# EXPERIMENTAL INVESTIGATION OF USING LNG IN VEHICLES

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## ABSTRACT

Nowadays fossil rooted fuels used in the internal combustion engines being exhausted and taking form harmful exhausted gases conclusion of burning these fuels soiling environment have cause to increase investigations about alternative fuels used in the internal combustion engines. If a fuel use in an internal engine, that can be easily evaporate, easily mixed with air, get high energy, easily burn, easily obtain. Liquid hydrocarbon fuels which obtained in fossil (petrol), includes nearly all these properties. Because of this, diesel and gasoline which are the famous petrol products raise the first line. By this time, petrol reserves limited and not separated on regularly. And by the extremely usage of these, that causes various local air currents, air pollution and potential climatic currents. Lots of various alternative fuels were attempted since diesel and gasoline become a fuel in internal engines. Lots of these alternative fuels get low emissions than diesel and gasoline. But that can not found market place because of these limited reserves and higher prices. Nowadays, few of alternative fuels use as a commercial mark. It is necessary using alternative fuel in vehicles because of high petrol price and air pollution is a result of using fossil fuels in vehicles. Although natural gas (NG) is fossil fuel but in gas form is cleaner than petrol and diesel, and has large reserve than petrol. Because of these reasons NG becomes an important alternative fuel. Unfortunately, storing the NG as Compressed Natural Gas (CNG) form brings many problems. The most important problem is especially in small vehicle like cars; 200 bar resistant tanks are heavy and big volume. As a result of this, the vehicleĝs distance of range using CNG is different according to tank volume that is about 150 km. However, storing the NG as Liquid Natural Gas (LNG) form in the same tank volume, the tankĝs weight becomes lower, by the same time distance of range approaches the petrol using vehicles. In this study, we work at the properties of natural gas (LNG) and the usage of NG in internal engines. Experiments were studied at Erciyes University Mechanical Engineeringĝs Engines Laboratory. Ford brand, 105 Hp, 1800 cc motor was used in experiment. Exhaust emissions was measured in SUN MGA 1500 gas analyser.

**Keywords:** LNG, Alternative Fuel, Storing of Natural Gas, Vacuum Insulation

## 1.Introduction

As alternative fuel, natural gas provides a low CO emission rate and holds a dominant position with widely distributed resources in the world compared with the other fuels for vehicles. Natural gas should be widely used in liquid phase (LNG) specially in automobile use because of its energy density [1]. LNG requires large insulated tanks to keep the liquefied gas at a very low temperature and is therefore seen as more suitable for long-haul trucks [2]. Liquefied Natural Gas (LNG) offers the possibility of using this fuel for heavy-duty road transport applications due to its higher energy density. It should be taken into account that a temperature of -162°C [3] is required (at atmospheric pressure) to maintain the fuel in liquid state, therefore the main issue of this technology lies on the cryogenic tank installed on board with a thermal behaviour control system and the board vaporizer required to feed the internal combustion engine.

The scientific literature concerns LNG with its various implementations. In one of studies, it has been seen that the components of LNG system (LNG tank, vaporizer, LNG control valve and gas injector) were developed. In addition, the LNG tank and the LNG control valves also were insulated to prevent gas boil off. In this way, the LNG engine system provided a high compression ratio, manifold gas injection, and spark ignition for the effective use of natural gas. Tests were carried out for exhaust gas emissions, vehicle dynamics and driveability and as a consequence, the exhaust gas emissions were seen lower Japan 10 and 11 mode regulations [1].

A life cycle assessment has been carried out to quantify the energy saving and environmental emission of a remanufactured LNG engine and newly manufactured diesel engine. As to result of tests, compared with diesel engine, LNG remanufacturing could reduce 42.62% of primary energy demand (PED); the environmental impacts reduction of acidification potential (AP) and nutrient enrichment potential (EP) could reach to 69.61% and 71.34%, which are most distinct; global warming potential (GWP) and photochemical ozone formation potential

(POCP) could be reduced by 46.42% and 43.90% respectively [4].

In another study was focused on improving performance of LNG. For this aim, a set of intake air supply device was designed and coupled to a LNG engine and the performance of LNG engine with intake air supply was compared with the original engine. The results indicate that engine torque could be improved obviously at low-speed, while the specific gas consumption (SGC) was almost unchanged with intake air supply. At 1000 r/min, the torque could be increased by 31%, and the SGC was decreased by 1.64%. Based on the test results, the optimal injection pressure of supplied air at various speeds was determined. Finally, the vehicle test of intake air supply was also conducted under road conditions. Compared with the original natural gas vehicle, the acceleration time was decreased by 14.7ï 30% through intake air supply, and the higher gear ratio contributed to the better acceleration performance. [5]

It was seen that liquefaction of natural gas provided a safer and economical alternative for transportation and also increased its storage capabilities in another study. LNG transported in cryogenic vessels offers several advantages [6] over pipeline transport of natural gas especially when the gas consuming areas are far away from the gas producing areas. In the study, it was also investigated about characteristics of LNG compared with the other fuels (diesel, gasoline and LPG).

