Penetration of warm heavy fuel oil waste in gypseous soil

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Abstract. Gas power plants are the most common power plants, due to lower construction costs, shorter construction, and operating times than other power plants. However, the growing demands for more electrical power requires the construction or expansion of many power plants. The using of Heavy Fuel Oil (HFO) in the gas power plants needs a sequence of treating processes in a special treating unit. The HFO treating processes produce large quantities of the wastewater. Before treatment, the wastewater accumulated commonly in a large lagoon. During the high summer temperature, the stored wastewater in the lagoon, also, the concrete channels transferring it is warmed to a temperature of (60°C) as it exposed to the sun. In this research, an experimental device was manufactured to estimate the periods for percolation of contaminated waste material into different gypseous soil samples. In addition to the effect of wastewater on the characteristics of these soils, the results showed that as HFO waste temperature increases the percolation speed in the early stages of the percolation increases rapidly, and the degree of saturation of soil decreases. Also, increase in the HFO waste temperature decreases the settlement for soils of high and medium gypsum content, whereas it increases for soils with a low gypsum content.

1. Introduction
As a result of industrial development, there is an enormous increase in the use of oil, but the various technical treatment and management of waste generated still lags behind. Therefore, there are lots of untreated wastewater to being spilled in water or on the ground resulting in pollution. Treating HFO waste sources is very broad. The oil used in power production industries, power plant treatment units; oil refining, oil storage, transportation, and petrochemical industries in the production process generate much oily wastewater, [1], and [2].

Gas power plants are the most widely recognized power plants due to lower construction costs, shorter construction, and operating times than other power plants. The using of Heavy Fuel Oil (HFO) in the gas power plants needs a sequence of treating processes in a special treating unit. The HFO treating processes produce large quantities of the wastewater. Before treatment, the wastewater is accumulated commonly in a large lagoon. During the high summer temperature, the stored wastewater in the lagoon, also, the concrete channels transferring it is warmed to a temperature of (60°C) as it exposed to the sun.

The contaminant usually forms in a liquid or solid and being either physically or chemically adhered to the soil particles or it comes trapped in the porous vaults among the soil particles, [3]. The distribution processes for the contaminant (Fuel) spilled on grounds can be described as advection, molecular diffusion, or mechanical dispersion. It depends on the spreading type, soil type, and its geology as well.
as weather conditions (especially temperature) and diameter of the pool. For gasoline-like volatile compounds, vaporization can be very effective so that only a portion of spilled oil penetrates the soil, [4].

Numerous studies and researches have been devoted to studying and understanding the method of spreading pollutants to soil and soil behavior as a result.

Khamehchiyan et al. [5] investigated the physical and engineering properties of clayey and sandy soils contaminated by crude oil. The results revealed a reduction in the shear strength, the dry density, optimum moisture content, and Atterberg’s limits with increasing the content of crude oil in the soil. Taha et al. [6] study the effectiveness of petroleum material in the enhancement of gypseous soils properties; they found that these materials improved the engineering properties of gypseous soils as these soils submerged in water. Halmemies et al. [4] used a special column experimental device to test the percolation of oil in sandy soils. The results showed that the vertical seepage velocities in gravely sandy soils had a lower percolation velocity for viscous fuels than the percolation velocity for lighter fuels, because of horizontal seepage and backpressure caused by saturated zone. In the case of gravely sand, the gasoline seepage velocity is almost five times faster than the diesel oil. On the other hand, the seepage velocity in sandy soil or peat is only three times faster for gasoline than diesel oil.

Armo et al. [3] studied the crude oil migration and its rate of percolation, where an experimental model was designed consisting of two separated columns, filled with soil and other rock types as the real case scenario. The results indicated that percolation depth was greater in the wet soil during the early stages rather than in the dry soil. Overall percolation in the final stage was found to be significantly higher in the dry system. Also, it was observed that during crude oil migration in the dry system, separation of crude oil components occurred obviously. The effect of crude oil on the mechanical and physical properties of clayey soils was investigated by Al-Adhamii, [7].

The main objective of the study carried out by Bello and Anobeme, [8] was to determine the damages caused by the oil spill to the soil and environment. The samples were collected from the oil spill affected soils and non-oil affected soils to serve as a control. Some physicochemical properties that reflect soil nutrients content status (Ca$^2+$, Mg$^2+$, Na, K, C, N, P, pH, ECEC, particle size, electrical conductivity, and hydrocarbon content). It was noticed that there was a significant decrease in Ca$^2+$, Mg2, K, silt fraction, clay fraction in soils contaminated and a significant increase in the sand fraction content, Na content, electrical conductivity, hydrocarbon content.

