

**A STUDY ON THE OPTIMUM NATURAL GAS STORAGE TANK DESIGN  
USING THE GAS ADSORBENT APPLICATION**

**MUHAMMAD KHIDIR BIN ABDUL RAHMAN**

**UNIVERSITI TEKNIKAL MALAYSIA MELAKA**

'I/We\* admit that have read this dissertation and in my/our\* opinion this dissertation is  
satisfactory in the aspect of scope and quality for the bestowal of  
Bachelor of Mechanical Engineering (Automotive)'

Tandatangan :.....  
Nama Penyelia I : Mr. Razali bin Mohd Tihth  
Tarikh :.....

Tandatangan :.....  
Nama Penyelia II : Mr. Mohd Nazim Abd Rahman  
Tarikh :.....

**A STUDY ON THE OPTIMUM NATURAL GAS STORAGE TANK DESIGN  
USING THE GAS ADSORBENT APPLICATION**

**MUHAMMAD KHIDIR BIN ABDUL RAHMAN**

This report is submitted to the Faculty of Mechanical Engineering  
in partial fulfillment of the partial requirement for awarding the  
Degree of Mechanical Engineering  
(Automotive)

Faculty of Mechanical Engineering  
Universiti Teknikal Malaysia Melaka

MAY 2009

“I admit that this report is my own work except the summary and some statement which is each of them, I already state the source of it”

Signature : .....

Author Name : Muhammad Khidir bin Abdul Rahman

Date : .....

## ACKNOWLEDGEMENT

First of all, I would like to express all my praise to Allah the Almighty because without His blessings I will not be able to complete my Projek Sarjana Muda 1 and II (PSM), which is part of the course requirement that I have to go through in Universiti Teknikal Malaysia Melaka (UTeM).

Especially, my most gratitude goes to those individuals who have contributed immeasurable amount of guidance, advice and assistance along the project period; the first person that really helps in my research is my dedicated supervisor, En. Razali Mohd Tihth, who has supportively guiding and teaching a lot of valuable knowledge, also for the opportunities he has given me in exposing myself to research and development environment.

And also the supportive BMCA member, I would like to thank all of them for lending their hands and giving continuous support during my project period in order to achieve the objective of study. With the full cooperation from the people above, I have successfully achieved the objectives of PSM I and II.

## ABSTRACT

A natural gas is one of the alternative fuels for vehicles around the world and most of the vehicle nowadays used Compressed Natural Gas (CNG). Among the problem of using the CNG equipment is on the storage tank size and its high operating pressure. The storage tank is bulk, thick and heavy because it has to sustain the higher compression of methane ( $\text{CH}_4$ ) gas. In this research, the application of carbon adsorbent is used in ANG concept storage tank. This study is focusing on the amount storage capacity of Adsorptive Natural Gas (ANG) compared to the available existing 12 litre CNG tank in the market. Methane adsorptive storage will be done using the designed adsorbent tank concept. This carbon adsorbent will be used in the process of design and studies the new storage tank in the future. The expected result in this research is being able to set up an experiment procedure for testing the adsorbent ability storage using coconut palm shell carbon. This carbon adsorbent will be applied in the ANG storage tank concept. If this research success, the problem such as large size and high pressure of natural gas storage can be solve.

## ABSTRAK

Gas asli ialah salah satu alternatif minyak untuk kenderaan di seluruh dunia dan kebanyakan kenderaan sekarang menggunakan storan gas asli termampat (CNG). Antara masalah daripada penggunaan storan gas asli termampat (CNG) ialah pada saiz storan tangki dan operasi tekanan yang tinggi. Storan tangki gas asli termampat besar, tebal dan berat kerana terpaksa menampung tekanan mampatan gas metana yang tinggi. Dalam penyelidikan ini, aplikasi penjerap akan digunakan di dalam gas asli terjerap (ANG) storan konsep tangki. Kajian ini bertumpu pada jumlah kapasiti storan penjerapan gas asli (ANG) tangki berbanding dengan 12 liter storan tangki termampat (CNG) yang sedia ada di pasaran. Storan penjerapan metana akan dilakukan dalam rekabentuk konsep penjerapan tangki. Karbon penjerap ini akan digunakan dalam mereka bentuk dan kajian tentang storan tangki baru pada masa akan datang. Jangkaan keputusan dalam penyelidikan ini ialah dapat menyediakan satu kaedah eksperimen untuk menguji kebolehpayaan storan penjerap menggunakan karbon tempurung kelapa sawit. Karbon penjerap ini akan digunakan dalam gas asli terjerap (ANG) storan konsep tangki. Jika penyelidikan ini berjaya, masalah seperti saiz storan tangki yang besar dan tekanan tinggi daripada storan gas asli dapat diselesaikan.

