INITIATING LNG-FUEL TECHNOLOGY IN THE NIGERIA TRANSPORTATION SECTOR: A FUNCTION OF BETTER ENGINE EFFICIENCY

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ABSTRACT

The transport sector fuel in Nigeria is dominated by two fossil fuels (PMS and diesel) which are products of Petroleum refinery. With the moribund state of Nigeria refineries and the challenges faced with the facet of fuel importation, the demand for transportation fuel has tripled in a geometric progression. The need to seek for other alternatives to bolster the country's transport sector cannot be overemphasized. Natural Gas has been researched as one of the most energy sources and fortunately, there is a profuse deposit in Nigeria, with total proven reserves of >187tcf. Thus, the initiative of employing Liquefied natural gas (LNG) will be systematically established. This paper is aimed at integrating LNG-fuel technology in transport sector to accelerate the transportation sector by looking into the exergy energy of using the boil-off gases from LNG into conventional vehicle engines. The analysis shows 24% exergy efficiency compared to conventional engines.

Keywords: LNG-fuel; Boil-off Gases; Exergy; Efficiency

1. INTRODUCTION

In Nigeria, in line with the report of the National Bureau of Statistics**,** Nigeria within the first quarter of 2017 spent $2.49 billion (N761 billion) on import of refined petroleum products of which 70% is consumed by the transport sector. Before this time, the main purpose of Natural gas liquefaction has been for its transport by vessel over stretched distances. In order to get it ready for additional transport by pipelines it has to be reduced again to a gaseous state, usually by upgrading the temperature through the use of sea water. Hence research has shown that LNG can be stored in small thermo-cooled bottles and utilized as fuel for vehicle transport. With the amount of money Nigeria spend on import of petroleum product, after much painstaking investigation it is clear that the country can build LNG refuelling stations and setup small scale plant for conversion of PMS cars to LNG cars across the country due to better engine performance. The transportation structure is principally made up of roads, rail transport, sea ports, internal waterways and airport via aviation respectively, of which road, air transport make up the major ones. The process will need the alteration LNG from a liquid phase to a gas phase for additional use authorize the use of exergy of LNG to various applications, which most times for electricity generation but here for car engine combustion. Energy access in transportation in the country lies below 50% as shown on the (NBS, 2017) report despite a rising trend in GDP and overall energy access. The rise in the global demand for natural gas is due to the high volume of reserves discovered in the world and it is straightforward to process and its multiple applications in different sectors. The production and processing of LNG in its vaporization state as Boil-off gases (BOG) attracted more research in different sectors of the energy usage value chain.

Figure 1 LNG Value Chain Modified

Conventionally, LNG is basically used as a carrier gas in vessels solely for the basis of exportation. During exploration and production, Natural Gas exists as an associated state in most wells and sometimes as a non-associated gas. Its treatment is vital due to the other constituents of hydrocarbons present in it. These other constituents like the Liquefied Natural Gas (LPG) are separated from Natural Gas and sent to homes leaving pure LNG (methane). This purified natural gas is then Liquefied into Liquid to accommodate for larger sizes in vessel and then exported to countries for usage in several sectors. The job of receiving LNG terminal is to receive the cargo of LNG from peak-shaving plant, in line with the operation plan – to process liquid LNG in the gas phase and at a particular pressure to introduce gas into the transmission system. Strategically, the LNG regasification facility begins playing a critical role. Notwithstanding the advancement of liquefaction methods and the technical know-hows concerned with the dropping of the energy consumption, liquefaction remains a very energy-consuming process at the place where it is performed (Remeljej, 2006). Based on several researches conducted by different scientist on the usefulness of LNG,in developed technologies the LNG can be used as a cold source in the direct production of electric energy (Liu & You, 1999). (Hisazumi*et al.* 1998) studied the possibilities of utilizing waste heat from A-gas-operated power facility for LNG evaporation. The cause of warmness in the Rankine cycle is condensation enthalpy from a steam turbine and heat of waste gases in the waste boiler. (Olivetti *et al.* 2012) investigated the problem of optimum thermodynamic use of cold sources, exemplified by LNG, to the electric energy production. The efficiency of thermodynamic process has been recently investigated by several others. (Dobrota, *et al.* 2013), investigated the “Problem of Boil - off in LNG Supply Chain,” and the module regasification with ethane or ethylene for generating electric energy and energy transport within the established range of temperatures. (Liu and Guo 2011) initiated a process of thermal energy recapturing from LNG regasification with the use of two-component mixtures (tetrafluoromethane and propane) connected with steam absorption processes. Therefore, LNG as a cold energy source seems to be advantageous in any case when thermal energy waste is generated to the environment (Hang & Lior, 2006).The proposed configuration of LNG cryogenic tank installation will be based on the analysis of engine combustion performance to improve its efficiency as far as the produced energy and also thermodynamic efficiency.

