Design of Packed Bed Column to Remove Emulsified Oil from Refinery Wastewater

By

Team Members:
Abdullah YOUSEF BEAITE
MOHSIN MOHAMMD JAFRI
MOHAMMD ABDU AWAGI
MOHAMMD YAHYA MAGRASHI
MOHAMMD ABDU ZAMIM
MOHAMMD YAHYA MAHNASHI
GASIM MOHAMMD AL-AJAM

Supervisor: Dr. MUBARAK ABDALLA ELDOMA

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عبدالله يوسف بعيطي
محسن محمد جعفري
محمد عبد عواجي
محمد يحيى محرشي
محمد عبد زميم
محمد يحيى محنشى
قاسم محمد الأعجم

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Design of Packed Bed Column to Remove Emulsified Oil from Refinery Wastewater

APPROVAL RECOMMENDED:

PROJECT SUPERVISOR  
Dr. MUBARAK ABDALLA ELDOMA

DATE:

HEAD OF DEPARTMENT
Dr. Saleh Matar

DATE:

COURSE INSTRUCTOR

DATE:

APPROVED:

DEAN, COLLEGE OF ENGINEERING

DATE:
This research concerns with the study of sawdust material in the removal of emulsified oil from wastewater. Synthetic oily wastewater was prepared by mixing 2.5 ml of engine oil with 97.5 tap water (2.5 %). Chemical analysis for synthetic oily wastewater and treated water was carried out to determine the parameterse.g. presence of hydrogen (pH), total dissolve solid (TDS), Total Suspended Solid (TSS), total hardness (TH), Turbidity and Oil Content.

The effect of different particle size of sawdust material say 0.35 mm, 0.50 mm and 1.00 mm) is detected at constant wastewater flow rate, bed weight and bed height in the removal of emulsified oil from oily wastewater was studied in fixed bed column; the highest level of removal of emulsified oil was in the case of 0.50. Fixed packed bed experiments was also conducted, using three different packed bed weight [50 g, 75 g and 100 g] at constant particles size, wastewater flow rate and bed height. The packed bed weight of 100 g is found to be more effective for the removal of emulsified oil under all the tested conditions.

The sawdust adsorbent was found to be an efficient media for the removal of emulsified oil from wastewater using fixed bed column.
DEDICATION

We would like to dedicate this work to our family who support us financially and morally during the whole project, without their support this work was not possible.
ACKNOWLEDGEMENT

In the name of Allah, the creator of all creations, all praises due to Him, the most beneficent and merciful. Alhamdulillah, I had completed this work successfully.

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CHAPTER (1)

INTRODUCTION

1.1. Literature Review

Wastewater is a mixture of liquid wastes from two types of sources. The first source, sanitary sewage, is generated from homes. The second source is the wastewater from businesses, institutions and industries.

Water is of multiple uses for all living organisms because of its unique properties. Water is absolutely essential for life. Human beings depend on water for almost every development activity. Water is used for drinking, irrigation, and transportation, washing and waste disposal for industries, in oil drilling and as a coolant for thermal power plants. Oil pollutes water almost in all steps of production, from upstream to downstream. Water is produced during production operation leaving behind a vast amount of ponds. Several processes should be undertaken before disposable.

In oil refinery, water is usually used in various operations. In short, one can expect wastewater stream coming out from refinery to be loaded with different types of pollutants at various concentrations.

The quality of water, whether it is used for drinking, irrigation, or recreational purposes, is significant for health in both developing and developed countries worldwide.

Meeting the water needs of those that populate earth is an on-going challenge. New approaches to meet these water needs will not be easy to implement: economic and institutional structures still encourage the wasting of water and the destruction of ecosystems. Water quality is important; it can have a major impact on health, both through outbreaks of waterborne disease and contributions to the background rates of disease. Accordingly, water quality standards are important to protect [1]. Water quality, refers to those characteristics or range of characteristics that make water appealing and useful. The ultimate impact of these imperceptible qualities of water (chemicals) on the user may be nothing more than loss of aesthetic values. On the other hand, water-containing water quality monitoring, refer to monitoring practice based on three criteria:
1. To ensure to the extent possible that the water is not a danger to public health
2. To ensure that the water provided is as aesthetically pleasing as possible
3. To ensure compliance with applicable regulations to meet these goals, all public systems must monitor water quality to some extent.[2]

Until the mid-18th century, water pollution was essentially limited to small, localized areas. After industries revolution which results into the development of the internal combustion engine, and the petroleum-fuelled explosion of the chemical industry. With the rapid development of various industries, a huge amount of fresh water is used as a raw material as a means of production (process water), and for cooling purposes. Many kinds of raw material, intermediate products and wastes are brought into the water when water passes through the industrial process. So in fact the wastewater is an "essential by-product" of modern industry, and it plays a major role as a pollution source in the pollution of water environment. [3]

Sources for industrial water usages and various industrial processes have a requirement of water use. There are various avenues where industry can use water more efficiently. Machinery, industrial processes and related support services require large quantities of water which can be reduced significantly by introducing water efficient technology. The quality of water required depends not only on the type of industry, the oil or mining industries, for instance, do not require quality as high as the pharmaceutical industry, but also on its use within the process, so that a single industrial plant may need different qualities of water for different processes. [4]

1-1-1 Characteristics Wastewater

The characteristics of wastewater can be classified into three major categories: physical characteristics, chemical characteristics and biological characteristics. Each one of these categories can be further classified into different types of tests and measurements.

1-1-1-1 Physical Characteristics

The principal physical characteristics of wastewater are its solids content, color, odor and temperature. The total solids in a wastewater consist of the insoluble or suspended solids and the soluble compounds dissolved in water. The suspended solids content is found by drying and weighing the residue removed by the filtering of the sample. When this residue is ignited
the volatile solids are burned off. Volatile solids are presumed to be organic matter, although some organic matter will not burn and some inorganic salts break down at high temperatures.

1-1-1-1 Color

Color is a qualitative characteristic that can be used to assess the general condition of wastewater. Color is measured by comparison with standards. Wastewater that is light brown in color is less than 6 hour old, while a light-to-medium grey color is characteristic of wastewaters that have undergone some degree of decomposition or that have been in the collection system for some time. Lastly, if the color is dark grey or black, the wastewater is typically septic, having undergone extensive bacterial decomposition under anaerobic conditions.

