ANALYSIS OF CUMULATIVE LIQUID CONTAMINANT CONTENT ACCUMULATED IN CNG TANK

by

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ABSTRACT

The utilization of natural gas as vehicles' fuel (BBG) is now being developed in Indonesia for either private cars or public cars. The reasons of using BBG are (1) the price of BBG is lower than fuel oil (BBM), (2) the cost of BBG's cars maintenance is lower than BBM's cars maintenance, (3) BBG is an environmentally friendly fuel. Moreover, BBG's infrastructure has been built in some big cities.

However, the main problem occurred is the formation of cumulative liquid in CNG's tank in a certain period of time that may cause the following problems:

a. The decrease of BBG's tank capacity that may result in reducing the capability of vehicles for covering a distance and increasing BBG's filling time.

b. The presence of liquid in BBG's tank will disturb gas supply system from BBG's tank to combustion chamber that may have further effect on engine performance disturbance.

c. The presence of liquid in BBG's tank will also cause internal corrosion. This may hazard the people as the gas pressure in BBG's tank is around 200 bar.

From laboratory analysis, it can be identified that cumulative liquid formed is resulted from gas condensation process due to pressure and temperature changes, and from lubricant carryover of gas compressor in filling station.

I. INTRODUCTION

In order to support the Government Policy on Energy Diversification and reduce the consumption of BBM, BBG is an alternative fuel for vehicles that may be mostly interested in. This may be because the price of BBG and the maintenance cost of BBG's cars are lower than BBM. Moreover, gas emission produced from BBG's cars is relatively clean.

Nevertheless, there is a problem related to liquid accumulated in BBG tank in a certain period of time. The presence of liquid contaminant may cause several problems, such as decreasing BBG's tank capacity that may reduce the capability of vehicles for covering a distance, and disturbing engine performance (such as power losses and the engine stop). Liquid contaminant will interrupt gas flow system from BBG's tank to combustion chamber.

From a laboratory analysis, it can be identified that this liquid contaminant is produced from gas condensation and lubricant carryover of gas compressor. Therefore, this paper will discuss liquid contaminant sources, its effects on engine performance, and the solution of its negative effects.

II. THE CONNECTION BETWEEN BBG'S QUALITY AND PHASE TREATMENT

To recognize when liquid contaminant is formed, it is necessary to discuss the relationship between the quality of BBG and a phase treatment. Liquid contaminant collected in BBG's tank in a certain period of time is identified from gas condensation due to pressure and temperature changes. In order to recognize when liquid contaminant is formed, it is important to look at the result of gas simulation produced from HYSYM's software. As an example, it has been analyzed the composition of BBG that has been collected from filling station (SPBG) at Jalan Margonda Raya, as described in Table 1.

From Figure 1 and 2, it can be seen that the gas, that enters the SPBG (the BBG station) system at pressure 6 bar and the temperature 20°C, is still in the form of gas. When the pressure of the gas rises to 250 bar (3,675 psia), the condition of BBG is still in the form of gas. The gas is compressed from 6 bar to 250 bar (3,675 psia) through three stages. First stage, the gas is compressed from 6 bar, 20°C to 24 bar 125°C then from 23 bar 30 °C to 76 bar 123.°C in the second stage. Third stage, the gas is finally compressed from 74 bar 30.°C to 250 bar 130°C

Table 1
Laboratory analysis of BBG's composition from SPBG at Jl. Margonda Raya-Depok

Composition	Before compressor % mole	After compressor % mole
CO_2	5,546	5,085
N_2	0,461	6,512
CH_4	89,100	81,571
C_2H_6	2,338	2,135
C_3H_8	1,562	1,530
nC_4H_{10}	0,177	0,238
iC_4H_{10}	0,331	0,392
nC_5H_{12}	0,054	0,134
iC_5H_{12}	0,143	0,290
nC_6H_{14}	0,176	0,601
C_7H_{16}	0,071	0,746
C_8H_{18}	0,031	0,486
C_9H_{20}	0,007	0,153
$C_{10}H_{22}$	0,003	0,100
$C_{11}H_{24}$	0,000	0,027
Total	**100,00**	**100,00**

and gas in BBG tank 200 bar 15°C. In this condition, BBG is in the form of gas.

