Enhanced Discharge of ANG storage for vehicle use

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Abstract:

Discharging the ANG storage tank from 3.5 MPa to a depletion pressure results in temperature fall within the ANG vessel. The fall of storage pressure was from a rapid to slow rate along with constant rate of gas removal while the temperature was falling drastically with depressurization as a result of heat of desorption and partly due to pressure drop. In the present study the characteristics of ANG storage system during discharge has been studied. When gas was discharged at discharge rate 1, 5, 10 l/min, a much drop in bed temperature occurred. Bed Preheating was investigated as a solution to enhance the discharge process and to avoid much amount of gas retained (not desorbed). Improvement in the amount desorbed and capacity was recorded as a result.

Key words: ANG; adsorptive natural gas, CNG; compressed natural gas, NGV; natural gas vehicle

1. Introduction:

When a natural gas storage vessel is charged with a suitable adsorbent material, the energy density will be greater than that of the same vessel without the adsorbent when filled to the same pressure [1,2]. Employing the porous adsorbents, ANG at low pressure (3.5-5.0MPa) can reach almost the same energy density of CNG at high pressure (20MPa) [3,4].

Theoretically, the amount of natural gas stored of ANG at 3.5MPa is near 210v/v [5,6], actually at one sixth the pressure, it stores about two thirds the amount of CNG at 20MPa in the current level [7]. Because of relatively low pressure, ANG has some obvious advantages in weight of storage vessel, shape of the vessel, safety, and cost .

Elevated temperature during charge cycle and temperature drop during discharge cycle eliminate the enhancement of ANG storage capacity. J.P.B.Mota has studied thermal energy supply to the storage tank to enhance the discharge capacity. He employed theoretically a jacketed tank [10] .

Big thickness of the high pressure storage vessel decreased the efficiency of the jacket to provide thermal energy to the tank.

In this study, thermal energy was provided to the inside of the tank employing helical tube, which was immersed in the adsorption bed. That way affected positively to enhance the heat transfer within the storage tank and improvement in the characteristics of the discharging was recorded.

1.1 ANG Storage capacity:

Compared to the conventional CNG storage, the ANG storage stored 2/3 (67%) of the amount that could be stored with a vessel without adsorbent but at 1/6 of its pressure [8]. This is illustrated in Figure 1 [9], shows the capacity of methane (g/l) stored in an empty cylinder and the capacity stored in an adsorbent-filled cylinder with an increase in pressure. It is obvious that ANG storage is capable to store more gas at lower pressure than CNG storage. Subsequently, this will allow more gas to be stored at lower pressure because the ANG vessel can be charged or pressurized with more gas, as the pressure is still low.