A study from Austria has showed that there are severe barriers which impede the application of LNG in the landlocked areas of Europe. The objective of the present work is to build a basement for launching LNG in this region. This carried out in two stages: First by deliberately examining the potential demand for LNG and second by identifying the stakeholders which have to be taken into account to successfully accomplish this process. LNG application have been categorized and prioritized using Maslow's hierarchy of needs. The results revealed that interest for LNG exists and the potential for introducing LNG in landlocked Europe is given [7].

For refrigerated vehicles, it has been conducted in the other study, an additional advantage is that recovering of the LNG cold energy during vaporization will provide the refrigerating effect and therefore reduce the engine power used to drive the conventional vaporï compression system (VCS). Analysis of the feasibility of a self-refrigerated vehicle by recovering the cold energy of LNG fuel. A prototype of a self-refrigerating system was constructed and its refrigeration performance has been investigated experimentally. The interrelations of the refrigerating temperature, the cooling capacity and the consumption rate of LNG fuel were studied.

The experiment results showed that the refrigerating temperature of the compartment could be kept lower ï 20 °C when the LNG consumption rate is larger than 5.607 kg/h. This value of LNG consumption rate could be achieved when the power output of the engine for the LNG-fueled refrigerated vehicle is more than one third of its maximum output power (75 kW) [8] under the full-load operating condition.

There were performed to compare the life cycle, in terms of greenhouse gas (GHG) emissions, of diesel and liquefied natural gas (LNG) used as fuels for heavy-duty vehicles in the European market (EU-15). Two possible LNG procurement strategies were considered. These were purchasing it directly from the regasification terminal (LNG-TER) or producing LNG locally (at the service station) with small-scale plants (LNG-SSL). The use of LNG-TER enables a 10% [9] reduction in GHG emissions by comparison with diesel, while the emissions resulting from the LNG-SSL solution are comparable with those of diesel.

In another study, it has been seen that if LNG is used in a direct-injection engine having the same efficiency as a diesel engine, the ñwell-to-wheelò lifecycle greenhouse gas(GHG) emissions were typically around 19% lower than conventional diesel, or around 17% lower than diesel containing 7% FAME (B7). As a consequence, different sources of LNG might have higher or lower savings, depending on the efficiency of liquefaction and the shipping distance. In the best cases, the Well to Wheel reduction might be as high as 25% [10].

Potential of LNG as vehicle fuel was shown positive and negative aspects related to its introduction and comparing the different supply options. The analysis has pointed out that purchasing LNG at the regasification terminal is convenient up to a terminal distance of 2000 km from the refuelling station. The liquefaction on site, instead, asks for liquefaction efficiency higher than 70% [11] and low natural gas price.

It was investigated effects of compression ratio on performance and emissions of a modified diesel engine fuelled by HCNG in another study. They investigated the effects of compression ratio (CR) have been investigated engine performance and emissions characteristics of a modified diesel engine fuelled by HCNG (hydrogen enriched compression natural gas) blends (100% CNG, 95% CNG +5% H-2, 90% CNG + 10% H-2 and 80% CNG + 20% H-2). The experiments have been carried out using a modified Isuzu 3.9 L diesel engine having 9.6, 12.5

and 15 different compression ratios at 1500 rpm under full load conditions [12]. Engine brake torque, brake specific fuel consumption, combustion analysis and emissions parameters (CO, THC and NOX) have been realized at 10 CA BTDC ignition timing and different excess air ratios. As seen above, NG uses in vehicle have become increasingly very important in the past decades and will be more in the near future. Hence, this paper presents investigation of using LNG in vehicle at various scenarios.

## 2.Material and methods

### *2.1. Experimental set up:*

There is a saturated liquid-gas mixture in pressure tank. When the LNG tank which is initially in 0.5 bar gauge pressure receives 1258.55 kJ heat from environment, relief valve opening pressure reaches 4.9 bar gauge pressure. If it still receives more heat, depending on this heat, the relief valve will be open and discharge this overpressure. It is determined initial gauge pressure as 0.5 bar and relief valve set gauge pressure as 4.9 bar in the calculations.

