TREATMENT OF GAS STATION WASTEWATER
USING PALM OIL SHELL ASH
AS ADSORBENT

PORNPAN SUPAWIMOL

With compliments
of
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The objective of this study was to determine the Chemical Oxygen Demand (COD), Suspended Solid (SS), and Oil and Grease (O&G) removal efficiency from gas station wastewater by using palm oil shell ash as adsorbent. The experiments were done by packing palm oil shell ash in an adsorption column with the heights of 30 and 50 cm, and then applying continuous downflow wastewater from the column with hydraulic loadings of 4.0 and 6.0 m^3/m^2/day. The experiments were carried out until the headloss reached 90 cm. The observation of the influent and effluent from the column-adsorption system in terms of COD, SS, and O&G was made and recorded.

Results indicated that the ranges of removal efficiency of COD, SS and O&G were 60.34-67.16%, 75.21-84.21% and 67.66-84.07%, respectively. The operating time ranged from 60 to 92 hours. When considering the hydraulic loading at 4.0 m^3/m^2/day, the SS and O&G removal efficiency was significantly greater than that at 6.0 m^3/m^2/day. However, the COD removal efficiency was not significantly different. The COD, SS and O&G removal efficiency at the packing adsorbent height of 50 cm was greater than that at 30 cm.

The optimum operating conditions for this study were the hydraulic loading of 4.0 m^3/m^2/day and the packing adsorbent height of 50 cm. These conditions yielded the removal efficiencies of COD, SS, and O&G of 67.16%, 84.21%, and 84.07%, respectively with 80 hours of operating time.

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พรพรรณ สุภาวิมล : การบำบัดน้ำเสียจากสถานีบริการน้ำมันเชื้อเพลิงโดยใช้เถ้ากะลาปาล์มน้ำมันเป็นตัวดูดซับ (TREATMENT OF GAS STATION WASTEWATER USING PALM OIL SHELL ASH AS ADSORBENT) คณะกรรมการควบคุมวิทยานิพนธ์ : สุวิทย์ ชุมนุมศิริวัฒน์ M.S. (Env.&Water Resource Eng.), ประยูร ฟองสถิตย์กุล Ph.D. (Env. Eng.), นิภาพรรณ กังสกุลนิติ Dr.P.H (Env. Health), กฤษณ์ เฑียรฆประสิทธิ์ M.S. (Env. Health), 100 หน้า ISBN 974-04-2559-3

การศึกษานี้ มีวัตถุประสงค์เพื่อศึกษาประสิทธิภาพการกำจัด COD SS และ O&G ในน้ำเสียจากสถานีบริการน้ำมันเชื้อเพลิง โดยใช้เถ้าจากกะลาปาล์มน้ำมันเป็นตัวดูดซับ ในการทดลองได้บรรจุเถ้ากะลาปาล์มน้ำมันในแท่งดูดติดผิวสูง 30 และ 50 เซนติเมตร โดยปล่อยน้ำเสียเข้าสู่แท่งดูดติดผิวแบบต่อเนื่อง ไหลจากด้านบนลงสู่ด้านล่าง ด้วยภาระปริมาณน้ำ (Hydraulic loading) 4.0 และ 6.0 ลูกบาศก์เมตรต่อตารางเมตรต่อวัน การทดลองกำหนดให้สิ้นสุดการดูดซับเมื่อมีค่าสูญเสียความดันเท่ากับ 90 เซนติเมตร ซึ่งการทดลองนี้ได้ทำการศึกษาและบันทึกข้อมูลของน้ำเสียที่ไหลเข้าและออกจากระบบแท่งดูดติดผิวในรูปของ COD SS และ O&G

ผลการศึกษาพบว่า ประสิทธิภาพในการกำจัด COD SS และ O&G อยู่ในช่วง 60.34 ถึง 67.16% 75.21 ถึง 84.21% และ 67.66 ถึง 84.07 % ตามลำดับ โดยมีอายุการใช้งานอยู่ระหว่าง 60-92 ชั่วโมง เมื่อภาระปริมาณน้ำมีค่า 4.0 ลูกบาศก์เมตรต่อตารางเมตรต่อวัน ประสิทธิภาพในการกำจัด SS และ O&G มีค่าสูงกว่าที่ภาระปริมาณน้ำ 6.0 ลูกบาศก์เมตรต่อตารางเมตรต่อวัน แต่ประสิทธิภาพในการกำจัด COD ไม่แตกต่าง เมื่อภาระปริมาณน้ำต่างกัน ส่วนความสูงของตัวดูดซับที่ระดับ 50 เซนติเมตร ประสิทธิภาพในการกำจัด COD SS และ O&G มีค่าสูงกว่าที่ระดับ 30 เซนติเมตร

สภาวะที่เหมาะสมในการศึกษาครั้งนี้คือที่ภาระปริมาณน้ำ 4.0 ลูกบาศก์เมตรต่อตารางเมตรต่อวัน และความสูงของตัวดูดซับ 50 เซนติเมตร ซึ่งมีประสิทธิภาพในการกำจัด COD SS และ O&G อยู่ที่ 67.16% 84.21% และ 84.07% ตามลำดับ โดยมีอายุการใช้งานนาน 80 ชั่วโมง

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CHAPTER I

INTRODUCTION

1.1 Statement of the Problem

Petroleum pollution has been of a great concern as a major environmental problem since the early 1980s because of population growth, industrial expansion, and increasing prosperity. In Thailand, spillage of petroleum products has frequently occurred from transportation, storage and use of petroleum products, underground storage tanks, service station, industrial site, refineries, and automobile maintaining businesses.

Gas station wastewater is a part of the environmental problem. It is generated from various activities, such as car washing, cafeteria, lubricant changing or floor cleaning. This is probably due to the petroleum oil will generally cause the contamination in the public water resource such as river or stream to a certain degree. It usually results in serious water pollution.

Oil and grease are among the most stable organic compounds and are not easily decomposed by bacteria. Their presence in wastewater can cause many problems in both sewers and waste treatment plants. If oil and grease are not removed before discharge of the waste, they can interfere with the biological life in the surface waters and create unsightly floating matter and films. Therefore, there is a need an active consideration at this stage, before it becomes too late to treat or control and causes a serious pollution in rivers and other inland water bodies.

Oil can present in wastewater not only as free oil, but also emulsified oil, which are the types of pollutant of gas station wastewater. Free oil can be removed by physical separation such as API oil-water separator, Corrugated Plate Interceptor (CPI) or oil and grease trap. Emulsion oil present in the oily waste is a major problem of oil-water separation. It cannot physically be separated from the wastewater. Then, it needs appropriate technology processes for the treatment. Emulsion oil may be removed by physical method, which includes heating, configuration, biological treatment, filtration-adsorption; and chemical treatments are done by adding salts or acids.

Adsorption is a term used to describe the process of collecting soluble substances that are in a solution on a suitable interface. Oily wastewater contains varying amounts of oil, suspended solids and other contaminants, thus the appropriate method is required for treatment and removal. In the past, the studies in this area were dealt with methods for the development of removing oil content from gas station wastewater and refinery industrials. However, the major treatment systems are done by the free oil separations or pumping of the oil wastewater mixture out. By doing this treatment, the problem of emulsification of oil-water is created.

Therefore, this study intends to investigate an alternative of emulsion oil treatment from gas station wastewater by the filtration-adsorption system packed with palm oil shell ash as an adsorbent.

1.2 Research Objectives

1.2.1 General objective

To investigate the removal efficiency of COD, SS, and O&G from gas station wastewater by using column packed with palm oil shell ash.

1.2.2 Specific objective

1) To determine the operating time at hydraulic loading of 4.0 and 6.0 m^3/m^2/day.

2) To determine the removal efficiency of COD, SS, and O&G from gas station wastewater at hydraulic loading of 4.0 and 6.0 m^3/m^2/day.

3) To determine the removal efficiency of COD, SS, and O&G from gas station wastewater at packing adsorbent height of 30 and 50 cm.

1.3 Research Hypotheses

1) The hydraulic loading of 4.0 m^3/m^2/day will give longer operating time than at 6.0 m^3/m^2/day.

2) The hydraulic loading of 4.0 m^3/m^2/day will give greater removal efficiencies of COD, SS, and O&G than at 6.0 m^3/m^2/day.

3) The packing adsorbent height of 50 cm will give higher removal efficiencies of COD, SS, and O&G than at 30 cm.

1.4 Research Variables

1.4.1 Independent variables

1) The hydraulic loading.
2) The height of packing adsorbent.

1.4.2 Dependent variables

1) The operating time.
2) The removal efficiency of COD, SS, and O&G from gas station wastewater.

1.4.3 Control variables

1) The diameter of column adsorption.
2) The particle size of adsorbent.
3) The weight of adsorbent per packing adsorbent height 1 cm.

1.5 Research Definitions

- **Oil and grease** : Any material recovered as a substance soluble in the solvent.
- **Gas station wastewater** : Wastewater from gas station after pretreatment by grease trap.
- **Adsorption column** : Acrylic column, 100 cm long and with a inner diameter of 8.4 cm.
- **Adsorbent** : The solid media from palm oil shell ash for the removal of COD, SS, and O&G from gas station wastewater.
- **Removal efficiency** : The percentage of a gas station wastewater treatment ability by palm oil shell ash.
- **Operating time** : The time period between the beginning of adsorption and the end when the headloss reached 90 cm.
- **Hydraulic loading** : Wastewater flow rate throughout the adsorption column

1.6 Scope of the Study

1) The experiment was conducted by using the adsorption system model at the laboratory scale.

2) The wastewater samples used in this study were collected by grab sampling from a gas station on Paholyothin road after passing grease trap.

3) Adsorption column used in the experiment was made from Acrylic, 100 cm long and with a inner diameter of 8.4 cm. The column was packed with palm oil

shell ash from a palm oil factory in Bangkok, Thailand. The particle size of the palm oil shell ash was 150-425μm.

4) The effluent samples were collected every 4 hours starting at the initial head of 154 cm until the headloss was reached 90 cm.

1.7 Conceptual Framework of the Study

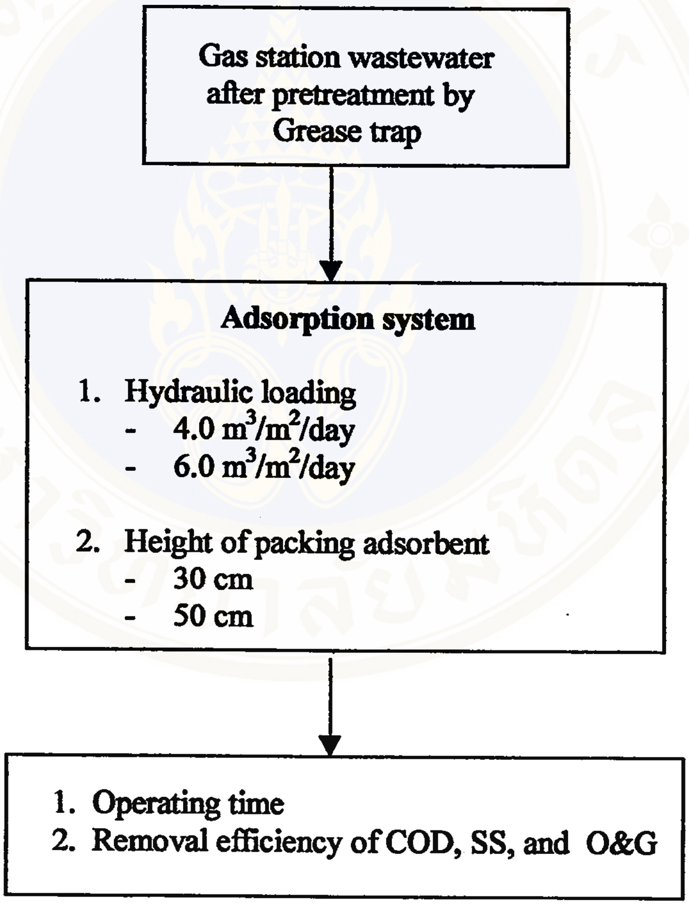


Figure 1 Conceptual framework of the study

CHAPTER II

REVIEW OF THE LITERATURE

2.1 Oil and Grease

Oil and grease (O&G) is defined as "any material recovered as a substance soluble in the solvent". Grease content is determined by extraction of the waste sample with trichlorotrifluoroethane (grease is soluble in trichlorotrifluoroethane). Other extractable substances include mineral oils, such as kerosene and lubricating and road oils (1).

Oils and fats are compounds (esters) of alcohol or glycerol (glycerin) with fatty acids. The glycerides of fatty acids that are liquid at ordinary temperatures are called oils, and those that are solids are called fats. They are quite similar, chemically, being composed of carbon, hydrogen, and oxygen in varying proportions.

Oil is classified as recalcitrant organic compounds. The reason for a compound to become recalcitrant may either be attributed to the structure of compound or the inability of microorganisms to assimilate it readily. The chemical structure influences the biodegradability of a compound in two ways. First, the molecule may contain groups or substituents, which prevent catabolism by constitutive or inducible enzymes. Alternatively, the compound may exist in such a physical state (absorbed, gas phase, insoluble form, etc.) where microbial degradation does not easily occur. Nonbiodegradability usually occurs with lipophilic compounds such as chlorinated pesticides, etc., which have very low solubilities in water.

2.2 Types of Oily Wastes (2)

Oily waste materials are often measured in terms of their hexane solubility, for purposes of pollution evaluation. Types of oily wastes are as followes:

- Light hydrocarbons includes light fuels such as gasoline, kerosene and jet fuel, and miscellaneous solvents used for industrial processing, degreasing or cleaning purposes. The presence of waste light hydrocarbons may make removal of other heavier oily wastes more difficult.
- Heavy hydrocarbons, fuels and tars includes the crude oils, diesel oils, No.6 fuel oil, residual oils, slop oil, asphalt and road tar.
- Lubricants and cutting fluids-oil lubricants generally fall into two classes; nonemulsifiable oils such as lubricating oils, cutting oils and drawing compounds. Emulsifiable oils may contain fat, soap, or various other additives.
- Fats and fatty oils-these materials originate primarily from processing of foods and natural product. Fats result from plant products. Quantities of these oils result from processing soybeans, cottonseed, linseed and corn.

2.3 Industrial Sources of Oily Wastes (2)

There are many industrial sources of oily wastes. Table 1 presents the major categories of industry producing oil and grease-laden waste streams, and lists characteristic types and sources of oily wastes associated with each category.

By far the three major industrial sources of oily waste are petroleum refineries, metals manufacture and machining, and food processors. Petroleum refineries produce large quantities of oil and oily emulsion wastes, because of the long history of pollution problems associated with petroleum refining.

In the metal industry, the two major sources of oily wastes are steel manufacture and metalworking. Oily wastes include both emulsified and non-emulsified or floating oils. In steel manufacture, steel ingots are rolled into desired shapes in either hot or cold rolling mills. Oily wastes from hot rolling mills contain primarily lubricating and hydraulic pressure fluids. In cold strip rolling, however, the steel ingot is usually oiled prior to rolling, to lubricate and to reduce rusting. Additional oil-water emulsions are sprayed during rolling to act as coolants.

Metalworking produces shaper metal pieces such pistons and other machine parts. Oily wastewater from metal working processes contains grinding oils, cutting oils, and lubrication fluids.

The third major source of oily wastes, and particularly greases, is the food processing industry. In the processing of meat, fish and poultry, oily and fatty materials are produced primarily during slaughtering, cleaning, and by-product processing.

Table 1 Industrial sources of oily waste

Industry	Waste Characteristics
Petroleum	Light and heavy oils resulting from producing, refining, storage, transporting and retailing of petroleum and petroleum products.
Metals	Grinding, lubricating and cutting oils employed in metalworking operations, and rinsed from metal parts in clean-up processes.
Food processing	Natural fats and oils resulting from animal and plant processing, including slaughtering, cleaning and by product processing.
Textiles	Oils and grease resulting from scouring of natural fibers (e.g., wool, cotton).
Cooling and Heating	Dilute oil-containing cooling water, oil leaked from pumps, condensers, heat exchangers, etc.

2.4 Physical Characteristics of Oil Contamination in Water

Oily wastewater contains varying amounts of oil, suspended solids and other contaminants. Pollutants may occur in wastewater in the following way:

- A floating layer of oil, fat or grease
- Coarse to finely dispersed particles e.g., clays or emulsions
- Colloidal solutions e.g., soaps and finely divided clays
- Solutions e.g., salts or starches

The oily impurities in the wastewater from refineries and other oil processing operation can be present in three different forms as follows:

2.4.1 Free Oil

Free oil impurity is usually more than 95% of oil droplet in the mixture of the water and the free oil is larger than 40 mm in size. It can rise to the surface of the water in which it is contained and is the most economically removed in an oil/water separator utilizing corrugated plates.

2.4.2 Emulsion Oil

The emulsions are formed when water and certain types of oils are intimately mixed in the presence of impurities either in the oil or water phase. This emulsion will remain as a layer of intermediate density, between the water layer and the less dense oil layer that floats above. Emulsions often develop physical properties that differ from those of either of the component fluids. They differ in viscosity and also are heterogeneous mixtures rather than fluids of uniform properties. There is one type of emulsion that consists of small globules of water floating in a continuous body of oil (water in oil) and another type consisting of small globules of oil floating in a continuous body of water (oil in water). Oil on water theoretically spreads in ever increasing area until reaching a thickness depending on viscosity and temperature.

Oil-water emulsions may be formed as a result of intimate contact between oil, water and emulsifying agents, or they may originate directly as industrial process by-products. The two liquid phases are usually referred to as dispersed and continuous phases. The phase that is in the form of finely divided droplets is called the dispersed or internal phase; and the phase forming the matrix in which these droplets are suspended is called the continuous or external phase. Based on the liquid phase, a typical water-oil emulsion may exist either as an oil-in-water or as water- in-oil emulsion. Water-in-oil emulsions are unstable and difficult to form in highly refined oils, whereas oil-in-water emulsions are comparatively more stable. Simple physical method for emulsion breaking is only effective in case of unstable emulsions, e.g., heating (3).