## TABLE OF CONTENT

<b>CHAPTER</b>	<b>SUBJECT</b>	<b>PAGE</b>
	<b>ACKNOWLEDGEMENT</b>	i
	<b>ABSTRACT</b>	ii
	<b>ABSTRAK</b>	iii
	<b>TABLE OF CONTENT</b>	iv
	<b>LIST OF TABLES</b>	vii
	<b>LIST OF FIGURES</b>	ix
	<b>LIST OF ABBREVIATIONS</b>	xi
	<b>LIST OF APPENDIX</b>	xiii
<b>CHAPTER 1</b>	<b>INTRODUCTION</b>	
	1.1 General Background	1
	1.2 Objectives	3
	1.3 Problem statement	3
	1.4 Scopes	4
	1.5 Benefit of Study	4
<b>CHAPTER 2</b>	<b>LITERATURE REVIEW</b>	
	2.1 Theory	6
	2.1.1 Advantages of Natural Gas Vehicle	9
	2.1.2 Disadvantages of Natural Gas Vehicle	9



2.2	Compressed Natural Gas (CNG)	10
2.2.1	Refueling	12
2.3	Liquefied Natural Gas (LNG)	13
2.3.1	Basic Facts	14
2.4	Adsorbed Natural Gas (ANG)	14
2.5	Fundamentals of Adsorbed Natural Gas Storage	19
2.5.1	Gas Adsorption	19
2.5.2	Theory Gas Adsorption	20
2.6	Adsorbent Materials	22
2.6.1	Adsorbent Properties	23
2.6.2	Characteristic and General Requirements	26
2.6.3	Activated Carbon	27
2.6.3.1	Properties of Activated Carbon	28
2.6.4	Factors Influencing the Adsorption Capacity of Natural Gas	31
2.6.4.1	Natural Properties of Adsorbent	32
2.6.4.2	Adsorbent Surface Area and Pores	32
2.6.4.3	Adsorption Temperature	33
2.6.4.4	Packing Density of Adsorbent	34
2.7	Storage Capacity	34
2.8	Summary	37

<b>CHAPTER 3</b>	<b>RESEARCH METHODOLOGY</b>	
3.1	Methodology for PSM I	39
3.2	Methodology for PSM II	41
<b>CHAPTER 4</b>	<b>CONCEPT DESIGN DEVELOPMENT</b>	43
4.1	Concept Design ANG tank	44
4.2	Details Drawing	46
4.2.1	CAD Drawing	46
4.2.2	Dimension of CAD Drawing	48
4.3	Experiment Set-up	49
4.3.1	Concept Experimental Rig	49
4.3.2	Measuring and Controlling Equipment	51
4.3.3	Experimental Description	52
4.3.4	Experimental Flow	55
4.3.5	Experimental Procedure	55
4.3.5.1	Pre-adsorption	56
4.3.5.2	Dynamic Adsorption	57
4.3.5.3	Isothermal Adsorption	57
<b>CHAPTER 5</b>	<b>DESIGN ANALYSIS AND DISCUSSIONS</b>	
5.1	Selection of Design Material	59
5.1.1	Material	60
5.1.2	Cost	60
5.1.3	Corrosion	61
5.1.4	Weight	61
<b>CHAPTER 6</b>	<b>CONCLUSION AND RECOMMENDATION</b>	62
	<b>REFERENCES</b>	64
	<b>APPENDIX</b>	67

**LIST OF TABLES**

<b>NO</b>	<b>TITLE</b>	<b>PAGE</b>
1	Malaysian Natural Gas Composition	7
2	Properties Diagram for Different Vehicles Fuel	8
3	Comparison Chart of Various Activated Carbons	24
4	Physical Properties of Commonly Used Adsorbents	24
5	Adsorptive Properties of Commonly Used Adsorbents	25
6	ANG Tank Specification	45
7	Measuring and Controlling Equipment	51
8	Loading Weight and Densities of Adsorbents	53
9	Data for 12 litre CNG tank	53
10	Data for 1.178 litre ANG tank	54
11	Loading Weight and Densities of Adsorbents	54

