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A Review of Produced Water TreatmentTechniques in Oil ProductionOperation: A Case Study of OML 42, Jones Creek, South-South, Nigeria

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ABSTRACT
The global energy crisis has consistently increased the desire for more oil and gas production over the years. This has been worsened by the current war between Russia and Ukraine, which has driven the need for more oil production due to the rising need for more energy. However, the increased demand for oil production comes with increased water production, and the challenges of its adverse effectsdue to the complexity of the high amount of waste that accompanied produced water.The treatment of produced water before disposal is very necessary in the oil industry because the unwanted effluent (produced water) is toxic to the environment and its organism. Moreso, in other to meet legal requirement for disposal into the environment (streams, rivers, ocean, etc.,), and technical requirements for reinjection into reservoirs for enhance oil recoverypurpose, it is necessary to treat produced-water in other to make it fit for disposal into the environment.Therefore, this research presents the major techniques for the efficient treatment and removal of produced-water'toxic effluent'and surface oil recovery methods prevalent in the oil industry, with a strong bias to Oil Mining Lease (OML42),South-South Nigeria, produced water treatment and disposal operation.

Key Words: Produced-Water treatment, oil, wastewater treatment, OML42, Jones Creek oil industry

I. INTRODUCTION

Production of oil is typically accompanied by substantial reservoir underground water. The produced-water is essentially formation water naturally present in thereservoir, or the water previously injected into the reservoir for enhance oil recovery purpose. These produced-waterusually contain high suspended solids such as sand, salinity,potentiallytoxic elements such as debris, suspended effluents, insoluble and soluble organic matter,chemicals, and radioactive pollutants that are difficult to remove, and ultimately worsened by the significant volume per day production.

Stephenson (1991) asserted that, the volume of water-produced in a matured, naturally declining production field that is fast approaching its recoverable oil reserveexhaustion,is ten times the volume of daily oil produced from such field.Hence, the final disposal of such magnitude of daily water-produced is of high concern to the operators, and also for the environment regulations.

Due to environmental legislations with regards to the existing standard required in the industry, produced-water always need to undergo efficient and thorough treatment with a view to its final disposal destination as required by regulatory authority in a given country (Nonatoet al, 2018). However, regulation varies from country to country depending on existing national laws. Also, in terms of reinjection into underground reservoirs for enhance oil recovery, underground storage, disposal or any other reuse in terms of offshore operation, the water-produced will need to be treated to meet the specific standards necessary and fit for theexact purpose.

The technology developed to solve theundesirable problem ofproduce-water treatment and disposal in the oil industry has evolved over the years, to a more sophisticated standard.However, there is need to study the suitable treatment that will be applicable for a specific matured oil field. This is required because of the complexity of the produced-water and its accompanying effluents which sometimes, require both physical, chemical, biological or combinational treatment methodology. The combinational treatment method can successfully reduce field energy consumption with efficient purification of the produced-water that is proving to be more reliable alternative measure with respect to legal and environmental regulatory requirements.

Therefore, the focus of this research is to review some of the critical techniques available in the oil industry for the treatment ofproduced-water, with respect to the technology application in the aforementioned (OML42) oil field as a case study.

II. LITERATURE REVIEW

Petroleum is derived from two Latin words “Petra” and “oleum”, which means (oil from the rock). The first ever successfully drilled exploratory oil wells on record is situated inthe United States of America (USA), in 1859 (Mendoncaet al, 2006).However, in Nigeria, the first commercial quantity of oil was discovered in Oloibiri, Bayelsa state, where the first oil well was also drilled.

OML42, which happen to be one of Nigeria most prolific onshore oil field, which comprises of four sub-flow station, namely: Jones Creek, Odidi, Egwe, and Batan, was discovered in (1967), and operated by Shell Petroleum Development Company of Nigeria Limited (SPDC), in joint venture partnership with Nigeria National Petroleum Corporation (NNPC) in a production sharing arrangement. The case study (Jones Creek) oil production field, is located at about 45km (approximately one hour, forty-five minutes, 75horsepower speed-boat) drive from Warri. It is situated in OML42, which extends into Chevron OML49 (SPDC, 2004). The field encompasses a stacked deltaic sequenced sand reservoirs confined within simple anticline that are bounded by major growth faults both at the north and south area of the reservoir.