1-1-1-2 Temperature

The temperature of wastewater is commonly higher than that of the water supply because warm municipal water has been added. The measurement of temperature is important because most wastewater treatment schemes include biological processes that are temperature dependent. The temperature of wastewater will vary from season to season and also with geographic location. In cold regions the temperature will vary from about 7 to 18 °C, while in warmer regions the temperatures vary from 13 to 24 °C [5]

1-1-1-3 Odors

Odors in wastes and wastewaters are typically the result of the emission of gases resulting from the anaerobic decomposition of organic matter contained in the waste. The determination of odor has become increasingly important as the general public has become more concerned with the proper operation of wastewater treatment facilities. The odor of fresh wastewater is usually not offensive, but a variety of odorous compounds are released when wastewater is decomposed biologically under anaerobic conditions. Importance of odors have been rated as the number one concern by local communities during siting of new wastewater treatment facilities. Although most odorous substances are not toxic at the concentrations at which they can be detected by humans odors can produce significant psychological stress.

The principal odorous compound is hydrogen sulphide (the smell of rotten eggs).

1-1-1-4 Solid Content
The solids content in industrial wastewater vary greatly, depending on the process generating the wastewater.

**1-1-1-2 Chemical Characteristics**

Chemically, industrial waste-water contains many organic and inorganic compounds in varying amounts. The chemicals that can exist in industrial waste-water are the same as those discussed earlier for sanitary waste-water. However, industrial waste-water does not contain human wastes and vegetable matter, so the biological organics are hydrocarbon compounds. Measurement of biological oxygen demand (BOD), chemical oxygen demand (COD), total organic carbon (TOC) and total oxygen demand (TOD) are important tests for industrial waste-water. [6] Industrial wastewaters frequently contain high levels of heavy metals and treatment is needed before disposal, in order to avoid water pollution. There are numerous sources of industrial effluents leading to heavy metal discharges apart from the mining and metal related industries. Heavy metal pollution frequently results from the industrial use of organic compounds containing metal additives in the petroleum and organic chemical industries [7]

**1-1-1-2-1 Presence of Hydrogen (pH)**

Determination of pH plays an important role in the wastewater treatment process. Extreme pH levels, presence of particulate matters, accumulation of toxic chemicals and increasing alkalinity levels are common problems in wastewater. This becomes a serious environmental concern in recent years. The pH analyses are important for neutralization, coagulation and other biological treatment process. pH analyses are probably the most recommended method for waste water treatment.

**1-1-1-2-2 Total Dissolved Solids (TDS)**

The term "dissolved solids" is very commonly used in discussion of wastewater. Dissolved solids are smaller in size than suspended and colloidal solids. As used, the term means all of the solids which pass through the filter pad of a Gooch Crucible. Of the total dissolved solids, about 90 percent are in true solution and about 10 percent colloidal. Dissolved solids, as a whole, are about 40 percent organic and 60 percent inorganic

**1-1-1-2-3 Dissolved Oxygen (D.O)**

The level of dissolved oxygen in water is used as an indication of pollution and its potability. This thus forms a key test in water pollution control activities and waste treatment process
control activities and waste treatment process control. The recommended guideline value for drinking water is a level not below 8 mg/l (WHO, 1984). Lower levels indicate microbial contamination or corrosion

1-1-1-2-4 Total Hardness (T.H)

Hardness of water is a measure of the total concentration of the calcium and magnesium ions expressed as calcium carbonate

1-1-1-2-5 Organic Materials

Materials consist of a mixture of organic carbon, hydrogen, oxygen and nitrogen, and in some cases some other important elements such as sulfur, phosphorus and iron are found in addition. The industrial wastewater containing small amounts of synthetic and organic molecules that varies with their chemical composition. Some materials such as surfactants (detergents) and persistent organic priority and volatile organic compounds and pesticides also vary with their chemical composition. The presence of these compounds to the many complexities of the operations of industrial wastewater treatment because most Oils, fats and grease. Fat is considered one of the most stable organic materials as they do not decompose easily by bacteria and up kerosene and lubricating oil to exchange via workshops and garages where floats on the surface of the water and sanitation remains a tiny part of it in the form of sludge. This mineral oils cause problems in maintenance as a result of its coverage of the surfaces. If the grease is not removed before the water discharge to the external environment, they may adversely affect the biological life in the surface waters, causing a layer of material floating invisible. The oil and grease substance tests to determine the components of hydrocarbons in industrial wastewater. These tests include greases and oils free and emulsified oils. These tests will determine the nature of the treatment required and are removed oil and grease free float or abrasion using a gravity separation of oils, while emulsified oils are removed using a dissolved air floating after fracturing chemical emulsified oils. In all cases, you must remove oil and grease prior to the biological treatment and only happens a blockage in the water distribution pipes and air distribution. [8]

1-1-1-2-6 Inorganic Materials:

Many of the indicators in inorganic wastewater are important for the development and control of the water quality standards of exchange. It must industrial wastewater treatment to
remove inorganic ingredients that are added during the use of water and increasing concentrations of inorganic components due to the natural process of evaporation, which get rid of some of the surface water leaving the inorganic materials in the waste water

1-1-2 Objective of Wastewater Treatment

The various objectives water treatment processes is to confer and preserve the inherent physical, chemical and biological qualities of water of different origins which make it suitable for specific uses such as water for drinking and for use in productive processes and to permit wastewater treatment which will protect the public from health risks without causing any damage to the environment [1]. Also the principal objective of wastewater treatment is generally to allow human and industrial effluents to be disposed of without any danger to human health or unacceptable damage to the natural environment. Irrigation with wastewater is both disposal and utilization and indeed is an effective form of wastewater disposal (as in slow-rate land treatment). However, some degree of treatment must normally be provided to raw municipal wastewater before it can be used for agricultural or landscape irrigation or for aquaculture. The quality of treated effluent used in agriculture has a great influence on the operation and performance of the wastewater-soil-plant or aquaculture system. In the case of irrigation, the required quality of effluent will depend on the crop or crops to be irrigated, the soil conditions and the system of effluent distribution adopted. Through crop restriction and selection of irrigation systems which minimize health risk, the degree of pre-application wastewater treatment can be reduced. A similar approach is not feasible in aquaculture systems and more reliance will have to be placed on control through wastewater treatment.