It has been noticed that previous studies focussed on the test of percolation of the pollutant into the soil and its effect on physical, engineering soil properties and environmental. However, these studies were conducted on pollutant and soil at laboratory temperature and did not consider the exposure of the pollutant to high temperature during the summer in dry and semi-arid regions. The aim of this research is to investigate the influence of contaminant (HFO waste came out from the fuel oil treatment units for the gas power stations) at different temperature (25-60) °C on the gypseous soil, where a laboratory model is developed to simulate the percolation of HFO waste through the soil with different field circumstances.

2. Basic Properties of soil samples and HFO waste

Four different soil samples (soil I soil II, soil III and soil IV) were collected from Baiji Gas Station site near the gathering basin area and at different depths (1, 2 and 3), respectively. The classification and physical properties of the soil samples are tabulated in table (1). All tests were carried out according to ASTM 4.08 and 4.09, [10]. The gypsum content of the above soil samples are shown in table (2). The contaminant material in this study was the heavy fuel oil waste produced from heavy fuel oil treatment
processes. Table (3) gives a summary of the basic HFO waste properties, including, viscosity, specific gravity, density, and water content.

3. Experimental Setup
In this research, a locally manufactured experimental device was developed to estimate the periods' percolation of contaminating waste material into different soil samples. The experimental device consists of four main parts; the model base, the specimen cylinder, specimen pipe, ball valve, and the model auxiliaries, as shown in ‘Figure 1’ and Plate (1). The auxiliaries, which consist of the following:
- (The supporting frame, Levelling Plate, Connecting Teflon bushings, O-rings, Measuring tape and an Electrical heater: a special heater of 1000 watt power, used to heat the HFO waste to 60 °C.) The heater is equipped with a thermocouple temperature controller. The heater is fixed inside a plastic container and isolating the electrical board (after making all required connections with the power cable) with silicone sealant to prevent any touch with the pollutant or moisture.

Table 1. Results of classification and physical properties tests.

| Properties                                           | Soil I | Soil II | Soil III | Soil IV |
|------------------------------------------------------|--------|---------|----------|---------|
| Depth of soil layer (m)                              | 3-3.5  | 2-3     | 1-2      | 0-1     |
| Minimum Unit weight (kN/m³)                          | 14.39  | 14.16   | 13.24    | 11.91   |
| Maximum Unit weight (kN/m³)                          | 17.17  | 16.49   | 16.44    | 15.88   |
| Field Unit weight (kN/m³) (CORE CUTTER METHOD at Baiji Gas Power Station) | 15.2   | 15.03   | 14.86    | 14.66   |
| Water content, (ω)%                                  | 33     | 41      | 56       | 75      |
| Relative density, (D_r) %                             | 2.64   | 2.61    | 2.58     | 2.55    |
| Specific gravity, (Gs)                               |        |         |          |         |
| Atterberg limits                                     |        |         |          |         |
| Liquid limit (L.L)%                                   | -      | 6       | 13       | 19      |
| Plastic limit (P.L)%                                  | -      | -       | -        | -       |
| Plasticity index (P.I)%                               | N.P    | N.P     | N.P      | N.P     |
| Coefficient of uniformity (C_u)                       | 3.34   | 3.6     | 3.65     | 3.18    |
| Coefficient of curvature (C_c)                        | 0.99   | 1       | 1        | 0.82    |
| Gravel %                                              | -      | -       | -        | -       |
| Sand %                                                | 96.53  | 94.24   | 93.9     | 93.18   |
| Silt %                                                | 3.47   | 5.76    | 6.1      | 6.82    |
| Clay %                                                | -      | -       | -        | -       |
| Unified Soil Classification System (USCS) group        | SP     | SP      | SP       | SP      |

Table 2. Results of gypsum content*

| Type of soil | Gypsum content (%) | Classification according to [9] |
|--------------|--------------------|--------------------------------|
| Soil I       | 2                  | Very slightly gypseous         |
| Soil II      | 10                 | slightly gypseous              |
| Soil III     | 22                 | Moderately gypseous           |
| Soil IV      | 40                 | Highly gypseous               |

* The tests were carried out according to [11] method.
Table 3. Oily wastewater properties

| Properties                  | Value |
|-----------------------------|-------|
| Viscosity (cst) at 40°C     | 369   |
| Density (gm/cm³) at 15°C    | 0.963 |
| Specific gravity            | 0.965 |
| Water content (%)           | 24    |

