THE COMPARISON OF LPG AND NATURAL GAS ADSORPTION CAPACITY IN CARBON ADSORBENT

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ABSTRACT

(Keywords: Gas Storage; LPG, Methane, Adsorption, Carbon Adsorbent; Waste Material)

The current research focuses on the experimental investigation of carbon adsorbent produced from oil palm shell as a raw material. These carbon materials can be used for catalyst supports and adsorbents because of its prominent characteristics, such as high surface area, relatively uniform pore size, ordered pore structure and good thermal and mechanical stabilities. The objective of the present research is to develop a liquefied petroleum gas (LPG) and methane gas storage as the alternative fuels for vehicles based upon the carbon adsorbents. Carbon adsorbent as a gas storage media for LPG and methane gas are an alternative way to overcome the disadvantages of pressurized vessel such as high-pressure flammable gas content, dimension of gas tank, and other dangerous aspects. This research will be conducted by designing and developing the experimental rig for preparing carbon adsorbent, which are consisted of a reactor, tube furnace, suction blower and some accessories. Other process, which is activation carried out in a same reactor, which blanketed by tube furnace where the pyrolysis take place. These research aims are used to the extending application of proposed framework to problem arising in the alternative fuel for vehicles.

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TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

Carbon adsorbents are versatile adsorbents. Their adsorptive properties are due their high surface area, microporous structure and a high degree of surface reactivity. Carbon adsorbent is the commonly known is an activated carbon. In its broadest sense, the activated carbon includes a wide range processed amorphous carbon-based materials. Activated carbons have a highly developed porosity and an extended interparticulate surface area. Their preparation involves two main steps: the carbonization of the carbonaceous raw material at temperature below 800°C in an inert atmosphere and the activation of the carbonized product. Thus all carbonaceous raw materials can be converted into activated carbon, although the properties of the final product will be different, depending on the nature of the raw material used, the nature of the activating agent, and the conditions of the carbonization and the activation processes [13]. Potential natural precursors for carbon adsorbents include coconut shells [2], coal [13], walnut shell, palm date pits [1] and oil palm shell [25, 8]. Their advantages as carbon feed stocks include high density, availability as renewable resources, low cost, low ash content, and they are capable of producing activated carbons of high adsorption capacity.

The research is focused on the experimental investigation of carbon adsorbent, which is prepared from oil palm shell as a raw material and other commercial activated carbon for comparison. These carbon materials can be used for catalyst supports and adsorbents because of its prominent characteristics, such as high surface area, relatively uniform pore size, ordered pore structure and good thermal and mechanical stabilities. Herawan (2000) produced carbon adsorbents from oil palm shell in order to achieve the desired application of gas separation such as nitrogen from air or CH_4 from CO_2. This study indicates that the modified char has a potential for use in O_2/N_2 separation whereas high temperature char prepared at 900°C is expected to be useful for the separation of CH_4 from CO_2/CH_4 mixture.

The experimental procedures and results obtained are comprehensively and systematically presented. The objective of the present research is to develop a liquefied petroleum gas (LPG) and methane gas storage as the alternative fuels for vehicles based upon the carbon adsorbents from palm oil shell as raw material.

1

Additionally, this research aims are used to overcome the extending application of proposed framework to problem arising in the alternative fuel for vehicles such as LPG and natural gas regarding the pressurized vessel, high-pressure flammable gas content, dimension of gas tank, and other dangerous aspects.

1.1   Alternative Vehicle Fuels

Petrol engine vehicles make up the majority of vehicles operating in the metropolitan area and contribute the majority of oxides of nitrogen (NO_X) and hydrocarbons. Emissions from petrol vehicles will improve over the next eight years. Therefore, the alternative vehicle fuels are needed to overcome the reduction of emissions. The alternatives to petrol and diesel include LPG which is at present the most common alternative fuel which is widely available from service stations across the country. The other alternative fuels are compressed natural gas (CNG) and biofuels that are produced from renewable organic sources.

1.2   Liquefied Petroleum Gas (LPG)

Liquefied Petroleum Gas (LPG) has been widely used in commercial vehicles, and promising results have been obtained from fuel economy and exhaust emissions points of view [4].   LPG can be produced from natural gas and crude oil [3, 4]. Dagaut and Ali (2003) stated that LPG mainly consists of propane and butane, and it may also include different hydrocarbons such as propane, iso-butane and n-butane in various proportions.   Bayraktar and Dungun (2005) reported that LPG and other gaseous fuels have common properties that provide them some advantages and disadvantages relative to gasoline.   On the basis of these considerations, their work in the case of using LPG in SI engines resulted that, the burning rate of fuel is increased, and thus, the combustion duration is decreased.   In recent years, the development of an economical carbon adsorbent has been widely investigated for natural gas storage. Carbon adsorbent as a gas storage media for LPG is an alternative way to overcome the disadvantages of pressurized vessel such as high-pressure flammable gas content, dimension of gas tank, and other dangerous aspects.   Hence, the effect of activation in

carbon adsorbent was observed during the adsorption and desorption processes of LPG gas.

1.3 Natural Gas

In recent years, large scale use of fossil fuels as primary energy source has resulted in large emissions of CO_2, the most important greenhouse gas (GHG). Emissions of GHGs are generally seen as a large problem since a temperature rise caused by the increasing concentrations of GHGs in the atmosphere is likely to influence global climate. An important sector regarding GHG emissions is road transport, accounting for nearly 30% of CO_2 emissions related to fossil fuel combustion. CO_2 emissions not only result from automotive fuel combustion on board the vehicle, but also from fuel extraction, transport, production and distribution [10]. In order to accomplish a reduction in CO_2 emissions, both the fuel supply industry and the car manufacturing industry are exploring alternative automotive fuels and technologies [26]. With respect to this, alternative fuel chains can involve the use of production methods, new automotive fuels, or innovative vehicle drive trains. Besides, primary energy sources or crude oil can be natural gas (NG), biomass, coal, and hydro-, wind or solar energy. Recent studies have been reported that a wide variety of energy carriers can be derived from these primary energy sources: gasoline, diesel, liquefied petroleum gas (LPG), liquefied natural gas (LNG), compressed natural gas (CNG), methanol, ethanol, hydrogen, and electricity. Based on Jin, et al. (2004), they suggested that to produce these energy carriers, different production methods can be employed.

Since the methane gas has a highest content in the composition of natural gas as much as 92.73% [23], this research is using the methane gas instead of the natural gas due to the limitation of gas handling unit in the laboratory.