1-1-3 Method of Wastewater Treatment

Wastewater can be treated through four stages these are preliminary, primary, secondary and tertiary methods.

1-1-3-1 Preliminary Treatment

As wastewater enters a treatment facility, it typically flows through a step called preliminary treatment. A screen removes large floating objects, such as rags, cans, bottles and sticks that may clog pumps, small pipes, and downstream processes. The screens vary from coarse to fine and are constructed with parallel steel or iron bars with openings of about half an inch, while others may be made from mesh screens with much smaller openings.

1-1-3-2 Primary Treatment
This is designed to remove gross, suspended and floating solids from raw waste water. It includes screening to trap solid objects and sedimentation by gravity to remove suspended solids. This level is sometimes referred to as “mechanical treatment”, although chemicals are often used to accelerate the sedimentation process. Primary treatment can reduce the BOD of the incoming wastewater by 20-30% and the total suspended solids by some 50-60%. Primary treatment is usually the first stage of wastewater treatment. Many advanced wastewater treatment plants in industrialized countries have started with primary treatment, and then added other treatment stages as wastewater load has grown, as the need for treatment has increased, and as resources have become available.

1-1-3-3 Secondary Treatment

This stage is for removal of the dissolved organic matter that escapes in primary treatment. This is achieved by microbes consuming the organic matter as food, and converting it to carbon dioxide, water, and energy for their own growth and reproduction. The biological process is then followed by additional settling tanks to remove more of the suspended solids. About 85% of the suspended solids and BOD can be removed by a well running plant with secondary treatment. Secondary treatment technologies include the basic activated sludge process, the variants of pond and constructed wetland systems, trickling filters and other forms of treatment which use biological activity to break down organic matter.

1-1-3-4 Tertiary Treatment

This is simply additional treatment beyond secondary treatment. Tertiary treatment can remove more than 99 percent of all the impurities from wastewater, producing an effluent of almost drinking-water quality. The related technology can be very expensive, requiring a high level of technical know-how and well trained treatment plant operators, a steady energy supply, chemicals and specific equipment which may not be readily available. An example of a typical tertiary treatment process is the modification of a conventional secondary treatment plant to remove additional phosphorus and nitrogen. Disinfection, typically with chlorine, can be the final step before discharge of the effluent. However, some environmental authorities are concerned that chlorine residuals in the effluent can be a problem in their own right, and have moved away from this process. Disinfection is frequently built into treatment plant design, but not effectively practiced, because of the high cost of chlorine, or the reduced effectiveness of ultraviolet radiation where the water is not sufficiently clear or free of particles. [9]
Fig. (1.1) Process flow diagram for refinery wastewater treatment.

1-1-4 Adsorption Process:

Adsorption is the adhesion of atoms, ions, or molecules from a gas, liquid, or dissolved solid to a surface. This process creates a film of the adsorbate on the surface of the adsorbent. This process differs from absorption, in which a fluid (the absorbate) permeates or is dissolved by a liquid or solid (the absorbent).

Adsorption is a surface-based process while absorption involves the whole volume of the material. The term sorption encompasses both processes, while desorption is the reverse of it. Adsorption is a surface phenomenon.

Similar to surface tension, adsorption is a consequence of surface energy. In a bulk material, all the bonding requirements (be they ionic, covalent, or metallic) of the constituent atoms of the material are filled by other atoms in the material. However, atoms on the surface of the adsorbent are not wholly surrounded by other adsorbent atoms and therefore can attract adsorbates. The exact nature of the bonding depends
on the details of the species involved, but the adsorption process is generally classified as physisorption (characteristic of weak van der Waals forces) or chemisorption (characteristic of covalent bonding). It may also occur due to electrostatic attraction.

Adsorption is present in many natural, physical, biological, and chemical systems, and is widely used in industrial applications such as activated charcoal, capturing and using waste heat to provide cold water for air conditioning and other process requirements (adsorption chillers), synthetic resins, increase storage capacity of carbide-derived carbons, and water purification. Adsorption, ion exchange, and chromatography are sorption processes in which certain adsorbates are selectively transferred from the fluid phase to the surface of insoluble, rigid particles suspended in a vessel or packed in a column. Lesser known, are the pharmaceutical industry applications as a means to prolong neurological exposure to specific drugs or parts thereof citation needed. [5]

1-1- 4-1 Activated Carbon
Activated carbon, also called activated charcoal, activated coal, or carbon activates, is a form of carbon processed to be riddled with small, low-volume pores that increase the surface area available for adsorption or chemical reactions. Activated is sometimes substituted with active. Due to its high degree of micro porosity, just one gram of activated carbon has a surface area in excess of 500 m², as determined by gas adsorption. An activation level sufficient for useful application may be attained solely from high surface area; however, further chemical treatment often enhances adsorption properties.

Activated carbon is usually derived from charcoal and increasingly, high-porosity biochar. It is on the World Health Organization's List of Essential Medicines, a list of the most important medication needed in a basic health system. Activated carbon is used in gas purification, decaffeination, gold purification, metal extraction, water purification, medicine, sewage treatment, air filters in gas masks and respirators, filters in compressed air and many other applications.

One major industrial application involves use of activated carbon in the metal finishing field. It is very widely employed for purification of electroplating solutions.
For example, it is a main purification technique for removing organic impurities from bright nickel plating solutions. A variety of organic chemicals are added to plating solutions for improving their deposit qualities and for enhancing properties like brightness, smoothness, ductility, etc. Due to passage of direct current and electrolytic reactions of anodic oxidation and cathodic reduction, organic additives generate unwanted breakdown products in solution. Their excessive build up can adversely affect the plating quality and physical properties of deposited metal. Activated carbon treatment removes such impurities and restores plating performance to the desired level [10]

1-1-4-2 Sawdust Material

Sawdust or wood dust is a by-product of cutting, grinding, drilling, sanding, or otherwise pulverizing wood with a saw or other tool; it is composed of fine particles of wood.