Over the years, a total of forty-six (46) wells have been drilled in the Jones Creek field alone, and forty-one (41) wells completed with dual string completions. Oil production operation fully started in 1969, and peaked in 1972 with over 144mmbl/d. over this period, daily production has declined due to high water cuts. However, in other to increase daily hydrocarbon recovery, additions offtake points are identified to develop the Jones Creek field into a model facility that could handle the produced-water, in compliance with statutory requirements.

It is a contemporary,knowledge that the formation of crude oiltakes thousands ofyears to achieve. Micro-organicmatter undergoes both physicalandchemicalprocesses with fragments of other organic materials. These materials are then depositedatthebottomof seas, lakes and streams, which slowly decomposed and covered by sediments under the effluence of high temperature and pressurethereby, causing complex chemical reaction that eventually result to the formation of hydrocarbon also known as crude oil (Cakmakci, 2008).

The accumulation of the deposited hydrocarbon generally depends on the existence of pore spaces of a porous reservoir sedimentary source rock which has the capacityto containandstore the hydrocarbon (crude oil) (Andrade et al, 2010).

The Oil and Gas Production Industry Produce-Water Treatment Challenges

The main challenge in the industry is to ensure that the produced crude oil and water is free of unwanted substances and at its required standard before it gets to the refinery. This is necessary inthesense that, unwanted substance such as nitrogen, sulfur, oxygenates, and other impurities if not removed will damageequipmentduring the refinery process that will help extract the final byproductsthat we need (Beychok, 1967).

Thepresenceofdissolvedsaltsin the produced-waste water is another malignant challenge that could cause corrosionto flowlines andreduction ofthe produced oil quality. Production of water in theform of dispersed emulsionwithhighsalinity generally contribute to degradation of both downhole equipment and surface facilities (Frinhaniet al, 2007), and (Gobbi, 2013).

Themainsourceof crude oil pollution in the industry is the produced water. It contains certain volume of contaminants thatincludes heavy hydrocarbon mentals, potential toxic elements, and chemicaladditives that are very cumbersome to undergo naturaldegradation (Adradeet al, 2010).Themostsolubleandtoxicclassof pollutant that existintheproduced-waterare the aromaticcompounds of toluene, benzene, xylene-isomers, ethylbenzene,and dispersed phenols (Coutinho, 1999).Moreso, total removal of these compoundsfrom the produced-water is verydifficult and,directbiological treatment method is not viable due to their high level of toxicity(Bader, 2007).

The amount of water-produced at the start of production, along with the crude oil is

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low.However, when the well ages toward the peak of production, and during production decline phase, the water produced might exceedseveral volumes more than the volume of oil produced daily due to the decays of oil and gas production in the field (Somerville et al, 1987), (Thomas, 2001). Though water is regarded as one of the major effluents associated with the mobility for the extraction and production of crude oil, it is treated sometimes with the singular purpose for enhance recovery in mind(Stromgrenet al, 1995).

Once the so required fraction of the treated water is used applied for the oil recovery purpose in form of reinjection into the reservoir, it also, help in the maintenance of reservoir pressure for the efficient flow of the crude oil to the surface thereby, increase daily production; and the residue fraction is then discarded to the sea after treatment.

In some region where oil and gas are produced, the residual fraction of produced-wateris said to be discarded without treatment as stated by (Canizareset al, 2008), cited in the works of (Nonatoet al, 2018). However, such practice is only practically possible or permissible in countries where the environmental legislation and regulatory authorities are weak or ineffective as can be find in most third-world countries such as Brazil and in some Africa countries. In most developed countriessuch as the UK, or USA, where environmental legislations are robustand the regulatory agency are effective, such practice will be met with hefty fines and remediation consequence (Metcalf, 2003).

