Comparison of wastewater treatment in oil and gas industry using conventional methods (chemical, physical and biological)

M Hamdy¹, ², Sudarno² and H S Huboyo²

¹HSE department, Cooperation petroleum, Cairo, Egypt
²Environmental Engineering Department, Diponegoro University, Semarang, Indonesia

Abstract. The oil and gas industry consumes tons of water, and the water produced from this industry contains harmful substances such as petroleum products and heavy metals that negatively affect humans and the environment. The objective of this research is to know the efficiency of the conventional wastewater treatment technologies (chemical by adding Alum, biological with aeration, and physical by filtration) to treat oily wastewater and the effect of the quantity of Alum on the treatment efficiency by using jar test and laboratory analysis beside modify the system to reuse the treated water in various activities. The treatment results showed a decrease of COD by 27%, BOD by 26.5%, oil and grease by 55%, and heavy metals by 95%, and the final results are compatible with the Egyptian standards. It is found that the optimum alum quantity that can be used is 15 mg/L which can remove 48% of oil and grease. Despite the simplicity and low cost of conventional methods for industrial wastewater treatment compared to advanced methods, they still give acceptable results. Reusing the treated water and sludge saves money, encouraging many industries to use it instead of discharging it.

1. Introduction

Freshwater has become an essential strategic resource, and rationalizing its consumption is no longer a luxury. The distribution and treatment of fresh water usually experience some associated problems such as water availability [1], water loss [2], and supply imbalances [3]. Recently, many disputes over freshwater, especially rivers, have escalated between countries, such as the conflict between Iran and Afghanistan over the Helmand River and between India and Pakistan over the Indus River, and the famous conflict between Ethiopia and the downstream countries of the Nile river (Egypt and Sudan) after the construction of the Ethiopian dam (GERD), which heralds the first war on the water in history.

Therefore, many countries have tended to treat wastewater and reuse it to rationalize the consumption of freshwater, and among these countries is Egypt, after expectations of a decrease in the level of the Nile River after the construction of the Ethiopian dam. Indeed, the largest wastewater treatment plant was built in Bahr al-Baqar in the Sinai Peninsula with a capacity of 64.8m³/s and an area of 650,000 m² (according to the Guinness world records).

The Environmental Affairs Agency in Egypt is concerned with the water treatment file, and all industrial facilities are required to treat water before discharging it. The most important industries that consume much water are the oil and gas industries, but most of the oil and gas sites discharge water
without using it, which wastes much water that can be saved and reused besides that oily wastewater produced from the oil and gas industry contains a lot of precious metals and petroleum products. Previous studies about Oily wastewater characteristics show that the pH of oily wastewater ranged between 7.5, 8.4 and for nitrates and phosphates, both are below 5 mg/L; total suspended solids can reach 3321 mg/L COD, and BOD can reach 2000 mg/L, 400mg/L respectively [4].

Also, many studies discuss oily wastewater treatment by both advanced and conventional technologies. The results show that the reliability of a single system or method is still questionable. Thus, the practical way to move forward is by integrating a few systems or methods [5] and from field study for the treatment of oily wastewater from an old processing plant of the North Oil Company, it was found that combined technology consisting of flotation and filtration-adsorption units was the most effective method in the treatment of oily wastewater [6].

Coagulation/flocculation can effectively remove most suspended oil and emulsified oil since aluminum or iron salts have a good coagulation effect on negatively charged oil droplets [7]. Due to the efficiency of Alum and its low price, many studies have focused on the efficiency of Alum as a coagulant in the treatment of oily wastewater, especially in the case of low percentages of oil. For initial oil and grease concentration of 300 mg/L and alum quantity of 100-200 mg/L, the oil removal efficiency ranged between 33% and 100% [8].

For oil concentration 500 mg/L at pH 4 and alum quantity 50 mg/L the removal rate was 93% [9]. For using blended kaolinite with Alum as coagulants, COD decreased from 4800 to 150 mg/l with a removal percentage of 96.9 %, BOD decreased from 1800 to 14 mg/l with removal percentage of 99.2% and Oil content decreased from 1800 mg/l to 0.0 with removal percentage of 100 %. Pb decreased from 14.7 to 0.55 mg/l with removal percentage of 96.3%, Cu decreased from 9.4 to 0.5 mg/l with removal percentage of 94.7%, Zn decreased from 11.5 to 1 mg/l with removal percentage of 91.3%, Fe decreased from 6 to 0.5 mg/l with removal percentage of 91.7% and Cd decreased from 0.2 to 0.0 mg/l with removal percentage of 100% [10].