1-2 Problem Statement Objectives

One of the main sources of many industrial contaminations is the wastewater produced by industries which must be treated in order to achieving local effluent discharge standards.

Refinery is an important step in oil production. Water is used here for several purposes at different stages of refining. An appreciable amount of wastewater is left behind in the process; pollution of water resource and environment nearby is expected.

Oil refinery, as one of the most important industries worldwide, especially in Middle East, produces a huge amount of poisonous and oily wastewater which needs complicated treatment systems. [11]

KSA is an oil producing country with more than nine refineries. In these refineries a lot of water is used in desalting, reboilers, condensers cooling towers, catalytic cracking, hydro-cracking and reformation. These wastewaters are contaminated with oils, phenols, salts, heavy metals, acids and other impurities that have an impact on the environment. These waste waters need to be treated properly and recycled again.

The available method of refinery waste water treatment under application for the time being is very expensive and complicated. The aim of this study is to remove the oil from waste water produced by Refineries. The main technique used in the removal of oily water is adsorption of oil using sawdust as absorbent material.
1-3 Problem Justification and Outcomes

The study is concern with an investigation into the different possibilities of recycling the treated wastewater. The aims of the study are to choose a suitable and proper method for treatment of a refinery wastewater, recycling of the properly treated wastewater and environment impact assessment of the process of treatment.

1-4 Problem Constraints

The treatment process depends on the nature of the waste-water and the quality of the effluent desired. The samples of waste-water were prepared by mixing tap water with engine oil which give the same specification of the oily waste water produced from refinery. The amount of waste-water used for chemical analysis experiments and treatment processes was 150 liters.
2-1 Design Approach

The packed bed column is designed to operate at atmospheric pressure in a continuous operation. The packing material is sawdust. Studies were carried out through three parts; chemical analysis of synthetic oily wastewater, design of a pilot plant for treating the wastewater and assessing the quality and quantity of the produced.

2-2 Design Methodology

The experiments are carried over a period of four months from January to April 2014.

2.2.1. Preparation of Sample of Oily Wastewater

Synthetic wastewater samples were prepared by mixing 25 ml of oil engine and 975 ml of tap water (concentration 2.5%). The amount of synthetic wastewater used for chemical analysis experiments and the treatment processes was 150 liters.

2.2.2 Chemical Analysis of Synthetic Oily Wastewater

The first step towards synthetic wastewater is to determine the values of presence of hydrogen (pH), Total Dissolve Solid (TDS), Total Suspended Solid (TSS), Total Hardness (TH), Turbidity and Oil Content.

The main techniques employed in chemical analysis of these samples are quantitative analysis, and the method used is gravimetric and other detection methods [12].

The main part of this kind of wastewater is oil (oily wastewater) and can be treated by the sawdust absorbent.

2-2-2-1 Determination of pH

Materials and apparatus

- pH Standard buffer solutions of pH values A = 4.0, B = 7.0 and C =9.0.
- Distilled water.
- Sample of synthetic oily wastewater.
- Microprocessor pH meter.

Procedure [12]

1- The pH standard buffer solution was used to calibrate the instrument and electrode. The buffer solution pH value should be closed to the pH of the water sample in the calibrate scale.

2- Distilled water was used to wash electrode after every test for several times. Then we took oily wastewater sample and measured the pH.

2-2-2-2 Determination of Total Dissolved Solid (TDS)

Materials and apparatus

- Distilled water
- Sample of synthetic wastewater
- Analytical balance of reciprocal sensibility $1.0 \times 10^{-4}$ g.
- Water- bath.
- Electrically heated thermostat.
- Porcelain evaporating dish.
- Silica gel as drying agent.
- Middle speed quantitative filter paper (diameter of hole is 0.45µm) was used.

Procedure:-

1- The evaporating dish was cleaned and put in oven at 105°C for 30 min, then allowed to cool.

2- The evaporating dish was weighed at analytical balance $w_1$.

3- The clear liquor of synthetic oily wastewater sample was filtered, 100 ml were taken to evaporating dish and put in to the oven for evaporating at 105°C for one hour, then cool down for 30 min and weighed, $w_2$.

Calculations

$$C = \frac{(W2 - W1)}{(100 \times 1000 \times 1000)} \quad (2.1)$$
Where:

\[ C = \text{Total dissolved solid in sample of synthetic oily wastewater, mg/l.} \]

\[ W_1 = \text{Weight of empty evaporating dish, g.} \]

\[ W_2 = \text{Weight of evaporating dish and total dissolved solid, g.} \]

**2-2-2-3 Determination of Total Suspended Solid (TSS)**

Materials and apparatus:

- Distilled water
- Sample of synthetic oily wastewater.
- Manganese sulfate solution 340 g/l
- Sulfuric acid solution 2 mol.
- Alkaline iodide reagent
- Starch indicator 1%.
- Sodium thiosulfate 0.01 mol/l.
- A narrow mouth bottle with volume of 250—300ml
- Digital burette –50 ml
- Hirschmann-Laborgerate.

Procedure [12]

1- The narrow necked bottle was filled with the synthetic oily wastewater sample.

2- 1 ml of MnSO\(_4\) and 2 ml of alkaline iodide solutions were added, the cover was closed carefully then shaken well and waited for five minutes.

3- 1 ml sulfuric acid solution and 3 drops of starch indicator were added and shaken well, and the contents of the narrow bottle were transferred to a clean conical flask.

4- The contents of the conical flask were titrated against Na\(_2\)S\(_2\)O\(_3\) from the burette till the end point.

Calculation:-

\[ C = \left( \frac{M_r \times V_2 \times C \times f_1}{4V_1} \right) \]  \hspace{1cm} (2.2)
Where:

- $M_r$ = Molecular weight of oxygen (32)
- $V_1$ = Sample volume for titration in ml, normally 100 ml.
- $V_2$ = Volume consumption of sodium thiosulfate for titration, in ml.
- $C$ = Actual concentration of sodium thiosulfate in mol/l.

\[
F_1 = \frac{V_0}{(V_0 - V)}
\]  \hspace{1cm} (2.3)

Where:-

- $V_0$ = Volume of narrow bottle.
- $V''$ = Actual volume of manganese sulfate solution (1.0 ml) and alkaline reagent (2.0 ml).