The direct discharge of the untreated produced-water into the stream or ocean have negative impact on the marine ecosystem. This is factual in the sense that, thecontinuous discharge of the untreated produced-water containsmorequantity of oil and grease (O&G's), and suspended gel-like particles that reduce the oxygen level in the marine ecosystem (Cheryan, 1998).

Therefore, oil and grease contents are regarded as a major parameter, and considered as one of the determinate factorsfor the disposal of produced-water into any ocean body (Cerqueira, 2011).

In thecurrent case study (OML42 Jones Creek) location, approximately (350m^3/h)of produced-water is generated in oil and gas production operation daily. Through the advances in oil production technology both in shallow and deepwaters,andthegrowingstringent ecologicalethics,thereisarisingobligationfor a matured oil field to have an economically viable produced-water treatmentplant, thatwill be a solutiontothechallengeof waste water in other to operate within the effluentdischargestandards.Itisestimatedthatwith the next 15years, the Jones Creek field will generate over 100 million m^{3}ofproduced- water. While in the (USA), onshore oil and gas production fieldsgenerate over 33millionbarrelsofproduced-water yearly ((Freire, 2001).Therefore, asystematic study is required to determinethemost appropriate treatment and disposal technology.

The Malignant Oil-Grease (O&G) Components in Produced-Water

The dispersed or emulsified oil and greasy components are the quantity of hydrocarbons existing in the produced-water of a given oil and gas production field.These greasy contents are extremely difficult to remove because of their high stability both in light and heat-treated eveninminorquantities and are not biodegradable. They are known for their ability to reduce the atmospheric water-air contact, and prevents oxygen transfer into the polluted water surface (Bader, 2007).

Crude oil and produced water separation is a very complex, and time-consuming process in the industry.Especially, if the produced water comes with substantial number of dispersed droplets of oil that is above the level approved, treatment and disposal will require strict compliance of the established environmental standards prevalent in the country of operation. Therefore, in order to avoid unnecessary fines and tax, industry management regards all produced-water as high-risk commodity (Stromgrenet al, 1995). Most oil and gas industry regulatory bodies are solely concern about the level of oil and grease parameters existent in every cubic meter of produced-water, and this differs from country to country. This is typically estimated as monthly average of approximately40 to 100 milligram per litre (Weber, 1986).

Petroleum Industry Regulation and Guidelines in Nigeria

There are several legal frameworks guiding the petroleum industry and its operationsin Nigeria.The ministry that has the primary responsibility for making policies direction and playing the overall supervisory role and oversight functions in the industry is the federal ministry of petroleum resources. In that capacity, the minister of the ministry issues regulations, directives and guidelines in pursuant to the petroleum industry act and all other enabling laws in of the petroleum sector.

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The Oil and Gas Regulatory Agencies in Nigeria

In 1977, the Nigerian National Petroleum Corporation (NNPC), was established to solely have the authority of overall regulatory activities. They are involved with the exploration, production, transportation, processing, refining, and also marketing of crude oil and its by-products through its subsidiary companies; which includes the Department of Petroleum Resources, (responsible for monitoring operating oil and gas companies, setting and enforcing environmental standards, supervises, and ensure compliance with oil industry regulations, etc.); and the National Oil Spill Detection and Response Agency (NOSDRA), just to mention a few, and a host of other regulatory bodies for the various segments in the industry.

Thus, the body responsible to operate and set the oil, grease and other effluent parameters in the Nigeria oil and gas industry is the Department of Petroleum Resources (DPR), now known as the Nigerian Upstream Petroleum Regulatory Commission (NUPRC) in the New Petroleum Industry Act No.6 (PIA), signed into law by the president (Mohammed Buhari) administration in 2021.The commission is responsible for the regulatory guidelines, and stipulate that the oil and grease contents in produced-water should not be above 10mg/L in Inland locations, 20mg/L in near-shore locations,40mg/L in offshore locations, and production facilities; as can be seen on the (DPR) effluent produced water discharge limit (Table 1) below.