2.0 STATEMENT OF THE PROBLEM

Preparing a carbon adsorbent from waste material, which well enough capability for adsorption and desoprtion of LPG and Natural Gas (Methane).

This problem can be overcome by conducting these steps as follows:
1. Design and develop the experimental rig for preparing carbon adsorbent
2. Prepare carbon adsorbent from waste materials such as coconut shell, oil palm shell, plastic bag that is treated in the difference conditions
3. Design and develop the carbon adsorbent test bed carbon adsorbent that is connected with a Hydrocarbon Gas Detector to determine adsorption and desoprtion ability
4. Analysis the surface area and pore distribution on carbon adsorbent using the N_2 adsorption.
5. Study the effect of carbonization, activation, on carbon adsorbent pore structure due to capability to adsorb LPG.
6. Compare the adsorption capacity between LPG and Natural Gas (Methane) on carbon adsorbent

3.0 METHODOLOGY

Designing and developing the experimental rig for preparing carbon adsorbent have conducted this research, which are consisted of a reactor, tube furnace, suction blower and some accessories as a first stage. At the same time, the carbon adsorbent test bed model is designed and developed, which has a column absorber for carbon adsorbent and is connected online with a Gas Detector to determine the breakthrough curves for LPG that can lead to determine adsorption selectivity for LPG.

Next stage is preparing carbon adsorbent from waste material (oil palm shell) and mixed with plastic bag using the experimental rig, which is processed by conventional method using pyrolysis technique. By varies the peak temperature of the sample, the optimization of it can be achieved. This process is carried out in a laboratory scale, fixed bed reactor, which blanketed by tube furnace where the pyrolysis take place.

Nitrogen gas is used to obtain an inert atmosphere in the reactor and CO_2 gas is used to activate the sample. A suction blower is used to remove volatile matter as well as other gases during the process as shown in Figure 3.1.
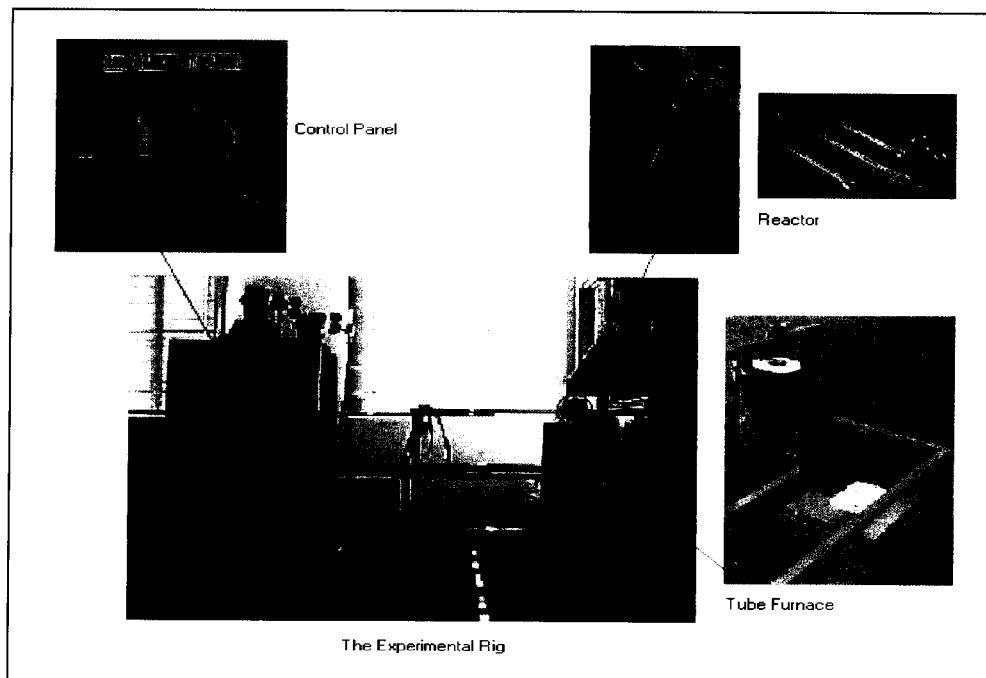
Figure 3.1: The Experimental rig for producing carbon adsorbent

For application purpose, carbon adsorbent test bed has been developed as shown in Figure 3.2. It is clear that the apparatus consists of a column for carbon adsorbent bed, which is blanketed with heating tape, temperature control for heating the sample due to desorption process, timer for calculating the adsorption time up to saturated condition, and gas detector in % Gas to detect the flue gas after exposes to the sample. The breakthrough curve can be used to obtain the data on the capacity and selectivity of the adsorption happened. The experiment will stop when the curves show the breakthrough (inlet =outlet concentration) for LPG at 1.5 ml/min of feeding and gas detector show data 5.0% of LPG gas.
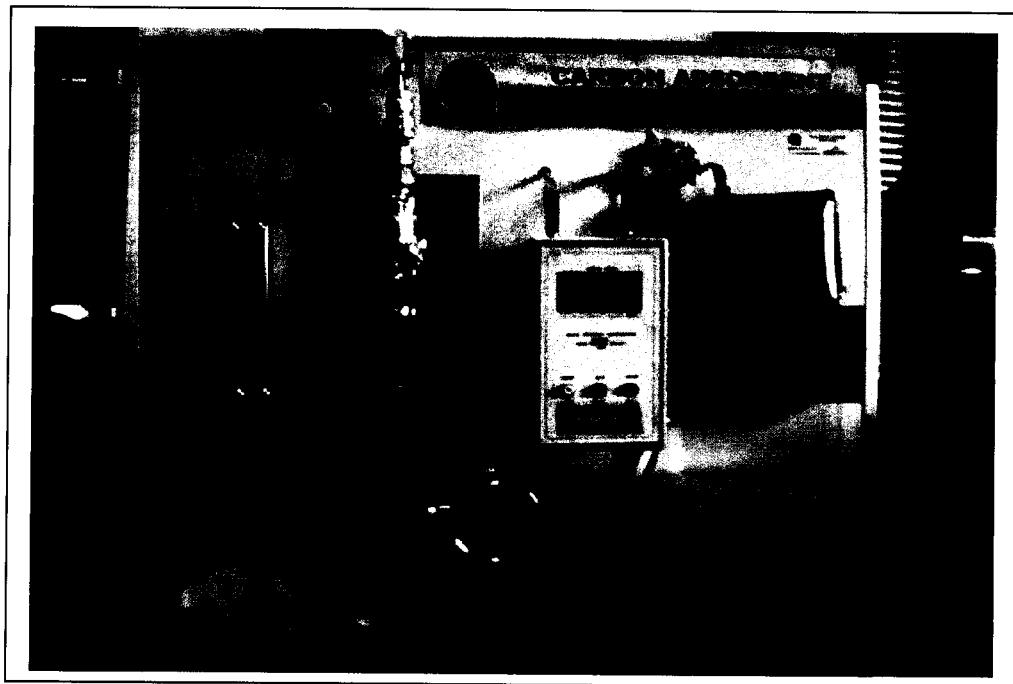
Figure 3.2: Carbon adsorbent test bed model