For this research, the efficiency of combined treatment methods (chemical, physical and biological) are evaluated to assess the compatibility of the results with the possibility of reusing the water resulting from the treatment.

2. Methodology

2.1. Site and activities description

As shown in figure 1. And figure 2. The site is a petroleum warehouse belongs to Cooperation Petroleum Company located in Sharqia governorate, Egypt, which used to store petroleum products preparing for transportation to petroleum stations and there is a lot of routine activities in the site such as Tank car washing; pipes drain, Tanks overflow, Mock extinguishing experiments, Tanks cooling and petroleum spillage.

![Figure 1. Site overview.](image-url)
2.2. Water consumption in petroleum warehouses
A survey made over six petroleum warehouses in different governorates in Egypt to find the average water consumption rate in June 2021 shows the results in table 1.

| Average temperature (°C) | Water consumption (m³) | Sites location |
|--------------------------|------------------------|----------------|
| 27                       | 3700                   | Alexandria     |
| 30                       | 4800                   | Cairo          |
| 31                       | 4800                   | Sharqia        |
| 35                       | 5000                   | Qena           |
| 32                       | 3500                   | Tanta          |
| 35                       | 1200                   | New valley     |

The results show that the average water consumption of fresh water is about 3800 m³/month, depending on many factors such as workload and temperature.

2.3. Wastewater characteristics
Two samples were taken from the inlet of the wastewater treatment unit on 2 different days to get the characteristics of the water coming out from the activities mentioned above, and the results are as shown in table 2.

| Characteristics 2 24/6/2021 | Characteristics 1 31/5/2021 | parameters |
|-----------------------------|-------------------------------|------------|
| 30                          | 20                            | temperature |
| 100                         | 70                            | COD        |
| 49                          | 29                            | BOD        |
According to the results, it is noted that the water resulting from oil and gas activities contains percentages of oils and grease, as expected, as well as percentages of heavy materials, which are represented in the lead in the form of tetraethyl lead and chromium in the form of hexavalent Chromium, which is highly toxic to humans and the environment. However, their small quantities made them ineffective, and a relatively small percentage of COD and BOD compared to sewage wastewater. The. The percentage is usually more than double that of industrial wastewater because it contains much organic matter.

The methodology process used in the research is as follows:

- The first step is to define all industrial processes in the site, including the materials used.
- Doing the Jar test with multiple quantities of Alum to find the optimum quantity that can be used with output wastewater
- Getting four samples from the wastewater treatment plant (from the inlet, after injecting Alum, after aeration tank and outlet)
- Analyze the samples to define the wastewater characteristics.
- Analyze each treatment method and compare it with Egyptian standards.
- Check if the results are consistent with the standards.
- If the results are within the standards, then assess each method
- If not, check the treatment process to get better results

2.4. Sampling Method

The samples will be taken from four oil and gas industry treatment units (Inlet, after alum injection, after aeration, and an outlet) with variant wastewater treatment methods.

2.5. Sampling Devices

Sampling devices and water quality monitoring devices will be used to obtain the results (spectrophotometer, ICP, buffer solution device, and pH meter).

2.6. Wastewater treatment unit specifications:

As shown in figure 2., the treatment unit consists of three stages, and it treats about 50m$^3$/hr described as follows:

2.6.1. Chemical treatment. The inlet wastewater enters the unit and is stored in the inlet tank. The coagulation process starts by injecting aluminum sulfate (Alum) injected in a certain quantity into the water, then pumping it and passes on corrugated plates. After that, oil and grease settled at the bottom of the tank.
2.6.2. **Biological treatment.** The second stage is aeration which the water enters an aeration tank and settles for one hour until bacteria can consume organic compounds.

