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Effect of Temperature and Total Dissolved Solids on thePerformance of Activated Sludge Process for Oil Refinery Wastewater: Case Study

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Abstract

This study was carried out to assess the performance of the activated sludge process (ASP) for the treatment of oil refinery wastewater. Seasonal variation for temperature and the total dissolved solids (TDS) of wastewater were the key parameters examined. The treatment system is a batch-laboratory column that is continuously fed with oil refinery wastewater after physical separation of the surface oil layer in the refinery (API Separator). The determination of optimum operating conditions was performed for the treatment system at different temperatures ranging from 20 °C to 35 °C. Two main groups were examined: fresh wastewater (Group A) had an average TDS of less than 3 g/L, and saline wastewater (Group B) had an average TDS of 10–15 g/L. Results indicated that removal percentages in fresh wastewater (Group A) for chemical oxygen demand (COD), biological oxygen demand (BOD), oil and grease (O&G), phenols, and total suspended solids (TSS) were (76%–83%), (80.9%–92%), (83.5%–100%), and (94%–100%), respectively, while removal percentages in saline wastewater (Group B) for COD, BOD, O&G, phenols, and TSS were (76%–81%), (85.3%–95.8%), (87.5%–90%), (100%), and (93%–92%), respectively. The highest removal efficiency for pollution parameters was obtained at an average temperature of 25–35 °C. In conclusion, the overall treatment efficiency of fresh wastewater is better than that of saline wastewater. The quality of treated effluents achieved complies with the permissible limits of Egyptian regulations. Finally, ASP is efficient for the oxidation of organic matter applied to oil refinery wastewater with similar characteristics.

Keywords*:* Activated sludge; aerobic biodegradation; oil refinery wastewater; temperature; total dissolved solids.

1. Introduction

The petroleum refinery sector is a giant industry that produces crucial stuff used for anthropogenic activities such as production plants, transportation, and construction processes. Petroleum refineries generate essential products like diesel, kerosene, lubricants, gasoline, jet fuel, and liquefied petroleum gas, which may be used as is or used for the synthesizing of other new products such as agrochemicals, synthetic materials, and plastics [1]. The need for petroleum and other energy resources has increased because of rapid worldwide economic development and the massive increase in population growth. By 2050, global energy use is expected toincrease by 50% compared with 2020 [2]**.** Water is an essential constituent in the refining of crude oil. Several operations involving distillation, desalination, thermal cracking, catalytic treatment processes, washing, and cleaning require huge amounts of water.The amount of wastewater generated by all of these processes is 0.4−1.6 times greater than the total amount of crude oil handled [3]. The increased water requirement for the oil industry is considered a great challenge in Egypt due to water scarcity. The total renewable water resources have declined in 2017 to about 628 m^3/year/capita, which is below the water scarcity level [4]. Wastewater treatment and the reuse of treated effluent in refining processes, such as water needed for cooling towers, is considered a sustainable and reliable source of water [5]. Large amounts of wastewater are produced during the refining process, which often contains many types of pollutants. The composition of oil refinery wastewater differs according to the crude oil quality. It mainly contains hydrocarbons, phenols, organic matter, ammonia, and sulphides [6]. These pollutants may lead to aquatic environmental pollution if they are discharged directly into water streams without treatment [7].Generally, there are different available techniques applied to oil refinery wastewater treatment (physical, chemical, and biological). Biological treatment is a popular method used for the degradation of organic matter and to increase the possibility of wastewater reuse. According to the availability of oxygen, there are two main biodegradation methods: aerobic and anaerobic. These are carried out by the action of microorganisms, which are responsible for the degradation of wastewater to produce carbon dioxide and water [8] and [9]. The most widely used technique for petroleum refining

