AN INDONESIAN EXPERIENCE, CONSUMERS' DEMAND FOR CNG COMPRESSION FACILITIES PERFORMANCE*

by

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ABSTRACT

Compressed Natural Gas (CNG) has been used to fuel vehicles in many countries, including in Indonesia. However, there are many difficulties to overcome in CNG public acceptance. In Indonesia, one of these may be CNG consumer's preference for certain CNG refueling stations over others. Finding causes of this may help increase acceptance of CNG by Indonesian motorists and enable CNG to make a better contribution to achieving the country's energy diversification policy.

It is hypothesized that the variation in intake pressures at CNG station to be a cause for preference by CNG consumers. This hypothesis is based on the variation in total energy of CNG delivered at the point of sale as a result of CNG compressor capacity.

It is found that, when the gas system pressure was less than CNG station inlet design pressure, the CNG produced in the fuel tank would not reach its design pressure. Consequently, its total energy per fuel tank and payback period of compression facilities investment was affected.

The analysis of CNG acceptance and a correlation with CNG station inlet design pressure and gas composition from the consumers' point of view will examine the following factors:

1. *The effect of various inlet pressures at CNG stations on the performance of existing CNG compressors and after-cooler.*
2. *The effect of CNG compressor discharge conditions and after-cooler performance on the total energy of CNG delivered to the fuel tank which in turn affects the heating value of the fuel to the vehicle engines.*
3. *Evaluation of CNG compressor discharge conditions effecting the payback period of CNG station investment and determination of potential significance to compression facilities acceptance.*

I. INTRODUCTION

Compressed Natural Gas (CNG) has been used to fuel vehicles in many countries, including in Indonesia. Recently, a pilot project has been completed to determine the feasibility of using CNG to fuel taxi cabs and of distributing CNG. However, there are still many difficulties in the public acceptance of CNG in Indonesia.

In a contribution to CNG utilization in Indonesia, a CNG vehicle road test has been conducted to evaluate its performance on the road. Moreover, CNG consumers (mainly taxi drivers) were interviewed, and it was found that they preferred to fuel their cars at certain CNG stations over the others. These preferences, in turn, lead to a concentration of CNG vehicles fueling at certain CNG stations and eventually will inhibit the advancement of CNG utilization programme in Indonesia.

It was felt that finding reasons for CNG consumers preferences would help to increase acceptance of CNG and enable CNG to make a better contribution to the Indonesian energy diversification policy. It was hypothesized that the variation in intake pressures at CNG stations could be a possible cause for CNG consumers preferences. This hypothesis was based on the variation

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in the total energy of CNG produced at the point of sale, as a result of CNG compressor capacity.

It was found that, the total energy of CNG produced per fuel tank was less when the gas system pressure was lower than the CNG station inlet design pressure,. This led to a reduction in sales and consequently resulted in a higher payback period for CNG station investment.

In this paper one of the difficulties in CNG utilization for Indonesia is identified, namely that CNG consumers prefer to fuel their cars at certain CNG stations. From the point of view of a CNG compressor consumer, this is due to existing CNG compressor performance in which less energy is delivered to a CNG consumer. If consumers demand for CNG compressor performance is fulfilled, public acceptance to CNG stations is likely to increase. This will ensure both CNG station investment and CNG consumer importance.

II. VARIATION OF CNG STATIONS LOCATION AND INLET PRESSURES

The gas supply for CNG stations in Indonesia is delivered by gas transmission lines. This gas has the calculated heating value of around 1022.47 BTU/SCF (38100 KJ/m^3). To form CNG, this gas is distributed to CNG stations by the gas distribution system .

To meet CNG consumers' needs, each CNG station has to be placed at locations which vary in distance from the gas line. This has led CNG stations to be connected at different points in the gas system which has resulted in a variation of intake pressures. For example, CNG Station-02 feeds gas from a medium pressure system (pressure range from 300 mBar to 4 Bar). It is located at about 6 m from main line with the average inlet pressure of 2.9 Bar. CNG Station-07 takes in gas from the transmission line (system pressure more than 16 Bar) at the distance of around 685 m and at average inlet pressure of 8 Bar. Other stations have been linked to high pressure system (pressure range from 4 Bar to 16 Bar). They are sited at locations between 25 m to 2100 m away from the gas line within average inlet pressure intervals from 3.9 Bar up to 5 Bar. The distances of CNG stations from gas line and the average inlet pressures are tabulated in Table 1.