*cst: Centi-Stoke = 1 mm²/s

The soil was sieved passing sieve (No. 4), different density for each type of soil is prepared. The required density was controlled by calculating the desired volume of soil needed. After placing the soil inside the cylindrical pipe, the ball valve is closed, the upper cylinder is filled with HFO waste. The filling of HFO waste into its cylinder considered with three different levels (1, 2 and 3m) for simulating the field HFO waste basin levels. The measuring tapes are used to identify the volume of HFO waste in the cylinder pipe. Finally, the stopwatch and setting things up for starting the experiment run cycle are prepared. The test started when the valve is opened, the drop of the HFO waste in the upper cylinder pipe and percolation of this material into the soil is also measured by using the tape for each internal time. The test will continue until the elevation of the HFO waste fixed at a certain level for more than 6 hours; this period is enough to ensure that the HFO waste material completely stopped penetrating the soil. After that, the device is dismantled, and the settlement (due to the weight of HFO waste head) of the soil in the specimen cylinder pipe is measured after removing the residues of the HFO waste from the top of the soil carefully. The Soil samples are taken from different depths directly weighed (to prevent any moisture evaporation from the specimen taken), the samples are oven-dried until it reached a fixed weight to determine the waste degree of saturation. The degree of waste saturation was calculated by taking several samples from known depths. For Warmth HFO a special heater of 1000 watt power, is used to heat the HFO waste to 60 °C.

Figure 1. Schematic of the experimental device

Plate 1. Experimental model at operation
4. Results and Discussion
In this research, the soils were modelled to simulate the real field conditions for different densities (field, loose and dense) with different gypsum content. The height of HFO waste was chosen to be (1, 2, and 3 meters) above the soil. Experiments accomplished once within the laboratory atmospheric temperature, i.e., 25°C, other time within (60°C) for a height of (1m) pollutant head. The reason behind increasing the contaminant temperature during the experimental phase is to simulate the real field conditions at summertime at Baiji thermal power station in Iraq.

4.1. Effect of temperature on percolation forwarding speed
‘Figures 2 to 5’ show the relationship between percolation forwarding speed and the percolation depth in the case of HFO waste 60°C heated system. In an early stage of the experiment (60 minutes) the observed forwarding of the percolation front speed was higher than that recorded in the laboratory temperature system, then it dramatically decreases after that. The decrease in the percolation speed schematically behavior appears at an almost a linear than to a curve. This behavior is attributed to the decrease in the HFO waste temperature inside the soil, causing a relatively increase in the HFO waste viscosity, making the percolation speed become less. This difference can be attributed to the change in viscosity due to heating.
4.2. Effect of temperature on gypsum content
The heating effect of the HFO waste on the relationship between the gypsum content and percolation depth at (24) hour, the results show a similar trend for that without heating, as shown in ‘Figure 6’, where the percolation depth decreased as the gypsum content increased. Also, it can be noticed that the percolation depth increased for warmed HFO when the gypsum in the soil is less than (24-28) %, this reflects the increment of gypsum dissolved as temperature increases. On the other hand, for soil contain more than 28% gypsum the increase in temperature is insufficient to dissolve more gypsum as the gypsum particles may become smaller in size, which makes the soil denser.

4.3. Effect of Temperature on Percolation Depth
The effect of HFO waste temperature increase on the percolation depth into the soil concerning time was found to be same as in the case on the non-heating condition, both systems (HFO waste laboratory temperature system and HFO waste 60°C heated system) show a nonlinear evolution.

‘Figures 7 to 9’ show the comparison between the percolation depth at 24 hours and the temperature in both systems (laboratory temperature system and at the 60°C heated system). From these figures, the observation can be drawn for soil I and soil II; the depth of percolation front was higher in the heated system than laboratory temperature system, because of the low HFO waste viscosity due to heating.

In soil III, soil II increment in percolation depth under heated system than the laboratory temperature system.

For soil IV, the percolation depth in the heated system was less than that observed in the laboratory temperature system for all densities. This behavior may be attributed to the increase in the HFO waste temperature, which maximizes the breaking of the bonds between gypsum particles, which leads to a collapse in soil structure, and this collapse reduces permeability (the soil collapse and particles movement was clearly observed visually during the run cycle via the clear walls of the PVC pipe).
4.4. Effect of temperature on Settlement

Table (3) shows that the increase of the HFO waste temperature has a different influence on the various tested soil types. Soils (I and II) show a significant settlement at HFO waste heating system that the laboratory temperature system, while soils (III and IV) show a minimal settlement resulted by the breaking of the bonds between gypsum particles due to the increasing of HFO waste temperature, what cause a collapse in the soil structure make it denser.

