An Effective Method for NGV Mileage Calculation

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Abstract — *In conventional gasoline run cars it is extremely simple to calculate the mileage in terms of miles per gallon (mpg). This obviously gives us the performance of the engine and points toward any problems in delivery or combustion systems. But unfortunately cars running on natural gas have no method of accurate mileage calculation. This paper presents an effective methodology for calculating the mileage and cost per kilometer in NGVs.*

Index Terms — Natural Gas Industry, Road Vehicle Electronics, Magnetic Transducers.

I. INTRODUCTION

Natural Gas Vehicle market has seen an exponential growth in the last two decades but its related electronics, especially its measuring systems have not witnessed any significant development. Throughout the world there are approximately 7 million cars that run on compressed natural gas[1], but not having any proper system for fuel consumption estimation. The main reason is that manufacturers produce the gas cylinder taking volume as their standard, whereas CNG filling stations use mass as standard for filling quantities of compressed gas into vehicles. To make things even worse, the driver cannot make any use of the volume of the cylinder because it is fixed, and the mass that was filled is not known. The only available information to the driver is the gas pressure that is totally different from the two earlier mentioned quantities. This paper describes the electronic method by which useful information can be delivered to the driver. In this process the units used for mileage calculation will be made similar to the units that are used for filling in the gas.

II. DIFFERENT UNITS USED IN NGV MARKET

Natural gas cannot be used in vehicles unless it is not compressed. This compressed gas is stored in a re-enforced cylinder in the trunk of the car. Unlike gasoline, where the tank is manufactured in terms of gallons and gasoline pumps also filling the tank in terms of gallons, compressed natural gas has a totally different scenario. The cylinder is built using liters i.e. volume as standard, and CNG filling stations deliver the fuel in terms of kilograms i.e. mass. The scenario is made difficult when we have pressure reading as the only available data on the vehicle itself.

Consumption estimation for any fuel is possible only when we have its input and output in the same units and scale. Hence the first goal of this paper is to unify these two parameters so that easily understandable / useful information is provided on the dashboard of the car.

Cylinder Standard	Filling Standard	Data Available
LITER (VOLUME)	KG (MASS)	BAR (PRESSURE)

Fig. 1. Quantities used in an NGV scenario.

III. EFFECT OF TEMPERATURE ON CNG READINGS

When calculating the pressure (the only available data to the driver), temperature is always taken for granted. The importance of taking it into consideration can be demonstrated by the Gay-Lussac's [2]. Here it is demonstrated how different temperatures of two cities can affect the pressure of a fixed mass of gas.

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

Where,

P_1 is the pressure of gas in City 1
P_2 is the pressure of gas in City 2
T_1 is the environmental temperature of gas in City 1
T_2 is the environmental temperature of gas in City 2

Temperature changes the results when the car is being driven between two cities with different environmental temperatures. For Example, if a car moves from city 1 to city 2 with 100 bars of initial CNG. On reaching city 2, the pressure is 80 bars. When we consider temperate in this scenario, we find that 80 bars is not a true reading because temperature in city2 is greater than city 1, and the pressure should have been 70 bars at the end of the journey instead of 80 bars. The 10 bars falsely added to the final reading is because of the expansion of the gas in a warmer environment.

For demonstrating, we take an example where two cities have different temperatures and for simplicity reasons, we consider that the car was air lifted from one city to another.

P_2 = ?
P_1 = 113.5 atm (115) bars
T_2 = 303 Kelvin (30° Celsius)

T_1 = 308 Kelvin (35° Celsius)

Here city 1 and city 2 have a 5° Kelvin temperature difference. Using the Gay-Lussac's Law we can find out the pressure in the other city that was previously 113.5 atm (115 bars).

$$P_2 = \frac{P_1}{T_1} \times T_2 = \frac{113.5}{308} \times 303 = 111.65$$

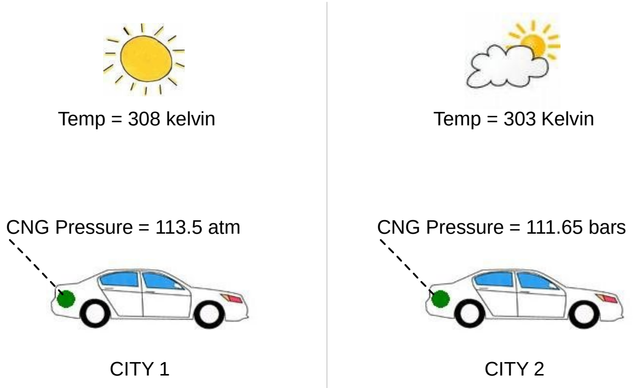

Fig. 2. Inaccuracy caused by temperature change.

