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Using Carbon Nanotube Filtration Technology and Ceramic Filter Membranes to Remove Salts from Oil Effluents

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Abstract

The performance of two types of reverse osmosis membranes, namely the Carbon Nano-Tube Filtration Membrane and the Ceramic Filtration Membrane, was evaluated in this study by comparing the removal efficiency of the conventional plant in the refinery and the reverse osmosis removal efficiency, after tracing the treated wastewater streamline in the Al-Qayyarah refinery treatment plant. In both membranes, the treated water has pH is 6.4, 6.2, lead (Pb) is 0.0449, 0.0016, cadmium (Cd) is 0.00443, 0.00255, copper (Cu) is 0.00443, 0.00255, cobalt (Co) is 0.0031, 0.00041, Total E-coli is 39, 27, conductivity less than 97, 83 µS/cm, (SO_4) less than 9.15, 4.416 ppm, chemical oxygen demand less than 9.346, 7.861 ppm, calcium carbonate ($CaCO_3$) less than (4.3, 1.1 mg/L), Sodium (Na^+) is 2.1, 2.61ppm, and total nitrogen (TNO_3 or NO_3) less than 0.34, 0.06 ppm, Orthophosphate (PO_4) is 0.081, 0.002, Sulfate (SO_4) is 9.15, 4.416 , for Carbon Nano-Tube Filtration Membrane and the Ceramic Filtration Membrane, respectively. It concluded that the Carbon Nano-Tube Filtration Membrane is more efficient in terms of treatment, and the Ceramic Filtration Membrane has a stronger texture and longer working life. The proposed treatment strategy is expected to make a significant reduction in the amount of water in refinery primary water withdrawal possible as a result of its reuse in the cooling system.

Keywords: Reverse Osmosis, Membrane material, Desalination, Ceramic Filtration Membrane, Carbon Nano-Tube Filtration Membrane

1. Introduction

The world today suffers from a real scarcity of water suitable for drinking, use and agriculture [1]. Therefore, the importance of finding modern and alternative techniques to treat water in water bodies or those that result from human life and activities, the most important of which is industrial, is growing because it is the most complex and dangerous type of water as it contains many components that are not suitable for use [1]. To be put out directly, but it requires effective treatment to reduce the percentage of pollutants in it to the acceptable limits. Also, Wastewater produced by petroleum industries includes various kinds of contaminants, for example sulfides, hydrocarbons, heavy metals etc. [2]. During petroleum industry activities there are huge amounts of harmful materials are produced, for example through the oil production process or storage, which are all unsafe for the environment and human health [3]. Moreover, Oil production generates large volumes of produced water (PW) containing high salinity (10,000–

100,000 mg/L (TDS), dispersed oil droplets, surfactants, and suspended solids [4]. Traditional separation units, such as gravity separators and hydrocyclones, remove oil and solids but fail to eliminate dissolved salts. Therefore, advanced membrane technologies have emerged as potential solutions for desalination and reuse of oil effluents [5].

There are several processes for treating wastewater produced by the petroleum industry, including physical, chemical, and biological methods [6].

Therefore, the water used in the oil industries and refining operations has become one of the most frequently discussed topics due to its seriousness that can harm people, soil, water and the environment in general [7]. Whether through its production inside oil refineries or during its release to the environment again, especially with the lack of most of the refineries, especially the old ones, to the correct methods and appropriate plants to treat water before it is released, as it is considered one of the most dangerous wastewater due to its content of polluting materials and toxic and heavy metals that spread quickly to soil, surface and groundwater. The principle of desalination, is a technology that converts saline water into clean water prorated to use, gives one of the most important solutions to these polluted water problems [8]. Reverse osmosis (RO) is the global technology that used desalination. In the past decades, there were remarkable advances to made preparing RO membranes from different materials [8], as well as giving new researches into conventional polymeric RO membrane materials. Nanotechnology has given the chance to incorporating nanomaterial into RO processes [9]. Ceramic UF/MF membranes effectively remove >99% oil and suspended solids, improving feed quality for reverse osmosis (RO) or MD [10,11]. However, because their pores are relatively large, they cannot remove dissolved salts directly. Instead, they act as a pretreatment step to reduce fouling in downstream desalting units [12]. There is large volume of water consumed in refineries that can classified into four types of wastewater, the cooling water, process water, storm water and sanitary wastewater water that produced with oil and gas is the largest wastewater stream in the petroleum industry activities [13]. this Produced waters are having a high content of salts and oil which it contains high concentrations of aromatic hydrocarbons [14]. The high salt concentration can range from a few to 200000 mg/L; the total organic carbon (TOC) concentrations can be between 0 and 1,500 mg/L and oil and grease (O and G) concentrations can be between 2 and 565 mg/L (13-15) [15]. That makes the traditional wastewater plant of refineries not active or able to deal with this contaminated flow [16]. Carbon nanotubes possess smooth, hydrophobic nanochannels that allow ultra-fast water transport with low friction, while their tunable pore size and surface charge can selectively reject ions [17]. When functionalized with carboxyl or amine groups, CNTs exhibit improved hydrophilicity and anti-fouling characteristics [18]. Nano-osmotic filtration is a method based on membrane filtration that uses nanometer-sized openings that pass through the membrane. Ultrafiltration membranes have pore sizes 1-10 nm, smaller than those used in microfiltration and ultrafiltration, but only larger than that in reverse osmosis [19]. The films used are mostly made of polymer thin films [20].

Commonly used materials include polyethylene or metals such as aluminum. Pore dimensions are controlled by pH, temperature and time during development with a pore density ranging from 1 to 106 pores per cm2. This membrane, which contains a myriad of micropores, only allows water molecules to pass through, and does not allow salts to pass through and removes them from the water and produces usable salt-free water. This method can produce thousands of tons of water per day, twice what is currently produced in conventional treatment plants. In the last decade, an innovative reverse osmosis membrane was developed in which Carbon Nano-Tube Filtration Membrane CNTFM was mixed with traditional crosslinked aromatic polyamide. By mixing the optimum number of nanomaterials, the membrane became positively charged, and surface concavities and bumps were reduced [21]. As a result, it became difficult to adhere to the impurities called "foulant" [22]. This gives the filters a long life and durability, in not break down early, and then the required improvements were made to make it suitable for treating industrial, chemical, and oil wastewater [23]. This research will address the most important modern technologies in the management and treatment of this type of polluted water using membrane technology RO compared with the traditional method based on the subtractions of the treatment plant for Al-Qayyarah refinery in the city of Mosul. This work has been done in the area of study treatment plant belonging to the Al-Qayyarah refinery, south of Nineveh Governorate, on the west bank of the Tigris River, and about 60 km south of Mosul. Samples were collected and analyzed for three months.

The challenge faced by this work is contamination of surface water near the Al-Qayyarah refinery plant with untreated wastewater. The aims of this research were the find modern technological alternatives to reduce and treat pollution caused by the inefficient work of water treatment plants for some refineries. Shedding light on the importance of rationing water consumption sources and the need to find ways to recycle it instead of wasting it. Reducing the percentage of pollutants resulting from the Al-Qayyarah refinery that are thrown into the Tigris River and improving its quality.

