UNIVERSIDADE ESTADUAL PAULISTA
"JÚLIO DE MESQUITA FILHO"
CAMPUS DE GUARATINGUETÁ

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Analysis of water reuse systems in offshore oil platform

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To all the hardships that I have been through, to all the times that I wanted to give up. To my dear parents, in memory of my father….

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ABSTRACT

Water is a necessary asset in the daily life of all living beings, however, it is a finite asset and in some regions of the planet it has already become scarce. Offshore oil and gas extraction platforms have a voluminous water cycle. Produced water is considered the largest by-product of the oil extraction process, for each barrel of oil obtained about 3 to 5 barrels of produced water are also extracted. For the produced water to be disposed or reused it is necessary to go through a series of previous treatments before being reapplied or released into the environment, each country has its own legislation and regulatory agencies responsible for the quality of this water. This work aims to provide an overview of the water cycle inside offshore platforms from its acquisition, treatment, reuse and final disposal. In addition, a case study about four platforms of Petrobras company will be presented to show how the management of water and effluents are done inside these platforms. In conclusion, the water cycle inside offshore platform is complex because it involves different types of water (potable, produced, reuse and waste), several logistics and engineering processes for the treatment, reapplication and subsequently disposal of the water. In Petrobras platforms, potable water was obtained by both ways via transportation and desalination. Another important finding was that in Petrobras semi-submersible platforms, there was not available a treatment system for effluents or produced water. The reason why the percentage of produced water reuse is small and not always viable is due to the costs of treatment, transportation and storage of the water.

KEYWORDS: Offshore. Water. Produced Water. Reuse.

RESUMO

Á água é um bem necessário no dia a dia de todos os seres vivos, porém é um bem findável, tanto que em algumas regiões do planeta já tem se tornado escasso. Plataformas *offshore* de extração de óleo e gás possuem um volumoso ciclo de água. A água produzida é considerada o maior subproduto do processo de extração de petróleo, para cada barril de óleo são extraídos também cerca de 3 a 5 barris de água produzida. Para a água produzida ser descartada ou reutilizada é necessário passar por uma série de tratamentos prévios antes de serem reaplicadas ou lançadas no ambiente, cada país possui suas legislações e órgão regulamentadores responsáveis pela qualidade dessa água. Este trabalho visa fornecer uma visão geral do ciclo da água dentro de plataformas offshore desde a sua aquisição, tratamento, reutilização e descarte final. Além disso, um estudo de caso de quatro plataformas da empresa Petrobras será apresentado com a finalidade de mostrar como é a gestão da água e efluentes dentro de plataformas. Em conclusão, o ciclo da água dentro da plataforma *offshore* é complexo porque envolve diferentes tipos de água (potável, produzida, reutilizada e residual), vários processos logísticos e de engenharia para o tratamento, reaplicação e subsequente eliminação da água. Nas quatro plataformas da Petrobras estudadas, a água potável tem sido obtida por ambos os métodos: via transporte e por dessalinização. Outra descoberta importante foi que nas plataformas semissubmersíveis não existiam um sistema de tratamento de efluentes ou de água produzida. A razão pela qual a percentagem de reutilização da água produzida é pequena e nem sempre viável, deve-se aos custos de tratamento, transporte e armazenamento da água.

PALAVRAS-CHAVES: Offshore. Água. Água produzida. Reúso.

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LIST OF ABBREVIATIONS

ANVISA	Agência Nacional de Vigilância Sanitária
BBL	Barrel of oil
CONAMA	Conselho Nacional do Meio Ambiente
FPSO	Floating Production, Storage and Offloading
IBAMA	Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis
MARPOL	International Convention for Prevention of Marine Pollution for Ships
SDG	Sustainable Development Goal
SM	Standard Method
UN	United Nation
WHO	World Health Organization

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1 INTRODUCTION

Water is essential for humans, animals, plants and for the maintenance of the planet. However, potable water is a unique and limited resource. According to the United Nation (2021) water is under extreme threat from the growing population, increasing demands of agriculture, industry, and the worsening impacts of climate change.

Billions of people still do not have access to potable water and with the COVID-19 pandemic, the situation became even worse (UNITED NATION, 2021). This exposed the importance of sanitation and hygiene in critical times, since handwashing is considered one of the most effective actions to reduce the spread of pathogens and prevent infections, including the COVID-19 virus (WORLD HEALTH ORGANIZATION, 2020)

Another worrying fact is that more than 80% of the wastewater from industrial processes are discharged into rivers and seas without any prior treatment. The consequences are alarming, due to the neglect and water scarcity in many regions (WWAP, 2017). Even though, this concern has been included as one of the Sustainable Development Goals (SDGs), as target 6 for Clean Water and Sanitation to ensure availability and sustainable management of water and sanitation for everyone. The challenges are still enormous to protect, mitigate and prevent the scarcity of this valuable asset for the planet.

In offshore oil and gas extraction platforms, the volume of water used and produced in the process is in the house of millions of m^3 (PETROBRAS, 2018). The amount of water employed in all of the processes reinforces the importance of analyzing the use, treatment and reuse of this water inside and outside the platforms, in order to reduce the impacts caused to the environment.

Water transport logistics to offshore platforms is a complex operation with many limitations (DUARTE *et al*., 2017). Since water is employed in all processes from drilling, extraction, cleaning to workers use, consume, sanitation and so on.

This work aims to provide an overview of the water cycle inside offshore platforms from its acquisition, treatment, reuse and final disposal. In addition, it also presents a literature review about the Brazilian regulations and a case study of four platforms from the Brazilian company, Petróleo Brasileiro S.A. (Petrobras).

2 LITERATURE REVIEW

2.1 POTABLE WATER ON OFFSHORE PLATFORMS

According to Devold (2013) and Fatah *et al*. (2017) when the size of the offshore site is small, potable water is transported by supply vessels or tank trucks to the platforms. On the other hand, when the offshore platforms are larger, potable water is provided on site by desalination of seawater through distillation or reverse osmosis.

It can also be related to the limited space onboard, logistics and equipment´s cost. For example, some companies prefer to fetch potable water from near platforms, which contain desalination plants, instead of getting their own desalination plant.

2.1.1 Water transportation in tanks and vessels

The potable water provided in vessels or tanks need to be of high quality, since a water-borne epidemic can infect many individuals within a short time and it will become difficult to maintain the operation of the unit (ANDERSEN; LØFSGAARD, 2017). Therefore, there are several requirements from cleaning and conservation of the vessels to the maintenance of the pipes and hose that will distribute the potable water inside the platforms.

The water storage duration in these tanks and vessels should be minimized to avoid stagnation. Good practice would be to dispose all water in such tanks after 14 days of continuous storage, because if the water is stored too long, an unpleasant taste and odor may appear, increasing the risk for microbial and biofilms growth in the system (ANDERSEN; LØFSGAARD, 2017; MARINE SAFETY FORUM, 2013).

On Figure 1 is presented an example of water storage tank for offshore purposes from HB Rentals (2021) company, which offers tanks with two different sizes (4.000 or 8.000 gallons), featuring a 5.5 micron filter, which filters the water before it enters the tank. The water distribution systems also include two motors and pumps.

Figure 1. Water vessel example from HB Rental.

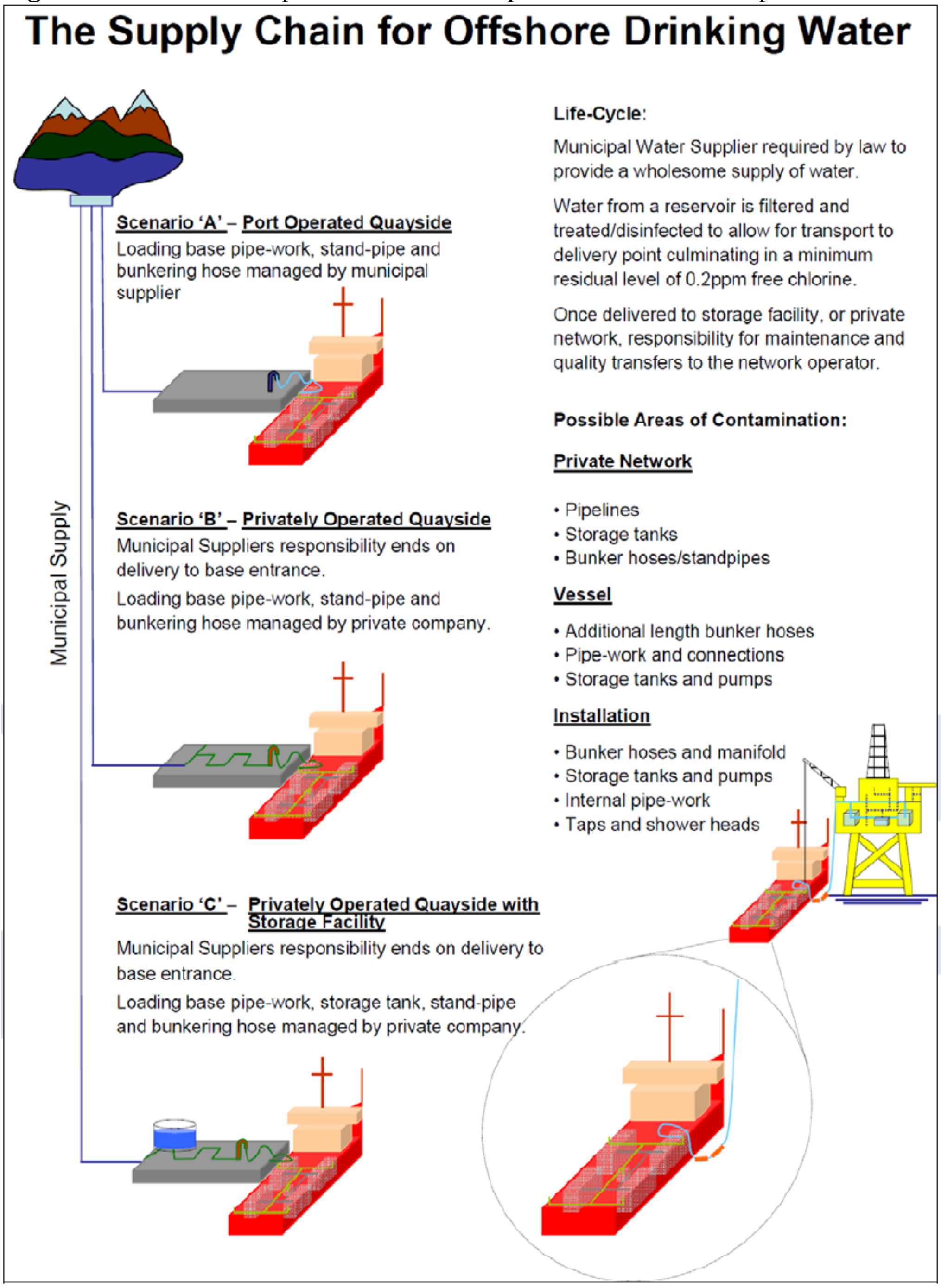
Source: HB Rental (2021).

