

Treatment of Oily Wastewater Produced From Old Processing Plant of North Oil Company

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Abstract

The main objectives of this research were to study and analyses oily wastewater characteristics originating from old-processing plant of North Oil Company and to find a suitable and simple method to treat the waste so it can be disposed off safely.

The work consists of two stages; the first was the study of oily wastewater characteristics and its negative impacts. The results indicated that oil and grease were the most dominant pollutant with concentration range between 1069 – 3269.3 mg/l that must be removed; other pollutants were found to be within Iraqi and EPA standards. The next stage was the use of these characteristics to choose the proper technology to treat that wastewater. This stage was divided into two stages: the first stage was a jar tests to find the optimum doses of alum, lime and powdered activated carbon (PAC). The second stage was the treatment by a batch pilot plant constructed for this purpose employing the optimum doses as determined from the first stage to treat the waste using a flotation unit followed by a filtration-adsorption unit. The removal efficiencies of flotation unit for oil and grease, COD, and T.S.S found to be 0.9789, 0.974, and 0.9933, respectively, while the removal efficiency for T.D.S was very low 0.0293. From filtration – adsorption column the removal efficiencies of oil and grease, T.D.S, COD, and T.S.S were found to be 0.9486, 0.8908, 0.6870, and 0.7815, respectively. The overall removal efficiencies of pilot plant were 0.9986, 0.8939, 0.9921, and 0.9950, respectively. The results indicated that this type of treatment was the simplest and most effective method that can be used to treat produced oily wastewater before disposal.

Keywords: Oily wastewater, North Oil Company, Pilot plant, Filtration-adsorption unit.

معالجة المخلفات النفطية الناتجة من وحدة التركيز القديم لشركة نفط الشمال

الخلاصة

الهدف من البحث هو دراسة خواص المخلفات النفطية ومحاولة ايجاد طريقة مناسبة وسهلة لمعالجتها والوصول بها الى حد مقبول للطرح. تضمن البحث مرحلتين ، الأولى هي دراسة خواص للمخلفات النفطية ، حيث بينت النتائج إن هناك زيادة في تراكيز بعض العناصر وخاصة الدهون والزيوت. المرحلة الثانية انقسمت إلى قسمين، الأول تضمن إجراء فحوصات الجرة لإيجاد الجرعة المثالية للشب، الجير، ومسحوق الكاربون المنشط. أما الثاني فهو تصميم وإنشاء محطة بحثية تألفت من وحدتي معالجة رئيسيتين هي التطويق و الترشيح -الامتزاز. بينت النتائج ان لعملية التطويق القابلية العالية لإزالة الدهون والزيوت ، COD، T.S.S، وبمعدل ازالة 0.9789، و0.9740، و0.9933، على التوالي. أما عملية الترشيح - الامتزاز فكانت نسبة إزالة جميع المواد عالية جدا بمعدل إزالة 0.9486، 0.8908، 0.6870، و0.7815 للدهون والزيوت ، T.D.S، COD، و T.S.S على التوالي. وكان معدل الإزالة الكلية 0.9986، 0.8939، 0.9921، و0.9950 على التوالي.

الكلمات الدالة: المخلفات النفطية ، شركة نفط الشمال ، المحطة البحثية ، وحدة الترشيح-الامتزاز.

Introduction

Oil has been refined for various uses for at least 1000 years ago. An Arab handbook written on approximately 865 A.D. by Al-Razi described distillation of (naphtha) for use in lamps and thus the beginning of oil refining (Forbes, 1958)^[1].

The most important pollutants in the oil processing wastewater are conventional pollutants such as oil and grease, suspended solids and pH, and non-conventional pollutants such as phenolic compounds, COD, sulfide and ammonia. Among these, oil and grease are one of the most complicated pollutants to remove (Noh, 1988)^[2].

The main two sources of oil and grease in wastewater are petroleum refining and used re-refining (free oil, dispersed oil, emulsified oil, soluble oil or as a coating emulsified oil,) (Rhee et. al., 1983)^[3].

