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Produced Water Treatment Design Methods in the Gas Plant: Optimization and Controlling

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Abstract

Oil and gas industry produces a huge volume of produced water that contains hydrocarbons, heavy metals, and other pollutants. In the oil and gas industry, produced water, treatment, and management represent a growing challenge. Increasing the oil and gas industry activities, the production of produced water is increased all productions areas all over the world. Its treatment for reuse, management, and disposal represents a significant challenge from an environmental perspective. It is estimated that for every 1 barrel of oil produced, there are 8 to 10 barrels of produced water recovered. In this paper, a comparison of the different techniques for the primary and secondary produced water treatment that are widely applied in industry was investigated to choose the best applicable technology to achieve the required treated produced water specification in the gas project. A technical and economic comparison were conducted. It has been found that de-oiling hydrocyclone followed by induced gas flotation unit is the best choice.

Keyword: CPI separator, DAF, IGF, hydrocyclone, condensed water, CAPEX, OPEX.

1. Introduction

The world daily petroleum consumption would increase from 85 million barrels in 2006 to 106.6 million barrels by 2030. Petroleum is produced with large volumes of waste, with wastewater accounting for more than 80% of liquid waste and as high as 95% in ageing oilfields. Generally, the oil/water volume ratio is 1:3[1-3].

Produced water composition can be classified into organic and inorganic compounds, including dissolved and dispersed oils, grease, heavy metals, radionuclides, treating chemicals, formation solids, salts, dissolved gases, scale products, waxes, microorganisms, and dissolved oxygen. Globally, -/+ 250 million barrels of water are produced daily from both oil and gas fields, and more than 40 % of this is discharged into the environment [4, 5].

Produced water presents serious operating, economic, and environmental problems. Production of water with the crude oil or natural gas reduces the productivity of the well due to the increased pressure losses throughout the production system. Produced water also results in serious corrosion problems, which add to the cost of the operation. Production of water requires the use of three-phase separators, emulsion treatment, and desalting systems, which further add to the cost of the operation [6,7].

The produced water must be treated before it is disposed of or injected into the reservoir to remove the oil from the water such that the remaining amount of oil in the water and the oil droplet size are appropriate for the disposal or injection of the water [8,9].

The main objective of this study is to select the best technology in the market to achieve the required treated produced water specifications in the gas project based on the technical & economical comparison and the suitability of the technology in North Africa region between the equipment, which should be used in the

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primary and secondary stage for the produced water treatment.

2. Gas Project Description

Figure 1 reveals the major processing units in the central processing facility CPF. The gas will be exported via the export gas pipeline, and the condensate will be shipped via export pipeline to the oil terminal.

The water outlet from process facilities in the gas project will be treated in produced water treatment package and finally evaporated from the evaporation pit.

3. Treated Produced Water Specifications in the Gas project

The oil content in the water from the inlet separator is expected to have oil droplets with a maximum diameter of 150 µm, the oil content in the water from the water/ condensate separator is expected to have oil droplets with maximum diameter of 50 µm, the produced water from these separators is routed to the produced water treatment unit. Table (1) displays the treated water specifications in the gas project.

Table 1: Treated Produced Water Specification.

Hydrocarbon content	ppm vol.	< 20
Suspended material	ppm vol.	< 30
Sulfate reduction bacteria	population / cm^3	< 10
Mercury content	ppb	< 20

4. Produced Water Sources in the gas plant

Production water is divided into two different kinds of water

4.1 Condensed Water

This is the water bound inside the gas that separates because of changes in operating pressure and temperature. The maximum volume of condensed water to be used as a basis of design is around 100 m^3/d. The condensed water system will receive water from the inlet separator, dehydration unit, flash drums, condensate stabilizer, chilling unit, drainage of storage tanks, and closed drain network.

4.2 Produced Water

Produced water will come out of the formation together with the reservoir hydrocarbons. The gas project is not expected to produce water during the initial period of production. After 2 to 4 years, the water cut is expected to rise to approx. 25% of the condensate produced, i.e., up to between 300-500 m3/day. Water analyses are available, and they indicate a very high salinity.