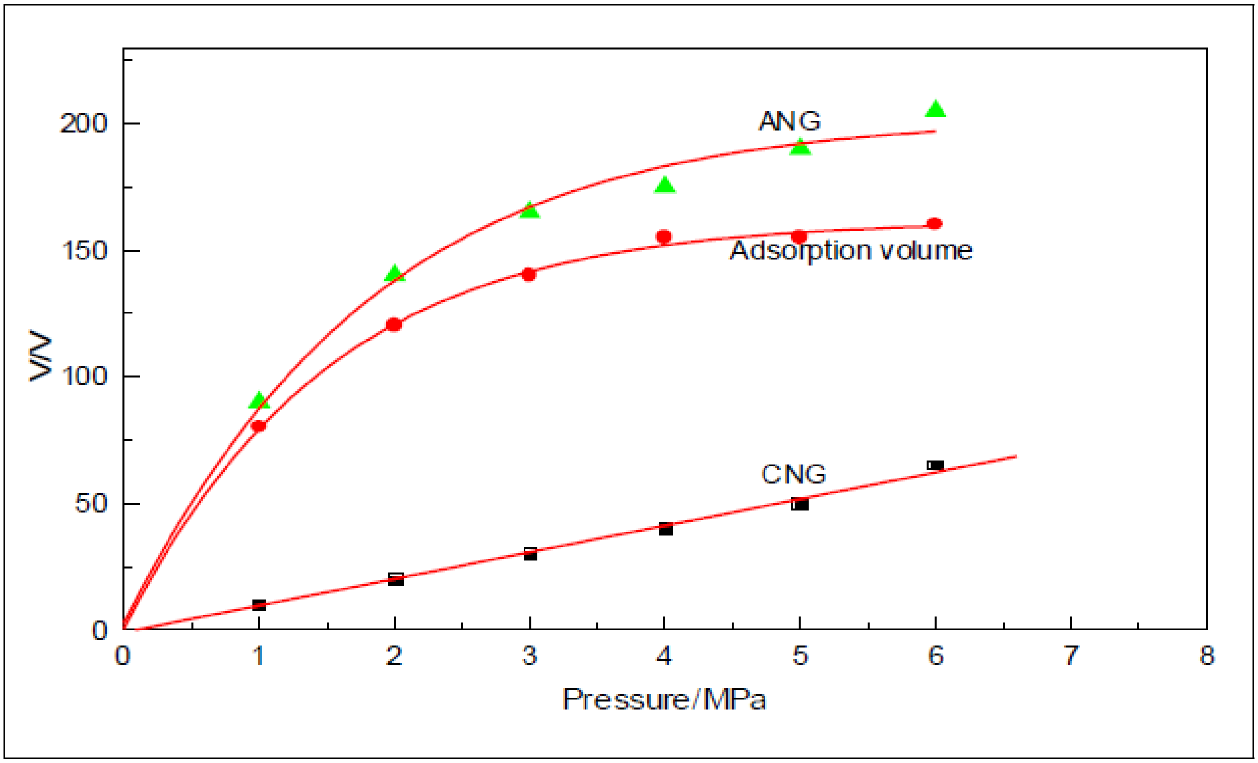

Figure 1: ANG capacity and CNG capacity [9]

1.2 ANG Principle and Characteristics

The characteristics of ANG projects are summerized in Table 1. Theoretically, the amount of natural gas stored of ANG at 3.5MPa is near 210v/v [10], actually at one sixth the pressure, it stores about two thirds the amount of CNG at 20MPa in the current level [11,12]. Because of relatively low pressure, ANG has some obvious advantages in weight of storage vessel, shape of the vessel, safety, and cost.

Since adsorption of natural gas on adsorbent follows pore filling mechanisms, therefore the adsorption are dependent on the pore shape and are influenced by the properties of the adsorptive and by the adsorbent-adsorbate interactions [13]. The whole of the accessible volume present in micropores may be regarded as adsorption space. The properties of an adsorbent that is suitable for natural gas storage can be summarized in the following four points. The material should have:

(1) a high adsorption capacity;
(2) a high packing density;
(3) a high adsorption/desorption rates; and
(4) a ratio between the amount desorbed at depletion and the amount adsorbed at 3.5 MPa, as close as possible to 1 [14].

Table 1: Comparative characteristics of some ANG projects

PARAMETERS AND CONDITIONS	AGLARG (Atlanta Gas Light Adsorbent Research Group)	EU FP5 LEVINGS program (coordination by FIAT)	OAK RIDGE NATION. LABO-RATORY (ORNL)	HONDA MOTORS	UNIVERSITY OF PETROLEUM CHINA (UPC)		Brazilian Gas Technology Center (CTGÁS)
Years	1990-1999	1997-2000	? -2000	From 2000	1994-95		From 2000
Investigation method	Chrysler B-van, Dodge Dakota Truck	FIAT Marea, On-board, field testing	Laboratory Investiga-tions	Tank development Adsorbent - laboratory tests	Car XIALI 713IU On-board, field testing		Laboratory investigation on full-size prototype
Pressure, bar	35-40	35-40	35	35	50	125	35-40
Tank uptake V/V	150 in laboratory condition, 142 on-board	123	150	155	100-110	170-180	130-150
Tank delivery V/V (to engine)	135 (approx)	107	Not relevant	-	Un-known	Un-known	Unknown
Adsorbent presumed cost	Prohibitive	High, but about 10 times less than the AGLARG	Supposedly very high	Supposedly similar to AGLARG	Un-known	Un-known	Unknown
Vessel (tank) design features	Multicell of extruded aluminum	Multicell of steel tubes	Small laboratory vessel of volume 0,05 L.	Multicell	Un-known	Un-known	Cylindrical form with volume 30 liters