Therefore, it can be observed in this case that 5 Kelvin change in temperature has affected the pressure by 1.85 atms. Therefore NGV users in counties with diverse temperature difference will have a huge difference in pressure readings for the same mass of gas in their cylinders. An example can be taken in which an NGV vehicle in Canada at 268 Kelvin (– 5° Celsius) has 100 atms of gas pressure. The same car, if brought to a warm country like Pakistan would read 118.65 atm at 318 Kelvin (45 ° Celsius). This difference in pressure is an astonishing 9.44% of the maximum safe CNG pressure of the car.

IV. Conventional Ways of Estimating Mileage

A. First Conventional Method

The first conventional way of estimating mileage in NGVs is through noting down the pressure on the cylinder barometer, driving for some distance and then again checking the barometer reading. This gives the total bars consumed in the journey, and hence giving a gross mileage to the driver. This method cannot be accurate/reliable because of the temperature factor that in turn changes the pressure inside the cylinder, as discussed in Section III.

B. Second Conventional Method

The second conventional method used by some NGV users is by "topping up" the cylinder to a full 200 bar limit, then consuming the whole cylinder and estimating the mileage by using the total kilometers driven using those 200 bars of gas. This method is also not reliable as the driver cannot be sure how much compressed gas was put into the cylinder when it was "topped up". If the compressor/storage facility at the CNG filling station is regulated at a low temperature, more gas will be put into the car as the gas will have more density. Incase of a filling station whose gas is warm due to poor compression system and storage facility, less mass of gas will be filled in the user's cylinder at the same 200 bar pressure.

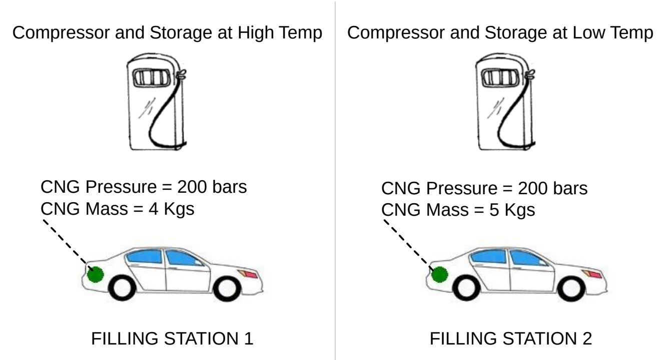

Fig. 3. Effect of compressor/storage cylinder temperature.

It is the Kgs of gas that are "consumed" by internal combustion, not the pressure. So, it is important to estimate for how much mass of gas was consumed if accurate mileage reporting is required.

V. Related Work

The method for accurate mileage calculation presented in this paper requires precision measurement of pressure in the CNG cylinder. The technique used for pressure monitoring used here comes from an IEEE research paper[3], that utilizes a non contact single axis hall effect integrated circuit for measuring analog voltages with respect to pressure. This analog value is converted to digital through a 10-bit A/D converter.

VI. Methodology for Calculating Mass of Gas

To accurately calculate the mass of gas required for mileage calculation, the number of moles of gas present in the cylinder must be calculated first. The available parameters are given in Figure.4.

VOLUME	PRESSURE	TEMPERATURE	MASS
Fixed	Measurable	Measurable	Required

Fig. 4. Parameters available for mole calculation.

These parameters are used in the Van Der Waals Equation[4] to calculate total moles of methane present in the cylinder. The equation states that :

$$\left(p + a\left(\frac{n}{\tilde{V}}\right)^2\right)(\tilde{V} - nb) = nRT$$

Where,

P is the pressure of methane in cylinder
n is the total number of moles of methane in cylinder
V is the total volume of the cylinder that is fixed for a car
R is the gas constant and is equal to 0.0821 L.atm/mol.k
T is the environmental temperature in Kelvin
a is a constant describing the force of attraction between methane atoms. Its value is 2.283.
b is a constant describing the volume occupied by methane atoms. Its value is 0.04278.

Moving average of the analog pressure readings are taken after digitization. Incase of temperature, an integrated temperature sensor is used to give us temperature directly in Celsius scale. Its 20 values are taken and then averaged to make the reading smooth.

