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DEDICATION

This work is dedicated to my beloved parents Mr. and Mrs. Atuure. I would also like to dedicate this work to Major Atarah RA, his wife and Rev Fr Jonas Atarah for their love, support, prayers and inspiration given me to pursue my education up to this level. I say more grace to their elbows ☺☺☺

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ABSTRACT

Produced water quality has become an increasingly large area of concern for the oil production industry. A great deal of scientific research has been carried out to determine the consequences of long term exposure of produced water on the environment. Some of this research has given alarming results. It is reported that some of the toxic components in produced water may cause irreversible damage to the surrounding environment. Because of this potential risk, very considerable efforts are being expended by the oil companies operating in the North-East Atlantic into developing new techniques to better manage produced water. 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.

Over the years a variety of oil/water separation methods have been developed throughout the world, including gravity separation, corrugated plate interceptors, centrifugal separation, hydrocyclones, induced gas flotation and many other emerging technologies. With increasingly tight legislative limits on OIW (Oil in Water) discharges, it is important that oil and gas operators have an effective produced water treatment system.

To meet these required limits for discharges depends largely on the choice of technology system. However, there are different technologies used for produced water treatment but this thesis takes a closer look at the various flotation technologies commonly used by many industries for produced water treatment.

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CHAPTER 1

AN OVERVIEW OF PRODUCED WATER

1.1 Introduction to Produced Water

In subsurface formation, naturally occurring rocks are generally permeated with fluid as water, oil, or gas (or some combination of these fluids). Thus, reservoir rocks normally contain both petroleum hydrocarbons (liquid and gas) and water. Sources of this water may include flow from above or below the hydrocarbon zone, flow from within the hydrocarbon zone, or flow from injected fluids and additives resulting from production activities. This water is frequently referred to as "connate water" or "formation water" and becomes produced water when the reservoir is produced and the fluids are brought to the surface [1].

Produced water is the largest volume waste stream in the oil and gas exploration and production processes. It is a by-product of the production of oil and gas hydrocarbons from underground reservoirs which consists of formation water that is naturally present in the reservoir and/or in the case of gas production called condensed water. Produced water is any water that is present in a reservoir with the hydrocarbon resource and is brought to the surface together with the crude oil or natural gas. Produced water in any particular reservoir increase as the oil and gas field reaches maturity.

The composition of produced fluid is dependent on whether crude oil or natural gas is being produced and varies from field to another, within the field and during the life span. Fields that produce gas or gas/condensate usually produce only condensed water, a fluid that contains very few salts and inorganic compounds during their early life, but contain high concentrations of dissolved light hydrocarbons. Productivity of gas wells decreases very rapidly (even stops) when significant quantities of reservoir water are being produced, hence the quantity of water in gas production is typically low [2].

On the other hand, oil fields usually start producing reservoir water at a rather early stage of production at low water to oil ratios. Later, as the field mature, the ratio between water and oil could reach high values (thus up to 10:1) and the composition of the produced reservoir water changes. Also oil field production is often enhanced by injection of water, to maintain the reservoir pressure. When this injected water breaks through into the production stream it dilutes the formation water and the discharged produced water progressively approaches the injected water in composition and character.

However, in general terms, produced water is composed of organic constituents, inorganic constituents, production and processing chemicals and other substances and properties. Around 17 million cubic meters of water are produced daily in offshore operations worldwide together with the 120 million barrels of oil equivalent. About 40 % of the daily water production (7 million cubic meters) is discharge offshore.

When hydrocarbons are produced, they are brought to the surface as produced fluid mixture. The composition of this produced fluid is dependent on whether crude oil or natural gas is being produced and generally includes a mixture of either liquid or gaseous hydrocarbons, produced water, dissolved or suspended solids, produced solids such as sand or silt, injected fluids and additives that may have been placed in the formation as a result of exploration and production activities [1]. The produced water and hydrocarbon production profile for a typical oilfield (North East Atlantic) is illustrated in Figure 1 below. The Figure demonstrates the significant change in water-oil ratio when the oilfield reaches maturity and water by far becomes the biggest fraction of the production [3].

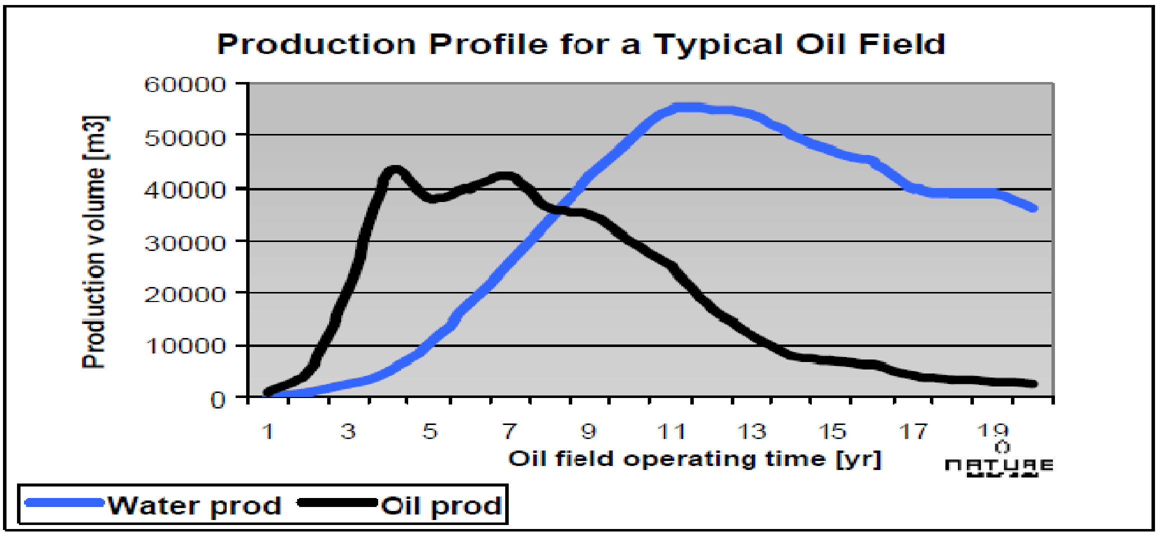

Figure 1.1 Typical Productions Profile For An Oilfield In The North East Atlantic [3]

1.1.1 The Origin of Produced Water

Water is very often found together with petroleum in the reservoir where the water as a consequence of higher density than oil, lays in vast layers below the hydrocarbons in the porous reservoir media. This water, which occurs naturally in the reservoir, is commonly known as formation water. At a particular time in an oil and gas production, the formation water will reach the production wells and water production will begin to initiate. The well water-cut will normally increase throughout the whole oil and gas field lifetime, such that when the oil production from the field is shut down and the oil content can be as low as a couple of percent 98 % water.

Also in order to maintain the hydraulic pressure in the petroleum reservoir which is reduced as soon as production is initiated, seawater is commonly pumped into the reservoir water layer below the hydrocarbons (Figure 2). This process, as a way of pressure maintenance due to water injection, causes high extensions in recoverable hydrocarbons but simultaneously contributes to increased water production [3].

Figure1.2 Re-Injection of Separated Water From An Offshore Installation [3]

1.1.2 Overview of Produced Water Characteristics

Produced water properties and volumes can vary considerably depending on the geographical location of the oil field and the geological formation throughout the lifetime of a reservoir. However, having a good understanding of produced water characteristics can facilitate operators to increase production. For instance, parameters such as total dissolved solids (TDS) can help define pay zone when coupled with resistivity measurements. Also, by knowing produced water constituents, producers can determine the proper application of scale inhibitors and well-treatment chemicals as well as identify potential well-bore or reservoir problem areas [1].

Knowledge of the constituents of specific produced water is needed for regulatory compliance and for selecting management/disposal options such as secondary recovery and disposal. Oil and grease are the main constituents of produced water that has received the most attention in both onshore and offshore operations while salt content (expressed as salinity, conductivity or TDS) is a primary constituent of concern in onshore operations. In addition, produced water contains many organic and inorganic compounds that vary greatly from location to location and even over time in the same well.

1.1.2.1 Produced Water From Oil Production

The organic and inorganic components of produced water discharged from offshore wells can be in a variety of physical states including solution, suspension, emulsion, adsorbed particles and particulates. In addition to its natural components, produced water from oil production may also contain groundwater or seawater (generally called “source” water) injected to maintain the reservoir pressure as well as miscellaneous solids and bacteria. Most produced waters are more saline than seawater and may include chemical additives used in drilling and production operations in the oil/water separation processes. In produced water, these chemicals can affect the oil/water partition coefficient, toxicity, bioavailability and biodegradability.

The treatment chemicals are typically complex mixtures of various molecular compounds and may include the following [1]:

1. Corrosion inhibitors and oxygen scavengers used to reduce equipment corrosion.
2. Scale inhibitors used to limit mineral scale deposits; biocides to mitigate bacterial fouling.
3. Emulsion breakers and clarifiers to break water-in-oil emulsion and reverse breakers to break oil-in-water emulsion.
4. Coagulants, flocculants and clarifiers to remove solids.
5. Solvents to reduce paraffin deposits.

1.1.2.2 Produced Water From Gas Production

Produced water from gas production have higher contents of low molecular-weight aromatic hydrocarbons such as benzene, toluene, ethylbenzene and xylene (BTEX) than those from oil operations: hence they are relatively more toxic than produced waters from oil production.

Studies have indicated that produced water discharged from gas/condensate platforms are about 10 times more toxic than produced water discharged from the oil platforms. However, for produced water discharged offshore, the volumes from gas production are much lower and so the total impact may be less [1].

1.2 Conventional Oil And Gas Production PW Constituents

Organic constituents are normally either dispersed or dissolved in produced water and include oil and grease and a number of dissolved compounds.

1.2.1 Dispersed Oil

Dispersed oil consists of small droplets suspended in the aqueous phase and if the dispersed oil gets in contact with the ocean flow, contamination and accumulation of oil on the ocean sediments may occur, which could disturb the benthic community. The less dense dispersed oils can also rise to the surface and spread. Causing sheening and increases the biological oxygen demand (BOD) near the mixing zone [1].

1.2.2 Treatment Chemicals

Treatment chemicals such as biocides, reverse emulsion breakers and corrosion inhibitors pose the greatest concerns for aquatic toxicity. However, these substances may undergo reactions that reduce their toxicities before they are discharged or re-injected. For example, biocides react chemically to lose their toxicity, and some corrosion inhibitors may partition into the oil phase so that they never reach the final discharge stream. Nonetheless, some of these treatment chemicals can be lethal at levels as low as 0.1 ppm. In addition, corrosion inhibitors can form more stable emulsions, thus making oil/water separation less efficient [1].

1.2.3 Produced Solids

Produced water can contain precipitated solids, sand and silt, carbonates, clay, propant, corrosion products and other suspended solids derived from the producing formation and from well bore operations. Quantities can range from insignificant to a solids slurry, which can cause the well or the produced water treatment system to shut down. The solids can influence produced water fate and effects. Fine-grained solids can reduce the removal efficiency of oil/water separators, leading to excedances of oil and grease limits in discharged produced water [1].

1.2.4 Dissolved Or Soluble Organic Components

Hydrocarbons that occur naturally in produced water include organic acids, polycyclic aromatic hydrocarbons (PAHs), phenols and volatiles. These hydrocarbons are likely contributors to produced water toxicity (and their toxicities are additive) although individually the toxicities may be insignificant when combined aquatic toxicity can occur [1].

Soluble organics are not easily removed from produced water and therefore are typically discharged to the ocean or re-injected at onshore location. Generally, the concentration of organic compounds in produced water increases as the molecular weight of the compound decreases. The lighter weight compounds (BTEX and naphthalene) are less influenced by the efficiency of the oil/water separation process than the higher molecular weight PAHs and are not measured by the oil and grease analytical method.

Volatile hydrocarbons can occur naturally in produced water and the concentrations of these compounds are usually higher in produced water from gas-condensate-production platforms than in produced water from oil-production platform [1].

Organic components that are very soluble in produced water consist of low molecular weight (C2-C5) carboxylic acids (fatty acids), ketones and alcohols. They include acetic and propionic acid, acetone and methanol. In some produced waters, the concentration of these components is greater than 5000 ppm. Due to their high solubility, the organic solvent used in oil and grease analysis extracts virtually none of them and therefore, despite their large concentrations in produced water they do not contribute significantly to the oil and grease measurements [1].

Partially soluble components include medium to higher molecular weight hydrocarbons (C6-C15). They are soluble in water at low concentrations but are not as soluble as lower molecular weight hydrocarbons. They are not easily removed from produced water and are generally discharged directly to the sea. They contribute to the formation of sheen but the primarily concern involves toxicity. These components include aliphatic and aromatic carboxylic acids, phenols and aliphatic and aromatic hydrocarbons.

Naphthalene is the most simple PAH, with two interconnected benzene rings and is normally present in crude oil at higher concentrations than other PAHs (In Norwegian fields, for example naphthalene comprises 95 % or more of the total PAHs in offshore produced water). PAHs range from relatively "light" substances with average water solubility to "heavy" substances with high liposolubility and poor water solubility. They increase biological oxygen demand (BOD), are highly toxic to aquatic organisms and can be carcinogenic to man and animals. All are mutagenic and harmful to reproduction. Heavy PAHs bind strongly to organic matter (e.g. on the seabed) contributing to their persistency. Higher molecular weight PAHs are less water soluble and will be present mainly associated with dispersed oil. Aromatic hydrocarbons and alkylated phenols are perhaps the most important contributors to toxicity. Alkylated phenols are considered to be endocrine disruptors and hence have the potential for reproductive effects. However, phenols and alkyl phenols can be readily degraded by bacterial and photo-oxidation in seawater and marine sediments [1].

1.2.5 Scales

Scales can form when ions in supersaturated produced water react to form precipitates when pressure and temperatures are decreased during production. Common scales include calcium carbonate, calcium sulfate, barium sulfate, strontium sulfate and iron sulfate. They can clog flow lines from oily sludge that must be removed and form emulsions that are difficult to break [1].

1.2.6 Bacteria

One of the major concerns in the Oil & Gas sector is corrosion. This is often linked to sulfate reducing bacteria (SRB) and the acid producing bacteria (APB). One reason for this is that the very reductive conditions encourage the SRB to generate hydrogen sulfide (H_2S) gas. This gas has not only a foul odor ("rotten egg") but also start off process of electrolytic corrosion which can rapidly corrode steel. Bacteria can clog equipment and pipeline and can form difficult-to-break emulsion and hydrogen sulfide that are corrosive.

1.2.7 Metals

The concentration of metals in produced water depends on the field particularly with respect to the age and geology of the formation from which the oil and gas are produced. Metals typically found in produced waters include zinc, lead, manganese, iron and barium.

Metals concentrations in produced water are often higher than those in seawater. However, potential impacts on marine organisms may be low because dilution reduces the concentration and because the form of the metals adsorbed onto sediments is less bioavailable to marine animals than metal ions in solution. Besides toxicity, metals can cause production problems such as by reacting with oxygen in the air to produce solids, which can interfere with processing equipment such as hydrocyclones and can plug formations during injection or cause staining or deposits at onshore discharge sites [1].

1.2.8 pH

Reduced pH can disturb the oil/water separation process and can impact receiving water when discharged. Many chemicals used in scale removal are acidic.

1.2.9 Sulfates

Sulfate concentration controls the solubility of several other elements in solution particularly barium and calcium [1].

1.2.10 Naturally Occurring Radioactive Material (NORM)

The most abundant NORM compounds in produced water are radium-226 and radium-228 which are derived from the radioactive decay of uranium and thorium associated with certain rocks and clays in the hydrocarbon reservoir. As the water approaches the surface, temperature changes cause radioactive elements to precipitate. The resulting scales and sludge may accumulate in water separation systems [1]. Table 1 summarizes a case study of the major characteristics of PW in the North Sea [4].

Table 1.1 Showing A Typical North Sea Produced Water Characteristics [4]

Component	***Unit***	***Major Oil field***	***Major Gas field***
Water production	m^3/d	***30000***	***160***
Temperature	^oC	***75***	***75***
Suspended oil	***mg/l***	***30 (15-40)***	***40 (15-100)***
Aliphatics < C5	***mg/l***	***1 (0-6)***	***1 (0-6)***
≥C5	***mg/l***	***5 (0-30)***	***10 (0-60)***
BTX (Bezene, Toulene, Xylene)	***mg/l***	***8 (0-20)***	***25 (0-50)***
Naphthalenes	***mg/l***	***1.5 (0-4)***	***1.5 (0-4)***
Fatty acids(carboxylic acids)	***mg/l***	***300 (30-800)***	***150 (0-500)***
Phenols	***mg/l***	***5 (1-11)***	***5 (0-22)***
Salinity	***%***	***3.5 (1-8)***	***0.5 (0.01-3)***
Sulphate	***mg/l***	***500***	***50***
Barium	***mg/l***	***30***	***10***
Strontium	***mg/l***	***40***	***20***
Calcium	***mg/l***	***450***	***400***
Suspended solids	***mg/l***	***< 2 (1-20)***	***< 2 (1-20)***

Component	***Unit***	***Major Oil field***	***Major Gas field***
Residual prod. Chem.:	***mg/l***		
Corr. Inhibitor		***4 (2-10)***	***4 (2-10)***
Scale inhibitor		***10 (4-30)***	***0***
Emulsion breaker		***1 (0.1-2)***	***0***
Coagulant		***2 (0-10)***	***0***
Biocide		***0 (0-200)***	***0***
Methanol		***0***	***2000 (1000-15000)***
Glycol		***0***	***1000 (500-2000)***
Heavy Metals:	***µg/l***		
Cadmium Cd		***50 (0-100)***	***50 (0-100)***
Chromium Cr		***100 (0-390)***	***100 (0-400)***
Copper Cu		***800 (0-1500)***	***800 (0-1500)***
Lead Pb		***500 (0-1500)***	***500 (0-1500)***
Mercury Hg		***3 (0-10)***	***3 (0-10)***
Nickel Ni		***900 (0-1700)***	***900 (0-1700)***
Silver Ag		***80 (0-150)***	***80 (0-150)***
Zinc Zn		***1000 (0-5000)***	***1000 (0-5000)***

CHAPTER 2

IMPACT AND MANAGEMENT OF PRODUCED WATER

2.1 Impacts of Produced Water Discharges

Produced water can have different potential impacts depending on where it is discharged. For example, discharges to small streams are likely to have a larger environmental impact than discharges made to the open ocean by virtue of the dilution that takes place following discharge.

Numerous variables determine the actual impacts of produced water discharge. These include the physical and chemical properties of the constituents, temperature, content of dissolved organic material, humic acids, presence of other organic contaminants and internal factors such as metabolism, fat content, reproductive state and feeding behavior [5].

A key concern is the potential for toxicity effects (Table 2.1) on aquatic organisms resulting from produced water discharges to marine and estuarine environments. Numerous toxicity studies have been conducted and EPA continues to require a series of toxicity tests by each produced water discharger on the Outer Continental Shelf. A constituent may be toxic but unless absorbed or ingested by an organism at levels above a sensitivity threshold effects are not likely to occur.

Table 2.1 Showing Environmental Effect of Components In PW Discharges [4]

Component	Toxicity	Biodegradation	Bioaccumulation
Aliphatic	Low	High	No
Aromatic& phenol	Medium- high	Variable	Variable
Production chemicals	Variable	Variable	Variable
Carboxylic acids	Low	High	No
Heavy metals	Variable	-	Variable

According to a research conducted by Statoil AS, dilution after discharge is usually much more efficient than predicted by mathematical models. This is believed to be due to the air that is discharged with the water causing high degree of mixing and stripping effect. Volatile organics rapidly disappear from the water and zones of acute toxicity only exist a few meters (typically 10-50 m) away from the point of discharge [4].

2.2 An Overview of International Agreement

A common legislation for produced water discharges to sea from offshore installations has been 40 mg/l (ppm) OIW. The Oslo Paris Convention (OSPAR) has agreed that the maximum discharge limit is reduced to 30 ppm OIW for the petroleum companies operating in the North-East Atlantic and that the overall oil discharges in produced water are reduced by 15 % from 1999 levels. In Norway, the oil operators have agreed to implement a policy of zero environmental harmful discharges. There shall be no harmful discharges from any new installation, and existing installations shall continuously work against a practically achievable zero environmental discharge. Some of the options available to oil and gas operators for produced water management are:

2.2.1 Discharge of PW

Approximately 500 000 000 tons per year of produced water is discharged to the Norwegian and the British part of the North Sea. Currently the discharge limit for PW set by the Norwegian Pollution Control Authority (SFT) is 30 mg/l average per month. The oil and gas industry has demonstrated no adverse environmental effects from PW discharges and that a reduction would be very costly in terms of NOK/kg oil removed. However, the increasing use of production chemicals will be very necessary for many installations to reduce the discharge below 30 mg/l. More focused has been made on the reduction of some dissolved components, particularly on water soluble heavy aromatics of phenols.

2.2.2 *Re-injection of* PW

Injection of produced water into the same formation from which the oil is produced or handle to another formation maintains the reservoir pressure [6]. Re-injection of PW has been the most recent but sophisticated technology employed in many technologies. However, the set back of reservoir souring, loss of injectivity, uncontrolled fracture growth, scaling, increased corrosion, erosion increased energy consumption and bacterial growth are the associated problems with this technology [4].

2.2.3 Reuse In Oil And Gas Operation

Treat the produced water to meet the quality required to use it for usual oil and gas fields operations [6].

2.2.4 Consume In Beneficial Use

Produced water treatment to meet the quality required for beneficial uses such as irrigation, rangeland restoration, cattle and animal consumption and drinking water. Treatment of produced water is an effective option for produced water handling [6].

2.2.5 What Is Worse; Discharge To Sea Or Re-injection?

Comparing the two tables shown below of re-injection and discharge to sea, Table 2.2, there is no clear cut as to which is most appropriate operation tool in the oil and gas industry. However, re-injection of all produced water (PW) is normally not possible, although re-injection dramatically reduces the discharges to sea, this is partly off-set by an increase in emissions to atmosphere due to the high pumping pressure (energy) required. Available models for comparing of discharge to sea with emission to the atmosphere (due to re-injection) are not yet sufficiently developed to allow a fair comparison. Also the adverse long-term effect of produced water discharges is considered unlikely, the knowledge of the long-term effects however is limited and continuous research is required in order to validate this.

Table 2.2 Comparing Amount of PW Discharge To Sea With Amount of R-einjection [4]

Reinjection(gram)	
CO_2	***1500-3000***
CO	***0***
Nox	***1.5-2.5***
Methane	***0.5-1.0***
VOC	***0.2-0.4***
These emissions cause greenhouse effect, acid rain and increased levels of ozone at ground level.	

Discharge to sea (gram)	
Total organics	***50-800***
Carboxylic acids	***20-700***
Suspended oil	***15-25***
Phenols	***1-10***
Aromatics	***1-5***
Prod. Chemicals	***0-20***
These discharges may cause damage to individual species, can affect reproduction and may accumulate in the food web.	