Table 1
Typical CNG Stations Location and Inlet Pressure

CNG station	Distance from the gas line, m	Average Inlet Pressure, Bar
01	30.0	5.0
02	6.0	2.9
03	25.0	3.9
04	428.0	3.9
05	395.0	3.9
06	100.0	5.0
07	685.0	8.0
08	2100.0	3.9

It is known that the system pressure fluctuates in proportion to consumer charges. It goes down on peak days when more consumers use gas but it leaps if there are no consumers. These phenomena greatly influence the gas system pressure at CNG station inlet point, known as CNG station inlet pressure. They also instantaneously change if the system pressure alters.

III. CNG STATION INLET PRESSURE EFFECT ON ENERGY OF CNG PRODUCED

One of the main factors to be considered by a CNG compressor producer when designing a CNG compression facility is its suction pressure. This suction design pressure is merely CNG station inlet pressure. Therefore, the gas system pressure behaviour not only alters CNG station inlet pressure, but also controls CNG compressor output performance.

A typical CNG compressor with suction pressure is designed to operate between 2 Bar and 4 Bar pressure. The average CNG station inlet pressure is set for 2 Bar to 8 Bar. CNG compressor output performance is estimated in Table 2 and Figure 1.

Table 2 shows that for CNG station inlet pressure of around 2 or 3 Bar, which is lower than CNG compressor suction design pressure 4 Bar, the output pressure of the CNG compressor is about 100.4 or 152.2 Bar. This is lower than the fuel tank design pressure of 200 Bar. When CNG station inlet pressures are equal to, or greater than CNG compressor suction design pressure, the discharge pressure of the CNG compressor is the same as the fuel tank pressure. Moreover, an interpolation on Figure 1 at the abcis inlet point of 4 Bar, will get the ordinat point at the 204.7 Bar pressure. This indicates, for this typical CNG compressor, if CNG station inlet pressure is lower than the CNG compressor suction design pressure, the fuel tank will never reach 200 Bar pressure. This causes a decrease in the total energy of CNG contained in the fuel tank due to sensitivity characteristics of CNG to pressure and temperature.

The total energy of CNG per fuel tank produced at various CNG station inlet pressures can be predicted based on the calculated energy content of the feed gas, and using a real gas equation of state. The results are shown in Table 3 and in Figure 2.

Table 3 shows that the energy of CNG of approximately 266.8, 322.9, 375.6 and 421.2 thousand KJ is produced from typical CNG compressor for inlet pressures of 2.0, 2.5, 3.0 and 3.5 Bar, respectively. However, when the inlet pressure at a CNG station is equal to the suction design pressure of typical CNG compresor of 4 Bar or more, the energy of CNG resulted is equal to or greater than 463.3 thousand KJ. Comparatively, the energy of CNG produced from typical CNG compressor for various CNG station inlet pressures is pointed out in Figure 2. The inlet pressure point of 4 Bar is used as reference, in which approximately 463.3 thousand KJ of

Table 2
Estimated CNG Station Inlet Pressure Effect on CNG Compressor Output Performance

Average CNG Station Inlet Pressure,Bar	Estimated Final Discharge Pressure, Bar	Estimated CNG Temperature, °C
2.0	100.40	6.0
2.5	126.30	15.0
3.0	152.20	22.5
3.5	178.15	29.0
4.0	204.70	32.0
4.5	230.00	31.0
5.0	255.90	30.5
5.5	281.85	30.0
6.0	307.75	29.0
6.5	333.70	28.0
7.0	359.65	27.0
7.5	385.50	26.0
8.0	411.70	25.0

Table 3
Estimated CNG Station Inlet Pressure Effect on Energy of CNG per Fuel Tank Produced and Annual Gross Sale Capacity