2. Methodology

The materials and chemicals detailed in Table 1 were used in this experiment, which are waste water sample brought from Al-Qayyarah refinery and Carbon Nano-Tube Filtration Membrane (CNTFM), and a Ceramic Filtration Membrane (CFM). chemical oxygen demand (COD).

Table 1: The materials and chemicals were used in this work

Materials and chemicals	Source	Notes
Wastewater	Al-Qayyarah refinery	2 L
CNTFM	University of Mosul	-
CFM	University of Mosul	-

2.2. Experimental work

The electrical conductivity of the water samples was measured in the field using a conductivity meter, and the results were expressed in (micromhos/cm). The turbidity of the water samples was measured by using the Nephelometric method and the Nephelometric Turbidity Unit. The results were expressed in (N.T.U) units. The pH function of water samples was measured using a pH meter after adjusting and calibrating the device using buffer solutions with values (7 and 9). The titration method was used, and the results were expressed in units (mg / L in terms of calcium carbonate). The sulfate ions SO4 were determined by turbidity method using a spectrophotometer with a wavelength of 420 nm, and the results were in (mg/L). The nitrate (NO-1) concentration was estimated by the violet ultra method using a UV and visible spectrometer, as the absorbance was measured for each sample at wavelengths 220 nm and 275 nm. In units (mg/L) Orthophosphate (PO+4) was estimated by chloride stannous method. The absorbance was measured by a spectrophotometer at the wavelength 690 nm, and by reference to the standard curve, the orthophosphate concentration in the sample was determined, and it was expressed in the unit (mg/L). The Sodium (Na+1) and Potassium (K+1) concentrations of the filtered samples were measured using a flame photometer, and then the readings were compared with the standard curve for each element and the concentrations were determined in units (mg/L). The concentrations of the heavy elements under study (lead, copper, cadmium, cobalt) were estimated based on the method mentioned in APHA by the method of atomic absorption by flame. Chemical oxygen demand (COD) perform the test by (Method Reflux Open) and according to standard methods. Oils and grease compounds measured via the amount of the sample is placed in the funnel separator, then the solvent (petroleum ether) is added above the sample in the separating funnel and the solution is constantly shaken, then left to settle and the aqueous and organic layers are isolated and the organic layer is taken after its separation and placed in the drying oven for two hours at a temperature of 105 ° C [24]. The Biological tests (Total Bacteria Count), the Counting Plate Standard Method, was used to find the total number of bacteria, which was approved by the World Health Organization WHO [25].

Results and discussion

3.1. Electrical conductivity

Table 2, ad Figure 1 shown the value of the electrical conductivity is (1390) µmoh/cm before the treatment process, while Table 3 showed that the highest value of the electrical conductivity is (97 and 83) µmoh/cm after the treatment process with the CFM and CNTFM, and this is due to the decrease in the co CNTFM concentrations of dissolved salts and their ions after the treatment process according to the RO technique. The increase in the values of electrical conductivity may be due to the decomposition processes of organic materials and the reactions that occur in water, which lead to the dissolution of some of the compounds in it [26].

Table 2: The compositions in wastewater after treatment by CFM CNTFM, WHO

Composition elements	Composition in wastewater	Treatment using CFM	Treatment using CNTFM	WHO Limitation
PH	8.7	6.4	6.2	6.5-8.5
EC	1390	97	83	750
Ca^{+2}	73.7	7	4.4	100
Mg^{+2}	188	12.2	10.44	100
Na^{+}	39	2.1	2.61	200
K^{+}	1.82	0.113	0.108	100
COD	193	9.346	7.861	< 50
SO_4^-	96.353	9.15	4.416	400
NO_3^-	3.736	0.34	0.06	10
PO_4^-	0.962	0.081	0.002	0.30
Cu	0.614	0.031	0.004	1.3
N.T.U	36.2	2.2	1.1	1-5
$Caco_3$	168	4.3	1.1	75
Co	0.0736	0.0031	0.00041	1.00
Pb	1.827	0.0449	0. 0016	0.05
Cd	0.14236	0.00443	0.00255	0.005
Total E-coli (cell/ml)	870	39	27	<3
Grease and oil	22.61	0.2	0.5	0

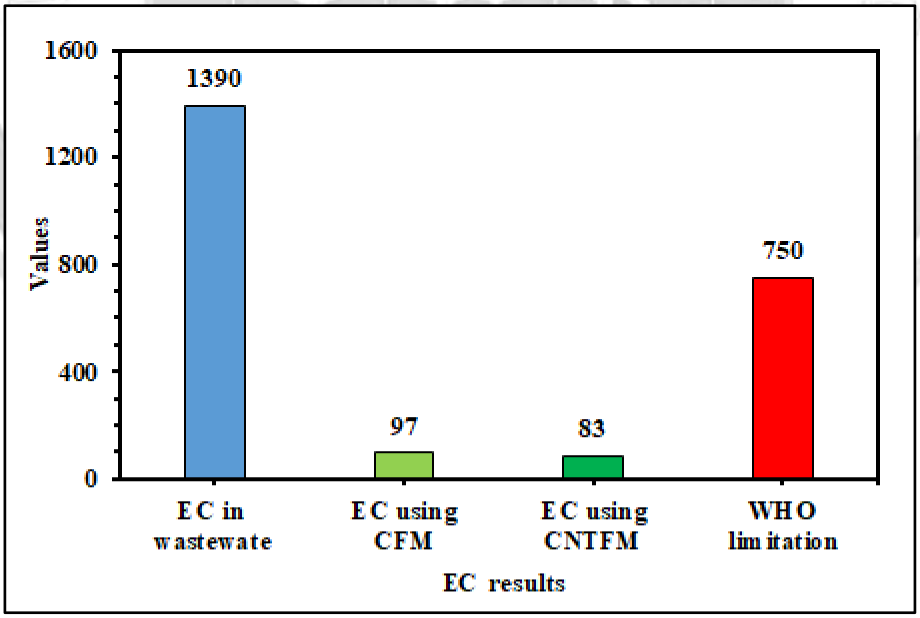

Figure 1: Concentration of EC in petroleum wastewater, CFM, CNTFM and limitations

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3.2. Turbidity

Table 2, and Figure 2 shown he turbidity values were recorded during the study period, is (36.2 N.T.U), which ranged before the treatment process compared to its average after the treatment process using the CNTFM and CFM with values ranging between (2.2, 1.1 U.T.N) respectively. This difference in the turbidity values is due to the organic plankton (colloids and the like) in addition to the presence of many particles and plankton before treatment, which usually drifts with the various washing processes in the treatment plants [27]. A direct relationship between the degree of turbidity and the activity of microorganisms, as microorganisms activate and multiply in a direct proportion to the concentration of plankton in the water [28]. As a result of its stagnation for a long time. When using RO filters, all the previous reasons that caused the increase of turbidity were exceeded, this explains the significant decrease in the number of turbidity units.

