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Comparative Study Between Conventional And Tangential Microfiltration For The Treatment Of Produced Water

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Abstract
This study aims to conduct a comparative analysis between conventional microfiltration and tangential filtration applied to produced water treatment from the Fazenda Bálsamo field located in Esplanada, Bahia, Brazil. Produced water is the effluent resulting from primary oil processing. Its disposal poses a significant challenge for oil companies due to the large volumes generated during oil production. An appropriate alternative for its final disposal is reinjection into oil wells after treatment to meet the required process standards. To facilitate this purpose, the water must undergo treatments to prevent damage to production facilities and the environment. Filtration involves the retention of suspended solids in a particular fluid through a filtering medium. Consequently, two vacuum filtration systems were developed, one conventional and the other tangential. The suspension to be filtered was obtained from preliminary treatment of the produced water through chemical oxidation followed by coagulation-flocculation. The filtration systems' performance was measured in terms of filtered water turbidity and efficiency in removing total solids, fixed solids, volatile solids, suspended solids, and oils and greases. For the evaluated parameters, both vacuum microfiltration systems demonstrated satisfactory values in reducing solids, turbidity, and removal of oils and greases. However, tangential microfiltration showed superior removal rates for parameters such as total solids, fixed solids, volatile solids, and suspended solids, while conventional microfiltration exhibited greater removal of oil and grease content and turbidity. This observation motivates further studies, particularly concerning the regeneration of filtering media, as well as the application of these systems to other fluids.
Keywords: *Produced water, reinjection, conventional and tangential microfiltration*

I. INTRODUCTION

Environmental degradation due to anthropogenic activities is a daily concern. The pursuit of improved quality in processes, materials, and techniques primarily stems from the necessity to align polluting activities with legal requirements. Within the exploration and production of oil and gas, residues and effluents are generated, prominently featuring produced water. Produced water refers to water trapped in underground formations brought to the surface alongside oil and gas during production activities. Noteworthy aspects of produced water include its high volumes and complex composition, necessitating specific management considerations not only in technical and operational realms but also in environmental aspects. Consequently, managing produced water incurs considerably high costs, representing a significant percentage of production expenses.

The volume of produced water generated in oil production activities varies based on the characteristics and age of the field, with more mature reservoirs responsible for the highest quantities of this effluent (Neff et al, 2011a). The composition of produced water may vary depending on the geological formation and the well's production time. However, generally, it includes dissolved salts such as sulfides and ammonium salts, dissolved and dispersed hydrocarbons, organic compounds like PAHs (polycyclic aromatic hydrocarbons), phenols, and carboxylic acids, contributing to approximately 90% of the total organic carbon content. Additionally, it contains BTEX (benzene, toluene, ethylbenzene, and xylene), heavy metals, chemical additives like surfactants, flocculants, and corrosion inhibitors, suspended solids, and sometimes exhibits higher salinity than seawater. Commonly adopted management strategies for addressing this issue involve disposal into the sea or reinjection into underground formations for well pressure maintenance, enhancement, or recovery. However, in all these cases, specific treatment of produced water is necessary.

In this context, one of the significant challenges concerning produced water treatment is finding an economically viable treatment technique for the intended purposes. Commonly available methods for treating produced water include air flotation (Arnold and Stewart, 2011), hydrocyclones (Saidi et al., 2012), coalescing media (Sokolović et al., 2009), membranes (Chakrabarty et al., 2008), and filtration (Mota et al., 2014). According to HydroGrou (2021), microfiltration (MF, ranging from a few microns to 0.1 μm), ultrafiltration (UF, with membrane pore sizes between 0.1 μm and 0.01 μm), nanofiltration (NF, with membrane pore sizes between 0.01 μm and 0.001 μm), and reverse osmosis (RO, with membrane pore sizes between 0.001 and 0.0001 μm) are the most applicable techniques for separating pollutants in produced water."

Microfiltration removes materials such as sand, oil, and clays from produced water. Motta et al. (2014) investigated the removal of oils and greases from synthetic produced water with oil concentrations ranging from 200 to 400 mg/L. The results indicated a total removal efficiency reaching 93–100%, with treated water oil content varying from 0.1 to 14.8 mg/L. Ebrahimi et al. (2010) reported oil content removal of up to 93% using MF. Wang et al. (2011) also applied microfiltration in produced water treatment, reporting removal of <8 mg/L oil concentration, <3 mg/L suspended solids, and <2.0 μm average particle size of suspensions.