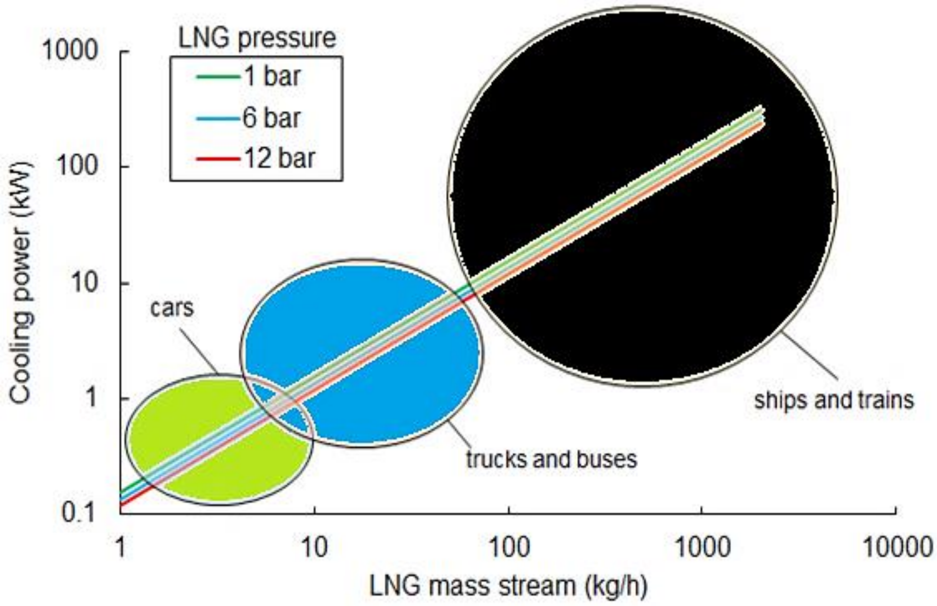

Fig 2- Cooling power systems for different LNG vehicle applications

From the figure 2, which is the cooling power system for different LNG transport applications, the allowable LNG mass stream (kg/h) shows the different mass flow rate into different vehicle engine rates. It can be seen that for small car engines, a mass flow rate arising from the boil-off rate from the cryogenic tank is between 1-10 kg/h. The range for buses and ship are at 10-100 kg/h and 100-10,000 kg/h respectively. These boil-off LNG are regulated by exchanging a coolant heat with the cryogenic tank with the surrounding. It can be seen that a cooling power of 0.1-1KW is necessary to maintain the boil-off rate from the cryogenic rank. The same can be seen for trucks and ships ranging from 0.5-10KW and 1-1000KW respectively. Different cryogenic tank pressures were tested for the fed tanks from 1bar -12 bars and it was noted that the pressures had little influences on the boil-off rates and the cooling power needed as shown in Figure 2. Although one the downside is that LNG boil-off can be a source of risky pressure increase in LNG tanks. There is therefore the need to research into other ways of controlling boil off buildup and reducing pressure of the boil-off gas and to avoid emitting of the boil-off natural gas in stored tank. The LNG business contributes to the country's economy, by creating employment through the construction and installation of new gas stations and plants respectively.Nwosi.*et al.*(2018). Using liquefied natural gas has numerous significance to our every living, especially in a developing nation like Nigeria where oil and gas companies even the host government is making effort to trim down gas flaring as a result, diversifying the usage of conventional fuel to gas is of major importance to the increasing the economy, because LNG is of less noise, cheap and pollution free due to its ability to absorb CO_2, thereby curtailing the emission of Carbon dioxide into the air that causes pollution which result in a terminal ailments. The gas utilization is done through the application of gas characterization technology, to characterize the gas either for industrial or domestic usage or external usage as air-conditioner in football stadium and offices that requires it through a condenser technology.