1) Mechanically emulsified oil

Exposure of the free oil and water mixture to sewer turbulence will break up into very small droplets or particles ranging in size from 10 to 40 mm in size and which are more or less stable. Oil in size range 10 to 40 mm is generally classified as mechanically emulsified oil. The factors which govern the mean droplet diameter of the emulsion are the quantity of dissipated energy necessary to create turbulence and the oil-water interfacial tension. Turbulence generation should be avoided where possible; so as to avoid the formation of mechanically emulsified oil.

2) Chemically emulsified oil

A surface-active agent is an asymmetrical molecule with a hydrophobic end. This asymmetry causes the molecules to become localized preferentially at the oil-water interface. Chemically emulsified oil particles are less than 1 mm in size. They do not rise to the surface of water in which they are contained. Chemically, emulsified oil in wastewater is usually due to the presence of detergents or alkali contaminants. This particular localization has two consequences(4):

- The interfacial oil-water tension is greatly lowered. For the same quantity of dissipated energy, a much large oil-water interfacial area can thus be created and the mean droplet diameter of the emulsion is thereby greatly reduced.
- The ionization of the surfactants hydrophilic sites gives rise to superficial charges on the hydrocarbon droplets. This results in a considerable increase in the stability of these emulsions.

2.4.3 Dissolved oil

Despite their low solubility in water, all oil are not insoluble to the same extent, in general, if we consider oil of the same series (4):

- The solubility increases as the molecular weight decreases. The volatility and solubility evolve, therefore, in the same direction and the lighter hydrocarbons are the most soluble and the most volatile;
- The solubility increases with unsaturation.

Table 2 Solubility of hydrocarbon in water

Straight chain hydrocarbon C8		Straight chain hydrocarbon C6		Cyclic hydrocarbon C6	
n-octane	0.66 mg/l	n-hexane	9.5 mg/l	Cyclohexane	55.0 mg/l
Octene-1	2.70 mg/l	Hexene-1	50.0 mg/l	Cyclohexene	213.0 mg/l
Octyne-1	24.00 mg/l	Hexyne-1	360.0 mg/l	Benzene	1650 mg/l

Dissolved oil is not present in the form of discrete particles; therefore, it can not be removed from the flow stream with an oil/water separator. Dissolved oil is present in quantities sufficient to warrant removal, the use of activated carbon adsorption columns or biological treatment may both be considered. Selection of the most cost effective dissolved oil removal system depends upon the kinds of oils present and their concentrations (5).

2.5 Behavior of Oil and Grease in Water and Effects of Weathering

An understanding of the behavior of oil in water and the effects of weathering can often assist identification of a potential source of pollution. Reference to hydrographic and wind data can retrace oil movement.

2.5.1 Spreading

The first observable phenomenon following a spill is the tendency of the oil to spread into a slick over the water surface. All oils which are fluid under ambient conditions will spread horizontally over the water surface, even in the absence of wind and water currents. While rates of spreading will vary depending upon the properties of the oil and the ambient conditions. It can be taken as a rough guide that most crude oils will spread to a thickness of approximately 3 mm in one hour and to an average of approximately 0.3 mm in ten hours. In the absence of other influences spreading would continue until the oil approaches monomolecular thickness (approximately 0.1 µm), only discernible as an area where the surface capillary waves are damped and giving the appearance of a slight silvery sheen. Spreading assists all the processes of weathering and natural dissipation is rapid once the oil has thinned to a silvery sheen.

2.5.2 Evaporation

The most significant initial weathering process for oil spills on the sea is evaporation. The more volatile fraction of an oil (the light ends) is lost within the first few hours. The less volatile component remaining will have higher density, viscosity, pour/flash point and sulphur, carbon residue, wax, asphaltenes and metals content than the original oil. The last two properties listed only apply if the oil spilt contained residual material, e.g. a crude or fuel oil. The rate of evaporation from a spillage decreases with time. Whilst the rate of evaporation is influenced by factors such as air and water temperatures, sea state, wind and rate of spreading, it is the volatility of the various components present that is the crucial factor determining the extent of evaporative loss. It is therefore highly dependent upon the type of oil spilled; its distillation characteristics provide a means of determining what proportion of the oil can be expected to evaporate. Under moderate conditions components with carbon numbers up to C_{10} are lost within 8 hours, while compounds boiling above 250 °C are lost only after considerable exposure, say over a week. This is the most significant factor for most crude oils and for the lighter products, but not for distillation residues. For example, in temperate waters most crude would lose a quarter or more of the initial weight spilt in the first 24 hours whereas heavy residual fuel oils would show little evaporative loss.

2.5.3 Emulsification

The formation of water-in-oil emulsions is generally a negative factor in the natural dissipation of spilled oil from the sea and shore. The formation of these emulsions usually occurs during the first 8 hours or so after the spillage. The rate and extent to which water-in-oil emulsions are formed depends upon the type of oil involved and the Sea State prevailing, although they can be generated by even slight wave action. They may contain up to 80 percent water and are usually very stable. Their viscosity is higher, usually very much so, than the parent oil and there appearance is also quite different.

2.5.4 Dispersion and Dissolution

The layer of oil in the surface is broken into droplets by wave action; they are held in suspension by the turbulent motion of the sea. Dissolution and biodegradation are also enhanced because surface area is increased by droplet production.

Dissolution and evaporation are competitive processes. The most soluble components are also volatile but evaporation takes place more rapidly. Although some polar materials may dissolve preferentially, the change in concentration of these species is likely to be masked by much larger evaporative losses.

2.5.5 Oxidation

Petroleum oils can be oxidized by the action of the ultraviolet radiation in sunlight (photooxidation) and by marine microorganisms which utilize them as a food source (biooxidation or biodegradation). Both processes take place at the oil-water interface and produce oxidation products which are generally more soluble than the parent oil. The former is the faster process overall but the different components vary widely in the rates at which they oxidize.

Photooxidation takes place at the surface and occurs most rapidly when the oil is spread as a thin film. The precise mechanism is not well understood but it is thought to result in the loss of about 1- percent of the oil volume per day.

Biodegradation has a slow but significant effect on the removal of oil from the marine environment. No single microbial species can utilize more than two or three hydrocarbon types and most preferentially consume the light ends. The rate of degradation is dependent upon a number of factors including temperature, the availability of nutrients containing nitrogen and phosphorus, oxygen, and the type of oil and stage of weathering. As bacteria can only attack that part of the oil which is in contact with the water the opportunity for degradation is enhanced by thinly spread oil or by oil-in-water dispersions where a greater surface is exposed for microbial attack. Conversely, water-in-oil emulsions degrade at a much slower rate since any microorganisms are effectively surrounded by oil, which reduces the rate of replenishment of vital nutrients and oxygen. It is unlikely, therefore, that oil samples will contain any appreciable concentration of degradation products since it is primarily only dispersed oil that is biodegraded and the products are generally soluble.

2.5.6 Movement

Oil on the surface of the sea moves under the influence of wind and current. The effect of current alone is direct, i.e. the surface slick will move in the same direction and at the same velocity as the surface water. Wind alone moves oil at about 3 percent of its own velocity; thus a wind of 60 km/h will move oil downwind at

2 km/h. when both wind and current are significant, their effects are additive with the resulting movement being a vector of the two components.

2.6 Problem of Oily Wastewater Occurrence (6)

1) Oil and emulsions of oil adhere to the epithelial cells of the gills of fish and interfere with normal respiration. Under conditions of relatively mild pollution, the mucus that is produced by fish as a defensive mechanism may wash away the oil. In heavy pollution, however, the oil cannot be washed away and tends to accumulate on the gills.

2) Oil and emulsions of oil and water can coat algae and other plankton and thus destroy them. These plants are a source of food for fish. The organisms, which have been destroyed, tend to clump together, settle to the bottom, and decompose.

3) Oil and oily substances, which settle, may coat the bottom of a natural body of water. In this way, the bethel organisms are destroyed and spawning may be prevented.

4) Oils contain soluble materials. Fish may eat these soluble materials, along with emulsified components. The flavor of the fish flesh may become tainted and thus will be unmarketable.

5) If sufficient oil is present as a pollutant, it acts like any other organic substance and tends to deoxygenate the waters; if the deoxygenation is severe enough; fish will be killed.

6) If a coating of oil is fairly thick on the surface of the water, it can interfere with reaeration of the body of water at the air-water interface. Moreover,

photosynthesis may be interfered with. Tests have indicated that light films of oil are not detrimental to reaeration or photosynthesis.

7) All oils, even those which are highly purified, contain water-soluble materials which can directly poison fish or fish-food organisms. In some instances, the materials are toxic enough or in large enough amounts to cause immediate death. With other oily materials, slow death or disability may result. Ordinarily, if death or disability occurs within ninety-six hours or less, acute toxicity is concluded. Chronic toxicity implies an effect over a long period of time; this effect may result from a cumulative action of the toxicant or may result from subthreshold changes in the environment.

8) Water birds die by the external effects of oil on the feathers. The oil cause the feathers to become wet and the birds drown. Moreover, oil-soaked birds can not fly.

2.7 Draft of Effluent Standard for Gas Station Wastewater

Table 3 shows the draft of effluent standard for gas station wastewater of Thailand.

Table 3 Draft of effluent standard for gas station wastewater of Thailand.

Parameters	Unit	Allowable value
pH	-	5.5-9
COD	mg/l	200
SS	mg/l	60
O&G	mg/l	15

Source: Pollution Control Department (2002)(7)

2.8 Oil Removal Methods

There are so many types of oily waste treatment, namely, physical treatment, chemical treatment and biological treatment. The selection of method used depends upon the type of waste, quantities of waste and quality of effluent required.

In view of the difficulties associated with biological treatment of various insoluble hydrocarbons with biological treatment of various insoluble hydrocarbons, it appears germane to explore pretreatment steps that might be employed to prohibit such materials from entering the biological system in the first place. Both physical and chemical systems have been studied and included coagulation, adsorption, flotation, and filtration.

2.8.1 Biological Treatment

A large number of microbes growing on hydrocarbon as sole carbon source have been shown to produce emulsifying agents which cause a dispersion of the oil such as *Pseudomonas aeruginosa* SB1, *Acinetobacter calcoaceticus* RAG-1 (8).

Bio-oxidation is used extensively in the treatment of refinery wastewaters. Both trickling filters and activated sludge have been adapted to the treatment of selected waste streams and to total effluents, and bio-oxidation ponds also are widely used. A high degree of treatment can be attained with any one of these methods, comparable to that obtained in the treatment of food waste and sanitary sewage. However, a longer period of time is required on refinery effluents. In some plants, biotreatment has been limited to selected streams, usually those containing phenolic compounds. However, as water usage declines, refinery effluents become of poorer quality, and the need for treatment is greater, even though the absolute amount of polluting materials may be less than it was when effluent volumes were greater. Furthermore, regulatory requirements grow more stringent. Consequently, the trend is strongly toward treatment of the total effluent, excluding only storm and surface drainage from oil-free areas.

Selection of type of biotreatment depends largely on costs and space available for the treatment plant. It is advisable to study all three methods in pilot plants, if possible; or at least those that can be adapted to the area and terrain.

2.8.2 Chemical Treatment

For chemical treatment has listed the alternative processes of demulsion as: adding of coagulation salts, acids, salts and treatment by the electricity and acid plus organic cleaving agent (9).

Chemical flocculation consists of the addition of a reagent to a wastewater to form a precipitate removable by settling. Coagulation in employed for the removal of waste materials in suspended or colloidal form. Colloids are represented by particles over a size range of 10^{-5} cm to 10^{-7} cm. The vast majority of colloids in wastes possess a negative charge, so coagulation can usually be induced by the addition of high valence cations such as ferric chloride, aluminum sulfate and aluminum chloride (10). In some instances, substances present in the wastewater, such as calcium bicarbonate and magnesium carbonate, may be made to form precipitates and so serve as flocculating agents. When the pH of the wastewater is controlled within the proper range, hydrated reaction products of the flocculating agents result; these relatively insoluble compounds, initially present as colloids, agglomerate as flocs. During agglomeration, they become associated with other colloidal and suspended matter. As the floc particles grow, their apparent density increases and they settle, carrying with them whatever insoluble matter may have become trapped during the growth period. Polyelectrolytes are frequently used to hasten the flocculation process.

2.8.3 Flotation

Flotation is used for the removal of suspended solids, oils, and greases from wastes as well as for the separation and concentration of sludges through gravity force. This is a gravity separator in which oil accumulates on the surface and heavy solid settle to the bottom. Oil skimming and bottom sludge removal are required periodically. The performance of a flotation system depends upon having sufficient air bubbles present to float substantially all of the materials (10).

Consider the emulsion, the most frequent from of pollution. The specific gravity of oil (S_o) is lower than the specific gravity of water (S_w); thus oil droplets move to the surface of the water. Droplet diameters are always low, and their displacements are always laminar; therefore Stokes' law can be used:

$$V = (\delta s.g.dp^2)/(18n)$$

Where V = droplet final velocity

dp = droplet mean diameter

g = gravitation acceleration

n = dynamic viscosity

$\delta s = S_w - S_o$

The API gravity separator has been used for several decades. It is effective in removing free oil, emulsified and soluble oil fractions are most removed in any appreciable amount. Oil removal efficiencies reported for refinery wastewater range from 50% to 90%. Flow rate and influent oil concentration are the two most important parameters in separating free oil from water.

Recent, dissolved air flotation has been applied to oil/water separation following API gravity separation of refinery and petrochemical wastes. The process basically involves the pressurization of the influent or recycled wastewater. In the air flotation process, wastewater is saturated, usually under pressure, with a gas such as air. Air is dissolved under pressure of 2.8 to 4.9 kilograms per square centimeter in the wastewater. It is then admitted through a pressure-reducing valve to a flotation tank where the air comes out of solution and forms minute bubbles throughout the entire volume of liquid. As the bubbles rise, they trap or adhere to oil globules. The resulting bubble-oil complex rests to the liquid surface due to differential gravity. These techniques are only efficient for the larger droplets – those with average diameters greater than 20 micron (4).

Air flotation offers the advantage of a faster rate of separation than gravity separation and space requirements for a particular treatment job are generally less. The combination of air flotation with chemical flocculation is more effective than air flotation alone; it produces about the same degree of treatment as chemical flocculation, but does it faster, minimizes some of the effects that upset simple chemical flocculation, and accomplishes at least a minor degree of oxidation. Air flotation, with or without chemicals, can yield a greatly improved effluent insofar as appearance and oil content are matters of concern. Where oxygen demand requirements are not important, it can serve as the final treatment for refinery effluent.

2.8.4 Tilted Plate Separation

The tilted plate separator is a modification of the conventional API separator. If the separator channel is divided by equally spaced inclined plates (at 45 degrees) into a number of sections, the surface area is increased thus causing a decrease in the overflow rate. The coalesced oil, which collects against the bottom side of each plate, will creep upward and form large globules as it rises to the surface of the separator. Similarly, the sludge, which collects on the topside of the plate, will slide sown to the bottom of the separator.

The surface area is the parameter that best describes the performance of and existing gravity type, oil/water separator and was used to develop a design procedure for a rectangular separator. The most efficiency of tilted plate separator for removal of oil is about 55 % to 65% (11).

2.8.5 Filtration

The possible use of synthetic fibers as a method for removal of oily materials was studied. The synthetic materials tested included nylon, Dacron, (a tradename of E.I. DuPont de Nemours and company), polypropylene, and acrylic fibers of different mesh sizes. A large amount of oil was eventually adsorbed on the fiber, causing clogging of the test material and the passage of oil into effluent. The effectiveness of the filtration process in breaking oil-in-water (O/W) emulsions is probably due to the rupture of the oil globules on passing through the filter medium, allowing these particles to coalesce into separate; gases. If soluble and emulsified oils are present in significant amounts, additions of polyelectrolytes may be helpful (11).

2.8.6 Adsorption

Organic material in a waste can frequently be removed by adsorption on an active solid surface. A solution in contact with a solid surface has the tendency to condense upon that surface. This phenomenon is defined as adsorption.

Removal of pollutants from a solution in an adsorption process is dependent on both chemical and physical properties. The adsorptive capacity of an adsorbent is dependent on the characteristics of both the adsorbent and the waste. The rate of adsorption varies inversely with the particle diameter of the adsorbent, increase with increasing concentration of solute, increases with increasing temperature and increases with decreasing pH due to surface charges of the adsorbent. In addition, the rate of adsorption varies with the contact with the waste. Activated carbon is the most commonly used adsorbent.

Inorganic materials, one can consider things like glasswool, verticulite, or other similar exfoliated micas, organic ash or pumice and the manufactured insulated materials, mineral wool or rock wool which can all be used.

Natural organic materials, which have the largest distribution and are widely used around the world. The materials include straw, hay, reeds, sea grass, peat, sawdust and gorse, together with other available local materials such as baggasse or dried palm fronds.

Synthetic materials have many different properties, and by alterations in their compositions. Polyurethane, polyether, fibres made of various materials, nylon and Oliophilic resins (12).

2.9 Adsorption

Adsorption is the physical and/or chemical process in which a substance is accumulated at an interface between phases (13).

Adsorption involves, in general, the accumulation of solute molecules at an interface. The accumulation per unit area is small; thus, highly porous solids with very large internal area per unit volume are preferred. The surfaces are usually irregular, and the bondingenergies (primarily from Van der Waals forces, as in vapor condensation) vary widely from one site to another. However, with "molecular sieves", the adsorptive surfaces are provided by channels or cavities within a macrocrystal structure; the sieves exhibit high uniformity of adsorbent surface with a practically constant binding energy (14).

At the ordinary temperatures, adsorption is usually caused by intermolecular forces rather than by formation of new chemical bonds; it is then called physical adsorption, or physisorption. At higher temperatures (above about 200°C, or 400°F), the activation energy is available to make or break chemical bonds, and if such a mechanism prevails, the adsorption is called chemisorption or activated adsorption.

