Petroleum Technology Development Journal

Hydro-Cyclone De-oiler Enhancement for Produced Water Treatment

By

Philip Ajie*, **Victor Aimikhe***, **and Dulu Appah***

ABSTRACT

This study investigated the effect of retrofitting and systematic upgrade of the Hydro-cyclone De-oiler unit during produced water treatment. The internal orifice of the oil reject cones attached to the end of the oil reject Liners was mechanically and sequentially increased and the performance tested from 1mm up to 2.0mm; and then dimensioned to a maximum of 3.0mm internal diameter. A single centrifugal pump (maximum flow-rate of 199m^3/hr (30,000 Barrels per Day) and a pressure of 10 -15 bar-g), was installed along a 6-inch produced water outlet spool of source production separator leading to the De-oiler. This was done in order to boost the operating pressure of the Hydro-cyclone De-Oiler unit to at least, the threshold limit of 5.7 bar-g. Keeping the operating pressure of the De-oiler below 4.2 bar-g, increasing the internal diameter of the oil reject Liner Cone orifice, followed by soaking and cleaning up of the clogged Liner tangential inlet with a 4:1 dilute hydrochloric acid, resulted in an increase in the reject oil production rate from 1.19 barrels per day/orifice to 4.45 barrels per day/orifice (a 374% increase). The introduction of the booster centrifugal pump increased the hydro-cyclone operating pressure from an inlet pressure of about 3.5 bar-g to 7.0 bar-g, accelerated the outward acting centrifugal and G-forces to about 10 times its original value and increased the rising velocity of oil droplet size. The Hydro-cyclone De-oiler increased produced water throughput from the critical flow-rate of 77.0 m^3/hr to a maximum capacity of 201 m^3/hr. The main contribution of this research is the fact that produced water treatment unit Hydro-cyclone De-oiler oil reject flow-rate can actually be enhanced to about 177% with about 300% increase in initial oil reject cone orifice internal diameter; as long as the critical pressure drop ratio across the De-oiler or choked flow ratio is below 1.0 bar-g.

1. Introduction

Produced water is any water layer (connate or formation water) that is present in the reservoir rocks with the hydrocarbon fluid and is produced to the surface with crude oil or natural gas. Produced water is a complex compound that contain traces of dispersed and dissolved oil, heavy metals, boron, corrosive fluids such as hydrogen sulfide and carbon dioxide, production chemicals, radioactive isotopes, formation minerals and other solids[1]

The selection of suitable treatment methods and technologies depends on the water characteristics and chemistry, discharge plan or objective which may include; re-use, re-injection or disposal, target treated-water quality; capital and operating costs, facility space constraints, durability, ease of operation, maintenance, waste-stream-by-products pre- or post treatment requirements and treatment-unit mobility[2].

* Department of Gas Engineering, University of Port Harcourt, Port Harcourt, Nigeria.
Corresponding author's email: victor.aimikhe@uniport.edu.ng

[1] Reed, M. and Johnsen, S., Eds. Produced Water 2, Environmental Science Research, Volume 52, Plenum Press 1996, ISBN 0-306-45308-8

[2] Alastair Sinker, Cyclotech Ltd "Produced Water Treatment Using Hydro-cyclones: Theory and Practical Application" - 14th Annual International Petroleum Environmental Conference, Houston 2007.

Produced water management and cost control can be achieved by choosing an appropriate water disposal options or by finding a suitable beneficial use for the water. The general plan is to select the cheapest method which assures the achievement of targeted final output criteria. The estimated cost of produced water management in an actual conventional produced water treatment facility of capacity 20,000 –200,000 barrels per day during oil production, may cost an average of $0.578 per bbl/d. This estimate includes capital and operating expenditures, utilities and production chemicals, lifting, separation, de-oiling, filtering, pumping, and injection into disposal wells[3]

1.1 Hydro-Cyclone De-Oiler Unit

This unit is basically responsible for the removal of oil contaminants in produced water treatment process. The usual failure of this unit as a result of numerous operational factors, has led to inefficiencies in oil removal in the treatment of produced water. Numerous operational and design problems from the upstream source separator to the downstream cascading vessels, directly or indirectly, account for the spontaneous malfunction and efficiency decline of the Hydro-cyclone De-Oiler unit which can result in the under listed problems.