3.1   Gravimetric Testing Method

Cylindrical Test Bed (CTB) is used in this research, which is a device for testing the materials in the form of powder, particle, or granular to determine the adsorption and desorption capacities of the materials using the gravimetric method, when introduced by a certain gas. This device consists of a cylinder with 30 mm inner diameter and 150 mm length, pressure gauge, which is attached to the cylinder, digital balance in the range of 0.00 – 3000.00 grams, vacuum generator to vacuum the cylinder, and gas feeder, which are LPG and methane gas as is shown in Figure 3.3.

The first step undertaken was to determine the amount of gas in the empty cylinder by weighing the cylinder before and after feeding the gas. The next step was to fill the cylinder with carbon adsorbent, and to determine the amount of gas adsorbed in the carbon adsorbent by weighing the cylinder before and after feeding the gas.

For LPG gas feeder, the experiments were conducted in the three different conditions, which feed the LPG into the cylinder:

    1. Up to 2 bar (gauge) and 31°C (room temperature)

2. Up to 4.5 bar (gauge) and 31°C (room temperature)

3. Up to 4.5 bar (gauge) and 2°C (almost freezing point for water)

For methane gas, the experiment was conducted at 31°C (room temperature), which feed the methane gas into the cylinder up to 7.5 bar (gauge).
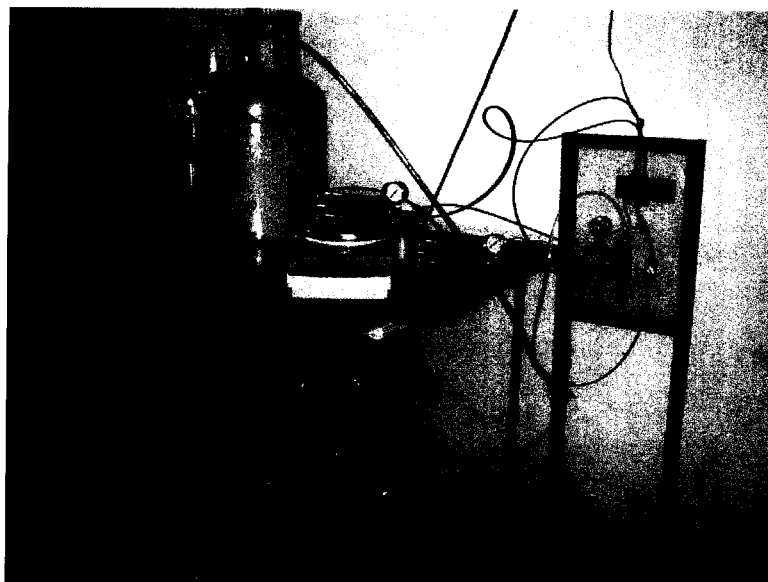
Figure 3.3: Cylindrical Test Bed

3.2   Preparation of Carbon Adsorbent

Oil palm shells were crushed and sieved to a size of 250 – 425 μm separately. About 40 grams of each formed particles were fed in the reactor. The char was prepared at 10°C/min of the heating rate, in between 300°C up to 800°C and was maintained for 60 minutes in 1.5 l/min of N_2 (99.98% of purity from Linde) flow.

Next stage is preparing activated carbon from char products. By varies the peak temperature, heating rate, and residential time of the sample, the optimization of it can be achieved. This process is carried out in a laboratory scale, single step fixed bed reactor, which blanketed by tube furnace where the pyrolysis take place. Nitrogen gas is used to obtain an inert atmosphere in the reactor and CO_2 gas is used to activate the sample. A suction blower is used to remove volatile matter as well as other gases during the process.

7

All the sample will be characterized using a constant volume adsorption apparatus (N_2 adsorption) is used for determining Average Pore Diameter, Surface area, Micropore Distribution, Micropore Volume of carbon adsorbent. For application, a carbon adsorbent test bed is used to observe the adsorptive and desorptive capacity of hydrocarbon gas at carbon adsorbent.

4.0   RESULTS AND DISCUSSION

4.1   Characterization

The specific surface area (S_{BET}), Micropore volumes determined according to the DR method (V_o), total pore volume (V), and pore size distribution (PSD) for Commercial Activated Carbon (CAC) are presented in Table 4.1. The CAC obtained exhibited a BET surface area of 785 m^2/g, with total pore volume of 0.59 cm^3/g and a micropore volume of 0.37 cm^3/g, and with 18.96 Å of pore size distribution. The high pore volume can be partly attributed to the high cellulose content of biomass. The cellulose material has a significant effect on the pore structure of the pyrolysis char. Surface area and porosity are important factors to consider when further converting the pyrolysis char to activated carbon with oxidants. Table 4.1 gives possible assignments of BET surface area and micropore volume give effect to adsorption time [5]. They indicate that when BET surface area and micropore volume larger, the faster time to adsorb LPG gas. For further study, comparison for CAC must continue with activated carbon sample for all samples and get sample weight change to know their LPG adsorption.

The weight change characteristics for various carbon samples due to the different temperatures for the carbonization and the activation process are shown in Table 4.2. These results show that all the chars have a consistent increment of burn off from 48% to 79% from the initial weight of feed. This indicates that when the temperature increased, the percentage of burn off will be increase due to the most of the volatile matters in the sample. This is true for both activation and carbonization process. However for the activation process, the percentage of weight changes smaller than carbonization process. It can be observed that all the volatile matter was released most

in the carbonization process. It is also indicate that carbonization and CO_2 activation has greatly modified the solid structures of the samples by removing the carbon atoms in large amount as the temperature was higher. These results are based on the methods, in which for activated carbons preparation from oil palm shells by physical treatments, carbon dioxide activation was used for single-step methods of preparation Research done by Molina-Sabio et al. (1996) shows that activated carbons prepared by CO_2 activation showed a larger micropore volume and narrower micropore size distribution after with those prepared by carbonization. This report also stated that in CO_2 activation, the reaction is more localized in the interior of the micropores and faster creation of active sites for larger micropore volume.