In the past, the adsorption process has not been used extensively in the wastewater treatment, but demands for a better quality of treated wastewater effluent have led to an intensive examination and use of the process of adsorption on the activated carbon. Activated carbon treatment of wastewater is usually thought of as a polishing process for water that has already received a normal biological treatment. The carbon in this case is used to remove a portion of the remaining dissolved organic matter. Depending on the means of contacting the carbon with the water, the particulate matter that is present may also be removed (1).

Major uses of liquid-phase adsorption include:

1. Decolorizing, drying, or degumming of fuel and lubricants, organic solvents, vegetable oils, and animal oils.
2. Recovery of biological chemicals (antibiotics, vitamins, flavorings) from fermentation broths or plant extracts.
3. Clarification of food and drug products.
4. Decolorizing of crude sugar syrups.
5. Purification of process effluents for pollution control.
6. Water-supply treatment for odor, tastes, or colors improvement.

7. Separation of isomeric aromatic or aliphatic hydrocarbons.

2.10 Factors Influencing Adsorption

2.10.1 Characteristics of the adsorbate

The chemical character of the adsorbate is important for a number of reasons. It is this character which determines the size as well as the configuration of the particular molecule to be adsorbed. Molecular size is important for two reasons. First, for any homologous series of organic molecules, as size increases solubility generally decreases. A material, which has low solubility in water, will have a higher affinity for solid surface than for the water and will therefore have a tendency to concentrate on those surfaces, i.e., to adsorb. Molecular size in also important for the perspective that all adsorbents depend upon internal surface area for the full use of their adsorption capabilities. If the molecular size is too large, adsorption will be hindered and the adsorption capacity will decrease as very large molecules block or cannot penetrate pores or pathways within the adsorbent. One furthers aspect slowly from solution and therefore will require longer times for full equilibrium adsorption capacity to be realized.

2.10.2 Characteristics of the adsorbent

The chemical and physical properties of the used adsorbent to remove a material from solution are quite important. Chemical properties include the degree of ionization of the surface of the surface of the adsorbent, the types of functional groups, which are present on the adsorbent, and degree to which these properties may be changed by contact with the solution. The presence of ionized or otherwise active functional groups on the adsorbent surface allow chemical interactions of "chemisorption" which usually produces effects different from and less reversible than physical adsorption. This effect may be advantageous or not, depending on a particular application. Further, the general ability of the chemical nature of the adsorbent to change the chemical characteristics of the solution to be treated can also have either beneficial or adverse effects on the adsorption process. This is particularly important where the treated solution is to be reused, or is for human consumption.

The physical properties of the adsorbent are like-wise important. The adsorbent can be in the form of granules of particles which may have a density near or very different from the solution to be treated or the adsorbent may be in very fine powdered form which may be easily suspended in the solution to be treated. These physical properties have most effect on the selection of the mode of application of the adsorption process using that particular adsorbent.

2.10.3 Characteristics of the solution

The three major waste solution characteristics, which have particular impact on adsorption, are the solution pH, its temperature, and the presence of other competing adsorbate compounds.

The pH of a solution is of significance for its effect on the adsorbent, as well as on the adsorbate. Both adsorbate and adsorbent may have chemical characteristics, which are affected by the concentration of hydrogen ions (H^+), in the solution. Some adsorbents have affinity for H^+ or OH^- ions and can directly affect the solution pH and therefore solubility and adsorption capacity. This effect must be considered during test design where large quantities of virgin adsorbent may be used per volume of solution. The pH change may not be quite so evident in full-scale operation where large volumes of solution are treated. Thus, significant differences between laboratory and full-scale results can be realized. Adsorption from solution can be highly isoelectric point or neutral point on the pH scale. It is at this point where maximum adsorption can be achieved since solubility is minimized and the non-polar adsorbent has greatest affinity for non-ionic materials. In many cases solution pH change is possible in full scale, and it is relatively simple effect to simulate in laboratory testing; it should not be overlooked.

The temperature of a solution has two major effects on adsorption. First, the rate of adsorption is usually increased at higher temperatures. This is due primarily to the increased rate of diffusion of adsorbate molecules through the solution to the adsorbent. Further, since solubility and adsorption are inversely related, as temperature affects solubility it will therefore affect the extent of adsorption or capacity of the adsorbent for the particular adsorbate. Temperature effects should be simulated carefully in the laboratory to reproduce expected full-scale conditions. In cases where change of process temperature is possible, it should be evaluated for possible beneficial effects (15).

A major influence of the solution character on adsorption is the presence of competing adsorbate compounds. Few adsorbents demonstrate controllable selectivity for specific compounds and therefore all absorbable compounds present will compete for adsorption sites. Further, since physical adsorption is a reversible phenomenon, the presence of materials with a particularly high affinity for the adsorbent will, under continued application, tend effect can result in what is known as a chromatographic effect. For the adsorbent system operated in a fixed bed mode, this effect can have particularly dramatic consequences for the quality of an effluent.

2.11 Palm Oil Shell Ash

The palm oil industry plays a major role in the economic development of several tropical countries. Palm oil cultivation in Thailand has shown increasing economic significance with its expanding market demand at an average growth rate of 15% a year (16). In processing palm oil fruit for oil extraction, palm oil mills produce a considerable amount of solid waste by-products in the form of fibers, nut shells, and empty fruit bunches.

Currently the shell and fiber are used extensively as fuel for the production of steam in the palm oil mills, which provides a means of waste disposal and energy recovery. After combustion in the steam boiler, there is approximately 5% ash produced. Since the shell-fiber ash does not have sufficient nutrients to be used as a fertilizer, it is dumped in open fields in the vicinity of the palm oil mills.

From proximate analysis in Table 4, it was observed that palm oil shell have properties similar to coconut shell but palm oil shell has more ash than coconut shell and BET surface area showed that palm shell has higher number of external pore than coconut shell (17,18).

Physical characteristics and partial chemical compositions of palm oil shell ash are presented in Table 5 (19).

Table 4 The proximate analysis and the BET surface area, compared of coconut shell and palm oil shell.

Raw material	% Volatile matter	% Ash	% Fixed carbon	Surface area (m^2/g)		
				S_{total}	S_{micro}	$S_{external}$
Coconut shell	80.80	0.40	18.80	0.9	0.0	0.9
Palm oil shell	69.87-79.66	2.05	18.29	12.2	0.0	12.2

Table 5 Physical and chemical properties of the palm oil shell ash.

Properties	Palm oil shell ash	
	Range	Average
Moisture content (%)	0.48-0.73	0.59
Specific gravity	1.78-1.87	1.84
Loss-on-ignition (%)	16.20-21.13	18.22
Bulk density (kg/m^3)	473-504	493
Chemical composition (g/kg)		
Al	20.7-32.7	24.6
K	26.3-41.0	32.0
Si	29.3-54.3	34.3
Mg	20.3-22.0	21.1
Fe	11.4-20.3	14.9
Na	1.0-3.8	2.3
Ca	34.0-39.9	37.8
Mn	0.2-0.4	0.3
Zn	0.1-0.3	0.2
Cu	0.05-0.1	0.1
Cr	0.02-0.2	0.05
Ni	0.02-0.3	0.1
Pb	0.02-0.1	0.3

2.12 Previous Research

Rizzo (20) studied the treatment of wastewater from refinery industry by fixed-bed GAC. There were 12 fixed-bed tanks, each containing GAC with the height of 13 ft. The result showed that the removal of COD was more than 90% (influent COD was 250-450 mg/l and effluent COD was less than 37 mg/l). After that, People et al. (21) studied the pretreatment of wastewater from refinery industry by sand filtration before treatment with activated carbon. The experiment had four series of column, with diameter of 5 inches. The first column packs GAC with the height of 0.9 meters and the others with 1.5 meters. The influent flow rate was at 1.9 l/min. The removal efficiency of SS, BOD, TOC, Oil and Phenol were 62, 85, 65, 85 and 99 % respectively.

In 1988, Viraraghavan and Mathavan (22) reported that peat offers itself as an excellent medium for treating oil-in-water emulsions. The column studies were conducted with cast acrylic pipe in a 100 mm in diameter and 600 mm long. Two different peat depths (250 and 300 mm) were used in the experiments, operating time 8 hours and flow rate of the emulsion was 12 ml/min in downflow mode. The effective of removal oil&grease was 90-99%. Next, Viraraghavan and Mathavan (23) studied the treatment of oil-in-water emulsion by column testing with packing the peat at 300 mm high, operating time of 8 hours and flow rate of wastewater at 12 and 48 ml/min. The efficiency of peat to remove oily emulsion was 80%. Then, Mathavan and Viraraghavan (24) examined the coalescence/filtration of oily emulsion in a 2.4 m long column and 1000 mm peat bed at six different flow rates (165, 198, 231, 284, 297 and 331 ml/min). It was found that the removal efficiency of oil and grease ranging from 95.7-99.3%.

Bose and Theodore (25) designed the cellulose bed adsorption using kenaf as the medium to remove oil-in-water emulsion. The unit consists of a 5 cm long Plexiglass pipe with inner diameter of 4.6 cm. The removal of O&G varied from 70-95% for 500 mg/l oil-in-water emulsion. They found that the oil removal was better for larger oil drops, finer media particles, higher filtration pressure, lower pH, cationic surfactant and deeper media.

Mahaphrom (26) studied the adsorption column for the treatment of gas station wastewater. The column studies were conducted with glass pipe in a 2.54 cm diameter and 1 m long, packed with GAC height of 15 and 30 cm and continuous down flow with hydraulic loading of 0.6 and 1.2 m^3/m^2-hr. The best removal efficiency was 0.6 m^3/m^2-hr of hydraulic loading and 30 cm of GAC height. The average efficiencies of the system of 30 days for oil&grease, COD and SS removal were 62.3, 75.9 and 90.2 %, respectively.

Sahairaksa (27) compared the removal efficiency of granular activated carbon (GAC), resin and straw in removing emulsion oil from gas station wastewater. The tested column-adsorption system was made from a 75 cm glass tube with a diameter of 2.54 cm, and packed adsorbent height of 30 and 45 cm. The continuous downflow wastewater was at the rate of 10 ml/min. The greatest oil removal efficiency was observed when the GAC was used as the adsorbent and the packing height of 45 cm. The mean percentage of oil removal efficiency was 87-94.

CHAPTER III

MATERIALS AND METHODS

The study was conducted to determine the operating time and removal efficiency of COD, SS, and O&G from gas station wastewater by using column packed with palm oil shell ash. The experimental set-up was installed at the laboratory of the Sanitary Engineering Department, Faculty of Public Health, Mahidol University.

3.1 Experimental Set-Up

3.1.1 Wastewater Sample

The gas station wastewater sample used in the study was randomly collected from the gas station on Paholyothin road, Bangkok.

3.1.2 Preparation of adsorbent

The adsorbent used in the study, palm oil shell ash, is shown in Figure 2. The palm oil shell ash was collected from a palm oil factory in Bangkok, Thailand. This adsorbent was dried in hot air oven at temperature of 103°C for 2 hours, then sieved for packing in the column by using the 40-100 mesh sieve (150-425 μm).

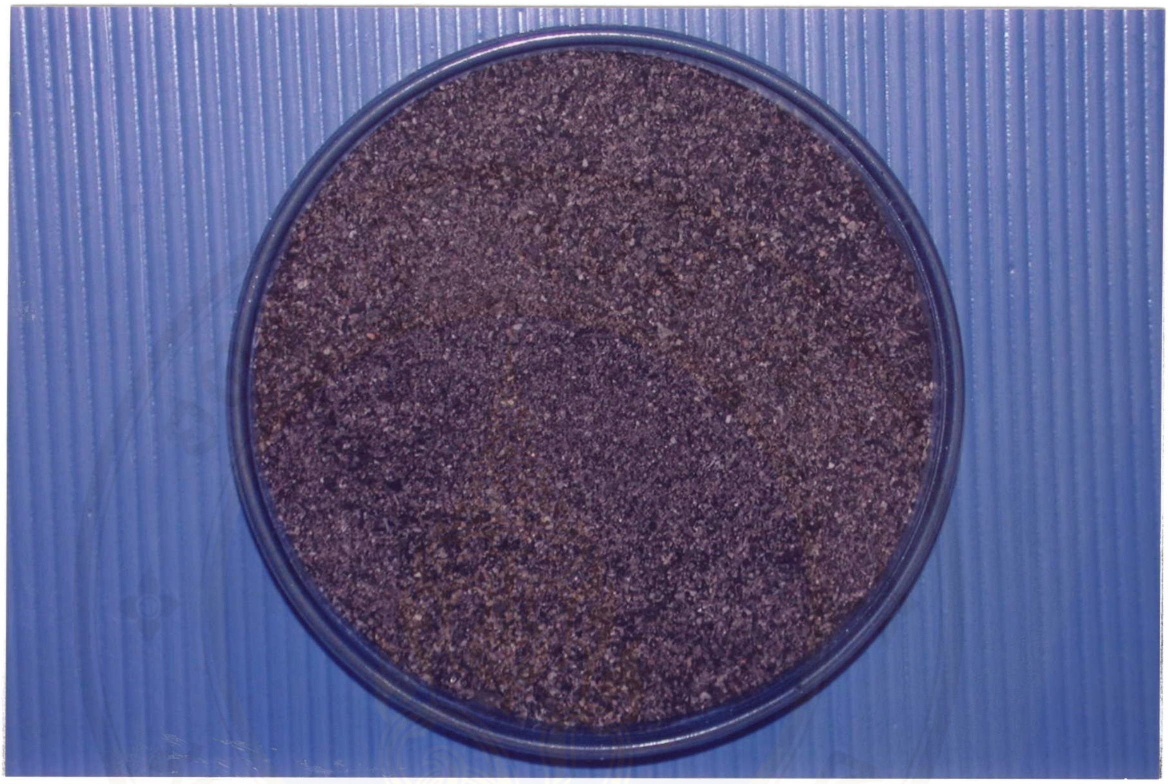


Figure 2 The palm oil shell ash

3.1.3 Construction of column-adsorption system

The schematic diagram of wastewater delivery and wastewater flow through the column adsorption system was shown in Figure 3.

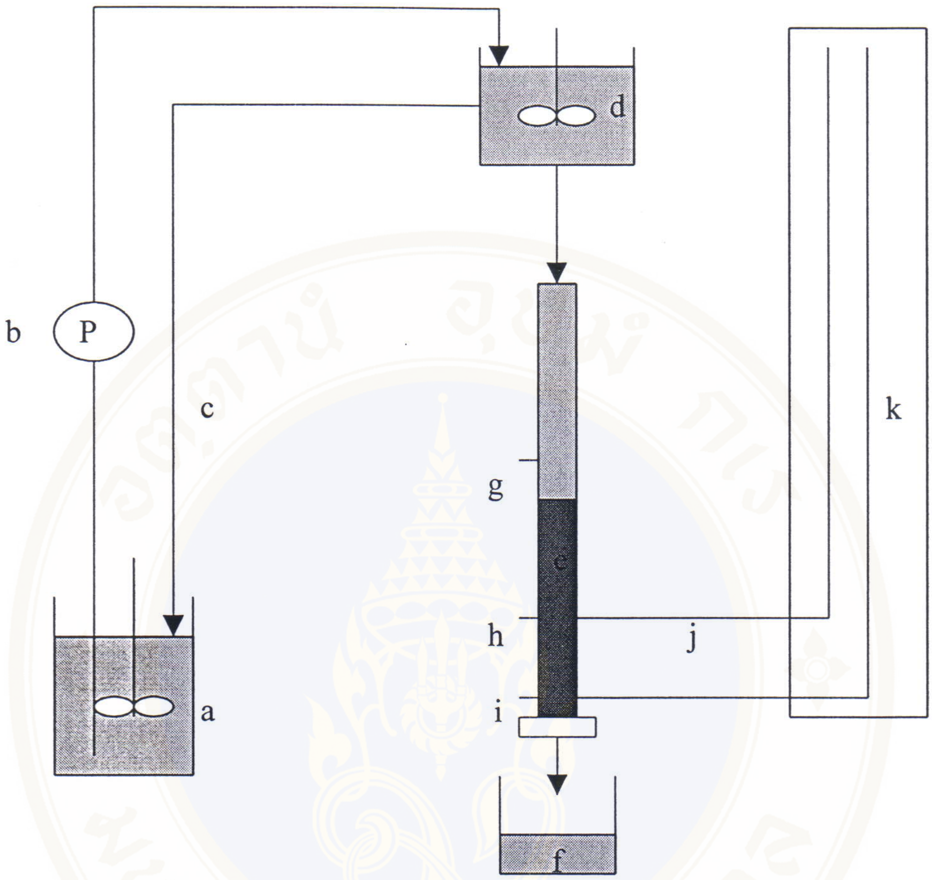


Figure 3 The schematic diagram of experimental adsorption system

a = Raw wastewater tank

b = Pump

c = Over flow line

d = Constant head tank

e = Adsorption unit

f = Treated effluent

g = Raw wastewater influent sampling

h = Treated effluent at 30 cm depth

i = Treated effluent at 50 cm depth

j = Peizometer connections

k = Peizometer board

An adsorption column was constructed by an acrylic column 100 cm long and inner diameter of 8.4 cm. It was packed with palm oil shell ash and was connected to piezometer tubes for head loss development monitoring. The piezometer tubes was connected to pressure taps along the depth of adsorbent by using flexible rubber tubes.

A water-submersible centrifugal pump (Heto, Model QD-3800) was used to deliver untreated wastewater to the constant head tank. This pump can deliver the water at the rate of 25 L/min with a 2.3 meters head of water.

The constant head tank was built by the 11.4 Liters (20 cm*30 cm*19 cm) acrylic container. This tank was 40 cm high from the adsorption column. The tank was kept by an overflow, which recycled the excess wastewater from the constant head tank to the raw wastewater tank.

The blended dispersions kept in the raw wastewater tank was used to store and maintain homogeneity of raw wastewater being fed to the experiment. The raw wastewater tank was a 65 liters plastic tank.