1.3 Adsorbent Material:

1.3.1 Performance of Adsorbents:

Adsorbent that is useful to adsorb the natural gas in ANG storage is a substance that having a molecular structure that will allow methane (dominant component in natural gas) molecules to penetrate its surface area and be kept inside the pores between its molecules, in which pore filling adsorption mechanism takes place. The pore sizes in the adsorbent solid must be of a suitable size to admit, hold, and discharge individual gas molecules. If the pores are too small, the gas cannot be admitted. If they are too large, too many molecules of gas are admitted, and they display the characteristics of gas under pressure: frenzied movement, and constant molecular collisions [15,16].

Many studies on ANG storage are focusing on development and evaluation upon adsorbent with storage capacity (Table 2) comparable to the CNG storage capacity, if not exceed. The other types of potential adsorbent rarely employed for ANG storage are molecular sieve zeolites and hydrophobic silica xerogel [17].

According to the research made by the Atlanta Gas Light Adsorbent Research Group (ARLARG) (1997), the best performing materials developed thus far are derived from organic materials including coconut shells and peach pits.

These materials have a naturally occurring pore structure that can be optimized for the adsorption of the methane in natural gas. The method of densifying or compacting the adsorbent is also critical to achieving acceptable performance. Proprietary densification techniques were developed during the course of the research to form solid carbon monoliths and briquettes that match the profile of the tank for easy insertion.

Table 2 : Adsorptive properties of commonly used adsorbents (Spang, 1997)

Material	Bulk Density (kg/m^3)	Specific Surface Area (m^2/g)	Specific Heat Capacity (kJ/kg.K)	Desorption Temperature range (°C)
Activated carbon	300 - 500	600 - 1500	0.84	100 - 150
Silica gel	400 - 800	600 - 800	0.92	120 - 250
Activated aluminas	700 - 850	100 - 400	0.85 - 1.05	150 - 320
Molecular sieves	600 - 900	500 - 1000	0.95 - 1.05	200 - 300
Polymer resins	300 - 320	550 - 800	0.35	80 - 140

2. Experimental Work:

Schematic diagram of the experimental setup is given in Figure 2. The experimental setup consists of the main components, adsorption-Desorption Cell; where the adsorption and desorption processes takes place. Pressurized Hot Air Vessel; provides high temperature, pressure air when preheating of the adsorbent bed was required. Conditioning Chamber; provides constant surrounding temperature to the adsorption cell. Gas Detection Equipment (manufactured by GMI).

Data Logger (manufactured by "FLUKE" model 2625), its function it to register the temperature history of different channels.