Table 1: Produced water/effluent disposal Limit in the Niger Delta oil and gas Industry (DPR, 1990)

S/N	Effluent Characteristics	Inland	Near-Shore	Offshore
1	pH	6.5 - 8.5	6.5 - 8.5	No limit
2	Temperature	25	30	
3	Oil/Grease Content(Mg/L)	10	20	40
4	Salinity	600	2,000	-
5	Turbidity	>10	>15	-
6	Total Dissolved Solids	2,000	5,000	-
7	Total Suspended Solids	>30	>50	-
8	Chemical Oxygen Demand	10	125	-
9	Biochemical Oxygen Demand	10	125	-
10	Lead	0	No limit	-
11	Iron	1	No limit	-
12	Copper	2	No limit	-
13	Chromium	0	0	-
14	Zinc	1	5	-
15	Sulphate Mg/L	0	0	0
16	Sulphate SO4 - Mg/L	200	200	300
17	Mercury Mg/L	0	-	-
18	Turbidity	10NTU	10NTU	10NTU

However, research done by Isehunwa and Onovae (2011), which comprehensively evaluate the physio-chemical properties and constituents of water-produced in the oil industry in the Niger Delta region, in other to determine the level of compliance with the required global standard, and the (DPR) guidelines.It was observed that the prevailing limits of oil and grease content, and other parameters as highlighted, are way above the stipulated limit as can be seen in (Table 2) below, which ranges from (65 – 80 Mg/L). It is also observed that, most of the flow-stations andterminals within the Niger Delta region does not have the basic produced-water gravity separation facility and some operators only indulge in dilution with dispersant before disposal into the environment (Adaobi, 2016), which is not an effective treatment procedure.

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Table 1: Effluent Constituents of Produced-Water from oil fields inthe Niger Delta (Isehunwa and Onovae, 2011)

S/N	Parameters	allowable Limits	Flow stations X	Y	Z	Terminals A	B
1	pH @75^{o}F	6.50 - 8.50	8.12	8.53	7.88	8.10	8.43
2	Resistivity @ 65^{o}F	-	0.45	0.68	1.58	0.37	8.40
3	Oil/grease content (Mg/L)	10.00	65.00	42.00	64.00	80.00	40.00
4	Copper (Mg/L)	1.00	0.25	0.01	0.37	0.44	0.08
5	Lead (Mg/L)	0.05	0.05	0.03	ND	ND	0.04
6	Iron (Mg/L)	1.00	0.40	0.15	0.35	0.17	0.13
7	Nickel (Mg/L)	1.00	0.50	0.49	0.54	0.33	0.65
8	Barium (Mg/L)	-	16.00	8.00	5.00	20.00	11.00
9	Zinc (Mg/L)	1.00	0.10	1.80	0.98	0.09	0.85
10	Magnesium (Mg/L)		56.00	34.40	165.00	4.86	14.75
11	Chloride (mg/l)	600.00	5,100.00	2,583.00	3,589.00	4688	3,970.00
12	Sulphate (Mg/L)	200.00	12.00	2.00	-	-	30.00
13	Carbonate (Mg/L)	-	16.00	220.00	200.00	180.00	110.00
14	Bicarbonate (Mg/L)	-	2,000.00	980.00	4,720.00	1036.00	710.00
15	Total dissolved solids	2,000.00	9,000.00	3,978.00	5,300.00	6,850.00	6,440.00
16	Total suspended solids	30.00	60.00	80.00	138.00	104.00	94.00
17	BOD (Mg/L)	10.00	500.00	8.50	4.50	8.68	5.33
18	Discharge temp(^{o}F)	-	85.00	84.00	92.00	85.00	82.00

This goes a long way to show that, even though there are legal frameworks available to be complied with by the operators in the industry, most times the operating companies flagrantly disregards and flaw such laws, and the enforcement agencies are not doing enough to ensure strict compliance.

Major Produced-Water Treatment Technology and Techniques

There are several produced-water treatment technologies and techniques currently available due to the advancement of the separation processes in the industry, specifically aimed at the removal of maximum effluents, oil and grease contents associated with the water. On offshore location, the most viable option most operators deploy for the treatment of produce water is the hydro-cyclone and floatation techniques.