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wastewater is the aerobic process by activated sludge, where flocks of microorganisms and wastewater are found in suspension and contacted with each other for treatment. The second type is the fixed film process, where biologically fixed films are attached to support wastewater treatment [10]. Despite the high efficacy of aerobic treatment, some limitations have been reported, such as the high amount of sludge produced and the high consumption of energy due to the aeration process [1]. The activated sludge process for refinery wastewater could remove about 95–97% of COD, 88–95% of BOD, and 98–99% of phenol [11].Gasim et al. [6] reported that 87% of organic matter in the form of COD was removed from 2582 mgO_2/L petroleum refinery wastewater with a residual value of 140 mgO_2/L by the extended aeration process. Also, in the same study, they reported that phenol didn't hinder the aeration process up to 0.49 mg/L in the influent wastewater. However, some chemical and physical limiting factors affecting the biodegradation of petroleum hydrocarbons have been reported [12]. The first important factor is the composition and inherent biodegradability of the petroleum hydrocarbon pollutants. On the other hand, physical factors such as temperature and salinity are of great importance in hydrocarbon biodegradation because they affect the chemistry of the pollutants directly as well as the physiology and diversity of the microbial flora [12]. The volatility of the toxic low-molecular-weight hydrocarbons is reduced, while the viscosity of the oil increases at low temperatures, resulting in a reduction in the biodegradation rate [13]. At temperatures ranging from 30°C to 40°C, the hydrocarbon metabolism rate reached its maximum level [14]. Salinity also has a great effect on the biodegradation process by affecting both microbial growth and diversity [15]. Therefore, the aim of this study is to assess the effect of temperature and total dissolved solids on the efficiency of biodegradation by using the activated sludge process for oil refinery wastewater.

2. Materials and Methods

2.1. Sampling campaign

Composite wastewater samples were received from different sites for oil refinery wastewater (influent), allocated in the Suez Canal, Al Qalyubia, and Alexandria Governorates, Egypt.Here, the refineries use either fresh water from the nearest water source (samples obtained from Alexandria and Al Qalyubia) or saline water from the nearest seawater (samples obtained from Suez Canal).The samples collected were stored in glass containers in an ice box and transported to the National Research Centre for analysis and carrying out the experimental runs. The treated effluents andsludge samples from the batch laboratory were also analyzed.

2.2. Experimental set-up

Four batch-laboratory plexiglass columns similar to those used by Fawzy et al, [9] were utilized to evaluate the performance of the activated sludge process for treating oil refinery wastewater. Fig. (1) shows a flow diagram of the treatment process. The three columns were run at the same time to compare the performance of groups A and B under varying temperatures, while one column was operated to be used as a control in case of any failure.

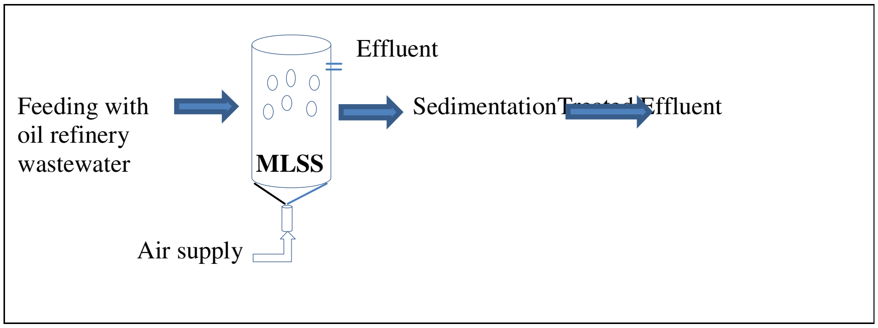

Figure (1): Flow diagram of the treatment process

2.3. Bioreactor operation

At first, the columns were fed with pre-aerated sludge which is obtained from Zenin Wastewater Treatment Plant (WWTP), Giza, Egypt. The initial concentration of mixed liquor suspended solids (MLSS) was about 3-4 g/L containing almost 75% of volatile matter. An aerator was used to provide a constant air flow rate (3 L/min) with minimum dissolved oxygen concentrationof (2-3 mg/L). The COD, Total Kjeldahl Nitrogen (TKN), and Total Phosphorus (TP) (C: N: P) concentration ratio was adjusted to be 100:5:1 according to Burton et al, [16]. To compensate any nutrients deficiency, ammonium dihydrogen phosphate ($NH_4H_2PO_4$) was added. Oil refinery wastewater was gradually added to the aerated columns of sludge adaptation. The feeding ratio of sewage water to oil refineries wastewater was started by 75%: 25%, then this ratio decreased gradually to 50%: 50%, then 25%: 75%, and finally, full feeding of oil refinery wastewater (100%) was added till achieving a steady state which indicated by measuring of residual COD (> 60 % removal or constant removal rates). The acclimatization period was about 21 days under continuous operation. Then, a growth rate experiment was carried out to determine the optimum retention time needed for biodegradation. The treated effluents were withdrawn from the laboratory columns after stopping the air supply and settling for one hour, then withdrawn for analysis. Moreover, within the aeration process, the sludge samples were withdrawn for microscopic examination and analysis.