CHAPTER 3

SESEPARATION TECHNOLOGIES

3.1 Introduction

Oil water separation technologies can be broadly separated into two main types, namely gravity, and non-gravity based separation technologies. The most common and widely used non-gravity based separation technologies are: Hydrocyclones, Filtration (Walnut Shell Filters, Sand Filters and Multi-Media Filters), Coalescing Media and Absorption and Non-Recoverable Media [5].

Gravity separation technologies rely on the fact that the specific gravity of oil is less than that of water. If oily water is left to stand the oil will rise to the surface of the water where it can be skimmed off. Gravity separation technologies can broadly be divided into two main categories, those that operate with, and those that operate without the assistance of gas in the flotation process. Non gas assisted flotation includes gravity separation tanks and corrugated plate interceptors [5].

3.2 Introduction To Flotation

Many aging oil and gas production fields are experiencing rising water cuts which have increased the necessity for the handling of greater volumes of produced water. The need for more efficient treatment of produced water is exacerbated by the ever tightening discharge regulations and the need of increased production given the current high price of oil. As a result of this the demand for more cost effective and efficient oil and water separation technologies has greatly increased, and will continue to do so in the future.

To obtain this acceptable oil and grease effluent limits there are a number of widely accepted conventional separation methods that have been in use for a long time and with great success. However, despite many companies allocating large sums of money to research and development of new products there have been relatively few genuinely new technologies that have emerged over the past few years. Many newer designs have relied on modifications of old designs to improve efficiencies, or different combinations of the same equipment [5].

Flotation is a process in which gas bubbles are used to separate small, suspended particles that are difficult to separate by settling or sedimentation (Figure 3). The principal advantages of flotation over sedimentation are; very small or light (low density) particles that settle slowly can be removed more completely and in shorter time [7], high rise velocity permits small tankage, ability to handle variable solids loading (can adjust air flow), can provide high float concentration (good thickening).

Gas is injected into the water to be treated and particulate and oil droplets suspended in the water are attached to the air bubble and they both rise to the surface. The dissolved gas can be air, nitrogen, or another type of gas. The bubbles attach to the particulate matter and the buoyant force of the combined particle and gas bubbles is great enough to cause the particle to rise to the surface. Particles that have a higher density than the liquid can thus be made to rise. The rising of particles with lower density than the liquid can be facilitated (e.g. oil suspension in water) Once the particles have been floated to the surface, they can be collected by skimming operation [7].

Gas flotation technology is subdivided into dissolved gas flotation (DGF), induced gas flotation (IGF) and vacuum flotation. The three technologies differ by the method used to generate gas bubbles and the resultant bubble sizes.

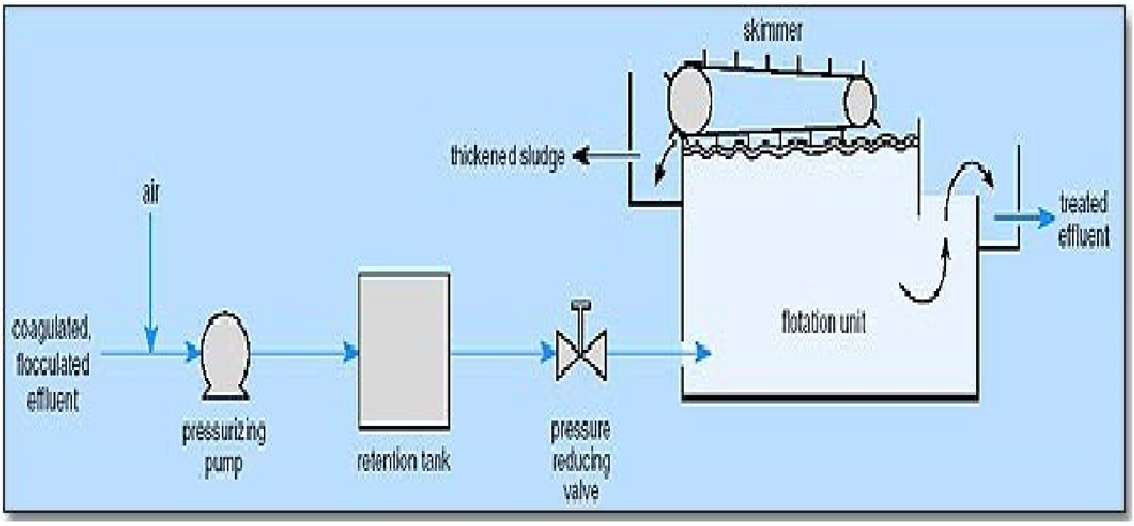

Figure 3.1 Flotation Unit [8]

3.2.1 Dissolved Gas Flotation

In DGF units, gas (usually air in land industries) is fed into the flotation chamber, which is filled with a fully saturated solution. Inside the chamber, the gas is released by applying vacuum or by creating a rapid pressure drop. In the flotation unit the solid particles are carried by the bubbles toward the surface of the water where they are skimmed off by a skimming mechanism. The clarified water passes under a baffle (which prevents the floating solids from being discharged with the effluent water) and is discharged by passing over a weir.

Flotation units can be provided with a recycle to prevent the incoming solids to be subjected to the shearing action of the pressurizing pump [9]. Dissolved air flotation (DAF) can remove particles as small as 25µm. If coagulation is added as pretreatment, DAF can remove contaminants 3 to 5µm in size [8]. Dissolved air/gas flotation can also be used to remove volatile organics and oil grease. Dissolved air flotation units have been widely used for the treatment of produced water.

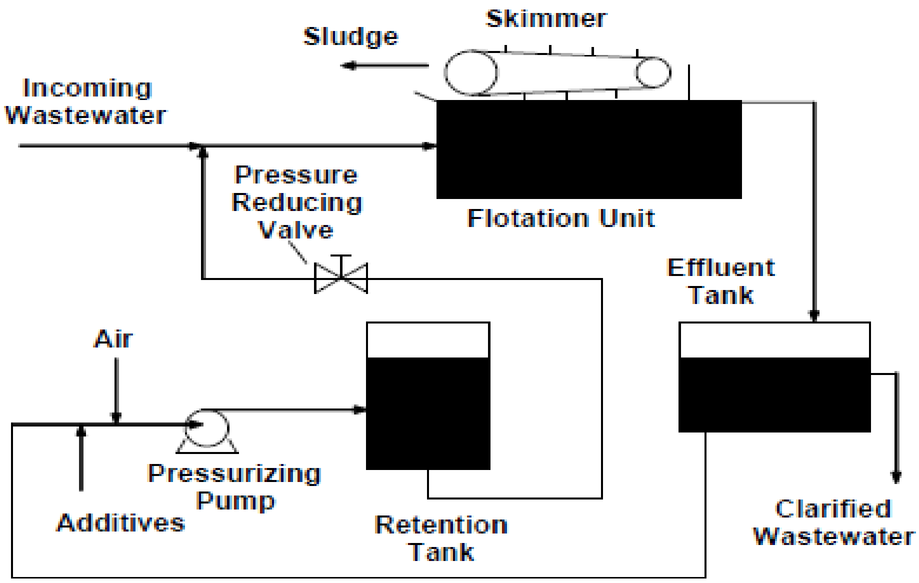

Figure 3.2 Dissolved Air Flotation Process With Recycle [9]

3.2.2 Dispersed/Induced Gas Flotation

IGF mostly used in municipal wastewater treatment but also for industrial removal of emulsified oil and suspended solids from high-volume water or process water. In this system, air bubbles are formed by introducing the gas phase directly into the liquid phase through a revolving impeller. The spinning impeller acts as a pump, forcing fluid through dispenser openings and creating a vacuum in the standpipe (Figure 5). The vacuum pulls air (or gas) into the standpipe and thoroughly mixes it with liquid. As the gas/liquid mixture travels through the dispenser, a mixing force is created that causes the gas to form very fine bubbles. The liquid moves through a series of cells before leaving the unit. Oil particles and suspended solids attach to the bubbles as they rise to the surface. The oil and suspended solids gather in dense froth at the surface and are removed by skimming paddles. The advantages of IGF systems are: compact size, lower capital cost and capacity to remove relatively free oil and suspended solids. However, this system requires higher connected power, performance dependent on strict hydraulic control and less flocculation flexibility [7].

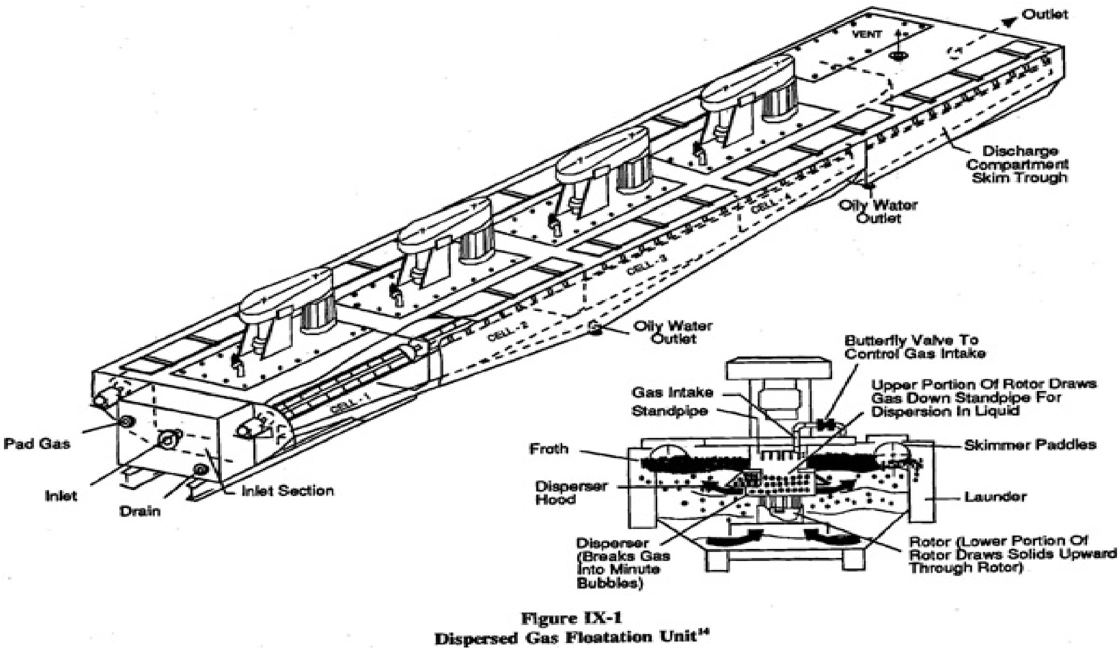

Figure 3.3 Schematic of Induce Gas Flotation Unit [33]

3.2.3 Vacuum Flotation

Vacuum flotation consists of saturating the wastewater with air either directly in an aeration tank or by permitting air to enter on the side of a wastewater pump. A partial vacuum is applied, which causes the dissolved air to come out of the solution as minute bubbles. The bubbles and the attached solid particles rise to the surface to form scum blanket, which is removed by a skimming mechanism [7]. In this case the suspension is saturated with air at 1atm then a vacuum is applied to create relative super-saturation resulting in bubble formation. Because there is a maximum of 1atm pressure difference there is a severe limitation on the amount of air available for flotation. This limits the applicability of this process.

Table 3.1 shows a general overview of flotation technology in the oil and gas industry. The Table illustrates the trend in terms of requirement in its operation and maintenance, chemicals usage in pretreatment, effluent quality and all that need to be considered in operating a flotation technology.

Table 3.1 General Flotation Assessment [8]

Criteria	*Description/Rationale*
Industrial Status	*Widely used for PW treatment, primarily for conventional oil and PW*
Feed water quality bins	*High TOC, oil and grease, particulates < 7 % solids. Not ideal for high temperature feed streams*
Product water quality	*93 % oil removal, 75 % COD removal, 90 % removal of* H_2S
Production efficiency (recovery)	*High recovery, nearly 100 %*
Infrastructure considerations	*Dissolved air flotation requires an external pressurized tank*
Energy consumption	*Energy is required to pressurize the system to dissolve gas in the stream.*
Chemical use	*Coagulant chemical may be added to enhance removal of target contaminants.*
Expected lifetime of critical components	*No information available.*
O&M considerations	*Chemical coagulant and pumping costs are the major components of O&M cost for flotation.*
Capital and O&M costs	*No information available. Contact vendor.*
Pretreatment of feed water	*Coagulation may be used as a pretreatment for flotation.*
Post treatment of PW	*No post treatment required.*
Concentrate management or waste disposal	*Solid disposal will be required for the sludge generated from flotation*

CHAPTER 4

BASIC OPERATION PRINCIPLES OF FLOTATION

4.1 Principles of Flotation

Flotation, such as DAF, is purely physical process which operates based on a reasonably simple design philosophy. Incoming effluent may require pre-treatment as necessary, e.g. the addition of chemical coagulant(s) and/or flocculent(s) may be required with associated mixing and coagulation/flocculation stages. Adjustment of pH may also be a consideration to ensure optimum conditions for coagulation and flocculation.

Flotation systems may be designed for pressurization and air dissolution of the total flow or more commonly the incoming effluent enters the flotation vessel where it comes into contact with a portion of recycled, treated effluent (sometimes termed whitewater). The percentage of the total effluent flow into which air is dissolved under pressure and subsequently recycled will be determined by several factors. Increasing the pressure within the vessel where the air is being dissolved ensures that a higher concentration of air dissolves into the liquid phase than is possible at atmospheric pressure. Once this portion of saturated effluent enters the flotation tank the pressure is released back to atmospheric pressure. This immediately results in the recycled flow becoming supersaturated, resulting in the generation of micro-bubbles as the dissolved air comes back out of solution. These bubbles attach to and form within the solids or chemical flocs entering the vessel causing them to float to the surface where they are retained and subsequently removed by a mechanical skimmer

There are limits to what can efficiently be removed by applying flotation technology. It would therefore seem like a logical step to apply flotation such as DAF systems to effluents where the solids present are of approximately neutral or perhaps even positive buoyancy, so that the bubbles produced are working with gravity rather than against it. Under these circumstances flotation would appear on first approximation, to be a process worthwhile of consideration should standard sedimentation systems not provide the required removal of contaminants [11].

4.2 Key Design Parameters of Flotation

Inevitably the design details for any given effluent treatment system will be dependent on a number of specific factors. There are however several key design parameters, which are commonly applied when considering and assessing the design of a flotation system. The basic principles of operation of a flotation system are evolved from [11]:

1. Henrys Law
2. Nucleus Theory
3. Stokes Law

4.2.1 Henrys Law

W. Henry discovered in the year 1803 that the amount of air that can be partitioned into a liquid is directly proportional to the pressure of the gas. Thus, the saturation concentration of a gas in equilibrium with a solution is expressed as.

$$C = K_H P$$

Where C [mg/l] is the saturation concentration or solubility, K_H [mg/l/atm] is Henry's constant and P [atm] is the applied pressure. The above equation shows that Henry's Law is a function of temperature and applied pressure [12].

The constant K_H is different for each system and varies with temperature as the greater the pressure the more air can be absorbed into the water at a constant temperature. As an example, if you double the pressure on a liquid, the solubility of the solution is double.

When air is injected into a fluid under pressure the fluid will absorb more of the air than if the fluid were not under pressure. Conversely, as the fluid pressure is relieved, under proper hydraulic conditions, the air comes out of solution in minute bubbles or molecular form and occurs regularly in carbonated beverages. Before a carbonated beverage is opened the pressure of gas is not visually apparent; however, after the cap is removed with the subsequent loss (or equalization) of pressure, the gas burst from solution and rises to the surface in bubble form [11].

4.2.2 Nucleus Theory

The second primary principle of operation of a flotation system is the nucleus theory, which is defined as a phenomenon where a gas coming out of a solution from a liquid will preferentially form a bubble on a finite nucleus. In other words, molecules tend to attach themselves to a nucleus (contaminant in waste water) and within some seconds, a sufficient number of air molecules have been collected to form "life preservers" around contaminant nuclei and float the contaminant to the water's surface. The combination of sufficient amount of air molecules with the contaminants (solids) to form "life preservers" result in the combination of air/solids mass that have a specific gravity less than the liquid. Therefore, the solids that would eventually settle or perhaps remain in suspension float to the top of the flotation cell, where they can be easily removed from the top of the flotation cell [11].

4.2.3 Stokes Law

In 1845, an English mathematician named George Stokes first described the physical relationship that governs the settling solid particles in liquids (Table 4). Flotation units make use of the size and density parameters in Stokes equation. Stokes equation states that the rise velocity is dependent on bubble/droplet diameter and density difference. Oil droplet size is therefore very important, the smaller the droplets the slower the rise velocity. Attaching gas to oil reduces the oil density, thereby increasing the density difference between the oil agglomerates and water and increases the agglomerate diameter thereby producing a faster rise rate [13]. This same relationship also governs the rising of light liquid droplets within a different heavier liquid. This law is expressed as shown in the following equations with a negative velocity referred as the particle (or droplet) rise velocity [11].

Table 4.1 Showing Various Ways of Expression Stoke's Law

$V_t = \dfrac{gd^2(\rho_v - \rho_m)}{18\mu}$	***Terminal, fall or settling velocity (V_t)***
$g = \dfrac{18\mu V_t}{d^2(\rho_v - \rho_m)}$	***Acceleration of gravity (g)***
$d = \sqrt{\dfrac{18\mu V_t}{g(\rho_v - \rho_m)}}$	***Particle diameter (d)***
$\rho_m = \rho_v - \dfrac{18\mu V_t}{gd^2}$	***Density of medium, ρ_m, (e.g. water, air, oil)***
$\rho_v = \dfrac{18\mu V_t}{gd^2} + \rho_m$	***Particle density (ρ_v)***
$\mu = \dfrac{gd^2(\rho_v - \rho_m)}{18V_t}$	***Viscosity of medium (μ)***

The law only and only function based on the condition of the following assumptions:

1. Particles are spherical
2. Particles are the same size
3. Flow is laminar, both horizontally and vertically. Laminar flow in this context is equal to a Reynolds number less than 500.

The variables are the viscosity of the continuous liquid, specific gravity difference between the continuous liquid and the particle, and the particle size. The rise rate of oil droplets is also governed by Stokes' Law. If the droplet size, specific gravity and viscosity of the continuous liquid are known, the rise rate may be calculated. Calculation of rise rate by this method is a gross simplification of actual field conditions because oil droplets are not all the same size, and they tend to coalesce into larger droplets. Furthermore, inevitable turbulence within a separator makes an orderly rise of very small droplets impossible.

Droplets will rise following Stokes' Law as long as laminar flow conditions prevail. When the particle size exceeds that which causes a rise rate greater than the velocity of laminar flow, the flow around the droplet (as they rise) begins to be turbulent. Particles of this size and larger do not rise as rapidly as would be expected from calculations based on Stokes' Law because of the hydrodynamic drag. They do, however, rise very quickly in relationship to smaller droplets and will be removed by a properly designed separator.

Very small particles, such as those of 10 microns (micrometers) and less in diameter, do not rise according to Stokes' Law (or hardly at all) because the random motion of the molecules of the water is sufficient to overcome the force of gravity and therefore they move in random directions. This random motion is known as Brownian Motion. Fortunately, the volume of a droplet decreases according to the cube of the diameter, so these very small droplets tend to contain very little oil by volume. And unless there are extremely large quantities of very small droplets (such as would be present with an emulsion or created by using a centrifugal pump to pump the water) they contain negligible amounts of oil [11].

4.2.4 Rate of Rise Theory

The separation process can be accomplished and enhanced in a variety of ways and with a variety of equipment configurations. One common way to improve separation without increasing the need for floor space is to install a multiple plate pack that will create many separation chambers in one vessel, each with a shallow depth. This is done by adding a series of appropriately spaced plates. The flow is distributed through the plates and the rate of rise of the droplet is applied to the application. The advantage of multiple plates is that surface area is increased without requiring additional floor space.

The most efficient oil/water separators are designed to exploit Stokes' Law and the rate of rise for a given droplet. In order for a particle to be removed according to Stokes' Law, the separator must conform to several critical design criteria:

1. Laminar flow conditions must be achieved (Reynolds "Re" number less than 500) in order to allow a droplet to rise.
2. Hydraulic flow path must distribute influent AND effluent flow in such a way as to ensure complete utilization of the coalescing surface area, in order to take full advantage of the plate pack coalescing surface area. Design of the flow distribution must be such as to prevent any hydraulic short circuiting of the plate pack, which would be detrimental.
3. Horizontal flow-through velocities in the separator must not exceed 3 feet per minute, or 15 times the rate of rise of the droplets - whichever is smaller - per the American Petroleum Institute's Publication 421 of February 1990.
4. Coalescing surface area must not become clogged during use, which would adversely alter flow characteristics, possibly creating hydraulic short circuiting and increasing the "Re" number past 500.
5. If inclined parallel plates are used, they must be at the proper angle of repose to allow solids to settle in a liquid medium (ideally 55-60 degrees from horizontal) and they must be smooth enough to allow the unhindered migration of a solid particle to the bottom of the plate pack and an oil droplet to the top of the plate pack, where they will exit the waste stream.

4.2.5 Air-To-Solids Ratio

Flotation technology involves the interaction of gas to solid (bubble-particle) and gas to liquid (gas dissolving into liquid and precipitated as fine size bubbles). The amount of gas (air) dissolving into the liquid solution determines the availability of gas bubbles for interaction with the suspended particles. The air to solids ratio (A/S) is considered one of the most important parameter in the design of air flotation system particularly for wastewater or aqueous suspensions with high solid contents. This ratio refers to the amount of air available for flotation of bubble-solid complexes to be floated in the feed stream. Typical A/S ratios needed in the process of thickening sludge in wastewater treatment plants range from 0.005 to 0.060 ml (air)/mg (solids) [12].

However, different types of influent characteristics generate different ranges of A/S ratios. The optimal A/S range for a particular feed must be determined experimentally. The equation for A/S is expressed as [12]:

$$\frac{A}{S} = \frac{1.3C_s\,(fP - 1)}{S_a}$$

Where A/S is the air to solids ratio in milliliter (ml) of air to milligrams (mg) of solids, Cs is the air solubility, *f is* the fraction (an efficiency term) of gas dissolved at pressure P, and Sa is the sludge solids concentration of total suspended solids. The saturator efficiency applied in this experiment was not determined experimentally in this study. Therefore, a conservative *f* value of 0.5 was selected. In typical practice, *f* is 70 % for unpacked saturators and 90 % for packed saturators. The corresponding equation for a system with only pressurized recycle is [12]

$$\frac{A}{S} = \frac{1.3C_s\,(fP - 1)R}{S_aQ}$$

In this expression, R is the pressurized recycle and Q is the influent flow rate. The factor of 1.3 is the weight in milligrams of 1 ml of air and the term (-1) accounts for the system operating at atmospheric conditions (gage pressure). The dry density of dry air is 1.3 mg/ml at 1atm and 0 ^oC.

The Air/Solids (A/S) ratio may be reported as a volume/mass ratio or a mass/mass ratio and will be application specific. To give an idea of the range of A/S ratios commonly applied, typical values range between 0.005 – 0.06 ml/mg which, at 20 ^oC and atmospheric pressure (say 1.0133 bar) is equivalent to 0.006 mg – 0.072 mg of air per mg of solids to be removed [11].