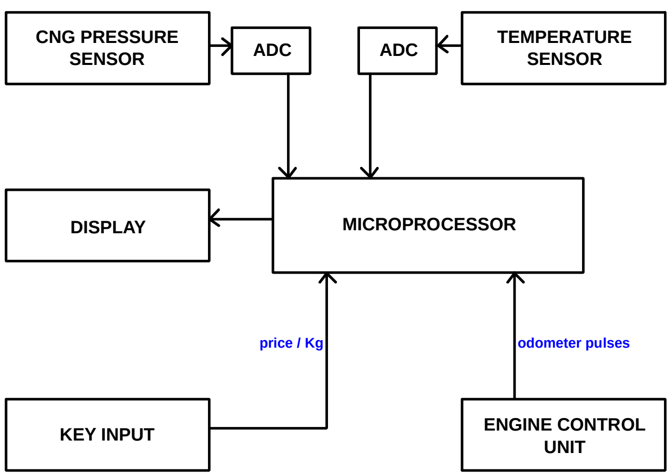

Fig. 5. Block diagram of the system.

In Figure 6, it can be seen that Van Der Waal's Equation solving block (Section 1) is the heart of the system that is utilizing constants *a* and *b*, molar mass of methane, pressure and temperature values that we already obtained previously. The output of Section 1 is Kilograms of methane actually present in the cylinder. What Section 1 is actually doing can be described by taking arbitrary values for input parameters. Here, we consider:

Pressure = 93.67 atm (95 bars)
Volume = 55 Liters
Temperature = 303 Kelvin (30° Celsius)

Using the Van Der Waal's Equation, we get:

$$\left(93.67 + \frac{n^2 \times 2.283}{(55)^2}\right)\left(55 - n(0.04278)\right) = n \times 0.0821 \times 303 \quad (1)$$

$$(93.67 + 0.000754n^2)(55 - 0.04278\,n) = 24.876\,n \quad (2)$$

$$-0.00003225\,n^3 + 0.04147\,n^2 - 28.883\,n + 5151.85 = 0 \quad (3)$$

This cubic equation is to be solved to get three results, out of which two are complex and will be ignored. The remaining result is 251.3455, which is the total number of moles of methane in cylinder.

Number of grams = (No. of moles) × (Molar Mass)
= 251.3455 x 16 = 4021 grams

Therefore total mass of gas in cylinder is 4.021 Kgs.

Once the mass of gas is known, it is passed to the Section 2 in Figure 6. This section, also receives a pulse from the Engine Control Unit when the car covers a distance of 100 meters. These pulses from the Engine Control Unit are originally meant to be fed to the digital odometer in the dashboard of the car. As soon as this section detects that 1 Kg of gas has been consumed, it calculates mileage in Kilometers/Kg and also Cost/Kilometer. This data is updated on the display and also sent to the EEPROM so that last known values can be displayed when the device boots the next time.

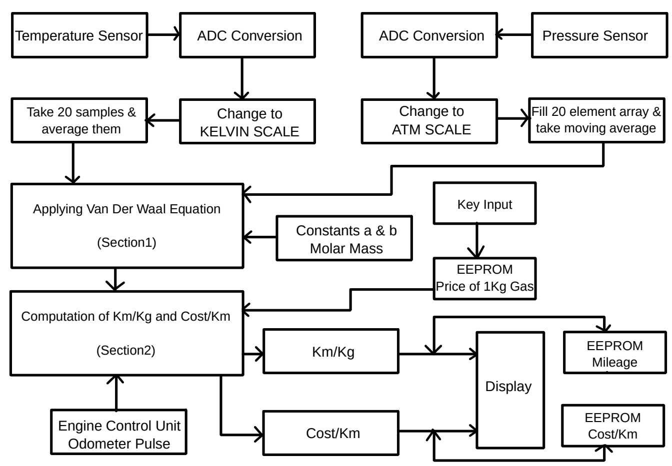

Fig. 6 Flow Chart of the system.

The pressure sensor is a single axis hall effect IC, which works in proximity of a permanent magnet. Distance between this IC and magnet is varied by a rack-and-pinion mechanism operated by varying gas pressure. The output is almost linear with respect to pressure in bars. 10 bit A/D conversion of this analog value gives us highly accurate value of gas pressure. Because the formulae used in the system accept pressure in atmospheres, the incoming value in bars must be converted. A moving average ensures that fluctuations in the incoming pressure readings are minimized.

VII. CONCLUSION

An accurate and cost effective system is thus designed that can be plugged with most of the conventional engine control units. This system is vendor independent and can virtually be installed with all compressed natural gas regulators. This solution is a long awaited answer to the critical question of accurate and reliable mileage calculations in NGVs. Future developments can include sub-systems for leakage/over-consumption detection, tuning suggestions, optimum speed suggestions for least CNG consumption etc.

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