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THERMODYNAMIC CONSIDERATIONS FOR THE APPLICATION OF LIQUEFIED NATURAL GAS AS TRANSPORTATION FUEL

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Abstract

This study aims to analyze the thermodynamic considerations for the application of liquefied natural gas (LNG) as a transportation fuel. It is designed to solve transport fuel problems and tackle public health issues associated with vehicular engine emission, and vehicle fuel shortages. It considers the economic and technical viability of applying low-temperature fluid as fuel in an LNG-fuel Spark Ignition Engine through computer simulation. Process design configuration was achieved using the User Define Function (UDF) in fluid simulation software (ANSYS Fluent), Finite Element Analysis and Aspen Hysys. 12 kg capacity volume cryogenic tank design was done through Autodesk inventor with an initial temperature of -162^{0}C and pressure of 1 bar and ambient temperature application ranges of 20^{0}C to 40^{0}C. The ANSYS simulation result showed a thermodynamic effect of heat and mass transfer rate range of 1.6% to 7% W/m^{2}k concerning the time taken by the tank to absorb heat through temperature ranges of -155^{0}C to 250^{0}C. Also, 0.04kg/s was the total volume of boil-off gas (BOG) produced, while the maximum exhaust gas emissions recorded was 0.254kg/s. The advantage of this technology was the minimal volume of greenhouse gases released during combustion relative to gasoline and diesel, signifying less pollution, and buttressing the applicability and adoption of LNG-Fuel as a transport fuel.

Key Word: *Thermodynamic properties; LNG Utilization; Transportation Fuel; ANSYS; Exhaust gas.*

1.0 Introduction

In recent years, the world has witnessed an unprecedented rate of urbanization leading to an increase in vehicular emissions and subsequent deterioration of air quality. This has prompted the need for alternative fuels that are sustainable, clean, and eco-friendly, such as Liquefied Natural Gas (LNG) [1]. LNG is a cost-effective and low-emission alternative to traditional fossil fuels that has emerged as a viable option for transportation. However, the efficient and practical application of LNG as a transportation fuel requires a detailed understanding of its thermodynamic characteristics [2]. In this study, we aim to investigate the thermodynamic considerations for using LNG as a transportation fuel. The study on thermodynamic considerations for the application of liquefied natural gas as transportation fuel is significant because it addresses the increasing demand for sustainable and cleaner energy in the transportation sector. It provides an understanding of the energy efficiency, and environmental performance of using LNG as a transportation fuel. The results of this study can assist policymakers, industry experts, and researchers in making informed decisions regarding the growing implementation of LNG as an alternative fuel for transportation in most countries of the world, thereby reducing greenhouse gas emissions, improving air quality, and contributing to the sustainable development of the transportation sector. Liquefied natural gas (LNG) is an innovative technology that showcases a high prospect for out of harm's way natural gas treatment, storage, management and transportation [3,4]. LNG is natural gas in liquid form with a reduced temperature of (-256^{o}F) or degree C, we record LNG as having a temperature of (-162^{o}C) and under an atmospheric pressure (1atm) [5]. At this point LNG is regarded or classified as a concentrated liquid gas that has been converted to liquid, for the reason that the process takes place at a very