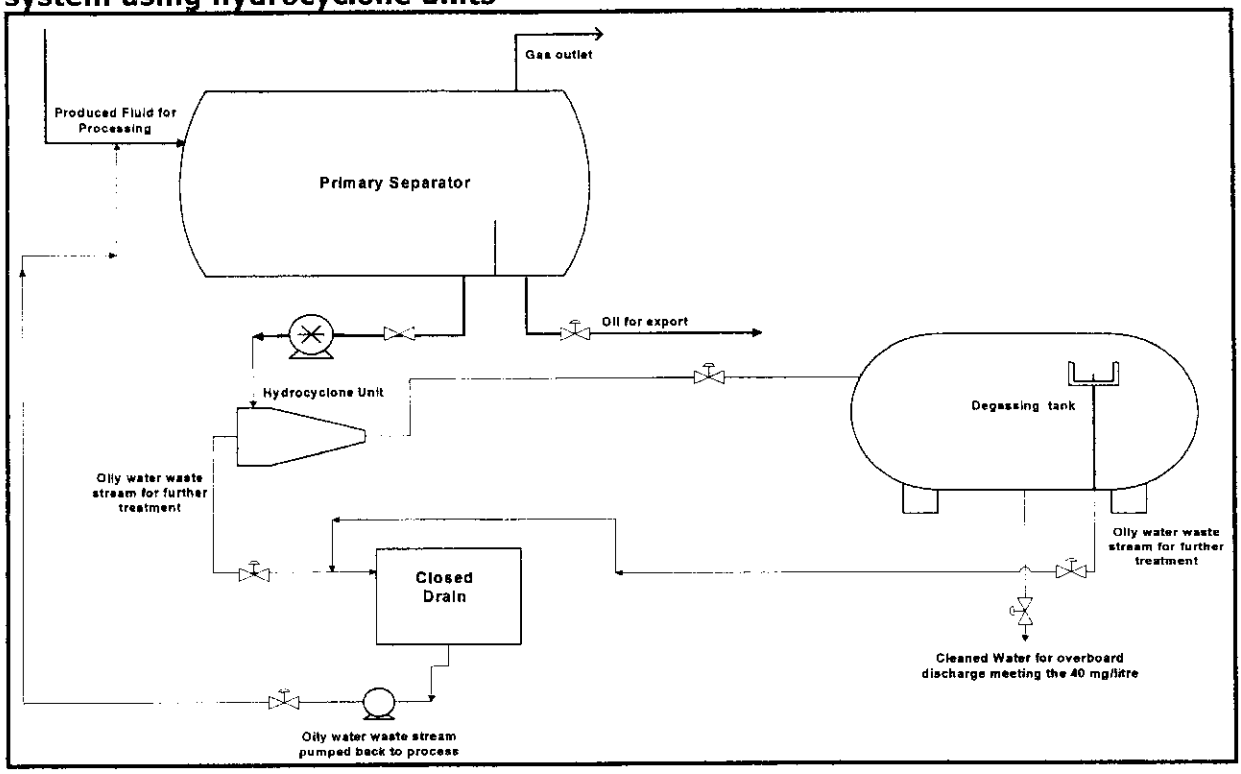

Figure 4: Typical Produced water treatment facilities using flotation and coalescing system