4.2.6 Hydraulic Loading Rate

Flotation hydraulic loading rate is a measurement of the volume of effluent applied per unit effective surface area per unit time.

Thus $$V_c = \frac{Q}{A} = \frac{V}{At}$$

Where V_c is the surface overflow rate, Q is the flow rate, t is the time and A is the surface area. This result in process design figures expressed as equivalent up-flow velocities with units of m/h. This figure should be application specific but as a general guide the figures which should be expected would be between 2 m/h and 10 m/h. The key consideration with regard to this design parameter is whether the loading rate includes the recycled volume as well as the influent wastewater volume being applied per unit area of the system [11].

Solids loadings are normally given in units of mass per unit area per unit time (kg/m^2h). Typical figures encountered range from around 2 kg/m^2h up to15 kg/m^2h, although again the design will be application specific, depending on the nature of the solids to be removed and the extent to which chemical aids are used [11].

4.2.7 Recycle Ratio

The recycle ratio is determined as the fraction of the final effluent produced which is returned and saturated under pressure prior to entering the flotation vessel where the pressure is subsequently released and the bubbles are generated. The recycle ratio can vary immensely with recycle ratios being typically 15-50 % for water and wastewater treatment application. However, for activated sludge flotation thickening, up to 150-200 % recycle rates have been applied. Air dissolution rates are proportional to absolute pressure (i.e. system gauge pressure + atmospheric pressure) in accordance with Henry's Law of partial pressures of gases adjacent to liquids. Thus, for a given application, the higher the operating pressure of the air/water saturation vessel, the lower the required percentage recycle – and vice-versa. Operating pressures can therefore vary widely but are typically in the range 3-7 barg [11].

4.2.8 Saturation of Effluent

The production of saturated water from which the micro-bubbles are generated is normally achieved in two ways. The first, common to potable water treatment, involves passing the required flow of treated effluent through a packed bed system which is pressurized using a pump and is often a centrifugal pump. In systems where solids are likely to be encountered, e.g. sludge treatment, the saturation vessel is likely to be empty to prevent the fouling of any packing materials. The percentage of saturation which can be achieved will depend on the design of the system but, with good design, saturation efficiencies of up to 80-95 % can be expected [11].

4.2.9 Flow Regime

To ensure that flotation systems operate as designed, it is important to ensure that the system does not encounter sudden changes in the flow regime. For this reason some form of flow balancing or regulation is recommended to ensure a consistent flow rate. Another consideration is to develop a flow path through the flotation tank, which ensures the maximum removal of solids via their entrainment in the air micro-bubbles generated [11].

CHAPTER 5

COMMERCIAL SOLUTION IN THE OIL/GAS MARKET

5.1 Epcon Compact Flotation Unit (CFU) Technology

Since 1999, CFU technology has been under development and in joint testing with oil companies operating in the North Sea. Today, it is a well-proven environmental solution to treat the increasing volumes of produced water. Major operators' world-wide have tested and/or installed the EPCON CFU technology [14]. It is proven to reduce the oil in PW content to below 5 ppm. It has also been shown to significantly reduce harmful soluble oil pollutants such as PAHs, alkylated phenols and BTEX compounds. The EPCON CFU technology is a reliable and cost-efficient alternative to traditional produced water treatment systems [15].

5.1.1 Principle of Operation

The EPCON CFU technology is a vertical compact flotation vessel that separates oil from water. It has a smaller volume and shorter retention time than traditional flotation units. The water enters the EPCON CFU vessel horizontally, in a tangential direction. The separation process is aided by internal devices and a gas flotation effect caused by the release of residual gas from the water and/or added gas. Oil droplets are made to agglomerate and coalesce, facilitating separation from the water. Treated water exits through the bottom of the EPCON CFU vessel. Separated oil and gas is removed in a continuous process via a suspended pipe at the top of the vessel. This multiphase flow – called reject – is controlled by a valve located on the outlet pipe. The liquid rate of the reject reflects typically 1 % of the overall inlet water flow to the EPCON CFU system, and the oil content in this liquid is normally 0.5 to 10 %. A vessel with an operation volume of only 2.4 m^3 (83 ft^3) can treat a water flow up to 220 m^3/h (33 000 bpd) [15].

5.1.2 Measurable Results

Enhanced separation efficiency can be achieved by the introduction of chemicals such as flocculants and water clarifiers. In relation to soluble oil pollutants, optimized reduction in dispersed oil and use of flotation gas has generated a reduction in PAHs of up to 83 % and in BTEXs of up to 88 %, due to the stripping effect [1].

The Epcon Compact Flotation Unit (CFU) is a multiphase (oil/water/gas) separator, with no moving parts. It requires no external energy and is reliable and highly efficient in the separation of water, oil and gas to achieve a high standard of treated water. The CFU also has a smaller volume and shorter retention time than traditional flotation units currently in use offshore. Several combined processes, including gas flotation and induced centrifugal inertia forces, act on the fluid components of different specific gravities. The small oil droplets are made to agglomerate and coalesce to produce larger oil droplets, easier to separate from the water. Eventually, a continuous oil or emulsion layer at the upper liquid level of the flotation chamber is created. The separation process is aided by internal devices in the chamber and by a simultaneous gas flotation effect caused by the release of residual gas from the water.

On occasions, process optimization can be achieved by the introduction of external gas and/or flocculants. The separated oil and gas is removed in a continual process via an outlet pipe. Overall, fluid retention time is remarkably short for achieving satisfactory separation [1].

The Epcon CFU is a vibrant technology with many various competitive advantages. Table 5.1 illustrates among many these various benefits of the technology in the use of produced water treatment in the Oil & Gas sector.

Table 5.1 Competitive Advantage [16]

Simple to operate	❖ ***Minimal maintenance requirement*** ❖ ***No operator assistance***
Efficiency	❖ ***High oil and aromatics removal effectiveness*** ❖ ***Low residence time***
Small footprint and weight	❖ ***1/3rd the size and weight of traditional technologies***
Scalability	❖ ***Test units offer similar relative performance as full scale units*** ❖ ***Ability to perform testing to secure customer buy-in and facilitate sale***
Low cost	❖ ***Limited capex and opex requirements*** ❖ ***No external energy requirement***
Wide operational window	❖ ***Continued high operational performance (down to 20 % flow) under varying conditions*** ❖ ***Performance < 10 milligrams per litre (mg/l)***
Flexibility	❖ ***Effective at many different applications in the process streams.*** ❖ ***Good performance on 'rolling' surfaces such as FPSOs***
Robustness	❖ ***No small bore openings or filters easily clogged by solids*** ❖ ***Not sensitive to high motion operation*** ❖ ***No rotating parts***

The conclusion has so far been higher capacity and better performance at a lower cost.

The single CFU separation step has been proven to reduce the oil-in-water content to below 20 mg/l, while simultaneously degassing the water. Two CFUs in series have been proven to reduce the oil-in-water content further to below 10 mg/l. A retention time as short as 36 seconds is enough to achieve a sufficient separation result. A chamber with an effective separation volume of 2 m^3 will be able to treat a produced-water flow between 40 m^3 and 200 m^3 per hour (m^3/h). Today, Epcon has delivered two sizes of CFU – vessels able to handle 200 m^3 and 400 m^3/h (actual capacity), respectively. However, the size can easily be adapted to local conditions and requirements [17].

The following Tables (Table 5.2, Table 5.3, Table 5.4, Table 5.5 and Table 5.6) summarize the reference installations history of the Epcon CFU used by various companies in the Oil and gas industry for produced water treatment:

- ❖ Table 5.2 shows the overview test of the Epcon CFU
- ❖ Table 5.3 illustrates the overview installations of the technology
- ❖ Table 5.4 and Table 5.5 also shows the various installations in the Oil & Gas industry in the NCS and internationally respectively
- ❖ Table 5.6 demonstrates the difference by higher priority in terms of weight and capacity offered by the Epcon CFU in contrast to the traditional PW treatment systems (hydrocyclones and degassing drum).

5.1.3 *Epcon CFU Technology, Facts & Figures* [16]

1. First full scale system delivered in 2001
2. 28 Full scale system in operation
3. Overall treating some 11.000 m^3/h (1.650.000 bwpd in 1 or 2 stages)
4. Removing totally some 300 bpd of oil (~66 mill NOK/year of recovered oil)
5. Delivering CFU systems to treat ~ 7000 m^3/h (1 050 000 bwpd) in 2008

5.1.4 *Operational Challenges With Epcon CFU* [16]

1. Scale problems in inlet lines
2. O_2 from Nitrogen reacts with iron (from water)
3. Need to reduce O_2 content in Nitrogen supply or use Fuel Gas as additional flotation gas
4. Internal lining possible to slow down “fouling”
5. Naphtenate
6. Reject valves clogging due to asphaltenes and heavy wax and solids/fine particles in oil

Table 5.2 Epcon CFU Overview Tests [17]

Company	Tested 2001–2004	Planned tests – 2004	
Statoil	Aasgaard A Gullfaks B Norne	< 5 mg/l < 5 mg/l < 5 mg/l	Statfjord field Gullfaks field
Waha Oil Libya	Gialo	< 15 mg/l	
Shell	Draugen	< 5 mg/l	
Petrobras	Garoupa P-31	< 5 mg/l (Unsuccessful so far)	Enchova P-31
Talisman	Buchan Alfa	< 20 mg/l	
Canadian Natural Resources Ltd (CNR)	Murchison	< 5 mg/l	Ninian South
Paladin Resources	Montrose	< 5 mg/l	
BHP Billiton	Douglas	< 5 mg/l	
Shell UK	North Cormorant Tern	< 10 mg/l < 10 mg/l	Brent Bravo
Kerr McGee	Gryphon FPSO	< 25 mg/l	New test is planned
Maersk	Danish Sector		Danish Sector + Qatar
NAM			F-3
BP UK - PGS	Foinaven FPSO		14-18/6
Amerada Hess			Triton FPSO

Table 5.3 Epcon CFU Overview Installations [17]

Company	*Installed – under installation*	*Tested 2001–2004*	*Planned tests – 2004*
Norsk Hydro	*Brage 1 stage < 15 mg/l* *Troll C 2 stages < 10 mg/l*	*Oseberg A < 15 mg/l* *Oseberg C < 10 mg/l*	
Statiol	*Snorre/Vigdis 2 stages < 10 mg/l* *Heidrun 2 stages < 15 mg/l*	*Heidrun < 5 mg/l* *Aasgaard A < 5 mg/l* *Gullfaks B < 5 mg/l* *Snorre A < 5 mg/l* *Norne < 5 mg/l*	*Statfjord field* *Gullfaks field*
ConocoPhillips	*Ekofisk J 2 stages < 30 mg/l*	*Ekofisk J < 10 mg/l*	
ChevronTexaco	*Chevron Alba 2 stages*	*< 15 mg/l*	
Petrobras	*Garoupa 2 stages*	*< 5 mg/l*	*P-31 Enchova*

Table 5.4 Epcon CFU - Full Scale Installations August 2010 (NCS) [15, 18]

Company	*Location*	*Installation*	*Capacity*	*Comments*
StatoilHydro	*Norway*	*Brage*	*37 500 bpd*	*Installed 2001*
		Brage Ext.	*75 000 bpd*	*Installed 2007*
		Troll C	*36 000 bpd*	*Installed 2003*
		Troll B	*245 000 bpd*	*Installed 2006*
		Oseberg OSF	*35 000 bpd*	*Rental skid 2007-2009*
		Snorre/Vigdis	*75 000 bpd*	*Installed 2004*
		Snorre/Vigdis Ext.	*150 000 bpd*	*Installed 2006*
		Heidrun	*33 200 bpd*	*Installed 2004*
		Heidrun Ext.	*81 500 bpd*	*Installed 2005*
		Norne FPSO	*163 000 bpd*	*Installed 2006*
		Norne FPSO Ext.	*163 000 bpd*	*Installed 2009*
		Kristin/Tyrihans	*50 000 bpd*	*Installed 2009*
		Veslefrikk	*190 000 bpd*	*Installed 2009*
		Gjøa 1	*4 500 bpd*	*Installed 2009*
		Gjøa 2	*99 000 bpd*	*Installed 2009*
		Gjøa 3	*7 500 bpd*	*Installed 2009*
ConocoPhillips	*Norway*	*Ekofisk J*	*12 000 bpd*	*Installed 2003 – Demob. 2008*
BP	*Norway*	*Valhall*	*33 000 bpd*	*Delivered on schedule August 2010*

Table 5.5 Epcon CFU - Full Scale Installations August 2010 International [15, 18]

Company	Location	Installation	Capacity	Comments
Chevron	UK	Alba Northern Alba Northern II	66 400 bpd 360 000 bpd	Installed 2005 (replaced 2006) Installed 2006
Exxon Mobil	UK	Beryl Alpha Ballast. Beryl Alpha Buckland	80 000 bpd 35 000 bpd	Installed 2005 Installed 2006
Talisman	UK	Montrose	40 000 bpd	Delivered 2006
Total E&P UK	UK	Elgin PUQ	25 000 bpd	Commissioning delayed
Total E&P Cameroun	Cameroun	BAP ESP1	55 000 bpd 7 000 bpd	Installed 2010 Installed 2010
Marathon Oil	UK	Brae A (West) Brae A (S/C/T)	35 000 bpd 72 000 bpd	Installed 2007 Installed 2007
Maersk	UK	Gryphon FPSO	122 300 bpd	Installed 2006
Maersk	Denmark	Dan	37 500 bpd	Rental skid 2006-2007
PetroCanada	Canada	Terra Nova	8 000 bpd	Rental skid 2006
ExxonMobil	Canada	Hibernia	37 500 bpd	Rental skid 2007-2008
Vermillion	Australia	Wandoo	45 000 bpd	Installed 2007
ConocoPhillips China	China	Xijiang 30-2 & 24-3	56 000 bpd	Installed 2008
Petronas	Malaysia	Kumang Cluster	20 000 bpd	Delivered –ready for commissioning
Petrobras	Brazil	Garoupa	33 200 bpd	Rental skid 2004-2005

Table 5.6 Epcon CFU Versus Traditional PW Treatment Systems (Hydrocyclones And Degassing Drum) [17]

System	*Capacity*	*Wet Weight (metric ton)*	*Footprint*	*Performance*
Traditional Water train (hydrocyclones, degassing vessel)	*90 600 bpd (600 m^3/h)*	*45*	*30 m^2*	*< 40 ppm*
1 Stage Epcon CFU (3 vessels in parallel)	*90 600 bpd (600 m^3/h)*	*14*	*9 m^2*	*< 20 ppm*
2 Stage Epcon CFU (3 trains in parallel, 2 vessels per train)	*90 600 bpd (600 m^3/h)*	*27*	*18 m^2*	*< 10 ppm*

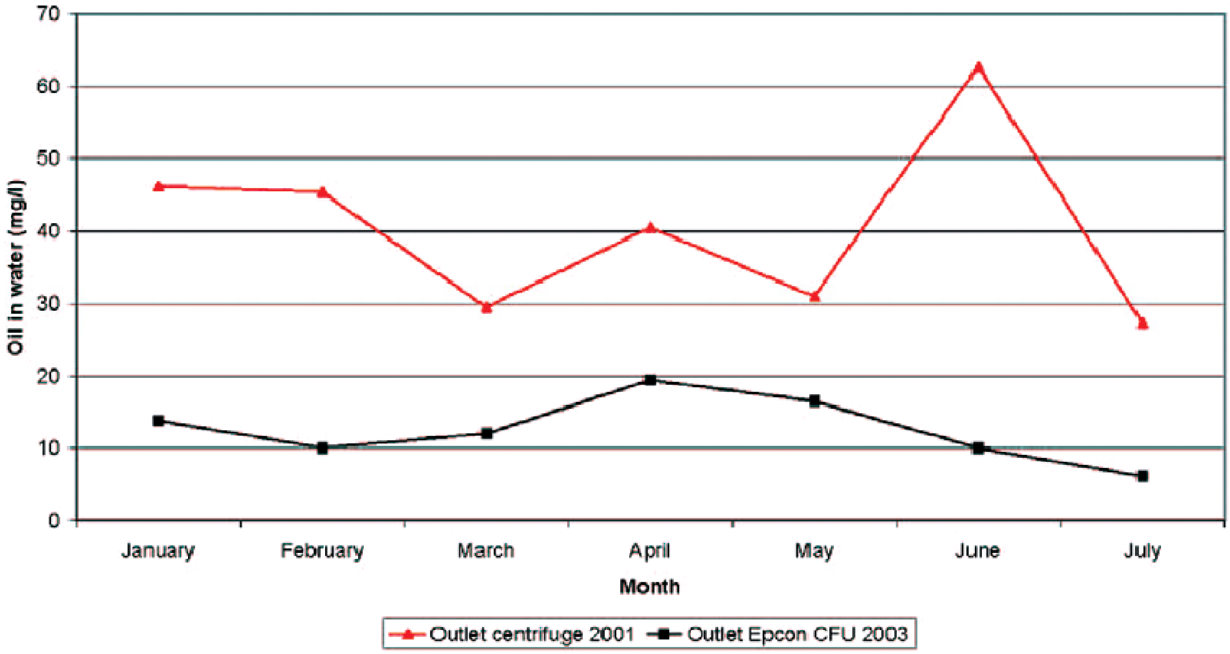

Figure 5.1 Comparison of Monthly Average Outlet Concentrations From Centrifuge (2001) And Epcon CFU (2003) [17]

5.2 Siemens Secondary Water Treatment Technology

Produce water is generated in the process of lifting oil and gas from water-bearing formations typically sea or lake beds. As oil and gas is lifted to the surface, water is brought along with it. This water must be treated prior to discharge or re-injection. Siemens water technologies have been meeting the water treatment needs of the oil and gas industry for decades. They offer a complete range of equipment and processes to solve produced water treatment problems, designed to meet rigorous oil field production standards and to withstand harsh operating environments. Siemens water technologies offer the widest range of proven filtration and separation technologies in the industry for produced water treatment. Some of these include; solids separation, advanced treatment, solids handling, primary, tertiary and most especially secondary oil water separation that are briefly discuss below.

5.2.1 Siemens Quadricell Induced Air Flotation Separators

The Quadricell separator has been engineered to provide the most efficient means of removing oil and suspended solids from produced water in large volumes. These units can process solids and oils in the 50 ppm to several hundred ppm range with product effluents containing less than 5 ppm. Quadricell separators combine 95-percent efficiency with high throughput for treating highly entrained streams that require intensive aeration for flow rates of up to 5 000 gallons per minute [19].

5.2.1.1 The Principles of Flotation Process

The Quadricell separator operates on a low energy, low capital cost, mechanical air (gas) induction principle to process streams that are characterized by the presence of mostly free oil, non-dissolved solids, and the absence of any emulsifying agents such as soaps and caustics.

In the system design, a rotating shaft and impeller create a vortex, which draws the air (gas) down the draft tube, entraining it in the water and forcing the air-rich water throughout the cell.

Cells can operate in any order, removing 75 percent of contaminants. Because the cells operate independently of each other, the system will remain operational even if one cell is shut down.

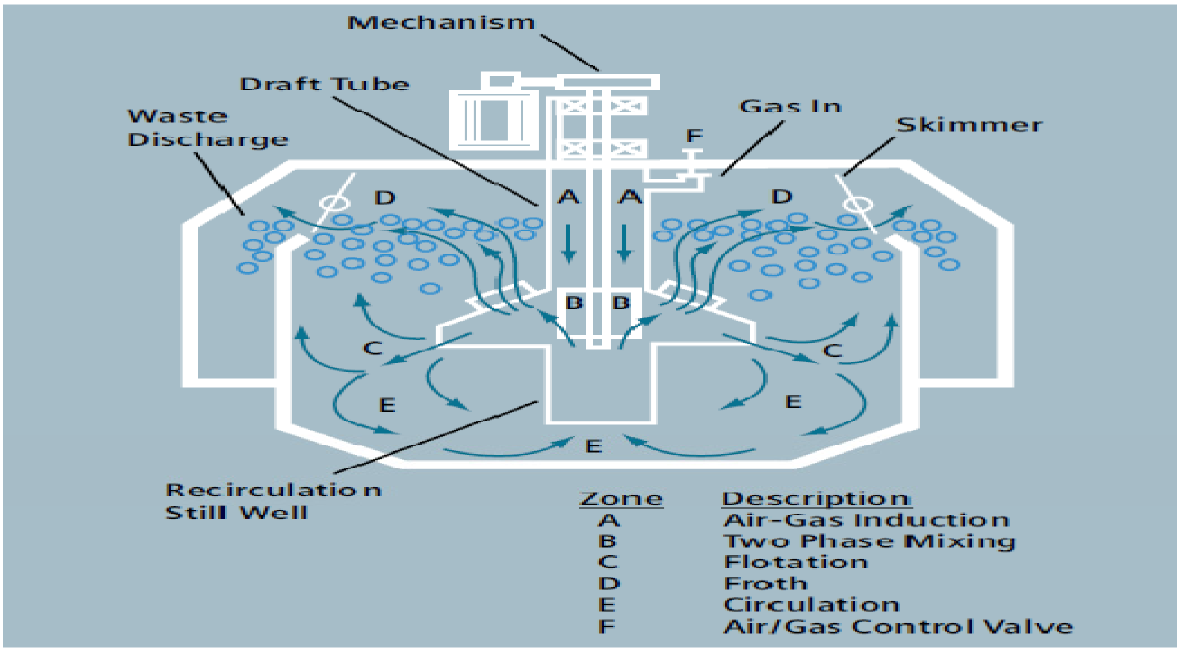

Figure 5.2 Quadricell Induced Air Flotation Separators [19]

Quadricell separators also incorporate a unique patented feature to assist in contaminant removal and enhance the efficiency of the unit. After contaminants are floated to the surface froth, they are immediately removed to prevent re-entrainment into the liquid. The separator then directs a small portion of the air/water mixture upward and radially outward, keeping the froth moving towards the skimmers where contaminants can be removed [19].

5.2.1.2 Features And Benefits [19]

1. Patented design assists in contaminant removal and enhances efficiency
2. Once contaminants are floated to the surface froth, they are immediately removed to prevent re-entrainment into the liquid
3. Four cells in series ensure maximum liquid/air contact

4. Cells are individually adjustable for maximum skimming efficiency and optimum air introduction
5. Optional gas-tight design ensures containment of volatile organic compounds.

5.2.2 Siemens Spinsep Vertical Flotation System

The Spinsep vertical flotation system incorporates several unique methods for removing oil from produced water and wastewater streams before they are discharged or injected. Improve technology and a vertical vessel design reduces the footprint required for this innovative flotation system. The Spinsep flotation system can be designed as an ASME code or a non-code vessel [20].

5.2.2.1 The Priciples of Flotation Process

As the influent stream enters the Spinsep vessel, it flows through a centrifugal coalescing device (Spiralsep system) installed in the inlet piping to the vessel. This component initiates gravity separation of the incoming liquid and if necessary, mixes incoming flotation aids such as chemical water clarifiers.