low temperature below (-100^{o}F) we also classify LNG as a cryogenic fluid [6]. Another huge advantage associated with the process of NG Liquefaction is that after the gas is decreased in volume to the liquid fluid by the time it's converted back to gaseous outward or physical appearance its volume expands and increases to the degree of six hundred (600) times [7,8]. Consequently, presenting it as a more cost-effective means of transport sandwiched between or involving continental business in a particular configured ocean cargo yacht. The old traditional method or long-established pipeline means of transportation systems perhaps is not advisable due to multiple issues such as distance or would generally be less reasonably attractive. A report by the U.S Department of Energy, states that 80 per cent of the global transportation fuels used nowadays are produced via the derivatives of hydrocarbon. These products consist of Premium Motor Spirit or Gasoline, Marine fuel, Automated Gas Oil or Diesel, Jet fuel and LPG (Liquefied Petroleum Gas) [9,10]. Transport fuels are forms of energy starting points that power a mixture of transport means, usually to provide energy for internal conventional combustion vehicle engines [11,12]. The various means of transportation that make up the sector include rail (trains), air transport, water (cargo ships) and road transport which comprises trucks, passenger cars and buses. Currently, these are the various means of transporting goods and the populace from one point of destination to another point. A report indicates that the sector is the largest consumer of oil refinery products and shares about 20% of the worldwide energy utilization [13]. Production of Transport fuels which are fossil fuel-based is the consequence of the drilling of oil and gas from various reservoirs. To the flow station operations that prepare the crude oil for pipeline quality for refining to transform the energy extracted from oil and gas resources into end-user specifications [14,15]. Due to the principal source of liquid fuels, they vary based on their chemical makeup and characteristics. The molecular structure of the mixture of elements in a fossil fuel source (carbon, hydrogen, nitrogen and others) determines the phase of physical appearance as fuel. Liquid fuel sources consist of ammonia, crushed coal, petroleum, alcohols, hydrogen, natural gas and bio-fuels. [16]. Each refinery configuration is designed to feed on a particular crude oil to distil and refine a variety of liquid fuels which is dependent on the chemical composition and mixture [17,18] Bio-mass is another form of liquid fuel which is converted as a result of technological processes while Ethanol and biodiesel are the two regular bio-fuel types that are currently gaining a widespread in the global transport fuel market today. Combustion of gasoline and diesel is polluting the environment in most cities around the world. Hence LNG utilized as a transport fuel will reduce pollution owning to its lighter carbon association, unlike heavier hydrocarbon products. [19]. Public health problems associated with road vehicle transport have turned out to be more severe on the environment. Advancing the use of LNG as a transport vehicle fuel is a solution to trim down emissions, modify the path for road goods and services transport progression, and construct a resource-saving civilized society. For LNG to be utilized as transport fuel the retention time for cold energy storage is a problem and the thermodynamic stability and determination of phase equilibrium is one of the most central problems associated with the calculation of multi-component mixtures thermodynamic properties [20,21].