Average CNG Station Inlet Pressure (Bar)	Energy of CNG per Fuel Tank Produced (thousand KJ)	Annual Gross Sale Capacity (million KJ)
2.0	266.8	63,634.8
2.5	322.9	84,276.9
3.0	375.6	98,031.6
3.5	421.2	109.933.2
4.0	463.3	120,921.3
4.5	463.3	120,921.3
5.0	466.8	122,356.8
5.5	466.8	122,356.8
6.0	470.4	122,774.4
6.5	473.9	123,687.9
7.0	473.9	123,687.9
7.5	480.9	125,514.9
8.0	484.4	124,428.4

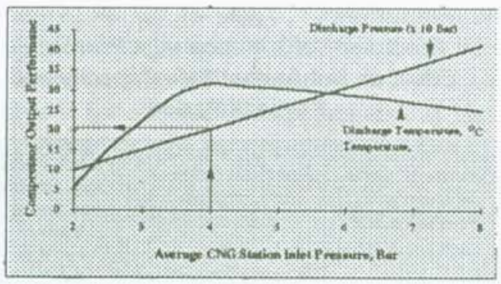

Figure 1
Prediction of CNG Station Inlet Pressure Effect on CNG Compressor Output Performance

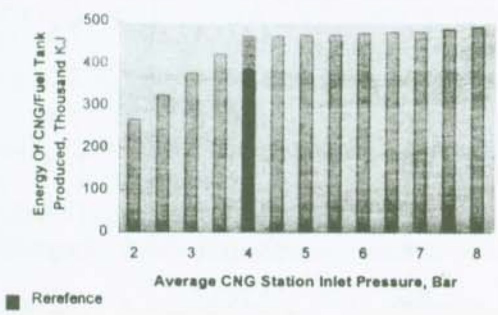

Figure 2
Comparison of Estimated CNG Station Inlet Pressure Effect on Energy of CNG per Fuel Tank Produced

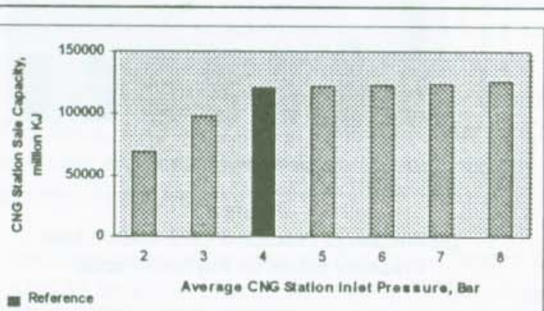

Figure 3
Contrast of Estimated CNG Station Inlet Pressure Effect on Sale Capacity.

energy is received by CNG consumers. When CNG station inlet pressures are lower than CNG compressor suction design pressure, i.e. less than 4 Bar, energy of CNG obtained by CNG consumers is less than 463.3 thousand KJ. However, their fuel tank will be full of approximately 463.3 thousand KJ of energy if CNG station inlet pressures are equal to 4 Bar or more. Therefore, CNG consumers in Indonesia prefer to fuel their cars at the CNG station which give them more energy of CNG. In other words, for getting a higher energy of CNG, the consumers tend to fill their fuel tanks at the CNG station with a CNG compressor in which the suction design pressure is lower than the gas system pressure. Since there are many existing CNG stations in Indonesia, these preferences have led to a concentration of CNG vehicles fuelling at the CNG station which gives more energy. Therefore, the higher the energy of CNG acquired by CNG consumers, the more preferable the CNG station and the more acceptance to CNG compressors.

IV. CNG STATION INLET PRESSURE EFFECT ON SALE CAPACITY

Once a CNG station has been constructed for a CNG station inlet pressure, based on existing gas system pressure. CNG station sale capacity will mainly depend on the gas system pressure, CNG station inlet pressure, and CNG compressor capacity.