1. Decline in source wells' flowing pressure and oil production rate.
2. Operating pressure down-grading in the 2^{nd} stage source separator
3. Hydro-cyclone De-oiler operating pressure decline
4. De-oiler throughput decrease and reject oil flow resistance
5. Mineral scale deposits and restrictions observed in De-oiler reject cone orifices.

This study involves the empirical investigation of produced water treatment system with emphasis on Hydro-cyclone De-oiler enhancement. Due to the strategic importance and implications of the system failure, which impacted negatively on an existing allocated export quality, and by diligent examination and observations of past and present data and operations of the Hydro-cyclone De-oiler, the facts and nature of failure can be revealed in order to gain an in-depth understanding into the problem and underlying reasons or causes and as such, the qualitative approach of research method was selected for this purpose.

[3] Salem Alzahrani, and Abdul Wahab Mohammad, National University of Malaysia, September 2014 (DOI:10.1016/J.JWPE.2014.09.007)

Plate 1: Hydro-cyclone De-sander and De-oiler Unit

2. Study Objectives

The specific objectives of this research were

1. To investigate and proffer solutions to the identified problems affecting the Hydro-cyclone De-oiler unit and

2. To enhance the produced water oil recovery efficiency of the unit, restoring full functionality, availability and reliability of the De-oiler.

3. Research Methods

To achieve the laid down objectives of this study, the following methodology was adopted:

I. The internal orifice of the Oil Reject Cones attached to the end of the oil reject liners was mechanically and sequentially increased and performance tested from 1mm to 2.0mm, and dimensioned to a maximum of 3.0mm internal diameter, using a high strength tungsten carbide drilling bits through a lathe machine. The dummy Liners, oil reject cones and blank orifices tentatively left in place were replaced with active Liners and cones of equivalent and corresponding nozzles sizes.

II. Corrective maintenance and mechanical removal (with the aid of hydro-blasting machine) and chemical cleansing with dilute hydrochloric acid on the ratio of 4:1 of the already formed scale deposits from the nucleation sites and internal structures, Liner ports and tiny orifices of the De-oiler oil recovery system was carried out.

III. A high flow-rate 199m^3/hr (30,000 Barrels Per Day) maximum and low pressure 10 -15 bar-g (maximum discharge pressure) and, single or multistage centrifugal pumps, by two (alternating between service and stand-by mode) was installed along the 6-inch produced water outlet spool of source production separator leading to the De-oiler, in order to boost the operating pressure of the Hydro-cyclone De-Oiler unit to at least, the threshold limit of 5.7 bar-g and to the original design limits.

IV. After the retrofitting, successful Non Destructive Examination (Magnetic Particle Inspection –MPI and Dye Penetrant Tests, to identify surface cracks in Field-Joint welds and component spool), High Velocity Water Flushing (HVWF) at a minimum fresh water velocity of 10m/s, and Hydrostatic Pressure testing of the skid-mounted, retrofit produced water treatment upgrade and multistage hydro-cyclone unit; comprising the upstream De-sander, midstream De-oiler and downstream Flash Vessel; were carried out.

V. The initial Site Acceptance Test Experiments and documented pre-commissioning parameters were used as the control test, toward which subsequent tests were compared in order to minimize the effects of variables other than the single independent variables being tested.

VI. During the pre-commissioning process and control test, the independent variables which include operating pressures, system back pressure, liquid flow-rates, and oil in water concentrations were periodically manipulated and dependent variables like viscosity, relative density of oil and water among others were strictly measured on-line.

At first, the De-oiler was operationally by-passed, directly lining and linking up the upstream De-sander with the downstream Hydro-cyclone Flash Vessel. Gradually, the Hydro-cyclone unit was about 80% by-passed and the oily water diverted to the old drainage system (Flash Vessel, Corrugated Plate Interceptor (CPI) Skimmer and Induced Gas Floatation (IGF) Unit respectively). The essence of maintaining and allowing 20% total produced water volume through the less effective De-oilier unit was to reduce entrained Basic Sediments & Water (BS&W) in the stabilized daily crude oil production with standard Reid's Vapour Pressure (RVP), by maintaining the effective separation liquid levels and reducing high-high level of water and water carry-over through the demarcating weir into oil compartment. The initial operating pressure adjustment reduced the De-sander inlet pressure from about 8.2 Bar-g to 6.0 Bar-g, before cascading down through the six-inch oily water outlet to the immediate downstream De-oiler horizontal vessel.