Environmental pollution problems with conventional fuels have paved the way and served as an encouragement for researchers to think of how to solve the problem of global public health issues. Low domestication of natural gas resources in some host nations, developing nations with abundant proven reserves of natural gas but lacking basic infrastructure for utilization has led to wastage. The low price of LNG in the international market is paving the way to seek alternatives for domestic utilization [22]. This study aims to conduct a computer-aided engineering simulation to determine the thermodynamic effect of LNG as a transport fuel. To simulate the impact of the thermodynamic properties of the LNG stored tank and to utilize the Finite Element Analysis (FEA) and Computational Fluid Dynamics (CFD) to run the simulation analysis. To calculate the impact of heat gain from the surroundings to the shell of the cryogenic tank. Through the application of ASPEN HYSYS software, sources real-life data as input data into the software. To determine the volume of BOG before entering the engine, use the simulation result to confirm the required volume of boil-off gas generated within the cryogenic tank and the volume required by the engine for combustion reaction. To use ANSYS to run a combustion Simulation of the engine. Use the software to analyze the volume of emission of two different fuels as compared with LNG as fuel. Calculate the impact of pressure and temperature of the four strokes spark internal combustion engine as compared with the conventional fuels [Premium Motor Spirit and Diesel].

2.0 Materials and Method

2.1 Materials

The research design for this work was based on simulations involving thermodynamic properties, internal combustion engines, cryogenic tanks, natural gas, liquefied natural gas premium motor spirit and diesel. Thermodynamic consideration of Models, continuing functions, equations, variables involving pressure, temperature, heat and mass transfer and flow rates were utilized from real data sourced from literature. The three-dimensional (3D) model of the cryogenic tank was achieved using a computer-aided design (CAD) package where the boil-off gas determination was attained from a prototyped design using numerical simulations like the computational fluid dynamics (CFD) approach. This involves using thermal conditions from ambient conditions and also forced thermal inclusion. The physio-chemical properties were further explored using a Computer Aided Engineering package (CAE) to simulate in real-life effect of the entire process. The Process flow diagram (PFD) of the process was deduced and calculated using the ASPEN Hysys package which utilizes the thermodynamic models and process conditions to determine the outcome of the desired investigation. At the tail end, the results from the process were fed into a car’s internal combustion engine (SI Engine) which was carried out using simulations to determine the output of the power production of the engine. The CFD approach with proper meshing of the model was carried out effectively.

2.2 Method

The method includes a Cryogenic Tank Multi-Layer Shielding and Insulation (MLI) design and a computer-based simulation. The multi-layer shielding and tank insulation are technologies developed by cryogenic engineers to handle the technical difficulty of unregulated temperature and pressure. This challenge could lead to pressure build-up, increase in temperature and explosion as a result of improper design calculation and material selection. MLS and MLI were used to make adequate cryogenic tank design considerations within the internal region. There are several types of excessive heat flux and transfer control and preventive measures or technology. The equation for the calculation of the Multi-Layer Shielding system is presented in equation (1) and for n shields in association with the system emissivity e, the heat transfer exchange consideration is based on.

$$q_r = \left(\frac{\varepsilon}{(n+1)(2-\varepsilon)}\right)\sigma\left(T_1^4 - T_2^4\right) \quad ...(1)$$

This is defined in such a way that considering the factor of 1/n + 1, the emissivity $\varepsilon << 1$, is reduced to q_r. Hence the analysis is based on the fact that the distribution of temperature shield across the tank system is not uniformly circulated, for the reason that the heat transfer exchange is not linear.

