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Hexane Vapors Adsorption by Kapok and Rayon Industrial Waste

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***Abstract*— Air pollution is a global concern because it can contribute to serious health and environmental impacts. Various techniques have been used to mitigate air pollution. One of the popular techniques is adsorption. This research studied hexane vapor adsorption by adsorbents prepared from a mixture of kapok fiber and waste from rayon industry in fixed bed. The Effect of physical parameters, such as adsorbent types, gas flow rate and packing styles on adsorption efficiency was investigated and the results were compared to commercial adsorbents. Kapok fiber is a hollow fiber and has hydrophobic characteristics that are advantages for use as adsorbent because of the high surface area and the affinity for organic compounds. Rayon fiber is used to improve the strength of adsorbents. The adsorbent was prepared by various concentrations of phosphoric acid, 10, 30 and 50 percent. The adsorbents characteristics, including structure, chemical composition, surface area, humidity and density were determined by SEM, FT-IR, Surface analyzer and Hot air oven method. The hexane concentration was analyzed by Gas chromatography. The results show that the suitable flow rate for hexane adsorption is 2 L/hr. and hexane adsorption efficiencies of kapok, rayon, mixed and sandwich fibers are 80, 35, 15 and 40 percent, respectively.**

***Keywords*— Adsorption, Rayon Industrial Waste, Hydrophobic, Volatile Organic Compounds**

I. Introduction

Many Volatile organic compounds are toxic gases. According to the European Environmental Agency (EEA) around 40% of non-methane VOCs (NMVOCs) comes from the solvent [1]. Various organic solvents have been annually produced from a variety of industrial sources. The emission of these organic solvents in the atmosphere has caused harmful effects on human health and on the environment [2]. Hexane is volatile organic compounds (VOCs) commonly used as solvents in industrial. Many methods are used to treat organic solvents. They are classified in to two broad groups: I. Oxidation method and II. Recovery method. Oxidation is simple method to destroy the structure of organic solvents into CO_2 and H_2O, but it is unable to reuse the VOCs. The more expensive and energy exhausting methods, including condensation, adsorption, ion-exchange, and membrane filtration, can be used for treatment and recovery of VOCs [3]. Adsorption has been successfully applied for commercial applications for the removal of VOCs. Activated Carbon is usually used in many adsorption applications because it has a higher adsorption capacity and a lower price. However, it's difficult to regenerate due to its thermal and chemical instabilities, which may cause safety problem [4]. In this research, industrial waste was used to make adsorbent for pollutant adsorption. Many kinds of waste such as rayon fiber viscose liquid and sodium sulfate were generated from the rayon Industry. All of these wastes have to be eliminated by secure landfills.

The main objectives of this study were I. Develop sorbents for volatile organic compounds adsorption from industrial wastes and green chemicals. II. Study hexane adsorption efficiency of prepared sorbents and compare adsorption with a commercial sorbent.

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II. Materials and Method

A. *Materials*

Hexane analytical grade (AR) was used in the experiment. Industrial wastes, rayon fibers, viscose liquid and sodium sulfate salt were received from Thai Rayon Company. Kapok fiber was purchased from a local market. Nitrogen gas 99.5% was purchased from Praxair Company. Air Sampling Tedslar bags 0.5 L were purchased from Entech Company.

TABLE I. CHARACTERISTICS OF ADSORBATES

Properties	Adsorbate/values
Name	Hexane
Formula	$CH_2CH_2CH_2CH_2CH_2CH_2$
Molecular weight (g/mol)	86.2
Density at 25°C (g/ml)	0.66
Boiling point (°C)	69
Vapor pressure at 25 °C	150
Polarity	Non-Polarity

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TABLE II. CHARACTERISTICS PROPERTIES OF MATERIAL

Properties	Type of Adsorbents	
Material	*Kapok*	*Rayon*
Diameter of fiber (μm)	21.5	9.37
Density (g/cm^3)	1.3 a	1.49 [b]
Tensile strength (MPa)	93.3 c	637 [b]
Moisture (%)	8.48	5.61
Specific gravity	0.055 c	1.52 [b]
Surface	Smooth	Rough
Color	Yellow-brown	White
Sorption	Hydrophobic	Hydrophilic