3.2 Analytical Equipment and Chemical Reagents

3.2.1 Analytical Equipment

- Electrical balance

- Refrigerator
- Hot air oven
- COD tubes
- Filter pump
- Buchner funnel and suction flask
- Dessiccator
- Water bath, capable of maintaining 85°C.
- Separation funnel
- Evaporating dishes
- Cylinder
- Filter paper, Whatman No.40 and GF/C

3.2.2 Chemical reagents

- $K_2Cr_2O_7$
- H_2SO_4
- Ag_2SO_4
- Ferroin Indicator
- $Fe(NH_4)_2(SO_4)_2$
- Hexane
- Na_2SO_4

3.3 Preliminary Parameter Screening

1) The size of column was a minimum of 7.5 cm (3 inches) in diameter to minimize side wall effects for media sizes normally used in water treatment (0.5-1.5 mm) (13).

2) Most palm oil shell ash in this study had paticle size of 150-425 µm.

3) The hydraulic loadings of this study were in the range of slow sand filter (2.4-9.6 m^3/m^2/day) (28). From pretest, the operating time at the hydraulic loading of 7.8 m^3/m^2/day was very short (22 hrs); and the hydraulic loading of 3.1 m^3/m^2/day could not treat high volumn of wastewater.

4) The heights of packing adsorbent in this study followed those used in the research of Viraraghavan and Mathavan (22,23), Mahaphrom (26) and Sahairaksa (27), which the packing adsorbent heights 15-45 cm.

3.4 Experimental Methods

The experimental methods were shown in figure 3 and described as follows:

1. Glass beads were filled at the bottom of the column, to support the bed layer was 2 cm thick.

2. Palm oil shell ash prepared in the item 3.1.2 was packed into the column to 50 cm. Each column contains 24±2 g of dry weight of palm oil shell ash and has bed depth of 1 cm.

3. The initial gas station wastewater were continuously pumped to the constant head tank and flowed down to the column. The overflow from the constant head tank was returned to the raw wastewater tank.

4. The required hydraulic loading (4.0 and 6.0 m^3/m^2/day) was adjusted by a control valve at the effluent point and monitored frequently during each run.

5. Effluent samples were collected periodically at the effluent points (30 and 50 cm depth) every 4 hours, until breakthrough occurs. The breakthrough of this adsorption occurs when the headloss reached 90 cm. Before taking samples each time, headloss at various points of adsorption column were monitored by using peizometer. The calculated headloss was obtained from the difference between the initial headloss and the measured headloss at various points prior to sampling each time.

6. The effluent samples were measured for COD, SS, O&G and pH.

7. The adsorption cycle was repeated by using various heights of the packing adsorbent and the hydraulic loading. Each adsorption cycle was replicated three times.

3.5 Parameters Analyzed

Parameters to be determined in the experiment were described in Table 6. All parameters were determined according to the Standard Methods for Examination of Water and Wastewater. 20th Edition,1998 (29).

Table 6 Analytical methods

Parameters	Methods of analysis
COD	Dichromate digestion-closed reflux method
Oil and Grease	Partition gravimetric method
SS	GF/C filtration method
pH	Glass electrode instrument

3.6 Experimental Framework

The diagram of experimental framework is shown in Figure 4:

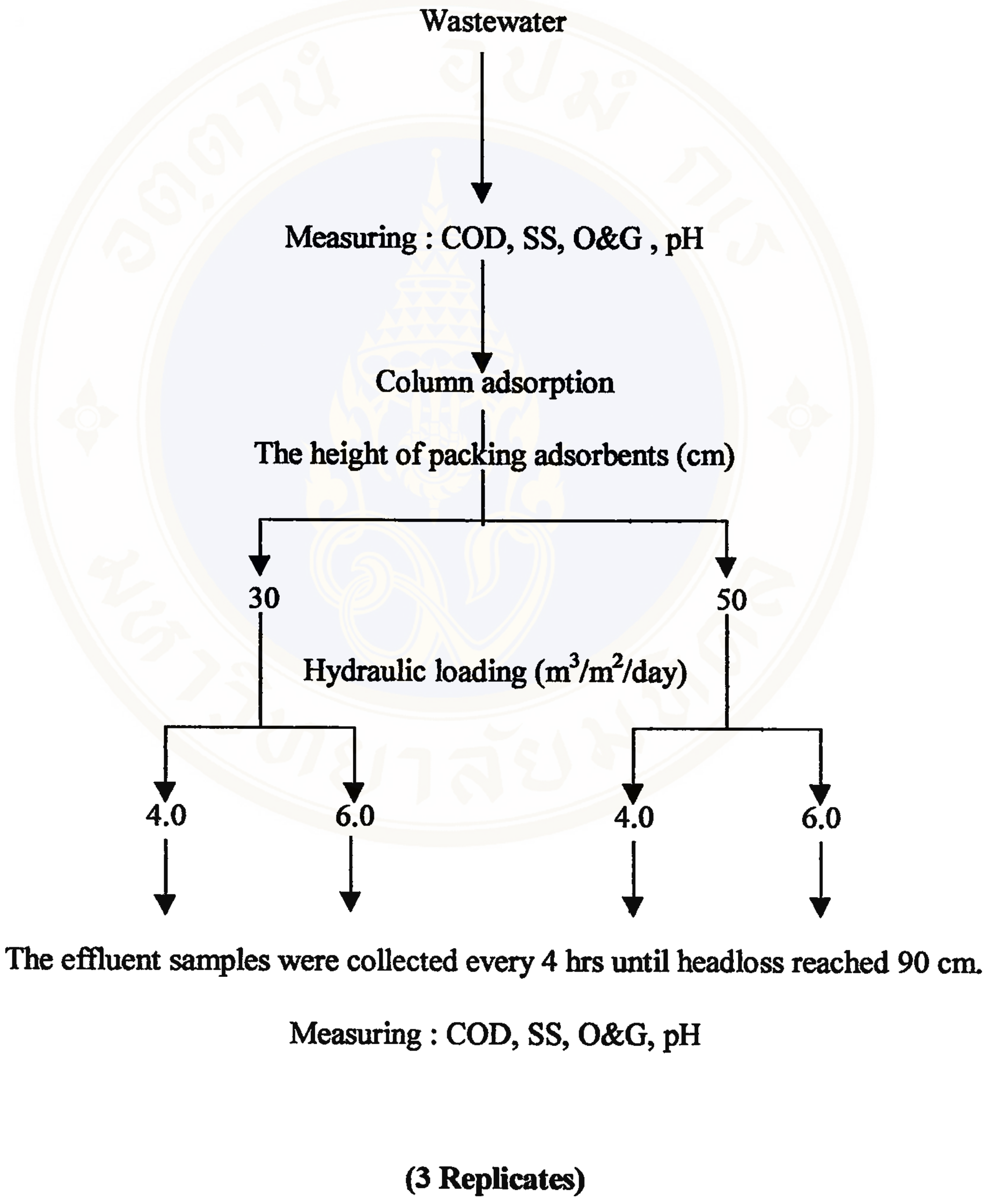


Figure 4 Experimental Framework Chart

3.7 Statistical Analysis

The adsorption run time (hrs) and adsorption removal efficiency (%) was reported in average value (Mean) and the standard deviation (SD). The independent samples t-test was used for comparing the adsorption removal efficiency of system in which parameters were different (Hydraulic loading and height of packing adsorbent). The significant difference of variables was determined at the α level of 0.05.

CHAPTER IV

RESULTS

This chapter presents the results from the laboratory scale experiments for the treatment of gas station wastewater. The specific objectives of the study were to determine the operating time and the removal efficiency of COD, SS, and O&G from gas station wastewater by palm oil shell ash.

4.1 Characteristics of Gas Station Wastewater

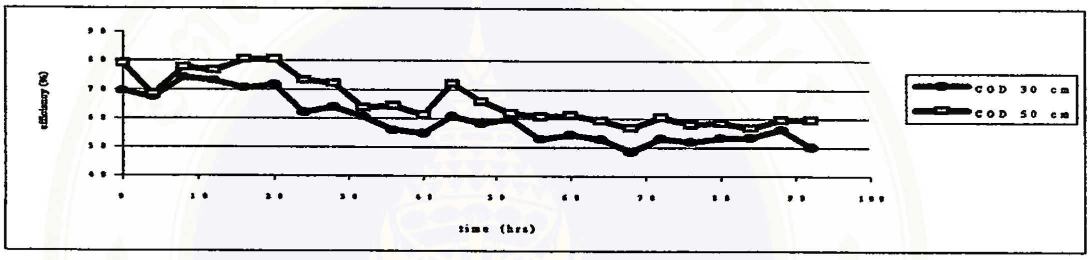
The characteristic of gas station wastewater is illustrated in Table 7. The pH of the wastewater ranged from 7.5 to 8.0. The concentration of COD ranged from 87.75 to 368.39 mg/l. The concentration of SS ranged from 30.67 to 250 mg/l. The concentration of O&G ranged from 5.6 to 40.7 mg/l.

Table 7 The characteristics of gas station wastewater.

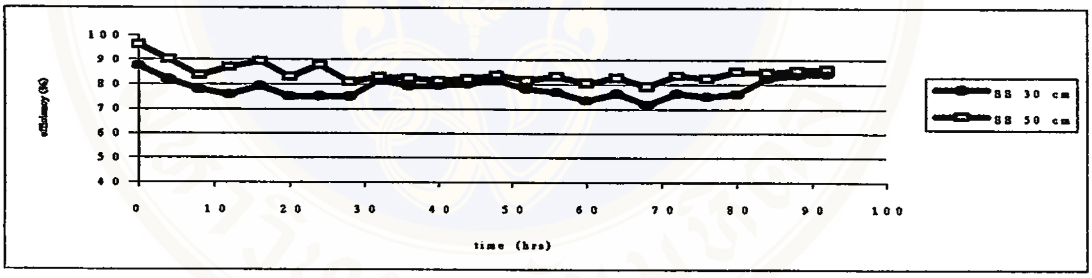
Parameter	Concentration	Mean	S.D.
pH	7.5-8.0	7.78	0.18
COD (mg/l)	87.75-368.39	193.2	84.57
SS (mg/l)	30.67-250	84.23	59.06
O&G (mg/l)	5.6-40.7	22.13	7.23

4.2 The Removal Efficiency of COD, SS, and O&G

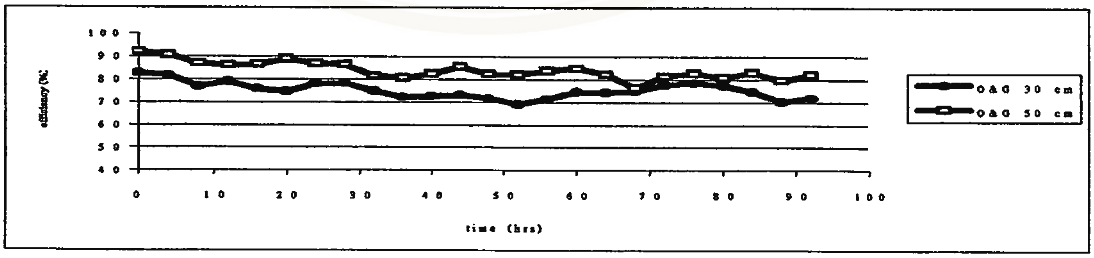
The experiment was conducted to investigate the removal efficiency of COD, SS, and O&G at hydraulic loading of 4.0 and 6.0 m^3/m^2/day, and the packing adsorbent height of 30 and 50 cm. The treated wastewater was collected every 4 hours until the headloss reached 90 cm, as shown in Figure 5 and 6.



(a) The removal efficiency of COD at packing adsorbent height of 30 and 50 cm

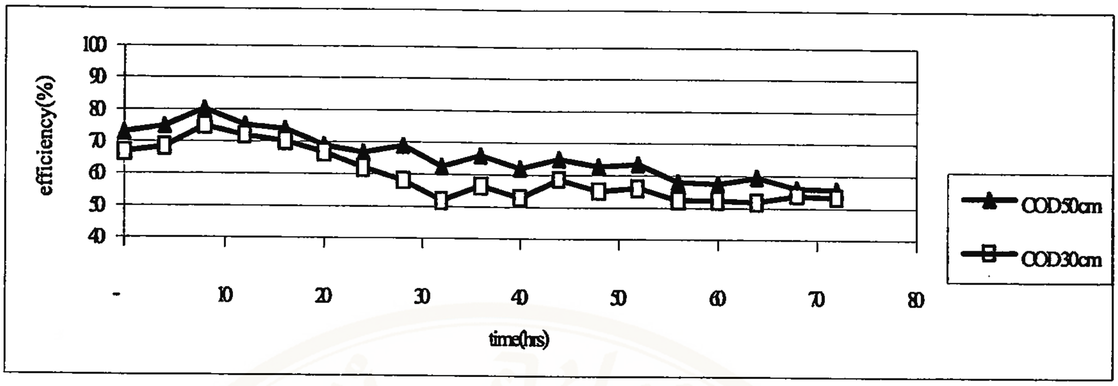


(b) The removal efficiency of SS at packing adsorbent height of 30 and 50 cm

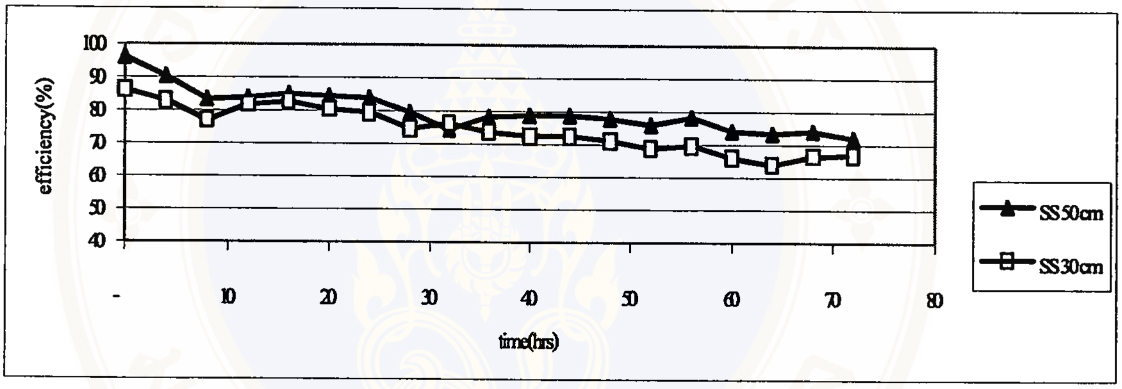


(c) The removal efficiency of O&G at packing adsorbent height of 30 and 50 cm

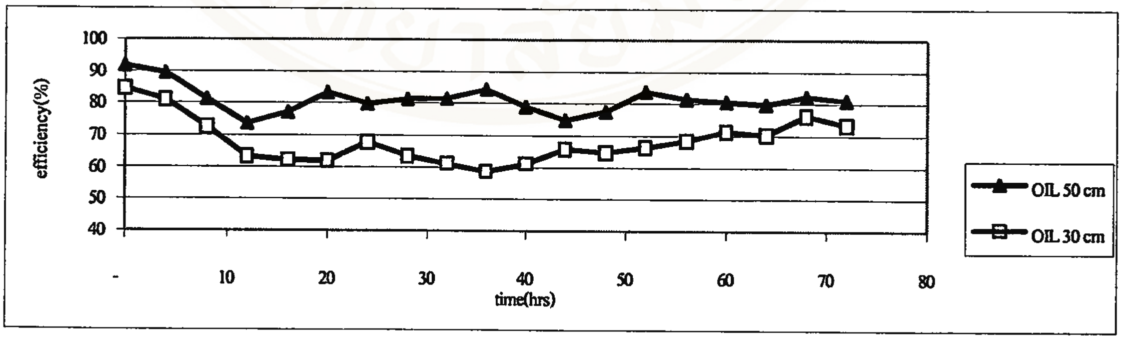
Figure 5 The average removal efficiencies at hydraulic loading of 4.0 m^3/m^2/day (a) COD removal efficiency (b) SS removal efficiency (c) O&G removal efficiency



(a) The removal efficiency of COD at packing adsorbent height of 30 and 50 cm



(b) The removal efficiency of SS at packing adsorbent height of 30 and 50 cm



(c) The removal efficiency of O&G at packing adsorbent height of 30 and 50 cm

Figure 6 The average removal efficiencies at hydraulic loading of 6.0 m^3/m^2/day (a) COD removal efficiency (b) SS removal efficiency (c) O&G removal efficiency

4.3 The Operating Time at Different Hydraulic Loadings

All experiments were carried out until the headloss reached 90 cm which was mornitored by piezometer. At the hydraulic loading of 4.0 m^3/m^2/day, the ranges of operating time of filtration-adsorption were 68-92 hours; and at 6.0 m^3/m^2/day were 60-72 hours, as shown in Table 8.

Table 8 The operating time at different hydraulic loadings

Hydraulic loading (m^3/m^2/day)	Operating time (hrs)	mean	S.D.
4.0	68-92	80	12
6.0	60-72	65.3	6.1

The comparison of mean operating time between hydraulic loading of 4.0 and 6.0 m^3/m^2/day, shown in Figure 7, illustrated that the operating time at hydraulic loading of 4.0 m^3/m^2/day was longer than at 6.0 m^3/m^2/day.