2.2.1 Description of the Entire Process

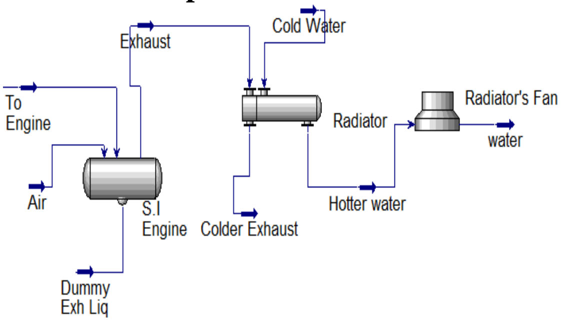

Figure 1: Simulated Spark Ignition Engine systems

The simulations of the LNG spark ignition engine system followed a series of feed gas sample analyses and the definition of the composition. Before this point in time all critical parameters had been analyzed on had been carried out. From the cryogenic storage tank, the LNG stream is defined as the inlet while the external heat stream is sourced from the atmospheric or ambient temperature. The atmospheric heat impact of 25^0C as against -162^0C LNG temperature stored tank internal temperature produced sufficient feed gas that is controlled through the flow line to the compressor where it is compressed to a non-return valve to the control volume as presented in Figure 1 above. From this point, the feed gas is pressurized with an increase in temperature to meet the engine specification for fuel combustion. The stream flow line continues through the steam tagged (feed gas to the engine) as an inlet stream to the engine while the second inlet stream attached to the engine is designed for air induction from the atmospheric air for the fuel-air ratio combustion. The dummy exhaust liquid is configured for the lube oil stream primarily for the lubrication of the engine. While the stream-tagged exhaust is for the removal of combustible or burnable exhaust gases which is, in this case, an extremely small quantity or infinitesimal volume of CO_2 and water based on the reaction of methane and oxygen, methane composed of one carbon atom and four hydrogen atoms reacting with oxygen will produce little carbon dioxide and water as against the conventional fuels with multiple carbon chains or atoms associated with several hydrogen atoms also as the result will produce enormous volume of CO_2 and water indication in chapter four. The exhaust gas stream design configuration in this process tagged (exhaust) is unlike the conventional tailpipe exhaust which is channeled to the atmosphere for the release of combustible gas but in this new process, it is designed to supply heat to the radiator. The radiator in this process has an inlet stream of the engine exhaust and the cold-water stream. Both the cold-water stream and the engine exhaust gas stream supply the radiator with the required temperature while the two other outlet streams [7]. The cryogenic tank system consists of a nozzle, cryogenic ball valve, LNG supply feed line, Vent, Safety relief valve, LNG flow meter, Gauge and LNG supply feed line to the engine. The fluid in the cryogenic tank (LNG) is separated into four parts: the vapour phase space, the thermal or heat leak region, the core body area, and the system boundary layer. The entire LNG-fuel technology for the spark ignition engine process is designed to clutch 20 20-litre volume LNG cryogenic tank. The setup contains a 12kg LNG sample, the 12kg was used as the capacity of LNG in the cryogenic tank with the volume, which is 12000 scf LNG equivalent when re-gasified as used in the stored tank. The cryogenic tank includes an intake nozzle which is the LNG supply feed line, it serves as the intake gas supply unit, the Vent unit is used to ventilate the thermal overfill which is not allowed to build up, an unstable storage condition will result in a major safety issue [13].

2.2.2 Tank Design Model Assumptions

We assume that the volume and mass of the LNG tank are 12,000 M^3 and 12kg respectively. The LNG cryogenic stored tank product is assumed as a sink; the heat source is the ambient condition or the atmospheric surroundings. Thermal conductivity, *k* (Watts/m/°C) is not state-dependent or temperature. For the Liquefied Natural Gas (LNG) cryogenic tank system design, certain considerations are very critical before designing the tank. We look at the material selection that will be able to withstand extremely low-temperature tank configuration. The tank Sizing, Rating, Volume m^3 of the tank, tank diameter (m), Length, head height (m), Nozzles, Heat loss, level of taps, tank geometry and orientation, flat cylindrical and horizontal and the shape of the tank [20].

Table 1: Stored Tank Design Dimensions

S/N	Rating	Head Height (m)	Volume (M^3)	29452.431 M^3
1	Geometry	Flat Cylinder	Diameter (m)	25 (m)
2	Orientation	Horizontal	Length (m)	60 (m)

The length and diameter of the tank which are in meters are calculated to be 25 meters and 60 meters correspondingly while the total volume capacity of the tank is calculated to be 12,000 M^3 the detailed design dimensions are presented in Figure 2: as shown below.

2.2.3 Simulated Cryogenic Tank Cycle Main Parameters

Table 2: Required Insulating Material Thickness for Spherical Storage Vessels for LNG

	Cp ($J\ Kg^{-1}\ K^{-1}$)	μ (Pa s)	K ($Wm^{-1}K^{-1}$)	ρ (kg m^3)	Emissivity
Perlite	UDF	-	387	50	0.55
Air	1006.43	$1.79e^{-5}$	0.0242	1.225	
LNG	3450	$1.46e^{-4}$	0.193	424.53	
Methane	2222	$1.09e^{-5}$	0.0332	0.6679	

Table 3: Thermal Conductivity of Glass Wool Insulations for Boundary Temperatures of -162°c and (-139⁻F) and of Foam Insulations for Boundary Temperatures of 300k (80⁻F) & 77k (-139⁻F)

			Thermal Conductivity	
Foam	**Kg/m³**	**Ibm/m³**	**mW/m-K**	**Btu/hr-ft—F**
Polyurethane	11	0.70	33	0.019
Polystyrene	39	2.4	33	0.019
Rubber	80	5.0	36	0.021
Silica	160	10.0	55	0.032
Glass Wool;	140	8.7	35	0.020