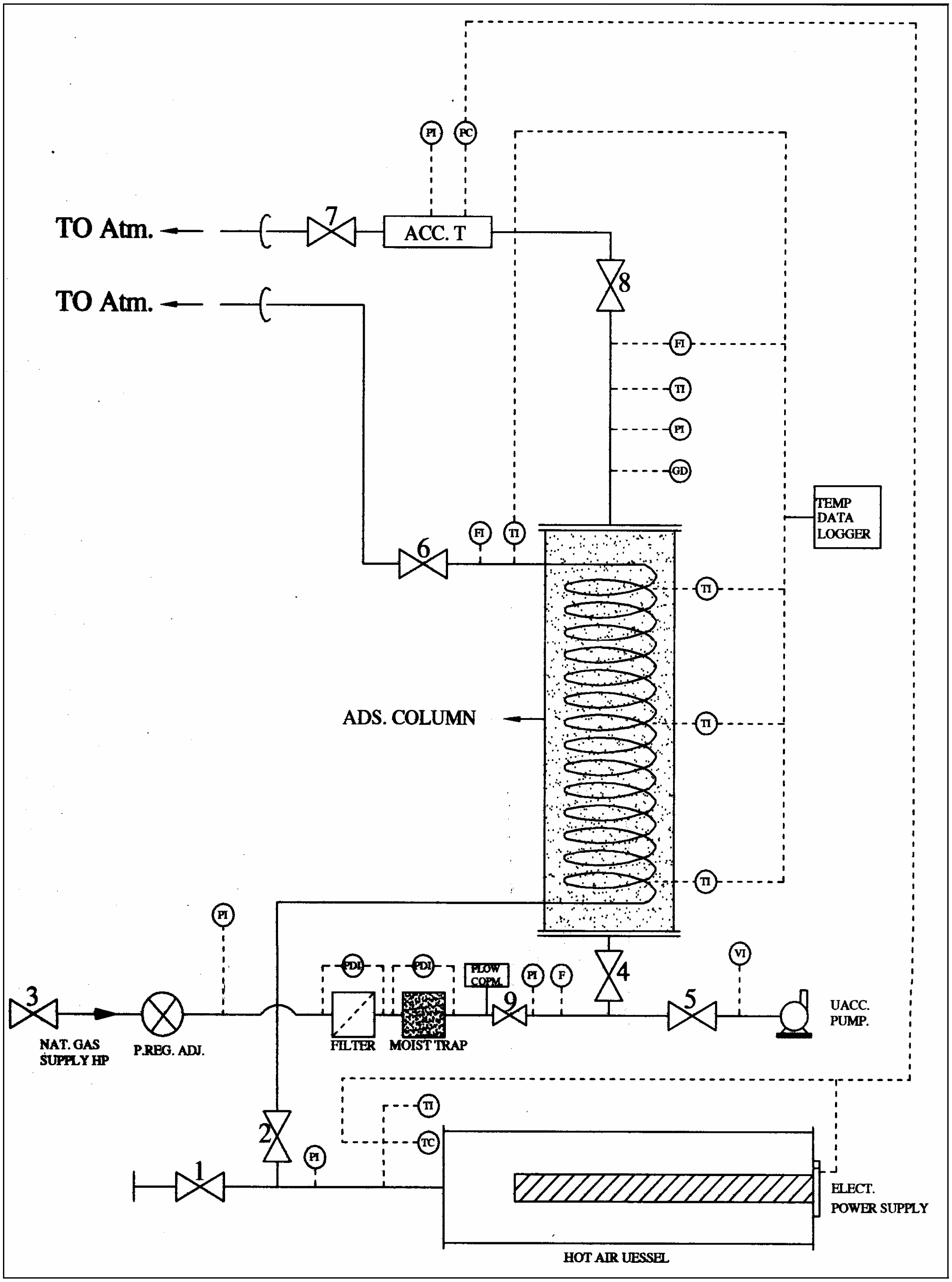

Figure 2: Schematic diagram of the experimental setup

3. Materials:

3.1 Activated Carbon:

It is used as a bed in the adsorption cell with the following specification:

Manufacturer: Starchem
Particle shape: granular
Mesh Size: 2.36 x 0.50 (mm)
Apparent Density (AD): 360g / liter
Apparent density: 0.42 - 0.52 g/cc
Ash content: < 3%

3.2 Natural Gas:

The composition of the natural gas used in this study is summarized in table 3.