2.4. Physico-chemical analysis

The samples collected were analyzed for various physical parameters including odor, pH (measured using pH meter - Jenway, 3510), total suspended solids (TSS) determination according to method (2540-D), and total dissolved solids (TDS) using a TDS meter (Jenway, 3510).Chemical properties such as biochemical oxygen demand (BOD) weremeasured according to method (5210-B), chemical oxygen demand (COD) wasmeasured using the dichromate method (5220-D), oil & grease was measured using the gravimetric partitioning method (5520-B) and phenol was determined by the direct photometric method (Method 5530-D) [17]**.**Sludge samples from the aerobic treatment unit were also analyzed for TSS and Volatile Suspended Solids (VSS). Additionally, microscopic examination was conducted during the study period [17].

2.5. Statistical analysis

Descriptive statistical functions, namely, average concentration and removal percentage, were calculated using the 2013 version of Microsoft Excel. Averages and standard deviations (SD±) were calculated using commercially available software (SPSS version 16.0).

3. Results and Discussion

3.1. Wastewater characterization

The characterization of groups (A) representing fresh water and (B) representing saline water is shown in Table 1. The results differ according to the water sources used for the refining process. It is obvious that the pH values of the two groups (A and B) varied from 6.44 to 8.5, which is favorable for the activated sludge process to take place. The results for group (A) have a minimum value of 540 mg/L and a maximum value of 2804 mg/L for total dissolved solids (TDS). Oil refinery wastewater is contaminated with organic pollutants presented in the form of COD and BOD, with an average concentration of 199.67 and 63.3 mg O_2/L, respectively. The ratio of BOD to COD (biodegradability index) was obtained; it varied between 0.32-0.44, which indicates efficient biodegradation. The TSS value ranged between 2 mg/L and 204 mg/L with an average concentration of 74.67 mg/L, and the content of oil and grease reached 18 mg/L. Also, the results showed that the total nitrogen (1.6 mgN/L) and total phosphorous (0.79 mgP/L) were not sufficient, and additional sources of nutrients were supplied to enhance the growth of microorganisms needed for efficient biodegradation of organic matter. While the phenol content ranged between 0.32 and 0.9 mg/L, which didn't affect the microbiological oxidation process for activated sludge. The average concentrations of cadmium, lead, silver, copper, nickel, tin, and arsenic were below the permissible limits, and the values detected were 0.05, 11, 0.5, 165, 1.7 and 0.5 µg/L. On the other hand, group (B) shows the data of oil refineries from saline origin with a minimum value of 1000 mg/L and up to 14320 mg/L TDS. Group (B) results indicated a wide variation in oil refinery wastewater quality. The wastewater had an aromatic odor; COD ranged from 195 to 409 mgO_2/L, while BOD ranged from 58 to 218 mg O_2/L, with mean values of 95 mg/L, 23.85 mg/L, and 2.165 mg/L for TSS, oil & grease, and phenol, respectively. Also, traces of heavy metals were detected with similar concentrations in fresh water for cadmium, silver, tin, and arsenic except for lead, copper and nickel with average values of 39, 30, and 208 µg/L, respectively. The significant variation is mainly due to variations in crude oil quality and the complexity of processes in the oil refinery, which play a crucial role in the pollution composition of refinery discharge [6][18]**.**

Table (1): Characterization of oil refinery wastewater from different sources

Parameters	**Oil refinery wastewater (Influent)**										
	Group (A)			**Average**	**SD (±)**	**Group (B)**				**Average**	**SD (±)**
TDS, mg/L	540	1000	2804	1448	1196.64	14320	14070	14300	10000	13172.5	2118
pH	7	7.43	6.44	--	0.50	7.6	7.5	7.6	8.5	--	0.47
TSS, mg/L	18	2	204	74.67	112.29	111	80	90	98	94.75	13.10
COD, mgO_2/L	195	158	246	199.67	44.19	409	249	229	195	270.50	94.99
BOD, mgO_2/L	42	78	70	63.33	18.90	218	120	78	58	118.50	71.19
Oil & Grease, mg/L	8	5	18	10.33	6.81	70.6	10	13.8	11	26.35	29.54
Phenol, mg/L	0.6	0.9	0.32	0.61	0.29	2.5	1.8	2.5	1.86	2.17	0.39