Table 4: The Characteristics of the BOG to be liquefied are the Following

Density (100 % Methane):	425 kg/m^3
Minimum temperature:	-163ºC
Tank volume:	294300 m^3 and 95 % tank filling
Design volume of BOG	0.15 % of cryogenic tank volume per day

Table 5: BOG-composition (mole %)

Methane	84-100 %
BOG pressure:	1.03 bars

Table 6: Compressor Operating Parameters

Suction Pressure:	1.03 bars
Suction Temperature:	-120ºC
Discharge Pressure:	2.5 bar
Discharge Temperature:	-31ºC (100 % CH4)

Initially, an experiment was conducted for proper material selection to determine the appropriate cryogenic tank that will hold LNG in a sport utility vehicle for a calculated period (48 hours) and a liquefied natural gas sample of 12kg was used to test run and 1m^2 surface area of the cryogenic tank. For an LNG tank carrier with an expected boil-off gas generation for immediate use, one of the major factors to be considered is the impact of the atmospheric heat or the thermal Radiation from room temperature which is above the LNG temperature and is the main source of boil-off gas production and also is one of the main heat loads in cryogenic systems. The Stefan-Boltzman constant has been used to determine the rate of emitted power against the wavelength of radiation of a calculated cryogenic system. Finally, Perlite material was used for the tank insulation with vacuum wall design due to it is temperature-depended and its lack of constant thermal conductivity [21].

$$E_b = \int_0 e_b (T, \lambda) d\lambda = OT^4 \quad \ldots(2)$$

$\sigma = 5.67 x 10^{-8} \, w/m^2 K^4$

The Emissivity in this case is the LNG tank carrier property of the exterior material that establishes and decides the division of radiant flux that is engrossed or emitted. The emissivity ε depends on material conductivity and temperature. ε Is also a function of wavelength, but engineering usually relies on average values measured for a range of temperatures.

For a real surface, $q_r \cong \varepsilon \sigma T^4$

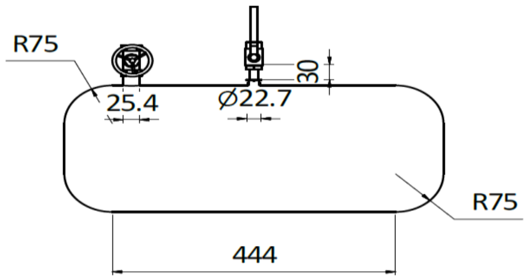

Figure 2: Cryogenic Tank Design with Dimensions

The Nickel Steel material was selected. A look at the basis for refrigeration as to maintaining the initial temperature of the system when the vehicle is static and when it is in motion because excessive boil-off gas can lead to explosion due to pressure surge and build-up within the tank. Another significant factor to be considered is the Heat exchange medium within the tank and the Thermal insulation of the system for the prevention and control of heat leakages.

The American Society of Testing and Materials (ASTM) set out the specifications for the material requirement for the design of very low-temperature substances. The ASTM A353 code is the specification for nine per cent (9%) nickel steel plates for cryogenic tanks that are double-normalized, and nickel steel is also applied for low-temperature substances container welded pressure vessels.

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Ordinary steel usually has two or more slip systems within a very freeze-up temperature. The area considered as two (2.) is the tank inlet valve with control elements attached, such as volume gauge and three (3.) is the outlet valve also with control element attached, such as pressure build-up relief systems.

$$\frac{d(heat\ flux)}{dx} + Heat\ \sin k\ \ per\ unit\ volume = o$$

$$\frac{d}{dx}\left(-k\frac{du}{dx}\right) + q(u.x) = o \qquad \text{...(3)}$$

Where

u = the temperature of Nodal in °C;

k = Thermal conductivities measured in Watts/m/°C;

q = The Heat sink for each unit volume in Joules/m3;

x = Distance of outer wall of outer spherical to inner wall of inner spherical shell in metres.