These tanks and vessel must be of materials that are resistant to corrosion with a design that is easy to clean and maintain. According to the Regulatory Standard NR-37 (MINISTÉRIO DO TRABALHO, 2018) and Resolution RDC Nº 72 (ANVISA, 2009) from *Agência Nacional de Vigilância Sanitária* (ANVISA), tanks must be cleaned and disinfected every 1 year or after each repair work and whenever there is suspicion of contamination.

Overall, an average platform employs around 60.000 liters of potable water for consumption and for processes per day (FREITAS, 2011). Potable water systems shall be dimensioned for a consumption of at least 200 liters of potable water per person per day (NORWEGIAN MARITIME, 2015).

According to Marine Safety Forum (2013) there are basically three scenarios for potable water transportation to offshore platforms. These processes are explained and illustrated in Figure 2.

Figure 2. Scenarios for potable water transportation to offshore platforms.



Source: Marine Safety Forum (2013).

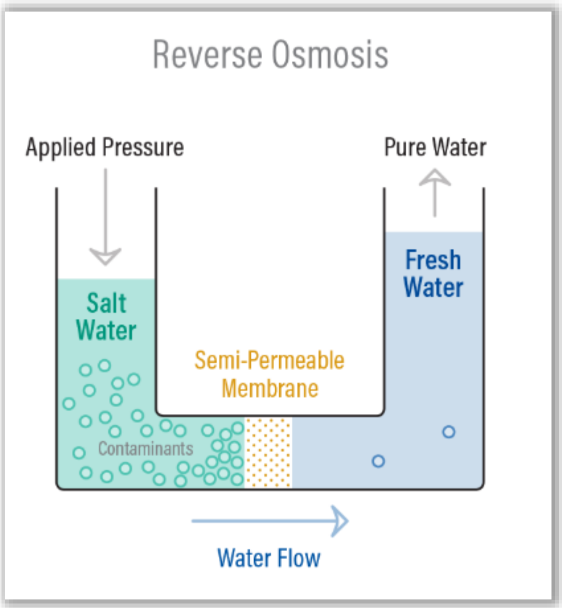
2.1.2 Seawater desalination and reverse osmosis

Seawater desalination is an important option for addressing the world's water supply challenges. Current desalination plants use enormous quantities of energy and cause a number of environmental issues (Li *et al*., 2018). However, renewable energy options, such as hybrid solar–wind power (AMIN *et al*., 2020) have been investigated for sustainability purposes.

According to Li *et al*. (2018) desalination cost is affected by several factors including: feed water characteristics, plant capacity, amounted of energy employed, operation and maintenance. Energy affects not only the cost of the water generated but also the choice of desalination technology.

Reverse osmosis is one of the most applied process for desalination, where seawater is forced under high pressure against a membrane with microscopic openings, as illustrated in Figure 3. The water molecules will pass the membrane and most of the salt and other contaminants will be held back (ANDERSEN; LØFSGAARD, 2017).

Figure 3. Reverse osmosis process.



Source: Puretecwater (2021).

Desalination plants from Suez (2021) company can produce potable water volume from 30 m^3 to 2500 m^3 per day. Another example, MakWater (2013) company manufactured a sea water reverse osmosis plant with a compact design, presented in Figure

4a, which was able to produce around 40 m^3 of potable water per day. Figure 4b shows the seawater reverse osmosis plant installed on site of an offshore platform.

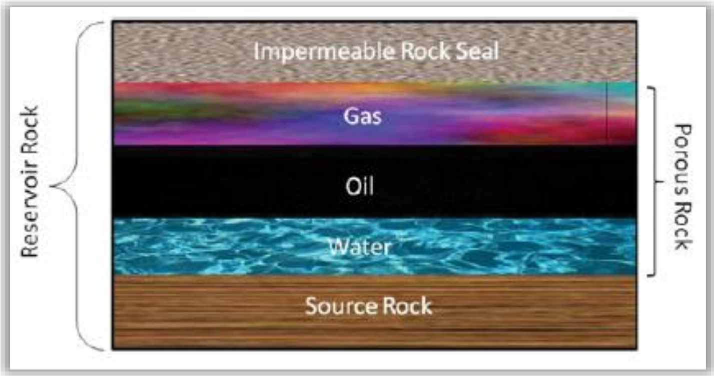
Figure 4. (a) Seawater reverse osmosis plant from MakWater (b) Installed on site.

Source: MakWater (2013).

2.2 PRODUCED WATER

Produced water is the largest by-product from oil and gas industry. The produced water is brought to the surface with the hydrocarbons (VEIL, 2020). The physical and chemical properties of produced water vary considerably depending on the geographic location of the field. Usually, its composition is a complex mixture of different types of water (formation and extraction), organic and inorganic components, dissolved gases, brine, microorganisms, pollutants, metals, heavy metals and even traces of radioactive materials (ZHENG *et al*., 2016; HEDAR, 2018). On Figure 5 is presented an example of a typical reservoir, showing how gas, oil and water can co-exist in petroleum traps.

Figure 5. Typical reservoir.

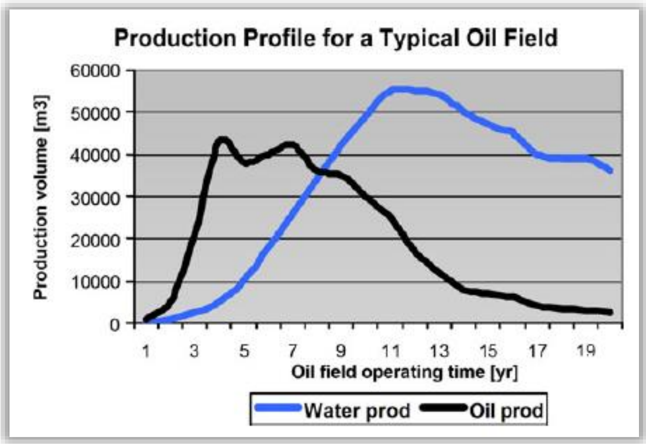


Source: Igunnu and Chen (2014).

According to Zheng *et al*. (2016) the volume of produced water extracted is about 3 to 5 times higher than the amount of oil and gas obtained. The volume of water produced tends to increase each year as the well matures, leading to a larger volume of waste to be handled.

Assunção, Vieira and Almeida (2018) states that new field produces around 5 to 15% of produced water volume and as the well reaches the end of its productive life, it can reach the range of 75 to 100 % of produced water. Figure 6 illustrates the production profile for a typical oil field.

Figure 6. Profile for a typical oil field.

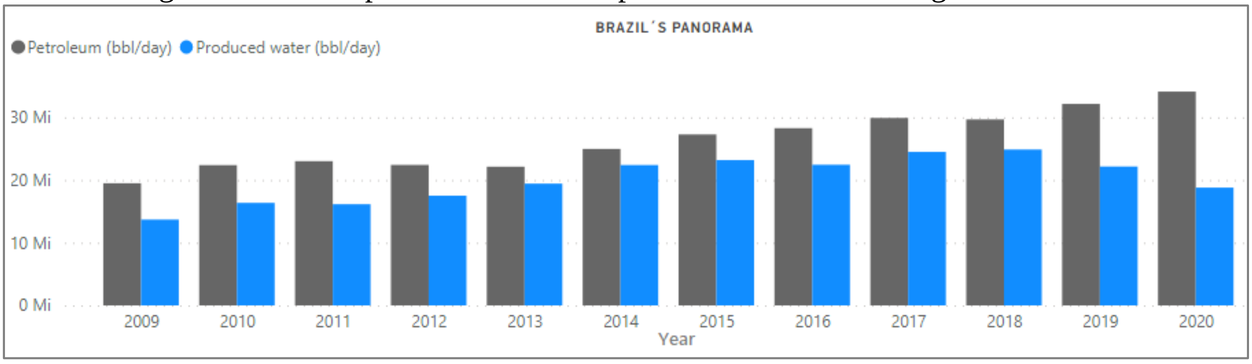


Source: Igunnu and Chen (2014).

2.2.1 Brazil´s panorama on water production from oil and gas field

Data from the National Petroleum Agency (ANP) shows that Brazilian´s wells are relatively young, since the number of barrels per day of produced water is below of the petroleum obtained over the last eleven years. This is due to the pre-salt discovery and exploration of new wells since 2015. On Figure 7 is presented the Brazilian´s panorama of petroleum and produced water obtained from 2009 until 2020. On Table 1 the values are displayed for each year, it also shows the total amount obtained for the exploration of eleven years in a row.

Figure 7. Brazil´s panorama on water production from oil and gas field.



Source: author's own production with data obtained from ANP (2021).

Table 1. Brazil´s panorama about produced water.

Year	Petroleum (bbl/day)	Produced water (bbl/day)
2009	19.489.441,92	13.693.984,37
2010	22.375.904,30	16.357.046,27
2011	23.010.707,69	16.144.983,66
2012	22.411.711,96	17.506.425,27
2013	22.128.571,38	19.428.281,22
2014	24.959.529,65	22.391.576,33
2015	27.273.286,18	23.175.289,53
2016	28.272.898,71	22.440.726,03
2017	29.903.227,43	24.490.012,60
2018	29.672.367,80	24.868.313,63
2019	32.146.414,92	22.156.813,68
2020	34.107.589,09	18.788.407,68
Total	**315.751.651.03**	**241.441.860.27**

Source: author's own production with data obtained from ANP (2021).

To show how different the values are from platform to platform, Table 2 presents an example of two different platforms of Petrobras obtained from August of 2021.

Table 2. Differences between platforms on produced water.

PLATFORM	PERIOD	PETROLEUM (BBL/DAY)	PRODUCED WATER (BBL/DAY)
PETROBRAS 56	2021/08	28.639,20	119.697,12
PETROBRAS 67	2021/08	145.254,40	3.435,45

Source: author's own production with the data obtained from ANP (2021).

Petrobras 56 platform has been operating since 2011, it produces 4 times more produced water than petroleum. On the other hand, Petrobras 67 platform has been operating since 2019, it produces around 42 times more petroleum than produced water. Those data are in accordance as described by authors Igunnu and Chen (2014) and Zheng *et al*. (2016), that the amount of produced water depends on the age of the well and it tends to increase each year as the well maturates.

2.3 BRAZILIAN AND INTERNATIONAL REGULATIONS

Several laws, resolution and conventions were made to protect the environment and oceans from the pollution of offshore exploration. Unanimously, all of them dictate that any kind of water and effluents from platforms or ship must receive treatments prior to final discharge in the ocean. Besides that, there are several requirements for the quality of the water, places that it can be discharged and ways of monitoring it. Each country has their own laws and resolutions, therefore, some quality parameters of the water can vary depending on the country.