It also can be seen that the critical temperature is occured at temperature 40°C. At the pressure 400 psia and temperature 40°C, condensation of the gas will begin to occur. When the volume of the gas in BBG tank reduced, it will be followed by decreasing pressure and temperature. If the gas condition enters two phase zones, BBG in the tank will condense to form liquid and gas phases.

III. LUBRICANT CARRY OVER OF GAS COMPRESSOR THAT ENTERS BBG'S STORAGE TANK

Gas compressor is very important for compressing the gas from 6 bar to 250 bar in the SPBG system. However, it needs consideration in the maintenance of the compressor as some aspects such as a lubricant system, reciprocating movement of the piston to cylinder block may cause worn out and increase the temperature of the cylinder. To solve these problems, it is necessary to install a compressor cylinder lubricant system.

The laboratory analysis of liquid content in BBG's tank has shown that there are lubricant flakes, which flow with the gas, then enter BBG's storage tank and finally

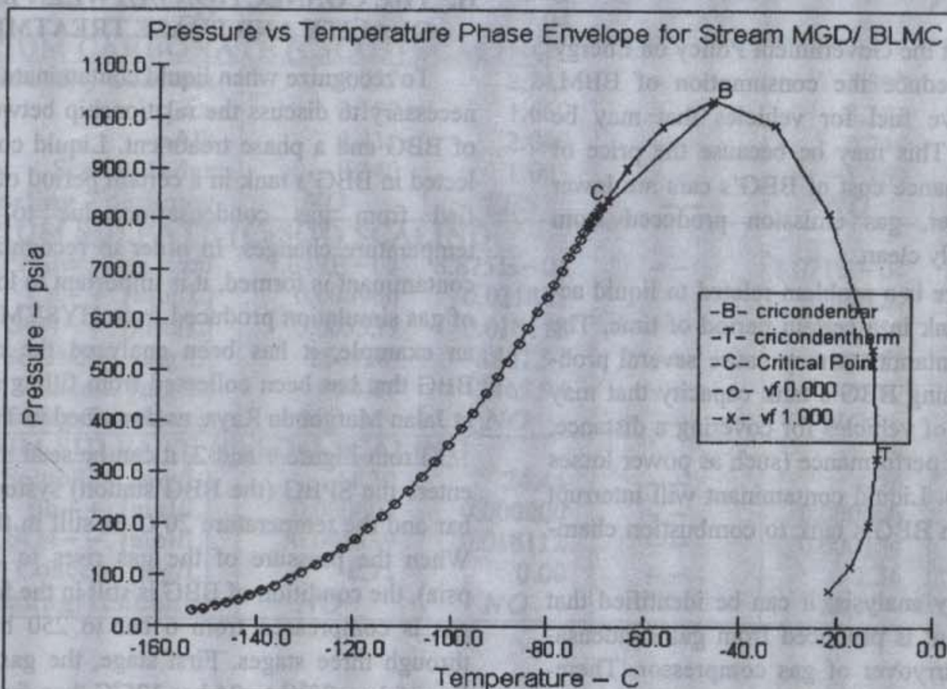

Figure 1
Diagram of phase envelope of BBG before compressor suction

go to BBG's tank . The main factor of lubricant carryover of gas compressor is broken seals of suction and discharge rings of the compressor. This is proven by the laboratory test by using infra red, as shown in Table 2.

From Table 2, it can be seen that liquid contaminant in BBG's tank will be diffused with lubricant type of Corena as absorpsivity value (a) of Corena is closed to the sample of liquid contaminant in the BBG's tank.

IV. BBG's PERFORMANCE IN BBG'S TANK

When the pressure of BBG in the tank is around 200 bar, all space of BBG's tank will be fully contained with the gas. However, by decreasing the pressure due to the