The central equation can be a consideration of forcing the residual to be zero in a spatially averaged good judgment. Resolving equations using the finite element approximation we divide the domain of the LNG tank into three major separated lengths to form the node. Each of the different lengths represents the node of the finite elements of the continuous unit field variable inside every one element by the approximation of parametric finite element. Considering the domain fundamental integral in solving Equation 1, we can determine and replace the fundamental sum of each of the integrals used differently over the three elements outer spherical shell, insulating material and inner spherical shell as shown in Figure 2.

$$\int_0^{x_3} dx = \int_0^{x_1} dx + \int_{x_1}^{x_2} dx + \int_{x_2}^{x_3} dx \qquad \ldots(4)$$

We use this equation to space and normalize all the element integral where dx/d$J x\varepsilon$ is considered as the Jacobian of the conversion or of transformation and change from x coordinates to coordinates ε. The element integrals taking place from the Left-Hand Side of the tank to the right will become the form shown in equation (3) equation can simply capture the values of 1 or 2. Now to explain and solve the stiffness matrix for element 1, the analysis for the finite element correlation involving x and ε coordinates is in use as and expressed as. $x = a\ \varepsilon$. a = the thickness of the element considered and calculated in meters. As a result, d$x / d\varepsilon = a$. Jacobian, J = d$x / d\varepsilon = a$. Substituting the Jacobian, J in Equation (3), automatically we have:

$$E_{mm} = a\int_0^1\left(\frac{1}{a_2}k.\frac{d\varphi_m}{d\varepsilon}\frac{d\varphi_n}{d\varepsilon} + \varphi_m\varphi_n\right)Jd\varepsilon \ldots(5)$$

Considering a situation where the indices m and n are 1 or 2. To analyze and evaluate ***E****mn*, we look for the alternatives of the basic functions by substituting 1, and 2 by substitute in addition to integrate. The above equations give the stiffness matrix for element 1; the ANSYS software was used to solve the finite element discretization of the cryogenic tank element node. The temperature of the system is uniformly distributed or is homogeneous for the vapor-liquid phase which is represented as (T_g) and (T_l) for each phase is considered as one with inter-phase heat transfer. The consequence of the turbulence of the host vehicle motion is not accounted for. A look at the interest in modelling principles and the energy balance for the liquid phase may be described below:

$$\frac{d}{dt}(mh)_l = Q_l - \dot{m}_b\, h_{g,i} \qquad \ldots(6)$$

Where the boil-off rate is represented by the m_b and the enthalpy of the gas-liquid is written as $h_{g,\ i}$, now the corresponding rate of heat transfer to the liquid phase is received from atmospheric air and the radiator heat flow line from this process. We used equation (6) to model the heat transfer from the first point of the superheated layer of the liquid to consider the superheated gas region to the vapour-liquid interface boundary as presented.

$$Q_l = Q_{a-l} + Q_{sw-l} + Q_{c-l} + Q_{g-l}$$
$$= (UA)_{a-l}(T_a - T_l) + (UA)_{sw-l}(T_{sw} - T_l) + (UA)_{c-l}(T_c - T_l) + fQ_{a-g} \quad (7)$$

Where:

$$Q_{a-g} = (UA)_{a-g}(T_a - T_g) \qquad \ldots(8)$$

Since the degree of heat from the environment is not at a steady state there is a provision for measure at every region of application. For the ambient air temperature (25^0C) to increase from one level to the other from the model relation as expressed it is a function of time and has been calculated right through the simulation work. [9] In their work on the method of modelling an LNG cryogenic system weathering-based non-equilibrium principle, they utilized the exchange mechanism of heat in the gas-liquid phase to investigate the relationship of a conduction heat transfer. From their findings, successful thermal energy conductivity was achieved for the LNG heat transfer mechanism to derive energy. To offer an efficient result based on other forms of heat transfer modelling calculation in the gas phase, the convective heat transfer mechanism was adopted. Already developed and modelling approach for gas-to-liquid heat transfer analysis tool hence current studies have modified what they did to a simpler model, although almost the same thing but with more interest in liquid to gas heat transfer mechanism. As the liquid is studied in this case as a constant fraction based on the heat gained from the gas phase, looking at it as the variations and deviation from the mass of liquid that will be sufficient within the stored tank for the process of evaporation to create the required boil-off gas, consequently the liquid phase mass balance is expressed as [10]:

$$\dot{m}_l + \dot{m}_b = 0. \qquad \ldots(9)$$

Based on the liquid phase mass balance, the phase for gas and the equivalent energy balance for the superheated region will be expressed as:

$$\frac{d}{dt}(mh)_g = \dot{m}_b h_{g,i} - \dot{m}_f h_g + Q_g \qquad \ldots(10)$$

Where m_f is the mass flow rate of the boil-off gas or processed gas created from the stored tanks and moving through the compressor flow line as fuel gas supply to control volume for engine combustion and Q_g is the total heat flow into the gas phase, consisting of the heat absorbed due to the ambient air Q_{a-g} and the heat transmitted from the gas to the liquid interface Q_{g-l}.

$$Q_g = Q_{a-g} - + Q_{g-l} \qquad \ldots(11)$$

Now we consider the total heat flux flowing to the LNG first based on the ambient air in Equations (11), before looking at or analyzing the heat flowing through the radiator heat as the second heat source to the LNG control volume stored tank. Also, the net or total mass transfer flow rate 8modelling of the gas phase is investigated as the variation involving the evaporated boil-off gas and the extracted mass flow rates:

$$\dot{m}_g + \dot{m}_b - \dot{m}_f \qquad \ldots(12)$$

We could not determine the net mass flow rate of the system without considering the volume of the system therefore in furtherance to the analyzed transfer models of mass and heat. The consideration for the volume of the tank will enable the realization of efficient and effective mass transfer volume which is constant and is written as:

$$\frac{d}{dt}(V_l + V_g) = \frac{d}{dt}\left(\frac{m_l}{p_l} + \frac{m_g}{p_g}\right) = 0. \qquad \ldots(13)$$

Consequently, the application of this model may differ as the case of a multi-component is brought to bear and also that of a single component. Now to determine direct application will require the analysis of the substance either a pure component such as methane or other hence for this study we are dealing with methane. Methane as the major constituent of LNG is considered here to be a single component although with other little fractions of ethane, propane and the rest of other components are negligible. Now a detailed application of equation (8) for T_l and T_g and solving equation (8), for the mass balances, we have:

$$T_l = \frac{\dot{Q}_l - \dot{m}_b \Delta h_{il}}{(mc_p)_l}, \quad \ldots(14)$$

And

$$T_g = \frac{\dot{Q}_g - \dot{m}_b \Delta h_{ig}}{(mc_p)_g}, \quad \ldots(15)$$

Where

$$\Delta h_{il} = h(p_g, T_i) - h(p_l, T_l) \ \ and \ \ \Delta h_{ig} = h(p_g, T_g).$$

Assuming we decide to increase the volume of the stored tank LNG cryogenic system, the boil-off gas that will be created as a result will have an increase in the mass flow rate and the tank volume constraint will be determined using equation (14) and also the application of equation (15), and the expression for the boil-off gas rate in the scenario is archived after a significant and substantial algebraic manipulation:

$$\dot{m} = \frac{\dfrac{\dot{m}_f}{p_g} + L\dfrac{Q_l}{(mc_p)_l} + \dfrac{G}{p_p}\left[\dot{p} - p_T\dfrac{Q_g}{(mc_p)_g}\right]}{\Delta p + L\dfrac{\Delta h_{il}}{(mc_p)_l} + G\dfrac{P_T}{p_p}\dfrac{\Delta h_{ig}}{(mc_p)_g}} \quad \ldots(16)$$

Where:

$$p_T = (\partial p / \partial T)_p, \ p_p = (\partial p / \partial p)_T, \Delta p = (1/p_g) - (1/p_l),$$