**Group A (fresh oil refineries wastewater) – Group B (saline oil refineries wastewater) – SD (standard deviation) – TDS (total dissolved solids) – COD (chemical oxygen demand) – BOD (biochemical oxygen demand) – TSS (total suspended solids).*

3.2. Determination of the operating conditions

The sludge inoculated for the adaptation process was gradually added to oil refinery wastewater in order to prevent the shock of microorganisms with the wastewater constituents. As the biodegradation mechanism in the activated sludge process (ASP) takes place through three consecutive steps, biodeterioration, biofragmentation, and assimilation [9].The adaptation period ranged from 20 to 30 days until almost constant COD removal rates were achieved. The end products of organic substrates are carbon oxide, water, cell biomass and other oxidized materials. This is done by the action of chemo-heterotrophic bacteria, protozoa, metazoa and autotrophic bacteria [19]. Sludge fed to the bioreactors was examined for TSS (3 g/L) and VSS (1.75 g/L). The data indicate the viability of the microorganisms with a good quality of sludge [9]. During the experiments, microscopic examinations of sludge were carried out to ensure the presence of living organisms required for the treatment process. Simple life forms were detected, such as *amoebas* and free-swimming *ciliates*, also multi-celled animals such as rotifers. The presence of these microbial forms in the sludge positively affects the treatment efficiency as they include both eukaryotic and prokaryotic bacteria, which help in wastewater purification [20] [21]. Extended aeration of the sludge (24 h) was performed to estimate the required time needed for the complete degradation of oil refinery wastewater (Groups A and B). It was clear that 86% of COD was removed efficiently within 24 hours for both groups (A and B). Although 83% of organic matter was removed at 18 h, lowering the time to 12 hours for both groups (A and B) does not affect the quality of the treated effluent (82% removal of COD). In conclusion, satisfactory removal rates in terms of COD (> 80%) were attained at 8 hours of operation for Group (A), while more time is required up to 12 hours of operation for Group (B). The selection was based on maximum efficiency with acceptable limits for energy consumption. During the experimental runs, the average concentrations of MLSS and MLVSS in fresh water were 3.4 and 2.1 g/L, respectively. While for saline wastewater, it decreased to 2.89 g/L MLSS and 1.2 g/L MLVSS.

3.3. Performance of activated sludge process

3.3.1. Fresh oil refinery wastewater

The performance of the activated sludge process for oil refinery wastewater obtained from fresh water sources under different temperature ranges is depicted in Table 2. High removal efficiencies for COD, BOD, O&G, TSS, and phenols were achieved after 8h and reached 83%, 92%, 100%, 100%, and 100%, respectively. It was clear that during the four experimental runs (A1–A4), the variation of organic load did not affect the performance of the treatment process, and the residual concentrations for COD varied between 27- 55 mgO_2/L with corresponding BOD values of 5-7 mgO_2/L. Variations in ambient temperature were studied to investigate the performance of ASP in oil refinery wastewater, as shown in Table (2). Starting with run A1 at a temperature range of 20–25 °C, satisfactory removal rates of COD reached 76%. Increasing the temperature from 25 to 30°C enhances the biodegradation process. An increase in temperature of 30–35 °C does not hinder the process. However, above 35 °C, it was noticed that the efficiency of the treatment process decreased by 4.1%. Notably, this was claimed by Norris [22] for the treatment of paper mill wastewater by a laboratory bench-scale ASP system. He found that raising the temperature above 35–45 °C deteriorated the overall efficacy of the ASP process. As the temperature increases as the quality of sludge declines, this is due to the development of filamentous bacteria, changes in the biomass composition, and the deterioration of dispersed single bacteria, which all in turn leads to poor quality and bulking of sludge. Finally, the operation of the AS system is favorable under a temperature range of 25–35 °C for the degradation of low-strength oil refinery wastewater contaminated by low-phenolic content (< 1 mg/L) [22]. These results are in agreement with Tejaswini et al.,[23] where, the maximum removal efficiency was achieved at 30°C. Also, the final treated effluent is in compliance with the permissible limits of Egyptian Environmental Regulation Law 48/1982 concerning the protection of the Nile River and waterways from pollution [24].