* a [5], b [6], c [7]

B. Adsorbents

In this study the viscose liquid was diluted with water at the ratio 1:6 (wt). The adsorbents, made from rayon fibers and kapok fibers were separated into 3 types based on the rayon: kapok ratio in the mixer (0:1, 1:0 and 1:1). The prepared fiber (15 grams) and the viscose solution were mixed and then sodium sulfate salt (size 150 microns) 75 grams was added in to the mixture and the mixture was mixed in the blender for 1 minute [8]. After that, the mixture was put into a container and washed with 10% Phosphoric acid for 30 minutes, washed with hot water (93°C) to remove sodium sulfate, then washed with water to remove impurities and dried in an oven at 60 °C for 18 hours.

C. Characterization of sorbent materials

The physical characteristics of the rayon fiber, kapok fiber, rayon-kapok fiber mixture were analyzed by a scanning electron microscope (SEM, JEOL type JSM-6480LV). The composition of the fiber and adsorbent was analyzed by Fourier Transform Infrared Spectrometer (FT-IR, Perkin Elmer type Spectrum One). The surface area was analyzed by a surface analyzer (Micromeritics type ASAP 2000). and The moisture content of materials was analyzed by the hot air oven method (Test method D2654).

D. Experimental Setup

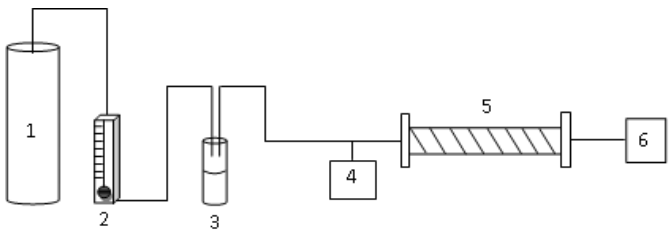

Figure 1. Schematic diagram of Experimental set up.

1. Nitrogen Gas 2. Flow meter 3. VOC Bottle 4. Sampling 1 5. Column 6. Sampling 2

Adsorption experiments were performed in a laboratory at the controlled temperature of 25 °C. Figure 1. shows the schematic diagram of experiment set up. An adsorption column was made from an Acrylic tube with a 14-mm diameter inside and a 10-cm length. Adsorbents were packed into the column with difference patterns. In the beginning step, the hexane bottle was placed until equilibrium between the liquid and gas phase was reached. Then the bottle was installed to the equipment as shown in Figure 1. Nitrogen gas was fed to the system through a flow meter and hexane bottle. Hexane vapors in the gas phase flowed into the column and a gas sample was taken for hexane concentration before and after the column by Sample bags. Hexane vapor concentration was analyzed by Gas chromatography (GC-Agilent Technologies 6890N). The analysis of the conditions of GC are summarized in Table III.

TABLE III. ANALYSIS CONDITIONS FOR HEXANE VAPOR BY GAS CHROMATOGRAPHY

GC	Agilent Technologies 6890N
Detector	FID (Flame Ionization Detector)
Oven temperature (°C)	100
Injector temperature (°C)	250
Detector temperature (°C)	300
Flow rate (N_2:H_2:Air, ml/min)	40:40:400

III. Results

A. Characteristics of adsorbents

The rayon fiber has a rough surface without internal structure and has a lengthwise line on fiber call striation, as shown in the SEM image in Figure 2(a). The kapok fiber has a smooth surface with a hollow internal structure, as shown in the SEM images in Figure 2(b). The Kapok fiber is hydrophobic which has a high affinity for oil and nonpolar chemicals [9]. On the other hand, rayon fiber is hydrophilic and can be used to improve the strength of adsorbents. Adsorbents were prepared with Phosphoric acid at 10, 30 and 50% respectively. The rayon adsorbent was prepared with 10% phosphoric acid. As show in Figure 2(c), the fiber still has a lengthwise line, and Na_2SO_4 remains on the fiber. The kapok fiber was damaged by acid addition. In Figure 2(e-g). shows the results of mixed adsorbents were added acid concentration at 10, 30 and 50% respectively the result shows the mixed fibers added acid 10% was better than another acid concentration.