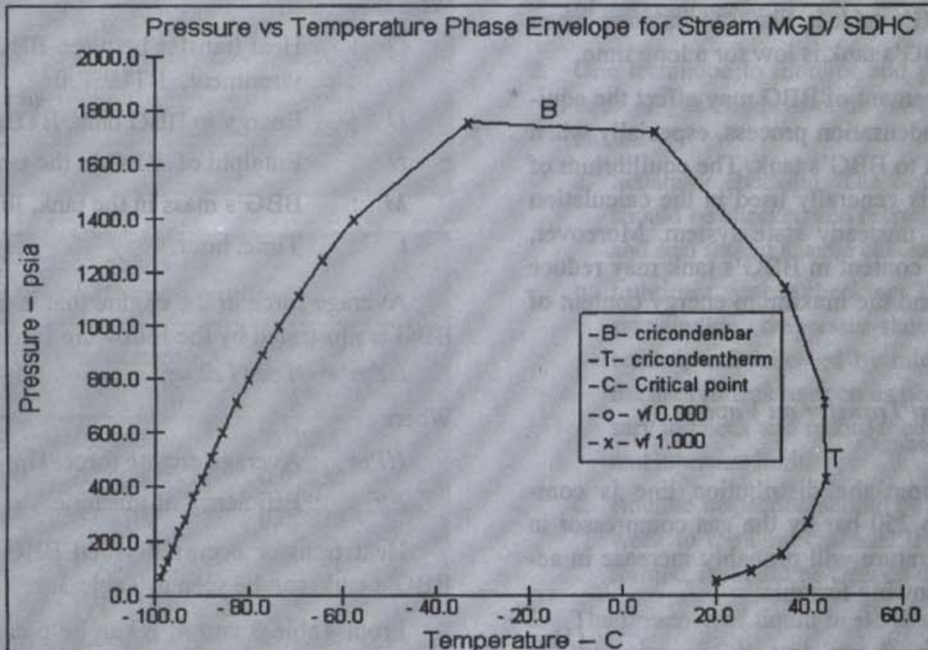

Figure 2
Diagram of phase envelope of BBG before compressor discharge

Table 2
Laboratory test of liquid contaminant in BBG's tank by using infra red

No.	Ratio	Mysella mobile	Corena P 150	Turalik 69	BBG's sample
1.	720 / 1375	0,380	0,310	0,333	0,374
2.	1600 / 1375	0,050	0,137	0,201	0,099
3.	1600 / 720	0,132	0,445	0,133	0,266
4.	810 / 1375	0,059	0,054	0,175	0,057
5.	810 / 720	0,155	0,174	0,122	0,153
6.	Absorpsivity value (a)	0,480	0,460	0,280	0,430

use of P = 400 Psig, T = 40 °C, it begins to occur condensation of process of light hydrocarbon of BBG. If the pressure continues decreasing to the critical condition, the water content of BBG will be separated from BBG.

From the calculation of BBG composition, it can be predicted that the water content of BBG is about 7 ppm per MSCF. At the gas pressure of 200 bar, water molecule is undetectable since at a high pressure the water will be diffused with the gas. Moreover, the effect of cohesion force among water molecules may accelerate a tendency to the formation of water/gas zone transition. Water content of BBG's tank is likely to increase when the gas pressure in BBG's tank is low for a long time.

Minimum water content of BBG may affect the equilibrium of BBG's condensation process, especially when BBG is being injected to BBG's tank. The equilibrium of BBG in BBG's tank is generally used in the calculation of energy balance of unsteady state system. Moreover, the presence of water content in BBG's tank may reduce the volume of BBG and the maximum energy content of BBG's tank.

A. *The Effect of Heat Transfer on Vapour Condensation Process*

When the gas from the distribution line is compressed from 6 bar to 250 bar by the gas compressor in SPBG, the gas temperature will probably increase in accordance with the following formula:

$$HP = sk_1 (sk_{2-1}) \quad (1)$$

$$sk_1 = (3{,}027 \text{ k Pb. } T_1 / \text{Tb } (k-1) \quad (2)$$

$$sk_2' = \frac{P_2}{P_1} Z^{(k-1)/k} \quad (3)$$

where:

- *HP* : Compressor Capacity (HP/MMSCFD)
- *Tb, Pb* : Basic Temperature and Pressure (60 °F, 14,7 psia)
- *T1* : Suction Temperature (°R)
- *P1* : Suction Pressure (Psia).

Discharge temperature can be predicted by the following formula :

$$T_2 = T_1 sk_2 \quad (4)$$

Where the value of *k* can be approached by the following formula:

$$k = (2{,}738 - \log (SG))/2{,}328 \quad (5)$$

From these formula it may be predicted that at the gas pressure of 200 bar and temperature of 42,37°C, BBG is still in the form of gas as illustrated in BBG's Phase Envelope Diagram.

