

Improved of Natural Gas Storage with Adsorbed Natural Gas (ANG) Technology Using Activated Carbon from Plastic Waste Polyethylene Terephthalate

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Abstract. Indonesia imports high amount of Fuel Oil. Although Indonesia has abundant amount of natural gas reserve, the obstacle lies within the process of natural gas storage itself. In order to create a safe repository, the ANG (Adsorbed Natural Gas) technology is planned. ANG technology in itself has been researched much to manufacture PET-based activated carbon for natural gas storage, but ANG still has several drawbacks. This study begins with making preparations for the equipment and materials that will be used, by characterizing the natural gas, measuring the empty volume, and degassing. The next step will be to examine the adsorption process. The maximum storage capacity obtained in this study for a temperature of 27°C and pressure of 35 bar is 0.0586 kg/kg, while for the desorption process, a maximum value for desorption efficiency was obtained on 35°C temperature with a value of 73.39%.

1. Introduction

Fuel Oil is the main form of fuel used by Indonesian people for transportation. Usage of Fuel Oil consumption in Indonesia increases because of the rapid growth of motor vehicle industry, around 5-6% annually [1]. Indonesia imports Fuel Oil in a huge amount, reaching 1.06 million tons or worth US\$ 1.13 billion [1]. Based on such issue, natural gas has a large potential to replace Fuel Oil as Indonesia possesses plentiful amount of natural gas reserve. Indonesia is the 14th highest country in the world for amount of natural gas reserve, with the reserve amounting to 103.3 trillion cubic feet [1].

The main issue in the usage of natural gas as fuel lies within the storage and distribution process, as under normal conditions natural gas is in the gas phase, storage capacity would become small and inefficient to be used. Currently, the method mainly used for natural gas storage is Compressed Natural Gas (CNG) and Liquefied Natural Gas (LNG). However, CNG technology requires very high pressure, which is > 250 bar. On the other hand, LNG technology requires extremely low temperature (- 161°C). Both of these technology have shortcomings in the technical and economic aspects. To overcome these issues, an innovation of natural gas storage is needed. Adsorbed Natural Gas (ANG) technology is a technique to store natural gas in a cylinder, through usage of activated carbon as adsorbent. This technology allows natural gas storage on a low pressure around 34 bar while still having high storage capacity [9].



Activated carbon as and adsorbent can be manufactured from the plastic waste polyethylene terephthalate (PET) for its abundance in Indonesia. The amount of polyethylene terephthalate waste generated each day reaches 26,500 tons [11]. Aside from statistics, activated carbon manufactured from PET possesses the highest surface area compared to PVC (polyvinyl chloride) and waste tires [9].

Unfortunately, ANG technology has not been applied much in motor vehicles although it has more advantages compared to CNG. One of the reasons for such cause is the adsorbent's capacity to adsorb natural gas. To improve the performance of ANG technology, PET-based activated carbon is used as adsorbent to find the optimum condition during adsorption process. Performance of ANG is attributed to several factors, which are the temperature and pressure of the operation. Keeping in mind such factors, in this study natural gas storage will be tested with ANG technology with variations being natural gas pressure and storage temperature to generate data of natural gas storage capacity inside ANG cylinders. Activated carbon will be made of polyethylene terephthalate from previous study.

2. Experimental

2.1. Equipment scheme and research flowchart

To examine the adsorption of methane gas in adsorbed natural gas (ANG) cylinder, the first step required is degassing. An amount of activated carbon which is to be tested is put inside the ANG cylinder. Circulating thermal bath (CTB) is then operated to increase and maintain vessel temperature at 26°C. Pressure output regulator on the methane gas cylinder is set at 3000 KPa (30 bar). Methane gas is then supplied through computer control and the accumulation capacity recorded through coriolis. In this study, storage and flow capacity is recorded through the accumulation of gas in and out of coriolis with a unit of gram. Figure 1 shows the natural gas storage scheme with ANG technology.

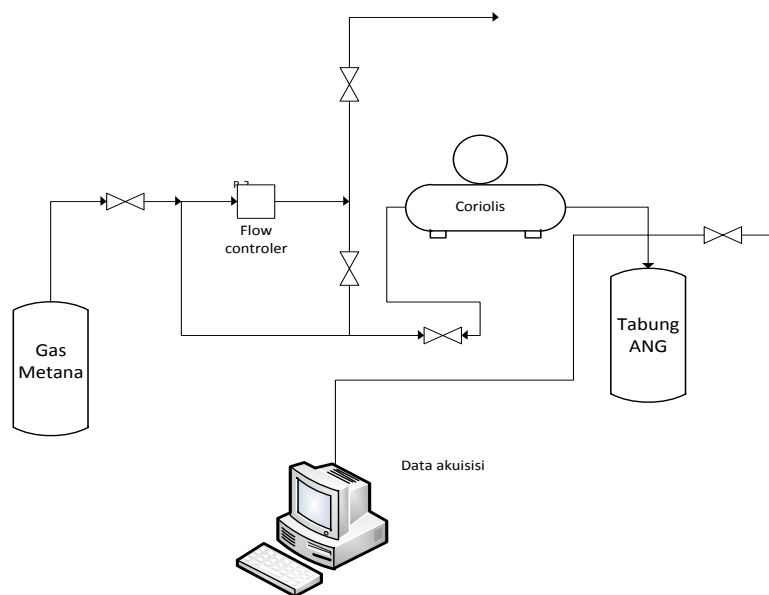


Figure 1. Schematic for storage process

2.2. Measurement of empty volume

Measurement of empty volume is conducted in order to find out the volume on measuring cell. The empty volume of the measuring cell is the total volume of empty space that existed on measuring cell.