Oil in a refinery wastewater stream may exist in one or more of three forms as presented by American Petroleum Institute (API), free oil (separate oil globules of sufficient size that they can rise as a result of buoyancy force), emulsified oil (much smaller droplets or globules which form a stable suspension in the water), and dissolved oil. Emulsified and dissolved oil may not be removed by gravity separation and other methods must be adopted (API, 1990)^[4].

The main purpose of this research is to study the most harmful pollutants originated from old-processing plant of North Oil Company which caused pollution to water and soil near the company and the surrounding area and to find the simplest and most suitable method of treatment which can be employed so that the effluent can be disposed safely.

Review of Literature

Oil and grease in the wastewater contained in oil processing industries can

be removed by the use of widely accepted techniques. Separation of oil from refinery wastewater is carried out by gravity separation using flotation of the oil droplets in the water, either natural or enhanced (API, 1990)^[4]. Many types of separation methods have been used to remove oil from refinery wastewater with varying degrees of success. Some of the systems currently in use are:

API separators: The primary function of an oil-water separator is to separate free oil from wastewater. Such gravity separators will not separate oil droplets smaller than the size of free oil nor will it break down emulsions. Three main forces acting on a discrete oil droplet are buoyancy, drag and gravity (Metcalf and Eddy, 2003)^[5]. They are designed to remove larger droplets and to generate effluent oil concentration down to about (150 mg/l). Because this does not meet the requirements of the clean water, API separators are usually not adequate to meet environmental requirements. Oil droplets rise according to Stokes law, but considerable turbulence and short-circuiting usually prevails in an API separator (Ford and Elton, 1977)^[6].

Chemical Technologies

If wastewater contains a stable emulsion of oil in water, the wastewater must be treated by chemical means if the oil concentration is to be reduced. Chemical flocculation units may be used where it is desirable or required to remove additional suspended solid particles not removed by gravity separation and / or to remove particulate sulfides in the water. The flocculants used are aluminum or ferric salts and sometimes the organic polymer. This method can also be used to remove emulsified oil (Edwards, 1995)^[7].

Air Flotation

Air flotation separators, both dissolved air flotation (DAF) and induced air flotation (IAF) separators utilize the gravity separation concept for the removal but tend to be more effective than API separators in removing the dispersed oil mixture because the buoyancy differential is enhanced by induced small air bubbles (Churchill, 1974)^[8].

The waste flow or a portion of clarified effluent is pressurized to (50 to 70) psi, in the presence of sufficient air to approach saturation. When this pressurized air-liquid mixture is released to atmospheric pressure, minute air bubbles are released from solution (Eckenfelder, 2000)^[9]. The air bubbles reduce the net specific gravity of the hydrocarbon air composite droplets, thereby increasing the rise velocity of the droplets. Air flotation is reported to be effective in treating wastewater containing hydrocarbon that are difficult to remove by gravity. DAF can remove particles down to about 5 microns in size and with demulsifying chemicals can remove stable emulsions down to 1 micron (Ryan, 1986)^[10].

Coalescing Plate Separators

Coalescing plate separators (CPI) and other enhanced gravity separators were developed to reduce the distance the droplets must travel before capture, therefore reducing the size of the separator required (De Kok and Marson, 1978)^[11].

Advantages of these separators over API separators are improved separation of both oil and sludge, laminar flow between plates, the efficient flow distribution, and easy removal of sludge, self-cleaning, compact size, and low construction cost. Disadvantages include plugging if over loaded with solids and possible overflows of water and oil over the plates (Morrison, 1970)^[12].

Multiple Angle Separators

They were developed to correct some of the problems associated with the use of CPI, notably plugging with solid particles and utilize coalescing plates that are corrugated in two directions instead of only one. They are designed to ensure low Reynolds number and therefore laminar flow, and low concentrations of hydrocarbons in the effluent water may be attained. But it is sensitive to upstream conditions (Mohr, 1992)^[13].