The circular motion created in the Spinsep vessel by the 90-degree inlet angle results in greater path distance the liquid must travel resulting in improved removal efficiency. The Spiralsep system also stimulates gas bubbles and oil droplet attachment.

Oil droplets grow on the surface of the pack medium until gravity brings them to the surface where they are skimmed into the oil bucket. Water flowing through the gas flotation zone below the packing scrubs is clean of attached oil. These droplets rise to the surface and are skimmed with incoming free oil [20].

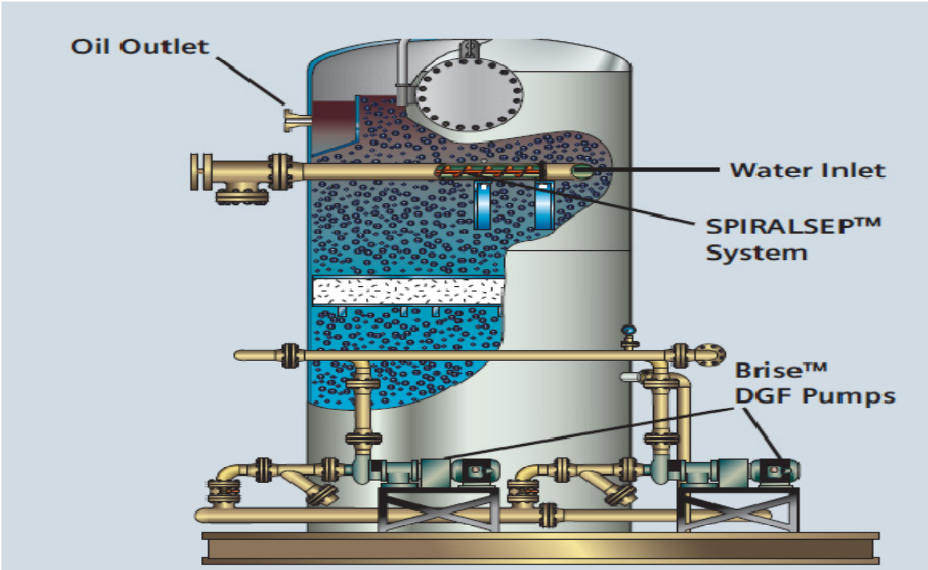

Figure 5.3 Spinsep Vertical Flotation System [20]

5.2.3 Siemens Veirsep Horizontal Flotation System.

The Veirsep system offers the greatest contaminate removal efficiency of any other flotation device configuration due to multiple compartments and increased flotation surface area. The increased efficiency of the Veirsep system results in reduced chemical usage and ensured environmental discharge compliance. The patented Veirsep horizontal flotation system incorporates several unique technologies to separate oil and various others contaminates from produced water and contaminated wastewater streams [21].

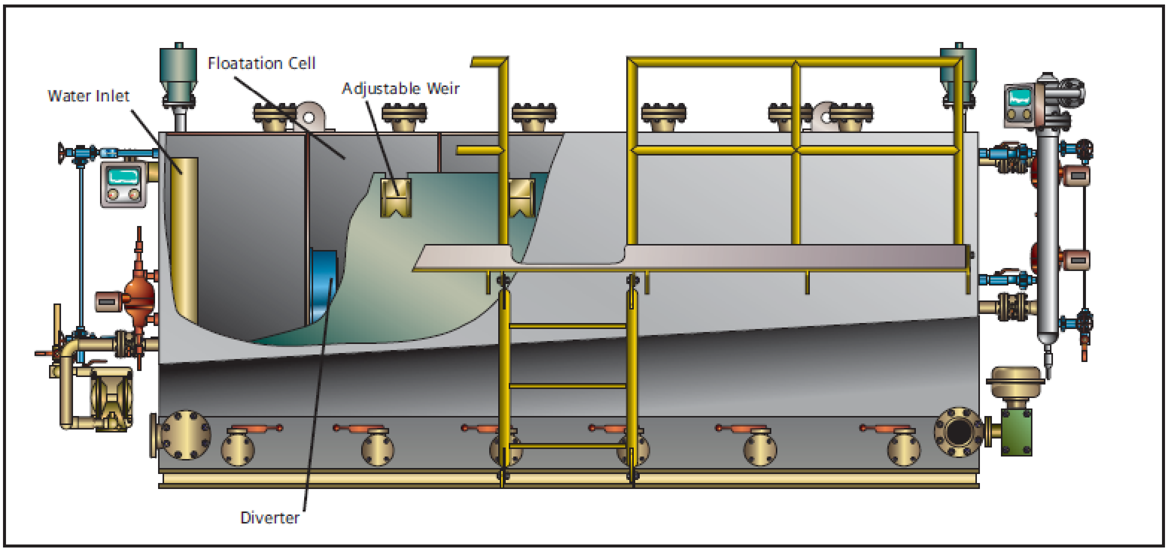

Figure 5.4 Veirsep Horizontal Flotation System [21]

Featuring a compact footprint, the unit is fully automated and can be designed to operate in an atmospheric or pressurized condition. The system is comprised of an inlet centrifugal coalescing device (Spiralsep system), influent and effluent surge compartments, four flotation chambers, an oil collection weir system, Brise DGF pumps for recycling fluid and generating varying micron size air/gas bubbles as well as all required control and operational accessories [21].

5.2.4 Siemens Vorsep Compact Flotation Unit

The Vorsep compact flotation unit incorporates several unique methods for removing oil from produced and wastewater streams before they are discharged, reused, or re-injected.

The unit is compact and lightweight, ideally suited for offshore applications where footprint and weight are critical. The Vorsep system can reduce the residence time necessary for separation by 80 percent or more, relative to standard flotation systems. This separation efficiency results in reducing the inventoried water in the system by the same percentage as the residence time, resulting in a system optimized for footprint and weight without reducing effectiveness. The Vorsep unit can be designed as a code or non-coded vessel [22].

5.2.4.1 The Principles of Flotation Process

As oily water feed enters the Vorsep compact flotation system, its flow is tangential to the walls of the internal vortex zone. The inlet flow is also combined with the first of two flotation zones. The gas-filled feed is accelerated by angled pipes to generate a vortex-induced separation of the incoming liquid. This motion created in the Vorsep system by the inlet angle results in accelerating the separation forces, improving removal efficiency.

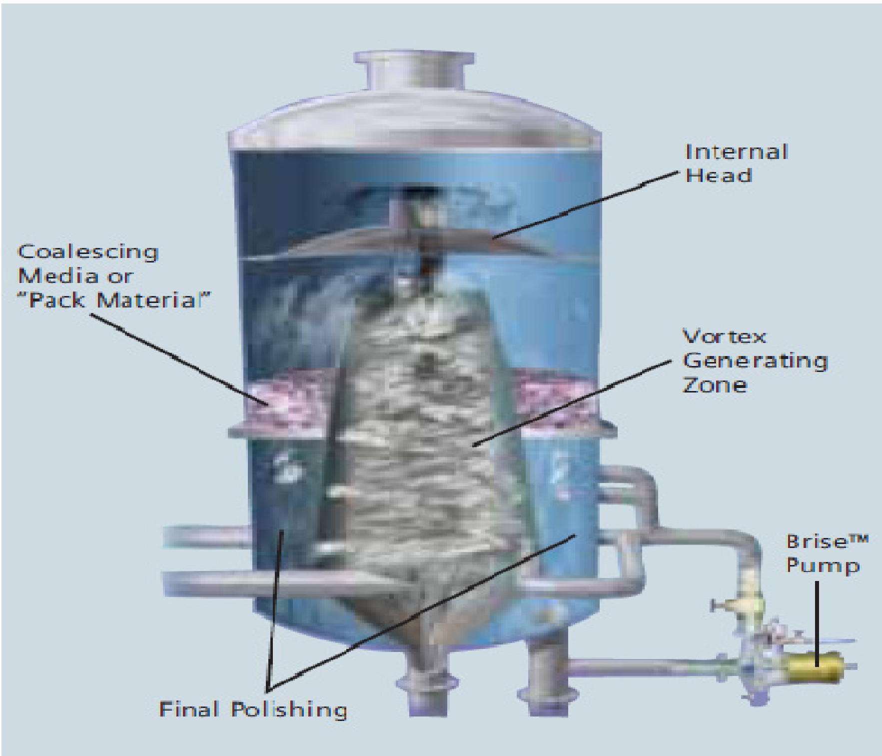

Figure 5.5 Vorsep Compact Flotation Unit [22]

As the oil droplets grow due to the voraxial motion, micro-bubbles attach aid and accelerate flotation of the oil to the surface. The rising oil droplets coagulate at the surface and are skimmed from the water. Clean effluent flows from the Vorsep system ready for discharge, reuse, reinjection, or further treatment. Conventional flotation technologies create gas bubbles by a number of different methods including eduction, sparge tubes or the dissolution of gas under pressure [22].

5.2.5 Siemens Brise Dissolved Gas Flotation (DGF) Pump System

The Brise DGF pump has proven to be one of the most effective solutions to treating produced waters. It works by using a dual-sided impeller that pulls both water and gas into the pump volute. The backside of the impeller has a "sub-atmospheric" zone that pulls vapor from the blanket gas source or other means and allows mixing with the incoming fluid. As this mixing occurs, the vapor is dissolved into the water creating micro-fine bubbles, which break out of the solution once a pressure drop is experienced. This pressure drop occurs once the fluids and dissolved gas are flowed across a globe valve prior to entrance into the flotation vessel [23].

Due to the close tolerance between the back vanes of the impeller and the back plate of the pump, the vapor is sheared into micro-fine bubbles piped into a vessel or tank allowing the fine gas bubbles to attach to the oil droplets. As the gas bubble attaches to the oil droplet, the droplet floats to the surface at an accelerated rate [23].

DGF technology can produce bubbles that range from 1 micron and greater. Currently, there are no other technologies that offer the flexibility and effectiveness of altering bubble size to optimize the efficiency of a flotation unit due to changing water chemistry [23].

5.2.6 Siemens Combosep System

The Combosep system is designed to replace the traditional use of separators, skimmers and flotation polishing systems. It can replace an entire produced water treatment system with two vessels, a vertical skimmer and horizontal flotation unit. The Combosep system has the ability to replace multiple treatment vessels due to flotation capabilities in both Combosep vessels.

The patented Combosep (COMBination Of SEParators) is typically comprised of a vertical and horizontal flotation system or vertical/vertical vessel, mounted on a common skid, complete with interconnect piping [24]. For extremely large flow rates, the vertical unit (Spinsep or Cyclosep) can be packaged on a skid separate from the horizontal Veirsep unit. This sophisticated design precludes the need for a gravity separator or skimmer upstream of the flotation system [24].

5.2.6.1 The Principles of Flotation

The vertical Spinsep or Cyclosep unit is the primary separator system of the Combosep system. The Cyclosep separator, if used in this application, would include a built-in hydrocyclone to separate the solids and oil from the produced water. The oil is processed within the cyclone to exit the top of the cyclone with the gas vapor. The cleaner water, with the solids, exits the bottom of the cyclone where they are separated and removed from the vessel.

The final polishing vessel of the Combosep would include a Veirsep flotation system that removes the remaining oil to achieve discharge limits. The unit is comprised of seven separation chambers, has no internal moving parts and can be equipped with either DGF or eductor technology to provide gas bubbles that attach and lift the oil to the surface where it is skimmed into the oil compartment [24].

5.2.7 Siemens Cyclosep Vertical Flotation System

The patented Cyclosep vertical flotation system is a unique concept in treating produced water and contaminated wastewater. It uses specialized cyclonic and flotation technology that removes oil, grease and solids in a single vessel arrangement.

State-of-the-art cyclonic technology installed in a vertical vessel removes solids without interrupting the processing of produced water. The internal design features a hydrocyclone that is not susceptible to plugging or short-circuiting due to solids. The Cyclosep flotation system can be designed as an ASME code pressurized or atmospheric vessel with the following applications [25].

1. Produced water containing high concentrations of produced sands or solids
2. Refinery wastewater treatment
3. Removal of pulp from wastewater in the paper industry
4. Treatment of oily wastewater containing solids

5.2.8 Siemens Hydrocell Hydraulic IAF Separators

Hydrocell hydraulic induced air flotation separators has been engineered to provide the most efficient means of removing oil and suspended solids from water in large volumes, and can process solids and oils from 50 ppm to several hundred ppm with product effluents containing less than 5 ppm.

Hydrocell separators use a single pump to drive four patented air (gas) eductors, instead of separate motor-driven impellers for each cell. This allows each eductor to saturate the entire volume of each separation cell with fine bubbles, ensuring efficient oil/water separation. The Hydrocell separator is used to process oil field-produced water, both onshore and offshore, or to process plant wastewater effluents prior to biological treatment or discharge into public waterways [26].

In the Hydrocell system design, a single pump is used to drive four patented air (gas) eductors, rather than having separate motor-driven impellers for each cell. With no moving parts, each educator efficiently saturates the entire volume of each separation cell with fine bubbles.

Figure 5.6 Cyclosep Vertical Flotation System [26]

The Hydrocell separator operates on a low energy, low capital cost, hydraulic gas induction principle to process streams that are characterized by the presence of mostly free oil, non dissolved solids, and the absence of any emulsifying agents such as soaps and caustics [26].

5.2.8.1 Features and Benefits **[26]**

1. Uses less power, is substantially lighter and has fewer moving parts than standard impeller-driven systems.
2. Four cells in series allow maximum liquid/air contact
3. Cells are individually adjustable for maximum skimming efficiency and optimum air introduction.
4. Optional gas-tight and pressurized designs ensure containment of volatile organic compounds
5. As complete, self-contained units, these separators occupy minimum space and can be easily installed for fixed or portable operation.

Table 5.7 illustrates these various secondary treatment technologies for produced water management offered by the Siemens Water Technology. The updated version of these technologies are shown on Table 5.8. The secondary treatment technologies, described above, demonstrate a large number of installations worldwide in the Oil & Gas industry. The technologies offer a variety of different installation with different modes and specification at different locations by many companies in the Oil & Gas industry.

Table 5.7 Siemens Flotation Cell Installation List [27]

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Flotation Cell Installation List

Customer Name	Project Name	Project No.	Bkg Date	Location	Product Model
AGIP			11/21/2001	GC 254	10M DGF-C
AGIP			7/27/2001	EB 927	10M DGF-C
Allen Process Systems			7/26/1999	NPDC Nigeria	6M Veirsep-Plus
Alliance Engineering/Shell	Perdido	V00008	8/1/2006	GOM	40M Spinsep P/HC
Amerada Hess			12/29/2004	Elon Project	60M Spinsep-P (DGF)
Amerada Hess/ Modec			1/5/2005	Okume Project	50M Spinsep-P (DGF)
Amerada Hess/ Modec			1/5/2005	Oveng Project	30M Spinsep-P (DGF)
Amoco			12/18/1998	WD 75	15M Veirsep
Amoco			10/20/1994	EI 215	10M Monosep-S
Amoco			7/28/1993	WD 90	25M Veirsep-C
Amoco			8/23/1989	WD 35	5M Veirsep
Apache			10/29/2004	SP-62-C	10M Skimmer
Apache			10/29/2004	SP-62-A	10M Combosep (DGF)
Apache			10/29/2004	SP-62-B	5M Combosep (DGF)
Apache			9/18/1996	SP BLK 12	5M Cyclosep
Aquila Energy			5/7/1990	EI 277	1M Veirsep
Aramco	Safaniya	V00010	1/8/2007	Saudi Arabia	170M Veirsep P
Aran			6/20/1995	SP 37-E	5M Skimmer-S
Arena/Jacobs Linder	Grand Isle 102-A		2010	GI 102-A	20M Veirsep
Arena		N00046	2/9/2007	HI A-547-B	7.5M Veirsep
Arena			5/27/2005	SMI 192-A	10M Spinsep (DGF)
Arena Offshore/M&H Energy	Arena Offshore		8/31/2006	GOM	4M Combosep
Aviara			5/12/2000	SMI 142-A	7.5M Veirsep (DGF)
BF Goodrich			3/4/1992	Kentucky	(3) 10M Veirsep-P
BG Trinidad		N00044	2/8/2007	Trinidad	20M Spinsep
BG Trinidad	BG Trinidad WT		4/28/2006	Trinidad	20M Veirsep w/ Skid Unit
BHP Billiton		N00022	5/1/2006	Neptune SPAR	30M Veirsep P (DGF)
Bluewater		N00043	12/8/2007	HI 589 A	5M Veirsep
Bois d' Arc		N00045	1/10/2007	MP-21	2.5M Spinsep P Sparging
Bois d' Arc			5/13/2005	VR 127	1M Spinsep - S
BP	Holstein	1N0009	6/28/2008	Holstein	50M Spinsep P
BP		N00041	3/1/2007	Nakika	20M Spinsep P
BP			1/1/2007	Nakika	20M Spinsep P (DGF)
BP			1/31/2003	Atlantis	75M Spinsep-P (DGF)
BP			6/10/2002	Mad Dog	50M Spinsep-P (DGF)
BP			9/27/2001	WD 133-B	10M Spinsep-P (DGF)
BP			3/29/2005	WC 66	15M Veirsep(DGF)
BP			11/2/2000	EC 261	10M Spinsep (DGF)
BP			12/27/1995	Venezuela	6M Veirsep
BP			7/7/1993	VK 989	40M Veirsep
BP			12/12/1990	MC 109-A	26M Sump Tank
BP			11/8/1990	MC 109-A	26M Veirsep
BW Offshore	Cascade Chinook	V00017	7/17/2008	Cascade Chinook	16-20M Spinsep/Veirsep
Braun			4/9/1990	Sweeney, TX	40M Multisep
British Gas/Fluor	BG Poinsettia	V00013	11/22/2006	Trinidad	12.5M Veirsep Skimmer Spinsep P
Burlington Resources			8/14/2000	Montana	20M Coversion to DGF
Burlington Resources			5/23/2000	Vermilion 119-D	5M Veirsep-Plus (DGF)
Burlington Resources			6/3/1997	Davis Project	5M Cyclosep-S
Burlington Resources			3/19/1997	EI 159-A	5M Cyclosep-S
Burlington Resources			10/28/1996	EI 206-A	5M Cyclosep
Cairn Energy			3/26/1998	ST 291	5M Veirsep
Chevron/SBM IMODCO	Frade	V00009	8/15/2007	Frade	120M Spinsep P
Chevron	Blind Faith	N00032	7/7/2006	Blind Faith	40M Spinsep (DGF)/HC

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Flotation Cell Installation List

Customer Name	Project Name	Project No.	Bkg Date	Location	Product Model
Chevron			5/3/2001	VERM 214 A & C	10M DGF Pump-Conversion of Column Flotation Unit
Chevron			7/30/1996	MP 69	16M Veirsep
Chevron			10/24/1995	BM 1	40M Veirsep-P (DGF)
Chevron			9/18/1995	MB 864-B	4M Veirsep-P
Chevron			3/13/1995	WD 97-A	5M Veirsep-S
Chevron			1/19/1995	MP 41-D	40M Veirsep
Chevron			8/1/1994	WC 534-A	1M Monosep-S
Chevron			4/8/1994	WC 564	5M Multisep-S
Chevron			9/19/1991	ST 177-A	30M Veirsep
Chevron			3/28/1991	BM H-H	55M Veirsep
Chevron / EXPRO Group			5/27/2005	Nigeria	10M Combosep (DGF)
Citgo			9/21/1999	Lemont, IL	75M Veirsep-P
CNG			2/15/1999	MP 225-A	5M Veirsep-Plus
CNG			1/8/1998	MP 281-A	15M Veirsep-Plus
CNG			8/18/1997	VR 313-C	7.5M Veirsep
CNG			8/10/1997	VR 313-B	15M Veirsep-Plus
CNG			9/25/1996	SS 246	5M Spinsep (DGF)
Coastal			5/13/1999	MP 223-A	5M Cyclosep
Coastal			8/14/1996	EI 327	5M Veirsep
Coastal			11/7/1995	WC 504-A	5M Cyclosep-S
Coastal			6/27/1995	GALV. 255	10M Veirsep
Coastal Oil			9/28/1999	EI 327-A	3M Spinsep
Coastal Oil			10/21/1996	WC 498-B-Aux	7.5M Veirsep
Coastline Process			11/16/2000	ST F & P	15M Veirsep
Colt/Nexen	Nexen Long Lake	N00036	3/30/2006	Canada	Veirsep
Conn Energy			11/10/1998	WC 171	1M Veirsep (DGF)
Connacher/BDR Engineering		N00040	4/18/2007	Canada Great Div	30M Veirsep P
Conoco			6/30/1993	WC 34-D	10M Cyclosep
Conoco			4/28/1993	WC 66-B	5M Cyclosep
CPO			9/21/1999	Venezuela	30M Cyclosep (DGF)
Delmar			5/4/1994	MP 259 Pabst	7.5M Veirsep
Devon Energy			8/25/2004	EI-330 "C"	25M Skimmer
Devon Energy			8/25/2004	EI-330 "C"	25M Veirsep (DGF)
Devon Energy	S.Marsh Island 330D	V00005	3/7/2006	GOM	5M Veirsep A
Devon Energy	S.Marsh Island 128C	V00005	3/7/2006	GOM	10M Skimmer(ASME code) Veirsep A
Devon Energy	S.Marsh Island 128B	V00005	3/7/2006	GOM	10M Skimmer(ASME code) Veirsep A
Devon Energy	S.Marsh Island 128A	V00005	3/7/2006	GOM	15M Skimmer(ASME code) Veirsep A
Devon Energy	Eugene Island 316-A	N00054	5/7/2008	Eugene Island 316-A	5M Veirsep
Dominion E & P	Ship Shoal 248 D	N00048	10/25/2006	GOM	5M Veirsep
Dominion E & P			3/8/2004	SS 246-A	5M Veirsep
Dominion E & P			11/12/2001	HI 571	5M Veirsep
Ecopetrol	Acacias Expansion-STAP		12/20/2009	Acacias Expansion	120M Veirsep (2)
EDC Noble China	CDX-SDP Offshore China		2010	China	60M Veirsep A
EDC China			3/6/2001	Dao Xi Field Devel.	40.5M Veirsep
EDC			12/7/1994	WD 83-E5	5M Cyclosep
EL Paso			2/9/2004	EI 372	5M Veirsep
EL Paso			2/15/2001	ST 204-B	5M Veirsep
EL Paso			11/9/2000	VK 385	5M Spinsep
EL Paso			7/21/2000	ST 48	4M Cyclosep
Elf Exploration			8/31/1990	EI 184	10M Veirsep

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Flotation Cell Installation List