$$V_{empty} = V_{MC} - V_{space \text{ filled with adsorbent}} + V_{adsorbent \text{ pores}} \quad (1)$$

Annotations:

V_{empty} = volume of empty measuring cell (m^3)

V_{MC} = volume of measuring cell filled with adsorbent (m^3)

This process begins with conditioning the charging cell at 30°C using circulating thermal bath. In the next step, helium gas is supplied to the charging cell by opening the valve until the desired pressure is achieved, while charging cell's initial condition is recorded. Helium gas is then streamed to measuring cell from charging cell until equilibrium is achieved, the time needed around 15 minutes. The charging and measuring cell's final condition is recorded as well. Data obtained during the procedure will then processed to obtain the value for empty volume.

2.3. Adsorption test

Study for isothermal adsorption is conducted with volumetric method. The basis for volumetric measurement is pressure, volume, and temperature in which data is recorded when adsorbate enters the chamber where adsorbent is present. After adsorption equilibrium is reached, the amount of adsorbate adsorbed is measured from the change in pressure using ideal gas equation. Mass balance for adsorbate vapor inside the charging and measuring cell can be assumed as follows [11]:

$$m_{d,mc} = |m_{cc}| - m_{ads} \quad (2)$$

Annotations:

$m_{d,mc}$ = mass of adsorbate in *measuring cell* (kg)

$|m_{cc}|$ = mass of adsorbate in *charging cell* which moved to *measuring cell* (kg)

m_{ads} = mass of adsorbate adsorbed by adsorbent (kg)

Where p_{cc} and p_{mc} are the density for adsorbate at a temperature and pressure inside charging cell and measuring cell. The value of p_{cc} and p_{mc} can be obtained by utilizing the software REFPROP.

3. Results and Discussions

3.1. Activated carbon

In this study, PET-based activated carbon is obtained from previous research [13]. The result for PET-based activated carbon characterization can be seen on Table 1.

Table 1. Characterisation of activated carbon

Characteristic	Value
Surface Area, Iod Value (m^2/g)	1591.72
Pores Volume (cc/g)	0.176
Micropores Volume (cc/g)	0.136
Pore Diameter (\AA)	15.2
Mesh Size	10

3.2. Natural gas composition

Adsorbate used to examine ANG is natural gas bought from Stasiun Pengisian Bahan Bakar Gas (SPBG) Pertamina. Results for natural gas composition characterization is obtained through gas chromatography seen on Table 2.

Table 2. Natural gas composition

No	Name	%
1	CH ₄	87.762
2	N ₂	4.698
3	C ₂ H ₆	3.781
4	CO ₂	2.260
5	C ₃ H ₈	1.278
6	C ₄ H ₁₀	0.222
	Total	100.0

3.3. Measurement of empty volume

In this study, measurement of empty volume on measuring cell is conducted, which is empty space on measuring cell cylinder which has been filled with activated carbon. 5 g of activated carbon is used. Examination of empty volume is needed as it is one of the parameters to measure adsorption capacity. Measurement of empty volume done three times, the results are averaged to obtain an accurate value for empty volume. From the data, it is seen that the average value for empty volume is 274.5 cm³, which means in the measuring cell cylinder there is 274.5 cm³ empty space, including the pores of activated carbon inside the cylinder. The results of the measurement can be seen from Table 3.

Table 3. Measurement of empty volume

Trial		Pressure (kPa)	Temperature (°C)	Z	n	ni	V empty (cm ³)
1	Initial pcc	724.5	29.5	1.0033	346.9	65.2	
	Final pcc	589.1	30.0	1.0027	281.7		274.9
	ρ mc	584.1	30.1	1.0027			
2	Initial pcc	750.6	30.0	1.0026	359.1	67.2	
	Final pcc	610.4	30.0	1.0027	291.9		273.9
	ρ mc	605.4	30.0	1.0026			
3	Initial pcc	712.1	29.0	1.0033	341.6	64.2	
	Final pcc	579.9	30.1	1.0027	277.3		275.2
	ρ mc	575.0	30.1	1.0026			
Average							274.5

3.4. Adsorption test

Adsorption test is done with variations to pressure and temperature. 5 g of activated carbon is also used on this test. The data obtained is storage capacity, obtained in natural gas weight (kg) adsorbed per activated carbon weight (kg) used. The following graph shows amount of gas adsorbed vs. pressure for PET-based activated carbon.