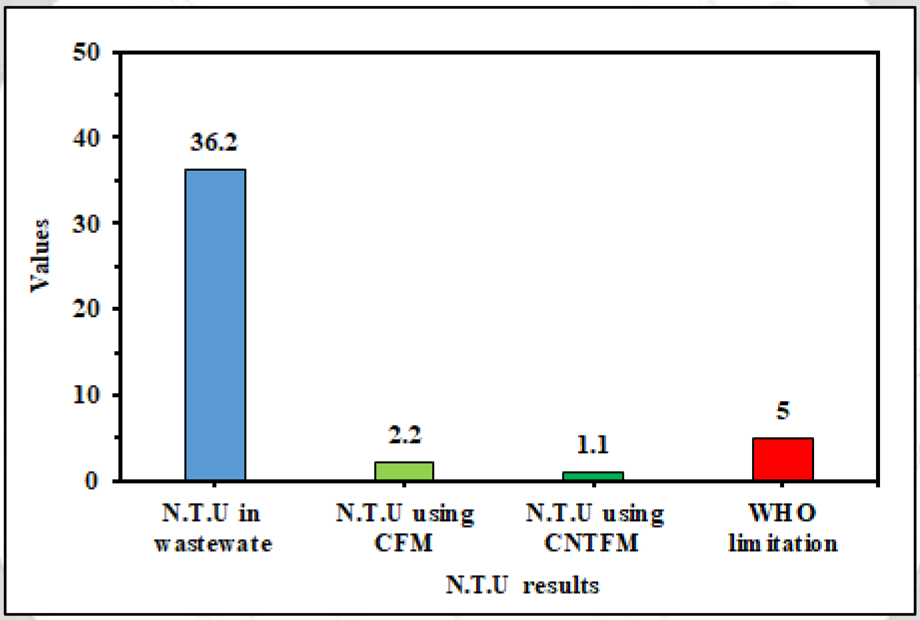

Figure 2: Concentration of N.T.U. in wastewater, CFM, CNTFM and limitation

3.3. pH

Table 2, and Figure 3 shown the value of the acidity function before the treatment is about (8.7), compared to its values after the treatment, which were (6.4 - 6.2) as shown in (Figure 4) for the CFM and CNTFM respectively, where the values were Acceptable and within the standards. As for the reasons for the acidity function, it is due to the dismantling of organic matter by microorganisms, which will release carbon dioxide gas, which works to balance the acidity function or the tendency towards alkalinity when forming bicarbonates, as the value of the acidic function Naturalness depends on the balance between CO2, bicarbonate and carbonate [29].

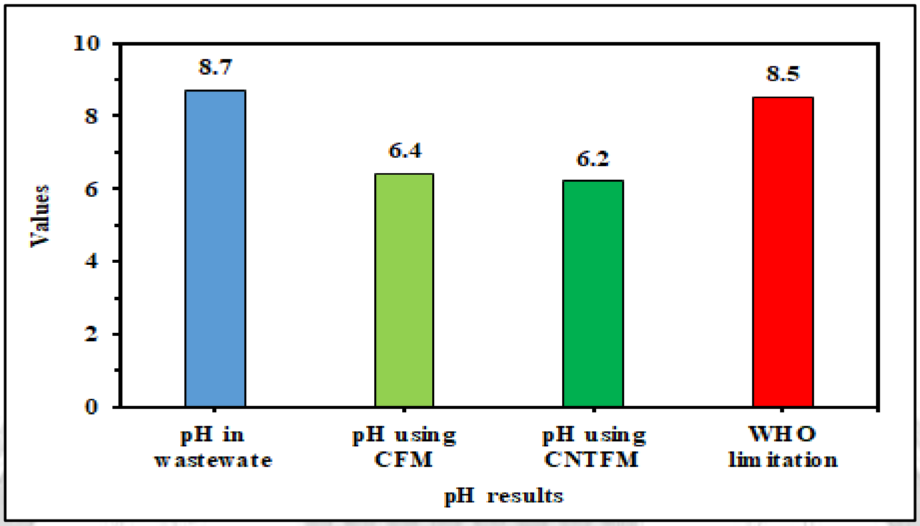

Figure 3: Concentration of pH in petroleum wastewater, CFM, CNTFM and limitation

3.4. Calcium and magnesium

Table 2, and Figure 4 shows that the hardness rates before the treatment process amounted to (168 mg / L) in terms of calcium carbonate, while the values of calcium hardness was (73 mg / L) and the values of magnesium hardness was (188 mg / L), while the three types of hardness after the treatment by RO Membranes process amounted to (4.3, 1.1) mg/liter in terms of calcium carbonate, for CFM and CNTFM, respectively. The difference in the values of the rates may be due to the nature of these subtractions or to the decomposition processes as a result of the presence of microorganisms on the organic materials and that led to the liberation of CO2, which it will interact with water. It is noted that the behavior of the calcium ion is similar to that of the magnesium ion [30].

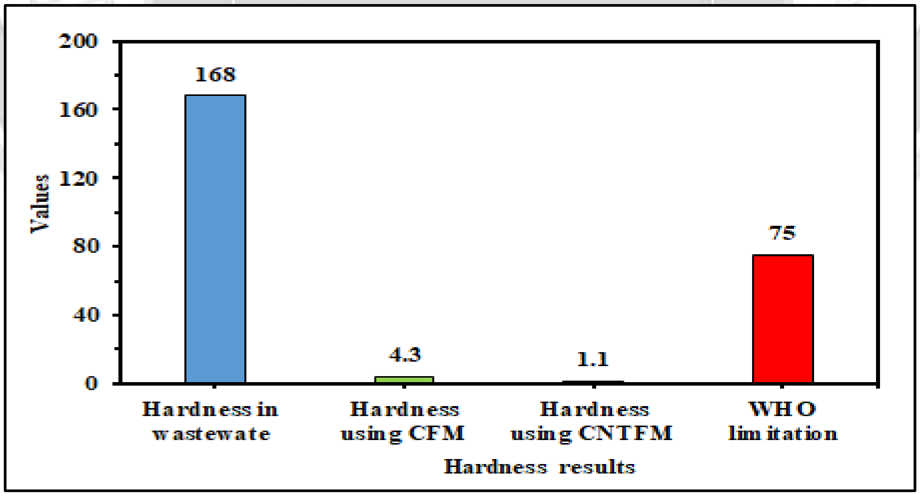

Figure 4: Concentration of hardness in wastewater, CFM, CNTFM and limitation

3.5. Sodium and potassium ions

Table 2, and Figures 5, 6 shown the concentrations of sodium and potassium ion which were (39 and 182 mg/L) respectively. Before the treatment process, while the concentrations of these two ions after the treatment process using the CFM and the CNTFM for sodium (2.1 and 2.61 mg/L) and potassium (0.113 and 0.108 mg/L) respectively. The difference is normal, and this is due to the fact that the concentration of sodium ion is often higher than the concentration of potassium ion, because pollutants from the oil industries and their refineries play a major role in raising the values of sodium and potassium salts of oil, plankton, sulfur compounds and sodium in particular [31].