Thus, the aim of this article is to conduct a comparative study between a conventional microfiltration system and a tangential one applied to produced water treatment. Despite the existing literature exploring microfiltration in produced water treatment, to the authors' knowledge, there is a lack of a comparative study between conventional and tangential techniques applied to real produced water. It is understood that real produced water obtained from oil fields possesses a highly complex composition, and reproducing it in a laboratory to obtain synthetic produced water is not a trivial task

Therefore, this article initially addresses aspects related to the theory of sedimentation and filtration, followed by the methodology employed in this study and an explanation of the experimental setup. Subsequently, the results of evaluations including turbidity, oils and greases, total solids, fixed solids, volatile solids, and suspended solids are presented and discussed. Finally, the conclusions drawn from this study are provided.

II. EXPERIMENTAL ASPECTS

Figure 1 illustrates the steps adopted in this study to treat produced water from petroleum. The suspension to be filtered was obtained from a preliminary treatment of the produced water through chemical oxidation followed by coagulation-flocculation. Subsequently, the produced water underwent both conventional and tangential microfiltration. The experiments and analyses were conducted at the Chemistry Laboratory, Centro Universitário Jorge Amado – UNIJORGE, Paralela Campus.

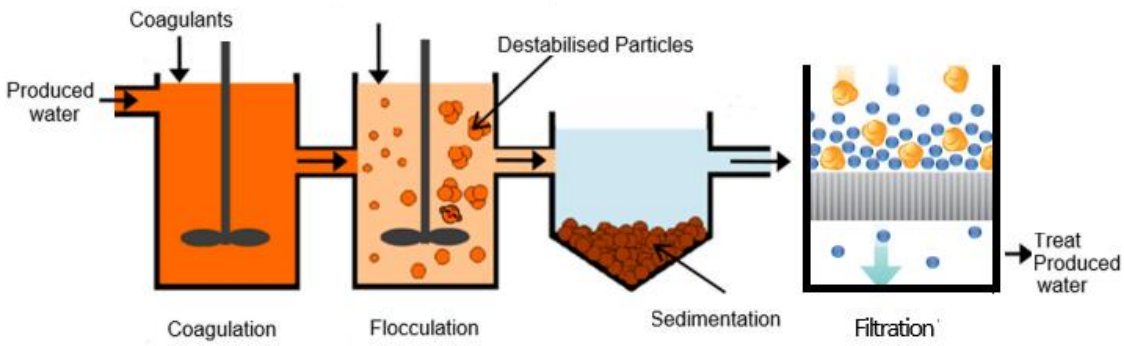


Figura 1: Produced Water Treatment Process Steps (Adaptation from Amakiri et al., 2022)

Produced water sampling

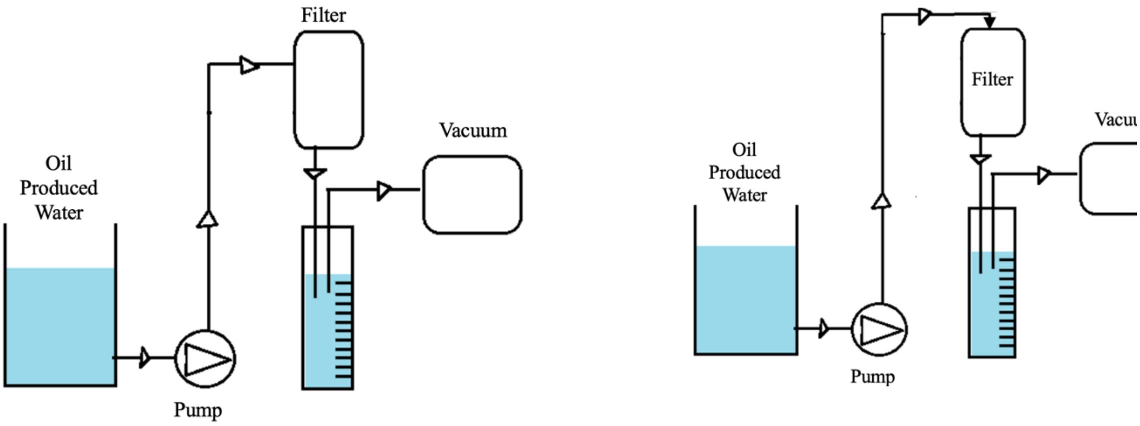
The sample of produced water to be treated by the conventional and tangential filtration systems was sourced from the Water Injection Station (WIS) at the Fazenda Bálsamo field, located in Esplanada, Bahia, Brazil. The collection of the sample was done in a carefully cleaned polyethylene container rinsed with distilled water to prevent effluent contamination. The characteristics of the utilized produced water are presented in Table 1.