Brazil is part of the International Convention for Prevention of Marine Pollution for Ships (MARPOL). The MARPOL (1973) is composed of six annexes, it is the main international convention covering prevention of pollution of the marine environment by ships from operational or accidental causes.

The Brazilian law N◦ 9.966 (2000) was released in complementation to MARPOL. It established the prevention and control of pollution caused by the release of oil and other dangerous substances in waters under national jurisdiction and made other provisions about inspection by regulatory agencies, the *Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis* (IBAMA) and Brazil´s Navy (Marinha).

The *Conselho Nacional do Meio Ambiente* (CONAMA) has released several resolutions about the quality of water and effluents from platforms, below are presented the most important ones and a brief review about them.

- CONAMA Resolution Nº 357 (2005): establishes the classification of bodies of water (fresh, brackish and saline) and guidelines for their categorization, as well as the conditions and standards for the effluents discharge.
  I - fresh waters: waters with salinity equal to or lower than 0.5 %.
  II - brackish waters: waters with salinity higher than 0,5 % and lower than 30%.
  III - saline waters: waters with salinity equal to or greater than 30%.

- CONAMA Resolution Nº 393 (2007): establishes conditions, standards and monitoring parameters for continuous discharge of produced water in offshore oil and gas platforms. It is forbidden to discharge produced water within a radius of less than ten kilometers of conservation units and within five kilometers of ecologically sensitive areas. The disposal of produced water must comply with the monthly arithmetic mean concentration of total oils and grease (TOG) up to 29 mg/L, with a maximum daily value of 42 mg/L. These values must be determined by the gravimetric method, but the environmental agency may accept other analysis methodologies, if provided statistically significant correlation with the gravimetric method. Yearly, each platform operating company must present to CONAMA a proposal to reduce the content of oils and grease in the discharge of produced water. On each six months, the operating companies must conduct experiments in certified laboratories with the purpose to identify the presence and concentration of some parameters, such as: inorganic compounds, radioisotopes, organic compounds, chronic toxicity, and complementary parameters. By March 31st of each year, they must also send a full report about the produced water discharge in the previous year.

The produced water quality reports are available to anyone interested to access them, and can be found on the website of IBAMA (2021) listed by the companies name, platforms and year: http://licenciamento.ibama.gov.br/Relatorios%20CONAMA%20393/

The concentration of oils and grease is quite controversial, since it must take into consideration the environmental, economic and social sensitivities of each region (GOMES, 2014). It still not completely known the real consequences or the long-term effects of oil and grease dilution in the marine ecosystem (BEYER *et al.*, 2020). It is alarming because offshore exploration has increased a lot over the years, especially with the pre-salt discovery.

On Table 3 are presented the limits of oil and grease concentration of some countries.

Table 3. Limits of oil and grease concentration of some countries.

Country	**Parameter**	**Concentration**
Argentina	Mean	15 mg/L
Australia	Mean	30 mg/L
	Max	50 mg/L
China	Mean	30 to 50 mg/L
	Max	75 mg/L
Brazil	Mean	29 mg/L
	Max	42 mg/L
Colombia	80% Removal of oil	-
Canada	Mean	30 mg/L
	Max	44 mg/L
Egypt	Max	15 mg/L
Indonesia	Max	50 mg/L
USA	Mean	29 mg/L
	Max	42 mg/L
Italy	Mean	40 mg/L
Mexico	Mean	40 mg/L
	Max	100 mg/L
Nigeria	Mean	40 mg/L
	Max	72 mg/L
Thailand	Max	100 mg/L
Tunisia	Max	10 mg/L
Trindad and Tobago	Max	40 mg/L
Venezuela	Mean	20 mg/L
Vietnam	Mean	40 mg/L

Source: Adapted from Gomes (2014) and Florido (2018).

- CONAMA Resolution Nº430 (2011): provides on conditions, parameters, standards and guidelines for the discharge of effluents in bodies of water. This resolution amends and complements CONAMA's Resolution No. 357 (2005).

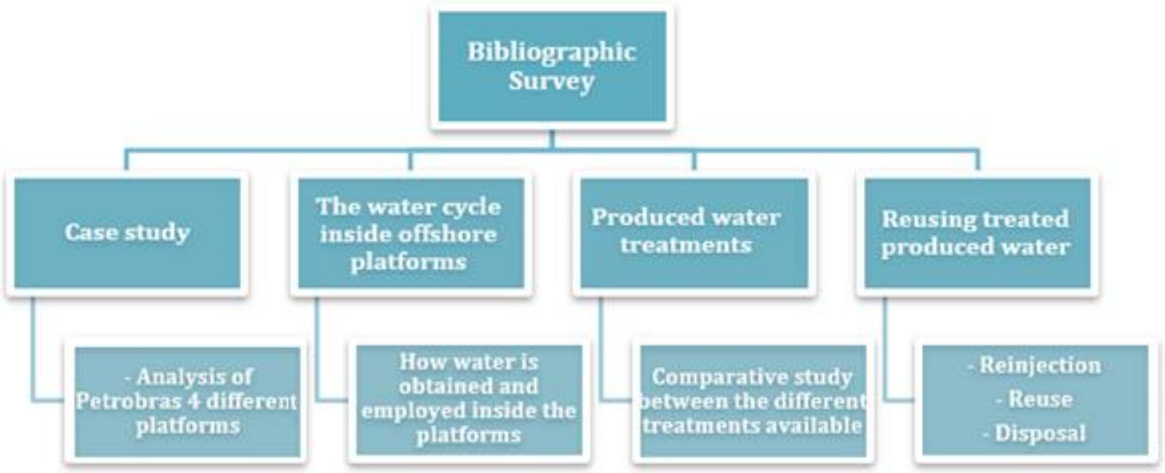
- IBAMA Normative Instruction Nº 1 (2018): provides guidelines for the use and disposal of fluids, gravels and cement pastes in drilling wells for oil and gas production activities. It is forbidden the disposal into ocean of water-based complementary fluid containing diesel, hexavalent chromium, ferrochrome lignosulfonate, chromium lignosulfonate, ferrochrome or zinc bromide alloys.

3 METHODS

The objective of this work is to analyze the water cycle for offshore platforms, from its collection, use, treatment, reuse and final disposal. In addition, the logistics of water transportation and its costs were investigated, as well as possible treatments technologies for produced water and the reuse of this water inside the platforms. Improvements in the systems currently employed are expected, aiming a reduction of costs and environmental impacts.

The methodology of this work consists of exploratory research that involves a bibliographic survey, analysis of examples and a case study of Petrobras. On Figure 8 is presented the flowchart of the work development.

Figure 8. Flowchart of the work development.



Source: author's own production.

The bibliographic survey was conducted on Google Scholar, Science Direct, ANP database and national government websites. Most of the material were obtained from Ph.D. thesis, Master´s dissertations, manuscripts from journals, laws and resolutions, reports and descriptive memorials from companies and government agencies.

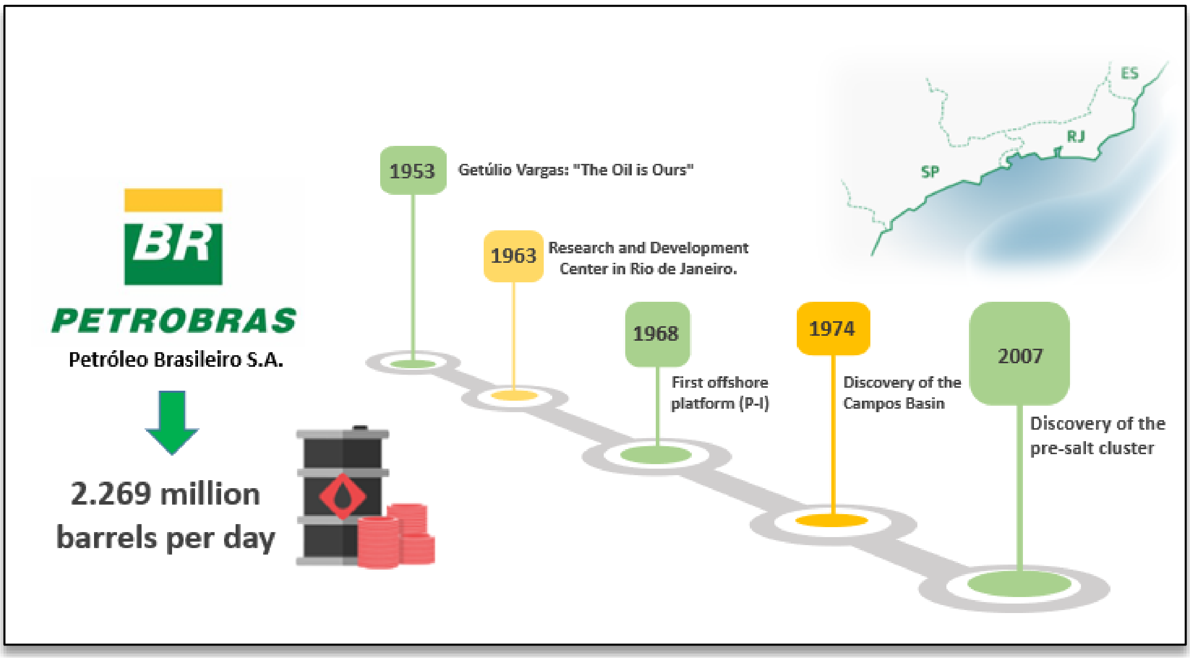
4 RESULTS AND DISCUSSION

4.1 CASE STUDY: PETROBRAS PLATFORMS

According to IBAMA (2018 b) Petrobras had to write a term of commitment that established measurements to adjust the discharge of produced water from 28 platforms located in Campos Basin, to meet the parameters defined in the Standard Methods for the Examination of Water and Wastewater (SM 5520-B) required by CONAMA. Besides that, Petrobras had to invest R$100 million reais in marine and coastal biodiversity conservation projects. This shows the relevance of complying with Brazilian´s legislations and the importance of analyzing the quality of the produced water, being it discharged or reused.

Petrobras (2018) is a Brazilian company created in 1953, it is one of the largest producers of oil and gas in the world, primarily engaged in exploration, production, refining, energy generation and trading. Figure 9 presents an overview of Petrobras story.