Table 2.1 shows that as evaporation loss ratio of tank increase, relief valvesô opening time is shortened. For the same loss ratio, as amount of fluid carrying in the tank increases, relief valve opening time is shortened again. Testing of relief valve and design of tank at higher pressure will extend relief valvesô opening time.

**Table 2.1.** Tankûs distribution of pressure, temperature and level received heat from external environment

| P [bar] | T [K] | mg [g] | mf [g] | Vg [l] | Vf [l] | x | U [kj/kg] | FR [%] |
|---|---|---|---|---|---|---|---|---|
| 1.5 | 117 | 12.31 | 15.877 | 4.603 | 38.297 | 0.00077 | -267.75 | 89.27 |
| 2.5 | 124 | 15.14 | 15.875 | 3.59 | 39.31 | 0.00095 | -242.94 | 91.62 |
| 5.9 | 139 | 9.58 | 15.880 | 0.992 | 41.91 | 0.00060 | -188.54 | 97.67 |

**P:** Absolute pressure [bar]
**T:** Temperature [K]
**mg:** Mass of gas [g]
**mf:** Mass of fluid [g]
**Vg:** Volume of gas [l]
**Vf:** Volume of fluid [l]
**x:** Dryness fraction
**U:** Internal energy [kj/kg]
**FR:** Fluid ratio [%]

### *2.2. Production of LNG Autogas Tank*

On-board fuel storage is considerably different between diesel and LNG. Standard diesel tanks are single-wall aluminum containers and cost in the hundreds of dollars, depending on size.

Tanks for cryogenic LNG require double-wall construction from stainless steel with super insulation and vacuum inter-tank space. (Fig. 2.1). Typical tank pressures are between 138 kPa to 1040 kPa, but the design must withstand more than two times that amount to compensate for heat gain when not in use. LNG fuel storage systems are significantly more complicated to design and manufacture and their cost is an order of magnitude greater than that of a diesel tank.

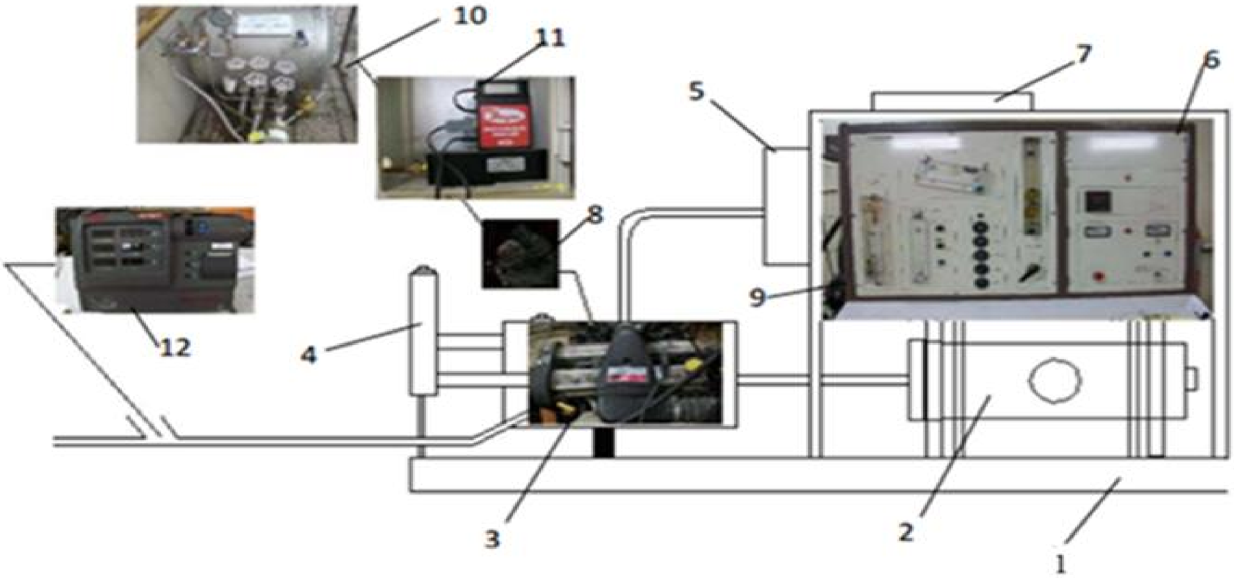
The weight of LNG is approximately 3.5 lb/gal, compared to diesel at 7.6lb/gal. Unfortunately, the more complex LNG fuel tank is substantially heavier. In total, given the difference in tank design and fuel density, LNG-powered tractors have suffered a weight penalty.