<b>NO</b>	<b>TITLE</b>	<b>PAGE</b>
12	Cost of Materials	60
13	Typical Mechanical Properties	61

**LIST OF FIGURES**

<b>NO</b>	<b>TITLE</b>	<b>PAGE</b>
1	Oil and Natural Gas Formation	2
2	Diagram of Simplest Saturated Hydrocarbon	2
3	Example of CNG Storage Tank	11
4	'Slow-Fill' Pump Method in Hom	12
5	The Schematic Picture of Gas Adsorption	15
6	Size Storage Tank Fit on the Motor Scooter	17
7	The Process of ANG from Corncob	18
8	Illustrate Attraction between Organic and Activated Carbon	22
9	Scanning Electron Microscope Images of Pore	28
10	Granular Activated Carbon	30
11	Powder Activated Carbon	30

<b>NO</b>	<b>TITLE</b>	<b>PAGE</b>
12	Pelleted Activated Carbon	30
13	Carbonized Coconut	31
14	Activated Coconut	31
15	Flow Chart for PSM I	39
16	Flow Chart for PSM II	41
17	Illustrated Schematic of Experiment Flow	43
18	Cross Section of Concept Design ANG Tank	44
19	Drawing inside the ANG Tank	46
20	Drawing Cover of ANG Tank	47
21	Drawing Assembly of ANG Tank	47
22	Drawing of ANG Complete Tank	48
23	Dimension CAD Drawing	48
24	Concept ANG Experimental Rig	50
25	Illustrated Schematic of Experiment Flow	52

## LIST OF ABBREVIATIONS

ANG	=	Adsorbed Natural Gas
CNG	=	Compressed Natural Gas
CO	=	Carbon Monoxide
LNG	=	Liquefied Natural Gas
MPa	=	Megapascal
NGV	=	Natural Gas Vehicle
NMHC	=	Non-methane Hydrocarbon
NO <sub>x</sub>	=	Oxide of Nitrogen
O	=	Oxygen
ppm	=	Part per million
psi	=	Pound per square inch (lbf/in <sup>2</sup> )
STP	=	Standard Temperature and Pressure
upm	=	Unit per million
V/V	=	Volume of Adsorbed Gas per Volume of Solid Adsorbent
V <sub>m</sub> /V <sub>s</sub>	=	Volume of Stored Methane per Volume of Storage Container

Ni = Nickel

Cr = Chromium

C = Carbon



**LIST OF APPENDIX**

<b>NO</b>	<b>TITLE</b>	<b>PAGE</b>
A1	Advanced Nanoporous Carbon from Corncob in University Of Missouri & Midwest Research Institute	68
A2	Natural Gas Storage by Royal Military College of Canada	69
A3	ANG tank Design and Fuel Delivery System by Midwest Research Institute	70
A4	The Use of Adsorbed Natural Gas in Vehicles	71
A5	Conversion of Corncobs to Activated Carbons for Natural Gas (methane) Adsorption	72
A6	Low Pressure Adsorbed Natural Gas for Vehicles	73
A7	Dimension of CAD Drawing	74

## CHAPTER 1

### 1.0 INTRODUCTION

#### 1.1 General Background

Natural gas vehicles or commonly known as NGV is one of the cleaner fuel used through out the worlds as the alternative to gasoline for most of the vehicles. Natural gas comes from the decay of ancient organism buried on the ocean floor. The tiny bacteria continuously brake down the remains of sea animals and plants. Over time, they were covered by layers of sedimentary rock. After millions of years the remains were buried deeper and deeper which turned them into the oil and gas because of the enormous heat and pressure under the ocean (Secondary Energy Info Book, 2007). Today, human drill down through the sedimentary rock layers to reach the oil and gas deposits as shown in Figure 1 below.

Natural gas consists of about 95% methane, a gas that is unable to be liquefied at ambient temperature by pressurization because of its critical temperature which is the  $T_c$  is  $- 82.6$  °C. Since it is a gaseous fuel, its volumetric energy content is low compared with those of liquid fuels (Mota, 1999). In fact, natural gas outcores petroleum-based fuels in every aspect except on board storage (Talu, 1992). Currently, natural gas is compressed at pressures up to 25 MPa (3600 psi) in order to be stored compactly on-board and dispensed quickly.

However, this storage method requires expensive and extensive high-pressure compression technology (Jasionowski *et al.*, 1989).