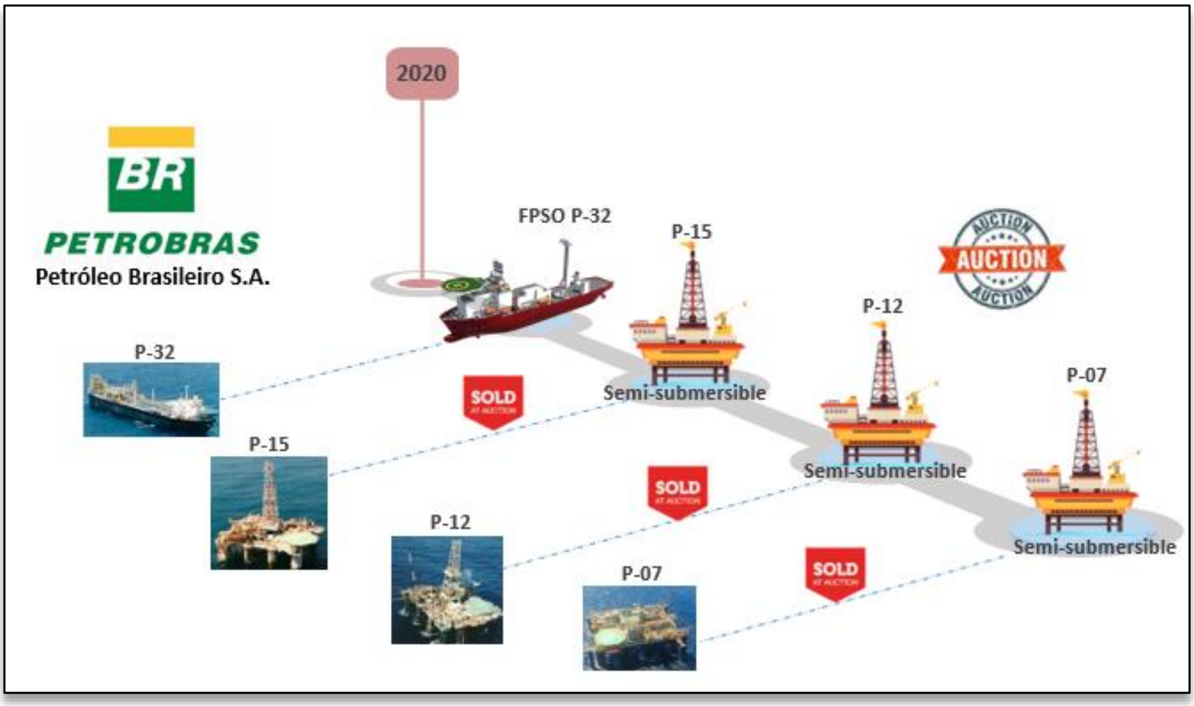
Figure 9. Overview of Petrobras story.



Source: Author´s own production with the data obtained from ANP (2021) and Petrobras (2020a).

The case study will focus on 4 decommissioning platforms from Petrobras (P-07, P-12, P-15 and P-32). Three of these platforms were already sold out in a public auction, in 2020, as illustrated in Figure 10 (PETROBRAS, 2020a).

Figure 10. Decommissioning platforms from Petrobras.



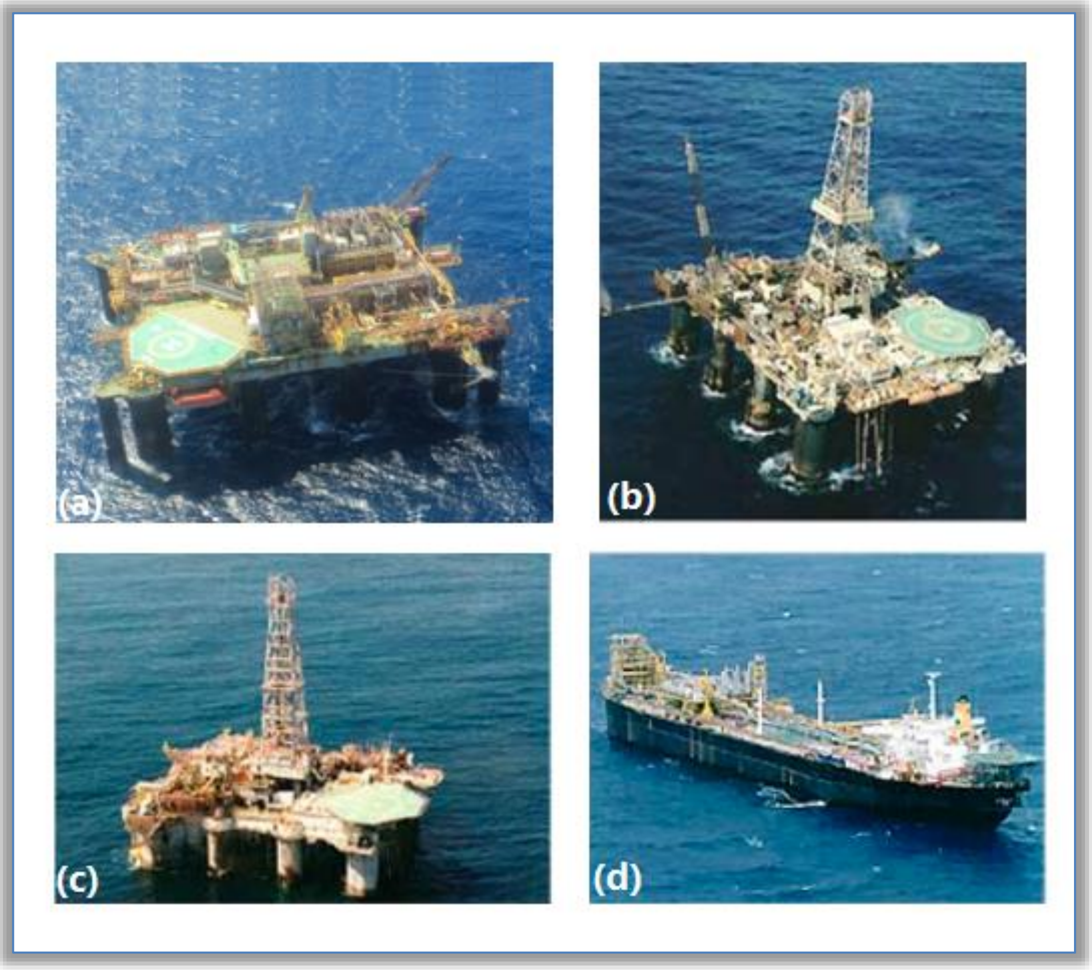
Source: Author´s own production with the data obtained from Petrobras (2020a).

Decommissioning is the process of ending offshore oil and gas operations and returning the ocean and seafloor to its pre-lease condition complying with international and local regulations (BUREAU OF SAFETY AND ENVIRONMENTAL ENFORCEMENT, 2021). For decommissioning purposes, platforms generally consist of two distinct parts: the topside (the facilities visible above the waterline) and the substructure (the parts between the sea surface and the seabed, or mudline) (BULL; LOVE, 2019).

Platforms can be decommissioned in different ways: conversion to an artificial reef or other purposes, mothballing on site which is the maintenance of the facility in a protective inert state without contaminants, relocation for another site for production, removal to land for disposal or recycling, on-site toppling or deep-water disposal (BOURBON, 2020).

In Figure 11 are presented the photos of each platform that were studied.

Figure 11. Platform’s photos: (a) P-07, (b) P-12, (c) P-15 and (d) P-32.



Source: Adapted from Marinha (2021) and ClickMacae (2021).

All four platforms were at the end of their productive life, with more than 40 years of operation each. The data about these platforms were collected from the descriptive memorial available online at Petrobras (2020) website and from ANP (2021) database. The descriptive memorials contained valuable information about the water management inside these platforms. On Table 4 are presented the information and characteristics about these four platforms.

Table 4. Information and characteristics about the four platforms.

Characteristics	Platforms			
	P-07	P-12	P-15	P-32
Type	Semi-submersible	Semi-submersible	Semi-submersible	FPSO
Construction	1977	1983	1983	1974
Basin	Campos	Campos	Campos	Campos
Field	Bicudo	Linguado	Piraúna	Marlim
Water depth	210 m	100 m	243 m	160 m
Total Length	108.20 m	108.16 m	104.50 m	337.10 m
Total Width	67.36 m	69.2 m	67.0 m	54.5 m
Accommodation Capacity	125 people	100 people	160 people	171 people
Water Demand (potable and industrial)	600 m³/month	1335 m³/month	1450 m³/month	3162 m³/month
Salt water input	11.760 m³/d	10.800 m³/d	11.760 m³/d	134.400 m³/d
Fresh water generator	50 m³/d	35 m³/d	50 m³/d	3840 m³/d
Potable Water from Land	Yes	Yes	Yes	Yes
Effluent Treatment	No	No	No	Yes
Oily Water Treatment	sent to P-65	sent to Platform PPM-1	sent to P-65	variable volume
Produced Water Treatment	sent to P-65	sent to Platform PPM-1	sent to P-65	3.120 m³/d
Fresh water tanks	6	5	7	2
Waste water tanks	2	2	3	3
Water Injection System	no	no	no	no
Year when production was halted	2016	2015	2017	Still Operating

Source: author's own production with the data obtained from Petrobras (2020b), Petrobras (2020c), Petrobras (2020d) and Petrobras (2020e).

Three platforms were semi-submersible and only one was a FPSO (Floating Production, Storage and Offloading). One important thing to note is that the three semi-submersible platforms had their production halted in the past few years, only the FPSO is still operating, but it is expected to halt it activities by the following years until 2025.

Comparing the three semi-submersible platforms P-07, P-12 and P-15, it can be observed that the demand for water is not really related to the size of the platform, since all of them have similar length but completely different values of water demand per month. Other important point is that none of these three semi-submersible platforms had treatment systems for effluents or produced water, in all of them the volume of effluents and produced water were sent to other platforms to be treated.

FPSO P-32 is the biggest one in size from the four platforms studied, it is around three times bigger than the platforms P-07, P-12 and P-15. Differently from the semi-submersibles, this FPSO P-32 presented a larger water demand of 3162 m^3/month and is the only platforms that had a treatment system for both produced water and effluents.

According to the descriptive memorials from the four platforms, salt water is constantly pump up and employed in a lot of applications inside the platforms from cooling the turbochargers, gas exchanger, air compressor, general service tank, cold rooms, houses to firefighting system and desalination.

In all platforms, there was a system for desalination of salt water and a specific place to receive potable water from land. Meaning that, in these offshore platforms both ways of obtaining potable water by transportation and desalination were applied.

4.2 THE WATER CYCLE INSIDE OFFSHORE PLATFORMS

Figure 12 presents a typical water cycle inside an offshore platform. This water cycle has been designed according to the information acquired with the case study from Petrobras and literature reviews insight.

Beginning with the potable water that is either transported by tank ships until the site or obtained via desalination plants, located inside the platforms. Part of the potable water is employed in the process (to supplement system losses in boilers and cooling systems in the units), while another part is for use and consumption of the workers inside the facilities.