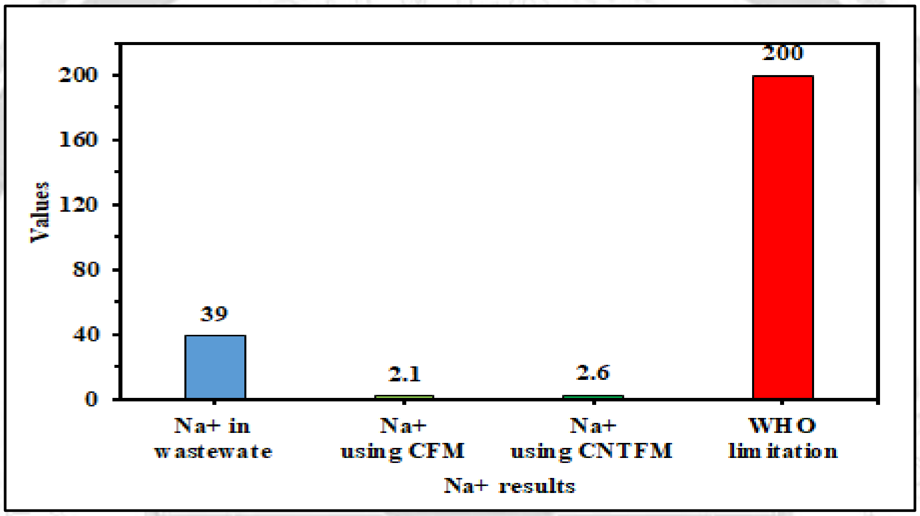

Figure 5: Concentration of Na+ in wastewater, CFM, CNTFM and limitation

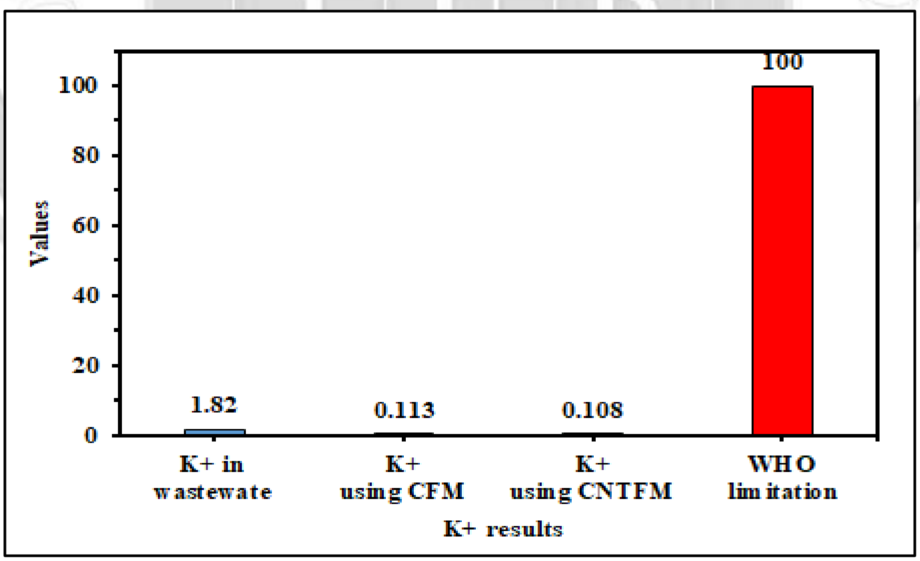

Figure 6: Concentration of K+ in wastewater, CFM, CNTFM and limitation

3.6. Sulfate

Table 2, and Figure 7 shown the sulfate concentration was (96.353 mg/L) before the operation. The treatment, compared with its concentrations after the treatment process, as its values were (9.15 mg/L) for the CFM and its concentration (4.416 mg/L) for the CNTFM as shown in Figure 7. This increase in the original values may be due to the high sulfur content in Al-Qayyarah oil. This is characterized by this area, which makes it a major obstacle to its industrial exploitation due to the high economic cost required by the treatment process. This problem can be solved by using carbon or ceramic reverse osmosis membranes to benefit from it economically, as the significant decrease in the percentage of sulfates was observed to the limits and standards accepted locally and internationally [32].

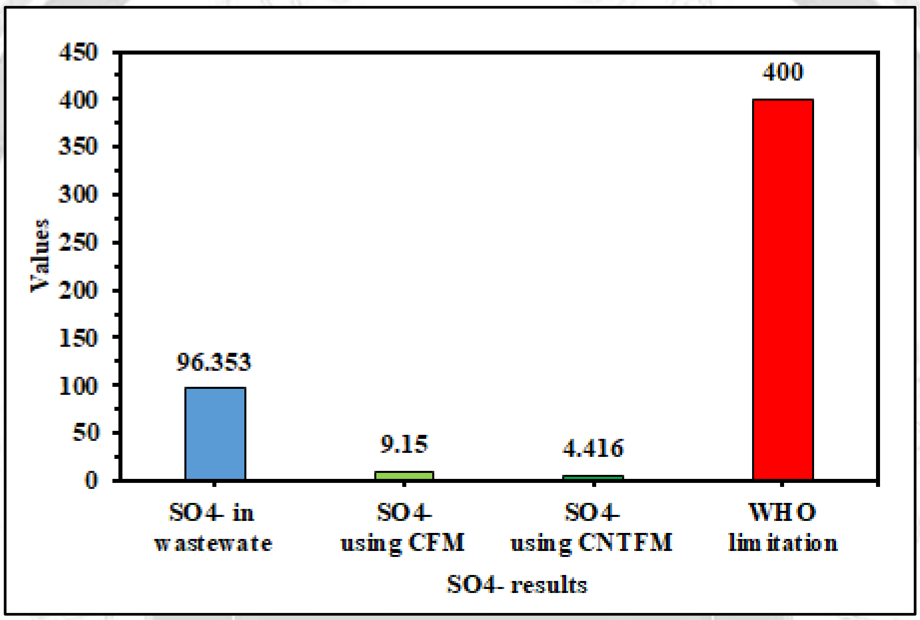

Figure 7: Concentration of SO4- in wastewater, CFM, CNTFM and comparisons with limitations

3.7. Phosphate

Table 2 and Figure 8 shown that the highest concentration of phosphate before the treatment process was (0.962 mg/ L) before the membrane treatment, while the concentration of phosphate after the treatment process reached (0.081 mg/ L) after treatment using CFM. It reached (0.002 mg/L) using CNTFM, as shown in Figure 8. These concentrations are less than the standards of the World Health Organization, which are about (2.0 mg/L). The main source of phosphate is phosphorous, which often increases when using detergents and their derivatives, and due to the lack of use of these detergents and their dissolution with the rest of the excretions in this water, which was reflected in the low concentration of phosphate in them [33], as well as the efficiency of the membranes in the treatment process, which made the concentrations very low.