2-2-2-4 Determination of Total Hardness (TH)

Materials and apparatus

- Distilled water.
- Sample of synthetic oily wastewater.
- Standard buffer solution of pH value 10.
- EDTA solution (Ethylene Di amine Tetra Acetic Acid)
- Eri chrome black T indicator.

Procedure [12]

1- Fifty ml of sample of synthetic oily wastewater were transferred into a clean conical flask.

2- Three drops of tri ethanol amine solution were added.

3- Five ml of buffer solution were added.

4- Three drops of Eri chromo black T indicator were added.

5- The contents of the conical flask were titrated against EDTA solution.
2-2-2-5. Determination of Oil Content Using Spectrophotometer

Procedure [12]

1. We took distilled water as reference in one cuvette and second cuvette was filled by sample up to mark.
2. Wavelength was fixed in UV-Visible range and run the sample.
3. All samples were tested one after one.
4. Graphs were plotted in excel sheet between wavelength (nm) and absorbance.

2-2-2-6 Determination of Voids of Packing of Sawdust

Material and apparatus
- 1.0 kilogram of sawdust.
- Distilled water.
- Adsorption packed bed unit. (Packed material is sawdust).
- Stop watch.

Procedure [13]

1- The water tank was filled up with clean water or filtered water.
2- The column was filled with certain weight of sawdust to the desired height. The following weight of sawdust 50, 100 and 150 g are used to obtain packed height of 40 cm to give different size of voids as shown in table (2.1)
3- The pump was switched on slowly, the valve was adjusted to obtain flow rate of 0.40 L/min.
4- The column was drained and the bed was changed with sawdust of different weight and constant height (40 cm).
5- The volume of sawdust was calculated by displace method.

The void fraction or porosity in a packed bed is defined as:-
\[ \varepsilon = \frac{\text{Volume of Void in bed}}{\text{Total volume of bed (i.e voids + solids)}} \]  \hspace{1cm} (2.5)

Where:

\[ \varepsilon = \text{Void fraction or porosity} \]
Total volume of bed = voids + solids.

The volume of bed = \( \pi D^2 / 4 \times 40 \) = cm\(^3\) \hspace{1cm} (2.6)

Table (2.1) Different Bed Weights at Constant Bed Height

<table>
<thead>
<tr>
<th>Weight of sawdust, g</th>
<th>Packed height, cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>40</td>
</tr>
<tr>
<td>100</td>
<td>40</td>
</tr>
<tr>
<td>150</td>
<td>40</td>
</tr>
<tr>
<td>200</td>
<td>40</td>
</tr>
</tbody>
</table>

2-2-2-7 Determination of Particle Size of Sawdust Using Sieve Shaker

Materials and apparatus

- ? kg of sawdust
- Electronic balance
- Sieve shaker
  - To determine the particle size of sawdust using a sieve shaker.

Procedure: [14]

- Prepare approximately 1.0 kg of dry sawdust
- Arrange the sieves in the stack with the smallest mesh at the bottom, above the pan.
- Pour the sawdust into the top most sieves and spread evenly.
- Set the timer to 20 minutes. Switch on the shaker and wait until it stops automatically.
- Carefully weigh the sawdust retained in each sieve.
- Perform sieve analysis.

Fig (2.1a) sawdust sample 0.35 mm
2-2-2-8 Removal of Oil from Wastewater Using Sawdust at Variable Particle Size and Constant Bed Weight, Flow Rate, and Bed Height.
Material and apparatus
- Sample of synthetic oily wastewater.
- 1.0 kilogram of sawdust.
- Distilled water.
- Adsorption packed bed unit. (Packed Material is Sawdust).

Table (2.2) Constant Bed Height at Different Voids

<table>
<thead>
<tr>
<th>Weight of Sawdust, g</th>
<th>Packed Height, cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>40</td>
</tr>
<tr>
<td>100</td>
<td>40</td>
</tr>
<tr>
<td>100</td>
<td>40</td>
</tr>
</tbody>
</table>

2-2-2-9 Removal of Emulsified Oil from Wastewater Using sawdust at Variable Bed Weight and Constant Flow Rate, Particle Size and Bed Height.

Material and apparatus
- Sample of synthetic oily wastewater.
- 1.0 kilogram of sawdust;
- Distilled water.
- Adsorption packed bed unit. (Packed material is sawdust).

Procedure: [15]
1. The water tank was filled up with synthetic oily wastewater.
2. The column was filled with certain weight of sawdust to the desired height. The following weights sawdust 50, 100 and 150 g are used to obtain packed height of 40 cm to give different size of voids.
3. The pump was switched on slowly, the valve was adjusted to obtain flow rate of 0.40 L/min
4- The column was drained and the bed was changed with sawdust of different weight and constant height (40 cm).

5- The experiment was continued with constant waste-water flow rate (0.40 L/min).

Fig (2.2) Sample of Synthetic Oily Wastewater
CHAPTER 3
THEORETICAL BACKGROUND

3-1 Design specifications and assumptions

The unit is designed to operate at atmospheric pressure in a continuous operation. It has the following special features, which is required in research study:

- Fully equipped allows convenient data collection and analysis.
- Glass column permit good visual monitoring of the process.
- Sampling points for composition analysis are provided at the columns’ liquid streams.

Description and Assembly

Refer to the process flow diagram in Figure (3.1).

1. Water Tank (B1)
   Rectangular tanks with removable top cover
   Capacity: 50-L
   Material: stainless steel
   Low level switch for protection of centrifugal pump from dry run

2. Water Tank (B2)
   Rectangular tank with removable top cover and level sight tube
   Capacity: 50L
   Material: Stainless steel

3. Circulation Pump (P1)
   Centrifugal pump
   Max. Delivery: 14.0 L/min
   Amp: 5.0 Amps
   Volts: 24 volts D.C
Max pressure: 45 psi

Material: polypropylene (PP)

Max. Flow rate in the system: 11 L/min

4. Absorption Column (K1)

Packed columns filled with sawdust material

Diameter: 50 mm Effective packing height: 90 m

Material: borosilicate glass

Fig (3.1) Schematic Diagram of Lab-scale Column Study
3-2 Mathematical models and formulations

The flow of fluids through beds composed of stationary granular particles is a frequent occurrence in the chemical industry and therefore expressions are needed to predict pressure drop across beds due to the resistance caused by the presence of the particles.