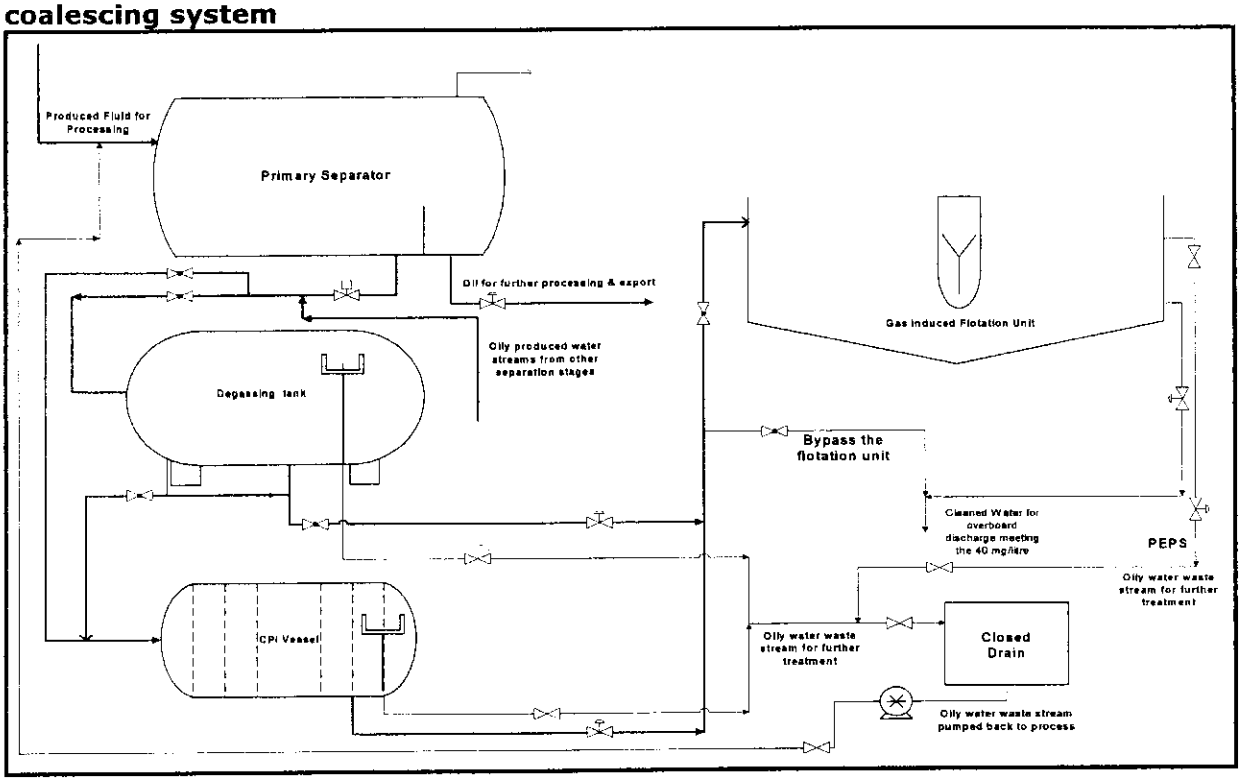

Figure 5: Typical Produced water treatment facilities using filtration system

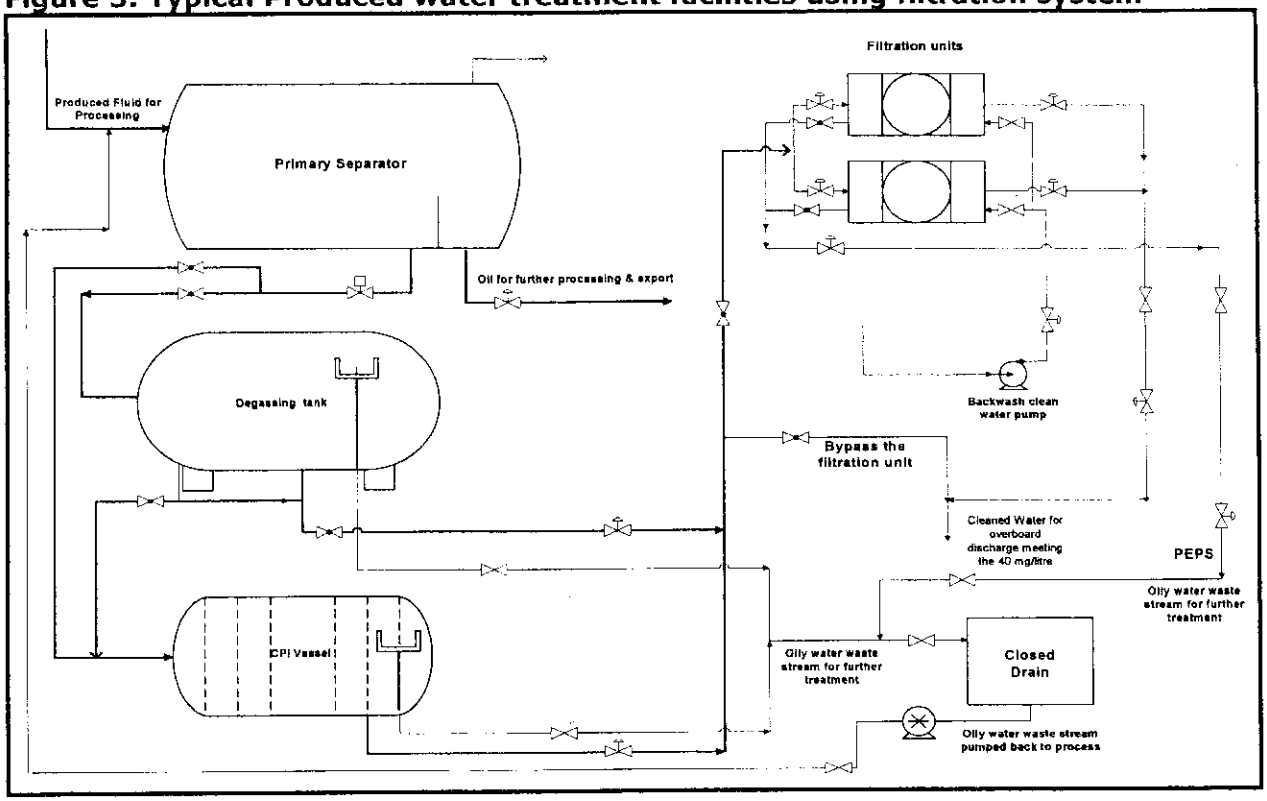

Figure 6: Typical Produced water treatment facilities using Centrifuge system