The aim of BOG liquefaction and utilization is lowering energy consumption. In the re-condenser both phases mixes: ca. 3 kg of cooled LNG per ca. 0.5 kg gaseous vapors, under a pressure of 4 to 6 bar. Gas liquefies through isobaric cooling process from the temperature gas has before the liquefaction to the temperature of boiling. Then in the course of Isobaric-isothermal transformations, condensation heat is recuperated. Liquefied gas exchanges heat with cooled LNG. Thermodynamic processes of LNG vaporization have been visualized in figure. 7. The course of plots illustrating the pathway of LNG starts from the inlet to the pump in the storing collector (point A), through the outlet of pump 1° (point B), inlet of LNG to re-condenser (point C – of the same enthalpy as point B), outlet of the evaporator (point D) and outlet of pump 2° (point E). Engine conversion is necessary to determine the suitability and ease of accommodating the newly introduced gas as fuel, the engine conversion will give rise to liquefied natural gas application in both transport sector and other usage in form of air-conditioner, energy to cars, engines and aeroplane. The liquefies natural gas(LNG) will use fuel engine consisting of natural gas that will be of less noise, cheap and anti-pollutants to human activities. One major advantages of liquefied natural gas (LNG) is that, it can be operated in compression ratio.

2. MATERIALS AND METHOD

2.1 Description of the Boil-off production from Car's cooling system

The materials consist of an LNG tank, LNG sample; a car and the process. The method will be conducted in line with a sequence of data collection, natural gas laboratory analysis. The method followed all thermodynamic processes connecting LNG at the LNG receiving terminals environment of the LNG Boil-off Gas production process flow, the LNG is fed into the cryogenic tank via stream one tagged LNG, the atmospheric heat flux to the tank system is supplied through stream two while the outlet streams consist of metering element and the produced Boil-off Gas. A non-return valve is installed to control volume to the control volume tank to supply the gas to the engine for combustion. Liquid evaporation on vapor-liquid interface is: the temperature in the vapor phase space, the thermal stratification region and the main body area are all uniform. Vapor phase space is filled with the overheating vapor. Besides, the main body area is occupied by the super-cooled liquid. Furthermore the temperature in thermal stratification region is higher than the main body area.