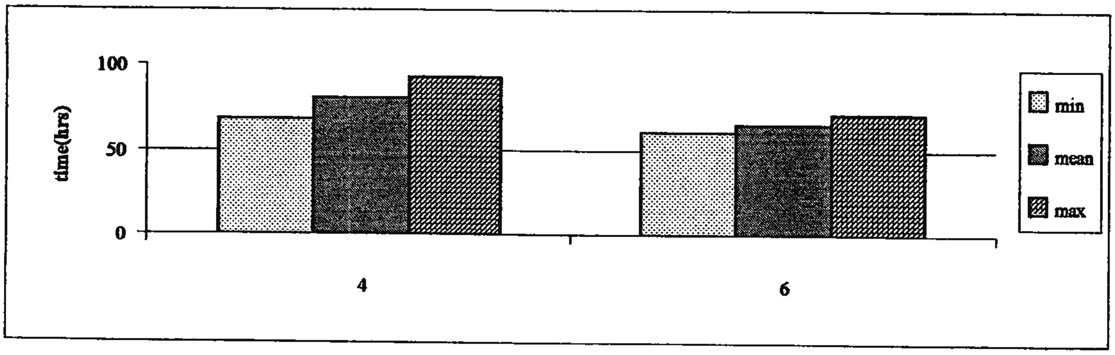


Figure 7 The comparison of operating time at hydraulic loading of 4.0 and 6.0 m^3/m^2/day

4.4 The Removal Efficiency of COD, SS, and O&G at Different Hydraulic Loadings

The experiments were conducted to study the removal efficiency of COD, SS, and O&G from gas station wastewater using palm oil shell ash packed in the column. The gas station wastewater was passed through the experimental column at two hydraulic loadings (4.0 and 6.0 $m^3/m^2/day$). The different hydraulic loadings were achieved by adjusting the control valve and monitoring frequently during each run. The results of the removal efficiency are described as follows:

4.4.1 Experiments operated at hydraulic loading of 4.0 $m^3/m^2/day$

The mean of COD, SS, and O&G removal efficiencies operated at hydraulic loading of 4.0 $m^3/m^2/day$ are illustrated in Table 9. The removal efficiencies for all parameters at the packing adsorbent height of 50 cm were greater than those at 30 cm.

Table 9 The removal efficiency of COD, SS, and O&G operated at hydraulic loading of 4.0 m^3/m^2/day.

Height (cm)	Parameter	The removal efficiency(%)	
		Mean	S.D
30	COD	60.35	10.05
	SS	78.05	8.62
	O&G	75.32	6.02
50	COD	67.16	9.93
	SS	84.21	6.31
	O&G	84.07	4.44

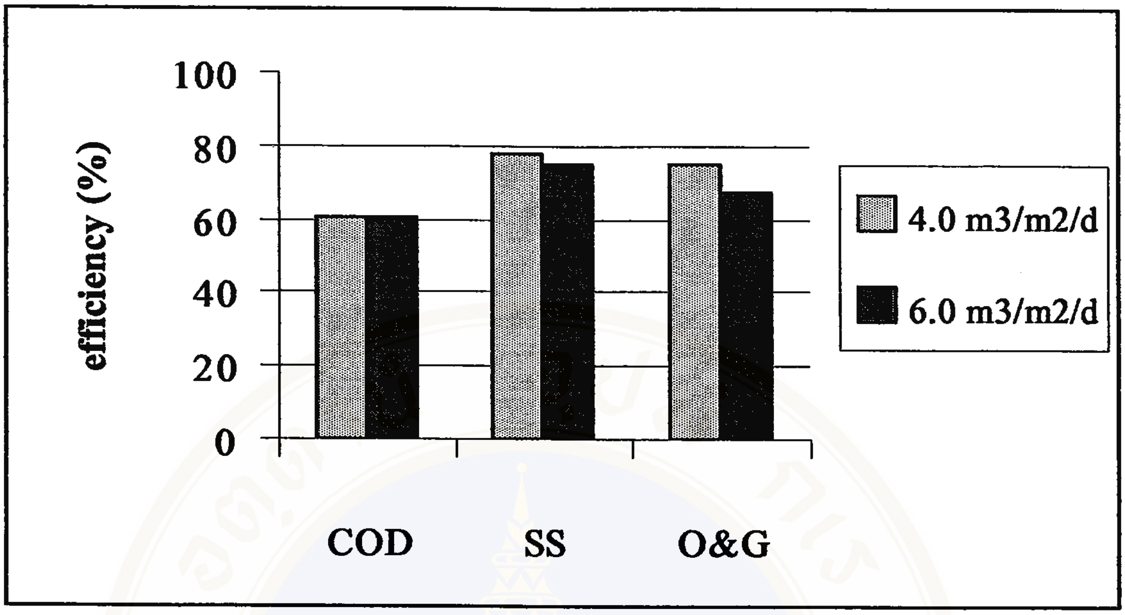
4.4.2 Experiments operated at hydraulic loading of 6.0 m^3/m^2/day

The mean of COD, SS, and O&G removal efficiencies operated at hydraulic loading of 6.0 m^3/m^2/day are illustrated in Table 10. The removal efficiency for all parameters at the packing adsorbent height of 50 cm were greater than those at 30 cm.

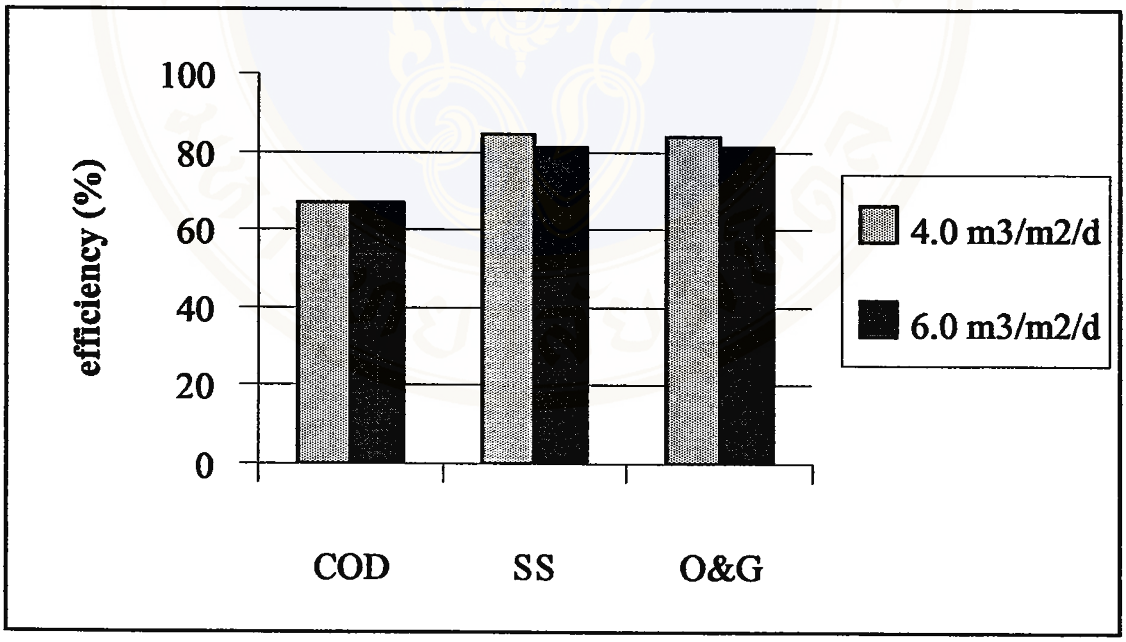
Table 10 The removal efficiency of COD, SS, and O&G operated at hydraulic loading of 6.0 $m^3/m^2/day$.

Height (cm)	Parameter	The removal efficiency(%)	
		Mean	S.D
30	COD	60.34	10.12
	SS	75.21	7.93
	O&G	67.66	9.94
50	COD	66.77	8.76
	SS	80.88	7.12
	O&G	81.29	5.92

The graphs in Figure 8 showed that at the hydraulic loading of 4.0 $m^3/m^2/day$, the removal efficiency of SS and O&G were slightly greater than those at 6.0 $m^3/m^2/day$. While, there was no difference of COD removal efficiency at both hydraulic loadings.



(a)



(b)

Figure 8 The COD, SS, and O&G removal efficiencies at different hydraulic loadings when operated at the height of packing adsorbent of 30 cm (a) and 50 cm(b)

4.5 The COD, SS, and O&G Removal Efficiencies with the Different Heights of Packing Adsorbent

The experiments were conducted to investigate the COD, SS, and O&G removal efficiency of the column system at the packing adsorbent heights of 30 and 50 cm.

4.5.1 The COD, SS, and O&G removal efficiencies at the packing adsorbent height of 30 cm

The mean of COD, SS, and O&G removal efficiencies operated at the packing adsorbent height of 30 cm are illustrated in Table 11. The COD removal efficiency at the hydraulic loading of 4.0 m^3/m^2/day was not different from that at 6.0 m^3/m^2/day. While, the removal efficiencies of SS and O&G at the hydraulic loading of 4.0 m^3/m^2/day were greater than those at 6.0 m^3/m^2/day.

Table 11 The removal efficiency of COD, SS, and O&G operated at the packing adsorbent height of 30 cm

Hydraulic loading ($m^3/m^2/day$)	Parameter	The removal efficiency(%)	
		Mean	S.D
4.0	COD	60.35	10.05
	SS	78.05	8.62
	O&G	75.32	6.02
6.0	COD	60.34	10.12
	SS	75.21	7.93
	O&G	67.66	9.94

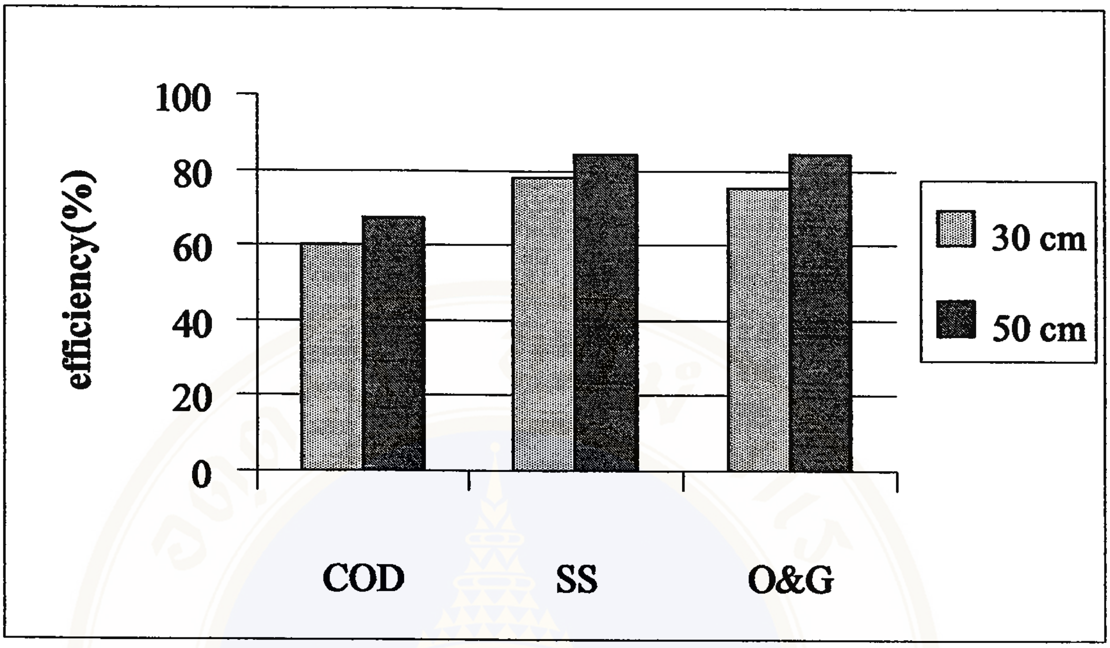
4.5.2 The COD, SS, and O&G removal efficiencies at the packing adsorbent height of 50 cm

The mean of COD, SS, and O&G removal efficiencies at the packing adsorbent height of 50 cm are illustrated in Table 12. The removal efficiencies of all 3 parameters at the hydraulic loading of 4.0 $m^3/m^2/day$ were greater than those at 6.0 $m^3/m^2/day$.

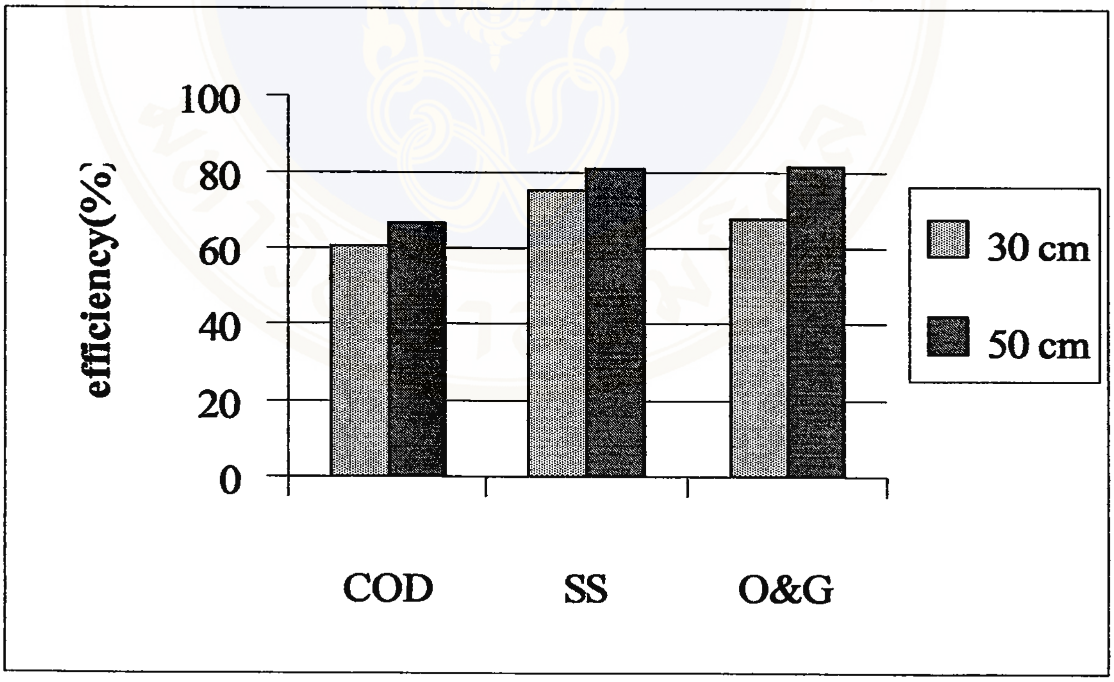
Table 12 The removal efficiency of COD, SS, and O&G operated at the packing adsorbent height of 50 cm

Hydraulic loading (m^3/m^2/day)	Parameter	The removal efficiency (%)	
		Mean	S.D
4.0	COD	67.16	9.93
	SS	84.21	6.31
	O&G	84.07	4.44
6.0	COD	66.78	8.76
	SS	80.88	7.12
	O&G	81.29	5.92

The removal efficiencies of all 3 parameters when operated at the packing adsorbent height of 30 and 50 cm are shown in Figure 9. It illustrated that at 50 cm height of packing adsorbent, the removal efficiency of all parameters were greater than those at the 30 cm height.



(a)



(b)

Figure 9 The removal efficiencies of COD, SS, and O&G at different heights of packing adsorbent when operated at hydraulic loading of 4.0 m^3/m^2/day(a) and 6.0 m^3/m^2/day (b)

4.6 Statistical Analysis

4.6.1 Statistical Analysis of different hydraulic loadings

The results of statistical analysis of COD, SS, and O&G removal efficiencies at hydraulic loading of 4.0 and 6.0 $m^3/m^2/day$ using the independent samples t-test shown in Appendix B are summarized in Table13.

Table 13 The statistical analysis of different hydraulic loading

Parameter	hydraulic loading ($m^3/m^2/day$)	The removal efficiency (%) Mean	S.D.	N	P-value
COD	4.0	63.73	10.45	126	0.900
	6.0	63.56	9.96	104	
SS	4.0	81.13	8.14	126	0.004
	6.0	78.04	8.02	104	
O&G	4.0	79.70	6.86	126	<0.001
	6.0	74.48	10.64	104	

Table 13 illustrated the removal efficiencies of all parameters at hydraulic loading of 4.0 and 6.0 $m^3/m^2/day$. The statistical analysis at 0.05 level of significance revealed that SS and O&G removal efficiencies at hydraulic loading of 4.0 $m^3/m^2/day$ were significantly higher than those at 6.0 $m^3/m^2/day$ ($P\text{-value}<0.05$), but COD removal efficiency was not significantly different ($P\text{-value}=0.900$).

4.6.2 Statistical Analysis of different heights of packing adsorbent

The results of statistical analysis by using the independent samples t-test to compare the COD, SS, and O&G removal efficiencies at the packing adsorbent height of 30 and 50 cm are illustrated in Table 14.

Table 14 The statistical analysis of the different heights of packing adsorbent

Parameter	Height of adsorbent	The removal efficiency(%)			
	(cm)	mean	S.D.	N	P-value
COD	30	60.35	10.04	115	<0.001
	50	66.96	9.31	115	
SS	30	76.76	8.40	115	<0.001
	50	82.70	6.87	115	
O&G	30	71.86	8.86	115	<0.001
	50	82.82	5.32	115	

In Table 14, at the packing adsorbent height of 30 and 50 cm, the mean of removal efficiencies of COD, SS, and O&G are presented. The statistical analysis showed that the means of removal efficiency of all parameters at the packing adsorption height of 50 cm were significantly higher than those at 30 cm (P-value <0.001).

CHAPTER V

DISCUSSION

5.1 Effect of Hydraulic Loading on Operating Time

The average of operating times at hydraulic loading of 4.0 and 6.0 m^3/m^2/day were 80 and 65.3 hours, respectively, which showed that the mean of operating time at hydraulic loading of 4.0 m^3/m^2/day was longer than at 6.0 m^3/m^2/day. This result corresponded to the first hypetheses, which stated that at hydraulic loading of 4.0 m^3/m^2/day the operating time would be longer than at 6.0 m^3/m^2/day.

It could be explained that when hydraulic loading increased the COD, SS and O&G loading would also increase. So, the upper portion of adsorbent becomes saturated in a short time (30); and more particles will be captured in the surface of adsorbent than at lower hydraulic loading (31). Therefore, headloss development at hydraulic loading of 6.0 m^3/m^2/day was faster than at 4.0 m^3/m^2/day. The headloss development of different hydraulic loadings are shown in Figure 10.