Customer Name	Project Name	Project No.	Bkg Date	Location	Product Model
Energy Partners			4/22/2005	ST 41	15M Combosep(DGF)
Eni Petroleum	Ship shoal 247-F	N00058	7/15/2008	Ship Shoal 247-F	Veirsep A
Enppi/PDVSA	Pagmi Phase I	V00016	1/4/2008	Pagmi Phase I	5M Veirsep A
Enron			7/18/1994	IBIS	10M Veirsep
Enserch			4/25/1997	GB 388	3M Spinsep-S
Enserch			7/2/1992	MC 441-SWF	5M Combosep
EPMI			6/17/1999	Larut-A Malaysia	40M CPI
EPMI			6/17/1999	Larut-A Malaysia	40M Veirsep
EPMI			6/2/1997	SeA Malaysia	100M Veirsep-P
EPMI			6/2/1997	SeA Malaysia	100M Veirsep-P
EPMI			6/2/1997	GuA Malaysia	12M Skimmed Oil Tank
EPMI			6/2/1997	SeA Malaysia	12M Skimmed Oil Vessel
EPMI			6/2/1997	GuA Malaysia	40M Cyclosep-SP
EPMI			6/2/1997	GuA Malaysia	40M Cyclosep-SP
EPMI			6/2/1997	SeA Malaysia	46M Cyclosep-SP
EPMI			6/2/1997	SeA Malaysia	46M Cyclosep-SP
EPMI			6/2/1997	SeA Malaysia	46M Cyclosep-SP
EPMI			6/2/1997	GuA Malaysia	70M Veirsep
EPMI			6/2/1997	GuA Malaysia	70M Veirsep
ERT			4/20/2005	VR-331	15M Veirsep (DGF)
Expro			5/27/2005	Nigeria (DIBI Proj)	10M Combosep (DGF)
ExxonMobil		N00031	9/1/2006	TCOT	35M Veirsep P
Fluor	Chayvo-Sakhalin Isl. Upgrade	V00018	2009	Sakhalin Island-Russia	100M Veirsep P
Forcenergy			1/26/1995	WC 205	5M Veirsep
Forcenergy			7/5/1994	SMI 6	5M Cyclosep
Forest Oil	Ship Shoal 277		3/8/2006	GOM	3M Veirsep
GSME			2/20/2004	Kuwait	5M Veirsep-P (DGF) (CAPS)
Hanover			4/10/2003	Pemex	4M Spinsep
Hanover			4/10/2003	Pemex	4M Spinsep
Hanover (Canada)			1/31/2003	Atlantis	75M Spinsep-P
Hardage House			6/12/1992	Lindsay, OK	1M Veirsep
Helis Oil & Gas /Audubon	Black Bay	V00004	3/22/2006	GoM	Spinsep
Helix Energy	Helix project 1240	V00011	10/30/2007	Pheonix	50M Spinsep P
Hess		N00020	5/1/2006	El Agreb West, Algeria	25M Cyclosep (DGF)
Hess		N00020	5/1/2006	El Gassi, Algeria	30M Cyclosep (DGF)
Hess		N00020	5/1/2006	El Agreb West, Algeria	25M Cyclosep (DGF)
Hunt Oil	Vermillion 229	N00060	1/21/2009	Vermillion 229	5M Veirsep w/sparging
Hunt Petroleum	ST 254		1/25/2007	ST 254	Spinsep A
Hunt Petroleum			10/15/2005	SMI 40-JA	15M Veirsep (DGF)
Hunt Petroleum			7/20/1995	EI 63	5M Veirsep
Kerr McGee	Boomvang	V00006	9/1/2006	Boomvang	40M Water Polishing Skids
Kerr McGee	Nansen	V00007	9/1/2006	Nansen	40M Water Polishing Skids
Kerr McGee			12/3/2002	SS 33	5M Veirsep
Kerr McGee			7/20/1998	SS 218	3M Veirsep-Plus
Kerr McGee			1/8/1998	EB 910	10M Veirsep
Kerr McGee			3/3/1995	BS 21	25M Veirsep
Kerr McGee			6/29/1992	SS 233-B	10M Veirsep
Kerr McGee			6/25/1992	SS 300-B	12.5M Veirsep
Kerr McGee			11/30/1990	SS 214-K	4M Veirsep
Kerr McGee			8/31/1990	SS 229-A	4M Veirsep
Kerr McGee			7/19/1990	WC 100	6M Veirsep
Kerr McGee			5/30/1990	MP 108-A	6M Veirsep
Kerr McGee			1/30/1990	EI 28	5M Veirsep
Kerr McGee			1/30/1990	Verm 114	5M Veirsep

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Flotation Cell Installation List

Customer Name	Project Name	Project No.	Bkg Date	Location	Product Model
Kvaerner			6/4/1998	Iraq	15M Veirsep-P (DGF)
Kvaerner (Canada)			11/22/2004	Deer Creek	30M Veirsep-P (DGF)
Kvaerner (Canada)			5/17/2004	Nexen Long Lake	(2) 105M Veirsep-P (DGF)
Kvaerner (Canada)			8/2/2000	ColdLake MahKeses	143M Veirsep
Kvaerner (UK)			7/26/2000	United Kingdom	40M Veirsep
Kvaerner (UK)			7/26/2000	United Kingdom	40M Veirsep
Lion Oil			7/7/1999	Eduardo, AR	7.5M Cyclosep (DGF)
LL&E			9/17/1997	VR 171	3M Combosep
LL&E			11/25/1995	WC 554	3M Mini-Veirsep
LL&E			5/17/1995	EI 108	3M Veirsep
LL&E			4/5/1995	EI 371	2M Mini-Veirsep
LL&E			6/13/1991	SS 202-B	10M Veirsep
LL&E			5/28/1991	HI A523	5M Veirsep
LL&E			4/17/1991	Verm 412	5M Veirsep
Marathon			5/25/1995	Verm 331	10M Veirsep-C
Marathon			3/8/1995	SP 87-D	10M Veirsep
Marathon			6/13/1991	SP 89-B	20M Veirsep-C
Marathon			5/28/1991	WD 79-B	30M Veirsep-C
Marathon			5/28/1991	WC 620	5M Sump Tank
Marathon			3/29/1990	WD 134	7.5M Multisep
Marathon			3/29/1990	WD 134	7.5M Veirsep
Marathon U.K.			1/17/2000	Brae 'A'	40M Veirsep
Maritech	East Cameron 328A	N00059	12/30/2008	EC 328A	7.5M Veirsep A w/skimmer
Mobil			10/7/1998	MP 283-A	10M Combosep
Mobil			11/7/1995	GC 18	25M Veirsep (Conversion DGF)
Mobil			11/7/1995	GC 18	25M Cyclosep
Mobil			2/10/1992	EI 105	6M Veirsep
Mobil			5/28/1991	EI 128	7.5M Veirsep-C
Mobil			4/1/1991	Verm 215	4.5M Veirsep-C
Mobil			12/28/1990	Matagor 665	1M Mini-Veirsep
Mobil			12/13/1990	Verm 131-CF	5M Veirsep-C
Mobil			10/31/1990	Matagor 487	2.5M Mini-Veirsep
Modec		N00025	8/1/2006	Stybarrow	95M Spinsep P (DGF)
Murphy Oil	FrontRunner Project		5/12/2003	FrontRunner Project	20M Spinsep-P
Murphy Oil	Medusa Project		7/30/2001	Medusa Project	20M Spinsep-P
Newfield		N00035	8/1/2006	MP138-G	10M Veirsep (DGF)
Newfield			3/7/2003	EI 182	5M Veirsep (DGF)
Newfield			3/7/2003	EB 947	5M Veirsep (DGF)
Newfield			8/9/2001	EB 947-A	3M Veirsep
Newfield			7/19/2001	EI 217-B	3M Veirsep
Newfield			3/16/2001	EC 330-B	5M Veirsep
Newfield			11/23/1999	EI 198-A	7.5M Spinsep
Newfield			5/7/1999	Verm 146	5M Veirsep
Newfield			9/25/1998	SMI 141-A	10M Veirsep
Newfield			2/6/1997	SS 354	5M Veirsep
Newfield			9/5/1996	Verm 398-A	10M Veirsep
Newfield			4/30/1996	EI 128	7.5M Veirsep
Newfield			3/27/1996	EC 47JP	7.5M Veirsep
Newfield			10/11/1995	EC 62-A	1M Pacsep
Newfield			9/26/1994	EC 330-B	10M Veirsep-C
Newfield			7/7/2005	SMI 147-A	5M Veirsep (DGF)
Newfield/Chieftan			10/13/2000	HI 531-A	10M Skimmer & Spinsep
Nippon Oil	Green WC 20	N00050	9/1/2007	Green WC 20	5M Veirsep

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Flotation Cell Installation List

Customer Name	Project Name	Project No.	Bkg Date	Location	Product Model
Nippon Oil		N00029	6/1/2006	MP 153-B	10M Veirsep (DGF)
Norcen			10/24/1995	EI 296-B	3M Veirsep
North Central Oil			8/7/1998	SP 24 WI Facility	10M Veirsep (Conversion DGF)
Nova Chemical (KPS)			6/4/1998	Canada	30M Veirsep-P
Ocean Energy			9/3/1997	MP 138-B	5M Veirsep
OEDC			11/5/1997	Destin Dome One	3M Cyclosep-S
OEDC			1/20/1997	VK 121	3M Cyclosep-S
OEDC			7/19/1995	MB 960	3M Cyclosep-S
OEDC			3/31/1995	VK 24	3M Cyclosep-S
OSFI (Seagull)			8/21/1996	SS 129	7.5M Veirsep
OSFI / Tarpon			5/19/2004	Mi-726	5M Veirsep
Oxy			10/6/1993	SP 45-A	10M Veirsep
Paloma Energy/Arena	Eugene Island 100	N00057	5/1/2008	EI 100	20M Veirsep
Paloma	Paloma		5/8/2006		10M Veirsep
Pegasus/Chevron	Eugene Island 361	N00053	5/1/2008	EI 361	5M Spinsep
Pemex				FPSO	4M Spinsep-P
Pemex / Ecomecatrorica	Ku-Maloob-Zaap		2007	Ku-Maloob-Zaap	Combosep
Pemex / ESISA			5/3/2004	Dos Bocas, Mexico	(2) 40M Veirsep-P (DGF)
Pemex / ESISA			5/3/2004	E-Ku-A2 – Mexico	1M Combosep (DGF)
PEMEX/ESISA			10/23/2004	E-Ku-A2 – Mexico	Sump
Pennzoil			5/26/1994	EI 330-C	10M Veirsep
Petro Canada			6/16/2004	MacKay River Canada	4-DA2 DGF Pumps
Petrobras	P-56		12/26/2007	P-56	DGF Pumps
Petrobras	P-53		9/1/2006	P-53	2-95M Spinsep P (DGF)
Petrobras	P-51		7/1/2006	P-51	4 DGF Pumps
Petrobras	P-54		5/1/2006	P-54	2-95M Spinsep P (DGF)
Petrobras	P-47		5/23/2003	Brazil	35M Spinsep-P(DGF)
Petrobras	P-47		5/23/2003	Brazil	35M Spinsep-P(DGF)
Petrobras			3/8/2002	Replan	5M Spinsep
Petrobras			10/5/2001		105M Veirsep-Plus (DGF)
Petrobras			10/5/2001		105M Veirsep-Plus (DGF)
Petrobras			7/14/2000	Replan	170M Veirsep-Plus (DGF)
Petrobras	P33		11/3/1998	P33	25M Spinsep-P (DGF)
Petrobras			8/17/1998	BrazilPNA-1	7.5M Veirsep
Petrobras			8/17/1998	BrazilPNA-1	10M Veirsep
Petrobras			4/7/1998	Pampo	75M Veirsep
Petrobras / TSL			11/30/2004	PCE platform-Brazil	31.5M Veirsep-Plus (DGF)
Pheco	MP 21		8/2/2006	GOM	Veirsep
Pinnacle Engineering	WC 661-A		6/21/2006	South America	5M Veirsep ATM
Pinnacle Engineering	ATP/Pinnacle A589 "A"		3/1/2006	GOM	5M Veirsep A
Pinnacle Engineering	Blue Water/ATP Oil		8/14/2006	GOM	5M Veirsep
Pluspetrol peru	Block 56	N00049	10/27/2006	Peru	5M Veirsep
Pogo			8/24/1994	MP 123-A	6M Veirsep
Samedan			6/18/1999	ST 196	10M Skimmer Converted to DGF
Samedan			9/25/1997	EC 320	5M Veirsep
Samedan			5/29/1996	WC 599-A	5M Cyclosep-S
Samedan			4/4/1995	Verm 371-A	10M Combosep
Samedan			6/6/1994	EC 332-A	10M Combosep
Santa Fe			3/24/1992	SS 229	6M Veirsep
SBM Atlantia/Murphy	Thunder Hawk	V00012	2/27/2007	GOM	Spinsep
Seagull			1/7/1996	Galv 349	3M Mini-Veirsep
Seagull			9/1/1995	Galv 393-C	5M Cyclosep

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Flotation Cell Installation List

Customer Name	Project Name	Project No.	Bkg Date	Location	Product Model
Seagull			8/18/1994	EI 45	1M Pacsep
Seagull			4/29/1994	Brazos 397	3M Cyclosep-(DGF)
Seneca			11/10/1995	Verm 252	5M Veirsep-S
Shell	Green Canyon 65		2007	Green Canyon 65	Veirsep
Shell	Nakika		9/21/2006	Nakika	50M Spinsep P
Shell			4/13/1995	SP 62-A	15M Veirsep-C
Shell			4/13/1995	SP 62-B	15M Veirsep-C
Shell UK	Shell UK		5/26/2006	USA	DGF
Siemens	Gulfinho II	N00026	5/1/2006	Gulfinho II	50M Spinsep P (DGF)
Sivalls, Inc.			10/31/2004		(3) DGF/pump pkgs
Sonat			5/10/1995	EC 46	10M Veirsep
Sonat			1/18/1994	EC 23	5M Veirsep
Sonat			11/25/1991	EC 231-A	10M Veirsep
Sonat			11/25/1991	SS 226-B	10M Veirsep
Spirit 76			3/9/2000	SS 295-A	10M Veirsep (DGF)
SPN Resources		N00042	1/5/2007	SP 60-D	7.5M Veirsep
SPN Resources Pegasus	WD 86 "A"	N00037	3/16/2006	GOM	5M Spinsep
Stone Energy	Stone Energy		6/7/2006	USA	5M Veirsep w/DGF
Stone Energy	Vermillion 256-E	N00027	5/17/2006	GOM	5M Veirsep (DGF)
Stone Energy	Vermillion 267 "F"	N00028	2/3/2006	GOM	5M Veirsep A
Stone Energy			6/11/2004	MP-72 "A"	5M Veirsep (DGF)
Stone Energy			7/2/2005	MP 177	5M Veirsep (DGF)
Tarpon		N00038	12/5/2006		5M Veirsep
Taylor Energy			5/11/2004	SMI 69	10M Veirsep (DGF)
Taylor Energy			9/9/2003		5M Veirsep (DGF)
Total	Total AKPO	V00002	1/1/2007	AKPO	Oil Drum Skimmer
Texaco			1/31/1991	GB 189-A	10M Veirsep
Texaco			9/27/1990	SMI 239-D	10M Veirsep
Thums			8/30/1999	Long Beach, CA	40M Veirsep (Conversion DGF)
Total	Matterhorn		2007		Veirsep A
Trinmar			1/31/1997	Trinidad	30M Veirsep
Trinmar			4/23/1992	Pt. Fortin	30M Veirsep
TSL	P-63 Papa Terra		8/5/2010	Brazil	Brise Pump (6)
TSL			4-Feb	Santos	7.5M Veirsep (DGF)
TSL			4-Feb	Cubotos	15M Veirsep (DGF)
TSL			Aug-00	Macae	5M Cyclosep (DGF)
Unocal			4/25/2003	EI 24-A	5M Spinsep-P
Unocal			3/6/2001	SS 266-B	5.5M Veirsep (DGF)
Unocal			5/12/1995	ST 53	15M Veirsep
Unocal			10/14/2004	EI 39	10M Spinsep-SP
Vastar (Now Dynamic Resources)			1/17/2001	MC 127	30M Spinsep-P (DGF)
Vastar (Now Dynamic Resources)			10/5/1999	MP 264	3M Flotation Cell (DGF)
Vastar (Now Dynamic Resources)			8/20/1999	GI 94-B	5M Veirsep-Plus
Vastar (Now Dynamic Resources)			8/17/1999	WC 645-A	6M Spinsep (DGF)
Vastar (Now Dynamic Resources)			5/12/1999	WC 66-C	3M Conversion (DGF)
Vastar (Now Dynamic Resources)			1/28/1999	WC 66-A	5M Spinsep-P (DGF)
Vastar (Now Dynamic Resources)			1/12/1999	MC 148	15M Veirsep-P (DGF)

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Flotation Cell Installation List

Customer Name	Project Name	Project No.	Bkg Date	Location	Product Model
Vastar (Now Dynamic Resources)			1/11/1999	WC 65-JA	5M Spinsep-P (DGF)
Vastar (Now Dynamic Resources)			12/4/1998	SP 60-D	15M Veirsep
Vastar (Now Dynamic Resources)			5/10/1995	EI 247H	3M Monosep-S
W&T			4/12/2001	EI 397-A	10M Combosep
W&T			6/5/1996	Verm 279	5M Spinsep-S
W&T Offshore	E Cameron 338A	N00047	9/21/2006	GOM	5M Spinsep A
Walter Oil & Gas			6/14/1999	MP 301	3M Veirsep
Wapet			3/15/1996	Australia	70M Veirsep
Westcomm Pump			5/7/2004	Canada	2.5 DA2 (4) DGF pumps
Wood Group/Onsite Services		N00015	2/1/2006	Trinidad	1M Combosep
Worley Parson	MEG Canada-Christina lake Phase 2B		2/17/2010	Christina Lake Ph 2B	135M Veirsep P
Zilkha			6/1/1995	S.Pel. 22	5M Mini-Veirsep
Zilkha			12/9/1994	WC 98	1M Pacsep
Zilkha			8/3/1994	EC 280	1M Pacsep

Table 5.8 Updated Flotation Cell List

Flotation Cell Installation List

Updated Dec 2009

Customer Name	Project Name	Project No.	Bkg Date	Location	Product Model
Total	Total AKPO	V00002	1/1/2007	AKPO	Oil Drum Skimmer
BP			1/31/2003	Atlantis	75M Spinsep-P (DGF)
Hanover (Canada)			1/31/2003	Atlantis	75M Spinsep-P
Wapet			3/15/1996	Australia	70M Veirsep
Chevron	Blind Faith	N00032	7/7/2006	Blind Faith	40M Spinsep (DGF)/HC
Chevron			10/24/1995	BM 1	40M Veirsep-P (DGF)
Chevron			3/28/1991	BM H-H	55M Veirsep
Kerr McGee	Boomvang	V00006	9/1/2006	Boomvang	40M Water Polishing Skids
Marathon U.K.			1/17/2000	Brae 'A'	40M Veirsep
Petrobras	P-47		5/23/2003	Brazil	35M Spinsep-P(DGF)
Petrobras	P-47		5/23/2003	Brazil	35M Spinsep-P(DGF)
Petrobras			8/17/1998	BrazilPNA-1	7.5M Veirsep
Petrobras			8/17/1998	BrazilPNA-1	10M Veirsep
Seagull			4/29/1994	Brazos 397	3M Cyclosep-(DGF)
Kerr McGee			3/3/1995	BS 21	25M Veirsep
Colt/Nexen	Nexen Long Lake	N00036	3/30/2006	Canada	Veirsep
Nova Chemical (KPS)			6/4/1998	Canada	30M Veirsep-P
Westcomm Pump			5/7/2004	Canada	2.5 DA2 (4) DGF pumps
Connacher/BDR Engineering		N00040	4/18/2007	Canada Great Div	30M Veirsep P
BW Offshore	Cascade Chinook	V00017	7/17/2008	Cascade Chinook	Spinsep/Veirsep
Kvaerner (Canada)			8/2/2000	ColdLake MahKeses	143M Veirsep
TSL			4-Feb	Cubotos	15M Veirsep (DGF)
EDC China			3/6/2001	Dao Xi Field Devel.	40.5M Veirsep
Burlington Resources			6/3/1997	Davis Project	5M Cyclosep-S
Kvaerner (Canada)			11/22/2004	Deer Creek	30M Veirsep-P (DGF)
OEDC			11/5/1997	Destin Dome One	3M Cyclosep-S
Pemex / ESISA			5/3/2004	Dos Bocas, Mexico	(2) 40M Veirsep-P (DGF)
Kerr McGee			1/8/1998	EB 910	10M Veirsep
AGIP			7/27/2001	EB 927	10M DGF-C
Newfield			3/7/2003	EB 947	5M Veirsep (DGF)
Newfield			8/9/2001	EB 947-A	3M Veirsep
Sonat			1/18/1994	EC 23	5M Veirsep
Sonat			11/25/1991	EC 231-A	10M Veirsep
BP			11/2/2000	EC 261	10M Spinsep (DGF)
Zilkha			8/3/1994	EC 280	1M Pacsep
Samedan			9/25/1997	EC 320	5M Veirsep
Maritech	East Cameron 328A	N00059	12/30/2008	EC 328A	7.5M Veirsep A w/skimmer
Newfield			3/16/2001	EC 330-B	5M Veirsep
Newfield			9/26/1994	EC 330-B	10M Veirsep-C
Samedan			6/6/1994	EC 332-A	10M Combosep
Sonat			5/10/1995	EC 46	10M Veirsep
Newfield			3/27/1996	EC 47JP	7.5M Veirsep
Newfield			10/11/1995	EC 62-A	1M Pacsep
Lion Oil			7/7/1999	Eduardo, AR	7.5M Cyclosep (DGF)
Paloma Energy/Arena	Eugene Island 100	N00057	5/1/2008	EI 100	20M Veirsep
Mobil			2/10/1992	EI 105	6M Veirsep
LL&E			5/17/1995	EI 108	3M Veirsep
Mobil			5/28/1991	EI 128	7.5M Veirsep-C
Newfield			4/30/1996	EI 128	7.5M Veirsep
Burlington Resources			3/19/1997	EI 159-A	5M Cyclosep-S
Newfield			3/7/2003	EI 182	5M Veirsep (DGF)
Elf Exploration			8/31/1990	EI 184	10M Veirsep
Newfield			11/23/1999	EI 198-A	7.5M Spinsep
Burlington Resources			10/28/1996	EI 206-A	5M Cyclosep
Amoco			10/20/1994	EI 215	10M Monosep-S
Newfield			7/19/2001	EI 217-B	3M Veirsep