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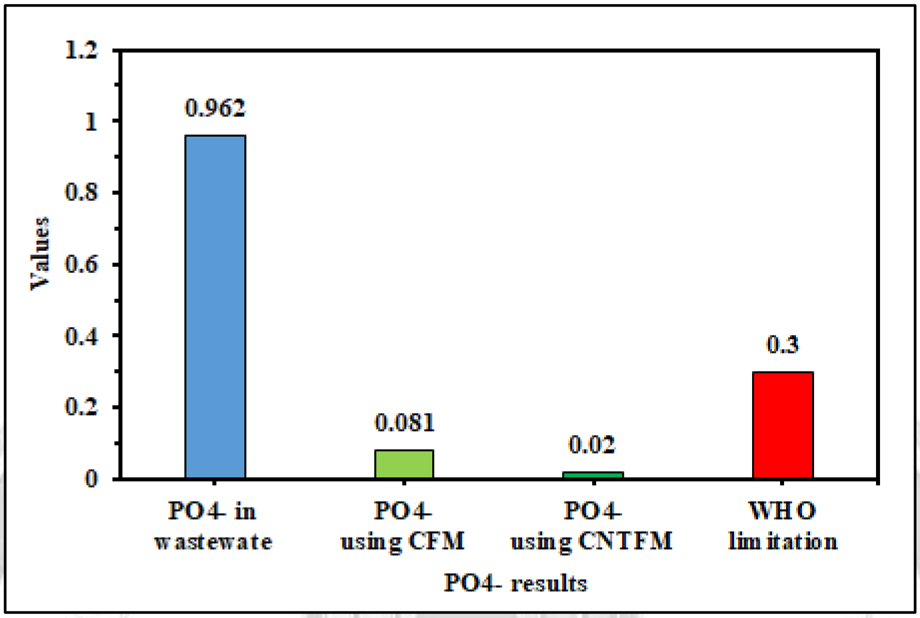

Figure 8: Concentration of PO4- in wastewater, CFM, CNTFM and limitation

3.8. Nitrates

Tables 2 and Figure 9 shown the concentrations of nitrates before the membrane treatment process were approximately (3.736 mg/L) and it was (0.34 mg/L) after the treatment process using CFM, and that the concentration of nitrates after the treatment process was (0.06 mg/ L) using CNTFM, and this is expected due to the nature of the waste that contains high concentrations of nitrogenous substances resulting from organic materials, whose decomposition by microorganisms leads to an increase in these compounds [34]. However, the use of membrane technology may eliminate this problem completely, making it an ideal solution to treat this type of pollutants.

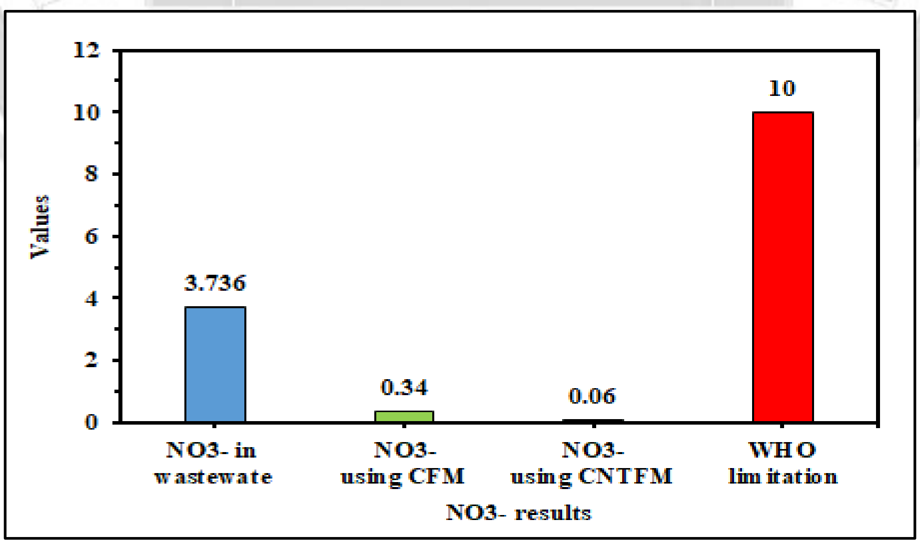

Figure 9: Concentration of NO3- in wastewater, CFM, CNTFM and limitation

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3.9. Heavy metals

Table 2 and Figures 10, 11, 12, and 13 shown the results the concentration rates of lead, cobalt, cadmium and copper amounted to (1.827, 0.073, 0.1423, 0.614 mg/L) respectively, before the treatment process, using membrane calculations, while their rates after the ceramic membrane treatment process were (0.0449, 0.0031, 0.00443, 0.031 mg/L) respectively and using carbon nanoparticles (0.0016, 0.00041, 0.00255, 0.004 mg/ L) respectively. The term heavy metals mean metals with a density of more than 5 g / cm, which are elements found in nature and which have toxic effects to a certain degree [28]. The atomic weight ranges between 63.545 and 200.5 grams and they are also called toxic metals. Heavy metals are found in water to a large extent with a concentration of calcium and magnesium (hardness), so the permissible concentrations depend on their presence on the hardness factor [35], and many studies have proven that the toxicity of both zinc and cadmium increases as the pH value increases from 5 to 9 when the ratio of calcium and magnesium is fixed, and this fact contradicts what is commonly known that the toxicity of metals related to the degree of solubility of mineral salts and that a higher pH value reduces the toxicity. The final fate of heavy metals in water is their adsorption on plankton or in the form of sediments in the sediments of the water source, so studies must depend in large part on measuring the concentration of heavy metals in the sediments, but some factors may affect the re-dissolving of these elements and their return to water again, and among these factors is the acidic function [30], while he notes how the ceramic and carbon films work to permanently get rid of the high concentrations of these minerals, making the disposal of treated water a safe process.