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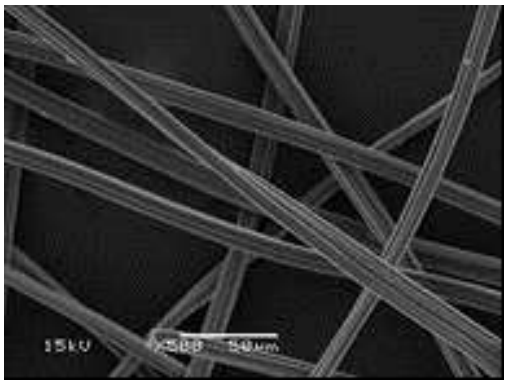
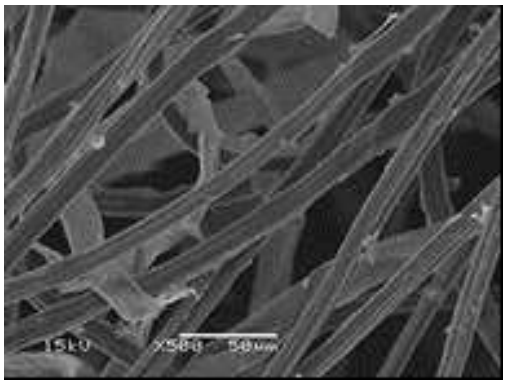
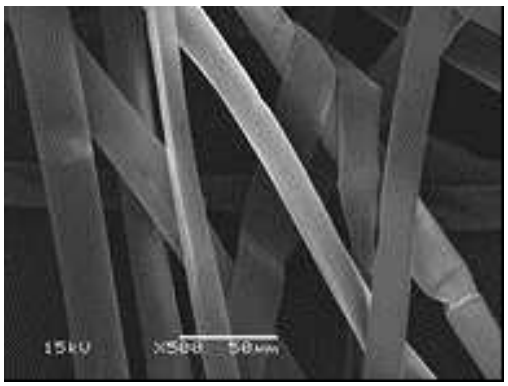


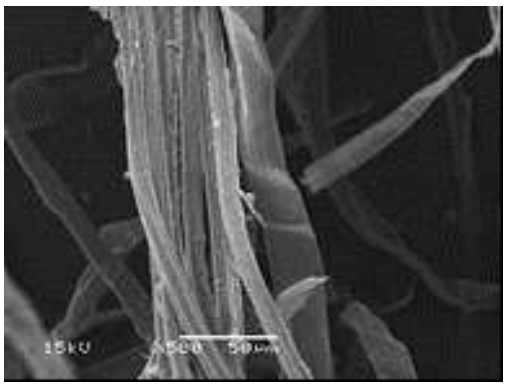
(a)



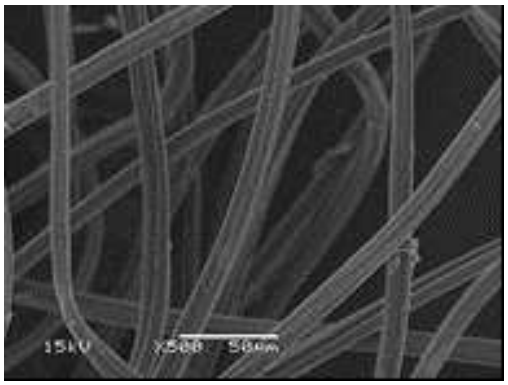
(e)



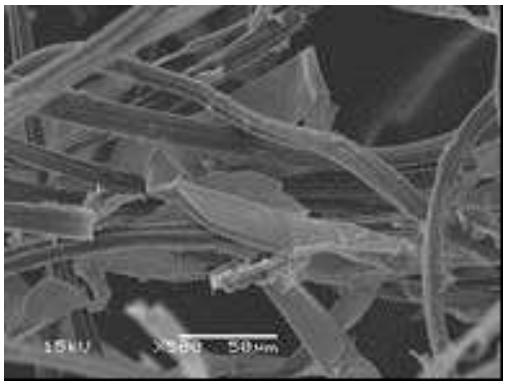
(b)