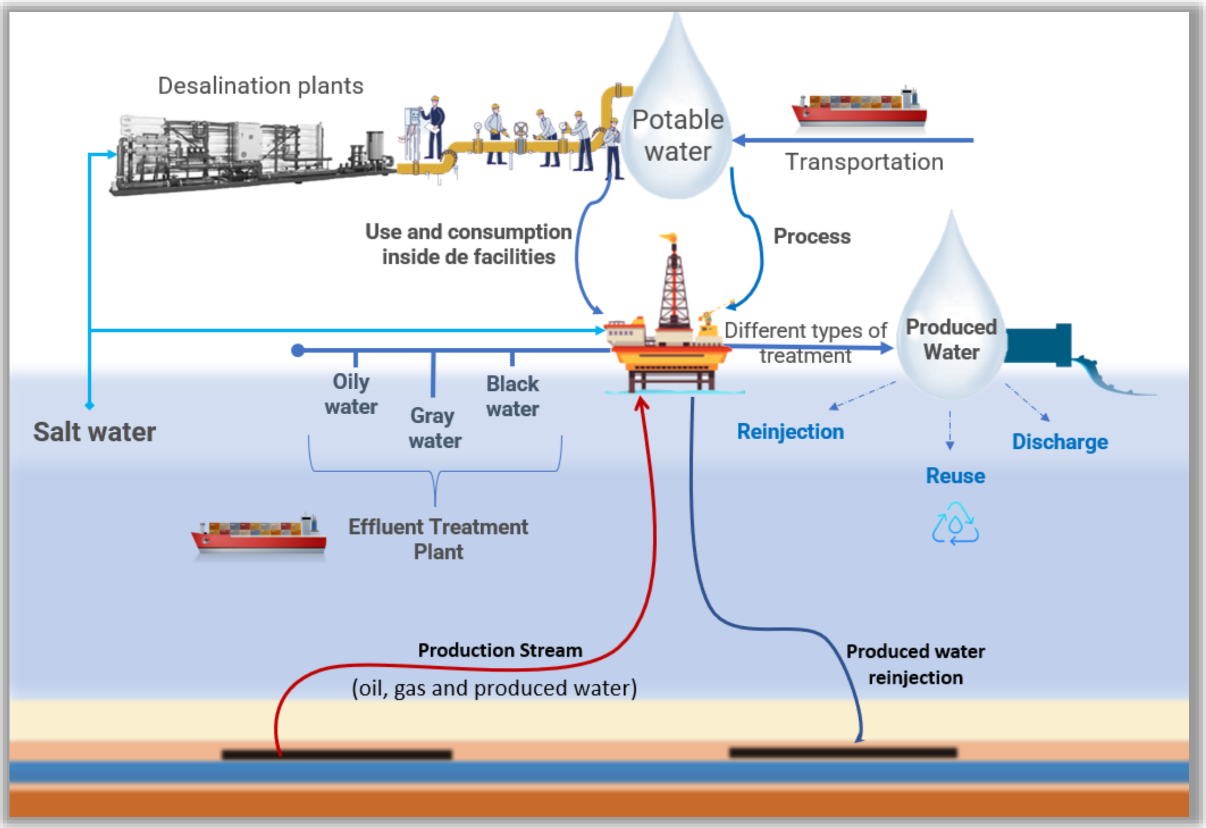
The potable water after being employed in the process and consumed by the workers can turn into three types of water: oily water, gray water (from sinks and showers) and black water (from toilet bowls and grease sinks of the kitchen). These types of water must go through an effluent treatment plant. However, not all platforms possess a plant to treat the effluents, so one solution is to transport the effluents to a nearby platform to treat them, as seen in P-07, P-12 and P-15 from Petrobras.

Secondly, salt water is often utilized for desalination and for many other applications inside the platforms from cooling machines to firefighting system alarm.

Finally, the produced water generated with oil and gas extraction, depending on the platform it can generates hundred thousands of barrels per day of produced water, which is a considerable amount. This produced water must be treated either on site or sent to another platform. Produced water must be treated accordingly to the destination of the water, which can be either by reuse, reinjection or discharge.

It is important to note that all types of water inside a platform must go through treatments before being reused or final disposed. Each country has their standard and regulations that must be followed strictly.

Figure 12. The water cycle inside offshore platforms.

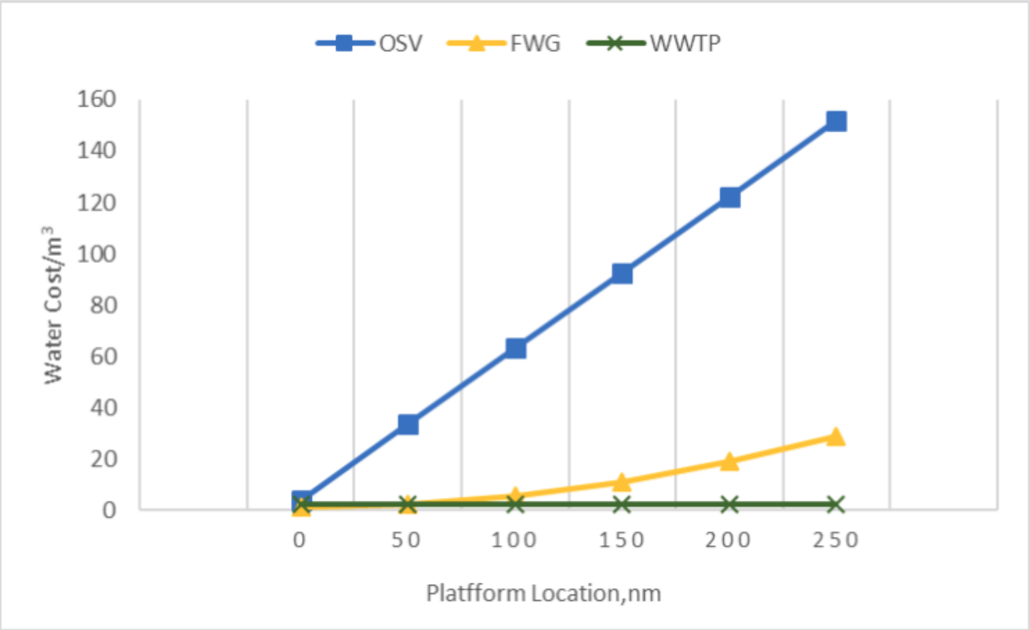


Source: author's own production.

4.2.1 Potable water costs

Costs is an important factor that must be considered when thinking about offshore operations. The cost for desalination varies a lot since it depends on the amount of water obtained per day, the quality of the water input, the technology employed and so on. For water desalination, Silva (2016) states that the cost is around US$ 3.00 per cubic meter of desalinated water, which includes US$ 0.60 of operational cost and US$ 2.00 of depreciation or amortization cost of the equipment. On the other hand, the cubic meter of water transported by tugboats to offshore platforms costs an average US$ 20.00 but depending on the distance from the shore this value may increase. In Figure 13 is presented the cost estimation by Ismail *et al*. (2019) via a mathematical model namely Economic Water Supply Model. Where: OSV - offshore supply vessel; FWG - freshwater generator; WWTP - wastewater treatment; NM – Nautic Miles.

Figure 13. Cost estimation between OSV (offshore supply vessel); FWG (freshwater generator); WWTP (wastewater treatment) by NM (Nautic Miles).



Source: Ismail *et al*. (2019).

As can be seen, the highest cost is from water transportation OSV. In this case, the cost is proportional to the distance of the platform location, mostly due to fuel cost.
On the other hand, for FWG or desalination equipment, it has small changes with the platform location distance, this change in cost can be associated with additional transport of worker and periodic maintenance. For wastewater treatment WWTP there is no difference

in cost within the distance of the platform, since wastewater is generated and treated onsite in the platforms.

In Table 5 are presented six scenarios, using a mixture of the three technologies to obtain potable water.

Table 5. Different scenarios to obtain water and cost.

Scenario	Volume of supply (m^3)			Cost (USD)
	OSV	FWG	WWTP	
1	100	X	X	3355
2	X	100	X	236
3	50	50	X	1795.5
4	X	X	100	258
5	X	50	50	247
6	50	X	50	1806.5

Source: Ismail *et al*. (2019).

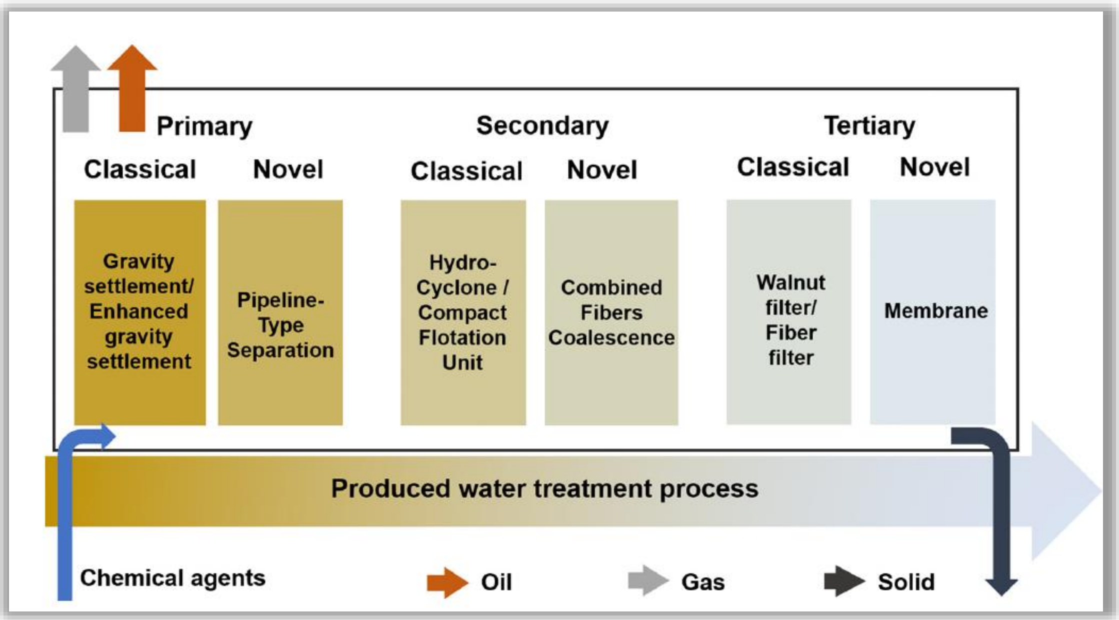
As presented in the case study from Petrobras, it seems like a normal practice to have more than one source for potable water inside offshore platforms. Since, in this way they can rely on one source if another one is contaminated or inadequate for consumption. On Table 5, can be observed a combination of these three techniques and the estimated cost when they are employed together. Another important information, is that for 1 m^3 the cost for OSV is around U$33.55, FWG U$2.36 and WWTP U$2.58, which are in accordance with the values reported by Silva (2016).

4.3 PRODUCED WATER TREATMENT COMPARISON

Produced water is conventionally treated through different physical, chemical, and biological methods. In offshore platforms because of the limited space on site, compact physical and chemical systems are applied (AHMADUN *et al*., 2009).

Figure 14 presents the produced water treatment process often employed for offshore oil field, which is composed of (1) Pretreatment, (2) Standard-reaching treatment and (3) Advanced purification treatment (LIU *et al*., 2021). On Table 6 are presented the removal efficiency from each step and the technology description applied.