2.6.3. **Physical treatment.** The third and last stage is filtering water by two sand filters to remove any remaining pollutants and, at last, discharge the treated water to the sewage network.

![Figure 3. Wastewater treatment plant.](image-url)

2.7. **Jar test**
To get the optimum quantity of Alum that is suitable for the system jar test used. By getting 4 samples from the inlet and putting them in four pots, adding different quantities of Alum in each pot, then mixing them at 150 rpm for 2 minutes and then decreasing it to 50 rpm for one minute and leaving them at room temperature for 30 minutes before analysis.

3. **Results and discussion**

3.1. **Results**
The results obtained from the jar test are as follow:

| Parameters          | 30 mg/L | 20 mg/L | 15 mg/L | 5 mg/L |
|---------------------|---------|---------|---------|--------|
| **PH**              | 6.8     | 7.1     | 7.2     | 7.4    |
| **COD**             | 90      | 93      | 95      | 97     |
| **BOD**             | 40      | 41      | 43      | 45     |
| **Oil and grease**  | 4       | 7       | 10.4    | 16     |

Table 3. Jar test results.
Results obtained from each phase in wastewater treatment plant at alum quantity = 15mg/ L are as follow:

Table 4. Samples results.

| Standards Article 52 of the law regulating the drinking water and sanitation sector | Outlet | After aeration | After injecting Alum | Inlet | parameters |
|---|---|---|---|---|---|
| < 43 C | 30 | 30 | 30 | 30 | temperature |
| <80 PPM | 70 | 73 | 95 | 100 | COD |
| < 60 PPM | 35 | 36 | 43 | 49 | BOD |
| 0.6-9.5 | 7.4 | 7.5 | 7.2 | 7.5 | PH |
| <10 PPM | 8.3 | 9 | 10.4 | 20 | Oil and grease |
| <50 PPM | 35 | 64 | 19 | 48 | TSS |
| <5 mg | .36 | 1.3 | 11.8 | 25.8 | Heavy metals |
| <25 PPM | ---- | ---- | 1.05 | 1.93 | PO4 |
| | ---- | ---- | | | |
| <100 PPM | .13 | 1.33 | 9.5 | ---- | NO3 |

3.2. Discussion

3.2.1. Alum effect. From table 3, it was noticed that, after adding Alum, there is a decrease in the alkalinity of the water because the PH of the Alum is equal to 3, as well as the higher the percentage of Alum, the lower the percentage of oil and grease. Coagulation/flocculation can effectively remove most suspended oil and emulsified oil since aluminum or iron salts have a good coagulation effect on negatively charged oil droplets [7].

Table 4. shows that the percentage removal of heavy metals from the industrial wastewater increases with the dosage of coagulants (local Alum) at a slightly alkaline PH, which is compatible with previous studies [11].

The results of adding Alum to industrial wastewater noticed the effect on Chromium and led at a percentage from 3 to 10 mg/L the removal percentage was between 88.5%-96.2% for Chromium and 33.3 to 100% for the lead, but for the results in oily wastewater, the removal percentage of heavy metals became 45.74 % at a dosage of 15 mg/L at PH= 7.5 [11].

3.2.2. Treatment efficiency. Aeration reduces COD and BOD in 2 ways: 1- Evaporating any volatile substances, 2- Adding oxygen to the water to speed up any biological oxidation of the organic substances by the bacteria that help in consuming organics and then filtered by sand filters.

This explains the installation of sand filters after the aeration tank and noting that there was no significant change in COD and BOD after the sand filter, but the most significant change was in TSS. Also noticed is that there is no change in the alkalinity of the water during the biological treatment due to the absence of any substances that affect the alkalinity of the water.
According to (Jency Nadayil, 2015), it was found that with the increase in flow rates, the percentage of removal of the mentioned components in Table 4 also increased [9]. Also, when the period for aeration increased, the removal rates increased. Therefore, in treating water resulting from oil and gas activities, with a decrease in the flow rate and period for aeration, the removal rates decreased. However, this decrease is suitable for the activity due to the necessity of treating large quantities of water in a short period and a lower percentage of COD and organic compounds in the water than the percentages found in the domestic wastewater.