Filtration and Ultra Filtration

Filtration system is capable of removing smaller oil droplets than either the API or CPI treatment technologies. The effective range of a sand filter started from above 250 down to less than 5 microns. This makes filter beds the most flexible oil/water separation technology in terms of droplets size (Ryan, 1986)^[10].

Microfiltration, ultrafiltration, and reverse osmosis differ principally in the size of the particles separated by the membrane. Microfiltration is considered to refer to membranes that have pore diameters from 0.1 (1,000 Å) to 10 µm. Ultrafiltration refers to membranes having pore diameters in the range 20-1,000 Å (Baker, 1991)^[14]. Membrane filtration using the reverse osmosis treatment is very effective to remove dissolved and emulsified oils. The concept is based on the sieving action of a membrane retaining molecules larger than the membrane pores (Goldsmith and Hossian, 1973)^[15]. The Existing microfiltration firms may not find the opportunity appealing, because of technical risks and competition from conventional alternatives (Simon, and Bruce, 2003)^[16].

Biological Treatment

Biological treatment is generally effective in degrading dissolved oil and other types of stabilized emulsions which cannot be destabilized by coagulants. It is only effective on highly dilute oil-contaminated wastewaters (EPA, 1975)^[17].

Adsorption Removal

Adsorption-specifically, the use of granular activated carbon (GAC) has been widely demonstrated as a feasible and the most effective technology for the removal of the broad spectrum of dissolved organic impurities from water and wastewater. The very large surface area provides many sites on which the adsorption of molecules takes place. The internal pore structure of this material also provides a very large surface (Srivastava and Tyagi, 1995)^[18].

Carbon adsorption is very effective to remove dissolved and emulsified oils. It can be used as a tertiary stage of oil removal (Ford and Elton, 1977)^[19].

Materials and Methods

The experimental works were divided into two parts, the first was the field work and the second was laboratory work.

Field Work

The field work conducted at the industrial region of North Oil Company near Kirkuk city. The work included the sampling of oily wastewater from station represent the source of industrial oily wastewater from old processing plant and testing of its parameters during year 2007 (April, May, and July). Samples were collected and analyzed according to the procedures recommended by the Standard Methods for the Examination of Water and Wastewater (20th edition, 1999). The tests were carried out in the water laboratory of the Ministry of Municipalities and General Works. Equipment's were calibrated prior tests.

Laboratory work

Laboratory works divided into two parts, i.e. jar test and pilot plant experiments. The oily wastewater that was used in the study was brought from the same previous sampling station which represented the source of industrial wastewater for the period of November 2007.

Jar Test

Jar tests were performed in order to find the optimum alum, lime and powdered activated carbon (PAC) dose, and the effect of alum addition on oil and grease, T.D.S, COD and T.S.S removal efficiency. The experiments were done using different alum and lime concentrations and then using PAC concentration to find the optimum dose that will remove the stated pollutants (after pH adjustment).

Bench scale pilot plant

It is necessary to utilize some technologies to remove oil and grease to less than the levels that can be disposed. Dissolved air flotation unit provide a good solution. Filter are often used downstream of a gravitational separator as a polishing stage, and carbon adsorption is very effective to remove dissolved and emulsified oils. So the use of GAC as a combined adsorbent-filter medium which serves to remove suspended matter and dissolved matter in the same unit was conducted by combining filtration and adsorption to works as filter and as adsorbent column at the same time.