In this process, the water-produced that comes from the three-phase separator basically undergoes oil residue removal stage in the hydro-cyclones batteries, then accelerated to the floaters by the process of induced gases. Also, centrifuge,mixed-bed, and walnut-shell filters process are accomplished in the process (Hansen and Davies, 1994).

Furthermore, other technologies readily available for improved management of produced-water in the industry includes, electrochemical process, adsorption technique, filtration and floatation techniques. Low cost of operation and high efficiency are some of the commonly considered parameters for the selection of a viable produced-water treatment technology or technique in a given oil production field, and there is no “one technology fits it all” approach in the industry. Due to space and weight constrain in offshore locations, the compatibility of a technology is also considered (Metcalf, 2003).Moreover, the type of oil reservoir parameters and process variable such as pressure, oil viscosity, temperature, stability of emulsion, oil droplet size, flowrate and salinity also contribute to

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the overall performance of the technology (Lawrence et al, 1995).

The Electrochemical Produced-Water Treatment Technique

This technique help deploy the electron toxic substance that will be harmful to the environment by way of oxidation-reduction reaction (ORR) transforming them into less toxic substance in the produced water before its disposal. This is also a viable option that can be effectively deployed in the petroleum industry as an alternative mechanism for the conventional physiochemical produced water treatment methods. Its advantages include; the availability of electricity in the flow stations, reactive power conditions, and easily controlled automation with relatively compact plant unit requirement (Ramalho, 2010) and (Cerqueira, 2009).

Moreso, it allows treatment capacity expansion of the physiochemical methods due to its application of the same basic coagulation and flocculation concepts and enhance the process by the generation of hydro-oxygen in the reaction that facilitates floatation of pollutant while increasing the treatment process efficiency (Chakrabarty, 2008).

Floatation Technique

One of the most commonly used produced-water treatment recovery process in the oil industry is floatation technique that is based ongravity separation process (Silva, 2014). Presently, the rate of oil removal efficiency for the floatation technique ranges from 85 – 90% with a comparably lower cost of installation and operation (Thomas, 2001). The technique consists of four main steps, which includes – produced-water air-bubble generation, suspended oil droplet air-bubble water contact, drop of oil joining with the air bubbles, and then lifting the cojoined oil-air bubbles to the surface for removal (Santos et al, 2005).

However, according to Ken and Maurice (1999),the floatation technique decreases retention time of the vessel and the separating vessel size requirement which hinders the specific droplet size that can float to the surface, and the size of oil droplet which can be captured for a specific separation vessel. The electro-floatation mechanism is the best floatation device or method due to its ability to float pollutant to the water surface by the use of tiny gas bubbles generated through electrolysis process at bottom an electrochemical reactor that promote effluent purification (Pletcher, 1990).

Flotation units are the only water treatment equipment that do not solely depend on gravity separation of produced-water effluent (oil) droplets. There are two distinct types of floatation unit in the industry. They are: dissolved gas units and the dispersed gas units, which are distinguished by the method deployed for the production of the small gas bubbles essential to contact the water surface (Ken, 1999).

Adsorption Technique

This technique is built on the liquid-solid surface interaction principle. The principle states that when a liquid and solid surface comes in contact overtime, accumulation of the solute molecules on the surface layer will occur due to the disproportional surface forces in existence between the liquid and solid phase (Braga et al, 2010). This phenomenon is closely related to the surface tension-solution principle. The force of its intensity is closely related to the temperature, nature, concentration of the substance to be adsorbed, and both the physical state of the adsorbent and the adsorbent fluid it's in contact.

Though, it is commonly used in high purification plants, it is also used in oil-water separation process at part of produce-water treatment techniques (Santos et al, 2007).The high price of adsorbents in the industry is one of the downsides of the adsorption technique. However, column packed with polymeric resins could be one of the alternative materials for produced-water treatment in place of adsorbent. According to (Queiroset al, 2006), this method can be very effective in reducing the oil and grease content of produced water by (1.0mg/L), and its efficiency could be up to 98% of the oil content reduction in the produced-water after treatment. (Bernardo, 1999).