**Figure 2.1.** The cryogenic LNG tank

External tank body has also been made taking into account the dimensions of the project. Fig. 2.2 shows that inner tank and external tank are nested with minimizing of heat bridges. After preparing vacuum filters, they are mounted between two walls.

**Figure 2.2.** Nested Inner and external tanks


**Figure 2.3.** LNG Autogas filled with LNG and mounted to experiment set




1. Engine Chassis
2. Dynamometer
3. Engine
4. Engine Cooling Unit
5. Air Tank
6. Control Unit
7. Gasoline Tank
8. Regulator
9. Fuel Selector Switch
10. LNG Tank
11. Flow Meter
12. Exhaust Gas Analyser

**Figure 2.4** Experimental setup

Completed assembly is seen Fig. 2.3 and its cold test has been conducted with liquid nitrogen. Firstly, the inner tanksô indoor temperature has been reduced gradually with purging tank by three times with nitrogen gas phase. Afterwards, the tank has been filled with a small amount of liquid nitrogen and it has been expected to evaporate it. After being discharged of vaporized nitrogen, the tank has been filled with liquid nitrogen until LNG filling. The cold test has carried out with nitrogen liquefying at -192 °C and atmospheric pressure.

Experiments has been carried out using LNG for different engine speeds (1500, 2000, 2500 rev/min.) and excess air coefficient values. The experimental set up is shown in the Fig. 2. 4.

**3.Results and discussion**

Fig. 3.1 indicates that full combustion is seen to better between the values of the excess air coefficient 1-1.3 depending on the engine speeds. In addition, while the engine speed is 2000 rev/min and excess air coefficient is 1.14, $\%CO_2$ is seen to be maximum level.

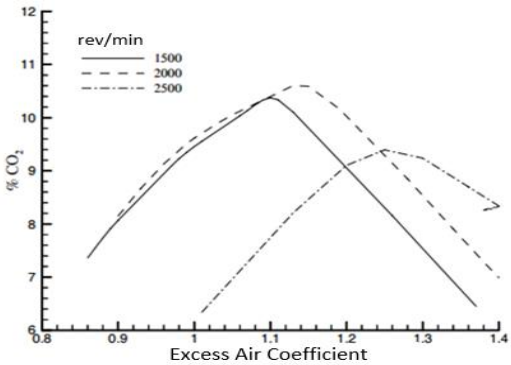



**Figure 3.1.** Changes of % $CO_2$ depending on excess air coefficient

Fig. 3.2 shows that, when the values of excess air coefficient is bigger than 1.1, it is seen to be fall in the values of %CO. It is also seen that while the engine speed is 2000 rev/min., %CO is seen to be minimum level.

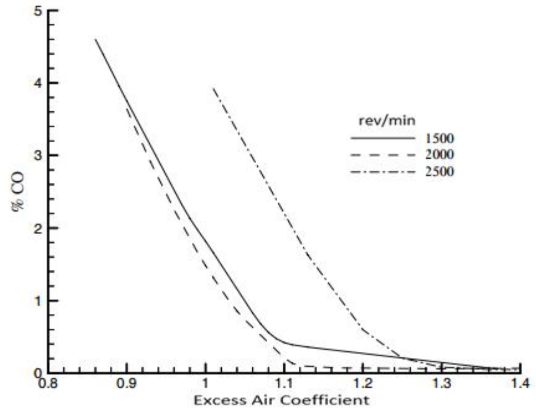



**Figure 3.2.** Changes of % CO depending on excess air coefficient

Fig. 3.3 indicates that, amount of the unburned fuel is seen to be least between the values of the excess air coefficient 1-1.3. As excess air coefficients move off from range of 1-1.3, it is seen to be rise in the amount of the unburned fuel. Also, while the engine speed is 2000 rev/min., the amount of HC is seen to be less than the other speeds.