A pilot plant was designed, built and operated for the experimental work as shown in Figure (1). Some details of its units are below:

i- Flotation jar equipment consists of four conical bottomed flotation jars 100 mm diameter and capacity 1600 ml. The air /recycle water is introduced at

the bottom of each jar via release nozzles.

ii- Stainless steel saturator 18 liters, suitable for a pressure up to 85psi. Recycle water is saturated with air under pressure and introduced to the jars. The added chemicals were mixed with water at a high speed followed by a slow speed.

iii- Air compressor with a capacity of 16 kg/cm² and air rota-meter 10-1200 l/ hr. was also used to measure air flow.

iv- Pyrex column 100 mm diameter and 300 mm height located lower than flotation jar to ensure gravity flow was used as filtration – adsorption column. The media was granular activated carbon (GAC) of size 0.6-1.1mm and height 250 mm. The column has a bottom drain to direct the effluent to collection tank.

Results and Discussion

Oily Wastewater Parameters:

The results of analysed of process wastewater from old process plant which contains free or suspended oil and emulsified oil and other important contaminants that must be removed before the wastewater can be discharge to Wadi Al Naft are presented in Table (1) and Figures 2, 3, and 4 which show the monthly data (one sample was taken each month).

Results indicate that concentration of oil and grease was very high and increasing levels of oil and grease from permissible limits of Iraqi and EPA Specifications (10 mg and 15 mg/l respectively) were clear in the test; the range was 1069 - 10283 mg/l with average value 4873.77 mg/l. The main sources of this pollutant were spillways and leakage from different units which discharge to manholes and then to Wadi Al Naft. The T.D.S concentrations also high and had a mean value of 976.33 mg/l near the maximum permissible limit of Iraqi Specifications (1000 mg/l)

but more than the EPA Specifications (500 mg/l). The COD values were also high and ranged between 640-960 mg/l with mean value 840 mg/l which was not within Iraqi and EPA Specifications (100mg/l) and need to be decreased before discharge. The range of electrical conductivity was 958-1109 $\mu\text{s/cm}$ which was more than the EPA Specifications (800 $\mu\text{s/cm}$). The pH values confined to a narrow range with mean value of 7.42 which was in the range of Iraqi Specifications which calls for (6-9.5) and EPA Specifications (6.5-8.5). The mean values of total hardness and calcium hardness were 826.66 and 726.66 mg/l respectively.

There were small variations in the values of bicarbonate with mean value of 288.33 mg/l. The sulfate with mean value of 367 mg/l was over the EPA Specifications (250 mg/l). The ranges of chlorides were within permissible limits of EPA and the WHO Specifications for Irrigation Water which calls for 600 mg/l. All measured values of calcium, magnesium, and sodium were less than the WHO Irrigation Water Specifications which call for (200, 150, and 70) mg/l, respectively.

There were some variations in concentration of some pollutants during studied period and this is normal due to variation of flow results from variation in oil processing, production, and dilution which lead to variation in concentrations of pollutants at collection manholes.

Jar and Pilot Plant Test:

Jar Tests

The next step after studying the characteristics of oily wastewater is to choose the proper technology to treat the wastewater. The results of field study indicated that oil and grease were the most important pollutants that must be removed. To ensure the removal of all

oil types, dissolved air floatation and filtration-adsorption units were selected. These units can be used also to remove others important contaminants. Some quantities of raw oily wastewater were taken from the same previous point of samples to be used in pilot plant experiments. Before the operation some important parameters of raw oily wastewater were tested and the results are given in Table (2) which shows the average of three readings. Comparison of these results with previous results listed in Table (1) indicated that some parameters increased especially oil and grease and COD and this may be due to variation in flow rate and oil processing.

Since chemical coagulants are used to promote agglomeration of the oil – breaking matter into large flocs which are more easily removed, chemical coagulants (alum, lime, and PAC) were used. From jar test experiments, the results show that the optimum dose of coagulants were (125 + 30 + 100) mg/l for (alum + lime + PAC), respectively. These doses were applied to pilot plant to get optimal removal efficiencies.

Pilot Plant Study

Three different runs of pilot plants were done to examine the efficiency of using floatation unit and filtration – adsorption unit for the treatment of oily wastewater. The operational parameters were well selected and fixed for all experiments. Some of these parameters and its values were as follow:

Recycle ratio	Flow rate (m ³ / hr.)	Saturation pressure (psi)	Air / solid
0.75	0.005	70	0.1

Results and removal efficiency of oil and grease, T.D.S, COD, and T.S.S. obtained from pilot plant are shown in Tables (3), (4), (5), and (6).