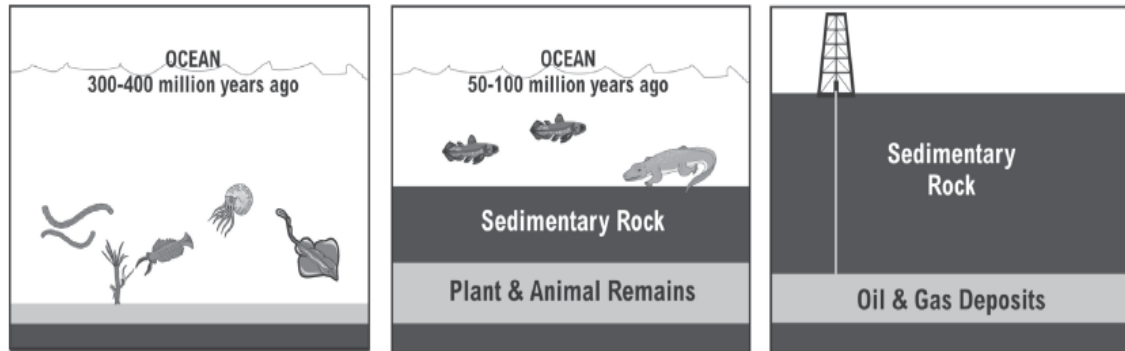


Figure 1: Oil and Natural Gas Formation

The primary component of natural gas is methane ( $\text{CH}_4$ ), the shortest and hydrocarbon molecules (Physical and Chemical Fundamentals McGraw Hill, 1975). The hydrocarbon in natural gas called saturated hydrocarbons because they contain hydrogen and carbon. This gas methane has to be compressed into the appropriate size storage tank cylinder with very high pressure due to the characteristic of methane molecules which are difficult to pack closely together, so natural gas must be subjected to high pressures to store enough of it to fuel a vehicle over a long distance.

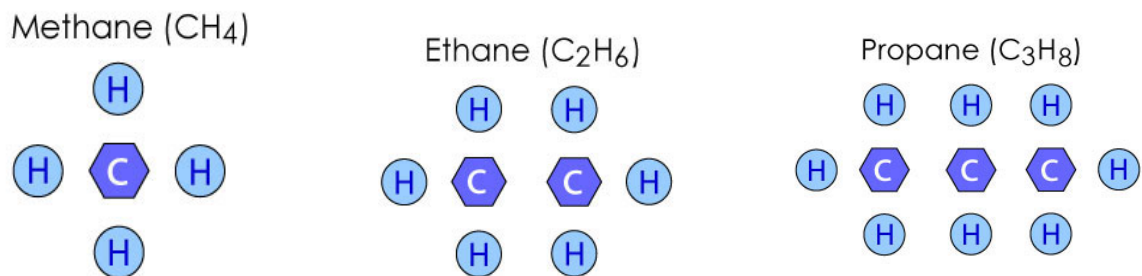


Figure 2: Diagram of Simplest Saturated Hydrocarbon

## 1.2 Objectives

This research is focusing on the studies the optimum natural gas storage tank design storage using coconut palm shell carbon as the gas adsorbent application and set up one procedure experiment to testing this adsorbent material in the ANG tank concept. All the measurement and control devices which is need to be used in this experiment will be identified and stated. The other objective of this study is to discuss the concept of new ANG storage tank.

## 1.3 Problem Statement

Nowadays NGV is widely used all around the world as the alternative fuel for vehicles. Lot of vehicle users today either passengers or commercials have installed the NGV kits on their vehicles because the vehicles users cannot follow up the increasing price for fuel in global state. But the side effect that has to be accepted by NGV users is they have to give most of their boot cars space to install the NGV storage tank since this storage tank designed in large size, thick walled and cylinder shape in order to withstand the high pressure from the methane molecules of NGV.

Currently, natural gas is most practical when fueling large vehicles such as buses and trucks because it must be stored in large tanks that would take up all the storage space in smaller car. Due to this problem many researchers has run some research and experimental process to find the other ways to reduce the size of storage tank. One of the efficient methods is using the gas adsorbent which generally known as Adsorbed Natural Gas (ANG).

## 1.4 Scopes

The scopes for this research are:

- To studies the optimum preparation process of carbon adsorbent material from waste material such as palm shell by applying the characteristic of natural gas adsorb and desorbs process to the carbon adsorbent material.
- To identify the related gas adsorption apparatus, measurement and control devices needed to be used in this experiment.
- To come out with the concept design of gas storage tank that fitted with the carbon adsorbent material by considering those characteristic.
- To set up one experiment procedure in order to testing the capability storage of carbon adsorbent material in the concept ANG tank.
- To discuss the ANG storage tank design material selection aspects.