Table 4.3 summarizes the results of the carbon adsorbents characterization with Nitrogen adsorption. The results indicate that the specific surface area for all samples range from 0.019 m^2/g to 369.59 m^2/g. Sample A700 have the higher BET surface area with 369.59 m^2/g and A300 is the lowest with 0.019 m^2/g. It is evident that the sample A700 have the highest adsorption capacity compare with other samples However, sample A700 have a lower BET surface area compare with CAC sample that have 785 m^2/g. This result shows that sample CAC has better adsorption with gas. It is also shows that as the temperature increased from 300°C to 700°C the carbon adsorption characteristics (i.e. BET surface area and total pore volume) increased. This points out that the temperature for carbonization and activation can affect the initial porosity development of char characterization results. Previous researcher assigned that adequate heat energy from carbonization temperature is needed for the evolution of volatiles for pore development [15]. From the results, it can be seen that more volatiles matters were released and new microporosities have been developed at higher temperature. When the temperature was further increased from 700°C to 800°C, BET surface area are decreased from 341.43 m^2/g to 24.17 m^2/g, previous trend was reversed where all the values were dropped. This may due to the creation of more and mainly fine microporosities which are in accessible to Nitrogen molecules and cause the reduction in pore surface area and volume.

It seemed that micropore surface area and pore volume have been increased along with the increase in temperature (see Table 4.3). This indicates that more and new microposities have been created when heat energy was supplied at higher

temperatures. In this experimental, single-step fixed bed reactor is used for preparation of carbon adsorbent because it slightly produce carbon adsorbent at larger adsorption capacity, wider microporosity, and at carbonization process create of carbon series with samples BET surface area and volume increased rather than double-step method. In term of economic point view, the single-step method can be considered cost effective, energy and time saving compared to double-step method and the characteristics of the carbons can be flexibly controlled [19].

Comparison of the data in Tables 4.2 and 4.3 reveals that the activation process has notable effect on the properties of carbons. Activation temperature and hold time affect not only the BET surface area but also the micropore surface area. Researched done by Lua and Guo (2001) shows that for a longer hold time of 60 min at 1173 K, the BET and micropore surface area decreased significantly due to the severe reaction between carbon and CO_2.

Table 4.1: Properties of the commercial activated carbon

Sample	Properties	Unit	Value
Commercial Activated Carbon	S_{BET}	m^2/g	784.542
	V_o	cm^3/g	0.368
	V	cm^3/g	0.587
	PSD	Å	18.762

S_{BET}: Surface area calculated using the BET equation
V_o : Micropore volumes determined according to the DR method
V : Total pore volume estimated by converting the amount of N_2 gas adsorbed
       at a relative pressure of 0.99 to liquid volume of N_2
PSD : Pore size distributions

Table 4.2: Weight change characteristics for various carbon samples due to the different temperatures for the carbonization and the activation process.

Sample	Temperature (°C)	Process	Weight change (%)
C300	300	Carbonization	48
C400	400		57
C500	500		65
C700	700		72
C800	800		79
A300	300	Activation	3
A400	400		5
A500	500		6
A600	600		8
A700	700		9

Table 4.3: Physisorption characteristics of microporous carbon adsorbents by Nitrogen adsorption.

| Sample	BET surface area (S_{BET}) m^2/g	Total Pore Volume (V_o) cm^3/g	Micropore Volume (V) cm^3/g	Average Pore Diameter Å
C300	0.575	0.00109	0.00292	34.5734
C400	1.258	0.00047	nm*	nm*
C500	344.843	0.16454	0.14369	19.029
C600	341.172	0.15635	0.14326	18.0344
C700	341.427	0.15968	0.14441	18.7073
C800	24.168	0.01019	0.01027	16.8795
A300	0.3175	0.0014	nm*	nm*
A400	0.0191	0.00069	nm*	nm*
A500	317.357	0.14969	0.12376	18.8669
A600	369.318	0.17338	0.15288	18.7785
A700	369.595	0.17698	0.15549	19.1536

*nm – not measured

11

4.1.1 Isotherms

Qinglin et al. (2003) stated that isotherm curvature can affect the concentration dependence of micropore transport parameters significantly, so that, an accurate model for the isotherm data is important. They also reported that an accurate representation of the individual isotherm is also important for reliable mixture equilibrium prediction. Figure 4.1 shows that the N_2 adsorption isotherm at 77 K for all carbon adsorbents and commercialize activated carbon. The shapes of the isotherms are observed as Type I according to IUPAC classification [17], which indicates the domination of microporosity as the main pore structure. The shape of adsorption isotherms can provide qualitative information on the adsorption process and the extent surface area available to the adsorbate. It also shows the major gas uptake behavior below a relative pressure of 0.1. From this result, the increases in the gas uptake as the activation and carbonization temperature and burn off increased indicate that more porosity are being created in the pore network, which are responsible for the high amount adsorbed. Heat treatment could open closed pores, thereby magnifying the adsorption capacity of modified carbon adsorbents for nitrogen. It has been reported that thermal treatment could alter the carbon adsorbent properties of the microporous carbons [22]. From Figure 4.1, the lower the activation temperature, the steeper the branches for a given activation duration; the shorter the activation duration, the steeper the isotherm for a given activation temperature. The development of microporosity, therefore, must have been favored by the higher temperature and longer duration. The higher temperature and longer duration often cause greater burn-off, as discussed earlier. Lua and Guo (2001) stated that the amount of adsorbed nitrogen is indicative of the adsorption capacities of the chars. Based on their worked, they found that at the higher pyrolysis temperature at 950°C, the chars has the lowest adsorption capacities.

Figure 4.2 shows the nitrogen adsorption/desorption isotherms obtained with CAC samples. The predominant character of all these isotherms is Type I [17] but with positive slope across much of the pressure range indicating the presence of mesopores beside micropores in the materials. Moreover, the isotherms exhibit a hysteresis loop usually associated with the filling and emptying the mesopores by capillary condensation.