Regarding floatation process, it is clear from these tables that floatation unit was very efficient and effective in the treatment of oily wastewater because floatation as process is efficient in removing oil and grease (oil droplets have less density than the fluid so they float on the surface of fluid), chemical oxygen demand (COD), and total suspended solids (T.S.S). The average influent concentrations were (7686.4, 2321.3, and 15816) mg/l, respectively, while the effluent concentrations from the unit were (158.87, 58.43, and 95.9) mg/l, respectively. So giving average removal efficiencies of (0.9789, 0.9740, and 0.9933) respectively. So wastewater with initial oil and grease concentrations in the range of (6856-8271.4) mg/l had been reduced to less than (104.8-198.6) mg/l. While low removal efficiency was obtained for total dissolved solids (T.D.S) of (0.0293) because gravity separators had low removal efficiency for dissolved solids, but it was removed by using specified units such that adsorption or reverse osmosis. It was notice that there were some variations in the influent concentrations and from the previous measured values this may be attributed to the change in operation conditions and the leakage as stated previously.

The treatable wastewater from the floatation unit passed through filtration-adsorption column and the effluent quality results were tabulated in the same above tables. The obtained results were very good because carbon adsorption and gravity filtration is very effective in removing emulsified oils, dissolved oils, and a large list of dissolved and suspended solids. The height of GAC medium selected in this study is enough because at the top of 25 cm layer of the GAC the solutes are completely removed from solution during the initial phase of operation.

Average influent concentrations of oil and grease, T.D.S, COD, and T.S.S entered to the filtration – adsorption unit were (158.86, 840.7, 58.43, and 95.5) mg/l respectively, while the average effluent concentrations were (8.73, 91.66, 17.9, and 21) mg/l, respectively. All effluents concentrations were within Iraqi and EPA Standards, and the average removal efficiencies were 0.9486, 0.8908, 0.6870, and 0.7815, respectively.

Finally the average overall removal efficiencies for pilot plant were 0.9986, 0.8939, 0.9921, and 0.995 respectively indicating that the pilot plant was very successful in treating oily wastewater with high removal efficiencies because the concentration of all effluents were within permissible limits of disposal.

It can be noted that only three runs were conducted because the results show high removal efficiencies at all these runs which mean that this type of treatment is suitable to treat the above wastewater.

Proposed Treatment Units of North Oil Company Waste

The control technology for oil and grease removal varies in complexity, and since it depends on the condition of the oil-water mixture, the unit must be selected carefully because the choice or performance largely depends on the characteristics of wastewater entering the system.

According to pilot plant study it can be conclude that the simplest treatment method for the processes oily wastewater include the following main units:

Oily wastewater influent collection, mixing and equalization tank, chemicals addition tanks, flotation unit, filtration and/or adsorption unit, effluent collection tank, sludge removal and treatment units, backwash equipment's, GAC regeneration unit, and other

equipment's required completing the work such that, fittings, pipes, pumps, air compressors, steam unit...etc. Figure (6) shows a schematic diagram for this proposed treatment plant.

Conclusions

A. Field study

1- Oily wastewater from old processing plant contained different pollutants that had to be removed and treated before disposed to the natural stream. The concentrations of some of them were higher than that reported in Iraqi and EPA Standards.

2- There were some variations in the concentrations of some pollutants due to the variation in the quantity of waste flow according to leakage, maintenance and washing, and operation processes.