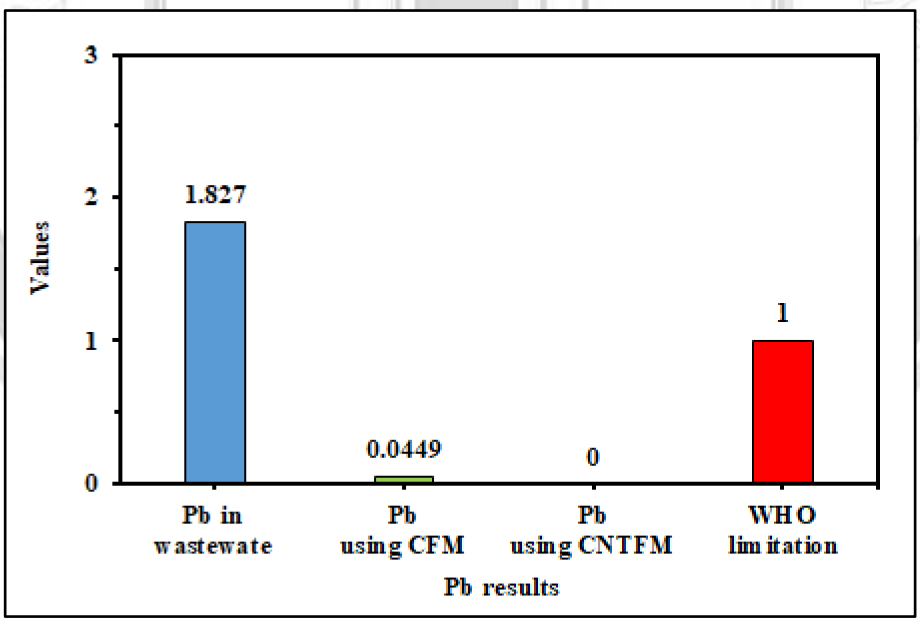

Figure 10: Concentration of Pb in wastewater, CFM, CNTFM and limitation

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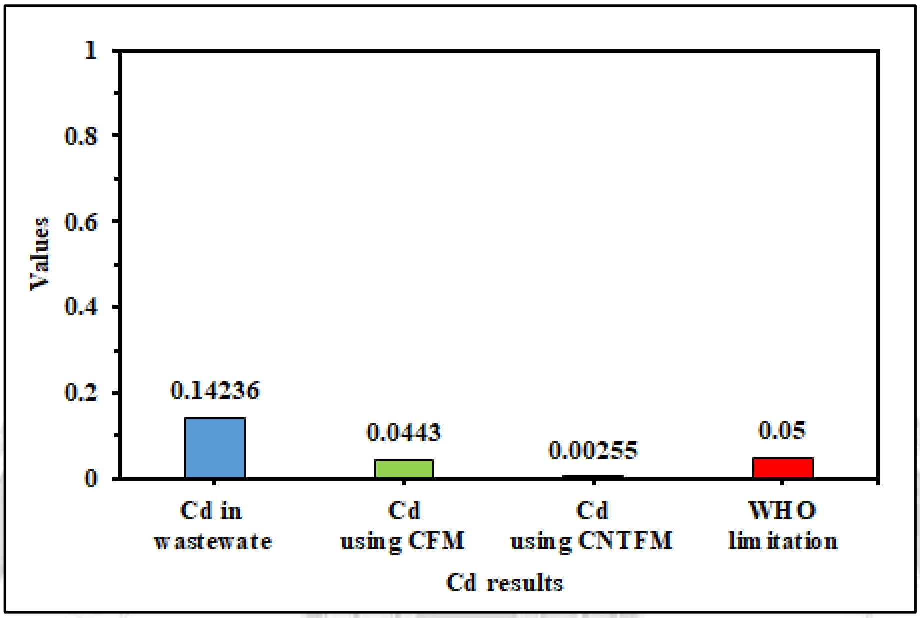

Figure 11: Concentration of Cd in wastewater, CFM, CNTFM and limitation

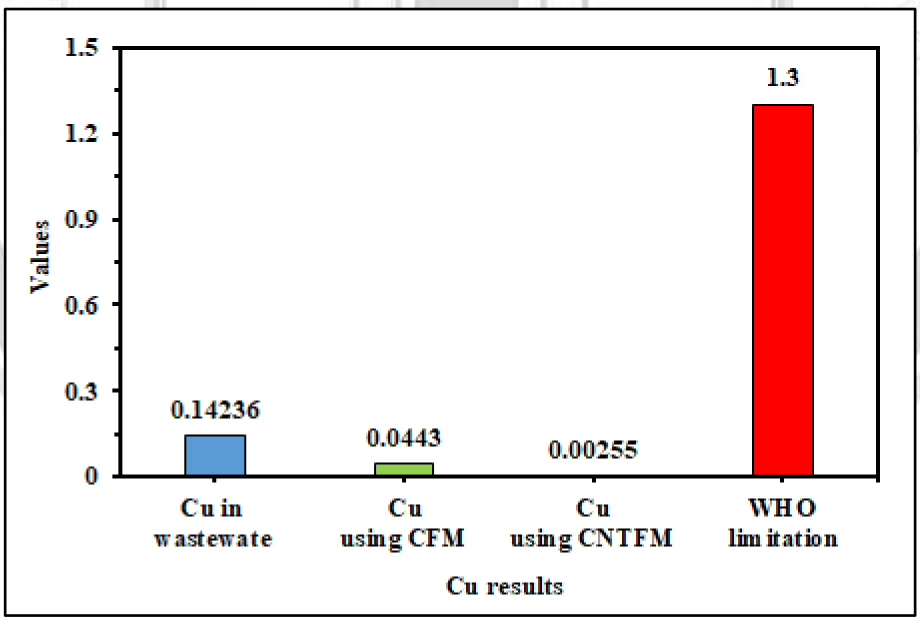

Figure 12: Concentration of Cu in wastewater, CFM, CNTFM and limitation

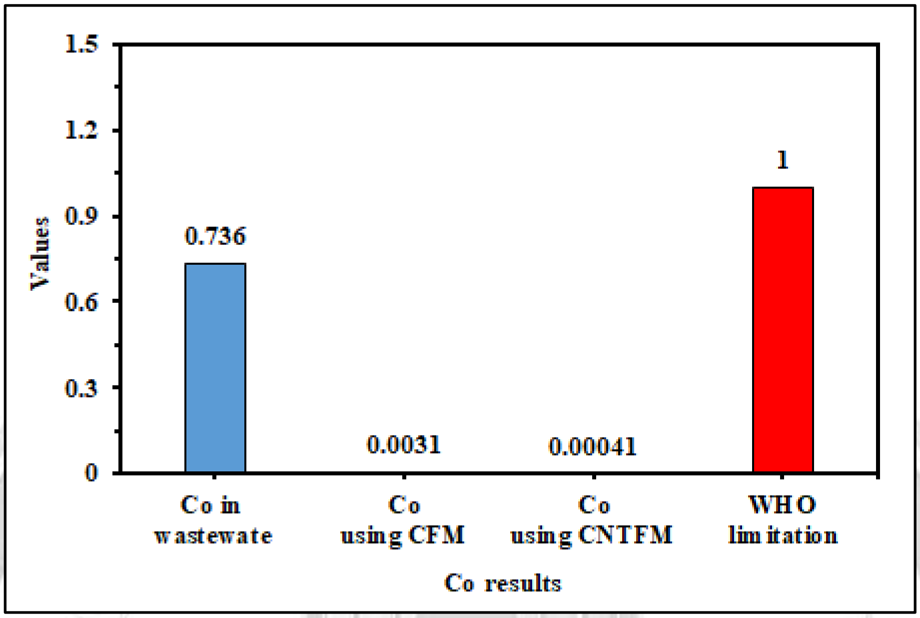

Figure 13: Concentration of Co in wastewater, CFM, CNTFM and limitation

3.10. Chemical oxygen demand

Table 2 and Figure 14 show the values of the chemical oxygen Demand were (193) mg/L before the treatment process, while its value after treatment using CFM and CNTFM was (9.34 and 7.861) mg/L, respectively, that this concentration before treatment, it is due to the nature of these excretions in the refinery, which are organic and inorganic substances, as these substances are naturally demanding on oxygen from the organic load and the reduced and drained inorganic compounds with the refined excretions from various production units and laboratories [36]. While we see that the membrane treatment reduces the demand for oxygen in a very large way compared to the traditional methods.