Ahmed [12] performed experimental and theoretical studies of strip footings on oil polluted sand. The results showed a decrease in the bearing capacity and increase in the footing settlement with the increase in depth and length of the polluted sand layer.
Table 4. Settlement value for various soil at variable conditions (temperature, HFO waste column head and densities)

| Variables       | Settlement (mm) |
|-----------------|-----------------|
|                 | Soil I          | Soil II         | Soil III        | Soil IV         |
|                 | Relative densities | Relative densities | Relative densities | Relative densities |
|                 | dense Field loose | dense Field loose | dense Field loose | dense Field loose |
| Temp. Of HFO    |                 |                 |                 |                 |
| Height , depth  |                 |                 |                 |                 |
| h=2m            | 1.8 16 49       | 3 27 62         | 3.5 34 87       | 4.1 44 105      |
| d=1m            | 2.0 2.0 3.0     | 1.5 1.5 2.0     | 1.5 1.5 2.0     | 1.0 1.0 1.5     |
| d=2m            | 3.5 29 90       | 6 49 112        | 6.8 66 158      | 8.4 91 207      |
| d=3m            | 3.0 3.5 4.0     | 2.5 2.5 3.0     | 2.0 2.0 2.5     | 1.5 1.5 2.0     |
| h=3m            | 6 50 153        | 10 84 193       | 12 109 269      | 14 146 348      |
| d=4m            | 3.5 4.0 5.0     | 3.5 3.5 3.5     | 3.0 3.0 3.5     | 2.0 2.5 3.0     |
| h=4m            | 2 18 52         | 4.5 32 66       | 3.2 30 79       | 3 26.6 58       |
| d=5m            | 2.0 2.0 2.5     | 2.0 2.0 2.0     | 1.5 1.5 1.5     | 1.0 1.0 1.0     |

*\(d= depth of soil column \ (mm)\) *\(h= height of HFO waste column \ (m)\)

5. Conclusions
The effect of HFO on the gypseous soil properties was carried out in an extensive laboratory-testing program. The following conclusions are based on these tests:

- The increment in HFO waste temperature increases the percolation front speed in the early stages of the percolation.
- The degree of saturation of soil decreases with the rise in waste temperature.
- Settlement due to the percolation of HFO waste through the soil increases with the minimizing of the soil density and increases with the increase of the soil gypsum content and increase of the HFO waste head.
- Very slightly gypseous and slightly gypseous soils show a significant settlement at HFO waste heating system than the laboratory temperature system, while Moderately gypseous and highly gypseous soils show a minimum settlement resulting in the breaking of the bonds between gypsum particles due to the increase in HFO waste temperature, which causes a collapse in the soil structure making it denser.

References
[1] Chen G H and He G H 2003 Separation of water and oil from water in oil emulsion by freeze/thaw method. Separation and Purification Technology 31, (1): pp 83–89
[2] Ahmed A F, Ahmad J, Basma Y and Ramzi T 2007 J Hazard. Mater; 141:pp 557–564
[3] Amro M M, Benzagouta M S and Karnanda W 2013 Investigation on crude oil penetration depth into soils. Arab J Geosciences 6 (3) pp 873–880
[4] Halmemies S, Grondahl S, Nenonen K and Tuhkanen T 2003 Estimation of the time periods and processes for penetration of selected spilled oils and fuels in different soils in the laboratory Spill Science & Technology Bulletin 8(5): pp 451–465
[5] Kamehchiyan M, Charkhabi AM and Tajik M 2007 Effects of crude oil contamination on geotechnical properties of clayey and sandy soils. *Engineering Geology* **89**: pp 220-229

[6] Taha M Y, Al-Obaidi A A and Taha O M 2008 The use of liquid asphalt to improve gypseous Soils. *Al-Rafidain Engineering* **16**(4): pp 13-29

[7] Al-Adhamii R A J, Fattah M Y and Al-Hadidi M Th. 2018 Crude Oil Effect on the Clayey Soil Mechanical and Physical Properties. *International Journal of Engineering & Technology*, **7** (4.20), pp 453-458

[8] Bello O S and Anobeme S A 2015 The effects of oil spillage on the properties of soil and environment around the marketing outlets of some petroleum marketing companies in calabar, cross river state, Nigeria. *Mayfair Journal of Soil Science* **1**(1) pp 1-14

[9] ASTM (American Society for Testing Materials), Vol. **04**.08 and **04**.09, 2010 *Soil and Rock, West Conshohocken*, United States,

[10] Al-Mufty A A and Nashat I H 2000 Gypsum content determination in gypseous soils and rocks. *3rd International Jordanian Conference on Mining*, Jordan pp 500-506

[11] Barazanji A F 1973 Gypserous soil of Iraq Ph.D. Dissertation, Ghent University, Belgium

[12] Ahmed, MAN 2009 Experimental and theoretical studies of the behaviour of strip footing on oil contaminated sand, *Journal of Geotechnical and Geoenvironmental Engineering*; **35**(12) pp 1814-1822