3- The oil and grease can be regards as the most dominant pollutant with high concentrations range (1069- 10283) mg/l. The Average concentration of T.D.S was (976.33) mg/l near the maximum permissible limit of Iraqi Specifications but more than the EPA Specifications like conductivity with average (1018 $\mu\text{s}/\text{cm}$). The COD values were also high and ranged 640-960 mg/l which was not within Iraqi and EPA Specifications. The pH, total hardness, calcium hardness, bicarbonate, and chloride all were within Iraqi and EPA Specifications, while sulfate was over the EPA Specifications. The Calcium, magnesium, and sodium were less than WHO Irrigation Water Specifications.

B. Pilot Plant Study

1. The average influent concentrations of some important parameters of oily wastewater applied to the pilot plant (oil and grease, T.D.S, COD, and T.S.S.) were 7686.4, 866, 2321.3, and 15816 mg/l, respectively. These values were

higher than that obtain at first part of research due to variation in processes.

2. The optimum doses found from jar tests using (alum + lime + PAC) were (125 + 30 + 100) mg/l, respectively.

3. Flotation unit was very efficient in the removal of some parameters with average removal efficiencies of 0.9789, 0.9740, and 0.9933 for oil and grease, COD, and T.S.S, respectively but low average efficiency in removing T.D.S (0.0293).

4. The obtained results from filtration-adsorption unit were very good. The average influent concentrations of oil and grease, T.D.S, COD, and T.S.S entering to the filtration – adsorption unit were 158.86, 840.7, 58.43, and 95.5 mg/l, respectively, while the average effluent concentrations were 8.73, 91.66, 17.9, and 21 mg/l, respectively. Which indicate that all types of oil were removed. All effluents concentrations were within Iraqi and EPA Standards, and the average removal efficiencies were 0.9486, 0.8908, 0.6870, and 0.7815, respectively.

5. Average overall removal efficiencies of the pilot plant units were high for removal of oil and grease, T.D.S, COD, and T.S.S (0.9986, 0.8939, 0.9921, and 0.9950), respectively. Which indicate that the pilot plant was very successful in treating oily wastewater giving high removal efficiencies of all important pollutants because the concentrations were within the permissible limits for the disposal to stream.

6. The proposed treatment units consists of influent collection and equalization tank, chemical tanks, flotation unit, filtration – adsorption unit, the sludge collection and treatment, effluent collection and disposal tank, and others important accessories.

Recommendations

The following recommendations for North Oil Company to be applied during operations and before the construction of the oily wastewater treatment plant:

1. Improve the operations in order to minimize the amounts of oil and grease in wastewater streams.

2. Recover small spills and leaks to further reduce the amount of oil and grease in the refinery effluents.

3. New design, and refinements of old design must be used to provide better treatment, and also a great deal of engineering effort will be expended to minimize energy and chemical use. This will provide benefits in cost reductions as well as reductions in chemicals.

4. Although there are different methods that can be employed to treat oily wastewater but the method of treatment that used in this study is simple, not complicated, applicable with low cost, and gives high removal efficiencies.

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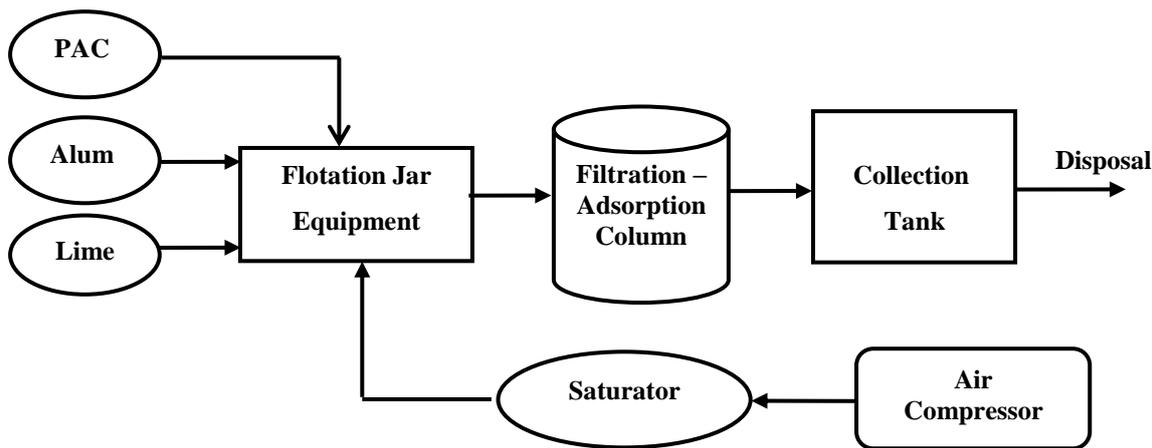