Plate Coalescers Technique

Plate coalescers are skimmer vessels which uses internal plates for improvement of the gravity separation technique. There are various configurations of the plate coalescer currently available in the industry. Most commonly used type includes: corrugated plate interceptors (CPI, crossflow separators (CFS), and parallel plate interceptors (PPI) (Maurice, 1989). They all depend on the principle of gravity separation, where the oil droplets rise to the plate surface for the occurrence of coalescences, and eventual capture; as shown in the (Figure 1) below.

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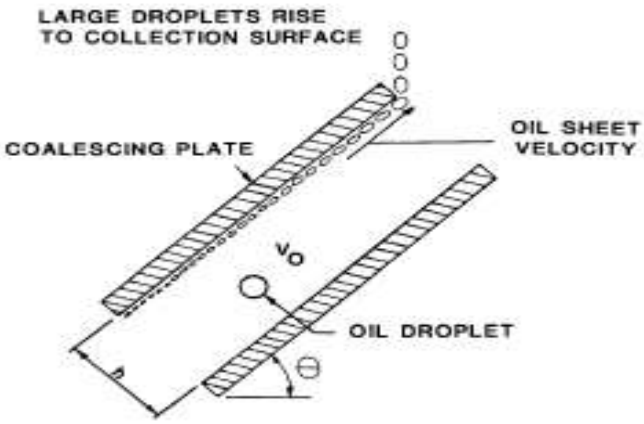

Figure 1 Schematic of a parallel plate interceptor (PPI) of a Plate coalescers (Ken and Maurice, 1999)

The flow of the effluent is split between a number of plates parallel to each other with a short distance in-between and are horizontally inclined in other to enable the effective capture of the oil droplets. The capture of small oil droplets as little as (1 – 10 microns) is achieved based on Stokes' law. Nevertheless, filed application indicates (30 microns) is the more reasonable set of droplets sizes that can be removed, and anything below these sizes with the effect of pressure fluctuation, and vessel vibration (in offshore fields), leads to obstruction of the droplets rise to the coalescing surface thereby, reducing the separation efficiency (Ken and Maurice, 1999).

Filtration Technique

Filtration is a produced-water purification technique in which the produced-water flows over a porous medium in other for the partial removal of colloidal and suspended effluents thereby, resulting to improved water quality by the reduction of bacteria concentration and change of the chemical constituents of the produced-water (Chervan, 1998).

The foremost separation technique been investigated in the petroleum industry for the separation of oil, suspended solids and grease effluents in a granular bed, with hard tangential microfiltration and ceramic intermediate is the filtration techniques (Nonatoet al, 2018).

This process deploys the membrane mechanismofmicrofiltration, nanofiltration, ultrafiltration, and the reverse osmosis procedure for the treatment of produced water with stable oil-water emulsion relatively than unstable free-floating oil-water emulsion. The membrane methods mentionedhere are most effective for the treatment of effluent water with micron size of less than (10µm) with oil of very low concentration, and cases that might be difficult to treat with the conventional methods of gravity separation, chemical, biological and thermal demulsification(Rosa, 2009). Coalescences ofmicro and submicrometric sizes of oil droplets into larger sizes for easy gravity removal is aided by the porous matrix membrane.

According to Rosa (2009), the use of porous ceramic medium for the crossflow microfiltration treatment has been observed to achieve oil-grease removal efficiency rate of (80%) with an average of (1.6 NTU) turbidity (Silva et al, 2012).