Table 1– Characterization of produced water in natura

Parameter produced water in natura		
Total Solids (mg/L)	**Turbidity (NTU)**	**Oil and grease content (mg/L)**
7223,0	140	557

Filtration system

The filtration system employed comprised an experimental setup consisting of: a porous ceramic filter medium, a centrifugal pump (Askoll brand, model 600092) for feeding the suspension, a MAXPUMP vacuum pump, and additional accessories installed in the feed, recycle, and filtrate lines. For the tangential arrangement (Figure 2a), the centrifugal pump connected to the effluent reservoir propelled the suspension to the upper orifice, introducing it tangentially into the annular space of the filter. The suspension flowed in a helical motion until reaching the outlet. The filtrate was collected in a measuring cylinder for filtration rate measurement. In the conventional system, the feed was introduced at the top of the filter, as depicted in Figure 2b. In both cases, the filtering medium had a filtration area of 126 cm^2 and was housed in a PVC housing. For the tangential feeding system, the housing had three orifices: one tangential (upper, suspension inlet) and two axial (lower, concentrated suspension outlet, and another for filtrate withdrawal). The conventional filtration system differed from the tangential one only in the solution's entry orifice. The assembly of the system was achieved using bolted flanges that connected the semicylindrical sections sealed by a rubber ring.



(a) (b)

Figure 2: Filtration system (a) tangential e (b) conventional

Decanting process

To conduct the tests, the produced water underwent a phase separation process, decantation, as shown in Figure 3. To carry out this process, 1 liter of water was placed in a glass beaker, and subsequently, 2 grams of aluminum sulfate (coagulant), a salt commonly used in water and effluent treatments, were added. The mixture was then transferred to a mixer, Fisatom 713D model, and stirred for 3 minutes at 1200 rpm. The mixture was left to stand for approximately 24 hours, allowing the denser particles to settle via decantation

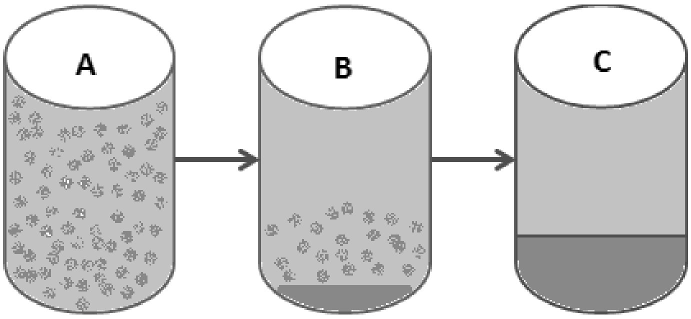


Figura 3: Decanting Zones

From Figure 3, initially in zone A, the suspension is homogeneous, where the particulate phase is distributed throughout. After some time, the denser particles than water begin to settle, forming a small layer of particles at the bottom of the vessel, as shown in zone B. As the settling progresses, the sediments form a larger layer at the bottom, creating a region with clear water above. Finally, in the last stage, zone C, there exists only the region of clarified liquid and the region of settled particles.

Analytical methods for determining the quality of treated produced water

Before and after each filtration test, the oil and grease content, total solids, dissolved, fixed, and volatile solids, as well as the turbidity of the mixture, were determined. These tests were essential for monitoring the filtration process and evaluating the efficiency of the proposed systems in this study. Consequently, the analytical methods are described in the following sections.

a. Turbidity

Turbidity is an expression of the optical property of light passing through a sample, being scattered or absorbed rather than following a straight path (Clesceri et al., 1998). The values are expressed in nephelometric turbidity units (NTU). The analysis of this parameter was conducted using the Turbidimeter equipment, Policontrol AP 2000 model, where three water samples were used: pure water, settled water, and filtered water, thus obtaining different results for comparison.

b. Solids

Solids consist of both organic and inorganic substances in a finely granular form present in liquids. These are associated with all matter that remains as residue after drying or calcination and evaporation of the sample at a given temperature for a fixed time. Therefore, Table 2 describes each of the solids to be analyzed as well as the method of calculating them. This table was constructed using information from the SABESP Internal Technical Standard NTS 013.