Table 3: Component Gases in the Fuel Used in the Tests

	Component	Mol %
1	CH_4	92.4
2	CO_2	0.92
3	N_2	0.166
4	Heavy hydrocarbons	6.5

4. Results and Discussion:

4.1 Thermal behavior of the adsorbent at dynamic conditions (without preheating):

Examination of the plot at Figure 4 indicates that the rate and the extent of temperature drop were greater for faster discharge than for slower discharge. During discharge at flow rate of 1.0 l/min, bed temperature drops from 35°C to the minimum value of –10 °C in 16 minutes. While at moderate discharging rate of 5.0 l/min, temperature drops from 35°C to the minimum –36 °C in 9 minutes. When discharging at 10.0 l/min, which depicted a fast rate, a temperature fall of 78°C (from 35°C to the minimum of –48 °C) takes place in 4.5 minutes. As the ambient is the only source of heat, natural convection heat transfer occurs between the storage tank and the ambient. The amount of heat supplied to the tank through natural convection is very small to eliminate the drop in temperature.

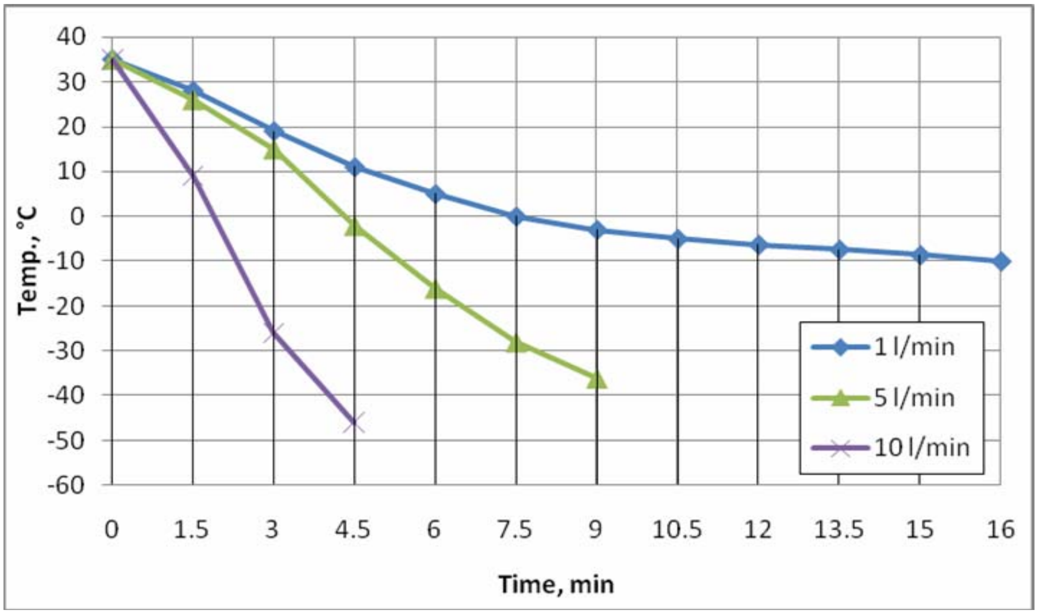

Fig. 4: The temperature drop during dynamic discharge (without preheating)

4.2 Thermal behavior of the adsorbent at dynamic conditions (with preheating):

Examination of the plot at Figure 5 indicates that during discharge at flow rate of 1.0 l/min, bed temperature drops from 160°C to the minimum value of 85 °C in 20 minutes. While at moderate discharging rate of 5.0 l/min, temperature drops from 160°C to the minimum 65 °C in 10 minutes. When discharging at 10.0 l/min, which depicted a fast rate, a temperature fall of 125°C (from 160°C to the minimum of 35 °C) takes place in 6 minutes.