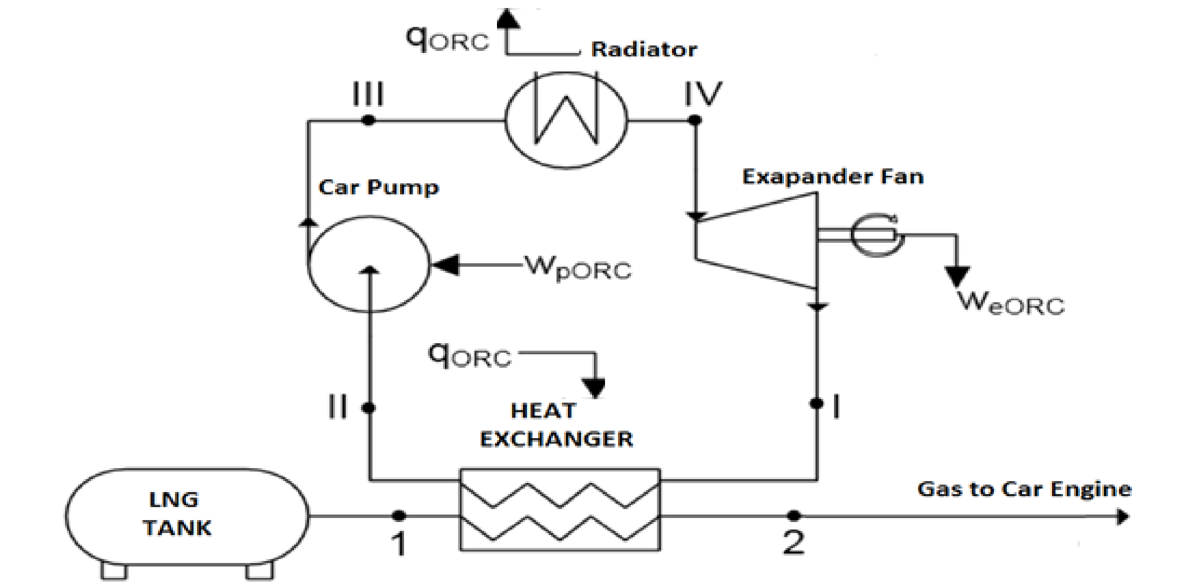

Figure .3 Description of the LNG Tank's Boil-off production process flow diagram

The re-gasification process from the cryogenic tank can be abetted more efficiently as shown in Figure 3. A heat exchanger can be used to exchange heat to the cryogenic tank to enhance the production of the boil-off gas by using the heat from the car's radiator. This heat raises the temperature of the circulating water and exchanges it with the LNG delivery stream to the car's engine. This gradually enhances the production of boil-off gases within its stream while the car's pump pushes the water back to the radiator to enhance its cooling efficiency. This process is made achievable due to the high vapor pressure of the LNG due to the methane constituents present within. Table 1 shows the vapor pressures of the different constituents of the Natural Gas according to Raoult's law.

Table 1. LNG AND BOG Composition (Łaciak, 2013)

Composition	Liquid Phase Mole Frac. [%] LNG	Vapor Phase Mole Frac. [%] BOG
Methane	89.87	94.011
Ethane	6.65	0.011753
Propane	2.30	0.00 (4.264×10^{-5})
n – Butan	0.57	0.00 (1.556×10^{-7})
i – Butane	0.41	0.00 (2.29×10^{-7})
n – Pentane	0.00	0.00
i – Pentane	0.01	0.00 (2.61×10^{-10})
Nitrogen	0.19	5.977

LNG density at temperature of -162°C (at pressure of 1 Bar) is 459.8 kg/m^3 and has calorific value equal to about 50 MJ/kg (21.5 GJ/m^3). In normal conditions, one cubic meter of re-gasified LNG has density about 0.79 kg/m^3, and its calorific value is about 34 MJ/m^3. If the whole change of enthalpy connected with LNG regasification from 112 K to ambient temperature is used, then the corresponding energy is about 724 kJ per 1 kg of LNG. Owing to the isobaric heating effect (from 112 K to ambient temperature), LNG undergoes the phase change and overheating.

2.2 Energy Consideration

Exergy E_x of heat Q given away to the environment is calculated as maximal work which the Carnot engine can perform at a given level of temperature

$$E_x = Q\left(\frac{T_n}{T}\right) \quad (1)$$

Where T-temperature of substance giving off heat and T_n is ambient temperature.