The Reverse Osmosis(RO)Technique

The reverse osmosis produced water treatment technique utilizes a connected weight in other to overcome the osmotic weight which is the colligative thermodynamic property that is driven by the potential contrast of dissoluble substances. This method has been available in the industry since 1970. With membrane pore sizes ranging from (0.0001µm – 0.001µm), the reverse osmosis is regarded as the finest partitioned membrane process available in the industry (Al-Jeshiet al, 2008). The reserve osmotic weight is basically more prominent eventhanmicrofiltration due to its capability to hold atoms of suspended effluent particles apart from water and the quality of its pore space (Al-Jeshiet al, 2008). Figure 2 below, illustrate a frequently deployed reverse osmosis membranes used for the treatment of produced-water in the oil industry.

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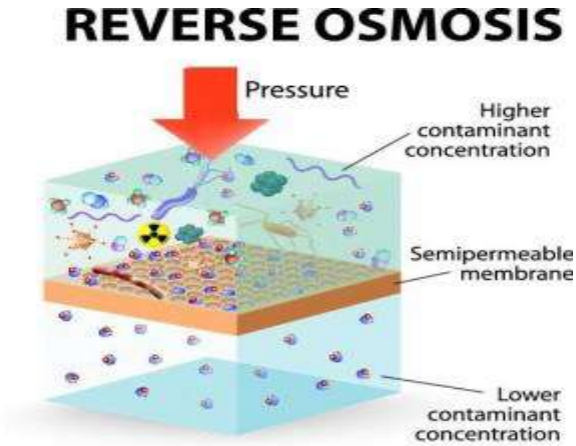

Figure 2: Schematic Mechanism for Reverse Osmosis for produced-water treatment (Al-Jeshi and Anne, 2008)

According to the experimental study done by Al-Jeshiet al, (2008), the reverse osmosis membrane can only treat produced-water with 50% volume of oil contamination. It also, has a questionable oily-water emulsion separation with high-pressure pump requirement to push water through the membrane and the rejection of salt passage through the membrane which require more energy consumption compared to conventional gravity separation methods available (Hayter et al, 2004).

Review of the OML42, Jones Creek Case Study Field, Produced-Water Treatment Plant

One of the newest units installed in the oil and gas production flow-station in the heart of the Niger Delta, the Jones Creek produced-water treatment plant comprises of majority of the treatment techniques and equipment earlier mentioned in the literature review. The installation of the plant is due to production decline that is accompanied with high water-cut. Over 11,000bbl/d of water is produced daily in this location hence, an efficient water treatment is required before disposal to the surrounding environment and at sea.The flow-station has a double-bank two-phase, three-phase separators, and an electrostatic heat-treater (EHT) units that help complete pre-treatment of the produced water before the effluent-water is flowed to the water-treatment plant.

The Jones Creek Produced Water Treatment Process/Major Equipment

The produced-water, after pre-treatment in the EHT flows throughthe three-phase water bulk line into the produced water coalescer unit for further, thorough treatment before disposal into the ocean.

The Coalescer Unit

In the coalescer unit, the effluent oil is separated through gravity-basedphenomenaas described in the plate coalescer techniques, while the water leaves the coalescer and move to the regen unit. A pictorial view of the coalescer unit is shown in (Figure 3) below:

Figure 3: Pictorial view of a produced water treatment Coalescer unit (Courtesy: researcher JC field visit)

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The produced water entered another equipment known as the "regen" for further treatment from the coalescer. The coalescer internals are arranged parallel to each other as discussed earlier, and the separation process is basically gravitational processwhere the oil and grease with all suspended particles flow upward, and the water is moved to the regen for further treatment. The heavy silts and debris move to the bottom of the coalescer for removal.

The Regen Unit

In the regen unit, the effluent water from the coalescer flow through the internal bed of the regen for further treatment. The internal bed of the regen are oleophilic and hydrophobic. Oleophilic means that they attract oily effluent and hydrophobic in the sense that they give up the treated water to be moved to the next treatmentunit (polishers) for further separation. It is also, worthy to note that, the effluent water from the coalescer enters the regen from the top, and leave from the bottom of the regen.

Figure 4: Regen water treatment unit (courtesy: researcher JC field visit)

However, during backwash (a reverse osmosis process that enable the cleaning of the regen internal bed in other to remove the oily grease once they are saturated), the treated effluent water leaves the regen from the bottom.Figure 4 above, shows a pictorial view of the regen unit. A total of four regen units are installed in a series arrangement at the Jones Creek field, foreffective effluent treatment in line with required environmental standard.