Table (2): Performance of activated sludge process using oil refinery wastewater (Group A) at different temperature ranges

Parameters	A1			A2			A3			A4			Permissible limits of Law 48/1982*
	Inf.	Eff.	R (%)	Inf.	Eff.	R (%)	Inf.	Eff.	R (%)	Inf.	Eff.	R (%)	
Temperature, °C	20-25			25-30			30-35			> 35			--
TDS, mg/L	540			1000			2804			2804			--
PH	7	8.5	--	7	8.36	--	6.06	6.96	--	6.44	6.7	--	6-9
TSS, mg/L	18	1	94	2	ND**	100	204	3.6	98.2	204	6.5	96.8	50
COD, mgO_2/L	195	48	76	158	27	83	246	45	81.07	246	55	77.6	80
BOD, mgO_2/L	42	8	80.9	78	5	92	70	7	90	70	7	90	60
Oil & Grease, mg/L	8	ND	100	5	ND	100	18	ND	100	18	3	83.3	10
Phenol, mg/L	0.6	ND	100	0.9	ND	100	0.32	ND	100	0.32	ND	100	0.05

**Egyptian Environmental Regulations Law No. 48 of 1982 concerning the protection of the Nile River and waterways from pollution.The Executive Regulation of this Law was amended by the Minister of Irrigation Decree 92/2013.*

***ND (not detected).*

****A1 (fresh oil refineries wastewater at an average temperature of 20-25 °C) – A2 (fresh oil refineries wastewater at an average temperature 25-30 °C) – A3 (fresh oil refineries wastewater at average temperature 30-35 °C) – A4 (fresh oil refineries wastewater at average temperature > 35 °C) – COD (chemical oxygen demand) – BOD (biochemical oxygen demand) – TSS (total suspended solids.*

3.3.2. Saline oil refineries wastewater

Oil refinery wastewater samples from saline origin with TDS concentrations ranging from 10 to 15 g/L were used to evaluate the performance of the activated sludge process at different temperature ranges, as presented in Table 3. The results showed that the acclimatization period takes more time by 10 days than that in the case of fresh water, and this is attributed to the high content of phenol and TDS. Nutrients were added to encourage the salt-tolerant microorganisms present naturally in the sludge to reproduce. This could be the cause of the high organic removals, although the high TDS concentration in the wastewater. The results, shown in Table (3) reported high efficiency in the removal of COD, BOD, O&G, TSS, and phenols, reaching 81%, 95.8%, 90%, 95%, and 100%, respectively. Also, the final treated effluent is in compliance with the permissible limits of the Egyptian Environmental Protection Regulation (Law 4/1994) concerning the protection of marine watercourses from pollution [25].

Table (3): Efficiency of ASP for oil refinery wastewater of saline origin (Group B) at different temperatures

Parameters	B1			B2			B3			B4			Permissible limits of Law 4/1994*
	Inf.	Eff.	R (%)	Inf.	Eff.	R (%)	Inf.	Eff.	R (%)	Inf.	Eff.	R (%)	
Temperature, °C	20-25			25-30			30-35			> 35			--
TDS, mg/L	14320			14070			14300			10000			--
PH	7.5	7.7	--	7.1	7.5	--	7.5	7.6	--	8	8.5	--	6-9
TSS, mg/L	111	7.6	93.2	80	4	95	90	5.4	94	98	6.2	93.7	60
COD, mgO_2/L	409	98	76	249	47	81	229	48	79	195	45	76.9	100
BOD, mgO_2/L	218	32	85.3	120	5	95.8	78	6.5	93	58	5.8	90	60
Oil & Grease, mg/L	70.6	8.8	87.5	10	1	90	13.8	1.5	89	11	1.2	89	15
Phenol, mg/L	2.5	ND**	100	1.8	ND	100	2.5	ND	100	1.86	ND	100	0.015