Customer Name	Project Name	Project No.	Bkg Date	Location	Product Model
Vastar (Now Dynamic Resources)			5/10/1995	EI 247H	3M Monosep-S
Unocal			4/25/2003	EI 24-A	5M Spinsep-P
Aquila Energy			5/7/1990	EI 277	1M Veirsep
Kerr McGee			1/30/1990	EI 28	5M Veirsep
Norcen			10/24/1995	EI 296-B	3M Veirsep
Coastal			8/14/1996	EI 327	5M Veirsep
Coastal Oil			9/28/1999	EI 327-A	3M Spinsep
Pennzoil			5/26/1994	EI 330-C	10M Veirsep
Pegasus/Chevron	Eugene Island 361	N00053	5/1/2008	EI 361	Spinsep
LL&E			4/5/1995	EI 371	2M Mini-Veirsep
EL Paso			2/9/2004	EI 372	5M Veirsep
Unocal			10/14/2004	EI 39	10M Spinsep-SP
W & T			4/12/2001	EI 397-A	10M Combosep
Seagull			8/18/1994	EI 45	1M Pacsep
Hunt Petroleum			7/20/1995	EI 63	5M Veirsep
Devon Energy			8/25/2004	EI-330 "C"	25M Skimmer
Devon Energy			8/25/2004	EI-330 "C"	25M Veirsep (DGF)
Pemex / ESISA			5/3/2004	E-Ku-A2 – Mexico	1M Combosep (DGF)
PEMEX/ESISA			10/23/2004	E-Ku-A2 – Mexico	Sump
Hess		N00020	5/1/2006	El Agreb West, Algeria	25M Cyclosep (DGF)
Hess		N00020	5/1/2006	El Agreb West, Algeria	25M Cyclosep (DGF)
Hess		N00020	5/1/2006	El Gassi, Algeria	30M Cyclosep (DGF)
Amerada Hess			12/29/2004	Elon Project	60M Spinsep-P (DGF)
Devon Energy	Eugene Island 316-A	N00054	5/7/2008	Eugene Island 316-A	Veirsep
Pemex				FPSO	4M Spinsep-P
Chevron/SBM IMODCO	Frade	V00009	8/15/2007	Frade	120M Spinsep P
Murphy Oil	FrontRunner Project		5/12/2003	FrontRunner Project	20M Spinsep-P
Seagull			1/7/1996	Galv 349	3M Mini-Veirsep
Seagull			9/1/1995	Galv 393-C	5M Cyclosep
Coastal			6/27/1995	GALV. 255	10M Veirsep
Texaco			1/31/1991	GB 189-A	10M Veirsep
Enserch			4/25/1997	GB 388	3M Spinsep-S
Mobil			11/7/1995	GC 18	25M Veirsep (Conversion DGF)
Mobil			11/7/1995	GC 18	25M Cyclosep
AGIP			11/21/2001	GC 254	10M DGF-C
Vastar (Now Dynamic			8/20/1999	GI 94-B	5M Veirsep-Plus
Alliance Engineering/Shell	Perdido	V00008	8/1/2006	GOM	40M Spinsep P/HC
Arena Offshore/M&H Energy	Arena Offshore		8/31/2006	GOM	4M Combosep
Devon Energy	S.Marsh Island 330D	V00005	3/7/2006	GOM	5M Veirsep A
Devon Energy	S.Marsh Island 128C	V00005	3/7/2006	GOM	10M Skimmer(ASME code) Veirsep A
Devon Energy	S.Marsh Island 128B	V00005	3/7/2006	GOM	10M Skimmer(ASME code) Veirsep A
Devon Energy	S.Marsh Island 128A	V00005	3/7/2006	GOM	15M Skimmer(ASME code) Veirsep A
Dominion E & P	Ship Shoal 248 D	N00048	10/25/2006	GOM	5M Veirsep
Forest Oil	Ship Shoal 277		3/8/2006	GOM	3M Veirsep
Helis Oil & Gas /Audubon	Black Bay	V00004	3/22/2006	GoM	Spinsep
Pheco	MP 21		8/2/2006	GOM	Veirsep
Pinnacle Engineering	ATP/Pinnacle A589 "A"		3/1/2006	GOM	5M Veirsep A
Pinnacle Engineering	Blue Water/ATP Oil		8/14/2006	GOM	5M Veirsep
SBM Atlantia/Murphy	Thunder Hawk	V00012	2/27/2007	GOM	Spinsep
SPN Resources Pegasus	WD 86 "A"	N00037	3/16/2006	GOM	5M Spinsep
Stone Energy	Vermillion 256-E	N00027	5/17/2006	GOM	5M Veirsep (DGF)
Stone Energy	Vermillion 267 "F"	N00028	2/3/2006	GOM	5M Veirsep A
W&T Offshore	E Cameron 338A	N00047	9/21/2006	GOM	5M Spinsep A
Shell	Green Canyon 65		2007	Green Canyon 65	Veirsep
Nippon Oil	Green WC 20	N00050	9/1/2007	Green WC 20	5M Veirsep
EPMI			6/2/1997	GuA Malaysia	12M Skimmed Oil Tank
EPMI			6/2/1997	GuA Malaysia	40M Cyclosep-SP
EPMI			6/2/1997	GuA Malaysia	40M Cyclosep-SP
EPMI			6/2/1997	GuA Malaysia	70M Veirsep

Customer Name	Project Name	Project No.	Bkg Date	Location	Product Model
EPMI			6/2/1997	GuA Malaysia	70M Veirsep
Siemens	Gulfinho II	N00026	5/1/2006	Gulfinho II	50M Spinsep P (DGF)
Newfield/Chieftan			10/13/2000	HI 531-A	10M Skimmer & Spinsep
Dominion E & P			11/12/2001	HI 571	5M Veirsep
Bluewater		N00043	12/8/2007	HI 589 A	5M Veirsep
LL&E			5/28/1991	HI A523	5M Veirsep
Arena		N00046	2/9/2007	HI A-547-B	7.5M Veirsep
BP	Holstein	1N0009	6/28/2008	Holstein	Spinsep P
Enron			7/18/1994	IBIS	10M Veirsep
Kvaerner			6/4/1998	Iraq	15M Veirsep-P (DGF)
BF Goodrich			3/4/1992	Kentucky	(3) 10M Veirsep-P
Pemex / Ecomecatrorica	Ku-Maloob-Zaap		2007	Ku-Maloob-Zaap	Combosep
GSME			2/20/2004	Kuwait	5M Veirsep-P (DGF) (CAPS)
EPMI			6/17/1999	Larut-A Malaysia	40M CPI
EPMI			6/17/1999	Larut-A Malaysia	40M Veirsep
Citgo			9/21/1999	Lemont, IL	75M Veirsep-P
Hardage House			6/12/1992	Lindsay, OK	1M Veirsep
Thums			8/30/1999	Long Beach, CA	40M Veirsep (Conversion DGF)
TSL			Aug-00	Macae	5M Cyclosep (DGF)
Petro Canada			6/16/2004	MacKay River Canada	4-DA2 DGF Pumps
BP			6/10/2002	Mad Dog	50M Spinsep-P (DGF)
Mobil			10/31/1990	Matagor 487	2.5M Mini-Veirsep
Mobil			12/28/1990	Matagor 665	1M Mini-Veirsep
Chevron			9/18/1995	MB 864-B	4M Veirsep-P
OEDC			7/19/1995	MB 960	3M Cyclosep-S
BP			12/12/1990	MC 109-A	26M Sump Tank
BP			11/8/1990	MC 109-A	26M Veirsep
Vastar (Now Dynamic Resources)			1/17/2001	MC 127	30M Spinsep-P (DGF)
Vastar (Now Dynamic Resources)			1/12/1999	MC 148	15M Veirsep-P (DGF)
Enserch			7/2/1992	MC 441-SWF	5M Combosep
Murphy Oil	Medusa Project		7/30/2001	Medusa Project	20M Spinsep-P
OSFI / Tarpon			5/19/2004	Mi-726	5M Veirsep
Burlington Resources			8/14/2000	Montana	20M Coversion to DGF
Kerr McGee			5/30/1990	MP 108-A	6M Veirsep
Pogo			8/24/1994	MP 123-A	6M Veirsep
Ocean Energy			9/3/1997	MP 138-B	5M Veirsep
Nippon Oil		N00029	6/1/2006	MP 153-B	10M Veirsep (DGF)
Stone Energy			7/2/2005	MP 177	5M Veirsep (DGF)
Coastal			5/13/1999	MP 223-A	5M Cyclosep
CNG			2/15/1999	MP 225-A	5M Veirsep-Plus
Delmar			5/4/1994	MP 259 Pabst	7.5M Veirsep
Vastar (Now Dynamic Resources)			10/5/1999	MP 264	3M Flotation Cell (DGF)
CNG			1/8/1998	MP 281-A	15M Veirsep-Plus
Mobil			10/7/1998	MP 283-A	10M Combosep
Walter Oil & Gas			6/14/1999	MP 301	3M Veirsep
Chevron			1/19/1995	MP 41-D	40M Veirsep
Chevron			7/30/1996	MP 69	16M Veirsep
Newfield		N00035	8/1/2006	MP138-G	10M Veirsep (DGF)
Bois d' Arc		N00045	1/10/2007	MP-21	2.5M Spinsep P Sparging
Stone Energy			6/11/2004	MP-72 "A"	5M Veirsep (DGF)
BP		N00041	3/1/2007	Nakika	20M Spinsep P
BP			1/1/2007	Nakika	20M Spinsep P (DGF)
Shell	Nakika		9/21/2006	Nakika	50M Spinsep P
Kerr McGee	Nansen	V00007	9/1/2006	Nansen	40M Water Polishing Skids
BHP Billiton		N00022	5/1/2006	Neptune SPAR	30M Veirsep P (DGF)
Kvaerner (Canada)			5/17/2004	Nexen Long Lake	(2) 105M Veirsep-P (DGF)
Chevron / EXPRO Group			5/27/2005	Nigeria	10M Combosep (DGF)
Expro			5/27/2005	Nigeria (DIBI Proj)	10M Combosep (DGF)
Allen Process Systems			7/26/1999	NPDC Nigeria	6M Veirsep-Plus
Amerada Hess/ Modec			1/5/2005	Okume Project	50M Spinsep-P (DGF)

Customer Name	Project Name	Project No.	Bkg Date	Location	Product Model
Amerada Hess/ Modec			1/5/2005	Oveng Project	30M Spinsep-P (DGF)
Petrobras	P33		11/3/1998	P33	25M Spinsep-P (DGF)
Petrobras	P-51		7/1/2006	P-51	4 DGF Pumps
Petrobras	P-53		9/1/2006	P-53	2-95M Spinsep P (DGF)
Petrobras	P-54		5/1/2006	P-54	2-95M Spinsep P (DGF)
Petrobras	P-56		12/26/2007	P-56	DGF Pumps
Enppi/PDVSA	Pagmi Phase I	V00016	1/4/2008	Pagmi Phase I	Veirsep
Petrobras			4/7/1998	Pampo	75M Veirsep
Petrobras / TSL			11/30/2004	PCE platform-Brazil	31.5M Veirsep-Plus (DGF)
Hanover			4/10/2003	Pemex	4M Spinsep
Hanover			4/10/2003	Pemex	4M Spinsep
Pluspetrol peru	Block 56	N00049	10/27/2006	Peru	5M Veirsep
Helix Energy	Helix project 1240	V00011	10/30/2007	Pheonix	50M Spinsep P
Trinmar			4/23/1992	Pt. Fortin	30M Veirsep
Petrobras			3/8/2002	Replan	5M Spinsep
Petrobras			7/14/2000	Replan	170M Veirsep-Plus (DGF)
Zilkha			6/1/1995	S.Pel. 22	5M Mini-Veirsep
Fluor	Chayvo-Sakhalin Isl. Upgrade	V00018	2009	Sakhalin Island-Russia	100M Veirsep P
TSL			4-Feb	Santos	7.5M Veirsep (DGF)
Aramco	Safaniya	V00010	1/8/2007	Saudi Arabia	170M Veirsep P
EPMI			6/2/1997	SeA Malaysia	100M Veirsep-P
EPMI			6/2/1997	SeA Malaysia	100M Veirsep-P
EPMI			6/2/1997	SeA Malaysia	12M Skimmed Oil Vessel
EPMI			6/2/1997	SeA Malaysia	46M Cyclosep-SP
EPMI			6/2/1997	SeA Malaysia	46M Cyclosep-SP
EPMI			6/2/1997	SeA Malaysia	46M Cyclosep-SP
Eni Petroleum	Ship shoal 247-F	N00058	7/15/2008	Ship Shoal 247-F	Veirsep A
Newfield			9/25/1998	SMI 141-A	10M Veirsep
Aviara			5/12/2000	SMI 142-A	7.5M Veirsep (DGF)
Newfield			7/7/2005	SMI 147-A	5M Veirsep (DGF)
Arena			5/27/2005	SMI 192-A	10M Spinsep (DGF)
Texaco			9/27/1990	SMI 239-D	10M Veirsep
Hunt Petroleum			10/15/2005	SMI 40-JA	15M Veirsep (DGF)
Forcenergy			7/5/1994	SMI 6	5M Cyclosep
Taylor Energy			5/11/2004	SMI 69	10M Veirsep (DGF)
Pinnacle Engineering	WC 661-A		6/21/2006	South America	5M Veirsep ATM
North Central Oil			8/7/1998	SP 24 WI Facility	10M Veirsep (Conversion DGF)
Aran			6/20/1995	SP 37-E	5M Skimmer-S
Oxy			10/6/1993	SP 45-A	10M Veirsep
SPN Resources		N00042	1/5/2007	SP 60-D	7.5M Veirsep
Vastar (Now Dynamic Resources)			12/4/1998	SP 60-D	15M Veirsep
Shell			4/13/1995	SP 62-A	15M Veirsep-C
Shell			4/13/1995	SP 62-B	15M Veirsep-C
Marathon			3/8/1995	SP 87-D	10M Veirsep
Marathon			6/13/1991	SP 89-B	20M Veirsep-C
Apache			9/18/1996	SP BLK 12	5M Cyclosep
Apache			10/29/2004	SP-62-A	10M Combosep (DGF)
Apache			10/29/2004	SP-62-B	5M Combosep (DGF)
Apache			10/29/2004	SP-62-C	10M Skimmer
OSFI (Seagull)			8/21/1996	SS 129	7.5M Veirsep
LL&E			6/13/1991	SS 202-B	10M Veirsep
Kerr McGee			11/30/1990	SS 214-K	4M Veirsep
Kerr McGee			7/20/1998	SS 218	3M Veirsep-Plus
Sonat			11/25/1991	SS 225-B	10M Veirsep
Santa Fe			3/24/1992	SS 229	6M Veirsep
Kerr McGee			8/31/1990	SS 229-A	4M Veirsep
Kerr McGee			6/29/1992	SS 233-B	10M Veirsep
CNG			9/25/1996	SS 246	5M Spinsep (DGF)
Dominion E & P			3/8/2004	SS 246-A	5M Veirsep
Unocal			3/6/2001	SS 266-B	5.5M Veirsep (DGF)
Spirit 76			3/9/2000	SS 295-A	10M Veirsep (DGF)

Customer Name	Project Name	Project No.	Bkg Date	Location	Product Model
Kerr McGee			6/25/1992	SS 300-B	12.5M Veirsep
Kerr McGee			12/3/2002	SS 33	5M Veirsep
Newfield			2/6/1997	SS 354	5M Veirsep
Chevron			9/19/1991	ST 177-A	30M Veirsep
Samedan			6/18/1999	ST 196	10M Skimmer Converted to DGF
EL Paso			2/15/2001	ST 204-B	5M Veirsep
Hunt Petroleum	ST 254		1/25/2007	ST 254	Spinsep A
Cairn Energy			3/26/1998	ST 291	5M Veirsep
Energy Partners			4/22/2005	ST 41	15M Combosep(DGF)
EL Paso			7/21/2000	ST 48	4M Cyclosep
Unocal			5/12/1995	ST 53	15M Veirsep
Coastline Process			11/16/2000	ST F & P	15M Veirsep
Modec		N00025	8/1/2006	Stybarrow	95M Spinsep P (DGF)
Braun			4/9/1990	Sweeney, TX	40M Multisep
ExxonMobil		N00031	9/1/2006	TCOT	35M Veirsep P
BG Trinidad		N00044	2/8/2007	Trinidad	20M Spinsep
BG Trinidad	BG Trinidad WT		4/28/2006	Trinidad	20M Veirsep w/ Skid Unit
British Gas/Fluor	BG Poinsettia	V00013	11/22/2006	Trinidad	12.5M Veirsep Skimmer Spinsep P
Trinmar			1/31/1997	Trinidad	30M Veirsep
Wood Group/Onsite Services		N00015	2/1/2006	Trinidad	1M Combosep
Kvaerner (UK)			7/26/2000	United Kingdom	40M Veirsep
Kvaerner (UK)			7/26/2000	United Kingdom	40M Veirsep
Shell UK	Shell UK		5/26/2006	USA	DGF
Stone Energy	Stone Energy		6/7/2006	USA	5M Veirsep w/DGF
BP			12/27/1995	Venezuela	6M Veirsep
CPO			9/21/1999	Venezuela	30M Cyclosep (DGF)
Kerr McGee			1/30/1990	Verm 114	5M Veirsep
Mobil			12/13/1990	Verm 131-CF	5M Veirsep-C
Newfield			5/7/1999	Verm 146	5M Veirsep
Chevron			5/3/2001	VERM 214 A & C	10M DGF Pump-Conversion of Column Flotation Unit
Mobil			4/1/1991	Verm 215	4.5M Veirsep-C
Seneca			11/10/1995	Verm 252	5M Veirsep-S
W & T			6/5/1996	Verm 279	5M Spinsep-S
Marathon			5/25/1995	Verm 331	10M Veirsep-C
Samedan			4/4/1995	Verm 371-A	10M Combosep
Newfield			9/5/1996	Verm 398-A	10M Veirsep
LL&E			4/17/1991	Verm 412	5M Veirsep
Burlington Resources			5/23/2000	Vermilion 119-D	5M Veirsep-Plus (DGF)
OEDC			1/20/1997	VK 121	3M Cyclosep-S
OEDC			3/31/1995	VK 24	3M Cyclosep-S
EL Paso			11/9/2000	VK 385	5M Spinsep
BP			7/7/1993	VK 989	40M Veirsep
Bois d' Arc			5/13/2005	VR 127	1M Spinsep - S
LL&E			9/17/1997	VR 171	3M Combosep
CNG			8/10/1997	VR 313-B	15M Veirsep-Plus
CNG			8/18/1997	VR 313-C	7.5M Veirsep
ERT			4/20/2005	VR-331	15M Veirsep (DGF)
Kerr McGee			7/19/1990	WC 100	6M Veirsep
Conn Energy			11/10/1998	WC 171	1M Veirsep (DGF)
Forcenergy			1/26/1995	WC 205	5M Veirsep
Conoco			6/30/1993	WC 34-D	10M Cyclosep
Coastal Oil			10/21/1996	WC 498-B-Aux	7.5M Veirsep
Coastal			11/7/1995	WC 504-A	5M Cyclosep-S
Chevron			8/1/1994	WC 534-A	1M Monosep-S
LL&E			11/25/1995	WC 554	3M Mini-Veirsep
Chevron			4/8/1994	WC 564	5M Multisep-S
Samedan			5/29/1996	WC 599-A	5M Cyclosep-S
Marathon			5/28/1991	WC 620	5M Sump Tank
Vastar (Now Dynamic Resources)			8/17/1999	WC 645-A	6M Spinsep (DGF)

Customer Name	Project Name	Project No.	Bkg Date	Location	Product Model
Vastar (Now Dynamic Resources)			1/11/1999	WC 65-JA	5M Spinsep-P (DGF)
BP			3/29/2005	WC 66	15M Veirsep(DGF)
Vastar (Now Dynamic Resources)			1/28/1999	WC 66-A	5M Spinsep-P (DGF)
Conoco			4/28/1993	WC 66-B	5M Cyclosep
Vastar (Now Dynamic Resources)			5/12/1999	WC 66-C	3M Conversion (DGF)
Zilkha			12/9/1994	WC 98	1M Pacsep
BP			9/27/2001	WD 133-B	10M Spinsep-P (DGF)
Marathon			3/29/1990	WD 134	7.5M Multisep
Marathon			3/29/1990	WD 134	7.5M Veirsep
Amoco			8/23/1989	WD 35	5M Veirsep
Amoco			12/18/1998	WD 75	15M Veirsep
Marathon			5/28/1991	WD 79-B	30M Veirsep-C
EDC			12/7/1994	WD 83-E5	5M Cyclosep
Amoco			7/28/1993	WD 90	25M Veirsep-C
Chevron			3/13/1995	WD 97-A	5M Veirsep-S
Hunt Oil	Vermillion 229	N00060	1/21/2009		5M Veirsep w/sparging
Paloma	Paloma		5/8/2006		10M Veirsep
Petrobras			10/5/2001		105M Veirsep-Plus (DGF)
Petrobras			10/5/2001		105M Veirsep-Plus (DGF)
Sivalls, Inc.			10/31/2004		(3) DGF/pump pkgs
Tarpon		N00038	12/5/2006		5M Veirsep
Taylor Energy			9/9/2003		5M Veirsep (DGF)
Total	Matterhorn		2007		Veirsep A

5.3 Veolia Flotation Technologies For Water Treatment

For many years produced water from offshore operations was disposed of directly into the sea with little or no treatment. This practice has been progressively legislated against and producers now seeks the services of specialist companies such as VWS Oil and Gas to develop solutions that remove pollutants; salts, suspended and dissolved solids, volatile compounds, organics, ammonia, hydrogen sulphide and oil prior to disposal or re-injection into the reservoir. Veolia Water Solution & Technologies is a fully owned subsidiary of veolia water. It is a design & build company and a specialized provider of technological solutions in water treatment for a low carbon future to meet the needs of municipal and industrial customers.

5.3.1 Veolia Mechanical Induced Gas Flotation (IGF)-AutoFlot

Whittier Filtration, a Veolia Water Solutions & Technologies company, offers AutoFlot, a Mechanical Induced Gas Flotation (IGF) separator [28]. Induced Gas Flotation separates oil from produced water or other oily water streams [29].

5.3.1.1 Design Operation And Applications

In this apparatus froth flotation occurs, which is the selective separation of solids and free oil based on the degree of surface hydrophobicity. The addition of cationic or anionic polyelectrolytes to the system causes particles to be selectively adsorbed. This will render one particle type hydrophobic while the other stays hydrophilic. Hydrophobic particles will attach to small air bubbles added into a mixture of oil, fine solids and water, and will float to the surface as froth and are skimmed into a launder. The introduction of air is performed by a mechanical device or agitator that creates and distributes fine air or gas bubbles [29].

The intensity of agitation required will determine the results of the separation. AutoFlot agitators are designed to impose the ideal intensity to each chamber, making these units highly efficient. This process of creating and dispersing bubbles is called mechanical induction. The AutoFlot tank is constructed to provide a total water retention time of four minutes. The total volume of the tank is divided into four chambers, or cells; therefore, the hydraulic retention time is expressed as one minute per cell. The AutoFlot unit includes inlet and outlet chambers.