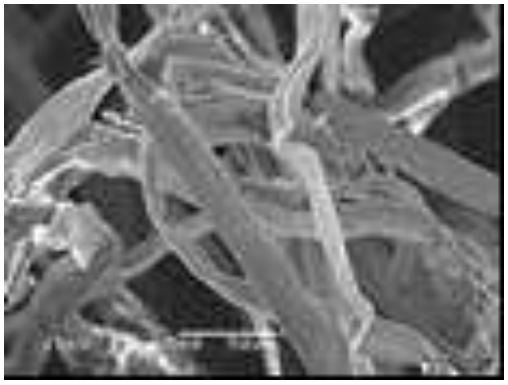
(f)



(c)



(g)



(d)

Figure 2. SEM images of material, (a) Rayon fiber, (b) Kapok fiber, (c) Rayon adsorbent 10% phosphoric acid, (d) Kapok adsorbent 10% phosphoric acid, (e) Mixed adsorbent (Rayon fiber and Kapok fiber ratio 50:50 (%wt)) 10% phosphoric acid, (f) Mixed adsorbent 30% and (g) Mixed adsorbent 50% phosphoric acid.

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B. *Effect of Hexane vapor flow rate*

Hexane vapor was introduced to the column at 2, 6 and 10 L/hr. in order to determine the suitable flow rate for adsorption. The result from experiment is presented in Figure 3-6. Figure 3 shows the hexane vapor adsorption efficiency by the rayon adsorbent at the flow rate of 2, 6 and 10 L/hr. The average adsorption efficiencies are 35, 30 and 35%, respectively. Figure 4 shows the adsorption efficiency of kapok adsorbent. The average adsorption capacity is 75% at the flow rate of 2 L/hr. The adsorption efficiency tends to decrease with increasing flow rate. Figure 5 shows adsorption efficiency of mixed adsorbent, and Figure 6 Shows the effects of the packing pattern on adsorption efficiency. The adsorption efficiency of the mixed adsorbent is generally lower than that of Kapok. However, the mixed adsorbent is more robust and easier to use.

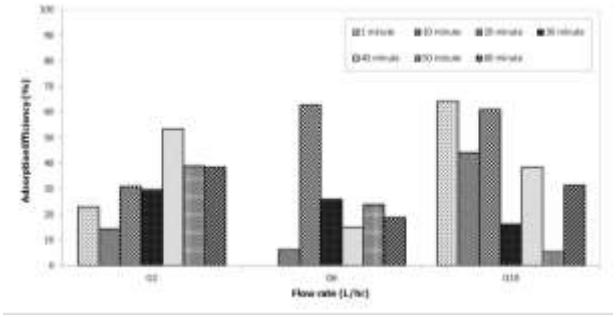

Figure 3. Adsorption efficiency of Rayon adsorbent of different flow rate at various sorption times.

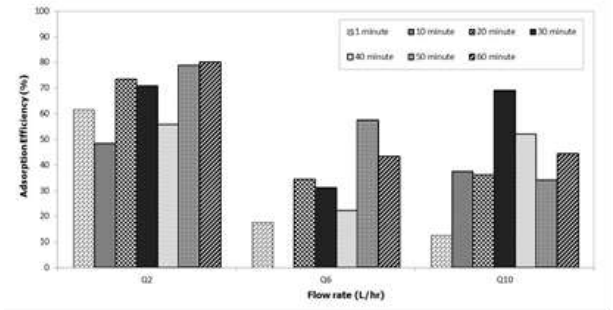

Figure 4. Adsorption efficiency of Kapok adsorbent of different flow rate at various sorption times.

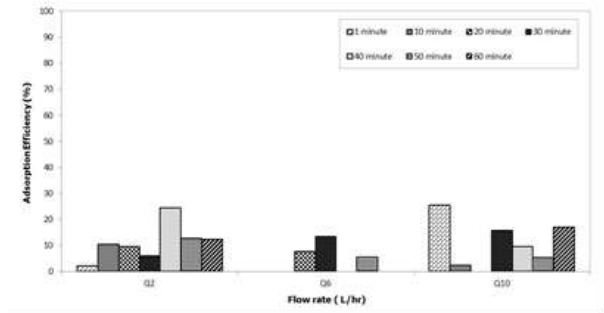

Figure 5. Adsorption efficiency of Mixed adsorbent of different flow rate at various sorption times.