Figure 14. Water treatment process often employed.



Source: Liu *et al*. (2021).

Table 6. Removal efficiency from each step treatment.

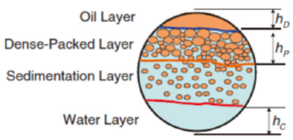
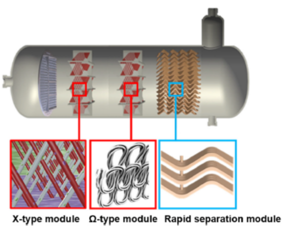
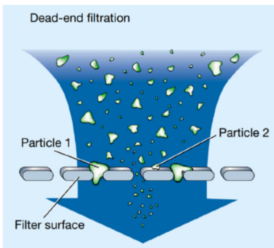
Treatment step	Removal efficiencies	Description	Technology	Technology description
Primary	Influent - 500-10,000 ppm total O&G and 200-500 ppm total suspended solids (TSS)	Typically removes a rough cut of TSS and free O&G	API (which is the organization that established the specifications for the industry in the United States)	Typically, a rectangular tank with gravity settling for solids and skimmer for free O&G
	Effluent - 200-500 ppm free O&G and 100-200 ppm TSS		Corrugated plate separators (CPS) or corrugated plate interceptors (CPIs)	Contains stacks of angled corrugated plates which result in a reduced settling distance for solids and rise distance for free O&G; prone to plugging in high solids/scaling applications
			Hydrocyclone	Typically used offshore due to space and weight constraints and not affected by boat's pitch and roll; no moving parts but requires pressure drop for separation; sizing based on differences in density; can for either a liquid/liquid (L/L) or solid/liquid (S/L) variety

Treatment step	Removal efficiencies	Description	Technology	Technology description
Secondary	Effluent - free O&G - 50-200 ppm* TSS - 50-100 ppm* *dependent on particle size	Typically, variety of flotation units introducing small gas bubbles (nitrogen, air, or fuel gas most common) to attach and float O&G with a bottom solids removal device; may use chemical (coagulant and/or flocculant) for better removal efficiencies; industry may use these terms interchangeably	Induced gas flotation (IGF)	Gas (nitrogen, air, fuel gas, etc.) introduced to a recycle stream via top mixers, which create a supersaturated solution. When the solution is reinjected to the flotator, bubbles are formed, resulting in flotation of solids.
	Effluent - free O&G - 20-200 ppm* TSS - 50-100 ppm* *dependent on particle size		Dissolved gas flotation (DGF)	Gas (nitrogen, air, fuel gas, etc.) introduced via pump or saturation tank system. Recycle steam is supersaturated and reinjected into the flotator, where solids float to the surface.
			Dissolved air flotation (DAF)	Same as above but specifically uses air (cannot always be used for produced water due to safety and environmental concerns).
			Dissolved nitrogen flotation (DNF)	Same as above but specifically uses nitrogen.
			Compact flotation unit (CFU)	Generic term for flotation unit with a short residence time, which is typically desired for offshore water treatment; tangential inlet (centrifugal force) aids in separation.
Tertiary	Effluent - 1-10 ppm free O&G and 1-10 ppm TSS* *dependent on particle size and media size	Various filtration methods	Nutshell or walnut shell filters	Bed of nut shells (typically 20-30 mesh) that naturally has affinity for free oil; periodically backwashed to remove the oil and dislodge suspended solids through agitation of the filter bed; although not designed for TSS removal, bed inherently also traps TSS.
			Filter media	Consumable media can be filter cartridges, bag filters, or proprietary (organoclay)
			Multimedia filters (MMF)	Bed with layers of media of different density and particle size to trap various-sized TSS; different media densities allow media to restratify during backwash to retain separate layers; not designed for O&G removal, but can be effective at polishing effluent from other treatment processes.
			Activated carbon filters	Granular activated carbon for removal of organics; typically used for offshore flowback with vessels returned onshore when job completed.
			Microfiltration (MF) or ultrafiltration (UF)	Ceramic or polymeric membranes provide a physical barrier to remove particles from the filtrate; few installations but emerging as a technology due to need for better particle removal.

Source: Water Environment Federation (2018).

According to Liu *et al*. (2021) novel methods are employed for overcoming the issues with conventional produced water treatment processes (lengthy procedure, space occupation and limited treatment efficiency). Novel methods are proposed by combining new technologies, such as: tubular separation, combined fibers coalescence, and membrane separation. On Table 7 are presented the principles, advantages, disadvantages, and the set-ups of these novel techniques.

Table 7. Novel techniques for produced water treatment.

Technologies	Treatment Stage	Principle	Advantages	Disadvantages	Development trend
Tubular separation	Pretreatment	1. The density differences between heterogeneous phases under the effect of gravity or the swirling flow field. 	1. Compact and can be installed under water.	1. The performance of the anti-fluctuation as a pretreatment needs to be proved.	Enhancement of adaptability to harsh conditions with fluctuation as a pretreatment technology that may be used under water.
Combined fibers coalescence	Standard reaching treatment	1. Coalescence of oil drops induced by oleophilic fibers. 2. Physical demulsification at the crossing point of hydrophilic and oleophilic fibers based on the different surface energies. 	1. The suspend solids can penetrate the fiber module without blocking. 2. Capable of handling PW with high oil content.	1. Blockage would be caused by solid particles with millimeter-scale dimensions. 2. Separation efficiency is affected by the parameters of fibers. The device should be designed according to the characteristics of PW.	Development of a general design principle based on the surface characteristics of materials.
Membrane separation	Advanced purification treatment	1. Function of filtration driven by pressure. 2. As the carrier of chemical agent, catalyst and microorganism. 	1. Purification is advanced. 2. Have separation effects on suspend solids. 3. Dissolved organic substances can be removed by choosing a suitable membrane.	1. Easy to be polluted. Backwashing is necessary. 2. Polymeric membrane material degradation when subjected to high temperature (>50 °C) temperature of PW is higher than 50 °C generally.	Novel membranes with high flux and pollution resistance based on material science.

Source: Adapted from Liu at al. (2021), Igunnu and Chen (2014).

4.4 PRODUCED WATER MANAGEMENT

According to Hale *et al*. (2019), Clark and Veil (2009) produced water represents the largest volume by-product associated with oil and gas exploration and production in offshore platforms. Its composition include water from the geological reservoir, water previously injected into the formation, and any chemicals added during the production processes. Besides that, depending on the location and the geological formation of the well it is common to find components such as dispersed oil, aromatic hydrocarbons, alkylphenols, organic acids, heavy metals, radioactive materials, and inorganic salts in the produced water composition.

Typical management of produced water in offshore environment is either discharge into the ocean after sufficient treatment, injection back into the reservoir or reused in another suitable application (AZIZOV *et al*., 2021).

4.4.1 Reinjection

The purpose of produced water reinjection into formation wells is mainly to compensate for the gradual loss of pressure inside the reservoir and to enhance oil recovery. The attractive goals of both saving freshwater usage along with reducing waste disposal or near-zero discharge, made reinjection as an example of smart water source management which turns waste into resource (SIAGIAN *et al*., 2018; MOTA *et al*., 2013).

Some care must be taken to implement the reinjection of produced water in adjacent wells. Due to the high content of solids (20 to 80 mg/L), and the presence of particles larger than 30 microns, filtering is necessary to meet the specifications, as well as the chemical separation process due to the high content of oils and grease, in order to prevent plugging wellbore, reservoir pores and prevent system failure (SILVA FILHO, 2013).

According Tiburcio *et al*. (2021) Bedrikovetsky *et al*. (2009) and Nihalani *et al*. (2010) the produced water employed for reinjection must be free of sulphate. Firstly, because seawater and produced water are sulphate-rich, which can cause sulphate salt deposition and consequent injectivity impairment. Secondly, due to the presence of harmful bacteria such as sulphate reducing bacteria (SRB), leading to hydrogen sulfide formation and consequently, causing cracking, corrosion, integrity and safety problems.

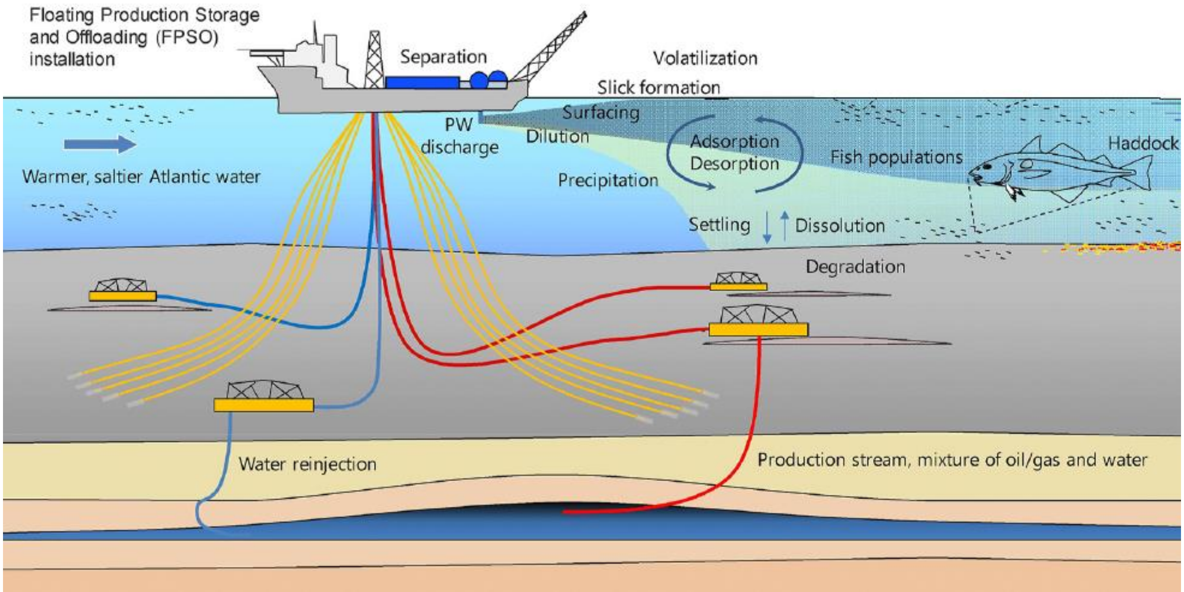
As reported by Azizov *et al*. (2021) produced water reinjection into the reservoir can be performed under two conditions: matrix injection and fracture injection. The decision on what strategy to follow depends on the goals of water injection, reservoir properties and associated risks.

- Matrix injection: assures optimal efficiency considering the heterogeneity of the reservoir, however, it is dominated by particle plugging of the formation, which can cause severe injectivity decline.

- Fracture injection: provides a way to mitigate the matrix plugging and gives higher long-term injectivity. Fracture injection allows poorer quality of the injection water, which reduces the costs of water treatment. On the other hand, there is a possibility that poor quality of water will cause excessive fracture growth (AZIZOV *et al*., 2021).