The oil reject orifice with an original internal diameter of 1.0 mm was bored to 2.0 mm, re-assembled on the Liner and De-oilier, flow tested and the performance, monitored for an interval of one week. For each step increment, parameters were sampled and analyzed bi-hourly, daily and weekly from pressure and temperature transmitters. Liquid (oil + water) flow-rates meters observed specific gravity for the relative densities of water and oil ascertained and degrees API at standard conditions.

Field analysis of the total oil in water concentration as contained in the produced water of the Hydro-cyclone De-sander and the De-oiler effluent to the final treatment/polishing stage (Flash Vessel), including the final effluent discharged to the marine environment through a dedicated and fixed, semisubmersible Sea sump (Caisson) were also monitored to ensure that the maximum approved limit of 40 ppm, was not exceeded.

4. Results and Discussion

The results and observations originating from the research methodology employed in this study are discussed in this section.

Results showed that when the De-oiler was operationally by-passed, directly lining and linking up the upstream De-sander with the downstream Hydro-cyclone Flash Vessel, an inadequate treatment, indicated by a rise from 14 parts per million (ppm) to 40 ppm in the final oil in water concentration analyzed in the Offshore Oil Field laboratory using OSPAR Reference Method, (ISO 9377-2 As Modified by OSPAR) was observed.

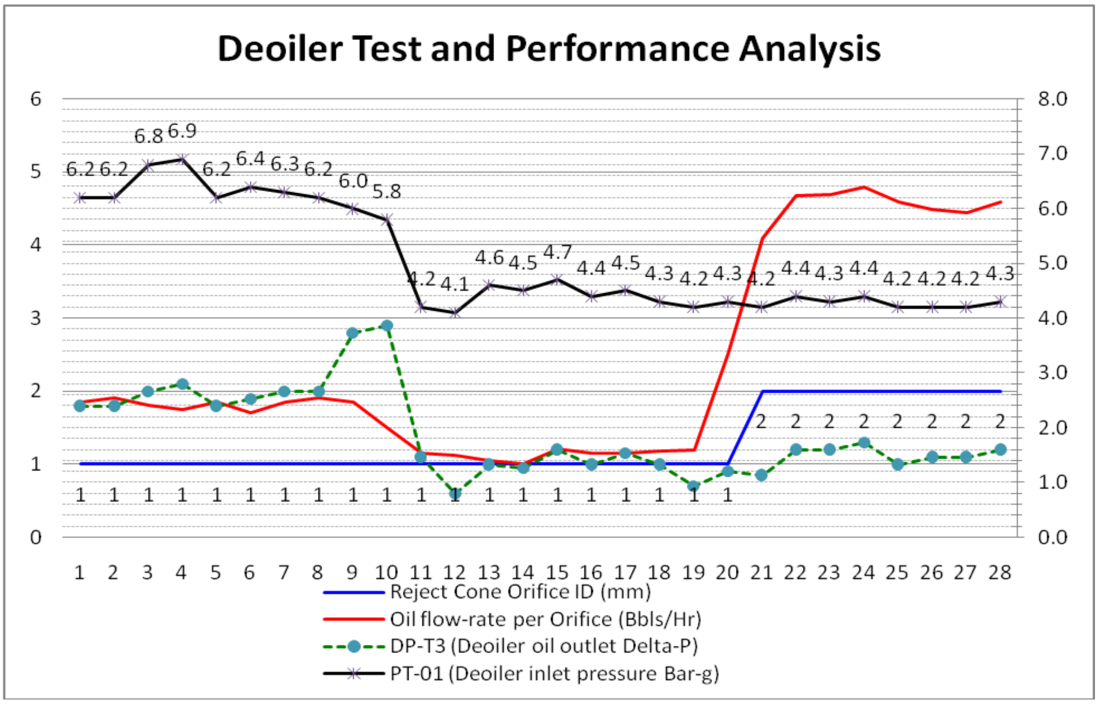

Figure 1: Hydro-cyclone de-oiler failure analysis and plant trail performance parameters

Figure 1 indicates that immediately the operating pressure of the Hydro-cyclone Unit, upstream the produced water supply vessel (Second-stage and three-phase, Process Separator unit) was downgraded (in order to enhance production rate from the very low pressure well Strings), the hydraulic and primary operating pressure of the downstream De-oiler unit, collapsed below the optimal working pressure of 7.0 Bar-g (101.5 psi-g).