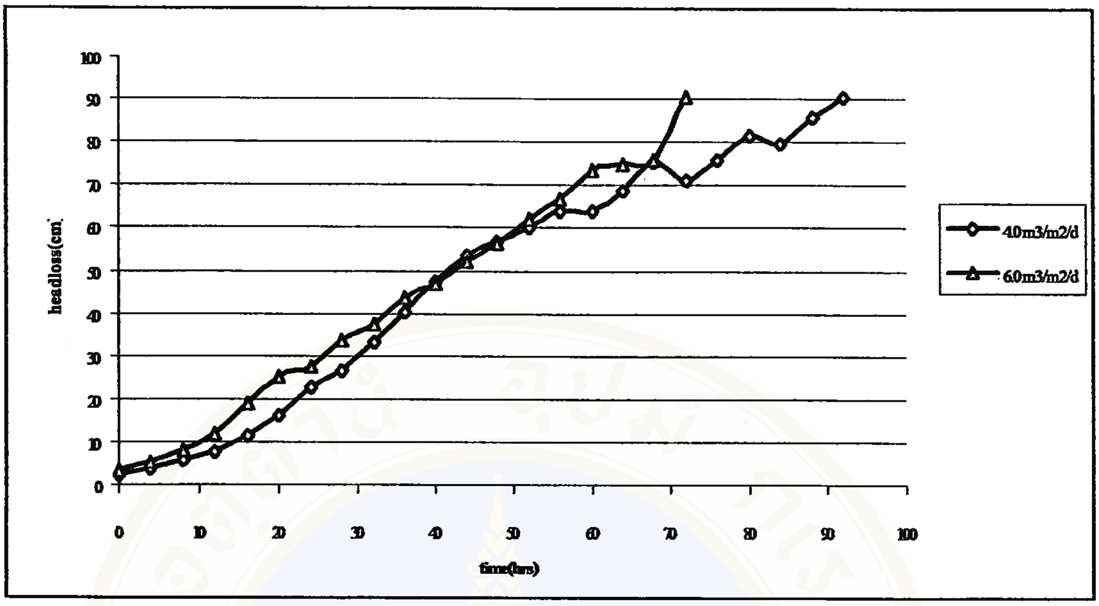


Figure 10 Headloss development of different hydraulic loadings

5.2 Effect of Hydraulic Loading on Removal Efficiency of COD, SS, and O&G

The data in Table 13 presented the mean values of the removal efficiency of all parameters. The result of statistical analysis revealed that for COD removal efficiency there was no significant difference (P-value>0.05) at both hydraulic loadings. This result did not correspond to the second hypothesis, which stated that the COD removal efficiency from gas station wastewater at hydraulic loading of 4.0 m^3/m^2/day was higher than at 6.0 m^3/m^2/day. However, SS and O&G removal efficiencies at hydraulic loading of 4.0 m^3/m^2/day were significantly higher than at hydraulic loading of 6.0 m^3/m^2/day. This result corresponded to the second hypothesis, which stated that the SS and O&G removal efficiency from gas station wastewater at hydraulic loading of 4.0 m^3/m^2/day was higher than at 6.0 m^3/m^2/day

This result is similar to the studies of Mathanvan and Viraraghavan (24), Mahaphrom (26) and Pibul (30), which noted that the removal efficiency decreased when increasing hydraulic loading. It is due to the fact that impurities are removed principally by two mechanisms; ion exchange and the formation of complexes. There are essentially four stages in the adsorption process: (i) transport of impurities from the bulk of solution to the exterior surface of the adsorbent; (ii) movement of pollutant across the interface and adsorption onto external surface sites; (iii) migration of pollutant molecules within the pores of the adsorbent; and (iv) interaction of pollutant molecules with the available sites on the interior surfaces, bounding the pore and capillary spaces of the adsorbent. One or more of the previous steps may control the rate at which pollutants are adsorbed and the quantity of pollutants adsorbed onto solid paticle. At low hydraulic loading, the boundary layer resistance will be significant and step (ii) will be important in the rate-controlling process (32). The rate of adsorption varies according to the contact with the pollutants. Increasing hydraulic loading results in insufficient contact time of pollutants onto all adsorbing site of adsorbent. Thus, the mean average of removal efficiencies of SS and O&G from gas station wastewater decreased.

5.3 Effect of the Height of Packing Adsorbent on COD, SS, and O&G Removal Efficiency

The mean removal efficiencies of COD, SS, and O&G operated at the packing adsorbent heights of 30 and 50 cm are summarized in Table 14. The result of statistical analysis at 0.05 level of significance revealed that the removal efficiencies for all parameters at the packing adsorbent height of 50 cm were significantly greater than that of 30 cm. The result was in agreement with the third hypothesis which stated that the COD, SS, and O&G removal efficiency increased when the height of packing adsorbent increased.

The COD, SS, and O&G removal efficiency increased when the height of packing adsorbent was increased. The explanation of this phenomenon could be that the increase of the height of packing adsorbent will result in the larger surface area and increased the detention time, thus the longer contact time of the wastewater with the adsorbent. In addition, this result was in agreement with the study of Bose and Theodore (25), Mahaphrom (26) and Sahairaksa (27), which found that removal efficiencies of adsorption column which increased the height of packing adsorbent was more efficient than the lower height of packing adsorbent. It indicated that the removal efficiency changed if the height of packing adsorbent changed.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

This study was conducted to investigate the COD, SS, and O&G removal efficiencies from gas station wastewater by using the palm oil shell ash as adsorbent. The conclusions from the results of this experimental research are as follows:

1) The operating time at hydraulic loading of 4.0 m^3/m^2/day was longer than at 6.0 m^3/m^2/day.

2) The mean SS and O&G removal efficiencies at hydraulic loading of 4.0 m^3/m^2/day was significantly higher than at 6.0 m^3/m^2/day. But, the mean COD removal efficiency was not significantly different.

3) The mean removal efficiencies of COD, SS and O&G at the packing adsorbent height of 50 cm was significantly higher than at 30 cm.

6.2 Recommendations

1) The experiment should be scaled-up in order to apply in the actual situation.

2) For increasing the removal efficiencies of COD, SS, and O&G, the study should be conducted in series filtration-adsorption columns.

3) The pretreatment is an important step for the operating time and the removal efficiencies of COD, SS, and O&G from gas station wastewater, because the pretreatment system will help to remove the COD, SS, and floating oil from the wastewater prior to the treatment in the column filtration-adsorption system. This will make the column adsorption system function efficiently to remove the COD, SS, and O&G from the gas station wastewater.

4) The filtration-adsorption system should be backwashed to extend the operating time of adsorbent.

5) The experiment should be studied in all seasons to investigate the effects of seasonal variation on the characteristics of wastewater.

6) The removal efficiencies of COD, SS, and O&G using palm oil shell ash from other sources should be studied.

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APPENDIX A

Data of the Experiment

Table A-1 The influent and effluent pH of gas station wastewater of hydraulic loading 6.0 m^3/m^2/day.

Time	Height	pH			
(hrs)	(cm)	1	2	3	ave
0	Inf.	7.7	7.5	7.9	7.7
	30	7.9	7.4	7.3	7.5
	50	7.5	7.2	7.2	7.3
4	Inf.	7.7	7.5	7.9	7.7
	30	7.9	7.5	7.5	7.6
	50	7.5	7.3	7.4	7.4
8	Inf.	7.9	7.5	7.9	7.8
	30	7.7	7.5	7.7	7.6
	50	7.4	7.4	7.5	7.4
12	Inf.	7.9	7.5	7.9	7.8
	30	7.7	7.5	7.6	7.6
	50	7.5	7.4	7.5	7.5
16	Inf.	8.0	7.5	7.8	7.8
	30	7.7	7.4	7.7	7.6
	50	7.5	7.3	7.6	7.5
20	Inf.	8.0	7.6	7.9	7.8
	30	7.9	7.5	7.7	7.7
	50	7.9	7.5	7.6	7.7
24	Inf.	8.0	7.5	7.9	7.8
	30	7.9	7.5	7.7	7.7
	50	7.8	7.5	7.6	7.6
28	Inf.	8.0	7.5	7.9	7.8
	30	7.9	7.4	7.9	7.7
	50	7.8	7.4	7.7	7.6
32	Inf.	8.0	7.5	7.8	7.8
	30	7.8	7.5	7.9	7.7
	50	7.8	7.4	7.7	7.6
36	Inf.	8.0	7.5	7.8	7.8
	30	7.8	7.5	7.8	7.7
	50	7.7	7.5	7.7	7.6
40	Inf.	7.9	7.6	7.8	7.8
	30	7.8	7.5	7.7	7.7
	50	7.8	7.4	7.7	7.6

Table A-1 The influent and effluent pH of gas station wastewater of hydraulic loading 6.0 m^3/m^2/day.(Continued)

Time	Height	pH			
(hrs)	(cm)	1	2	3	ave
44	Inf.	7.9	7.6	7.8	7.8
	30	7.7	7.5	7.8	7.7
	50	7.7	7.4	7.6	7.6
48	Inf.	7.9	7.6	7.9	7.8
	30	7.8	7.5	7.8	7.7
	50	7.7	7.4	7.8	7.6
52	Inf.	7.9	7.6	7.8	7.8
	30	7.8	7.5	7.7	7.7
	50	7.7	7.5	7.7	7.6
56	Inf.	7.9	7.6	7.8	7.8
	30	7.8	7.4	7.8	7.7
	50	7.7	7.4	7.7	7.6
60	Inf.	7.9	7.5	7.8	7.7
	30	7.8	7.5	7.8	7.7
	50	7.8	7.4	7.6	7.6
64	Inf.		7.8	8.0	7.9
	30		7.5	7.9	7.7
	50		7.5	7.8	7.7
68	Inf.			7.9	7.9
	30			7.9	7.9
	50			7.8	7.8
72	Inf.			7.9	7.9
	30			7.8	7.8
	50			7.6	7.6

Table A-2 The headloss of gas station wastewater of hydraulic loading 6.0 $m^3/m^2/day$.

Time (hrs)	Height (cm)	Headloss (cm)			
		No.1	No.2	No.3	ave
0	30	3.0	2.3	2.6	2.6
	50	3.5	3.0	3.6	3.4
4	30	3.6	4.3	4.3	4.1
	50	4.5	5.4	5.3	5.1
8	30	7.2	8.0	5.3	6.8
	50	8.4	9.2	6.7	8.1
12	30	11.9	13.1	6.5	10.5
	50	13.1	14.2	8.2	11.8
16	30	22.3	20.7	8.5	17.2
	50	24.5	21.7	10.1	18.8
20	30	30.6	28.8	10.5	23.3
	50	32.0	30.4	12.4	24.9
24	30	36.7	29.7	12.1	26.2
	50	38.1	31.1	14.0	27.7
28	30	49.5	32.3	14.5	32.1
	50	50.6	33.6	16.4	33.5
32	30	55.2	33.9	18.5	35.9
	50	56.2	35.4	20.6	37.4
36	30	61.0	42.9	22.1	42.0
	50	62.5	44.1	23.9	43.5
40	30	65.4	48.1	23.9	45.8
	50	66.0	49.3	25.3	46.8

Table A-2 The headloss of gas station wastewater of hydraulic loading 6.0 m^3/m^2/day. (Continued)

Time (hrs)	Height (cm)	Headloss (cm)			
		No.1	No.2	No.3	ave
44	30	70.6	55.5	26.3	50.8
	50	71.8	56.8	27.8	52.1
48	30	75.9	62.8	27.9	55.5
	50	77.0	63.7	28.3	56.3
52	30	81.5	69.3	31.3	60.7
	50	82.7	70.5	32.6	61.9
56	30	86.0	72.1	38.7	65.6
	50	87.4	73.6	40.0	67.0
60	30	90.8	77.5	48.8	72.4
	50	91.7	78.8	49.9	73.5
64	30		89.8	60.0	74.9
	50		88.2	61.6	74.9
68	30			74.3	74.3
	50			75.8	75.8
72	30			89.0	89.0
	50			90.3	90.3

Table A-3 The influent and effluent SS of gas station wastewater of hydraulic loading 6.0 m^3/m^2/day.

Time (hrs)	Height (cm)	SS (mg/l)			
		1	2	3	ave
0	Inf.	40.00	41.40	172.00	84.47
	30	6.00	8.80	8.20	7.67
	50	1.54	2.00	4.85	2.80
4	Inf.	40.00	41.40	172.00	84.47
	30	6.55	11.13	12.74	10.14
	50	5.32	4.48	7.20	5.67
8	Inf.	40.00	41.40	172.00	84.47
	30	8.94	14.23	21.72	14.96
	50	6.41	9.27	18.93	11.54
12	Inf.	68.00	77.17	250.00	131.72
	30	13.60	17.74	28.20	19.85
	50	10.47	15.43	31.82	19.24
16	Inf.	74.00	77.17	250.00	133.72
	30	21.00	11.38	21.37	17.92
	50	19.00	9.20	18.44	15.55
20	Inf.	74.00	36.25	250.00	120.08
	30	22.01	5.67	33.17	20.28
	50	17.51	4.78	24.47	15.59
24	Inf.	60.00	36.25	112.00	69.42
	30	15.00	7.61	17.50	13.37
	50	9.00	7.25	15.00	10.42
28	Inf.	60.00	36.25	112.00	69.42
	30	16.62	10.43	22.26	16.44
	50	10.97	9.58	18.39	12.98
32	Inf.	60.00	35.50	112.00	69.17
	30	16.00	8.76	22.58	15.78
	50	16.00	12.15	17.89	15.35
36	Inf.	60.00	36.25	112.00	69.42
	30	17.46	9.86	24.45	17.26
	50	14.25	8.61	18.69	13.85
40	Inf.	48.00	36.25	112.00	65.42
	30	13.44	11.01	25.81	16.75
	50	10.08	8.52	20.97	13.19
44	Inf.	48.00	38.40	112.00	66.13
	30	14.06	10.18	29.46	17.90
	50	10.84	8.17	21.97	13.66
48	Inf.	48.00	38.40	113.79	66.73
	30	14.80	10.55	31.86	19.07
	50	11.50	8.16	23.89	14.52

Table A-3 The influent and effluent SS of gas station wastewater of hydraulic loading 6.0 m^3/m^2/day. (Continued)

Time (hrs)	Height (cm)	SS (mg/l)			
		1	2	3	ave
52	Inf.	48.00	30.67	113.79	64.15
	30	14.39	10.67	32.91	19.32
	50	10.34	8.46	25.96	14.92
56	Inf.	48.00	30.67	151.92	76.86
	30	13.90	9.20	48.61	23.90
	50	10.05	6.80	33.42	16.76
60	Inf.	48.00	30.67	151.92	76.86
	30	15.16	10.96	51.95	26.02
	50	11.27	8.55	39.10	19.64
64	Inf.		30.67	151.92	91.30
	30		11.72	51.65	31.69
	50		9.20	34.94	22.07
68	Inf.			100.00	100.00
	30			33.60	33.60
	50			25.79	25.79
72	Inf.			100.00	100.00
	30			33.00	33.00
	50			27.89	27.89

Table A-4 The influent and effluent COD of gas station wastewater of hydraulic loading 6.0 m^3/m^2/day.

Time	Height	COD (mg/l)			
(hrs)	(cm)	No.1	No.2	No.3	ave
0	Inf.	160.00	176.73	362.15	232.96
	30	76.19	51.64	83.51	70.45
	50	60.95	43.64	65.56	56.72
4	Inf.	160.00	176.73	362.15	232.96
	30	60.95	46.55	109.27	72.26
	50	45.71	42.18	81.17	56.35
8	Inf.	160.00	176.73	362.15	232.96
	30	38.10	34.18	114.73	62.34
	50	30.48	26.91	91.32	49.57
12	Inf.	137.10	141.09	368.39	215.53
	30	34.29	41.45	108.49	61.41
	50	34.29	32.73	96.00	54.34
16	Inf.	160.00	141.09	368.39	223.16
	30	49.52	36.36	119.41	68.43
	50	38.10	37.82	101.46	59.13
20	Inf.	160.00	135.50	368.39	221.30
	30	54.86	45.82	115.51	72.06
	50	51.05	45.09	102.24	66.13
24	Inf.	131.05	135.50	272.13	179.56
	30	52.57	52.50	94.49	66.52
	50	31.24	57.75	90.71	59.90
28	Inf.	131.05	135.50	272.13	179.56
	30	51.05	57.75	120.19	76.33
	50	35.81	42.00	93.73	57.18
32	Inf.	131.05	87.75	272.13	163.64
	30	57.14	51.75	113.39	74.09
	50	35.81	39.00	109.61	61.47
36	Inf.	131.05	135.50	272.13	179.56
	30	46.48	47.25	110.36	68.03
	50	24.38	37.50	109.61	57.16
40	Inf.	115.81	135.50	272.13	174.48
	30	54.15	50.25	102.05	68.82
	50	34.15	39.75	105.83	59.91

Table A-4 The influent and effluent COD of gas station wastewater of hydraulic loading 6.0 $m^3/m^2/day$. (Continued)

Time	Height	COD (mg/l)			
(hrs)	(cm)	No.1	No.2	No.3	ave
44	Inf.	115.81	126.00	272.13	171.31
	30	55.58	50.63	98.27	68.16
	50	39.60	46.13	92.98	59.57
48	Inf.	115.81	126.00	293.16	178.32
	30	58.43	69.25	86.58	71.42
	50	45.59	55.08	82.78	61.15
52	Inf.	131.05	116.46	293.16	180.22
	30	62.38	62.16	90.38	71.64
	50	47.44	50.36	86.58	61.46
56	Inf.	131.05	116.46	249.11	165.54
	30	65.65	62.16	97.22	75.01
	50	51.50	58.23	91.14	66.96
60	Inf.	131.05	116.46	249.11	165.54
	30	65.00	64.52	94.18	74.57
	50	53.63	58.23	90.38	67.41
64	Inf.		116.46	249.11	182.79
	30		65.31	100.25	82.78
	50		53.51	86.58	70.05
68	Inf.			195.95	195.95
	30			90.38	90.38
	50			85.82	85.82
72	Inf.			195.95	195.95
	30			91.35	91.35
	50			86.71	86.71

Table A-5 The influent and effluent O&G of gas station wastewater of hydraulic loading 6.0 $m^3/m^2/day$.