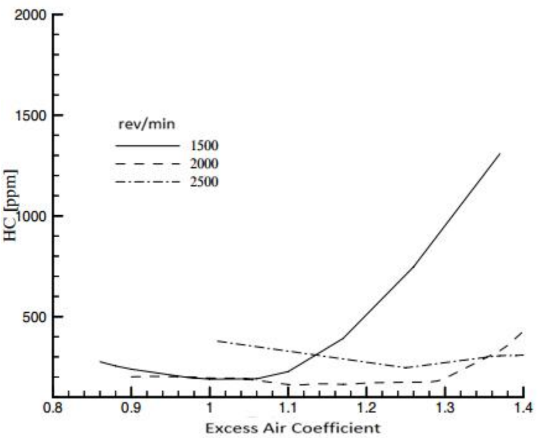



**Figure 3.3.** Changes of % HC depending on excess air coefficient

As seen Fig. 3.4 that torque is increased due to the increase in engine speed. Methane is stored in two phases, liquid and gas phase in the LNG fuel tank. When the tank pressure falls, gas flow from tank is reduced. After the engine speed exceeds 2000 rev/min, the amount of gas coming from tank is not been adequate. Actually, pressurisation circuit was applied for being increased pressure when the tank pressure falls. But methane was thrown the external environment, because relief valves were opened at 5 and 8 bar (false relief valve is fitted by the manufacturer). Hence, to avoid the increase of tank pressure, pressurisation circuit was been closed. In case of fixing the relief valves, torque will also increase with increasing number of speeds. This case will be also after occurring a fall in gas pressure following not end of the liquid in the tank. Thus, not using LNG alone as fuel, but it will be more accurate to use as alternative fuel such as LPG. It is seen parallels between torque and brake power.

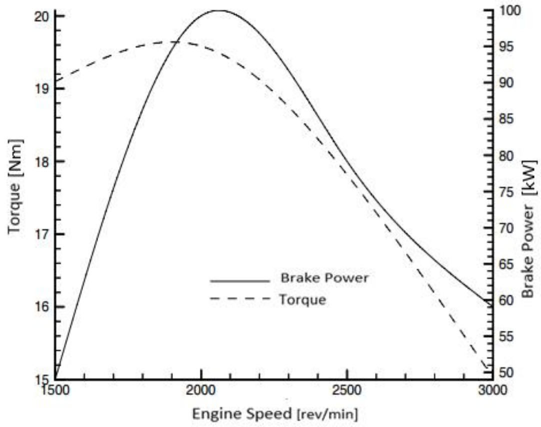



**Figure 3.4.** Changes of torque and brake power depending on engine speed

According to Fig. 3.5, due to the increase in engine speed the amount of specific fuel is increased. Brake efficiency is reduced due to the increase in engine speed, too. The decrease in brake efficiency and increase in specific fuel consumption is become more pronounced in case of exceeding of engine speed 2000 rev/min.

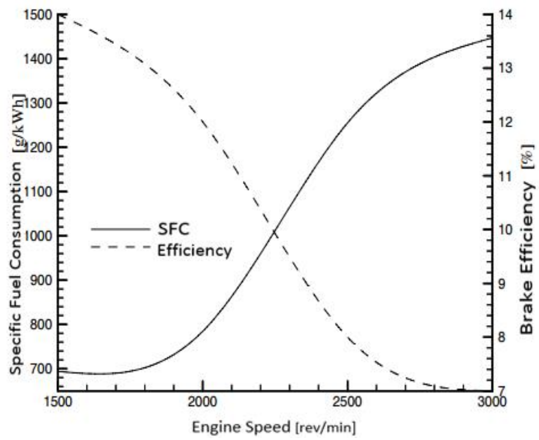



**Figure 3.5.** Changes of SFC and brake efficiency depending on engine speed

As to Fig. 3.6, it is observed an increase in pressure values depending on the angle the crankshaft. The increase in engine speeds lead to an increase in the cylinder pressure. It is seen to be fall at pressure due to increasing at excess air coefficient comparing with at the different excess air coefficients and the same speeds.

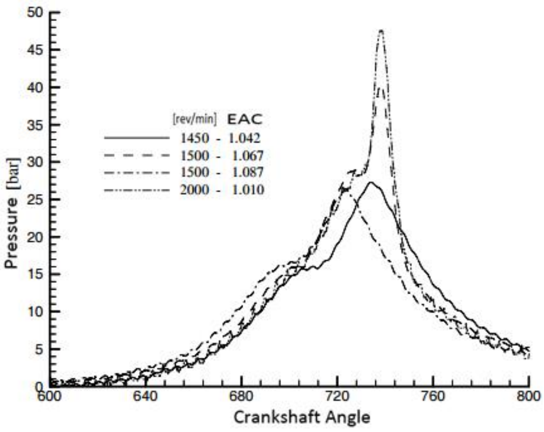



**Figure 3.6.** Changes of depending on crankshaft angle

LNG in the tank internal volume 42.9 liter has bigger 2.3 times equivalent energy than CNG which has 50 liter volume and 200 bar pressure. Vehicles using LNG as fuel has approximately 2.3 times greater range than vehicles using CNG.

Though currently the supply shortage of LNG, it is seen as an alternative fuel to be used widely in internal combustion engines in the future due to the low exhaust emissions that cause air pollution and having economic advantages comparing with conventional fuels. What is more, this also means more fresh air to be inhaled, a greener environment for us and extend the life of our old world.

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