## 1.5 Benefit of Study

Better understanding about the flow of NGV system, the characteristic, properties of natural gas and also the types of NGV. Most people did not realize that there are three types of NGV which are Compressed Natural Gas (CNG), Liquefied Natural Gas (LNG) and Adsorbed Natural Gas (ANG). This research will be focusing on the ANG but there are also some information about the CNG and LNG.

ANG is a new technology available to answer some difficulties of CNG storage for fleet application. In ANG storage, natural gas is adsorbed by a suitable high porosity adsorbent material packed inside the storage vessel. It takes place at a lower pressure, which is around 500 psi (3.5 MPa). When natural gas is charged into ANG tank, the energy density stored will be greater than of the CNG tank at the same pressure, increasing the amount of natural gas that can be stored. Subsequently, this will allow more gas to be stored at lower pressure.

By doing this research studies, hopefully at the end it will help the current problem that have to be faced by NGV user will be solved. The fuel vehicles user can take the alternative NGV as replacement of the fuel. These studies provide some info about the carbon adsorbent characteristic and gas adsorb-desorbs process which can be used for the further research. May be for the future the researcher can use the others waste material other than oil palm shell which suit with carbon characteristic to be used in the NGV storage tank.

## CHAPTER 2

### 2.0 LITERATURE REVIEW

#### 2.1 Theory

Natural gas is a gaseous mixture of light hydrocarbons which is found underground in sedimentary rock formations, often in the same location as crude oil. It is colorless, odorless fuel that burns cleaner than many other fossil fuels such as coal, gasoline, and diesel. Natural gas consists of mainly methane (85-95%) with a minor amount of ethane, and higher-order hydrocarbon compounds. Natural gas also contains a scant amount of unburned component such as carbon dioxide, nitrogen and sulfur. However, the percentage of natural gas composition is different from one reservoir to another (Parent, 1986). Natural gas composition from Malaysian reservoir is as presented in Table 1. Once the gas has compressed into the storage tank it's called Compressed Natural Gas (CNG). Under natural gas vehicle (NGV) actually have three type of NGV system which are Compressed Natural Gas (CNG), Liquefied Natural Gas (LNG) and Adsorbed Natural Gas (ANG).

Natural Gas Component	Volume Percentage	
	Before 1995	After 1995
Methane (CH <sub>4</sub> )	84.75	92.73
Ethane (C <sub>2</sub> H <sub>6</sub> )	10.41	4.07
Propane (C <sub>3</sub> H <sub>8</sub> )	0.98	0.77
i-butane (C <sub>4</sub> H <sub>10</sub> )	0.07	0.08
n-butane (C <sub>5</sub> H <sub>10</sub> )	0.04	0.06
Other hydrocarbons (C <sub>5+</sub> )	0.00	0.01
Nitrogen (N <sub>2</sub> )	0.39	3.36
Carbon dioxide (CO <sub>2</sub> )	3.36	1.83
Total	1.83	100.00
Gross Calorific Value, CV (Kcal/Sm <sup>3</sup> )	9.583	9.253
Specific Gravity	0.65	0.61

Table 1: Malaysian Natural Gas Composition (Gas Malaysia Sdn Bhd, 1995)

Since natural gas principal component is methane with 85 - 95% composition, therefore, the characteristics of natural gas are similar to methane. Methane is a colorless and odorless gas with a wide distribution in nature. At room temperature, methane is lighter than air. It melts at  $-183\text{ }^{\circ}\text{C}$  and boils at  $-164\text{ }^{\circ}\text{C}$ . Hence, at ambient temperature, methane cannot be liquefied by pressurization (Smith, 1990). This is because the critical temperature of methane which is  $-82.6\text{ }^{\circ}\text{C}$  is lower than ambient temperature ( $27\text{ }^{\circ}\text{C}$ ). It can be liquefied only by cooling method and natural gas in this form is called Liquefied Natural Gas (LNG). Methane is not very soluble in water. It is combustible, and mixtures of about 5 to 15 percent in air are explosive. Methane is not toxic when inhaled, but it can produce suffocation by reducing the concentration of oxygen inhaled (Shakhashiri, 2000).

A trace amount of smelly organic sulphur compounds is added to give commercial natural gas a detectable odour. This is done to make gas leaks readily