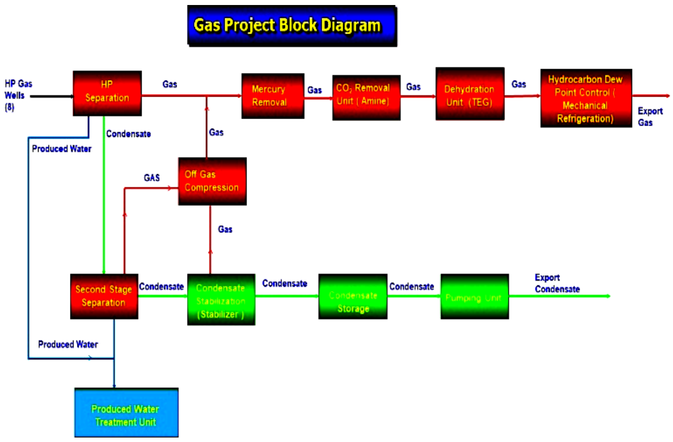

Figure 1: Schematic of the CPF Process Units.

The formation water properties at the gas wells are shown in table 2:

Table 2: Measured Formation Water Properties.

	Unit	Sample 1	Sample 2
Depth	M	3930.2	3826
Hydrocarbons	%	~ 30	~ 20
Color		Yellow turbid	Colourless, clear
pH-value		4.9	4
Alkalinity	mmol/l	0.4	-
Total alkalinity	mmol/l	0.9	0.2
Acidity	mmol/l	32.9	31.6
Total Hardness	mmol/l	975	1030
Total Hardness	°dH	5466	5775
Chloride	mg Cl/l	165565	168224
Bromide	mg Br/l	1683	1616
Sulphate	mg SO_4/l	8.0	4.3
Lithium	mg Li/l	21.3	19.6
Sodium, calculated	mg Na/l	61607	59127
Potassium	mg K/l	1239	1908

	Unit	Sample 1	Sample 2
Ammonium	mg NH_4/l	182	191
Magnesium	mg Mg/l	5063	10980
Calcium	mg Ca/l	30535	23071
Strontium	mg Sr/l	395	217
Iron, Total	mg Fe/l	301	1823
Phenols	mg/l	0.35	0.19
TDS, calculated	mg/l	266075	266621
Density @ 20 °C	g/cm^3	1.184	1.194

5. Methodology

The primary treatment provides removal of sand and free oils in water, but the stringent regulations (< 20 ppm oil in water specification) require complementary technologies to reduce the levels of oil and other contaminants further. Secondary treatment of produced water also tackles the issue of dissolved hydrocarbons in the water.

5.1. Produced Water Primary Treatment Methods

In this step, it is intended to reduce the oil content in the water stream from about 1.5 %v to max 100-150 ppm. The following options available for this step are hydro-cyclone and CPI Separator.

5.1.1. De-oiling Hydrocyclones

Fluids enter the hydro-cyclone through the tangential inlet at top, which causes the fluids to spin and attain high centrifugal forces. The clean water exits the hydro-cyclone through the open end of the tube at bottom [10, 11]. Table 3 illustrates the advantages and disadvantages of de-oiling hydrocyclone.

Table 3: Advantages and disadvantages of De-oiling hydrocyclone.

Advantages of De-oiling Hydrocyclones	Disadvantages of De-oiling Hydrocyclones
No moving parts saves maintenance time and costs.	Wear and tear of materials
Available as standalone equipment or complete skid packages	The need to buffer the supply flow to create a consistent supply to the hydrocyclone.
High Efficiency @ particle size less than 10 microns	High cost due to the Metallurgy-Erosion Issues
Modular Design gives flexibility for capacity enhancement	Energy Requirement to pressurize Inlet is high
Superior hydraulic stability even at very low flow rates due to tighter, axisymmetric oil core.	
Low and steady pressure loss provides predictable flow rates	

5.1.2. Corrugated Plate Interceptors (CPI Separator)

CPI includes corrugated plates arranged in a plate pack, which installed at an angle of 45°. The plate provides more surface for suspended oil droplets to coalesce into larger globules. Separated solids would slide down and separated oil drops move upwards due to its lesser density than water [12,13]. Table 4 displays the advantages and disadvantages of Corrugated Plate Interceptors.

5.2. Produced Water Secondary Treatment Methods

Gas flotation unit uses air or gas to float out oil more rapidly from the produced water. The density of oil particles will be reduced as they will attach to gas bubbles. Reduced density improves the speed of oil flotation to the surface. The oil globules on the surface are skimmed off [14].