The general structure of a bed of particles can often be characterized by the specific surface area of the bed and the fractional void age of the bed, the surface area presented to the fluid per unit volume of bed when the particles are packed in a bed. The fraction of the volume of the bed not occupied by solid material and is termed the fractional void age, or porosity.

Certain geometric relations for particles are used in the derivations for flow in packed beds. The void fraction or porosity in a packed bed is defined as [16]

\[
\varepsilon = \frac{\text{Volume of Void in bed}}{\text{Total volume of bed (i.e voids + solids)}}
\]  

\[\text{(3.1)}\]

In this case, the mass of the particle is constant. Hence, the equation can be written in terms of density;

\[
\varepsilon = 1 - \frac{\rho_b}{\rho_s}
\]

\[\text{(3.2)}\]

Where:

\(\rho_s\) = particle density

\(\rho_b\) = bed density

Table (3.1) shows the values of the porosity for various porous materials. Whereas the table (3.2) shows the results of experiment; the relationship between friction factor and Reynolds number.
For the packed beds Ergun defined the Reynolds number as:

\[ N_{Re\text{'}p} = \frac{D_p v' \rho}{(1 - \varepsilon)^{1/2} \frac{32 \mu}{32 \mu} \left( v'/\varepsilon \right) \Delta L} \]

\[ \Delta p = \frac{32 \mu v' \Delta L}{D^2} = \frac{(72) \mu v' \Delta L (1 - \varepsilon)^2}{\varepsilon^3 D^2 p} \quad (3.3) \]

Table (3.1) Some typical value of porosity for various porous materials is given in table below:

<table>
<thead>
<tr>
<th>Material</th>
<th>porosity</th>
<th>material</th>
<th>Porosity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Berl saddles</td>
<td>0.68 – 0.83</td>
<td>Brick</td>
<td>0.12 - 0.34</td>
</tr>
<tr>
<td>Catalyst Granules</td>
<td>0.45</td>
<td>Cigarette filter</td>
<td>0.17 – 0.49</td>
</tr>
<tr>
<td>Coal</td>
<td>0.02 - 0.12</td>
<td>Concrete</td>
<td>0.02 – 0.07</td>
</tr>
<tr>
<td>Crushed rock, granular</td>
<td>0.44 – 0.45</td>
<td>Fiberglass</td>
<td>0.88 – 0.93</td>
</tr>
<tr>
<td>Leather</td>
<td>0.56 – 0.59</td>
<td>Limestone</td>
<td>0.02 – 0.20</td>
</tr>
<tr>
<td>Limestone (dolomite)</td>
<td>0.04 – 0.10</td>
<td>Rasching rings</td>
<td>0.56 – 0.65</td>
</tr>
<tr>
<td>Sand</td>
<td>0.31 – 0.50</td>
<td>Sandstone</td>
<td>0.08 – 0.40</td>
</tr>
<tr>
<td>Silica powder</td>
<td>0.013 -0.051</td>
<td>Soil</td>
<td>0.43 – 0.54</td>
</tr>
<tr>
<td>Spherical packing, shaken</td>
<td>0.36 – 0.43</td>
<td>Wire rings</td>
<td>0.68 – 0.76</td>
</tr>
</tbody>
</table>

Table (3.2) experimentally, the relationship between friction factor and Reynolds number has been found to be reasonably modeled by:

<table>
<thead>
<tr>
<th>Range of Re</th>
<th>fp</th>
<th>Appellation</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 10</td>
<td>150/Re</td>
<td>Blake – Kozeny</td>
</tr>
<tr>
<td>10 &lt; Re &lt; 104</td>
<td>150/Re + 1.75</td>
<td>Ergun</td>
</tr>
<tr>
<td>&gt; 104</td>
<td>1.75</td>
<td>Burke – Plummer</td>
</tr>
</tbody>
</table>
The true $\Delta L$ is larger because of the tortuous path, and use of the hydraulic radius predicts too large a superficial velocity, $\nu'$.

Experimental data show that the constant should be 150, which gives the Blake-Kozeny equation for laminar flow, void frictions less than 0.5, effective particle diameter $D_p$ and $N_{Re,p}$ < 10:

$$\Delta P = \frac{150 \mu \nu' \Delta L (1 - \varepsilon)^2}{D_p^2 \varepsilon^3}$$ (3.4)

$\Delta P$ = pressure drop

$D_p$ = particle diameter

$\mu$ = viscosity

$\Delta L$ = length

$\nu'$ = superficial velocity

$\varepsilon$ = void friction

For highly turbulent the friction factor should approach a constant value. Also, it is assumed that all packed beds should have the same relative roughness. Hence the final equation for turbulent flow for $N_{Re,p}$ > 1000, which is called the Burke-Plummer equation becomes

$$\Delta P = \frac{1.75 \rho (\nu')^2 \Delta L 1 - \varepsilon}{D_p \varepsilon^3}$$ (3.5)

Adding equation (3.4) for laminar flow and equation (3.5) for turbulent flow, Ergun proposed the following general equation for low, intermediate, and high Reynolds numbers, which has been tested experimentally:

$$\Delta P = \frac{150 \mu \nu' \Delta L (1 - \varepsilon)^2}{D_p^2 \varepsilon^3} + \frac{1.75 \rho (\nu')^2 \Delta L 1 - \varepsilon}{D_p \varepsilon^3}$$ (3.6)
4-1 Design Procedures

Chemical analyses of synthetic wastewater are carried out to determine the pH, Total Dissolved Solid (TDS), Total Suspended Solid (TSS) and Total Hardness (TH). Turbidity and Oil content (4.1) also carried out for synthetic oily wastewater to determine the concentration of oil content. (Table 4.2)

The experiment was conducted to determine the voids of packing of the sawdust (Table 4.3) and in the determination of the size particles of sawdust (Table 4.4)