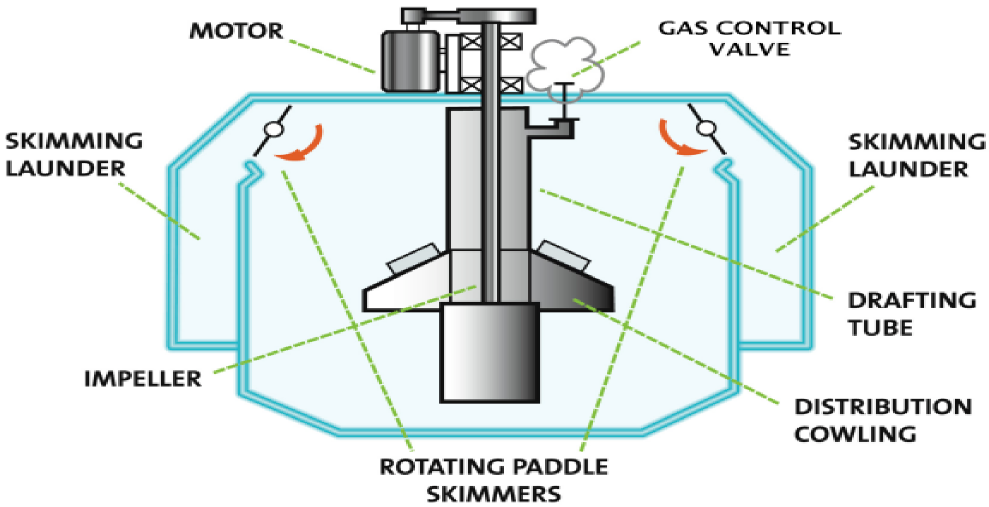

Figure 5.7 The AutoFlot [28]

The AutoFlot unit is a horizontal vessel. Each cell and outlet box is separated by a diaphragm. The diaphragms are metal plates welded to the sides of the vessel and are open across the bottom and top for free water passage across the bottom and air/gas across the top. Positioned on each side of the vessel is a skimming compartment, also referred to as launder.

Mounted on top of and inside each cell is the rotating air induction mechanism. The mechanism's main components are a draft tube, shroud and shaft with a specially constructed impeller. The entire mechanism assembly is bolted and sealed to the top of the vessel. Standard metallurgy is 316/316L stainless steel [28, 29].

Mounted within each of the launders is a skimming shaft that runs the full length of the vessel. On each shaft and at each cell are a series of adjustable skimming paddles. Typically, there will be six paddles in the first cell and four in each of the three remaining cells. Externally mounted electrical motors drive the skimming mechanisms. Each cell and the outlet box are equipped with a pair of fast opening doors. These doors can be opened to offer visual observance of the flotation and skimming operation. External to the vessel the flotation system may include piping, associated valves, instrumentation, control panel, and a chemical (polymer) feed system.

The AutoFlot separator may be a self-contained system with its own controls, or it could be equipped with transmitters to send signals to a control panel that oversees a complete treatment system [28, 29]. IGF oil water separation units typically form part of a treatment train to reduce free oil and solids by 90-95 % with maximum inlet concentrations of 200 mg/l of free oil and less than 100 mg/l of total suspended solids [28].

Table 5.9 shows a reference list of Mechanical Induced Gas Flotation Separators Whittier Filtration. Whittier Filtration is a part of Veolia Water Solutions & Technologies (VWS), the technical subsidiary of Veolia Water. The water division of Veolia Environment is the largest environmental company in the world. In this references list (Table 5.9), shows the installations history of the Mechanical IGF Rectangular Atmospheric Tanks, in Argentina, Venezuela and Singapore. The technology shows a higher effluent quality for various customers operating with the technology.

Table 5.10 also shows a partial installation list for Hydrocell Units while Table 5.11 shows the list of Quadricell installations, another floatation technology offered by the same Veolia Water Solution & Technologies. These two Tables (Table 5.10 & 5.11) adds to the already large number of installations, offered by the VWS technology in the increasing Oil & Gas industry, for treating produced water.

Table 5.9 Reference List [34]
Whittier Filtration, Inc.-Mechanical Induced Gas Flotation Separators
Rectangular Atmospheric Tanks
Argentina

Customer	***City***	***Application***	***Equipment***	***Effluent Quality***	***Flow rate***
Bolland	***Astra - El Porton, pcia. Mendoza***	***Secondary Treatment***			***748 gpm (170 m^3/h)***
Vintage de Petroleos S.A.	***Yacimiento El Huemul***		***IGF***	***< 1 ppm TSS & HC***	***2244 gpm (510 m^3/h)***
Tecpetrol Yacimiento Oeste	***Pcia. Chubut***	***Secondary Treatment***	***IGF***	***< 0.5 ppm TSS & HC***	***2244 gpm (510 m^3/h)***
Tecpetrol Yacimiento La Petiza	***Pcia. Chubut***	***Secondary Treatment***	***IGF***	***< 2 ppm TSS & HC***	***2244 gpm (510 m^3/h)***
YPF	***Yacimiento Vizcacheras – Mendoza***	***Secondary Treatment***	***IGF***	***< 15 ppm TSS & HC***	***2640 gpm (600 m^3/h)***
Repsol	***Yacimiento Las Heras***	***Secondary Treatment***	***IGF***	***< 20 ppm TSS & HC***	***1760 gpm (400 m^3/h)***
Repsol	***Yacimiento Los Perales***	***Secondary Treatment***		***< 20 ppm TSS & HC***	***1760 gpm (400 m^3/h)***
Bolland - Yacimiento Río Negro Norte for Chevron	***Pcia. de Río Negro***	***Secondary Treatment***	***IGF***	***< 1 ppm TSS & HC***	***183 gpm (1000 m^3/day)***
Tecpetrol	***Salta***	***Secondary Treatment***	***IGF***	***< 5 ppm TSS & HC***	***330 gpm (1800 m^3/day)***
Astra Evangelista	***Tecna para Petrobras Bolivia (Sábalo)***	***Secondary Treatment***	***IGF***	***< 5 ppm TSS & HC***	***220 gpm (1200 m^3/day)***
Tecpetrol Yacimiento La Petiza	***Pcia. Chubut***	***Secondary Treatment***	***IGF***	***< 2 ppm TSS & HC***	***2244 gpm (510 m^3/h)***
Tecpetrol Yacimiento Oeste	***Pcia. Chubut***	***Secondary Treatment***	***IGF***	***< 2 ppm TSS & HC***	***3080gpm (700 m^3/h)***
Repsol YPF	***Yacimiento El Portón***	***Secondary Treatment***	***IGF***	***< 5 ppm TSS & HC***	***1100 gpm (250 m^3/h)***

Customer	***City***	***Application***	***Equipment***	***Effluent Quality***	***Flow rate***
Repsol YPF	***Yacimiento La Ventana***	***Secondary Treatment***	***IGF***	***< 20 ppm TSS & HC***	***3080 gpm (700 m³/h)***
Sipetrol	***Magallanes***	***Secondary Treatment***	***IGF***	***< 20 ppm TSS & HC***	
Repsol YPF	***Las Heras IV***	***Secondary Treatment***	***IGF***	***< 20 ppm TSS & HC***	***1760 gpm (400 m³/h)***
OXY	***Occidental de Argentina***	***Secondary Treatment***	***Three (3) IGF***	***< 20 ppm TSS & HC***	***748 gpm (170 m³/h)***
OXY	***Occidental de Argentina***	***Secondary Treatment***	***IGF***	***Expected : < 20 ppm de TSS y de HC***	***2,200 gpm (500 m³/h)***
Bolland for Petrolifera Petroleum	***Yacimiento Puesto Morales - Neuquén Argentina***	***Secondary Treatment***	***IGF***	***Expected : < 20 ppm TSS & HC***	***484gpm (110 m³/h) Project in progress***
OXY	***Occidental de Argentina***	***Secondary Treatment***	***IGF***	***Expected : < 20 ppm TSS & HC***	***748 gpm (170 m³/h) Project in progress***

Venezuela

Customer	***City***	***Application***	***Equipment***	***Flow rate***
PDVSA	***San Joaquin***	***Produced Water Secondary Treatment***	***IGF***	***320 gpm (73 m³/h)***
Petrozuata	***Venezuela***	***Produced Water Secondary Treatment***	***IGF***	***210 gpm (47 m³/h)***
PDVSA	***Santa Rosa***	***Produced Water Secondary Treatment***	***IGF***	***210 gpm (47 m³/h)***
PDVSA	***Zapatos Mata R***	***Produced Water Secondary Treatment***	***IGF***	***320 gpm (73 m³/h)***
Petroquiriquire	***Menegrande***	***Produced Water Secondary Treatment***	***IGF***	***1600 gpm (364 m³/h)***

Singapore

1. **ABB-Lumus / Shell**
2. **Secondary Treatment –Flow rate: 320 gpm (73 m³/h)**
3. IGF

Table 5.10 Partial Installation List For Hydrocell Units [34]

Partial installation list for Hydrocell Units

	Job #	Customer	City	State	Equipment	Application	Market Segment
1	7917	P.T. CALTEX INDONESIA	RIAU, SUMATRA		H-50D HYDROCELL (1)	PRODUCED WATER	OIL & GAS
2	7787	PETRO ECUADOR	QUITO, ECUADOR		H-CELL H-20D (1)	PRODUCED WATER	PRODUCED WATER
3	7722	EQUATE ETHYLENE	AL-SHUAIBA, KUWAIT		H-CELL H-20 (1)	WASTE WATER	WASTE/POLLUTION CONTROL
4	7689	BOLLAND COMPANY	ARGENTINA		H-CELL H-40D	PRODUCED WATER	WATERFLOOD
5	7643	CHINA COMM. IMPORT/EXPORT	CHINA		H-CELL & H-20D	BALLAST WATER	WASTE/POLLUTION CONTROL
6	7619	Y P F	ARGENTINA		H-CELL H-340 (3)	REFINERY WASTE WATER	WASTE/POLLUTION CONTROL
7	7613	WEIHAI WHARF	CHINA		H-CELL H-7-1/2	BALLAST WATER	WASTE/POLLUTION CONTROL
8	7580	MARAVEN/KELLOGG	VENEZUELA		H-CELL H-20D	REFINERY RUNOFF WTR.	WASTE/POLLUTION CONTROL
9	7490	CAMP DRESSER & MCKEE	IRVINE	CA	H-40		MUNICIPAL
10	7454	AMOCO OIL COMPANY	YORKTOWN	VA	H-70D	REFINERY EFFLUENT	WASTE WATER
11	7437	HUDSON ENGINEERING	HOUSTON	TX	H-30D	WASTE WATER	OIL & GAS
12	7392	LTV STEEL	HAMMOND	IL	H-7.5D	COKE WASH WATER	WASTE/POLLUTION CONTROL
13	7326	STANVAC	INDONESIA		H-70D	PRODUCED WATER	OIL & GAS
14	7268	SHELL OIL COMPANY	ODESSA	TX	H-5D	REFINERY RUN-OFF	REFINING/PETROCHEMICAL
15	7225	TOTAL PETROLEUM	ARKANSAS CITY	KS	H-35D	REFINERY EFFLUENT	OIL & GAS
16	7219	ESSO RESOURCES CANADA	COLD LAKE, ALBERTA		H-30D	PRODUCED WATER	OIL & GAS
17	7175	CONOCO/FLUOR	MILNE POINT	AK	H-20D	PRODUCED WATER	OIL & GAS
18	7162	P.T. CALTEX	INDONESIA		H-230	PRODUCED WATER	OIL & GAS
19	7159	TENNECO OIL	BAKERSFIELD	CA	H-40D	PRODUCED WATER	OIL & GAS
20	7157	TENNECO OIL	BAKERSFIELD	CA	H-50	PRODUCED WATER	OIL & GAS

Partial installation list for Hydrocell Units

	Job #	Customer	City	State	Equipment	Application	Market Segment
21	7148	CONOCO. INC.	INDONESIA		H-45-OS	PRODUCED WATER	OIL & GAS
22	7143	CONOCO, INC.	NEW ORLEANS	LA	H-30-OS	PRODUCED WATER	OIL & GAS
23	7142	SHELL OIL COMPANY	NORCO	LA	H-230	SOUR WATER	OIL & GAS
24	7141	MOBIL OIL COMPANY	NEW ORLEANS	LA	H-03-OS	PRODUCED WATER	OIL & GAS
25	7138	MARATHON OIL	BRIDGEPORT	IL	H-160	PRODUCED WATER	WATERFLOOD
26	7123	MOBIL OIL COMPANY	MORGAN CITY	LA	H-21	PRODUCED WATER	OIL & GAS
27	7107	TOTAL PETROLEUM	ALMA	MI	H-75	REFINERY EFFLUENT	WASTE/POLLUTION CONTROL
28	7092	SHELL WESTERN	HACKBERRY	LA	H-75	PRODUCED WATER	OIL & GAS
29	7089	PETRO-LEWIS CORP.	HAMILTON DOME	WY	H-160	PRODUCED WATER	OIL & GAS
30	7088	SHELL OIL CO.	BAKERSFIELD	CA	H-340	PRODUCED WATER	OIL & GAS
31	7085	SHELL OIL COMPANY	FELLOWS	CA	H-50	PRODUCED WATER	OIL & GAS
32	7083	PACIFIC WOODTREATING	RIDGEFIELD	WA	H-4	WASTE WATER	PULP & PAPER
33	7082	SHELL OIL CO.	HACKBERRY	LA	H-4	PRODUCED WATER	OIL & GAS
34	7025	TEXACO INT'L TRADER	NIGERIA		H-160	PRODUCED WATER	WATERFLOOD
35	1982	LTV STEEL CO.	CHICAGO	IL	H-10	WASTE AMMONIA LIQ.	WASTE/POLLUTION CONTROL
36	1944	FRIENDSWOOD REFINERY	HOUSTON	TX	H-10	REFINERY EFFLUENT	REFINING/PETROCHEMICAL
37	1361	PHILLIPS PETROLEUM	SWEENY	TX	H-110	REFINERY EFFLUENT	OIL & GAS

Table 5.11 List of Quadricell Installations [34]

(WHITTIER) LIST OF QUADRICELL INSTALLATIONS

Job #	Customer	City	State	Equipment	Application	Market Segment
0095	COLT ENGINEERING	CALGARY, ALBERTA	CAN	Q-500 (2)	PRODUCED WATER	OIL & GAS
0060	USF ARGENTINA FOR TECPETROL		ARG	Q-230	OIL & GAS	OIL & WATER SEPARATION
0052	ENNPI FOR MIDTAP	ALEXANDRIA PORT	EGY	Q-21 QUADRICELL (1)	OIL & GAS	BALLAST WATER
0031	USF/ASIA for LG ENG./TPI PUBLI(	SINGAPORE	KOR	Q-50 (1)	HPI	OIL WATER SEPARATION
0016	USF/ARGENTINA	BUENOS AIRES	ARG	Q-75 & AWS-11-96	PRODUCED WATER	
7548	PETROSIN/GEPL SINGAPORE	PAKISTAN		Q-21 QUADRICELL	PRODUCED WATER	OIL & GAS
0052	ENNPI FOR MIDTAP	ALEXANDRIA PORT	EGY	Q-21 QUADRICELL (1)	OIL & GAS	BALLAST WATER
0031	USF/ASIA for LG ENG./TPI PUBLI(	SINGAPORE	KOR	Q-50 (1)	HPI	OIL WATER SEPARATION
0011	PROPAK	ALBERTA, CAN-VENEZUELA	VEN	CPS, Q-CELL, AWS, V.D.	OIL & GAS	PRODUCED WATER
8085	UNOCAL INDONESIA	SANTAN TERMINAL	INDO	Q-340 (1)	OIL & GAS	PRODUCED WATER
8062	USF/ARGENTINA / BOLLAND	BUENOS AIRES	ARG	Q-21 (1)	OIL AND GAS	OIL/WATER SEPARATION
8046	CONFAB INDUS. / PETROBRAS	MANAUS	BRAZ	Q-160 (1)	REFINING/PETROCHEMICA	OIL - WATER SEPARATION
8038	UNOCAL INDO/UNOCAL ATTAKA	ATTAKA PLATFORM	INDO	Q-110 (1)	OIL AND GAS	OIL-WATER SEPARATION
8026	JACOBS ENGINEERING	HOUSTON	TX	Q-32 QUADRICELL (1)	SPARATION	OIL/WATER
8003	JAPAN CANADA OIL SANDS	CALGARY, ALBERTA		Q-CELL Q-50 (1)	OILY WATER	OIL & GAS
8000	P.T. CALTEX PACIFIC INFO.	RIAU, SUMATRA		Q-CELL Q-230 (1)	PRODUCED WATER	OIL & GAS
7969	Y P F ARGENTINA	BUENOS AIRES, AR.		Q-160 (1)	PRODUCED WATER	OIL & GAS
7912	W. M. INDUSTRIES	SEOUL, KOREA		Q-15 QUADRICELL (1)	WASTE WATER	WASTE/POLLUTION CONTROL
7871	BOLLAND Y CIA, S.A.	BUENOS AIRES, ARG.		Q-160 (1)	PRODUCED WATER	PRODUCED WATER
7840	HANSUNG CLEANTECH CO.	SEOUL, KOREA		Q-10 (1)	OILY WASTE WATER	WASTE/POLLUTION CONTROL
7821	TOTAL AUSTRAL	ARGENTINA		Q-CELL Q-230 (1)	PRODUCED WATER	PRODUCED WATER
7817	YPF, LAS HERAS	ARGENTINA		Q-CELL Q-160 (2)	PRODUCED WATER	PRODUCED WATER
7809	AMOCO, CANADA	CALGARY, ALBERTA		Q-CELL Q-500	PRODUCED WATER	PRODUCED WATER
7808	HYORIM INDUSTRIES, INC.	SEOUL, KOREA		Q-CELL Q-4	OILY WASTE WATER	WASTE/POLLUTION CONTROL
7806	SAMYANG WATER & SEWAGE	SEOUL, KOREA		Q-CELL Q-15	CONDENSATE RUNOFF	CONDENSATE
7701	KOREAN ELECTRIC POWER	SEOUL, KOREA		Q-CELL Q-4	CONDENSATE RUNOFF	POWER PLANT
7684	SAMYANG WATER & SEWAGE	SEOUL, KOREA		Q-CELL Q-15	OILY WASTE WATER	WASTE/POLLUTION CONTROL
7599	CHINESE PETROLEUM CORP.	KAOHSIUNG, TAIWAN		Q-CELL Q-10 (2)	WASTE WATER	REFINERY/PETROCHEMICAL
7582	UNITED STATES NAVY	EVERETT	WA	Q-CELL Q-21 (2)	OILY WASTE WATER	MUNICIPAL
7564	HUNDAI/KOREAN ELECTRIC	SEOUL, KOREA		Q-21 QUADRICELL	OILY WASTE WATER	POWER
7509	ENPPI/SUMED PIPELINE	ALEXANDRIA, EGYPT		Q-340 (BY TECNIPLANT)	BALLAST WATER	WASTE/POLLUTION CONTROL
7501	ILSAN THERMAL POWER	KOREA		Q-15	WASTE WATER	POWER
7489	BECKER/FOX TRAP FIRE	ST. JOHNS, NEW BRUNS.		Q-50	OILY WASTE WATER	WASTE/POLLUTION CONTROL
7472	LOGAN ALUMINUM	RUSSELVILLE	KY	Q-340	WASTE WATER	STEEL & METALS
7469	ALBERTA OIL SANDS TECH.	FORT MCMURRAY, ALB.		Q-50	PRODUCED WATER	WATERFLOOD
7462	P.T. CALTEX INDONESIA	DURI, INDONESIA		Q-500	PRODUCED WATER	OIL & GAS
7451	KOREAN ELECTRIC	BUNDANG, KOREA		Q-15	OILY WASTE WATER	POWER

(WHITTIER) LIST OF QUADRICELL INSTALLATIONS

Job #	Customer	City	State	Equipment	Application	Market Segment
7450	KOREAN ELECTRIC	ANYANG, KOREA		Q-15	OILY WASTE WATER	POWER
7334	CHINESE PETROLEUM CO.	KAOHSUING, TAIWAN		Q-75 AND CPI SEP.	BALLAST WATER	REFINING/PETROCHEMICAL
7316	HUDBAY OIL COMPANY	JAKARTA, INDONESIA		Q-230	PRODUCED WATER	OIL & GAS
7307	SHELL CANADA, LTD.	VIRGINIA HILLS, ALBERTA		Q-500	PRODUCED WATER	WATERFLOOD
7298	SHELL OIL CO.	NORCO	LA	Q-160	REFINERY EFFLUENT	REFINING/PETROCHEMICAL
7293	HUFFCO INDONESIA	JAKARTA, INDONESIA		Q-160	PRODUCED WATER	OIL & GAS
7274	CELERON OIL & GAS CO.	MC KITTRICK	CA	Q-160	PRODUCED WATER	OIL & GAS
7254	IIAPCO	JAKARTA, INDONESIA		Q-340	PRODUCED WATER	OIL & GAS
7233	SHELL CANADA	VIRGINA HILLS, ALBERTA		Q-160	PRODUCED WATER	OIL & GAS
7214	CHEVRON U.S.A.	SEAL BEACH	CA	Q-32	PRODUCED WATER	OIL & GAS
7209	MOBIL OIL CORPORATION	INDONESIA		Q-75	PRODUCED WATER	OIL & GAS
7197	ULTRAMAR REFINERY	QUEBEC CITY, QUEBEC		Q-340	REFINERY EFFLUENT	WASTE/POLLUTION CONTROL
7166	CHEVRON PETROLEUM	PT. ARGUELLO	CA	Q-110	PRODUCED WATER	OIL & GAS
7136	CHEVRON OIL CO.	PT. ARGUELLA	CA	Q-75	PRODUCED WATER	OIL & GAS
7131	TEXACO, INC.	PT. CONCEPTION	CA	Q-160	PRODUCED WATER	OIL & GAS
7117	CALTEX PETROLEUM	DURI, SUMATRA		Q-110	TERMINAL EFFLUENT	OIL & GAS
7104	CALTEX PETROLEUM	DURI, SUMATRA		Q-500 W/AUX.	PRODUCED WATER	OIL & GAS
7058	R & R POULTRY PROCESSING	CARTHAGE	MS	Q-500	POULTRY PLANT EFFL.	WASTE/POLLUTION CONTROL
7038	IIAPCO	INDONESIA		Q-340	PRODUCED WATER	OIL & GAS
7029	IIAPCO	INDONESIA		Q-230	OILY WATER	OIL & GAS
1985	TENNECO OIL CO.	BAKERSFIELD	CA	Q-50	PRODUCED WATER	OIL & GAS
1984	DOW CHEMICAL	FREEPORT	TX	Q-32	ETHYLENE PLANT EFF.	CHEMICAL
1967	CAROLINA BY-PRODUCTS	FAYETTEVILLE	NC	Q-50	RENDERING PLANT EFF.	FOOD & BEVERAGE
1957	FIELDALE	CORNELIA	GA	Q-500	POULTRY PLANT EFFL.	FOOD & BEVERAGE
1922	CALCASIEU REFINERY	LAKE CHARLES	LA	Q-10	REFINERY EFFLUENT	REFINING/PETROCHEMICAL
1898	LOUISIANA OFFSHORE OIL	GRAND ISLE	LA	Q-21	BALLAST & BILGE WTR.	OIL & GAS
1888	FIELDALE CORPORATION	GAINESVILLE	GA	Q-340	POULTRY PLANT EFFLU.	FOOD & BEVERAGE
1876	TEXACO INCORPORATED	MORGAN CITY	LA	Q-75	PRODUCED WATER	OIL& GAS
1871	TENNECO OIL	BAKERSFIELD	CA	Q-10	PRODUCED WATER	OIL & GAS
1869	CONSUMERS POWER	MIDLAND	MI	Q-21 W/AUX.	PRODUCED WATER	WATERFLOOD
1854	SHELL OIL	FELLOWS	CA	Q-21	PRODUCED WATER	OIL & GAS
1851	CHEVRON	SANTA BARBARA	CA	Q-75	PRODUCED WATER	OIL & GAS
1843	ERGON/MCEVER	VICKSBERG	MS	Q-10	REFINERY EFFLUENT	WASTE/POLLUTION CONTROL
1833	CORPUS CHRISTI PETRO.	CORPUS CHRISTI	TX	Q-50 W/AUX.	WASTE WATER	OIL & GAS
1831	LOWER CO. RIVER AUTH.	LA GRANGE	TX	Q-50	OIL WASTE WATER	MUNICIPAL
1825	MESA PETROLEUM	MORGAN CITY	TX	Q-50	PRODUCED WATER	OIL & GAS
1823	CITIES SERVICE	GALVESTON	TX	Q-10	PRODUCED WATER	OIL & GAS

(WHITTIER) LIST OF QUADRICELL INSTALLATIONS

Job #	Customer	City	State	Equipment	Application	Market Segment
1815	CONOCO	INDONESIA		Q-110	PRODUCED WATER	OIL & GAS
1812	REICHHOLD CHEMICAL	OAKDALE	LA	Q 21	TALL OIL EFFLUENT	CHEMICAL
1810	HUNT WESSON FOODS	FULLERTON	CA	Q-50	VEGETABLEOIL WASTE	FOOD & BEVERAGE
1804	THUMS LONG BEACH CO.	LONG BEACH	CA	Q-110	PRODUCED WATER	OIL & GAS
0095	COLT ENGINEERING	CALGARY, ALBERTA	CAN	Q-500 (2)	PRODUCED WATER	OIL & GAS
0060	USF ARGENTINA FOR TECPETROL		ARG	Q-230	OIL & GAS	OIL & WATER SEPARATION

5.3.2 Veolia Compact Flotation Unit- Cophase CFU

Traditional produced water treatment is usually comprised of hydrocyclones followed by degassing or flotation processes. Increasingly stringent environmental discharge requirements plus the constant pressure to reduce equipment footprint have led to the development of the Compact Flotation Unit (CFU). VWS Oil & Gas has taken this process forward to the next level with the Cophase CFU [30].