From Figure 2, it can be inferred as pressure increases, adsorption capacity for the natural gas also increases. This indicates that the adsorption that happens on activated carbon is a physical adsorption. On the graph, the maximum point for adsorption value happens at 35 bar pressure for a value of 0.0586 kg/kg.

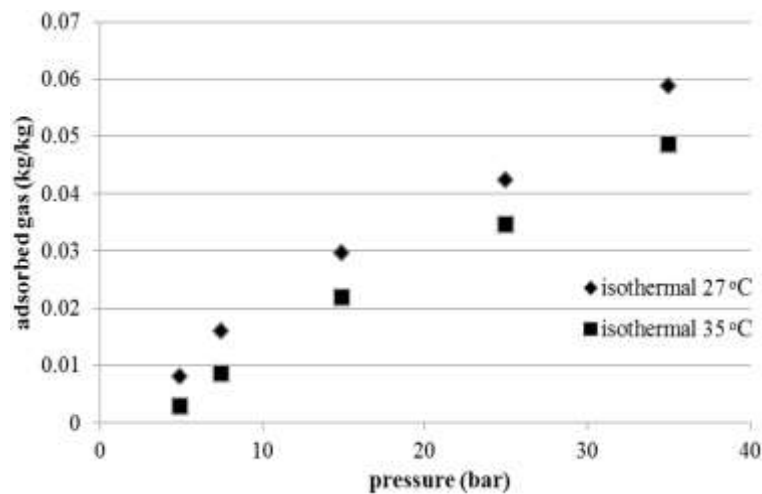


Figure 2. Change in adsorption capacity against pressure and temperature

3.5. Desorption capacity

Desorption capacity of an adsorbent is the ability of an adsorbent to release adsorbed adsorbate [4]. Desorption capacity is important as it indicates the amount of gas that could be released from the ANG cylinder. Percent efficiency here mirror the adsorbent's capacity to desorb adsorbed natural gas. Figure 3 shows, as temperature increases so is the efficiency of desorption. This happens because desorption is an endothermic process, desorption will increase if temperature is increased.

Figure 3 also shows that not all stored natural gas can be desorbed. In adsorbed natural gas (ANG) system, storage capacity is always higher than delivering capacity (desorption). Usually, storage capacity is 15 – 30% higher than delivering capacity [6]. The remaining amount of gas left inside the cylinder will depend on the type of activated carbon used, the bigger the micropores on the adsorbent, the higher the amount of remaining gas left [10]. In this study, desorption efficiency is found to increase with temperature, at 35°C giving an efficiency of 73.39%. The remaining efficiency data obtained is also in an excellent range between 70% - 85% [6].

Not all gas can be delivered, some are stuck. The mass of the stuck methane gas is caused because the adsorbate adsorbed to the adsorbent on ANG has a tendency to stay adsorbed to the adsorbent. To remove all adsorbate adsorbed off the adsorbent, an additional amount of energy is needed through heating in a high temperature.

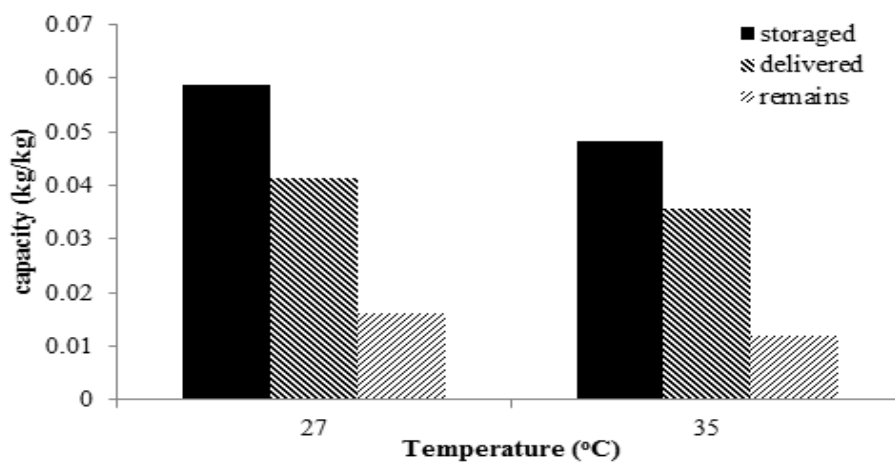


Figure 3. Effect of temperature to natural gas desorption capacity

4. Conclusions

From this study of Enhancement of Natural Gas Storage Through Usage of Activates Carbon Made from Plastic Waste Polyethylene Terephthalate, several conclusions can be made. As temperature increases, adsorption capacity will lower as adsorption is an exothermic process. As pressure increases, adsorption capacity will also rises as the amount of gas in contact with activated carbon's surface area increases. Highest adsorption capacity is reached at 27°C temperature and 35 bar pressure, with a value of 0.0586 kg/kg. As temperature increases, desorption efficiency will increases as well where at 35°C the efficiency has a value of 73.39%.

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