Experiments were performed to determine the efficiency of adsorption of the sawdust at constant wastewater flow rate, constant bed height and variable particle size of sawdust (Table 4.5) Figures (4.1a)(4.1b)(4.1c)

The experiments were also carried out with variable bed weight and constant flow rate, bed height. The particle size of sawdust determines the effects of bed weight on the adsorption process. (Table 4.6) figures (4.2a)(4.2b)(4.2c)
Table: (4.1) Results of chemical analysis synthetic wastewater

<table>
<thead>
<tr>
<th>Particle Size</th>
<th>Bed weight (gm)</th>
<th>Bed weight (gm)</th>
<th>Bed weight (gm)</th>
<th>Bed weight (gm)</th>
<th>Bed weight (gm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.355 mm</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>75</td>
<td>50</td>
</tr>
<tr>
<td>0.5 mm</td>
<td>0.5</td>
<td>1.0</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td></td>
<td>130</td>
<td>97.5</td>
<td>65.0</td>
<td>75</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>9.81</td>
<td>6.98</td>
<td>7.08</td>
<td>7.08</td>
<td>7.08</td>
</tr>
<tr>
<td></td>
<td>6.67</td>
<td>6.88</td>
<td>6.81</td>
<td>6.98</td>
<td>7.08</td>
</tr>
<tr>
<td></td>
<td>27</td>
<td>18</td>
<td>20</td>
<td>24</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>2600</td>
<td>2530</td>
<td>2550</td>
<td>2470</td>
<td>2470</td>
</tr>
<tr>
<td></td>
<td>840</td>
<td>800</td>
<td>830</td>
<td>810</td>
<td>870</td>
</tr>
<tr>
<td></td>
<td>8.78</td>
<td>5.99</td>
<td>6.42</td>
<td>6.04</td>
<td>3.61</td>
</tr>
</tbody>
</table>

Table (4.2) Determination of the voids of packing of the sawdust

<table>
<thead>
<tr>
<th>Weight (gm)</th>
<th>Void (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>130</td>
</tr>
<tr>
<td>075</td>
<td>97.5</td>
</tr>
<tr>
<td>050</td>
<td>65.0</td>
</tr>
</tbody>
</table>
Table (4.3) Determination of the size particles of sawdust

<table>
<thead>
<tr>
<th>Particles size (mm)</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.000</td>
<td>150 gm</td>
</tr>
<tr>
<td>0.500</td>
<td>500 gm</td>
</tr>
<tr>
<td>0.355</td>
<td>350 gm</td>
</tr>
</tbody>
</table>

Table: (4.4) Results of chemical analysis treated synthetic wastewater using sawdust at variable particle size and constant bed weight, flow rate, and bed height.

<table>
<thead>
<tr>
<th>Particle size (mm)</th>
<th>Concentration of oil</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00</td>
<td>8.988*10^-3</td>
</tr>
<tr>
<td>0.50</td>
<td>6.033*10^-4</td>
</tr>
<tr>
<td>0.355</td>
<td>3.68*10^-3</td>
</tr>
</tbody>
</table>

Table: (4.5) Results show the chemical analysis of oil content in synthetic wastewater variable bed weight with constant flow rate, bed height and particle size of sawdust

<table>
<thead>
<tr>
<th>Particle size (mm)</th>
<th>Bed weight in g</th>
<th>Concentration of oil</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.50</td>
<td>50</td>
<td>6.0333*10^-4</td>
</tr>
<tr>
<td>0.50</td>
<td>75</td>
<td>1.8682*10^-3</td>
</tr>
<tr>
<td>0.50</td>
<td>100</td>
<td>1.0153*10^-3</td>
</tr>
</tbody>
</table>
(Fig 4.1) Synthetic wastewater

(Fig 4.2a) Bed weight of 100 g and particle size 1.0 mm
Fig (4.2b) bed weight of 100 g and particle size 0.5 mm

(Fig 4.2c) Bed weight of 100 g and particle size 0.355 mm
Fig (4.3a) sample 1 sawdust of particle size 0.5 mm and bed 50 g

Fig (4.3b) sample 1 sawdust of particle size 0.5 mm and bed 75 g
4-2 Design Implementation

The chemical analysis involves pH, Total Dissolved Solid (TDS) Total Suspended Solid (TSS), Total Hardness (TH) and Turbidity were studied. The treated effluent was analyzed; the results do not depend on the parameters of bed weights and particle size in Table (4.1).

Chemical analysis was also carried out to determine the concentration of oil in synthetic oily. It was found to be $8.225 \times 10^{-3}$. Figure (4.1)

To determine the optimum wastewater flow rate, the void fraction for the packed bed column was calculated by carrying out an experiment at variable bed height and constant bed height and sawdust particle size. The voids fraction decreases with increasing the bed weight. Table (4.2)

To determine the size particle of sawdust material, experiment was carried out in sieve shaker equipment. Table (4.3)
This research has studied the effect of sawdust material in the removal of emulsified oil in wastewater using packed bed columns under a variety of operating conditions such as sawdust particle size and packed bed weight.

Also experiment was carried out to determine the optimum particle size of sawdust material (0.35 mm, 0.50 mm and 1.00 mm) in adsorption of emulsified wastewater. It is found that the particle size of 0.5 is the best one in removal of emulsified wastewater table (4.4).

In order to select the optimum bed weight for packed bed column to remove oily wastewater, the experiments were conducted with different bed weight, constant flow rate, and bed height and sawdust particle size. Figures (4.2a), (4.2b) and (4.2c)

Sawdust has a high efficiency for the adsorption of oils from wastewater. The results listed in Table (4.6) show that the concentration of oil contents values can be decreased by increasing the bed weight (sawdust) at constant particle size and wastewater flow rate, the optimum bed weight is 100g. Figures (4.3a), (4.3b) and (4.3c).
CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

A- Conclusion

1. It is possible to use sawdust as adsorbent material; which help in decreasing the dangerous environmental impact.
2. The removal efficiency increases with increasing bed weight and decreasing particle size of sawdust.
3. Adsorption of oil from oily refinery waste-water using sawdust packed bed column processes have economic advantages because there is no need to additional energy use and the low cost of sawdust compared to those of others wastewater treatments plants.
4. The quality of the waste-water treated by this system is conformable to the waste-water offloading to the environment standards. Moreover, this treated waste-water can be reused in cooling towers, irrigations, drinking for cattle and so on. This decreases the expense of raw water preparing, and has a positive influence on environment by decreasing the use of underground waters. In conclusion; the series of these tests performed in this research shows that it is possible to use sawdust as adsorbent material; which help in solving the problems of refinery waste-water treatment system, in order to decreases the dangerous environmental impact.