Table 2– Description of the solids evaluated

Solid	Description	Equation
TOTAL SOLIDS (TS)	Residue remaining in the capsule after drying a sample containing 100ml in an oven varying its temperature from 103-105°C until constant weight. Also called total residue.	$ST\ (g) = P_1 - P_1$ where P_1 is the tare weight of the capsule (g) and P_1 is the weight of the capsule with sample after drying (g).
FIXED SOLIDS (FS)	This is the portion of the total solids that remains after drying, and is sent to an oven with a temperature of 50°C for 15 to 20 minutes. Also known as fixed residue.	$SF\ (g) = P_3 - P_1$ where $P_1$is the tare weight of the capsule (g) and P_3 is the weight of the capsule with sample after calcination (g).
SUSPENDED SOLIDS (SS)	This is the portion of the total solids that is retained on a filter (nitrocellulose) that retains particles with a diameter greater than or equal to 0.9 µm. These come from drying a 100ml sample in an oven with a temperature ranging from 103 -105°C.	$SS\ (g) = P_4 - P_1$ where P_1 is the tare weight of the filter (g) and P_4 is the weight of the filter with sample after drying (g).
VOLATILE SOLIDS (VS)	This is the sum of the solids that have evaporated after heating the sample.	$SV\ (g) = (P_5 - P_2) + (P_2 - P_5)$ where P_2 is the weight of the capsule with sample after drying (g), P_5 is the weight of the capsule with sample after calcination (g) and P_5 is the weight of the capsule plus sample (g).

c. Oil and grease content

A spectrophotometry method using infrared was employed to determine the oil and grease content, utilizing an Infracal analyzer from Wilks Enterprise (USA), model 71 TOG/TPH Analyzer, following ASTM D 1129 standard.

III. RESULTS AND DISCUSSIONS

Once the experimental apparatus of the two filtration systems (conventional and tangential) presented in the previous section was set up, 1 liter of produced water was separated from the raw water, and the decantation process was initiated. At this stage, aluminum sulfate (coagulant) was added, and the mixture was allowed to settle for approximately 24 hours. Subsequently, the clarified zone of the decanted water was subjected to the developed filtration systems. Samples of the raw water, water after decantation, and filtered water were collected and underwent analyses that will be discussed later.

A vacuum-driven filtration of the flocculated suspensions obtained from the conventional and tangential microfiltration of produced water resulted in the filtered flux outcomes shown in Figure 4. It's noticeable that the tangential microfiltration yields slightly better results than the conventional system. In both cases, the filtered flux decreases over time. This can be attributed to the increased filtration resistance, meaning that if pressure is kept constant during filtration, the filtered flux will progressively decrease. This occurs because as solid particles are deposited (forming the filter cake), the flow resistance increases. The slopes of the tangents to the curves presented in Figure 4 are directly related to the resistance, which increases with pore blockage in the filtering medium or with an increase in the thickness of the filter cake.

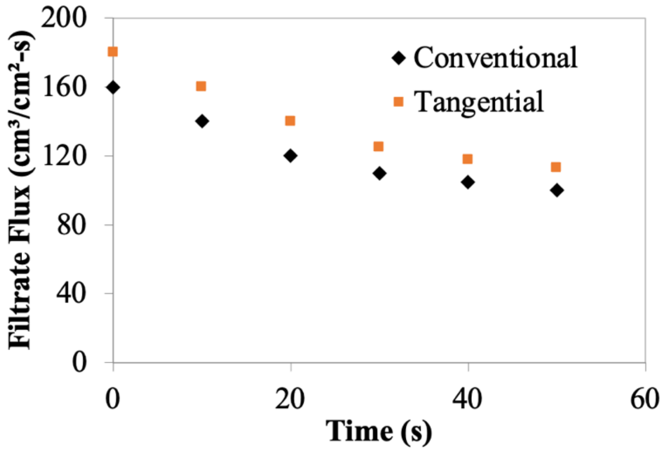


Figure 4: Filtrate flow versus time.

For a 100 mL sample of raw produced water, settled water, and filtered water, the following studies were conducted: total solids, fixed solids, volatile solids, and suspended solids. The obtained results are listed in Table 3. It is evident that both studied filtration methods (tangential and conventional) yield satisfactory results due to the significant reduction in solids compared to raw produced water. Solid removal is carried out through sedimentation and filtration processes and is directly associated with particle size. Particles larger than 1 µm can be separated by sedimentation through the addition of a coagulant. However, particles with a diameter smaller than or equal to 1 µm are retained by the filtration process.