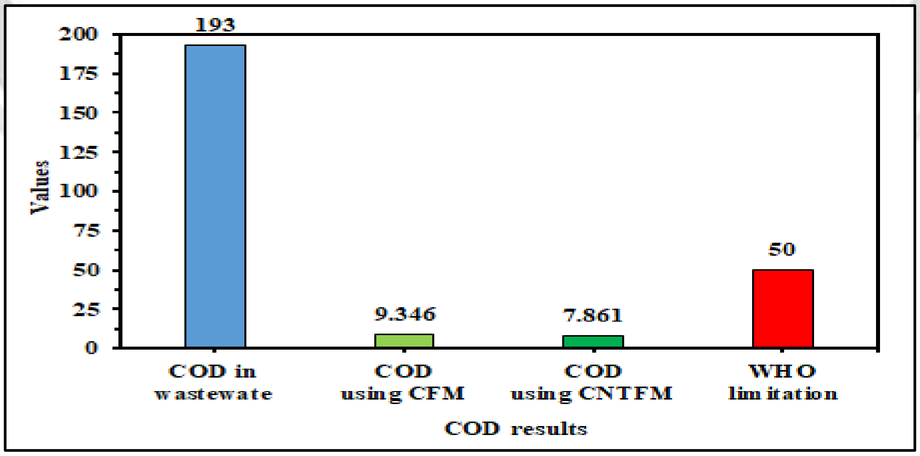

Figure 14: Concentration of COD in wastewater, CFM, CNTFM and limitation

3.11. Oils and grease

Table 2 showed the oil concentrations exceeded the standards specified by the Iraqi environment before the treatment process, reaching (23.61) mg / liter, while the oil concentrations decreased significantly after the treatment process, as the values were using 0.2 mg/liter for CFM and 0.5 mg/liter for CNTFM, as this rise in Figure 15 concentrations before the treatment process is due to the quality and nature of these wastes, which of course contain a lot of oils and greases, a small part of which is dissolved in water and another part settles at the bottom after losing. The volatile parts of them where their density becomes higher than the density of water due to the survival of the large and non-evaporable organic chain, while the largest part of them remains floating above the surface of the water [37], while the removal is complete by using ceramic membranes and carbon membranes.

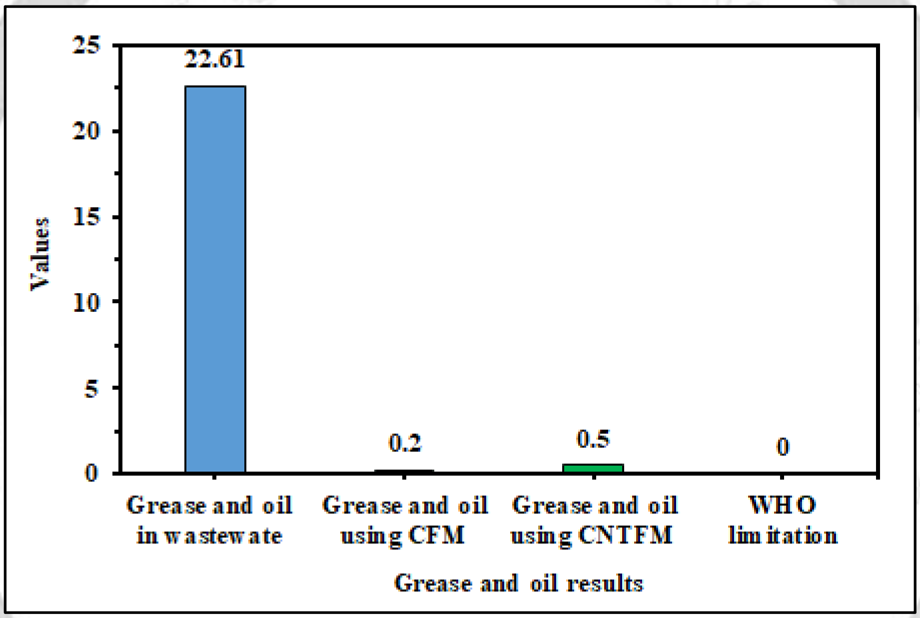

Figure 15. Concentration of grease and oil in petroleum wastewater, CFM and CNTFM and comparisons with limitation

3.12. The total number of bacteria

Table 2 showed that the number of bacteria reached (870) cells/ml, and this indicates the absence of any actual treatment process as shown in Figure 16. Therefore, the number of bacteria increases after treatment due to the presence of organic materials and nutrients that promote the growth of bacteria and increase their numbers as shown in the results [38], while if we compare it with its numbers after the treatment process, it reached (27 and 39 cells/ml), using the technique of CFM and CNTFM.

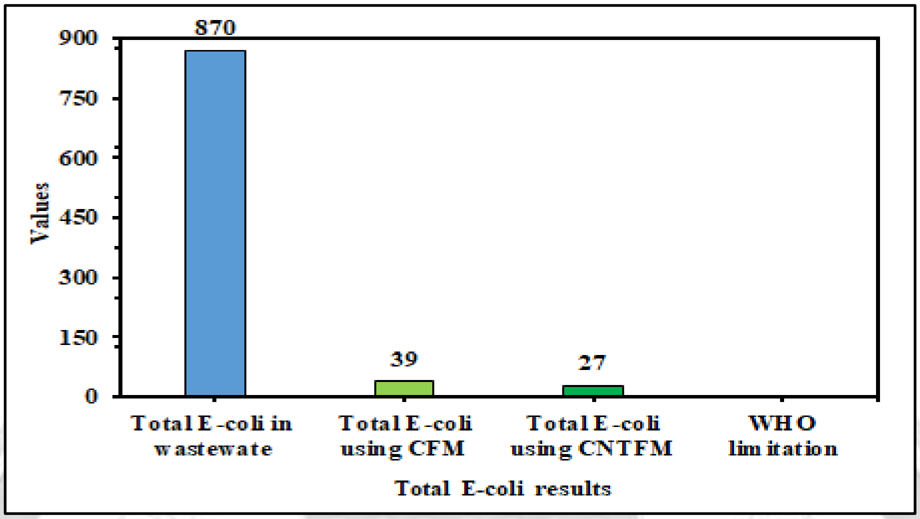

Figure 16. Concentration of Total E-coli in petroleum wastewater, CFM and CNTFM and comparisons with limitations

A comparison will be made between the applicable types of treatment and the treatment by membranes using Carbon Nano Tube Filtration membrane and Ceramic Filtration membrane by comparing the specifications resulting from each type of treatment and for the same characteristics. The research proves that the CNTFM is more efficient in terms of treatment and the CFM is stronger of texture and longer working life Table 3, and Figure 17.

Table 3. The compositions present in wastewater and the Efficiency of CFM& CNTFM.