The gas system pressure fluctuates in accordance with gas consumer demand. It declines when more consumers use gas, but increases if there are no or fewer consumers. Since a CNG station inlet point is part of the gas system pressure, a decline in the gas system pressure is instantaneously followed by the drop in CNG station inlet pressure. Moreover, due to the limitation of CNG compressor suction design pressure, or CNG compressor capacity, a lower CNG station inlet pressure brings about less energy of CNG obtained by CNG consumers and inevitably results in a decrease in CNG sale capacity. This is illustrated in Table 3. If the CNG station inlet pressure is 4 Bar, the CNG station will be able to sell around 463.3 thousand KJ of energy per car. Assuming CNG station capacity is equal to 750 cars per day, CNG sale capacity will be around 347,475 thousand KJ of energy per day or approximately 120,921.3 million KJ of energy per annum. However, if the gas system pressure falls and causes CNG station inlet pressure to go down to about 3 Bar, the CNG sale capacity will decrease to about 281,700 thousand KJ of energy per day or to 98,031.6 million KJ of energy per annum. This is shown in Figure 3, using the CNG station inlet pressure point of 4 Bar as reference. When the inlet pressures are 4 Bar or more, the figures of annual CNG sale capacity are high compared with the figures of the inlet pressures of less than 4 Bar. These declines of CNG sale capacity reduces CNG station revenue. Moreover, lower revenues result in a prolonged payback period of CNG station investment.

V. CNG STATION INLET PRESSURE EFFECT ON PAYBACK PERIOD

There is no doubt that a decrease in CNG sale capacity results from a deficient performance of the CNG compressor. This causes a revenue reduction and eventually a payback period extention of a CNG station investment. These circumstances occur when CNG station inlet pressure or gas system pressure is lower than CNG compressor suction design pressure. The payback period of the typical CNG compressor for various CNG station inlet pressures is calculated in Table 4.

If the energy price is US $ 2.85 / million KJ, and the Net Present Value of typical CNG compressor investment is approximately US $ 525 thousand, this investment will be equivalent to 184,210 million KJ of energy. This means, the CNG compressor payback time will be achieved if net cummulative CNG sale capacity of around 184,210 million KJ of energy is attained.

CNG station net revenue is given by the subtraction of maintenance and operating cost from CNG station gross revenue. If the average maintenance and operating cost of typical CNG station is around eighty percent, the net CNG station sale capacity will be twenty percent. Using this figure, the net CNG station sale capacity in an energy unit, KJ , is calculated. The results of the calculations are shown in Table 4 and in Figure 4.

It is indicated by Table 4 that, if CNG station inlet pressures equal the CNG compressor suction design

Table 4
Predicted CNG Station Inlet Pressure Effect on Net Annual Sale Capacity and Payback Period.

Average CNG Station Inlet Pressure,Bar	Net Sale Capacity, million KJ/Year	Payback Period of CNG Station Investment, Year
2.0	12,727.0	14.5
2.5	16,855.4	10.9
3.0	19,606.3	9.4
3.5	21,986.6	8.4
4.0	24,184.3	7.6
4.5	24,184.3	7.6
5.0	24,471.4	7.5
5.5	24,471.4	7.5
6.0	24,554.9	7.5
6.5	24,737.6	7.45
7.0	24,737.6	7.45
7.5	25,103,0	7.3
8.0	25,285.7	7.3

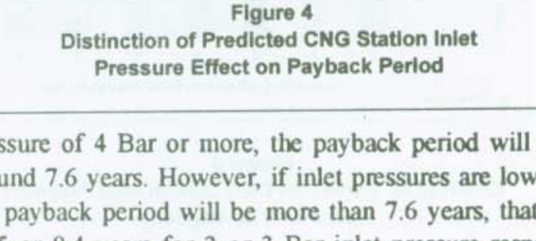

Figure 4
Distinction of Predicted CNG Station Inlet Pressure Effect on Payback Period

pressure of 4 Bar or more, the payback period will be around 7.6 years. However, if inlet pressures are lower, the payback period will be more than 7.6 years, that is 14.5 or 9.4 years for 2 or 3 Bar inlet pressure respectively. This extension is clarified by Figure 4. The payback period for the average CNG station inlet pressure of 2 or 3 Bar is high compared with the 4 Bar inlet pressure. Moreover, the payback period of CNG station investment is not affected by inlet pressures of more than 4 Bar. Those payback periods remain steady and at 7.6 years. It is clear that, a high payback period of CNG station investment is caused by low CNG station inlet pressure compared with the CNG compessor design pressure.