Table 3 – Evaluation of solids

Solid	Produced Water in natura	Decanted water	Filtered produced water	
			Conventional	Tangential
Total Solids (mg/L)	7223	7173	6154	6113
Fixed Solids (mg/L)	6953	6723	5874	5865
Volatile Solids (mg/L)	11493	9550	7330	7315
Suspended Solids (mg/L)	280	160	60	56

Analysis of turbidity was also conducted on the three samples (raw produced water, settled water, and filtered water). The results are presented in Table 4. As observed in Table 4, there was a significant reduction in turbidity in both studied filtration systems. This reduction is associated with the removal of solids retained in the filtration media of the systems evaluated in this study. According to CONAMA regulations (Brazil, 2005), the filtered water from both methods complies with the established parameters in Brazilian legislation, where the fluid can be reinjected or even designated for human consumption, as the legal limit is 5 NTU, and the values presented by both filtration systems are below this limit. Upon analyzing Table 4, it is evident that conventional filtration showed a lower turbidity value. This is perfectly understood when considering the nature of the relative particle-filter medium movement. In conventional filtration, the particle collides perpendicularly with the surface of the filter medium. However, in the case of the tangential mechanism, the particle approaches the pores obliquely, making it more challenging for them to pass through. These findings are in agreement with observations made by Rocha (2009) and Licona (2011).

Table 4 – Turbidity analysis

Turbidity (NTU)			
Produced Water in natura	Decanted water	Filtered produced water	
		Conventional	Tangential
140	50,1	3,2	4,3

Table 5 presents the results regarding the removal of oils and greases for both raw and filtered water using the two methods studied in this research. It's noticeable that the conventional filtration method exhibits a more pronounced reduction in oil and grease content. According to Yang (2007), in the tangential method, turbulence within the filter housing may favor the formation of a pasty mixture of oil and solid particles, thereby increasing the oil and grease content as well as the system's turbidity. This behavior was previously observed by Rocha (2009) and Licona and Marques (2007). It's essential to highlight that the filtration process also serves as a means of oil recovery, which, as per Gabardo (2007), can be recycled within the process, bringing both economic and environmental benefits. For these and other reasons, determining the oil and grease content (TOG) plays a crucial role in produced water treatment.

Table 5 – Analysis of oil and grease content

Analysis of oil and grease content (mg/L)		
Produced Water in natura	**Filtered produced water**	
	Conventional	**Tangential**
557	72	105

Table 6 – Removal Efficiency Analysis

Analytical parameter	(%)removal - Conventional	(%)removal - Tangential
Total Solids (mg/L)	14,80	15,36
Fixed Solids (mg/L)	15,52	15,64
Volatile Solids (mg/L)	36,22	36,35
Suspended Solids (mg/L)	78,57	80,00
Turbidity (NTU)	97,71	96,93
Oil and grease content (mg/L)	87,07	81,15

Finally, aiming to obtain a filtration curve for the system under study, Figure 5 represents the graph of filtrate volume versus time. It was observed that due to the use of the vacuum pump, filtration was accelerated, occurring between 0 to 50 seconds. The filtration curve is essential for future studies in assessing the regeneration of the filter medium.

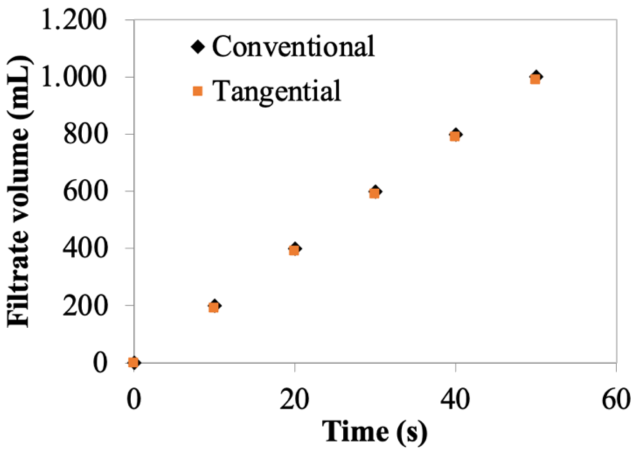


Figura 5: Filtrate volume versus time.

IV. CONCLUSÃO

In this study, the treatment of produced water from Fazenda Balsamo field, BA, was conducted using both conventional and tangential microfiltration, both under vacuum. The analyses conducted demonstrated that both systems operated satisfactorily, resulting in a reduction in levels of suspended solids, concentrations of dissolved solids, volatile and fixed solids, as well as turbidity and oil and grease content. Tangential filtration exhibited better removal rates for parameters such as total solids, fixed, volatile, and suspended solids. Meanwhile, conventional filtration showed higher removal percentages for oil and grease content and turbidity. This difference is related to the nature of the relative movement between particles and the filtration medium. In tangential microfiltration, particles approach the pores obliquely, making it more difficult for them to pass through. On the other hand, in the conventional mechanism, particles collide perpendicularly with the surface of the filtration medium. Therefore, this study motivates further research regarding the regeneration of the filtration medium or even the application of the techniques proposed here for treating other fluids.

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