There are two types of flotation systems:

5.2.1. Dissolved air flotation (DAF)

Dissolved air flotation uses an air compressor to inject and dissolve air into the produced water steam. Injection of the air while the liquid is under pressure, followed by the release of the pressure. [15,16]. Table 5 displays the advantages and disadvantages of the Dissolved air flotation (DAF).

5.2.2. Induced Gas flotation (IGF)

Induced gas flotation creates fine gas bubbles through mechanical, hydraulic or sparging systems. The induced gas bubbles adhere to the oil droplets as they move upward to the surface. [17,18]. Table 6 reveals the advantages and disadvantages of the induced gas floatation system.

6. Results and Discussions

6.1. Technical Comparison

6.1.1 Primary Treatment Methods

A comparison of the two technologies is displayed in the Table 7. It can be shown that De-oiling Hydrocyclones is much better than Corrugated Plate Interceptors due to many reasons such as availability, location, pressure drop, efficiency and outlet oil content.

Table 4: Advantages and disadvantages of Corrugated Plate Interceptors (CPI).

Advantages of Corrugated Plate Interceptors	Disadvantages of Corrugated Plate Interceptors
Corrugated plates enhance the degree of oil-water separation and therefore it requires significantly less space than a conventional API separator	Atmospheric Design cannot be used
Very low maintenance cost since there are no moving parts.	Need a degasser to be installed upstream
High efficiency and capacity combined with compact volume.	Large surface area required
Can handle shock loads of flow without affecting effluent quality significantly.	The effluent oil concentration is higher than that of other methods
	Ineffective with small oil droplets or emulsified oil, require long retention time to achieve efficient separation

Table 5: Advantages & disadvantages of the Dissolved air flotation (DAF).

Advantages Dissolved air flotation	Disadvantages Dissolved air flotation
High loading rate: typically, 10-20 m/h. New Process Variants have operated successfully up to 40-45 m/h	Requires a cover or housing to protect the float layer from wind and precipitation
Very Thick float (sludge) product: Typically, 2-3% total solids float can be achieved using hydraulic or mechanical skimming devices.	Mechanically more complex than conventional gravity clarifiers
Often, no polymers are required, as DAF does not require a large dense floc.	More power intensive as compared to the conventional flocculation and sedimentation (2.5-3 to 0.75-1 kWh/103 m3.d).
Shorter flocculation times, as compared to gravity separation, are possible, because a smaller floc particle size is required	Generally, not well suited for clarification of high turbidity slit-laden waters
Rapid start up, typically < 30-60 minute to reach steady state, depending on size	Because DAF is more mechanically intensive, may not be suitable for locations where equipment maintenance is likely to be neglected
Excellent algae removal efficiencies	
Excellent Giardia and cryptosporidium removal efficiencies (-/+ 2-2.5 log), depending on temperature	
Smaller footprint required as compared to conventional flocculation and gravity sedimentation	

Table 6: Advantages and disadvantages of the induced gas floatation system.

Advantages Induced Gas Flotation	Disadvantages Induced Gas Flotation
Fewer parts and therefore requires less overall maintenance.	If diffusers are used for introduction of air, they can become plugged requiring maintenance or reduced effectiveness.
Self-aspirating and simple to operate	Weak link is the single pump, which can also see lots of wear and a relatively short life
No compressor is required in IGF as the air is self-induced.	Power cost will be highest for the IGF due to the high pump pressure, followed by IGF, and then SAF has the lowest power cost.
Low residence time resulting in a smaller footprint.	Normally requires de-oiling chemical to be dosed upstream to optimize performance –High OPEX
Slightly to moderately lower capital cost.	Require steady flow for effective operation
Relatively insensitive to changes in oil droplet size	
High Inlet concentration can be acceptable	
Lower recycle rate necessary because of higher possible air injection rate, so smaller flotation cell and smaller over footprint.	

Table 7: Comparison of Primary Treatment Technologies.