Time	Height	O&G (mg/l)			
(hrs)	(cm)	No.1	No.2	No.3	ave
0	Inf.	29.20	9.20	40.70	26.37
	30	5.03	1.95	3.12	3.37
	50	2.13	1.16	1.85	1.71
4	Inf.	29.20	9.20	40.70	26.37
	30	5.58	2.45	4.47	4.17
	50	3.03	1.28	2.88	2.40
8	Inf.	29.20	9.20	40.70	26.37
	30	6.73	2.78	11.69	7.07
	50	5.18	1.66	8.23	5.02
12	Inf.	29.20	19.20	31.08	26.49
	30	8.94	6.64	13.81	9.80
	50	8.23	4.60	8.26	7.03
16	Inf.	29.20	19.20	31.08	26.49
	30	10.37	8.01	11.32	9.90
	50	8.50	3.40	6.76	6.22
20	Inf.	26.30	19.20	31.08	25.53
	30	10.04	9.02	8.98	9.35
	50	3.50	3.91	4.96	4.12
24	Inf.	26.30	19.20	17.14	20.88
	30	10.30	4.95	5.39	6.88
	50	4.63	4.41	3.44	4.16
28	Inf.	26.30	19.20	17.14	20.88
	30	9.76	1.60	9.31	6.89
	50	3.45	1.57	4.47	3.16
32	Inf.	26.30	5.60	17.14	16.35
	30	10.30	2.12	6.75	6.39
	50	4.04	1.05	3.70	2.93
36	Inf.	22.80	19.20	17.14	19.71
	30	9.30	2.80	5.71	5.94
	50	3.67	1.20	1.63	2.17
40	Inf.	22.80	19.20	17.14	19.71
	30	9.69	2.52	5.02	5.74
	50	4.80	1.52	2.51	2.94

Table A-5 The influent and effluent O&G of gas station wastewater of hydraulic loading 6.0 m^3/m^2/day. (Continued)

Time (hrs)	Height (cm)	O&G (mg/l)			
		No.1	No.2	No.3	ave
44	Inf.	22.80	19.20	17.14	19.71
	30	9.46	7.60	3.64	6.90
	50	5.40	5.60	3.85	4.95
48	Inf.	22.80	19.20	21.89	21.30
	30	8.85	8.14	5.32	7.44
	50	6.09	4.52	3.76	4.79
52	Inf.	20.73	19.20	21.89	20.61
	30	7.06	7.76	5.65	6.82
	50	3.44	4.39	2.04	3.29
56	Inf.	20.73	19.20	21.43	20.45
	30	6.74	7.35	5.01	6.37
	50	3.67	4.89	2.59	3.72
60	Inf.	20.73	19.20	21.43	20.45
	30	6.25	7.06	4.00	5.77
	50	4.04	4.76	2.92	3.91
64	Inf.		19.20	21.43	20.32
	30		7.34	4.47	5.91
	50		4.51	3.59	4.05
68	Inf.			18.49	18.49
	30			4.38	4.38
	50			3.27	3.27
72	Inf.			18.49	18.49
	30			4.90	4.90
	50			3.51	3.51

Table A-6 The influent and effluent pH of gas station wastewater of hydraulic loading 4.0 $m^3/m^2/day$.

Time	Height	pH			
(hrs)	(cm)	No.1	No.2	No.3	ave.
0	Inf.	7.7	7.5	7.9	7.7
	30	8.5	7.5	7.3	7.8
	50	7.9	7.2	7.1	7.4
4	Inf.	7.7	7.5	7.9	7.7
	30	8.5	7.5	7.4	7.8
	50	8.3	7.3	7.2	7.6
8	Inf.	7.9	7.5	7.9	7.8
	30	8.3	7.5	7.6	7.8
	50	8.3	7.4	7.3	7.7
12	Inf.	7.9	7.5	7.9	7.8
	30	8.2	7.5	7.5	7.7
	50	8.3	7.4	7.5	7.7
16	Inf.	8.0	7.5	7.9	7.8
	30	8.3	7.6	7.6	7.8
	50	8.2	7.4	7.4	7.7
20	Inf.	8.0	7.6	7.9	7.8
	30	8.5	7.6	7.6	7.9
	50	8.2	7.5	7.5	7.7
24	Inf.	8.0	7.5	7.9	7.8
	30	8.5	7.6	7.6	7.9
	50	8.3	7.5	7.5	7.8
28	Inf.	8.0	7.5	7.9	7.8
	30	8.4	7.6	7.8	7.9
	50	8.3	7.5	7.7	7.8
32	Inf.	8.0	7.5	7.8	7.8
	30	8.4	7.5	7.9	7.9
	50	8.3	7.5	7.6	7.8
36	Inf.	8.0	7.5	7.8	7.8
	30	8.3	7.5	7.8	7.9
	50	8.3	7.4	7.7	7.8
40	Inf.	7.9	7.6	7.8	7.8
	30	8.3	7.5	7.7	7.8
	50	8.2	7.4	7.7	7.8
44	Inf.	7.9	7.6	7.8	7.8
	30	8.3	7.5	7.7	7.8
	50	8.2	7.5	7.6	7.8
48	Inf.	7.9	7.6	7.9	7.8
	30	8.3	7.7	7.8	7.9
	50	8.2	7.5	7.7	7.8

Table A-6 The influent and effluent pH of gas station wastewater of hydraulic loading 4.0 m^3/m^2/day. (Continued)

Time (hrs)	Height (cm)	pH			
		No.1	No.2	No.3	ave.
52	Inf.	7.9	7.6	7.8	7.8
	30	8.2	7.5	7.7	7.8
	50	8.2	7.4	7.7	7.8
56	Inf.	7.9	7.6	7.8	7.8
	30	8.2	7.5	7.8	7.8
	50	8.2	7.5	7.7	7.8
60	Inf.	7.9	7.5	7.8	7.7
	30	8.2	7.5	7.8	7.8
	50	8.1	7.4	7.8	7.8
64	Inf.	7.8	7.8	8.0	7.9
	30	7.9	7.6	7.9	7.8
	50	7.9	7.5	7.8	7.7
68	Inf.	7.9	7.8	7.9	7.9
	30	8.0	7.7	7.8	7.8
	50	7.9	7.6	7.7	7.7
72	Inf.		7.8	7.9	7.9
	30		7.8	7.8	7.8
	50		7.6	7.7	7.7
76	Inf.		7.9		7.9
	30		7.8	7.8	7.8
	50		7.7	7.7	7.7
80	Inf.		7.9	8.0	8.0
	30		7.8	7.8	7.8
	50		7.7	7.6	7.7
84	Inf.			8.0	8.0
	30			7.8	7.8
	50			7.7	7.7
88	Inf.			8.0	8.0
	30			7.8	7.8
	50			7.7	7.7
92	Inf.			7.9	7.9
	30			7.8	7.8
	50			7.6	7.6

Table A-7 The headloss of gas station wastewater of hydraulic loading 4.0 $m^3/m^2/day$.

Time (hrs)	Height (cm)	Headloss (cm)			
		No.1	No.2	No.3	ave.
0	30	2.4	1.7	1.9	2.0
	50	3.2	2.2	2.4	2.6
4	30	4.0	2.9	3.1	3.3
	50	4.6	3.4	3.8	3.9
8	30	6.0	4.5	4.2	4.9
	50	6.9	5.1	5.0	5.7
12	30	8.2	6.3	5.5	6.7
	50	9.8	7.0	6.5	7.8
16	30	12.6	9.3	8.6	10.2
	50	14.3	10.0	9.5	11.3
20	30	17.0	16.8	12.6	15.5
	50	17.8	17.2	13.4	16.1
24	30	22.9	21.8	18.7	21.1
	50	24.7	23.4	19.9	22.7
28	30	29.6	23.0	24.2	25.6
	50	30.2	24.9	25.0	26.7
32	30	37.7	29.3	29.4	32.1
	50	38.8	30.1	30.4	33.1
36	30	45.6	36.0	34.6	38.7
	50	46.5	39.0	35.8	40.4
40	30	53.1	43.5	39.7	45.4
	50	55.4	46.2	40.3	47.3
44	30	62.0	51.0	43.9	52.3
	50	63.3	52.7	45.1	53.7
48	30	68.2	52.5	46.5	55.7
	50	70.1	53.5	47.6	57.1
52	30	72.8	55.4	49.8	59.3
	50	73.7	55.5	51.0	60.1

Table A-7 The headloss of gas station wastewater of hydraulic loading 4.0 $m^3/m^2/day$. (Continued)

Time	Height	Headloss (cm)			
(hrs)	(cm)	No.1	No.2	No.3	ave.
56	30	75.6	58.4	53.4	62.5
	50	76.9	59.8	54.9	63.9
60	30	77.5	62.8	48.9	63.1
	50	78.8	63.4	49.6	63.9
64	30	81.7	66.5	54.0	67.4
	50	82.5	67.7	55.3	68.5
68	30	90.5	71.1	59.8	73.8
	50	91.9	72.6	60.9	75.1
72	30		75.7	64.3	70.0
	50		76.6	65.6	71.1
76	30		82.0	67.5	74.8
	50		82.8	68.8	75.8
80	30		88.6	72.3	80.5
	50		89.8	73.6	81.7
84	30			78.1	78.1
	50			79.4	79.4
88	30			84.8	84.8
	50			86.0	86.0
92	30			89.5	89.5
	50			90.7	90.7

Table A-8 The influent and effluent SS of gas station wastewater of hydraulic loading 4.0 m^3/m^2/day.

Time (hrs)	Height (cm)	SS (mg/l)			
		No.1	No.2	No.3	ave.
0	Inf.	40.00	41.40	172.00	84.47
	30	5.01	8.80	6.91	6.91
	50	1.61	2.00	4.80	2.80
4	Inf.	40.00	41.40	172.00	84.47
	30	7.06	11.45	16.22	11.58
	50	4.02	5.34	11.95	7.10
8	Inf.	40.00	41.40	172.00	84.47
	30	8.75	13.88	19.92	14.18
	50	6.39	10.66	13.31	10.12
12	Inf.	68.00	77.17	250.00	131.72
	30	20.39	21.08	39.72	27.06
	50	13.12	8.08	23.42	14.87
16	Inf.	74.00	77.17	250.00	133.72
	30	31.00	9.39	20.75	20.38
	50	15.00	3.64	17.77	12.14
20	Inf.	74.00	36.25	250.00	120.08
	30	18.17	13.72	32.05	21.31
	50	13.76	6.37	37.07	19.07
24	Inf.	60.00	36.25	112.00	69.42
	30	10.00	16.06	15.70	13.92
	50	1.00	8.40	13.75	7.72
28	Inf.	60.00	36.25	112.00	69.42
	30	11.19	14.36	18.85	14.80
	50	8.04	10.77	16.63	11.81
32	Inf.	60.00	35.50	112.00	69.17
	30	8.00	8.40	20.28	12.23
	50	7.00	7.66	20.31	11.66
36	Inf.	60.00	35.50	101.92	65.81
	30	12.48	7.75	20.02	13.42
	50	11.85	6.30	16.03	11.39
40	Inf.	48.00	35.50	112.00	65.17
	30	11.11	7.87	16.67	11.88
	50	11.00	6.59	14.75	10.78
44	Inf.	48.00	35.50	112.00	65.17
	30	13.43	5.77	15.95	11.72
	50	11.74	5.60	14.13	10.49
48	Inf.	48.00	38.40	113.79	66.73
	30	14.00	5.30	14.35	11.22
	50	11.70	5.08	12.70	9.83
52	Inf.	48.00	38.40	113.79	66.73
	30	15.21	6.67	18.70	13.53
	50	12.57	5.63	16.74	11.65

Table A-8 The influent and effluent SS of gas station wastewater of hydraulic loading 4.0 m^3/m^2/day. (Continued)

Time	Height	SS (mg/l)			
(hrs)	(cm)	No.1	No.2	No.3	ave.
56	Inf.	48.00	30.67	151.92	76.86
	30	13.67	8.00	23.05	14.91
	50	11.39	4.40	19.06	11.62
60	Inf.	48.00	30.67	151.92	76.86
	30	13.24	10.07	30.12	17.81
	50	11.85	7.04	17.50	12.13
64	Inf.	48.00	30.67	151.92	76.86
	30	14.35	8.18	22.42	14.98
	50	12.13	4.17	20.77	12.36
68	Inf.	48.00	30.67	100.00	59.56
	30	15.44	10.60	18.59	14.88
	50	13.72	5.84	15.19	11.58
72	Inf.		35.50	100.00	67.75
	30		10.37	18.50	14.44
	50		6.22	15.86	11.04
76	Inf.		35.50	100.00	67.75
	30		11.02	19.07	15.05
	50		7.15	15.26	11.21
80	Inf.		35.50	128.33	81.92
	30		11.56	19.98	15.77
	50		6.60	14.51	10.56
84	Inf.			86.67	86.67
	30			15.51	15.51
	50			13.47	13.47
88	Inf.			86.67	86.67
	30			14.20	14.20
	50			12.61	12.61
92	Inf.			86.67	86.67
	30			13.86	13.86
	50			12.13	12.13

Table A-9 The influent and effluent COD of gas station wastewater of hydraulic loading 4.0 $m^3/m^2/day$.

Time	Height	COD (mg/l)			
(hrs)	(cm)	No.1	No.2	No.3	ave.
0	Inf.	160.00	176.73	362.15	232.96
	30	76.19	42.91	73.35	64.15
	50	41.90	39.27	53.85	45.01
4	Inf.	160.00	176.73	362.15	232.96
	30	64.76	51.64	103.80	73.40
	50	72.38	50.91	77.27	66.85
8	Inf.	160.00	176.73	362.15	232.96
	30	49.52	34.91	99.12	61.18
	50	38.10	36.36	83.51	52.66
12	Inf.	137.10	141.09	368.39	215.53
	30	30.48	43.76	103.02	59.09
	50	30.48	37.38	79.61	49.16
16	Inf.	160.00	141.09	368.39	223.16
	30	49.52	42.91	101.46	64.63
	50	38.10	21.82	72.59	44.17
20	Inf.	160.00	135.50	368.39	221.30
	30	49.52	36.36	101.46	62.45
	50	28.19	22.55	88.98	46.57
24	Inf.	131.05	135.50	272.13	179.56
	30	54.00	49.88	98.27	67.38
	50	24.38	44.25	80.13	49.59
28	Inf.	131.05	135.50	272.13	179.56
	30	48.00	45.00	105.83	66.28
	50	35.81	31.50	90.71	52.67
32	Inf.	131.05	87.75	272.13	163.64
	30	51.05	36.75	102.80	63.53
	50	50.29	33.00	90.71	58.00
36	Inf.	131.05	87.75	214.68	144.49
	30	60.19	34.50	102.05	65.58
	50	40.38	28.88	93.73	54.33
40	Inf.	115.81	87.75	272.13	158.56
	30	54.86	34.13	105.83	64.94
	50	44.95	33.00	86.93	54.96
44	Inf.	115.81	126.00	272.13	171.31
	30	53.33	41.63	83.15	59.37
	50	39.62	27.38	59.72	42.24
48	Inf.	115.81	126.00	293.16	178.32
	30	62.48	55.87	79.75	66.03
	50	51.08	43.28	71.39	55.25

Table A-9 The influent and effluent COD of gas station wastewater of hydraulic loading 4.0 m^3/m^2/day. (Continued)

Time (hrs)	Height (cm)	COD (mg/l)			
		No.1	No.2	No.3	ave.
52	Inf.	131.05	116.46	293.16	180.22
	30	68.25	48.79	78.99	65.34
	50	56.34	51.93	78.99	62.42
56	Inf.	131.05	116.46	249.11	165.54
	30	70.61	58.23	94.18	74.34
	50	60.17	48.79	75.19	61.38
60	Inf.	131.05	116.46	249.11	165.54
	30	72.28	55.08	86.58	71.31
	50	63.69	46.03	71.39	60.37
64	Inf.	131.05	116.46	249.11	165.54
	30	74.50	59.02	85.82	73.11
	50	66.40	48.00	76.71	63.70
68	Inf.	131.05	120.35	195.95	149.12
	30	75.69	63.62	86.58	75.30
	50	67.03	51.68	70.63	63.11
72	Inf.		120.35	195.95	158.15
	30		61.68	83.61	72.65
	50		51.82	71.23	61.53
76	Inf.		120.35	195.95	158.15
	30		64.01	84.39	74.20
	50		54.08	77.42	65.75
80	Inf.		120.35	193.55	156.95
	30		67.73	72.00	69.87
	50		58.14	67.35	62.75
84	Inf.			162.58	162.58
	30			75.87	75.87
	50			70.45	70.45
88	Inf.			162.58	162.58
	30			71.23	71.23
	50			65.81	65.81
92	Inf.			164.13	164.13
	30			82.06	82.06
	50			66.58	66.58

Table A-10 The influent and effluent O&G of gas station wastewater of hydraulic loading 4.0 $m^3/m^2/day$