Figure 4.3 illustrates the Nitrogen adsorption/desorption isotherms at 77 K for the C700 sample. The adsorption isotherm is Type I according to the IUPAC classification. An almost horizontal plateau at 0.3 to 0.6 relative pressures suggested highly microporous materials with a narrow pore size distribution, and the observed characteristics corroborated the presence of a considerable volume of micropores, where the adsorption proceeds on the principle of the condensation in pore volume and is in accordance with the high adsorption capacity of the sample (see Table 5.3). The loss of volatile materials was probably, at least partially, responsible for the creation of both macro- and micropores, resulting in samples of high surface areas. Similar results were obtained by Lua and Guo (2001) prepared activated carbons from oil-palm shell by CO_2 activation found that the higher the activation temperature, the greater the surface area of the resultant activated carbons. As an be discerned from the data in Table 4.3, both the surface area and the micropore volume were higher for all carbons obtained at the higher activation temperature compared to those obtained at the lower activation temperature. Notably, sometimes, a higher temperature causes micropores to widen because it burns away the walls between adjacent pores, thereby resulting in the enlargement of pores. This leads to a decrease in the fraction of micropore volume and an increase in the total pore volume.
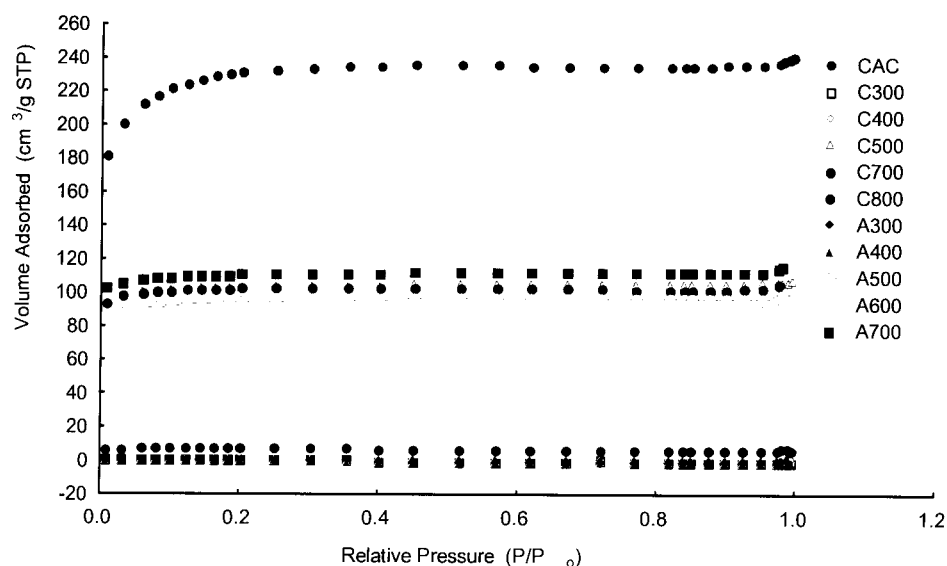
Figure 4.1: Nitrogen adsorptions (77 K) isotherm of commercial activated carbon and carbon adsorbents prepared by different carbonization and activation temperature at 1 hour hold time
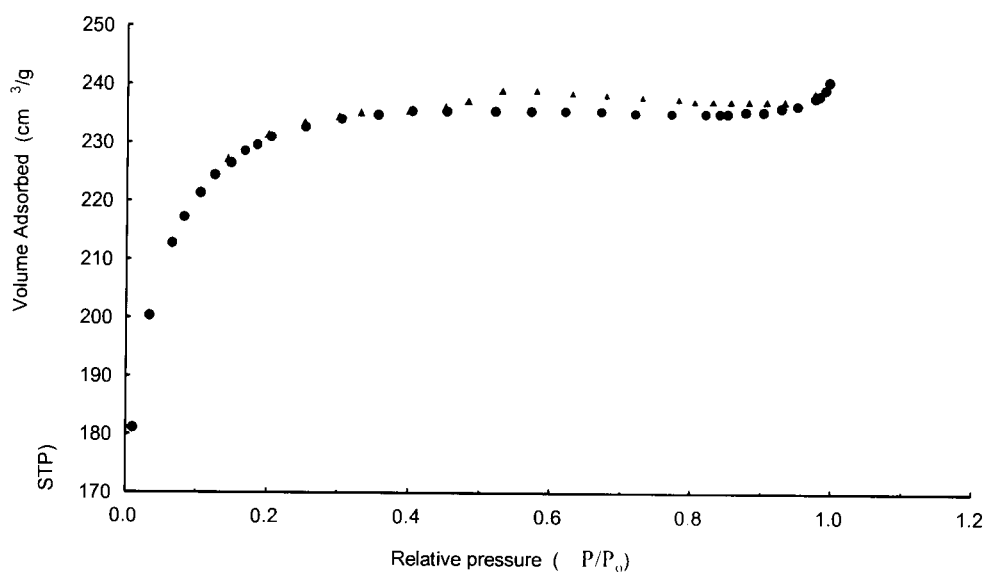
**Figure 4.2: Nitrogen adsorptions and desorption (77 K) isotherm of commercial activated carbon**
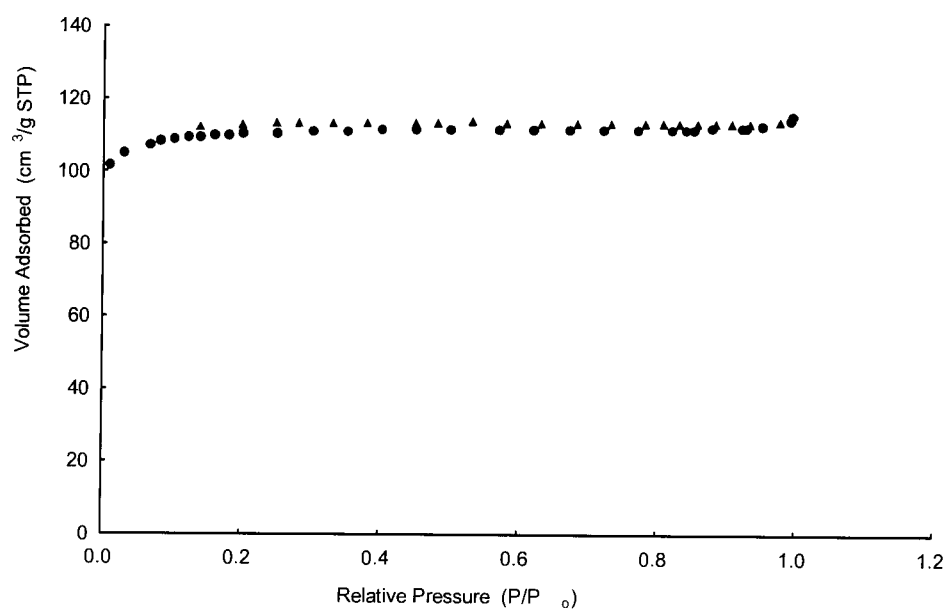
Figure 4.3: Nitrogen adsorptions and desorption (77 K) isotherm of activated carbon A700