Parameter	De-oiling Hydrocyclones	Corrugated Plate Interceptors
General	It has no moving parts, requires small footprint, and provides a good degree of separation.	Proven design has no moving parts and provides consistent operating results.
Pressure drop	Hydrocyclones operate at high pressures, and require a minimum available pressure drop of normally 5 to 10 bar to operate satisfactory.	Generally designed for low pressure operation, <3.5 barg.
Pressure requirement	The feed water should not be exposed to shear forces	The feed water should not be subjected to significant stress
Location	They are very compact	The CPI separator could be either an Atmospheric unit or a pressure vessel
Outlet oil content	The oil content at the outlet will be typically 25-100 ppm.	The oil content at the outlet will be typically 50-150 ppm.
Solid removal	No solids removed in the de-oiling hydrocyclones.	Can tolerate up to 1000 ppm total suspended solids
Turndown	High turndowns are possible by adding compartments to the vessel	Water recycle will be required to handle low unit turndown conditions.

6.1.2 Secondary Treatment Methods

Induced gas Flotation unit is better than Dissolved air flotation (DAF) unit for secondary produced water treatment regarding flexibility, efficiency, know technology in North African countries, power required, stability of flowrate and suitability for high turbidity.

6.2. Economic Comparison

6.2.1. Primary Produced Water Treatment

Figure 2 illustrate the Cost comparison between the de-oiling hydrocyclones and corrugated plate interceptors (CPI Separator), it can be shown that CAPEX of corrugated plate interceptors (CPI Separator) is higher than the de-oiling Hydrocyclones with 50,000 $.

6.2.2. Secondary Produced Water Treatment

Figure 3 shows the cost comparison between the dissolved air flotation and induced gas flotation for the secondary treatment of the produced water in the gas project. It can be noticed that CAPEX of Dissolved Air Floatation (DAF) is higher than Induced Gas Floatation (IGF) with 45,000 $.

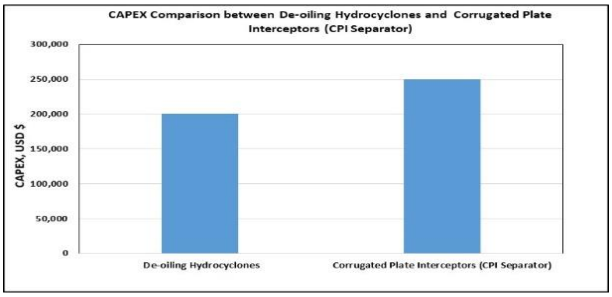

Figure 2: Cost comparison between the de-oiling Hydrocyclones and corrugated plate interceptors (CPI Separator).

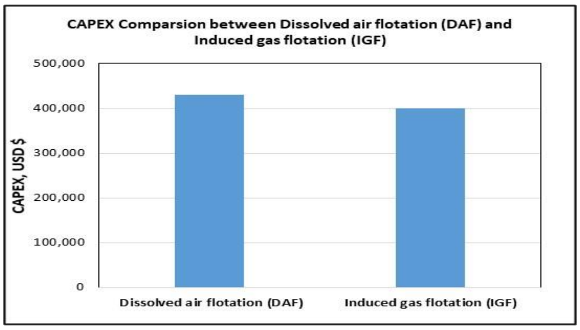

Figure 3: Cost comparison between the dissolved air flotation and induced gas flotation.

7. Conclusions & recommendations

Based on the technical & economic comparison and the suitability of the technology in North Africa region between the equipment, which should be used in the primary and secondary stage for the produced water treatment, it is recommended to use de-oiling hydrocyclone for the primary treatment followed by induced gas flotation unit for the secondary treatment to achieve the required produced water specifications.

In addition, according to the technical section, de-oiling hydrocyclone is better than CPI separator for the primary produced water treatment concerning availability, location, pressure drop, efficiency, and outlet oil content, while induced gas flotation unit is better than dissolved air flotation (DAF) unit for secondary produced water treatment regarding flexibility, efficiency, know technology in North African countries, the power required, stability of flowrate and suitability for high turbidity

Moreover, according to economic section, option one is cheaper than option two with 100,000 $

Nomenclature

Abbreviation	Description
CPI	Corrugated Plate Intercepto
CAPEX	Capital Expenditure
CPF	Central Processing Facility
DAF	Dissolved air flotation
HSE	Health, Safety, and the Env
IGF	Induced Gas Floatation
mg	Milligram
ppm	Part per million
OPEX	Operating Expenditure
TDS	Total dissolved solids
TSS	Total suspended solids
vol.	Volume
µm	Micrometre

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