Thermal exergy connection with a difference of temperature

$$E_{x,t} = E_x(p, T_o) - E_x(p T_o) \quad (2)$$

$$E_{x,t} = \left(\frac{T_n}{T_s} - I\right) r + \int_{T_n}^{T_s} cp\left(I - \frac{T_n}{T_s}\right) dT \quad (3)$$

Where r is the enthalpy of evaporation, being the enthalpy difference between gaseous and liquid phase,

Exergy coming from a difference of pressures (in constant temperature)

$$E_{x,t} = E_x(p,T) - E_x(pT_o) \quad (4)$$

$$Ex, p = \int_{pn,T_n}^{p,T_s} vdp \quad (5)$$

Total exergy is a sum of both terms;

$$E_x(p, T) = E_{x,t} + Ex, \quad (6)$$

3. RESULTS AND DISCUSSION

The Psychometric chart of the LNG was studied at the pressure - enthalpy relationship. Heat is being added as a result of the temperature from the ambient condition as well as from the heat from the radiator. This causes pressure build-up within the cryogenic tank still at the liquid phase and slightly some vapor components. The tank comes pressurized at an isobaric condition causing a drastic change in the phase of the LNG producing boil-off gases. These Boil-off gases still acquire heat addition and then are sent out to the engine for the car for fueling. Figure 4 shows the psychometric chart of the relationships of the LNG stream at different enthalpy and pressure conditions. The critical point is most best suited for the operating condition of the tank to sustain constant supply to the engine of the vehicle and the production of more boil-off gases to keep the process cycle in equilibrium. A deviation from the equilibrium will cause more pressure build-up as a result of less LNG mass stream to the engine or a drastic pressure drop as a result of more feed than boil-off production to the engine.