Regen Backwash Operation

The regen internal bedsare saturated over a period of time because they are oleophilic in nature. Thus, backwash operation is needed to clean the regen internal bed from the saturated oily grease. The backwash operation is done by back-flowing clean water from the clean-water holding tank with the aid of process pumps. The clean water will then enter the regen through a reserves osmosis process and strip the oil from the internal beds of the regens. Then the dirty effluent water is moved to another equipment called the "Decant" tank. From the decan tank, the stripped oil is moved back to the three-phase separator for father treatment, and theeffluent water is moved back to the coalescer from the decant tank for further separation, and the cycle continues.

The Polisher Unit

As the name implies, the polisher unit enable the final polishing/treatment process of the water from the regen unit, before the water is moved to the clean water holding tank. The polishers are arranged in both parallel and series form. Inside the polishers are internal beds that further stripped effluents oil from the regen treated water. At this point, the water is clean enough to be moved to the water holding tank for onward discharge into the streams and the ocean. A pictorial view of the polisher is shown in (Figure 5) below. There are nine polishers arranged in three trains of through pieces per train. The treated effluent water flows from the regen units into the polisher's unit. The water is then further treatment (polished and stripped of any oil) that flow with the treated water from the regen unit into the polisher unit.

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Figure 5: Jones Creek Produced water treatment Polishers train(courtesy: researcher JC field visit)

Once it enters the first polisher at the first train, the water will be treated by the separation process known as the membrane treatment, andthen moved to the next polisher for further treatment. The process continues until the water move to the last polisher of the last train, and move through the process line into the clean water holding tank for storage and onward disposal. At the storage (water holding tank), gravity separation process also take place for further separation of any oil-grease content that is still left in the water.

Once further separation occurs at the water holding tank, the oil ismoved back to the three-phase separator will the water is testedto determine the purity level, and to determine the level of any oil and grease still left, and if it meets the required environmental standard before discharge into the surrounding streams or ocean.

The Jones Creek produce-water treatment plan, treat approximately, 11,000bbl/d of produced water. Other equipment in the water treatment unit includes: the Human Machine Interface (HMI), where the process control is done, process pump skid, backwash pump skid, decant tank, water holding tank, process lines, and clean water discharge pumps.All these equipment is synchronized to efficiently and effectivelytreat the produced water daily, and as part of the operator's commitment to meet the required environmental standard set by the department of petroleum resources (DPR) now known as the Nigerian Upstream Petroleum Regulatory Commission (NUPRC).

III. CONCLUSION

The present research aimed at presenting some of the major produced water treatment techniques and equipment with a field case study to buttress the importance and application of the various equipment, and their treatment process. this has become imperative since the treatment process make it possible for the removal of oil, grease, and other suspended particles from the water, in other to meet the regulatory agencies environmental specification before disposal into the ocean, and without further harm to the environment. Among the methods studied, the most used methods are the absorption, filtration floatation and electrochemical techniques.

However, the filtration membranes process has higher value application when compared with other techniques due to internal filter medium used in the process.Also, due to the operating cost of the treatment process, it is recommended that further research need to be carried out in order to unveil more cheaper methods of treating produce water in the industry. Floatation stands out as the most applicable oil-grease recovery process for the treatment of various produced effluent in the industry, and as part of the gravity separation process because of its ease of operation.Itis also the process utilized atthe OML42, Jones Creek,case study flow station. The process is relatively efficient in treating the daily produced-water. However, the down side is also, the cost of replaying the internal beds of the regen, polishers and other processing equipment such as the process and discharge pumps, which is a bit financially challenging.

Furthermore, the combination of related treatment processes will help purify the treated water for reuse purpose such as re-injection into the reservoir for further enhance oil recovery; which is observed to be lacking in the case study field. Nevertheless, the cost of such combination of treatment process should be critically examined before embarking on the process due to its financial implication.

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