Figure (1) Schematic diagram of batch pilot plant

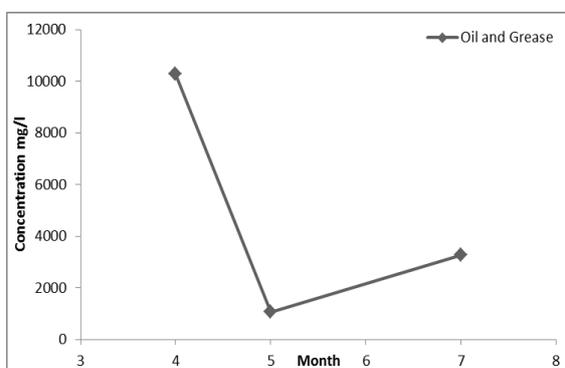


Figure (2) Average monthly concentration of oil and grease

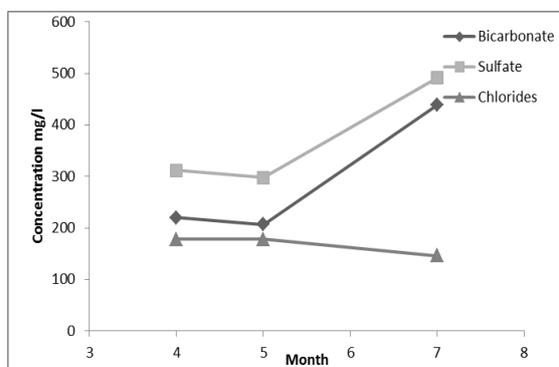


Figure (4) Average monthly concentrations of bicarbonate, sulfate, and chloride

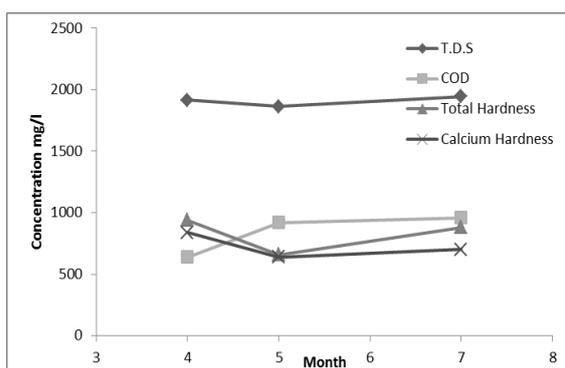


Figure (3) Average monthly concentrations of T.D.S, COD, total hardness, and calcium Hardness