It was also observed that the Hydro-cyclone De-oiler treatment unit, lost its vital internal energy and drive to cause enough separation of the produced water, saturated with dissolved and suspended mineral scale elements together with about 5% dispersed oil. This resulted in natural precipitation of calcium carbonate ($CaCO_3$) dissolved solids, plugging the De-oiler Liner inlet ports and outlet oil reject cone orifice, including the stationary internal mechanism, and a near stagnant water hold-up in De-oiler unit.

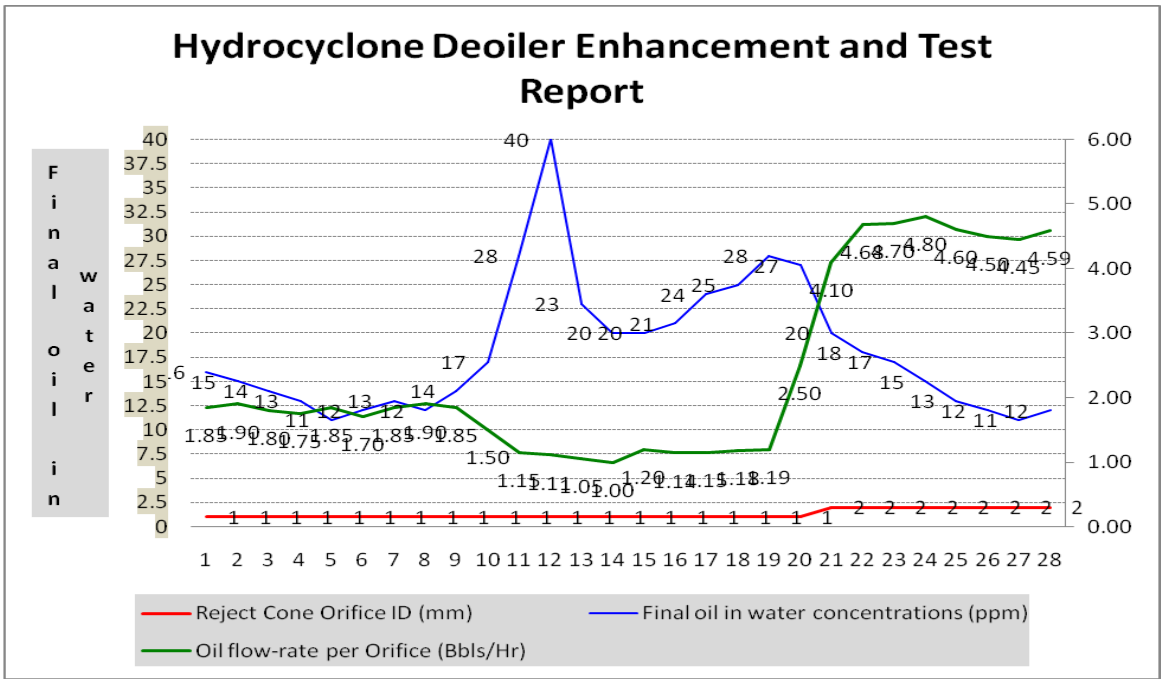

Figure 2: Deoiler enhancement and field performance test process parameters

Also, the demulsifier (emulsion breaker) chemical injection reciprocating pump, temporarily failed due to a stuck discharge piston. This led to a peak of 58 ppm of the concentration of oil in water. The final disposed waste water was found to equally increase to 40 ppm even when the De-oiler was by-passed, with an observed minimum concentration of 11 ppm after the orifice of the reject cone was re-sized to 2.0 mm and 3.0mm respectively (Figure 2).