Time (hrs)	Height (cm)	O&G (mg/l)			
		No.1	No.2	No.3	ave.
0	Inf.	29.20	9.20	40.70	26.37
	30	4.94	2.54	3.21	3.56
	50	2.88	0.58	3.41	2.29
4	Inf.	29.20	9.20	40.70	26.37
	30	5.24	2.80	2.90	3.65
	50	2.61	1.14	2.92	2.22
8	Inf.	29.20	9.20	40.70	26.37
	30	7.62	2.40	7.00	5.67
	50	4.49	1.41	3.50	3.13
12	Inf.	29.20	19.20	31.08	26.49
	30	5.71	4.52	6.38	5.54
	50	4.10	3.34	3.24	3.56
16	Inf.	26.30	19.20	31.08	25.53
	30	6.54	5.39	6.15	6.03
	50	4.13	3.40	2.34	3.29
20	Inf.	26.30	19.20	31.08	25.53
	30	6.86	6.40	5.28	6.18
	50	2.97	3.23	1.67	2.62
24	Inf.	26.30	19.20	17.14	20.88
	30	7.91	3.90	2.70	4.84
	50	3.34	3.34	1.61	2.76
28	Inf.	26.30	19.20	17.14	20.88
	30	6.41	1.21	4.85	4.16
	50	2.45	1.23	3.12	2.27
32	Inf.	26.30	9.20	17.14	17.55
	30	6.90	2.01	4.73	4.55
	50	4.50	1.72	3.48	3.23
36	Inf.	22.80	9.20	21.54	17.85
	30	6.18	2.42	6.53	5.04
	50	4.56	2.02	3.60	3.39
40	Inf.	22.80	9.20	17.14	16.38
	30	6.56	2.72	5.13	4.80
	50	3.83	1.70	3.86	3.13
44	Inf.	22.80	19.20	17.14	19.71
	30	6.68	6.05	4.26	5.66
	50	4.10	2.40	2.86	3.12
48	Inf.	22.80	19.20	21.89	21.30
	30	7.05	5.33	5.88	6.09
	50	4.46	3.03	3.90	3.80

Table A-10 The influent and effluent O&G of gas station wastewater of hydraulic loading 4.0 $m^3/m^2/day$. (Continued)

Time	Height	O&G (mg/l)			
(hrs)	(cm)	No.1	No.2	No.3	ave.
52	Inf.	20.73	19.20	21.89	20.61
	30	6.09	6.09	6.94	6.37
	50	3.83	3.51	3.75	3.70
56	Inf.	20.73	19.20	21.43	20.45
	30	5.97	4.58	7.23	5.93
	50	3.64	2.73	3.61	3.33
60	Inf.	20.73	19.20	21.43	20.45
	30	5.72	2.68	7.47	5.29
	50	4.32	2.29	2.80	3.14
64	Inf.	20.73	19.20	21.43	20.45
	30	6.33	3.45	6.14	5.31
	50	4.61	2.74	3.67	3.67
68	Inf.	20.73	19.20	18.49	19.47
	30	6.25	4.21	4.36	4.94
	50	5.63	4.09	4.22	4.65
72	Inf.		19.20	18.49	18.85
	30		4.73	3.67	4.20
	50		3.96	3.09	3.53
76	Inf.		19.20	18.49	18.85
	30		4.89	3.26	4.08
	50		3.94	2.67	3.31
80	Inf.		19.20	14.83	17.02
	30		4.60	3.13	3.87
	50		4.36	2.29	3.33
84	Inf.			15.64	15.64
	30			3.98	3.98
	50			2.68	2.68
88	Inf.			15.64	15.64
	30			4.65	4.65
	50			3.21	3.21
92	Inf.			13.45	13.45
	30			3.79	3.79
	50			2.43	2.43

Table A-11 The SS, COD, and O&G removal efficiencies of adsorption column at hydraulic loading 6.0 $m^3/m^2/day$.

Time	Height	SS removal efficiency (%)				COD removal efficiency (%)				O&G removal efficiency (%)			
(hrs)	(cm)	No.1	No.2	No.3	AVE	No.1	No.2	No.3	AVE	No.1	No.2	No.3	AVE
0	30	85.00	78.74	95.23	86.33	52.38	70.78	76.94	66.70	82.77	78.80	92.33	84.64
	50	96.15	95.17	97.18	96.17	61.91	75.31	81.90	73.04	92.71	87.39	95.45	91.85
4	30	83.63	73.12	92.59	83.11	61.91	73.66	69.83	68.46	80.89	73.37	89.02	81.09
	50	86.70	89.18	95.81	90.56	71.43	76.13	77.59	75.05	89.62	86.09	92.92	89.54
8	30	77.65	65.63	87.37	76.88	76.19	80.66	68.32	75.06	76.95	69.78	71.28	72.67
	50	83.98	77.61	88.99	83.53	80.95	84.77	74.78	80.17	82.26	81.96	79.78	81.33
12	30	80.00	77.01	88.72	81.91	74.99	70.62	70.55	72.05	69.38	65.42	55.57	63.46
	50	84.60	80.01	87.27	83.96	74.99	76.80	73.94	75.24	71.82	76.04	73.42	73.76
16	30	71.62	85.25	91.45	82.78	69.05	74.23	67.59	70.29	64.49	58.28	63.58	62.12
	50	74.32	88.08	92.62	85.01	76.19	73.19	72.46	73.95	70.89	82.29	78.25	77.14
20	30	70.26	84.36	86.73	80.45	65.71	66.18	68.64	66.85	61.83	53.02	71.11	61.98
	50	76.34	86.81	90.21	84.45	68.09	66.72	72.25	69.02	86.69	79.64	84.04	83.46
24	30	75.00	79.01	84.38	79.46	59.89	61.25	65.28	62.14	60.84	74.22	68.55	67.87
	50	85.00	80.00	86.61	83.87	76.16	57.38	66.67	66.74	82.40	77.03	79.93	79.79
28	30	72.30	71.23	80.13	74.55	61.05	57.38	55.83	58.09	62.89	82.61	45.68	63.73
	50	81.72	73.57	83.58	79.62	72.67	69.00	65.56	69.08	86.88	82.93	73.92	81.25
32	30	73.33	75.32	79.84	76.17	56.40	41.03	58.33	51.92	60.84	62.14	60.62	61.20
	50	73.33	65.77	84.03	74.38	72.67	55.56	59.72	62.65	84.64	81.25	78.41	81.43
36	30	70.90	72.23	78.17	73.76	64.53	46.15	59.45	56.71	59.21	50.00	66.69	58.63
	50	76.25	75.75	83.31	78.44	81.40	57.26	59.72	66.13	83.90	78.57	90.49	84.32
40	30	72.00	68.99	76.96	72.65	53.24	42.74	62.50	52.83	57.50	55.00	70.71	61.07
	50	79.00	76.00	81.28	78.76	70.51	54.70	61.11	62.11	78.95	72.86	85.36	79.05
44	30	70.71	73.49	73.70	72.63	52.01	59.82	63.89	58.57	58.51	60.42	78.76	65.90
	50	77.42	78.72	80.38	78.84	65.81	63.39	65.83	65.01	76.32	70.83	77.54	74.90

Table A-11 The SS, COD, and O&G removal efficiencies of adsorption column at hydraulic loading 6.0 m^3/m^2/day. (Continued)

Time	Height	SS removal efficiency (%)				COD removal efficiency (%)				O&G removal efficiency (%)			
(hrs)	(cm)	No.1	No.2	No.3	AVE	No.1	No.2	No.3	AVE	No.1	No.2	No.3	AVE
48	30	69.17	72.53	72.00	71.23	49.55	45.04	70.47	55.02	61.18	57.60	75.70	64.83
	50	76.04	78.75	79.01	77.93	60.63	56.29	71.76	62.89	73.29	76.46	82.82	77.52
52	30	70.02	65.21	71.08	68.77	52.40	46.63	69.17	56.07	65.94	59.58	74.19	66.57
	50	78.46	72.42	77.19	76.02	63.80	56.76	70.47	63.67	83.41	77.14	90.68	83.74
56	30	71.04	70.00	68.00	69.68	49.90	46.63	60.97	52.50	67.49	61.72	76.62	68.61
	50	79.06	77.83	78.00	78.30	60.70	50.00	63.41	58.04	82.30	74.53	87.91	81.58
60	30	68.42	64.26	65.80	66.16	50.40	44.60	62.19	52.40	69.85	63.23	81.33	71.47
	50	76.52	72.12	74.26	74.30	59.08	50.00	63.72	57.60	80.51	75.21	86.37	80.70
64	30		61.79	66.00	63.89		43.92	59.76	51.84		61.77	79.14	70.46
	50		70.00	77.00	73.50		54.05	65.24	59.65		76.51	83.25	79.88
68	30			66.40	66.40			53.88	53.88			76.31	76.31
	50			74.21	74.21			56.20	56.20			82.31	82.31
72	30			67.00	67.00			53.38	53.38			73.50	73.50
	50			72.11	72.11			55.75	55.75			81.02	81.02

Table A-12 The SS, COD, and O&G removal efficiencies of adsorption column at hydraulic loading 4.0 $m^3/m^2/day$.

Time	Height	SS removal efficiency (%)				COD removal efficiency (%)				O&G removal efficiency (%)			
(hrs)	(cm)	No.1	No.2	No.3	AVE	No.1	No.2	No.3	AVE	No.1	No.2	No.3	AVE
0	30	87.48	78.74	95.98	87.40	52.38	75.72	79.75	69.28	83.08	72.39	92.11	82.53
	50	95.98	95.17	97.21	96.12	73.81	77.78	85.13	78.91	90.14	93.70	91.62	91.82
4	30	82.35	72.34	90.57	81.75	59.53	70.78	71.34	67.21	82.05	69.57	92.87	81.50
	50	89.95	87.10	93.05	90.03	54.76	71.19	78.66	68.21	91.06	87.61	92.83	90.50
8	30	78.13	66.47	88.42	77.67	69.05	80.25	72.63	73.98	73.90	73.91	82.80	76.87
	50	84.03	74.25	92.26	83.51	76.19	79.43	76.94	77.52	84.62	84.67	91.40	86.90
12	30	70.01	72.68	84.11	75.60	77.77	68.98	72.04	72.93	80.45	76.46	79.47	78.79
	50	80.71	89.53	90.63	86.96	77.77	73.51	78.39	76.55	85.96	82.60	89.58	86.05
16	30	58.11	87.83	91.70	79.21	69.05	69.59	72.46	70.37	75.13	71.93	80.21	75.76
	50	79.73	95.28	92.89	89.30	76.19	84.53	80.30	80.34	84.30	82.29	92.47	86.35
20	30	75.45	62.15	87.18	74.93	69.05	73.17	72.46	71.56	73.92	66.67	83.01	74.53
	50	81.41	82.43	85.17	83.00	82.38	83.36	75.85	80.53	88.71	83.18	94.63	88.84
24	30	83.33	55.70	85.98	75.00	58.79	63.19	63.89	61.96	69.92	79.69	84.25	77.95
	50	98.33	76.83	87.72	87.63	81.40	67.34	70.55	73.10	87.30	82.60	90.61	86.84
28	30	81.35	60.39	83.17	74.97	63.37	66.79	61.11	63.76	75.63	86.85	71.70	78.06
	50	86.60	70.29	85.15	80.68	72.67	76.75	66.67	72.03	90.68	86.63	81.80	86.37
32	30	86.67	76.34	81.89	81.63	61.05	58.12	62.22	60.46	73.76	78.15	72.40	74.77
	50	88.33	78.42	81.87	82.87	61.63	62.39	66.67	63.56	82.89	81.30	79.70	81.30
36	30	79.20	78.17	80.36	79.24	54.07	60.68	52.46	55.74	72.89	73.70	69.68	72.09
	50	80.25	82.25	84.27	82.26	69.19	67.09	56.34	64.21	80.00	78.04	83.29	80.44
40	30	76.85	77.83	83.64	79.44	52.63	61.11	50.70	54.81	71.23	70.43	76.18	72.62
	50	77.08	81.44	85.53	81.35	61.19	62.39	59.51	61.03	83.20	81.52	82.08	82.27
44	30	72.02	83.75	84.35	80.04	53.95	66.96	61.27	60.73	70.70	68.49	80.22	73.14
	50	75.54	84.23	86.14	81.97	65.79	78.27	72.18	72.08	82.02	87.50	86.72	85.41

Table A-12 The SS, COD, and O&G removal efficiencies of adsorption column at hydraulic loading 4.0 m^3/m^2/day. (Continued)

Time	Height	SS removal efficiency (%)				COD removal efficiency (%)				O&G removal efficiency (%)			
(hrs)	(cm)	No.1	No.2	No.3	AVE	No.1	No.2	No.3	AVE	No.1	No.2	No.3	AVE
48	30	70.83	86.07	87.39	81.43	46.05	55.66	72.80	58.17	69.08	72.24	73.14	71.49
	50	75.63	86.65	88.84	83.70	55.89	65.65	75.65	65.73	80.44	84.22	82.18	82.28
52	30	68.31	82.47	83.57	78.11	47.92	58.11	73.06	59.69	70.62	68.28	68.30	69.07
	50	73.81	85.20	85.29	81.43	57.01	55.41	73.06	61.82	81.52	81.72	82.87	82.04
56	30	71.52	73.92	84.83	76.75	46.12	50.00	62.19	52.77	71.20	76.15	66.26	71.20
	50	76.27	85.65	87.45	83.13	54.09	58.11	69.82	60.67	82.44	85.78	83.15	83.79
60	30	72.42	67.17	80.17	73.25	44.85	52.70	65.24	54.26	72.41	86.04	65.14	74.53
	50	75.31	77.05	88.48	80.28	51.40	60.48	71.34	61.07	79.16	88.07	86.93	84.72
64	30	70.10	73.33	85.24	76.23	43.15	49.32	65.55	52.67	69.46	82.03	71.35	74.28
	50	74.73	86.40	86.33	82.49	49.33	58.78	69.21	59.11	77.76	85.73	82.87	82.12
68	30	67.83	65.44	81.41	71.56	42.24	47.14	55.82	48.40	69.85	78.07	76.42	74.78
	50	71.42	80.96	84.81	79.06	48.85	57.06	63.96	56.62	72.84	78.70	77.18	76.24
72	30		70.79	81.50	76.14		48.75	57.33	53.04		75.36	80.15	77.76
	50		82.48	84.14	83.31		56.94	63.65	60.30		79.38	83.29	81.33
76	30		68.96	80.93	74.94		46.81	56.93	51.87		74.53	82.37	78.45
	50		79.86	84.74	82.30		55.06	60.49	57.78		79.48	85.56	82.52
80	30		67.44	84.43	75.93		43.72	62.80	53.26		76.04	78.89	77.47
	50		81.41	88.69	85.05		51.69	65.20	58.45		77.29	84.56	80.92
84	30			82.32	82.32			53.33	53.33			74.55	74.55
	50			84.65	84.65			56.67	56.67			82.86	82.86
88	30			83.81	83.81			56.19	56.19			70.27	70.27
	50			85.63	85.63			59.52	59.52			79.48	79.48
92	30			84.20	84.20			50.00	50.00			71.82	71.82
	50			86.18	86.18			59.43	59.43			81.93	81.93

APPENDIX B

Statistical Analysis

Table B-1 The independent samples t-test analysis to compare the COD, SS, and O&G removal efficiency from gas station wastewater using palm oil shell ash with different hydraulic loadings.

Group Statistics

	LOAD	N	Mean	Std. Deviation	Std. Error Mean
EFF_SS	4.00	126	81.1283	8.1364	.7248
	6.00	104	78.0433	8.0226	.7867
EFF_COD	4.00	126	63.7308	10.4541	.9313
	6.00	104	63.5603	9.9592	.9766
EFF_OG	4.00	126	79.6978	6.8595	.6111
	6.00	104	74.4750	10.6405	1.0434

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
EFF_SS	Equal variances assumed	.019	.891	2.880	228	.004	3.0851	1.0712	.9744	5.1957
	Equal variances not assumed			2.884	220.921	.004	3.0851	1.0697	.9769	5.1932
EFF_COD	Equal variances assumed	.620	.432	.126	228	.900	.1705	1.3558	-2.5009	2.8420
	Equal variances not assumed			.126	223.332	.900	.1705	1.3495	-2.4888	2.8298
EFF_OG	Equal variances assumed	21.109	.000	4.494	228	.000	5.2227	1.1621	2.9329	7.5126
	Equal variances not assumed			4.319	169.362	.000	5.2227	1.2092	2.8358	7.6097

Table B-2 The independent samples t-test analysis to compare the COD, SS, and O&G removal efficiency from gas station wastewater using palm oil shell ash with different heights of packing adsorbent.

Group Statistics

	DEPTH	N	Mean	Std. Deviation	Std. Error Mean
EFF_SS	30	115	76.7640	8.4006	.7834
	50	115	82.7027	6.8657	.6402
EFF_COD	30	115	60.3481	10.0392	.9362
	50	115	66.9593	9.3076	.8679
EFF_OG	30	115	71.8565	8.8649	.8267
	50	115	82.8159	5.3247	.4965

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
EFF_SS	Equal variances assumed	7.483	.007	-5.870	228	.000	-5.9387	1.0117	-7.9322	-3.9452
	Equal variances not assumed			-5.870	219.3	.000	-5.9387	1.0117	-7.9326	-3.9448
EFF_COD	Equal variances assumed	.421	.517	-5.179	228	.000	-6.6112	1.2766	-9.1267	-4.0958
	Equal variances not assumed			-5.179	226.7	.000	-6.6112	1.2766	-9.1267	-4.0957
EFF_OG	Equal variances assumed	20.274	.000	-11.365	228	.000	-10.9595	.9643	-12.860	-9.0593
	Equal variances not assumed			-11.365	186.8	.000	-10.9595	.9643	-12.862	-9.0571

APPENDIX C

Design of Adsorption Column

Example Design Calculation

Given Hydraulic loading = 4.0 $m^3/m^2/day$

Flow rate = 5.0 m^3/day

Height of packing adsorbent = 0.5 m

The volume of adsorption column (no free board) packed with palm oil shell ash can be design as follow:

$$\text{Hydraulic loading (v)} = \frac{\text{Flow rate (Q)}}{\text{Surface area (A)}}$$

$$A = Q/v$$

$$= (5\ m^3/day) / (4 m^3/m^2/day)$$

$$= 1.25\ m^2$$

When assume that the adsorption column is cylindrical shape, the diameter of adsorption column is compute to be 1.26 m

The volume of adsorption column can be calculate as follow:

$$\text{Volume} = \text{Area} * \text{Height of packing adsorbent}$$

$$= (1.25\ m^2) * (0.5m)$$

$$= 0.625\ m^3$$

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