14

4.2 Adsorption and Desorption of LPG

Figure 4.4 is the adsorption isotherm for adsorption of LPG gas onto activated carbons. It shows that adsorption capacity increase when the temperature for CO_2 activation increase. It is noted that, during the activation process, pores are widened and micropore volume increases. At high concentrations the micropores become filled, and the more highly activated adsorbent with the most micropore volume (C700-CO2-60) will adsorb the most adsorbate. On the other hand, the LPG desorption rate has a much smaller for a sample with low temperature. Potential theory postulates that physical adsorption takes place in a space of fixed volume, called the maximum adsorption space, close to the adsorbent surface. The adsorbate is assumed to be in the liquid state when it is adsorbed. The adsorption potential is equal to the change in Gibbs free energy ($-\Delta G$) that results from transfer of the adsorbate from the bulk fluid to the adsorbed state. The maximum adsorption potential exists at the adsorbent surface, diminishing to zero where the adsorbed phase would be equilibrium with a saturated fluid.

Figure 4.5 shows desorption of LPG with different temperature of activated carbon. This dependence is a result of selected temperature of CO_2 activation and residence time. It is evident from the theory that the increasing of temperature will increase the adsorption-desorption process. The sample activated char C300-CO2-60 have a good desorption that it takes a 1200 second to reach 0.5 percent gas release and to maximum desorption process at 0.3 percent gas in 3610 s. Meanwhile, sample C300-CO2-60 show that this carbon adsorbent has small opened pore which is desirable to a gas since it just take short time to reach 0.5 percent gas in 200 second. Sample C500-CO2-60 and C700-CO2-60 show an average adsorption action and incapability to desorb LPG sufficiently that takes 1600 s to reach 0.5 percent. These results show that the activation process in carbon adsorbent can increase the ability to adsorb more LPG gas, which is a good agreement with Herawan (2000). From overall graph, it seems that the desorption of carbon adsorbents follow the breakthrough curve pattern, which start from 0% and will increase to maximum 0.25% gas and then decrease until 0% gas. It can be summarized that the samples which have a good adsorption capability, it does not mean that the samples have a good desorption capability.
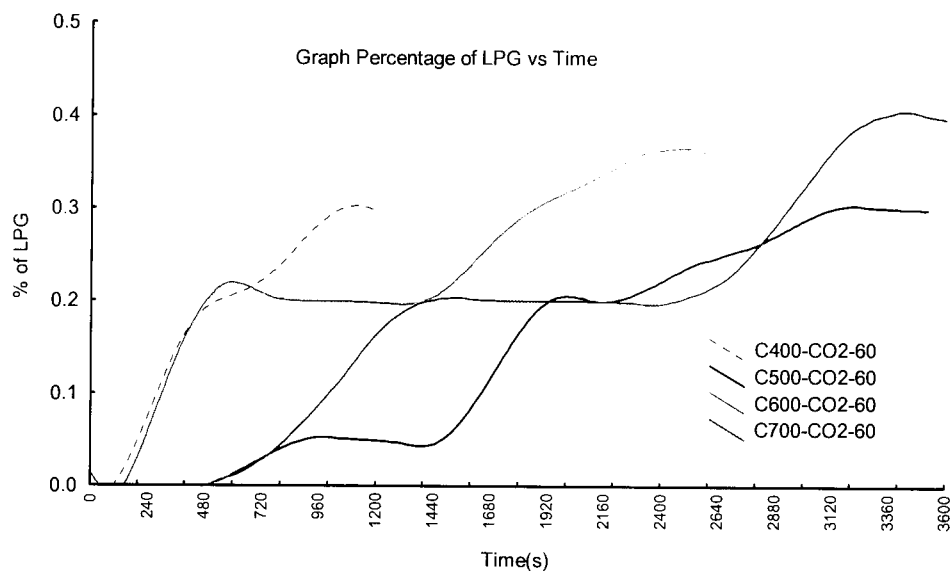
Figure 4.4: Graph LPG Adsorption for Activated Carbon samples 200 ml/min LPG adsorption using carbon adsorbent test bed model
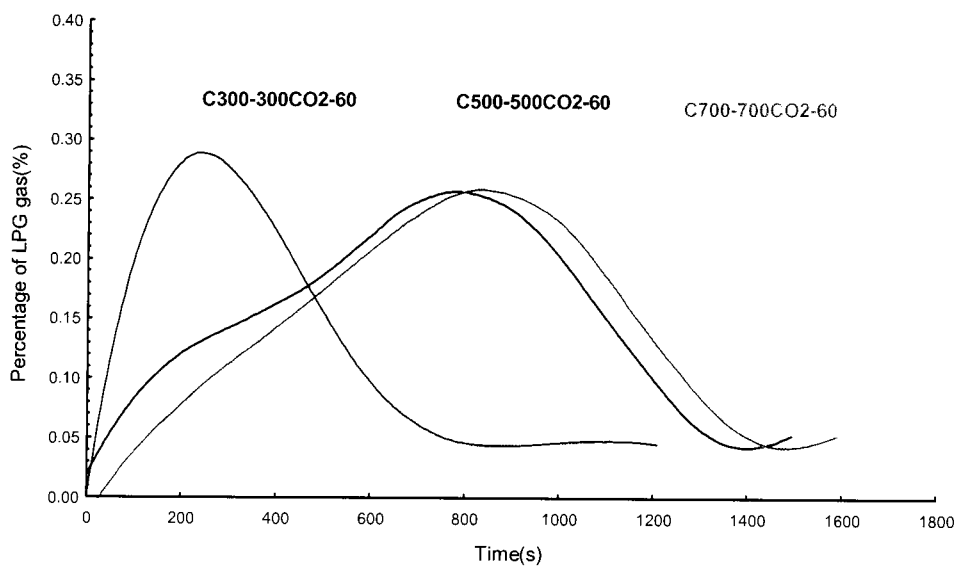
Figure 4.5: Graph Activated Carbon samples 200 ml/min LPG desorption using carbon adsorbent test bed model