The decrease of temperature from discharge to BBG's tank can be predicted by the formula of heat transfer, which is produced from the energy equilibrium concept for an open system with semi-steady state flow, as follows:

$$d = \frac{M.U}{dt} = Q + H \frac{dM}{dt} \quad (6)$$

Where:

- Q : Heat transfer between BBG tank and its environment, BTU/°F.ft^2
- U : Energy in BBG tank, BTU/lb
- H : Entalphi of BBG in the tank, BTU/lb
- M : BBG's mass in the tank, lb
- t : Time, hour.

Average force in the engine that is used for taking up BBG is illustrated by the following formula :

$$HPm = H.dM / dt. \, eff \quad (7)$$

Where :

- *HPm* : Average engine force, Hp
- *Eff* : Efficiency of machine

Heat transfer occurred when BBG is flowing from BBG's tank, can be seen in Table 3.

From Table 3 and 4, it can be predicted that the vapour in BBG's tank is formed due to the temperature drop followed by heat transfer from the compressor discharge to BBG's tank. However, if the pressure drop of BBG is not followed by heat transfer, the condensation of vapour may be avoided.

V. THE PROBLEMS AFFECTED BY CONTAMINANTS THAT ENTER GAS SUPPLY SYSTEM IN THE VEHICLES

The presence of contaminants in gas supply system in the vehicles may disturb the performance of BBG's vehicles such as a car is not running well and stalled. This is because of the presence of liquid contaminant that hampers gas supply system to the combustion chamber. It also affects air/fuel ratio that may result in imperfect condition. Therefore, it is necessary to install a kind of filter before and after the gas compressor and before entering combustion chamber in the vehicles in order to make the gas cleaner from other impurities component when entering the engine.

Table 3
Operational condition of BBG

Pressure (psig)	Temperature (°F)	Pressure (psig)	Temperature (°F)
2393,2	80	1765,7	43,0
2317,0	76	1703,7	38,8
2242,4	72	1643,2	34,4
2169,5	68	1584,0	30,0
2098,3	63,9	1526,3	25,6
2028,7	59,8	1469,9	21,2
1960,6	55,7	1414,9	16,6
1894,1	51,5	1361,2	12,1
1829,2	47,3	1308,8	75,5

Table 4
The effect of vapour content

Pressure (bar)	Temperature (°C)	Vapour (g/l) at temperature 30 °C
1,0	0,00469	0,0364
2,0	0,00237	0,01830
4,0	0,00120	0,00925
7,0	0,00071	0,00537
11,0	0,00047	0,00349
16,0	0,00033	0,00246
22,0	0,00025	0,00184
29,0	0,00020	0,00144
37,0	0,00017	0,00117
46,0	0,00014	0,00098
56,0	0,00013	0,00084
67,0	0,00011	0,00073
79,0	0,00010	0,00065
92,0	0,00009	0,00059
106,0	0,00009	0,00054
121,0	0,00008	0,00049
137,0	0,00008	0,00046
154,0	0,00007	0,00043
172,0	0,00007	0,00040
191,0	0,00007	0,00038
211,0	0,00006	0,00037
232,0	0,00006	0,00035
254,0	0,00006	0,00034

This filter should be changed in a certain period of time to make filter effectively and optimally. Generally, the filter will be changed when the engine power is not in normal condition.

VI. CONCLUSION

1. The presence of liquid in BBG's tank often causes some problems to the vehicles. There are two dominant factors that may form liquid in BBG's tank i.e. gas composition with a high water content and lubricant carryover of gas compressor.

2. One technique to monitor and protect lubricant carryover of gas compressor is routine inspection that includes:
   a. Separator checking. The liquid level and pressure should be checked and recorded periodically. Fitting and seal should also be checked.
   b. Lubricant system checking. The leak of lubricant in surrounding compressor should be checked and recorded, and followed by minimizing and repairing the area of leak as soon as possible. It is also necessary to check and record the information of pressure and lubricant limit.
   c. Routine inspection should be done minimum once a week to the base cascade. If the liquid has already formed, it should be cleaned directly.

3. The presence of liquid in BBG's tank will both reduce the volume of the tank and disturb the gas supply system to the combustion chamber as well as cause corrosion of BBG's tank. It should be considered as the pressure may be up to 200 bar. BBG's tank should therefore be checked routinely every 5 years to ensure that the tank is in a good condition.

4. To reduce liquid formation, it is suggested avoiding BBG's tank in a half volume or less condition for long time.

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