Composition of Each Element	Composition in Petroleum Wastewater	The efficiency of CFM%	The efficiency CNTFM%
PH	8.7	26.4	28.7
EC	1390	93.0	94.0
Ca^{+2}	73.7	90.5	94.0
Mg^{+2}	188	93.5	94.4
Na^{+}	39	94.6	93.3
K^{+}	1.82	93.8	94.1
COD	193	95.2	95.9
SO_4^{-}	96.353	90.5	95.4
NO_3^{-}	3.736	90.9	98.4
PO_4^{-}	0.962	91.6	99.8
Cu	0.614	95.0	99.3
N.T.U	36.2	93.9	97.0
$Caco_3$	168	97.4	99.3
Co	0.0736	95.8	99.4
Pb	1.827	97.5	99.92
Cd	0.14236	96.9	98.2

Total E-coli (cell/ml)	870	95.5	96.9
grease and oil	22.61	99.1	97.8
Average Efficiency of each Filter		90.61	93.10

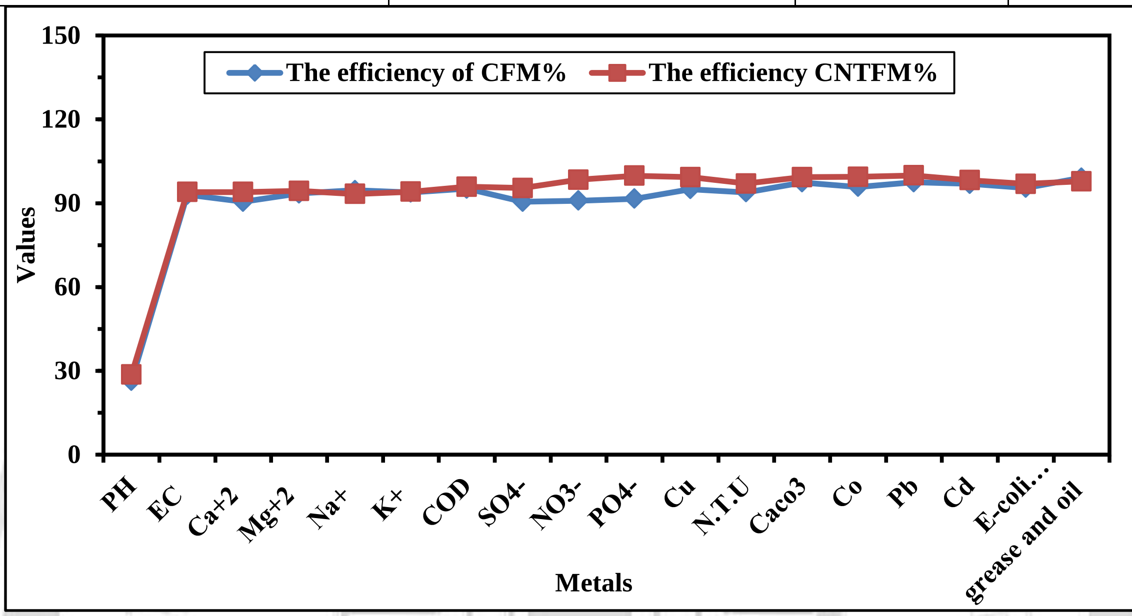

Figure 17: The comparison of removal efficiency of CFM with CNTFM

4. Conclusions

1. The results showed the inefficiency of the plant (the treatment plant) in removing pollutants, as no actual treatment operations are carried out in the plant except the process of skimming fats and oils, and no chemical substance is added for the purpose of treating the water leaving the filter, i.e. there is no type of treatment process on the outflowing water from the filter.
2. The results obtained through the use of reverse osmosis (RO) membranes fully show the efficiency of these membranes in removing all kinds of pollutants, getting rid of turbidity and removing fats and oils.
3. The ceramic membrane is stronger and more durable in work than the carbon membrane and the Carbon Nanotube membranes is better than ceramic membranes with approximately 93.1% and 90.6 for Ceramic filtration membranes.
4. The removal of oil and grease compositions was completely in both types of films and amounted to approximately 98.5% to 99%. All these data are well less than the thresholds for reuse in agriculture or to release into the environment. The results are stable, and no evidence of high levels of concentrations is found over the experimentation period (three months for the RWWTP).
5. The research concluded that the treatment of refinery wastewater by RO filtration membranes is very effective in producing acceptable quality water that can be reused in the CWS

(cooling water system) of the refinery or released to water streams, and it is more effective than the traditional treatment plant.

6. It is recommended to implement the CFM and CNTFM filtration unit as a final polishing stage before cooling-water reuse to reduce primary water withdrawal and align with refinery sustainability goals. Moreover, explore combining CFM and CNTFM in a sequential or composite configuration, ceramic for pretreatment, and CFM for polishing/desalination to achieve both durability and high selectivity.

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ARTICLE

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مـــجلــة جـــامعة بـــــابـل للعلــــوم الهندسية

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استخدام تقنية الترشيح بأنابيب الكاربون النانوية واغشية الترشيح الخزفية لإزالة الاملاح من مطروحات مصافي النفط

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الخلاصة

تم تقييم أداء نوعين من أغشية التناضح العكسي(RO) ، وهما غشاء الترشيح الأنبوبي النانوي الكربوني (CNTFM) وغشاء الترشيح الخزفي(CFM) ، في هذه الدراسة من خلال مقارنة كفاءة إزالة المحطة التقليدية في المصفاة وكفاءة إزالة التناضح العكسي، بعد تتبع انسيابية مياه الصرف الصحي المعالجة في محطة معالجة مصفاة القيارة. في كلا الغشائين، المياه المعالجة لها درجة حموضة 6.4، 6.2، الرصاص0.0449 ، 0.0016، الكادميوم0.00443 ، 0.00255، النحاس 0.00443، 0.00255، الكوبالت0.0031 ، 0.00041، البكتيريا القولونية 39، 27، الموصلية الكهربائية أقل من 97، 83 ميكروسيمنز/سم، الكبريتات أقل من 9.15، 4.416 جزء في المليون، الطلب الكيميائي للأكسجين أقل من 9.346، 7.861 جزء في المليون، كربونات الكالسيوم أقل من (4.3، 1.1 ملغ/لتر)، الصوديوم2.1 ، 2.61 جزء في المليون، والنيتروجين الكلي أو النترات أقل من 0.34، 0.06 جزء في المليون، أورثوفوسفات0.081 ، 0.002، كبريتات9.15 ، 4.416 لـ غشاء الترشيح الأنبوبي النانوي الكربوني (CNTFM) وغشاء الترشيح الخزفي (CFM) ، على التوالي. وخلصت الدراسة إلى أن CNTFM أكثر كفاءة ، وأن CFM يتمتع بملمس أقوى وعمر عمل أطول. ومن المتوقع أن تؤدي استراتيجية المعالجة المقترحة إلى تحقيق انخفاض كبير في كمية المياه في سحب المياه الأولية المستخدمة في المصفى نتيجة لإعادة استخدامها في نظام التبريد .

الكلمات الدالة: التناضح العكسي، مادة الغشاء، تحلية المياه، غشاء الترشيح الخزفي، غشاء الترشيح الأنبوبي