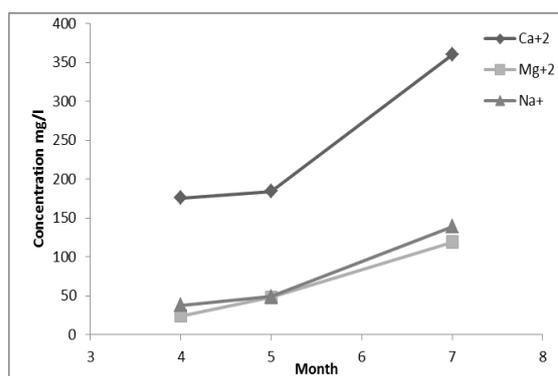


Figure (5) Average monthly concentrations of calcium, magnesium, and sodium

Table (1) Monthly average concentrations of oily wastewater parameters

Parameters	April	May	July	Average Concentration
Oil and Grease (mg/l)	10283	1069	3269.3	4873.77
T.D.S (mg/l)	1918	1864	1947	976.33
COD (mg/l)	640	920	960	840
Conductivity ($\mu\text{s}/\text{cm}$)	958	1109	987	1018
pH	7.27	7.67	7.34	7.42
Total Hardness (mg/l)	940	660	880	826.66
Calcium Hardness (mg/l)	840	640	700	726.66
Bicarbonate (mg/l)	220	207	438	288.33
Sulfate (mg/l)	312	298	491	367
Chlorides (mg/l)	178	178	146	167.33
Ca ²⁺ (mg/l)	176	184	360	240
Mg ²⁺ (mg/l)	24	48	119	63.66
Na ⁺ (mg/l)	38	49	139	75.33

Table (2) Influent concentrations of oily wastewater parameters

Parameters	Sample no.1	Sample no.2	Sample no.3	Average Concentrations
Oil and grease (mg/l)	7931.8	8271.4	6856	7686.4
T.D.S (mg/l)	846	932	821	866
COD (mg/l)	2360	2492	2112	2321.3
T.S.S (mg / l)	15200	15700	16550	15816
pH	7.1	6.95	7.0	7.01
E.C ($\mu\text{s} / \text{cm}$) 25 ° c)	964	980	930	958
Temperature (° c)	30	30.5	29.6	30

Table (3) Oil and grease removal efficiencies by flotation and filtration-adsorption units

Run No.	Influent Concentrations to Flotation unit (mg/l)	Concentrations after Flotation unit (mg/l)	Removal Efficiencies of Flotation Unit	Effluent Concentrations After Filtration-adsorption unit (mg/l)	Removal Efficiencies of Filtration-adsorption unit (mg/l)	Overall Efficiencies
1	7931.8	104.8	0.9867	3.2	0.9694	0.9996
2	8271.4	173.2	0.9790	10.3	0.9405	0.9987
3	6856.0	198.6	0.9710	12.7	0.9360	0.9981

Table (4) Total dissolved solids removal efficiencies by flotation and filtration-adsorption units

Run No.	Influent Concentrations to Flotation unit (mg/l)	Concentrations after Flotation unit (mg/l)	Removal Efficiencies of Flotation Unit	Effluent Concentrations After Filtration-adsorption unit (mg/l)	Removal Efficiencies of Filtration-adsorption unit (mg/l)	Overall Efficiencies
1	846.0	826.0	0.0240	109.4	0.8675	0.8706
2	932.0	898.3	0.0360	89.1	0.9008	0.9044
3	821.0	797.8	0.0280	76.5	0.9041	0.9068

Table (5) Chemical oxygen demand removal efficiencies by flotation and filtration-adsorption units

Run No.	Influent Concentrations to Flotation unit (mg/l)	Concentrations after Flotation unit (mg/l)	Removal Efficiencies of Flotation Unit	Effluent Concentrations After Filtration-adsorption unit (mg/l)	Removal Efficiencies of Filtration-adsorption unit (mg/l)	Overall Efficiencies
1	2360.0	24.0	0.9890	8.0	0.6666	0.9966
2	2492.0	78.5	0.9680	22.4	0.7146	0.9910
3	2112.0	72.8	0.9650	23.3	0.6799	0.9889

Table (6) Total suspended solids removal efficiencies by flotation and filtration-adsorption units

Run No.	Influent Concentrations to Flotation unit (mg/l)	Concentrations after Flotation unit (mg/l)	Removal Efficiencies of Flotation Unit	Effluent Concentrations After Filtration-adsorption unit (mg/l)	Removal Efficiencies of Filtration-adsorption unit (mg/l)	Overall Efficiencies
1	15200	81.6	0.9940	17.7	0.7830	0.9988
2	15700	107.3	0.9930	25.4	0.7632	0.9983
3	16550	98.8	0.9940	19.9	0.7985	0.9879