Figure 4.6 shows the difference conditions applied in term of weight sample from the adsorption and desorption process. Sample C700-CO2-60 adsorbed 0.54 g LPG gas, C500-CO2-60 adsorbed 0.42 g gas and C300-CO2-60 adsorbed 0.02 g gas. From Figure 4.4, it can be reveals that C700-CO2-60 samples have the higher capability to

adsorb the LPG gas rather than C300-CO2-60 and C500-CO2-60 samples. The adsorption and desorption weight for C300-CO2-60 sample remains the same as it shows the high capability of this sample in the adsorption-desorption processes of LPG. Sircar (2005) reported that the isosteric heat of adsorption is a critical design variable in estimating the performance of an adsorptive gas separation process and the heats can be strong and complex functions of adsorbate loadings when the adsorbent is energetically heterogeneous. It is noteworthy that ignoring these characteristics in process design can lead to serious errors. The relevant thermodynamic variable to describe the heat effects during the adsorption and desorption process inside an adsorber is the isosteric heat of adsorption. This statement clearly determined on the certain results insufficiently follows the thermodynamic theory.
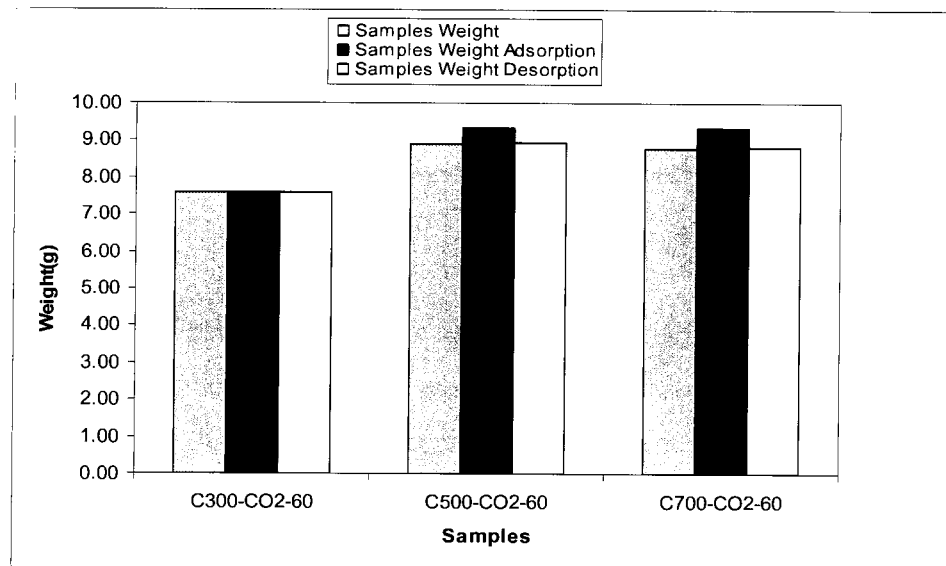
Figure 4.6: The Samples Weight on Conditions: Before Adsorption, Adsorption, and Desorption

4.3 Carbon adsorbents for LPG storage

Results from Figure 4.7 summarized the amount of LPG in the empty cylinder and cylinder with carbon adsorbent at different conditions. Results show for all conditions that the existing of carbon adsorbent inside the cylinder can increase the storage capacity of LPG without expanding the volume of the cylinder. The increasing capacity is in the range of 122% up to 291%. In the other words, the carbon

adsorbent can multiply the storage capacity more than double and up to almost fourth times.
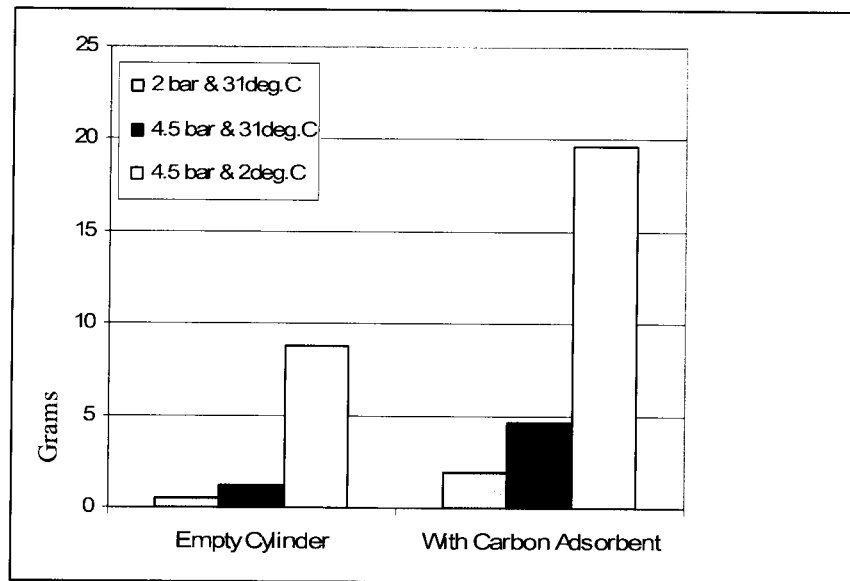
Figure 4.7: Comparison between Empty Cylinder and Cylinder with Carbon Adsorbent at different conditions due to the amount of LPG in the cylinder

The aims of running in different conditions are to observe the effect of the gas feeder pressure and the cylinder temperature. By increasing the gas feeder pressure, the amount of LPG in the cylinder will be increased. The surrounding storage temperature also plays an important rule, since the condensation and vaporization of LPG depended on pressure and temperature storage. The last condition, set 4.5 bar (gauge) and 2°C is meant to condense the LPG and to boost the amount of LPG stored in the cylinder.

The chemical composition of LPG consisted of 40% Propane, 30% i-Butane, and 30% n-Butane [23], therefore the propane and butane can be condensed when the properties are below the temperature vapor point and above the pressure vapor point. The butane gas can be condensed when applying the pressure 4.5 bar (gauge) and 2°C, and propane can be condensed mostly since the condition is totally close to the pressure and temperature vapor point [24].

Since a propane molecule has diameter of 0.49 nm, it can penetrate with ease into pores with diameters ranging from 1.0 to 2.0 nm [9]. It shows that the carbon adsorbent sufficiently help to store the LPG gas more in the storage. The work described here relates only to a laboratory-scale process, which must be further tested to determine the economic advantage or suitability for actual application. The potential for its application is enormous.