B- Recommendations

This research points towards the need for further investigations in the following areas:

1. The ability of others material such as charcoal in removing refinery oily waste-water comparing with sawdust adsorbent.
2. The sawdust which contains oil after adsorption process is considered as sources of energy.
References


[3] Hanchang SHI Department of Environmental Science and Engineering, Tsinghua University, Beijing, China


[5] The word "adsorption" was coined in 1881 by German physicist Heinrich Kayser (1853-1940)


[16] Coulson and Richardson’s, chemical engineering, volume 2, 5th edition, Particle Technology and Separation Processes,(2002)

APPENDIXES

A: Project Team with assigned responsibilities,

B: Faculty Advisers and Industry sponsors ................................

C: Project Budget and Expenses to date .................................

D: Drawing package (if applicable) ....................................... 

E: Manufacturing procedures, Test procedures and Test reports .......... 

F: Technical reports or evaluations ........................................

REFERENCES.................................................................

BIBLIOGRAPHY..............................................................
CAPSTONE DESIGN PROJECT

Project Submission

And

ABET Criterion 3 a-k Assessment Report

Project Title

Design of Packed Bed Column to Remove Emulsified Oil from Refinery Wastewater

DATE: / May / 1435

PROJECT ADVISOR: Dr. MUBARAK ABDALLA ELDOMA

Team Leader: ______________________________

Team Members: ______________________________

________________________

______________________________

______________________________

Design Project Information

Percentage of project Content- Engineering Science % ____________

Percentage of project Content- Engineering Design % ____________

Other content % All fields must be added to 100% ____________

Please indicate if this is your initial project declaration

□ Project Initial Start Version

□ Final Project Submission Version

Do you plan to use this project as your capstone design project? ____________________________

Mechanism for Design Credit

□ Projects in Engineering Design
Fill in how you fulfill the ABET Engineering Criteria Program Educational Outcomes listed below

Outcome (a),

An ability to apply knowledge of mathematics, science, and engineering fundamentals.

Please list here all subjects (math, science, and engineering) that have been applied in your project.

Example: let’s consider a HVAC (Heat Ventilation Air Conditioning) system, then, you would include:


Outcome (b).

An ability to design and conduct experiments, and to critically analyze and interpret data.

In this part, if the project included experimental work for validation and/or verification purposes, please indicate that.

Example: Consider the previous example (i.e. HVAC system)

Validation of Actual Heat Transfer Rates at the site, System Calibration Plan, etc.

Outcome (c).

An ability to design a system, component or process to meet desired needs within realistic constraints such as economic, Environmental, Social, political, ethical, health and safety, manufacturability, and sustainability

All projects should include a design component. By design we mean both physical and non physical systems.

Example: Designing a HVAC system, or Metal Coating system, Robot Arm would be considered a physical system. The trick here is to be precise in listing what you had actually designed and what you have acquired from the market.

On the other hand, if your project had a non-physical nature, such as:
designing a quality assurance system, a supply chain, or an ERP (Enterprise Resource Planning) System. Please note that you must be working with real data, i.e., data that has been supplied by a client in the industry. Hence, you must list the overall structure for the designed system, with its inputs, outputs, and constraints.

Outcome (d).

*An ability to function in multi-disciplinary teams.*

This outcome is achieved *automatically by the fact that all projects composed of at least 3 students.* However, if the project involved students from other departments, that would be a plus that is worth to be highlighted.

Outcome (e).

*An ability to identify, formulate and solve engineering problems.*

In order to meet this specific outcome, it would help *if you have a Problem Statement section in your project report.* If not, then briefly highlight how the “students” were able identify, formulate and solve the project’s problem.

Outcome (f).

*An understanding of professional and ethical responsibility.*

Here professional and ethical responsibility depends on the project context.

*Example in the HVAC project it would be not ethical for example to ignore having a ventilation and air conditioning for the rooms of the servants and janitors.*

Outcome (g).

*An ability for effective oral and written communication.*

Good report and good presentation will fulfill this outcome

Outcome (h).

This outcome is usually fulfilled by highlighting the economic feasibility of the project, and emphasizing that the project would
The broad education necessary to understand the impact of engineering solutions in a global economics, environmental and societal context.

Outcome (i).
A recognition of the need for, and an ability to engage in life-long learning.

This outcome is fulfilled by suggesting a plan for future studies and what else could be done based on the outcome of the current project.

Outcome (j).
A knowledge of contemporary issues.

Extensive literature review by the “students” for the current state of the art will fulfill this outcome.

Outcome (k).
An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

List all technologies included in the project (hardware and software)

By signing below certify that this work is your own and fulfills the criteria described above

Student Team Signatures

_________________________  __________________________
_________________________  __________________________
_________________________  __________________________
Title of Poster in Arial, Bold, 72-96 Points: Size Dependent on Length

Names of Authors, Date in Arial, 48 Points, Bold

Key Image 1

Figure 1. Caption in Arial, 28 points, bold.

Second heading or headline in Arial, 40 points, bold


Key Image 2

Figure 2. Caption in Arial, 28 points, bold.

Key Image 3

Third heading or headline in Arial, 40 points, bold


Key Image 4

Figure 4. Caption in Arial, 28 points, bold.

Key Image 5

Fourth heading or headline in Arial, 40 points, bold


Acknowledgments (Arial, 32 points, bold)

Acknowledgments in Arial, 32 points, bold—try to keep to one or two lines.

References (Arial, 32 points, bold)

First reference in Arial, 28 points, bold, with a reverse indent: alphabetical or numerical order.

Second reference in Arial, 28 points, bold, with a reverse indent: alphabetical or numerical order.