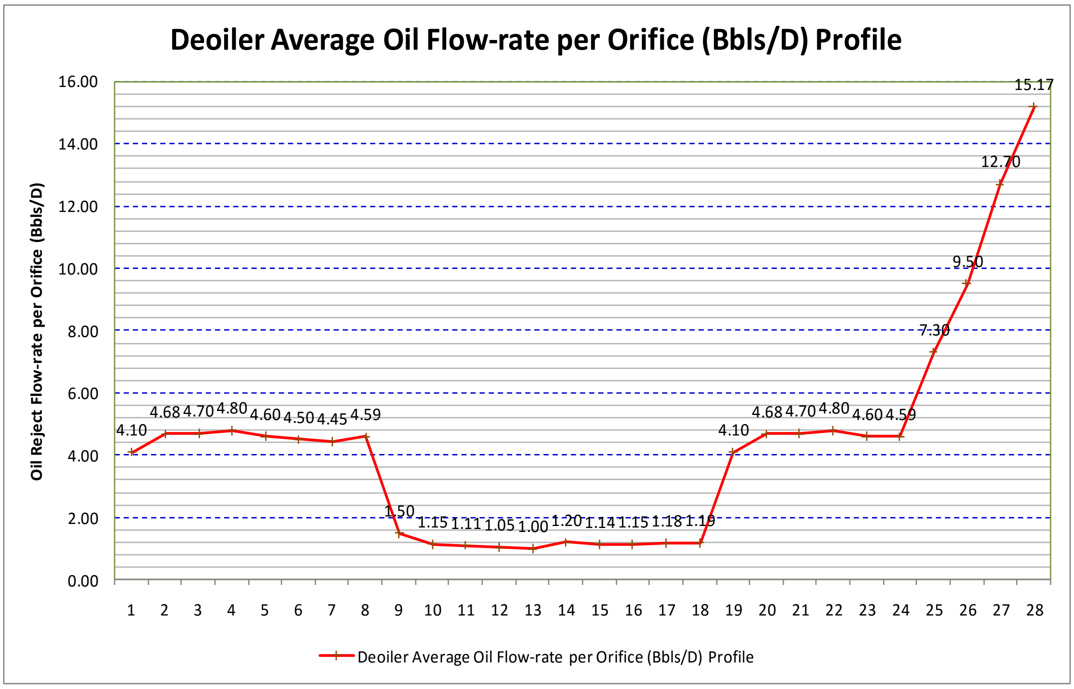

Figure 3: Hydro-cyclone de-oiler oil flow rate per reject cone orifice – profile

Figure 3 showed that from an average of 4.59 barrels per day oil reject flow-rate before the operating pressure downgrade, declined to an all time low of 1.0 bbls/day/orifice. This lasted for more than eight weeks until the functionality was restored by the sequence of executed action plans stated in this study.

After the Hydro-cyclone unit re-start-up, the volume of oil recovered compared to the initial rates and concentration of the feed water increased by more than 100%; according to monitored field reports and laboratory analysis periodically carried out on the De-oiler effluent and on the final effluent discharge through the atmospheric flash vessel; a testament to successful operations and enhanced efficiency.

The oil in water concentration in the produced water sample from the De-sander/De-oiler influent, and Flash Vessel effluent dropped from an initial average of 41ppm down to 10ppm, a value far below the recommended maximum limit of 40ppm concentration in an offshore oil Field waste water discharge system.