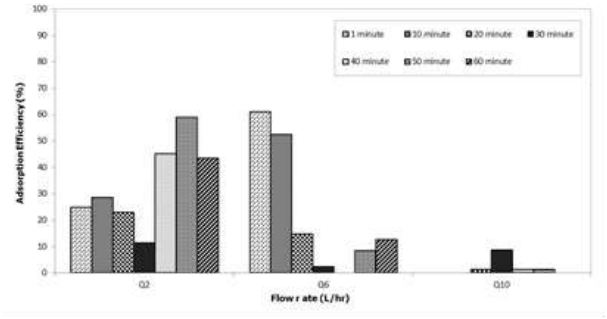

Figure 6. Adsorption efficiency of Sandwich adsorbent of different flow rate at various sorption times.

C. *Effect of adsorbents packing style*

In this part of experiment, hexane vapor was fed to the column at 2 L/hr. The column was packed with 4 different packing patterns. Hexane vapor was collected every 10 minutes for 1 hour. The adsorption efficiency is shown in Figure 7. The result showed that adsorption efficiency of kapok fiber is the highest at about 80%. From the initial time until 30 minutes, adsorption efficiency of kapok adsorbent was higher than for the kapok fiber at about 20-30% because the adsorbent's surface area was more than the fiber's [8]. After 30 minutes to 60 minutes, The adsorption efficiency of the kapok fiber and the kapok adsorbent were similar at about 80% which was the highest of the other adsorbents and fiber because kapok fiber and Hexane are non-polar [2]. Adsorption efficiency of the rayon fiber and the rayon adsorbent were about 15% and 35%, which were lower than kapok because 15% of the rayon fiber consist of the hydrogen and hydroxyl groups [6].This shows that the rayon fiber is polar fiber and a different polar from hexane [2]. The adsorption efficiency of the rayon adsorbent was higher than that of the rayon fiber in every sampling by about 10-50%. The adsorption efficiency of the mixed fiber and the mixed adsorbent was about 20% and 15%, which were similar to the rayon fiber because the pattern consist of rayon and kapok fibers 50:50 (%wt). The kapok fiber decreased 50% and the rayon fiber had a different polar from the hexane. The adsorption efficiency of the sandwich fiber and the sandwich adsorbent average was about 40% and 35%. When compared with the adsorption efficiency of kapok, it was found that the adsorption efficiency of sandwich adsorbent decreased 50% because the kapok fiber in the sandwich packing pattern decreased 50% too.

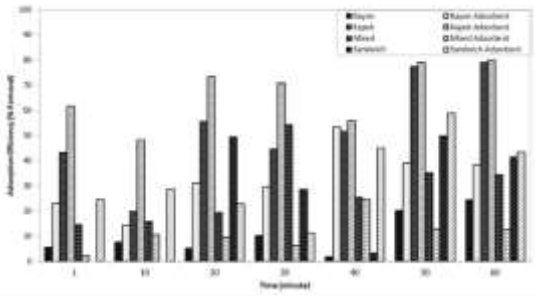

Figure 7. Adsorption efficiency of different adsorbents at various sorption times and flow rate 2 L/hr.

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IV. Conclusions

Based on the analysis of the experiment we can conclude that phosphoric acid concentration affects the adsorbent. The result shows that the suitable condition for preparing the adsorbent is 10% phosphoric acid. The hexane vapor flow rate affected the adsorption efficiency. The suitable flow rate in this system is 2 L/hr. and The best adsorbent is the kapok adsorbent because it has the highest adsorption efficiency of about 80%, which was followed by the rayon and the sandwich adsorbent, which were similar at about 35% and the mixed adsorbent, which was about 15%.

Acknowledgment

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This paper study about recycle and management waste from industrial to prepared adsorbents for remove hexane vapor by use adsorption technique because this technique is good, easy system and low price.

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