The produced water reinjection has also the mechanism of sweeping the oil on the rock, causing the displacement from the injector well to the producing well (SILVA FILHO, 2013). In Figure 15 is presented an example of produced water reinjection and discharge from a FPSO type of platform.

Figure 15. Produced water reinjection and discharge.



Source: Beyer *et al*. (2020).

4.4.2 Reuse

Reuse of produced water can provide important economic, social, and environmental benefits, particularly in water scarce regions (GRAY, 2020).

Nasiri *et al*. (2017) described that produced water can be employed for industrial purposes such as to make-up stream for cooling towers, which needs large quantities of water for continuous operation. This new option for makeup stream of cooling towers can eliminate some of the process costs.

For oilfield operations, produced water can be used for hydraulic fracturing, a type of well stimulation technique. According to the American Petroleum Institute (2021) hydraulic fracturing is an advanced technology that is used to enhance the flow of energy from a well after drilling is complete, it creates new fractures into the rocks and also enhances the size of existing fractures. This process is carried out by sending a mixture of water, sand and certain additives into a deep-rock formation at high pressure. Soon after the fracturing occurs, water returns to the surface as “flowback” or wastewater. At that point the wastewater needs to be recycled, treated or disposed of.

Gray (2020) stated that produced water can also be reused offsite for non-oilfield applications, such as crop irrigation, livestock consumption, municipal applications, industrial process and power generation. However, it is necessary to consider some factors for offsite reuse such as economic, regulatory, environmental/social and corporate policy challenges, as presented in Figure 16. It is important to think about transportation, storage, treatments, the public perception, costs involved and the impacts that it can cause on society.

According to the American Geoscience Institute (2018) less than one percent of produced water is reused outside the oilfield. In countries where water is already scarce treated produced water has already become a solution. One example is produced water being employed for dust and ice control in the USA (GOODMAN, 2017).

In Brazil, the reuse of produce water outside the oilfield is still not very affordable due to all the cost involved in treatments, transportation and storage. Therefore, there are only few studies about produced water being employed in non-alimentary agriculture such as sunflower, castor oil plant and ornamental pineapples (CRISOSTOMO, 2018).

Figure 16. Important factors to be considered for offsite reuse.

Source: Gray (2020).

4.4.3 Discharge

According to Siagian *et al*. (2018) discharge is the most common practice of produced water treatment. There are several studies searching a better method for produced water treatment being developed due to the more stringent regulation of water discharge.

As an example, Azizov *et al*. (2021) stated that on the Norwegian Continental Shelf, more than 75% of produced water is discharged into the ocean, after treatments to meet the environmental regulations specification.

Each country has its own regulations and water quality specifications for produced water discharge. This matter has already been discussed in chapter 2.3. In Brazil, it is necessary to follow the CONAMA Resolution Nº 393 (2007).

According to Al-Ghouti (2019) the traditional techniques such as hydrocyclone, gravity separation and media filters employed to treat produced water to be discharged or reinjected into the wells, the estimate cost is around $0.509/m^3 of water. However, for produced water to be reused in other applications, advanced desalination techniques are required, therefore the estimated cost is around $3.808/m^3 of water.

This might be one of the reasons why discharge is the most common option for produced water around the world. Even though, the cost for reusing treated produced water in other applications is considerably higher than for water reinjection or water disposal, it’s important to remember that reusing water can reduce the environmental impacts and decrease the demand for other water sources.

5 CONCLUSIONS

Through the findings presented in this work, it can be concluded that produced water is indeed the largest by-product of offshore exploration. Even though, Brazil´s wells are relatively young compared to the ones abroad, it still generates millions of barrels per year. It is really concerning since produced water contain toxicities and can generate environmental impacts on the marine ecosystem. This reinforces the need for water pre-treatments, correct handling, reuse and/or disposal according to the current laws, regulations and standards.

The water management inside an offshore platform is complex because it involves different types of water (potable, produced, reuse and waste). It was difficult to obtain information about water management of platform operating companies, probably due to data protection and privacy strategies. The only viable approach found in this study was to acquire information through the descriptive memorials that were available online for the platforms auction. Therefore, it was verified that in Petrobras platforms potable water was obtained by both ways via transportation and desalination. Another important finding was that in Petrobras semi-submersible platforms there was not available a treatment system for effluents or produced water. All the water volume had to be transported to a near platform to be treated.

Another important factor found in this works was about the cost of produced water treatments. The reason why the percentage of produced water reuse is small and not always viable is due to the costs of treatment, transportation and storage of the water. The cost for treating produced water to be reused in other applications is substantial higher than for treatments for produced water reinjection or discharge. Countries where water is not abundant are already reusing treated produced water in a variety of applications. In Brazil, this practice is still not disseminated, probably because Brazil is a blessed country and possess the largest amount of potable water in the whole world. However, it is possible that in a near future the reuse of produced water will be a common thing in our lives due to the cost reduction of the equipment and the water scarcity.

SCIENTIFIC COMUNICATION

Parts of this work have been presented in conferences and symposium as described:

Poster:

a) T.S.M. MUI; N. NASCIMENTO. **O ciclo da água em plataformas offshore**. II CoBICET - Congresso Brasileiro Interdisciplinar em Ciência e Tecnologia, 30 de agosto e 03 de setembro de 2021.

b) T.S.M. MUI; N. NASCIMENTO. **O caminho da água potável até plataformas offshore**. XXIII ENCOB - Encontro Nacional de Comitês de Bacias Hidrográficas, 04 a 07 de outubro de 2021.

c) T.S.M. MUI; N. NASCIMENTO. **Estudo da água produzida em plataformas offshore: reuso, reinjeção e descarte**. XXXIII Congresso de Iniciação Científica da UNESP, 09 e 10 de novembro de 2021.

Oral Presentation:

a) T.S.M. MUI. **Análise de sistemas de reuso de água em plataformas petrolíferas offshore**. IV Jobshop Oil & Gas International PRH-ANP/FINEP 34.1 FEG/UNESP, 2021.

b) T.S.M. MUI; N. NASCIMENTO. **Gestão de efluentes** em plataformas offshore. XVI Congresso de Iniciação Científica da Universidade de Araraquara, 22 a 26 de novembro de 2021.

c) T.S.M. MUI; N. NASCIMENTO. **The importance of reusing water in offshore platforms.** 2nd International Conference Strategies toward Green Deal Implementation - Water, Raw Materials & Energy, 8 Dec 2021 to 10 Dec 2021.

REFERENCES

AGÊNCIA NACIONAL DE VIGILÂNCIA SANITÁRIA - ANVISA. Resolução RDC Nº 72. **Diário Oficial da União**, Poder Executivo, Brasília, dez. 2009.

AGÊNCIA NACIONAL DO PETRÓLEO, GÁS NATURAL E BIOCOMBUSTÍVEIS, ANP. **Database**. Available at: https://www.gov.br/anp/pt-br/assuntos/exploracao-e-producao-de-oleo-e-gas/gestao-de-contratos-de-e-p/dados-de-e-p/dados-de-exploracao-e-producao Acess in: 20 Sep. 2021.

AHMADUN, F.R *et al*. Review of technologies for oil and gas produced water treatment **Journal of Hazardous Materials,** Amsterdam, v.170, p. 530–551, 2009.

AL-GHOUTI, M.A *et al*. Produced water characteristics, treatment and reuse: a review **Journal of Water Process Engineering**, Oxford, v.28, p. 222–239, 2019.

AMERICAN GEOSCIENCES INSTITUTE. **Report.** Using produced water recycling oilfield water in the oil and gas industry and beyond**.** Alexandria: Petroleum and the Environment, Part 5/24, 2018.

AMERICAN PETROLEUM INSTITUTE. **What's the difference between wastewater disposal and "fracking"?** Available at: https://www.api.org/oil-and-natural-gas/energy-primers/hydraulic-fracturing/whats-the-difference-between-wastewater-disposal-and-fracking Acess in: 20 Dec. 2021.

ANDERSEN, E.; LØFSGAARD, B. E. **Water report 129. safe, sufficient and good potable water offshore.** a guideline to design and operation of offshore potable water systems. 5th ed. the Norwegian Institute of Public Health Infection Control and Environmental Health. Oslo: water report, guidelines, 2017.

ASSUNÇÃO, M.V.D; VIEIRA, M.M.; ALMEIDA, M.R. Fatores influenciadores na produção indesejada da água produzida de petróleo: um estuda na bacia Potiguar/Brasil. **Holos,** Natal, v.2, n.34, p. 1-15, 2018.

AZIZOV, I. *et al*. Emulsions in porous media from the perspective of produced water re-injection: a review. **Journal of Petroleum Science and Engineering**, Amsterdam, v. 206, 109057, 2021.

BEDRIKOVETSKY, P. G. Produced water re-injection with seawater treated by sulphate reduction plant: Injectivity decline, analytical model. **Journal of Petroleum Science and Engineering**, Amsterdam, v.68, p. 19–28, 2009.

BEYER, J. *et al*. Environmental effects of offshore produced water discharges: a review focused on the norwegian continental shelf. **Marine Environmental Research**, Oxford, v. 162, 105155, 2020.

BOURBON, V. J. C. **Legal**, **environmental, and economic challenges of decommissioning of offshore o&g platforms**. 2020. Dissertation (Master of Science in Petroleum Engineering) – University of Aberdeen, Aberdeen, 2020.

BRASIL. **Lei No 9.966**, 28 de April de 2000. Dispõe sobre a prevenção, o controle e a fiscalização da poluição causada por lançamento de óleo e outras substâncias nocivas ou perigosas em águas sob jurisdição nacional e dá outras providências. Available at: https://www.planalto.gov.br/ccivil_03/leis/l9966.htm Acess in: 20 July 2021.

BULL, A. S.; LOVE, M. S. Worldwide oil and gas platform decommissioning: a review of practices and reefing options. **Ocean and Coastal Management,** Oxford, v.168, p. 274–306, 2019.

BUREAU OF SAFETY AND ENVIRONMENTAL ENFORCEMENT. **What is decommissioning of offshore platforms?** Available at: https://www.bsee.gov/public-faqs/what-is-decommissioning-of-offshore-platforms. Acess in: 20 Oct. 2021.

CLARK, C.E.; VEIL, J.A. **Report**. Produced water volumes and management practices in the usa. environmental science division. Chicago: Argonne National Laboratory Report, p. 1-60, 2009.

CLICKMACAE. **Plataformas.** Available at: https://clickmacae.com.br/petroleo-e-gas/pagina/263/as-plataformas. Acess in: 25 Oct.2021.

CONSELHO NACIONAL DO MEIO AMBIENTE. CONAMA Resolução nº 357: classificação dos corpos de água e diretrizes ambientais para o seu enquadramento. **Diário Oficial da União**, Brasília, DF, mar. 2005.