5.3.2.1 Design Philosophy

1. Remove the need for a pressurized gas supply
1. Improve oil removal efficiency
2. Minimize footprint and weight
3. Reduce maintenance
4. Extend operating life
5. Eliminate power requirements
6. On and offshore compatibility

5.3.2.2 The CFU Operating Principle

The Cophase CFU operates by combining the well established principles of gas flotation, oil droplet coalescence and centrifugal separation into a single process step. The efficiency of oil/water separation at low concentrations depends on maximizing the contact between the oil droplets and gas bubbles. The smaller and more densely packed the gas bubbles, the greater surface area the oil droplets have available to adhere to and agglomerate. In Cophase CFU the following principle of operation occurs to ensure greater oil droplet surface area [30]:

1. Oily water is distributed across the top plate
2. Water flows into the LoHead eductors
3. The head of the water draws gas from above the water
4. The gas/water mixture is discharged tangentially into the lower section causing rotation
5. The water spirals down the side of the vessel in plug flow, optimising retention time
6. A lower plate forces water back up the centre, carrying the oil droplets and gas bubbles to the surface, before recycling down the side of the vessel to the outlet
7. Oil is removed by a self-adjusting floating skimmer
8. Separated gas passes back up to the upper section for re-use
9. Turndown: the LoHead eductor inlets are set at different heights. As the flow is reduced, the liquid level in the upper chamber falls and the eductors progressively stop taking water, preserving rotation and the oil/gas contact efficiency
10. Efficiency is anticipated to be significantly better than Epcon/single cell IGF's
11. The objective is to achieve 100-200 ppm inlet, 15-20 ppm outlet
12. A 50 m^3/h pilot unit is operating in South America

5.3.2.3 Performance

1. Oil in Water 100-200 ppm inlet
2. 15-20 ppm outlet
3. A 50 m^3/h pilot unit is operating in South America

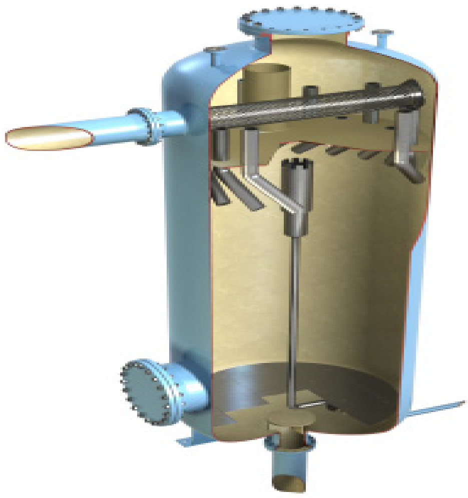

Figure 5.8 The Cophase CFU [30]

5.3.2.4 The Cophase CFU Lohead Eductor

The Cophase CFU LoHead eductor design is unique in that 100 % of the inlet flow is fed through the gas eductors, thus maximizing bubble generation and contact between the oil droplets and gas bubbles. By enhancing the opportunity for contact between the oil droplets and the gas bubbles, greater oil removal efficiency for a given vessel volume is achieved.

The LoHead eductor design also generates a vortex within the separation volume. This vortex applies centripetal force upon the heavier water and solids, forcing them to the periphery of the vessel and therefore concentrating the oil and gas bubbles in the centre and so aiding agglomeration and coalescence.

An important feature of the Cophase CFU is that this vortex, combined with the internal geometry of the vessel has been designed using Computational Flow Dynamics (CFD) to suppress backmixing in the vessel. This means that the water passes through the separation volume in what is termed "rotating plug flow", which leads to a higher oil removal efficiency than is achieved in the older designs of flotation units currently available [30].

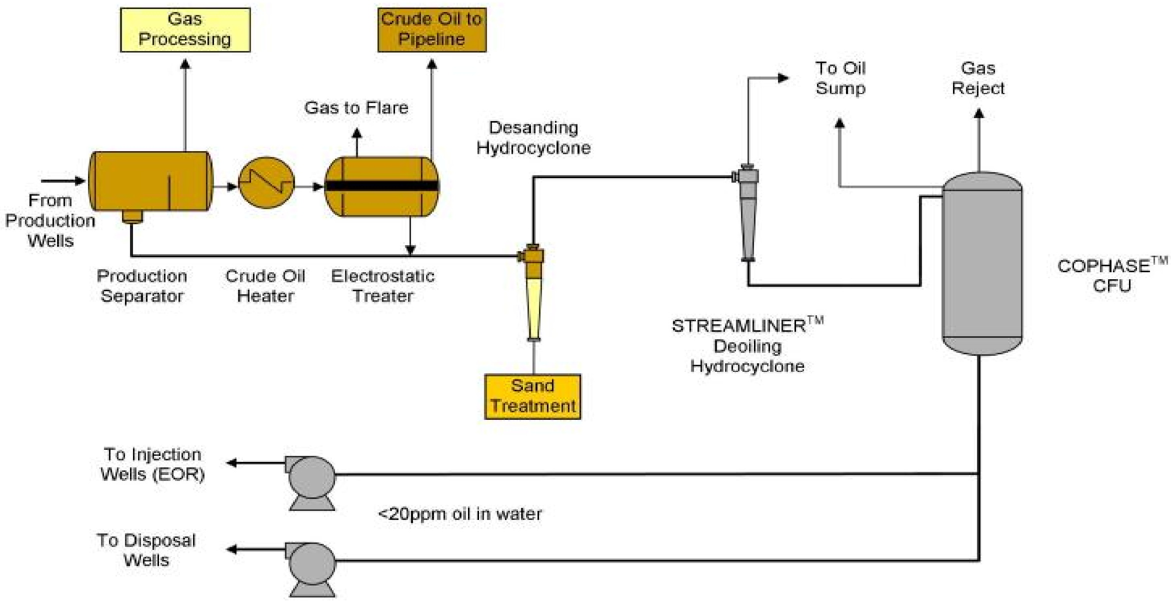

Figure 5.9 Typical Process Installation Diagram [30]

5.3.2.5 Cophase CFU Benefits

1. Highly tolerant of typical FPSO motion
2. Self regulating oil skimmer eliminates gas and reduces water in the reject stream
3. Skimmed flow minimized to < 1 % of total flow
4. One minute retention time reduces vessel size and weight
5. No motor or pump consuming power
6. Turndown performance is consistent
7. 100 % of the inlet flow passes through the LoHead eductors ensuring excellent gas/liquid contact and superior separation performance
8. No rotating parts to maintain
9. Designed for high flow rate
10. No need for pressurized water or gas, in most cases no gas consumption at all

5.4 *ProSep ProFloat Induced Gas Flotation System*

To recover oil and to condition waters for overboard discharge, re-injection or further polishing through filtration, ProSep's ProFloat Flotation Systems deliver highly efficient removal of oil and solids (10 000 to 100 000 BPWD with a separation efficiency of up to 98 %) while completely containing the process.

ProFloat is ideal for secondary treatment of produced and wastewaters in refineries, petrochemical plants and in the oilfield. The solution can integrate into existing systems as standalone vessels or be fully skid-mounted as a turnkey package. ProFloat employs induced gas flotation (IGF), as opposed to dissolved gas flotation (DGF), because of issues of solubility of inert and fuel gas at the high temperatures characteristic of produced water processes. The ProFloat IGF is available as either a vertical single-cell or a horizontal multiple-cell. Below is a practical example of a single-cell ProFloat IGF vessel [31].

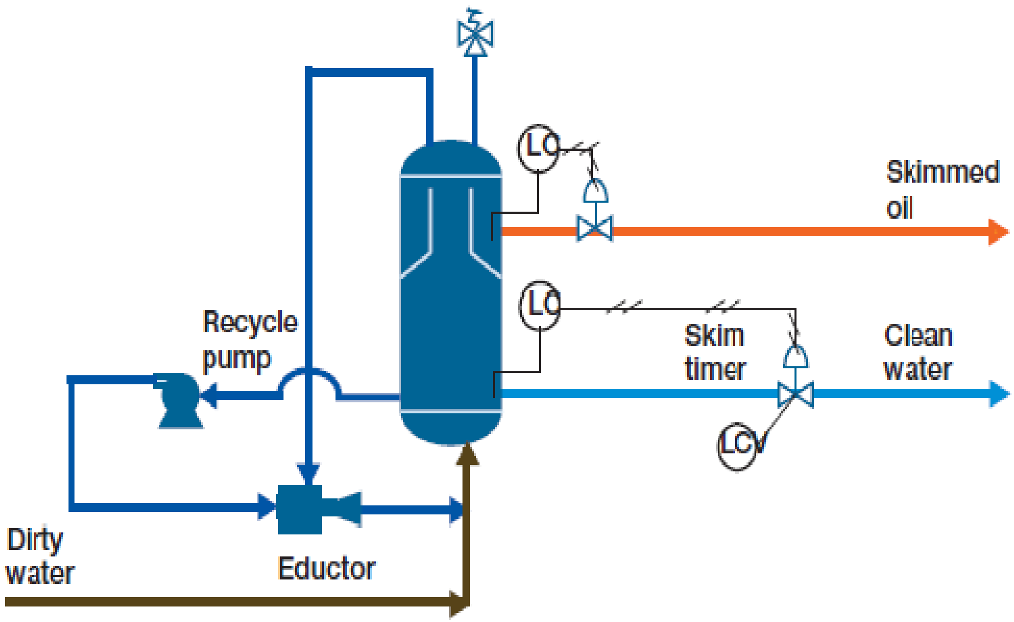

Figure 5.10 Single-Cell Induced Gas Flotation Vessel [31]

5.4.1 Features

1. Contained, gas-tight design
2. Compact skid design
3. Simple and reliable design and operation
4. No internal moving parts, no special parts needed
5. Availability of pressurized operation
6. Low skim rates
7. Operational and environmental safety
8. Minimal energy requirements

5.4.2 Principles of The ProFloat IGF

The highly efficient, motion-insensitive vertical induced gas flotation (IGF) process, with its small footprint, is ideal for space-limited installations, and especially for floating production applications. The process begins by providing a venturi-type eductor with pressurized water, which passes through and creates a vacuum at the gas suction port. The gas drawn from the vapor space in the IGF is induced into the recycle stream via an eductor. The gas is then thoroughly mixed with the water and contaminants through the aid of a static mixing device. This homogenous mixture is then released into a separation vessel. “Floated” oil and solids are skimmed from the surface of the vessel and clarified effluent exits from the bottom of the vessel. ProSep’s IGF has a vertical design that uses Stokes law by reducing the apparent density of oils and solids by their attachment to the finely dispersed gas bubble population in the separation vessel and by increased droplet size and buoyancy through coalescence.

Minimization of the liquid surface area susceptible to motion can be accomplished via the use of a compact and lightweight vertical single-cell or multiple vertical single-cell IGFs, as it is much easier to hold the liquid level control of a vertical vessel during operation due to its relatively small liquid surface area [31].

5.4.3 Horizontal Multiple-Cell IGF

The IGF is also available in horizontal multiple-cell when higher separation efficiencies and flow rates are required. Multiple-cell units are also better at handling upsets. ProSep's multiple-cell IGFs are ideal for many onshore and fixed offshore applications because of their ability to consistently achieve OiW concentrations near the lower limit of 15 mg/l [31].

5.4.4 Benefits of ProFloat IGF

1. Energy-efficient code and non-code designs
2. No hazardous off-gas emissions
3. Minimal moving parts
4. Single pumps (vs. multiple internal mixing mechanisms)
5. Compact, customizable skid-mounted equipment
6. Insensitive to FPSO and floating platform motions
7. Low skimmed oil rates (typically 1-3 %), minimizing
8. downstream tankage
9. Simple "set it and go" operation
10. Low chemical consumption
11. Low maintenance / operator intervention

CHAPTER 6

DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

6.1 Discussion

Produced water is water trapped in underground formations that is brought to the surface along with oil or gas. Produced water can be in contact with the hydrocarbon-bearing formation for centuries and because of this reason, produced water contains some of the chemical characteristics of the formation and the hydrocarbon itself. It may include water from the reservoir, water injected into the formation to maintain the reservoir pressure and any chemicals added during the production and treatment processes. However the major constituents of concern in produced water are:

1. Salt content (salinity, total dissolved solids TDS, electrical conductivity)
2. Oil and grease (this is a measure of the organic chemical compounds)
3. Various natural inorganic and organic compounds or chemical additives used in drilling and operating the well
4. Naturally occurring radioactive material (NORM)

This shows that produced water is not a single commodity and could contain a variety of the following constituents mention above in various proportions. Also, the physical and chemical properties of produced water vary considerably depending on the geographic location of the field, the geological host formation and the type of hydrocarbon product being produced. Produced water properties and volume can even vary throughout the lifetime of a reservoir and hence a concern area in the oil and gas industries to be fully understood to enhance higher oil recovery.

Produced water is by far the largest volume byproduct or waste stream associated with oil and gas exploration and production. Today produced water is the largest volume waste stream in oil and gas production with an estimated 240 million bbl/day requiring treatment and disposal.

Approximately 21 billion bbl (barrels; 1 bbl = 42 U.S. gallons) of produced water are generated each year in the United States from nearly a million wells representing about 57 million bbl/day, 2.4 billion gallons/day, or 913 000 m^3/day [33].

More than 50 billion bbl of produced water are generated each year at thousands of wells in other countries. The oil production is high while water production is at a lower rate in the early life of an oil well and over time, oil production decreases while the water production goes up. One other way of considering this is to examine the ratio of water-to-oil. For instance, worldwide estimate – 2:1 to 3:1 and U.S. estimate – 5.1 to 8:1 because many U.S. fields are mature and past their peak production [33], although the ratio may be even higher (such as > 50:1).

As wells mature oil and gas volumes in the production stream are gradually replaced by ever-increasing volumes of water and sand. At some point the cost of managing the produced water exceeds the profit from selling the oil and the well is shut down when this point is reached. However, in contrast to this phenomenon, coal bed methane well initially produces a large volume of water, which declines over time. The methane production starts low, builds to a peak, and then decreases. In any of these cases managing these waste streams efficiently and compliantly represents major separation, treatment and disposal challenges for operators around the world, especially those working offshore and in other environmentally sensitive regions. Sand and water production can also damage vital production equipment through corrosion, erosion and blockages. All of these processes, if left unaddressed could create flow assurance, health and safety or environmental problems. As production progresses, conditions change making the demands of each well different and the requirements of every solution unique.

Produced water management typically differs between onshore and offshore facilities. This is partly due to the space and weight restrictions at most offshore sites. Also the primary contaminant of concern is typically different between onshore discharges (salt content) and offshore discharges (oil and grease level).

Onshore produced water faces different options depending on where in the country the well is located and whether the water comes from an oil or gas well or from coal bed natural gas (CBNG – also known as coal bed methane or CBM) production. The management technologies and practices used by various companies in managing water can be grouped into three major categories: water minimization, recycle/reuse, and treatment/disposal. However, the categories overlap somewhat, for example many of the reuse opportunities require that the produced water is treated before it can be used for another purpose. These issues of produced water and its problems associated with the management process calls for more attention into a detail studies and research of the impact of produced water. There are various technologies implored by many companies in the management and handling of produced water.

However, this research work was aimed at considering flotation as one of the various method of technologies used in the oil and gas industries. The paper seeks to take a closer look at this technology and its trend in the oil and gas market usage in treating produced water. Flotation is only one among several of the physical methods of treatment technologies. The research work was conducted by identifying the various flotation technologies as a tool for water treatment, identify the supplier or producer of such technology and then contact the necessary personnel or appropriate channel for information regarding the technology. Information needed considering the structure for this research work was mainly questions concerning:

1. The working principle of the particular technology identified
2. A reference list of installation in the oil & gas market and
3. The results that these technologies offers to their customers

This information was a bit difficult to obtain from the various identified suppliers or producers of such technologies. However, some suppliers were convinced of the value of the thesis work as part of increasing the research base technology and as a way of marketing their products to the entire Oil & Gas industry. Thus embracing such an opportunity and willingly offered the necessary information at their disposal.

The results gathered from this piece of research work shows a tremendous improvement and an increase in the use of this technology in the treatment of produced water. This could be seen from information collected from Epcon CFU shown on ***Table 5.4 & 5.5*** of both reference installation list from Norwegian Continental Shelf and internationally worldwide. The results show a major development in flotation technology in the oil and gas market worldwide. A wide range of installation of this technology is ongoing that provides customers with a higher effluent concentration of produced water treatment.

Consideration of space and weight are very important parameters in the choice of a particular technology in an Oil & Gas platform for any industry. This is illustrated by the Epcon CFU technology in ***Table 5.6***. It is realized that for the same capacity of ***90 000 bpd*** the CFU provides a ***27 metric tons*** of weight, ***18 m^2*** of area and a less the than ***10 ppm*** performance in contrast with the traditional PW treatment system of using hydrocyclone and degassing drum (***45 metric tons, 30 m^2 and less than 40 ppm)***. These figures could even be further reduced by maximizing the order of arrangement also shown in this same ***Table*** 5.***6*** of three vessel in parallel with three trains in parallel, two vessels per train.

Furthermore, the reference list of installation from Siemens Water Technologies in ***Table 5.7*** shows no different from that of Epcon CFU. However, this technology of secondary produced water separation offers an even wider range of installations worldwide in the oil & gas industry. This is quite an impressive result and goes a long way to indicate how far this technology has gone breadth and length worldwide in the Oil industry. Customers in the Oil & Gas market have realized the qualities of this flotation technology and are fast embracing the technology.

The Veolia Water Solutions and Technologies is no exception as it can be seen from ***Table 5.8 & 5.9*** the various reference list of installation in the Oil & Gas industry. The reference list from this technology in ***Table 5.8*** also shows a very high quality of effluent concentration. This does not only add to the increasing growth of this technology, but also gives customers the opportunity to understand what this particular technology has to offer the ever increasing produced water in the Oil & Gas industry.

Finally, the ProSep ProFloat induced gas flotation system is yet another emerging technology in the industry. The technology has just begun with its major initial operation in Mexico [34] and hope to emerge as the best among the flotation technologies in the next five years.

6.2 Conclusions And Recommendations

Although this research work was successful, a set of challenges have to be overcome before any meaningful results could be obtained. Electronic mails have been sent several times to suppliers or producers identified with a flotation technology followed by phone calls as a way of convincing them. This was done on several occasions before being answered by the producer identified. The work has been a success by giving the valued customers an insight about how far the trend of this flotation technology has gone in the Oil & Gas market. It has given a clearer picture to customers in the Oil & Gas industry about this technology, in terms of produced water treatment, with many major installations and operations.

As a way of recommendation for further research studies, more work needs to be done on the treatment results, at least to the identified technologies. Several flotation technologies have been identified to be used by many companies, but as to what results these technologies have to offer to these companies is yet be answered. Hence, if further work needs to be done it should be focused on acquiring this information.

NOMENCLATURE AND SI UNITS

PW	***Produced Water***
OIW	***Oil In Water***
TDS	***Total Dissolved Solids***
COD	***Chemical Oxygen Demand***
BOD	***Biological Oxygen Demand***
BTEX	***Benzene, Toulene, Ethylbenzene And Xylene***
PAHs	***Poly-Aromatic Hydrocarbons***
NORM	***Natural Occurring Radioactive Material***
EPA	***Environmental Protection Agency***
OSPAR	***Oslo-Paris Commission***
SFT	***Norwegian Pollution Control***
DGF	***Dissolved Gas Flotation***
DAF	***Dissolved Air Flotation***
IGF	***Induced Gas Flotation***
IAF	***Induced Air Flotation***
CFU	***Compact Flotation Unit***
NCS	***Norwegian Continental Shelf***
VWS	***Veolia Water Solutions And Technologies***
CFD	***Computational Flow Dynamics***
CBNG	***Coal Bed Natural Gas***
CBM	***Coal Bed Methane***
SRB	***Sulfate Reducing Bacteria***

APB	***Acid Producing Bacteria***
ppm	***Parts per million***
mg/l	***Milligrams per liter***
µg/l	***Micrograms per liter***
m/h	***Meters per hour***
m^3/h	***Cubic meter per hour***
Kg/m^2h	***Kilograms per square meter per hour***
NOK/Kg	***Norwegian Kroner per kilogram***
bbl/day or bpd	***Barrel per day***
BWPD	***Barrel of water per day***
gpd	***Gallons per day***
gpm	***Gallons per minute***
atm	***Atmosphere***
mg/l/atm	***Milligrams per liter per atmosphere***
m^3	***Cubic meters***
ml	***Milliliters***
mg	***Milligrams***
barg	***Bar gauge***
m^2	***Square meters***
ft^3	***Cubic feet***
^oC	***Degrees Celsius***
µm	***Micrometer***
%	***Percentage***

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