### Table 5. Aeration efficiency.

| Parameter                  | Removal % (Jency Nadayil, 2015) Flow rate (3 L/min.) for 72 hr (domestic wastewater) | Removal % (Jency Nadayil, 2015) Flow rate (3 L/min.) for 24 hr (domestic wastewater) | Removal % (recently) Flowrate (0.8 L/min.) for 1 hr (industrial wastewater) |
|----------------------------|----------------------------------------------------------------------------------|----------------------------------------------------------------------------------|----------------------------------------------------------------------------------|
| COD                        | 94.05                                                                            | 85.6                                                                            | 23.16                                                                            |
| BOD                        | 97.17                                                                            | 88.91                                                                           | 16.28                                                                            |
| PH                         | 0                                                                                | 0                                                                               | 0.014                                                                            |
| Oil and grease             | 0                                                                                | 0                                                                               | 0.13                                                                             |

### 3.3. Modification of water treatment plant

The wastewater treatment plant mentioned above needs modification to transform it to a closed-cycle so the treated water can be reused.

The modification is shown in Figure 7. Involves adding chlorine for disinfection by a quantity of 0.5 mg/L (according to WHO) and then water stored in a tank to be reused in various activities on site.

![Figure 4. wastewater treatment plant modification.](image-url)
4. Conclusion
Wastewater treatment unit produces 1200 m$^3$/day that can be consumed in many activities in the site such as watering decoration plants in site, firefighting (mock fire drill consumes 10 tons of water per month), car washing, and personal uses (excluding drinking) Wastewater treatment also produce about (0.5 – 1) tons/month of sludge that can be used to recover precious metals such as lead. Sludge also contains a percent of oil and grease that can be perfect for fuel in the cement and iron industries.

The results show that the conventional wastewater treatment methods efficiency is acceptable in case of industrial wastewater with low contaminants and can be used in non-industrial oil and gas sites as warehouses, oil stores, and garages beside that these technologies are simple and low cost and the resulted water can be reused in beneficial ways. However, it needs more research to determine if its efficiency is suitable with wastewater resulting from sites with moderate contaminates as petrol filling stations.

References
[1] Syafrudin, Sarminingsih A, Krisbiantoro 2020 IOP Conf. Ser.: Earth Environ. Sci. 448 012102
[2] Sambodja KH, Samadikun B, Syafrudin 2020 IOP Conf. Ser.: Earth Environ. Sci. 448 012049
[3] Priyambodo S, Sarminingsih A, Syafrudin 2021 IOP Conf. Ser.: Earth Environ. Sci. 802 012058
[4] Phungula S, Tekere M and Maphangwa K W 2016 UNISA environmental science (South Africa)
[5] Abuhasel K, Kchaou M, Alquraish M, Munusamy Y and Jeng Y T 2021 Water (Switzerland MDPI) 13 980
[6] Al-Ani F H 2012 Tikrit journal of engineering sciences (Iraq) 19(1) 23-34
[7] Fard A K, Rhadfi, T, Al-marri M and Hilal N 2016 Chem. Eng. J. (Netherlands) 293 90–101
[8] Mazumder D and Mukherjee S 2011 IJESD (US) 2(1) 64-69
[9] Zhao C, Zhou J, Yana Y, Yang L, Xing G, Li H, Wua P, Wang M and Zheng H 2020 science of the total environment (Netherlands) 142795 765
[10] Abdelaal A M 2017 JPME (Egypt) 19(1) 57-62
[11] Ogunfowkan A O, Durosinimi L M, Oyekulne J A O, Ogunkunle O A and Igbafe L T 2007 IFE J. of science (Nigeria) 7(10) 1416-1421
[12] Nadayil J, Mohan D, Dileep K, Rose M, Rose R and Parambi P 2015 International J. of interdisciplinary research and innovations (India) 3(2) 10-15
[13] Wang L K, Wang M S, Hung Y T, Shammas N K and Chen J P 2018 Handbook Of Advanced Industrial And Hazardous Waste Management (US- CRC press)
[14] Inamuddin, Ahamed M I and Lichtfouse E 2021 Water Pollution And Remediation: Organic Pollutants, Environmental Chemistry For a Sustainable World (US- springer publishing) p 54