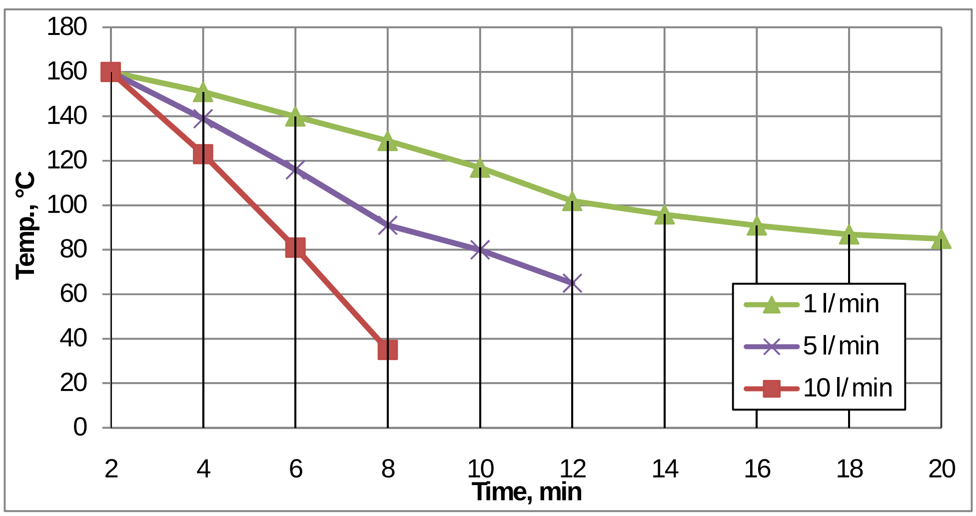

Fig. 5: The temperature drop during isothermal discharge (with preheating)

The heat is supplied to the inside of the tank through helical tube, which was immersed in the adsorption bed. That way affected positively to enhance the heat transfer within the storage.

Although the drop extent is higher when compared to the (no preheating) system, but the preheating step achieved the advantage of avoid the deep freeze temperature which affected positively on the amount of natural gas retained in the tank after depletion and enhancement of the discharge capacity.

When additional amount of heat was pre-supplied to the adsorbent results in the rate of temperature drop became slower than in the dynamic discharge. Which indicate to more stability in the desorption rate was achieved.

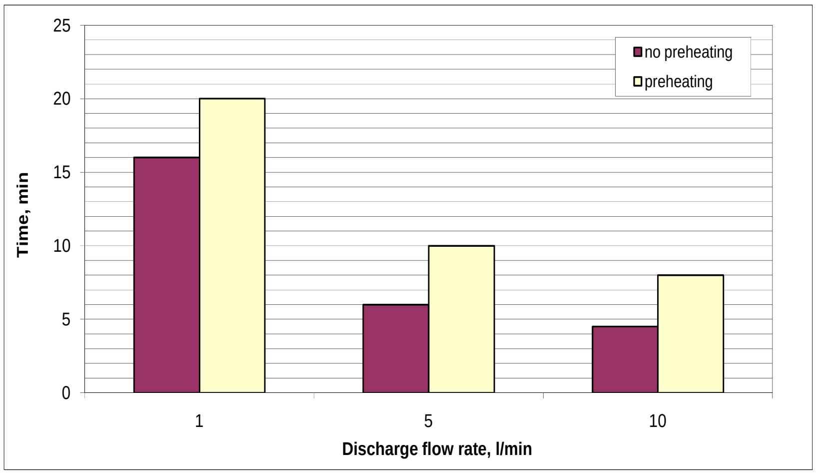

Fig. 6: Discharge Time at preheating and no-preheating Conditions

When the discharge time at dynamic conditions be compared to that at isothermal conditions, figure 6, an increase in the discharge time was recorded, which indicate to an additional amount of gas was delivered within the same discharge flow rate. By that way, the remaining amount of gas decreased.

5. CONCLUSION:

1. In terms of fuel economy, the ANG system had a better performance during dynamic discharge employing preheating.
2. The results showed that the storage capacity obtained under preheating conditions is higher than under dynamic conditions without preheating, due to extract additional amount of retained gas, which added and attractive economic value from the commercial viable solution point of view.

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