** Law No. 4 of 1994 Criteria and specification for certain substances when discharged into the marine environment.*

***ND (not detected).*

****COD (chemical oxygen demand) – BOD (biochemical oxygen demand) – TSS (total suspended solids) – B1 (saline oil refineries wastewater at average temperature 20-25 °C) – B2 (saline oil refineries wastewater at average temperature 25-30 °C) – B3 (saline oil refineries wastewater at average temperature 30-35 °C) – B4 (saline oil refineries wastewater at average temperature > 35 °C).*

3.4. The overall efficiency of oil refinery wastewater treatment by ASP

As seen in Fig. 2, satisfactory removal rates were observed for COD in the temperature range of 25–35 °C for both fresh and saline wastewater, with a maximum reduction of about 83% in fresh wastewater and 81% for saline wastewater; this is similar to that mentioned by Tejaswini et al. [23]. They observed that increasing temperature up to 35 °C improves the removal efficiency. However, the COD removals decreased at temperatures less than 20 °C and more than 30 °C. Consequently, the removal efficiency of BOD in saline wastewater was better than that of fresh wastewater, with average removals of about 95.8% and 92%, respectively. The variation is not too wide. However, the high removal efficiency of BOD in saline wastewater might be due to the high pH level (8.5) as mentioned by Sadeghi et al. [26].They demonstrated that BOD removal efficiency could be improved by increasing pH due to providing a suitable environment for microorganisms responsible for biodegradation. This result is slightly lower than that mentioned by Biswas et al. [27];they removed about 97 % of BOD using the MBBR (Moving Biological Bed Reactor) system for treating municipal wastewater. The best removal values of TSS were obtained at anaverage temperature of 25-35 °C in both fresh and saline wastewater, with a maximum reduction of about 100% in fresh wastewater. The TSS removal rate ranged from 93% to100% in different conditions. Our results were better than those obtained by Xie et al. [28]. They achieved 83% TSS removal using an aerated biological filter process for slightly polluted oil refinery wastewater treatment.

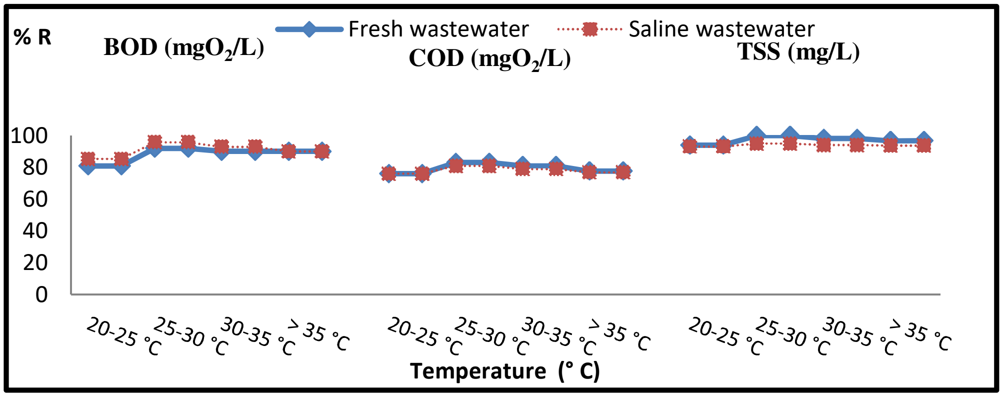

Figure (2): Removal efficiency of organic matters and suspended solids at different temperaturesof oil refinery wastewater