CONSELHO NACIONAL DO MEIO AMBIENTE. CONAMA Resolução nº 393: dispõe sobre o descarte contínuo de água de processo ou de produção em plataformas marítimas de petróleo e gás natural, e dá outras providências. **Diário Oficial da União**, Brasília, DF, ago., 2007.

CONSELHO NACIONAL DO MEIO AMBIENTE. CONAMA Resolução nº 430: dispõe sobre condições, parâmetros, padrões e diretrizes para lançamento de efluentes em corpos de água. **Diário Oficial da União**, Brasília, DF, maio, 2011.

CRISOSTOMO, L.A. *et al*. Risco de contaminação do solo e das plantas com metais pesados devido à irrigação com água produzida na extração de petróleo. **Boletim de pesquisa e desenvolvimento**, Fortaleza, Embrapa Agroindústria Tropical, n. 183, 2018.

DEVOLD, H. Oil and gas production handbook: an introduction to oil and gas production, transport, refining and petrochemical industry. **ABB Oil and Gas**, Oslo, n.3, 2013.

DUARTE, V.M. *et al*. Energetic aspects and opportunities for reusing water on offshore platforms in Campos Basin. **Rev. Ambient. Água**, Taubaté, v. 12, n. 5, 2017.

FATAH, M.C. *et al*. An Overview of seabed storage methods for pipelines and other oil and gas equipment. **Corrosion Science and Technology**, Seul, v.16, p. 76-84, 2017.

FREITAS, T.D.N. **Produção de água a bordo de navios e plataformas**. 2011. Trabalho de Conclusão de Curso (Graduação em Tecnologia em Construção Naval) - Centro Universitário Estadual da Zona Oeste, Rio de Janeiro, 2011.

FLORIDO, P. **Produced water treatment challenges in Petrobras, 2018**. Available at: https://www.tuvsud.com/uploads/images/1529667433640022490008/2.1-petrobras.pdf Acess in: 26 Sep. 2021.

GOMES, A.A.P. **Gestão ambiental da água produzida na indústria de petróleo:** melhores práticas e experiências internacionais. 2014. Dissertação (Mestrado em Planejamento Energético) – Universidade Federal do Rio de Janeiro, Rio de Janeiro, 2014.

UNIVERSITY OF COLORADO. **Report**. Beneficial use of produced water for roadspreading: perspectives for Colorado Policymakers. Department of Public Health and Environment. Dever: University of Colorado, 2017.

GRAY, M. Reuse of produced water in the oil and gas industry. *In:* SPE International Conference and Exhibition on Health, Safety, Environment, and Sustainability, SPE-199498-MS, 2020, Virtual. **Proceedings […]**. Virtual: One Petro, 2020. Available at: https://onepetro.org/SPEHSE/proceedings-abstract/20HSE/2 20HSE/D021S004R001/447171 Acess in: 05 Aug. 2021.

HB RENTAL. **Water tanks.** Available at: https://hbrentals.com/offshore-solutions/operating-essentials/water systems/skidded-potable-water-tank/ Acess in: 02 May 2021.

HEDAR, Y. Water pollution impact and alternative treatment for produced water. *In:* E3S Web of Conferences v.31, 03004, 2018, Changsha. **Proceedings […]**. Changsha: E3S, 2018.

INSTITUTO BRASILEIRO DO MEIO AMBIENTE E DOS RECURSOS NATURAIS RENOVÁVEIS – IBAMA. Instrução normativa nº 1: define diretrizes que regulamentam as condições ambientais de uso e descarte de fluidos, cascalhos e pastas de cimento nas atividades de perfuração marítima de poços e produção de petróleo e gás, estabelece o projeto de monitoramento de fluidos e cascalhos, e dá outras providências. **Diário Oficial da União**, Brasília, DF, jan. 2018.

INSTITUTO BRASILEIRO DO MEIO AMBIENTE E DOS RECURSOS NATURAIS RENOVÁVEIS, IBAMA. **Relatórios de água produzida.** Available at: http://licenciamento.ibama.gov.br/Relatorios%20CONAMA%20393/ Acess in: 20 Aug. 2021.

INSTITUTO BRASILEIRO DO MEIO AMBIENTE E DOS RECURSOS NATURAIS RENOVÁVEIS. IBAMA b. **Petrobrás assina termo de compromisso.** Available at: http://www.ibama.gov.br/noticias/422-2017/1373-petrobras-assina-termo-de-compromisso-com-o-ibama-para-adequar-plataformas-na-bacia-de-campos-rj-e-devera-investir-r-100-milhoes-em-conservacao-ambiental Acess in: 10 Oct. 2021.

INTERNATIONAL CONVENTION FOR THE PREVENTION OF POLLUTION FROM SHIPS, **MARPOL 73/78 Amendments**. International Maritime Organization. London: MARPOL, 1978.

IGUNNU, E.T.; CHEN, G.Z Produced water treatment technologies. **International Journal of Low-Carbon Technologies**, Oxford, v. 9, p.157–177, 2014.

ISMAIL, N. *et al*. Modelling of water supply cost for offshore platforms. **International Journal of Scientific & Technology Research**, Raipur, v.8, p. 58-64, 2019.

LI, Z. *et al*. Towards sustainability in water-energy nexus: ocean energy for seawater desalination. **Renewable and Sustainable Energy Reviews**, Oxford, v. 82, p. 3833-3847, 2018.

LIU, Y *et al*. A review of treatment technologies for produced water in offshore oil and gas fields. **Science of the Total Environment**, Amsterdam, v. 775, 145485, 2021.

MAKWATER. **Potable water offshore**. 2013. Available in: https://www.makwater.com.au/case/potable-water-offshore-oil-platform/ Acess in: 15 April 2021.

MARINE SAFETY FORUM. **Guidelines:** quality potable water to offshore installations, United Kingdom, n. 2, 2013.

MARINHA. **Petrobrás P-07.** Available at: https://www.marinha.mil.br/dpc/helidecks/petrobras-07 Acess in: 25 Oct. 2021.

MINISTÉRIO DO TRABALHO. Norma regulamentadora n.º 37: segurança e saúde em plataformas de petróleo. **Diário Oficial da União**, Poder Executivo, Brasília, DF, dez. 2018.

MOTA, A.R.P. *et al*. Tratamento de água produzida de petróleo para remoção de óleo por processos de separação por membranas: revisão. **Eng Sanit Ambiental**, Rio de Janeiro, v.18, n.1, p. 15-26, 2013.

NASIRI, M. *et al*. Oil and gas produced water management: a review of treatment technologies, challenges and opportunities. **Chemical Engineering Comunication**, Oxfordshire, v. 204, p. 990-1005, 2017.

NIHALANI, M.C. Managing sulphate reducing bacteria (srb) problem associated with produced water in one of the oilfields of india limited: a case study. In: SPE Oil and Gas India Conference and Exhibition, SPE-127418-MS, 2010, Mumbai. **Proceedings […]**. Mumbai: One Petro, 2010. Available at: https: https://onepetro.org/SPEOGIC/proceedings-abstract/10OGIC/All-10OGIC/SPE-127418-MS/109674 Acess in: 04 Jul. 2021.

NORWEGIAN MARITIME. **Regulations No. 1406 on potable water and potable water systems on mobile offshore units.** Oslo: Ministry of Industry and Ministry of Fisheries, 2015.

PETROBRAS. **Recursos hídricos,** 2018. Available at:https://petrobras.com.br/pt/sociedade-e-meio-ambiente/meio/recursos-hidricos/ Acess in: 07 Jan. 2021.

PETROBRAS. **Leilão de plataformas**, 2020a. Available at: https://petrobras.com.br/pt/canais-de-negocios/leilao-internacional-para-venda-de-plataforma/ Acess in: 01 Oct. 2021.

PETROBRAS. **Description of semi-submersible production unit**. PETROBRAS VII (P-VII). Addendum A: descriptive memorial. Rio de Janeiro: Petrobras, 2020b.

PETROBRAS c. **Description of semi-submersible production unit**. PETROBRAS XII (P-XII). Addendum A: descriptive memorial. Rio de Janeiro: Petrobras, 2020c.

PETROBRAS d. **Description of semi-submersible production unit**. PETROBRAS XV (P-XV). Addendum A: descriptive memorial. Rio de Janeiro: Petrobras, 2020d.

PETROBRAS. **Maritime facilities decommissioning program:** maritime installations FPSO P-32. Rio de Janeiro: Petrobras, 2020 e. v. 1.

PURETECWATER. **Reverse osmosis.** Available at: https://puretecwater.com/reverse-osmosis/what-is-reverse-osmosis. Acess in: 15 Jan. 2021.

SIAGIAN, U.W.R. *et al*. Oilfield produced water reuse and reinjection with membrane. **MATEC Web of Conferences,** v.156, 08005, 2018.

SILVA, F.R.S. **Dessalinização da água na indústria offshore**. 2016. Trabalho de Conclusão de Curso (Aperfeiçoamento para Oficiais de Máquinas) – Centro de Instrução Almirante Graça Aranha, Rio de Janeiro, 2016.

SILVA FILHO, D.I. **Processo da reinjeção da água produzida na recuperação secundária dos poços de petróleo de catuba, para reduzir os riscos ambientais**. 2013. Monografia (Especialização em Gestão Ambiental) – Universidade Tecnológica Federal do Paraná. Medianeira, 2013.

SUEZ. **Reverse osmosis desalination**. Available at: https://www.suezwatertechnologies.com/products/reverse-osmosis/seawater-packaged-desalination Acess in: 20 Jan. 2021.

TIBURCIO, S.R.C. *et al*. Sulphate-reducing bacterial community structure from produced water of the Periquito and Galo de Campina onshore oilfelds in Brazil. **Scientifc Reports**, Berlin, v.11, 20311, 2021.

UNITED NATION. **Water and sanitation**. Available at**:** https://www.un.org/sustainabledevelopment/water-and-sanitation/ Acess in: 15 Feb. 2021.

VEIL, J. U.S. Produced water volumes and management practices in 2017. Veil Environmental, LLC.Ground. **Water Research and Education Foundation**, Colorado, p. 1-135, 2020.

WATER ENVIRONMENT FEDERATION. **Produced water: o**il and gas terminology glossary. Fact Sheet WSEC-2017-FS-013, IWWC, Virginia: Water Environment Federation, 2018.

WWAP UNITED NATIONS WORLD WATER ASSESSMENT PROGRAMME. **Report**. Wastewater: The Untapped Resource. The United Nations World Water Development Report 2017. Paris: UNESCO, 2017.

WORLD HEALTH ORGANIZATION. **Guidance.** Water, sanitation, hygiene, and waste management for SARS-CoV-2, the virus that causes COVID-19. Geneva: WHO, Interim Guidance, 2020.

ZHENG, J. *et al*. Offshore produced water management: a review of current practice and challenges in harsh/Arctic environments. **Marine Pollution Bulletin,** Oxford, v. 104, p. 7-19, 2016.