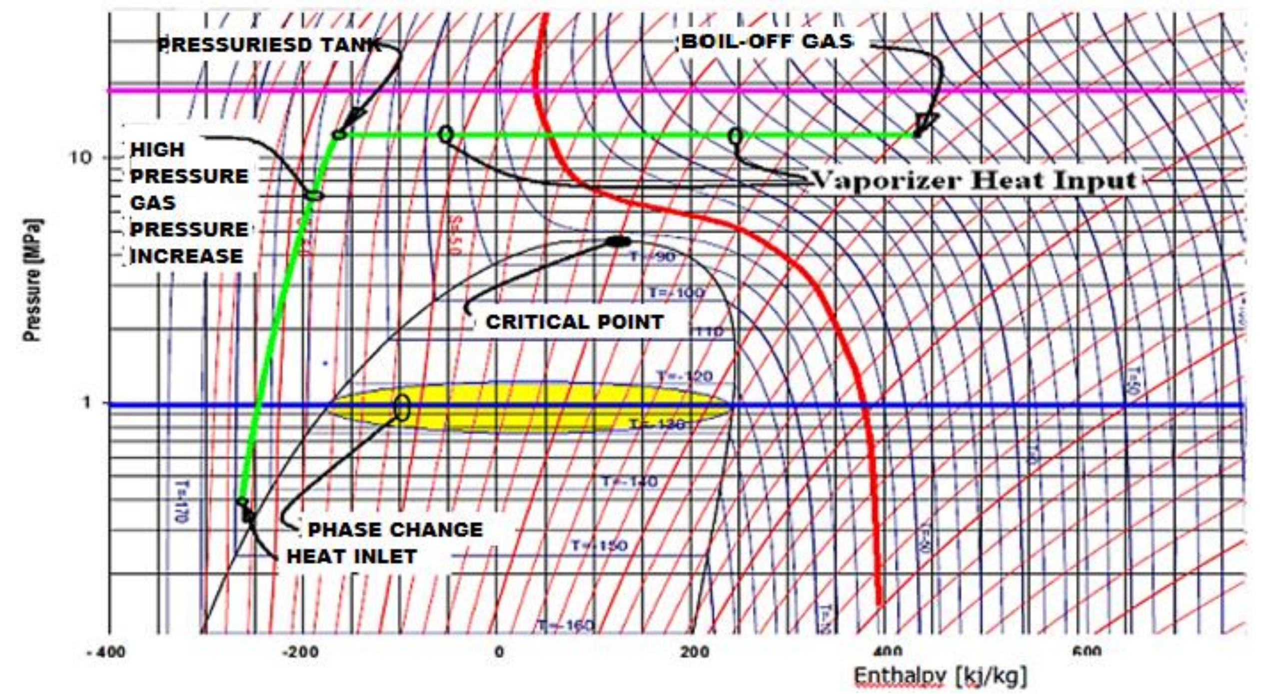

Fig 4. LNG Boil-off Pressure- Enthalpy process

Using the exergy analysis to determine the engine performance, it was deduced that the heat exchange creating the boil-off gas being fed to the energy is as a function of the expander work and the pump work of the cycle.

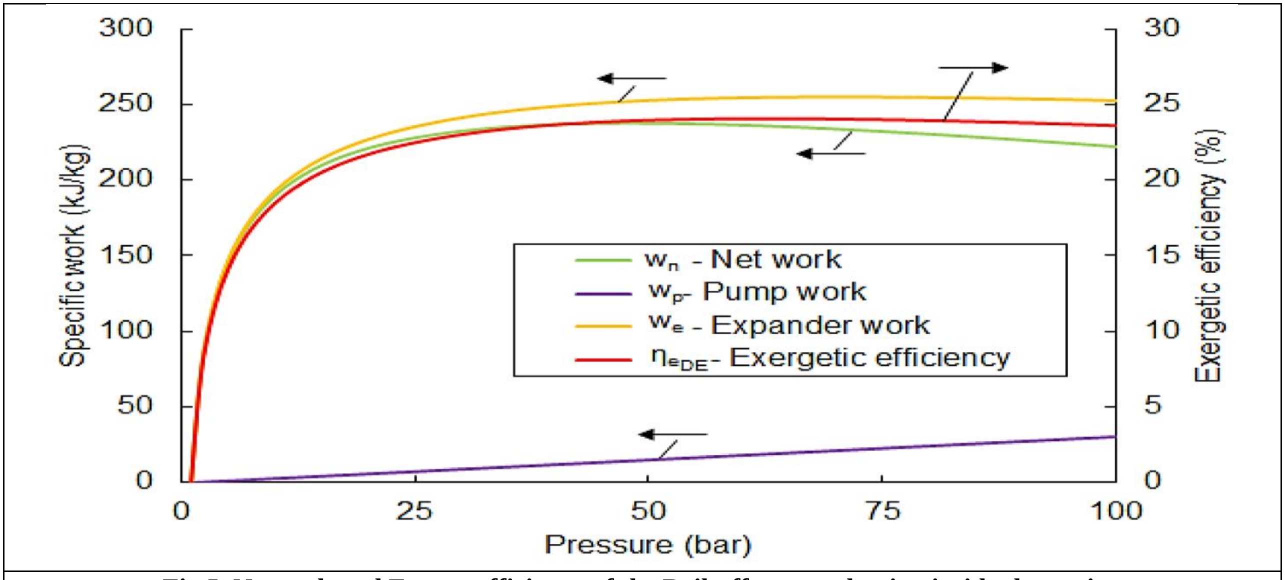

Fig 5. Network and Exergy efficiency of the Boil-off gas production inside the engine

The difference between the expender work and the pump work produces the net work of the gas in the engine. This is denoted by the area covered from the expander curve and the pump curve which equates to the net work curves from the base of the graph. This is stipulated at 22% efficiency. When considering the exergy of the system, which describes the useful work involved in the engine, the exergy efficiency amount to about 24% efficiency. This occurs at 230KJ/Kg.

4. CONCLUSION

In conclusion, the transport sector in Nigeria holds great business potentials and initiating LNG-fuel technology in the transportation sector which is a function of better engine efficiency. This new innovation will alleviate the hash economic challenges in the sector. The boil- off gas production from the build-up pressure in the cryogenic tank illustrates the LNG feed stream that is to be sent to the retrofitted car engine as a fuel.

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