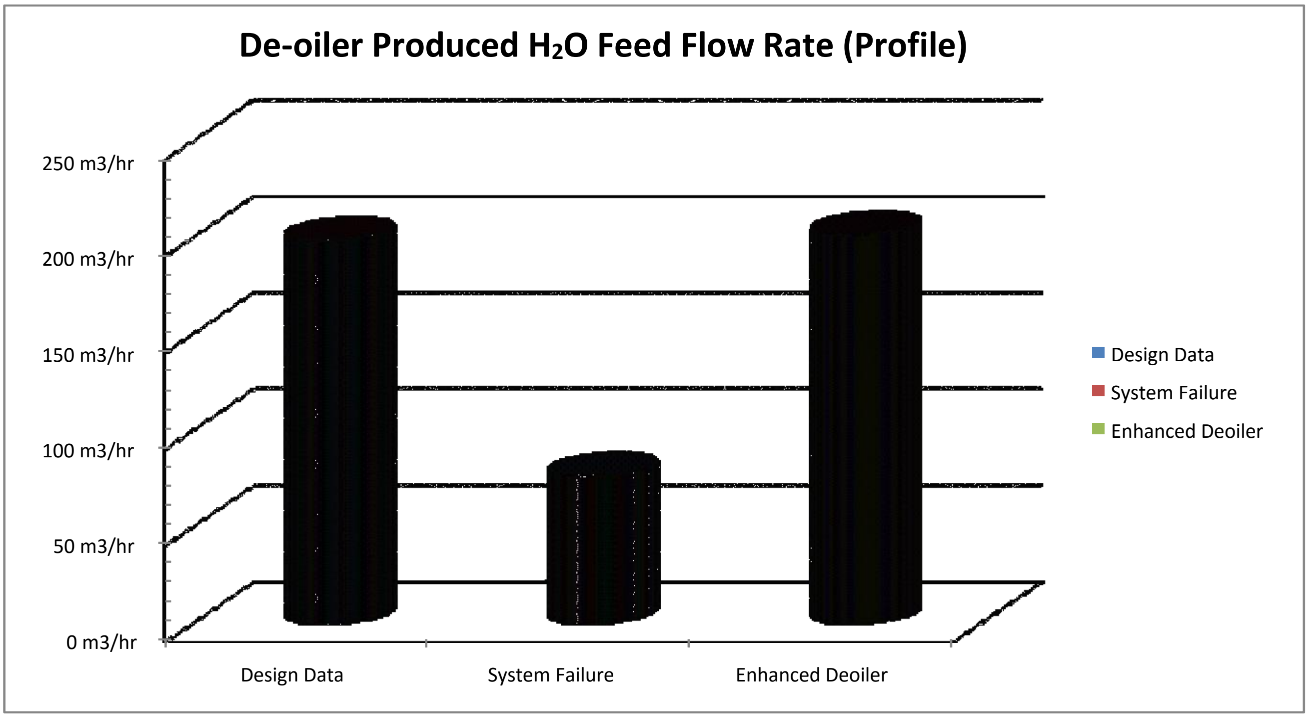

Figure 4: De-oiler post enhancement produced water flow-rate (average throughput) profile

Figure 4 showed the effect of retrofitting the Hydro-cyclone De-oiler on the produced water throughput the critical flow-rate. It indicated that there was an increase in produced water throughput from the critical flow-rate of 77.0 m^3/hr to a maximum capacity of 201 m^3/hr (30,342.05 Bbls/Day), observed and recorded through the field positive displacement meter (totalizer) on the final water outlet of the Hydro-cyclone Flash Vessel –downstream the De-oiler.

6. Conclusion

Based on the results and discussions in the preceding section, the following conclusions can be drawn:

1. Produced water treatment unit with a Hydro-cyclone De-oiler oil reject flow-rate unit, can be enhanced to about 177% with about 300% increase in initial oil reject cone orifice internal diameter and closed impeller, as long as the critical pressure drop ratio across the De-oiler or choked flow ratio of 1.0 bar-g is not reached.

2. Installation of a booster centrifugal pump eliminated the issue of drop in normal operating pressure of the Hydro-cyclone De-oiler and increased the tangential velocity, the radial acting centrifugal force as well as the pressure drop across the cyclone, there-by enhancing separation of the differential density oil and water produced component.

3. Inline Hydro-cyclone bulk de-oiler with smaller cylindrical size, lower pressure drops across the cyclone, lacked bulk flow volume/capacity for oil field de-watering operations due to significant reduction in size and thus cannot be used effectively for de-bottleneck operations in a mature oil Field.

4. It is mechanically efficient to increase the oil reject cone orifice internal diameter by boring than to decrease the existing nominal size by material refilling or outright replacement.

5. Hydro-cyclone De-oiler with an oil removal efficiency of 1–3% inlet oil concentration/flow-rate (droplet size ranging from 10-15 microns), can only be used as a last stage option for produced water treatment with a contingency plan in the event of failure where the produced water management objective is solely to discharge the effluent safely back to the marine environment.

6. Hydro-cyclone De-oiler should not be used where the produced water treatment objective is for re-use (irrigation, ground water re-charge, and domestic use) and re-injection through dedicated Well(s) for enhanced oil recovery.