4.4   Carbon Adsorbents for Methane Gas Storage

Results from Figure 4.8 summarized the amount of methane gas in the empty cylinder and cylinder with carbon adsorbent at 7.5 bar (gauge) and 31°C. Results also show that the existing of carbon adsorbent inside the cylinder can increase the storage capacity of Methane gas without expanding the volume of the cylinder. The increasing capacity is 147%, hence, the carbon adsorbent can multiply the storage capacity almost two and half times.
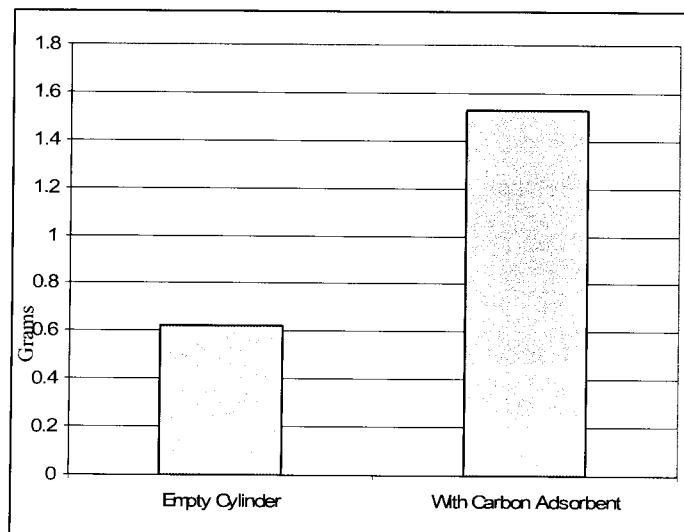
Figure 4.8: The amount of Methane gas in the empty cylinder and cylinder with carbon adsorbent

Figure 4.8 shows the results for the calculations of carbon storage model fill with Methane with carbonaceous adsorbents material with store in 7.5 bar, 31 °C (room temperature) and the weight of methane in the cylinder is 1.57 g. Qinglin et al. (2003)

found that transport of gases in the micropores of carbon adsorbent is controlled by a dual resistance. It reveals that the increasing amount that can be stored in storage tank model is due to the gas that fills into the micropore and the interactions with the van der walls between the gases. An optimal slit pore width for natural gas storage has been estimated by Monte Carlo simulation to be 1.14 [20, 12]. The results imply that the fraction of micropores in any of the carbon adsorbent was large and the pore size distributions of these activated carbons are suitable for natural gas storage. From the above experimental results, Chen (1969) has stated that the "effective micropore" volume comprises the pores with diameters ranging from three to six times adsorbate molecular size. Since a methane molecule has diameter of 0.382 nm, it can penetrate with ease into pores with diameters ranging from 1.0 to 2.0 nm. The carbon adsorbents have the diameter of most of the activated carbon's pores and are within such a range as much as 1.915 nm [9]. This implies that the pore size distribution's of the carbon adsorbent is suitable for natural gas storage.

5.0 CONCLUSION

From the development of porosity, especially microporosity by various processing techniques and conditions in this study is well understood. The oil palm shell has conformed to be good raw material in the preparation of carbon adsorbents for LPG gas adsorption and desorption application. It is also reveals that the activation process in carbon adsorbent indeed affects the capacity of LPG adsorption. The higher peak temperature can contribute more capability to adsorb LPG gas. It is found that sample C700-CO2-60 shows a higher capability to adsorb LPG than the other samples. The desorption of carbon adsorbents follow the breakthrough curve pattern, as similar with a normal distribution curve. The smaller LPG adsorbed in the carbon adsorbent, the faster desorption process occurs, and more LPG adsorbed in the carbon adsorbent, results longer time to desorb the gas.

From the experimental, carbon adsorbent test bed model can get stability and consistent data, this is because the test bed model decreased the loses of LPG during the adsorption and desorption process. It is evident that to get a good result, all the process must be done in direct operation. In line with this research and from previous

researcher, it is found that the most important property of the carbon adsorbent is its adsorptive capacity, which is related to the specific area, pore structure and the effect of temperature. These studies also shown that, during CO_2 activation, the particle size might influence CO_2 diffusion into the interior as well as the release of the gaseous products generated. It is notably that char yield and char characteristic are important in evaluating the performance of the reactor [21] that will be used in further analysis.

The aforementioned results show that the experimental rig and carbon adsorbent test bed were successfully developed and both of them can be used to prepare carbon adsorbent and analysis to determine adsorption and desorption ability for LPG gas respectively. The oil palm shell can be used for producing carbon adsorbent for LPG gas storage media since all the samples show capability to adsorb and desorption LPG.

Generally, the higher the activation temperature, the faster would be the activation reaction, resulting in greater carbon conversion. Compared with high temperature chars, the low temperature of chars were more stable for activation. To demonstrate further the effect of activation temperature on the activation reactivity, both the simulated and experimental should be considered. However, this research is still need to continue to explore more finding to achieve a better result in the future work.

The use of carbon adsorbents in LPG storage system for LPG gas is great application and expected to have market potential in future if the limitation such as fuel tank space can be overcome. Additionally, the required qualities of carbon adsorbents for this purpose can be obtained with the simple and well-known processing technologies and development in future works.

Cylindrical Test Bed (CTB) is a useful apparatus for determining the adsorption and desorption capacities of the materials in the form of powder, particle, or granular using the gravimetric method. The carbon adsorbent indeed can multiply the storage capacity for LPG and methane gas. The most important property of the carbon adsorbent is its adsorptive capacity, which is related to the specific area, pore structure and the effect of temperature. This research need to be continued to explore all possibilities to achieve a better result in the future work.

The oil palm shell has been confirmed to be a good raw material in the preparation of carbon adsorbents for storage of LPG and methane gas, which are the alternative fuel in vehicle. The use of carbon adsorbents in LPG and methane storage is a novel idea and expected to have market potential in future with the limitations of volume and space of fuel tank as a prerequisite. Additionally, the required qualities of carbon adsorbents for this purpose can be obtained with the simple and well-known processing technologies and development in future works.

Recommendation for future woks, a more overall study can be done in terms of carbon processing parameters, such as the considerations of particle size, BET surface area, porosity, pore volume, preparation procedures and different techniques to investigate the effects on the pore structures development because it is important in gas adsorption and desorption processes.

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