As shown in Fig. 3, the average removal of O&G obtained was 83.3% -100% at different temperatures and salinities, which indicates the high reduction efficiency of the system in various conditions. This exceeds the efficiency mentioned by Wang et al. [29];they reported 72% oil removal from high strength oil refinery wastewater by using an up-flow anaerobic sludge bed (UASB) reactor. The overall efficiency of oil & grease removal in fresh wastewater is better than that of saline wastewater at different temperatures. However, the results of removal in saline wastewater (87.5%-90%) were highly efficient and approximately similar to those ofMokhtari et al. [30].They reported 88% oil removal by using activated sludge followed by a sand filter column.The results also show that the performance of AS is not affected by phenol-contaminated oil refinery wastewater, and complete removal of phenol was achievedat different temperatures,as seen in Fig. 3. This may be due to the low concentration of phenol in the influent, which varies from 0.3-0.9 mg/L in fresh wastewater and from 1.8-2.5 mg/L in saline wastewater.Also, the temperature variation is between 20 °C to slightly above 35 °C. The most widely reported range is between (25 - 35 °C), which is the most appropriate for bioremediation processes [31]. These results comply with the results of Jou and Huang [32], they reported 100% phenol removal using a fixed film bioreactor for the treatment of oil refinery wastewater.Similar to Shabir et al. [33], they also reported 100% phenol removal from oil refinery wastewater using a fed-batch reactor (FBR), followed by coagulation and sand filtration (salinity >0.5%).Siripattan-Raputkdi [34] found that complete removal of phenol was achieved at an initial concentration of 10 mg/L. However, increasing the concentration to 100 mg/L resulted in the toxicity of AS, leading to a severe deterioration of 7.3%. The removal of phenol is attributed to the adsorption of phenol on the flocs of activated sludge, in addition to biodegradation.

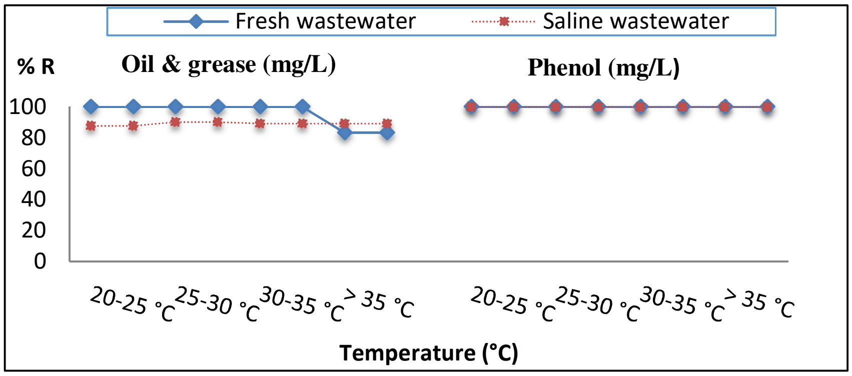

Figure (3): Removal efficiency of oil & grease and phenols at different temperatures of oil refinery wastewater

In conclusion, the overall removal efficiency in fresh oil refinery wastewater was better than in saline wastewater at different temperature ranges. However, the results show satisfactory removal rates in saline wastewater. Our results were better than those obtained by Kargi et al. [35].They reported low removal performance of COD and BOD at high salt concentrations (more than 2%). The quality of treated effluents achieved complies with the permissible limits of Egyptian Regulations. Finally, ASP is capable of removing organic matter, phenols, TSS, and oil and grease applied to oil refinery wastewater with similar characteristics. Short-time temperature variations throughout the day do not have a great impact on the effluent organic concentrations, but significant consequences may occur with long-term variations [36]. Momoh et al. [37] used the modified Monod Kinetic Model for oil refineries wastewater (R^2 value of 0.9745); the results revealed that activated sludge process is appropriate for biodegradation. The specific growth rate affects the rate of substrates utilization in the biodegradation [37], this explain the decline of Total phosphorus (TP) from 40.4 mg/L to 7.05 mg/L and decline of Total Kjeldahl Nitrogen (TKN) from 13.32 mg/L to 4.48 mg/L.

4. Conclusion

Treatment of oil refinery wastewater using the activated sludge process at different temperatures, from 20 °C to more than 35 °C, was effective in the removal of organic contaminants from both fresh and saline wastewater. The determination of optimum operating conditions revealed that 8 h and 12 h are effective for the complete degradation of fresh and saline wastewater, respectively. The maximum organic removals were obtained at an average temperature of 25–35 °C. However, the variations of removals at different temperatures were not wide, so ASP is very effective to be used at different temperature ranges of the year in Egypt. The treatment efficiency was found to be better for fresh wastewater compared to saline wastewater. However, increasing the total dissolved solids (TDS) to an average of 10–15 g/L did not significantly impact organic removal efficiency. Further research is needed to assess the impact of other factors such as pH and organic loads on the system's performance. Additionally, more studies are required to develop methods for treating exhausted sludge before safe disposal or potential reuse.

5. Conflicts of interest

There are no conflicts to declare.

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