VI. CONSUMERS' DEMAND FOR CNG COMPRESSION FACILITIES PERFORMANCE

It is found that a deficient performance of a CNG compressor is a result of low CNG station inlet pressure. This leads to a decrease in the total energy of CNG obtained by CNG consumers. This underfilling condition, which was a reason for CNG consumers preferences, has caused a decline in CNG sale capacity and resulted in a higher payback period of CNG station investment. Therefore, improvements are needed to overcome the deficient performance of CNG compression facilities.

Basically, a deficient of a CNG compressor performance arises because of the drop in gas system pressure to which the suction pressure was not designed to anticipate. In other words, to avoid a deficient performance of a CNG compressor, consumers demand for CNG compressor performance is pressure independency. This means, CNG compressor performance is independent of system pressure changes. Obviously, it is expected that the CNG compressor will run to specified performance, whatever the gas system pressure or CNG station inlet pressure. This could be accomplished by the following alternatives :

1. Suction pressure is one of the main factors that should be taken into account by a CNG compressor producer when designing a CNG compression facility. A decline in the gas system pressure, resulting in a drop of CNG station inlet pressure, causes a deficient performance of typical CNG compressor due to the higher suction design pressure. Therefore, anticipating the low gas system pressure, an improvement to maintain the specified performance of CNG compression facilities is low suction design pressure.
2. The suction design pressure correlates with other components of a CNG compressor, particularly its compression stages, to reach out the fuel tank design pressure. Setting a suction pressure has no effect without proper compression stages. For example, typical CNG compressor is a three-stage compressor. Its discharge pressure is less than the fuel tank design pressure when the CNG station inlet pressure is low compared with the CNG compressor suction pressure. This can equal the fuel tank design pressure, if the stages are properly designed to achieve an adequate performance. Another improvement to maintain the specified performance of CNG compression facilities is proper compression stages.
3. Once a CNG station has been established a definite suction pressure of a CNG compressor is set, based on a particular inlet pressure or gas system pressure. A decrease in the gas system pressure causes a deficient performance of CNG compressor in which sale capacity is inevitably reduced. This is eventually followed by a prolonged payback period of CNG station investment. It is a critical problem for a CNG station operator, because the lower the inlet pressure, the higher the payback period. To reach the implemented payback period, an improvement of CNG compressor performance is required. However, this can only be done by replacement of CNG compression facilities because the CNG compressor was not flexibly designed for modification. In this case, to attain the discharge pressure of 200 Bar, typical CNG compressor cannot be modified to four stages, but should be replaced by a new compressor. The third improvement to maintain the specified performance of CNG compression facilities is flexibility for modification.

VII. CONCLUSIONS

Based on CNG utilization experience in Indonesia, the following points can be concluded :

1. When the gas system pressure is lower than CNG station inlet pressure, the fuel tank design pressure can not be reached out by the pressure of CNG produced from typical CNG compression facilities.
2. A fall in the gas system pressure to which a CNG compressor capacity was not designed to anticipate, causes :
   - a deficient CNG compressor performance
   - a decrease in the total energy of CNG obtained by CNG consumers
   - a decline of CNG station sale capacity
   - a prolonged payback period of CNG station invesment.
3. A decrease in the total energy of CNG received by CNG consumers is a possible cause for CNG consumers preferences in fueling their cars at certain CNG stations.
4. The higher the energy of CNG acquired by the CNG consumers, the greater CNG compressor acceptance and the most preferable of the CNG station.
5. Consumers demand for CNG compression facilities performance is pressure independency. This means, CNG compressor performance is independent of system pressure alteration. It is expected that a CNG compressor will run to specified performance, regardless of the gas system pressure or CNG station inlet pressure. This may be achieved by improvements the design of CNG compression facilities, such as :
   - low suction pressure, subject to the lowest gas system pressure
   - proper compression stages
   - flexibility for modification.

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