The L and G represent liquid and gas phase interconnected quantities correspondingly:

$$L = \frac{m_l}{p_1^2}\left(\frac{dp_l}{dT}\right), G = \frac{M_g}{p_g^2}. \quad \ldots(17)$$

Conclusively for the modelling of transfer of mass and heat in a stored cryogenic tank, especially cold fluid at transient conditions and a single component, the expressions in equation (16) are considered as the most appropriate as the governing equations due to [5]. By random diffusion of molecules, there is an exchange of molecules in the z-direction. The movement is based on the transient regions of more rapidly or faster - to the lesser area of concentration or slower-moving level a layer. This equation demonstrates the boil-off gas moving through the pipes from the concentrated cryogenic tank to the retrofitted engine for the combustion process.

$$J_{AY} = -D_{AB}\frac{\partial Ca}{\partial y} \quad \ldots(18)$$

2.2.4 The Conceptual Framework of the Simulation Process

The conceptual framework of the LNG-Fuel technology was the first starting point while the research simulation process was based on three major engineering processes which include process design, process software simulation. The three processes were bounded by thermodynamic basic principles and properties to achieve the entire configuration of the process. For the process design, the cryogenic tank design was first initiated to attain the appropriate three-dimensional (3D) model design parameters with the aid of a computer-aided engineering design (CAED) tool. The Autodesk inventor professionals were used for the tank's actual sizing given the fixed LNG volume capacity of (12Kg) LNG that was used, three-dimensional 3D, the data for the tank sizing was inputted into the software. The model for net energy conservation: The fluid stored tank (LNG) is partitioned in layers of four: The boundary, thermal region, the core and the vapour phase, analysis through the ANSYS application [5].

$$Q = q_l \cdot F_{wl} + q_g \cdot F_{wg} \quad \ldots(19)$$

$Q = q_l$ is the heat leakage in the liquid phase and vapour phase per unit area and per unit time in the stored tank, in that order, W/m^2 while F_{wl} and F_{wg} indicate contact region of the interior with liquid-vapour phase m^2. Analysis based on the theory of liquid-vapour phase space. It is assumed that the heat leakage must have a constant value [13]. The irregular heat leakage owing to tank configuration is negligible, and heat flux densities are assumed to be similar within the tank.

$$M_{tdl} \cdot h_{tin} - M_{tdl} \cdot h_{tout} + F_{wtdl} \cdot q_l = 0 \quad \ldots(20)$$

M_{tdl} = fluid value interacting within wall limit layer per unit time; h_{tin} = *fluid* enthalpy transiting to fluid border layer, *J /kg*; h_{tout} = fluid enthalpy moving out of the fluid boundary stratum, *J / kg*; F_{wtdl} = relating region in fluid boundary stratum and core phase, *m*^{2}. If the boundary level is not present, F_{wtdl} = zero. The equation for conservation of mass, considering a system with little volume heat flux density. And if the flow condition of fluids and boundary layer are turbulent flow. For about one hour, calculated in M^2, now the upper atmosphere receives 1.367kWh of solar energy; this created the foundation for analyzing the capacity of heat leakage within the system, heat flux and mass flow rate computation within the stalled tank.

$$\frac{\partial}{\partial \tau}(\rho_{tmb} V_{tmb}) = M_{tdl} \quad \ldots(21)$$

ρ_{tmb} = density of tank main fluids, *kg / m*^{3}

V_{tmb} = volume of tank main fluids, *m*^{3}

The Liquid evaporation within the vapour-liquid edge is analyzed as a result of temperature change in the thermal stratification constituency of the containment hence the core region is uniform. [6] When the vapour segment is overflowing with overheated vapour and the molecule expands while the super-cooled liquid occupies the internal zone, they will be an interaction with the molecules. Still, the temperature in the thermal stratification region will always be higher than the central spot of the system.

$$G_f = G_{f1} + G_{f2} \quad \ldots(22)$$

G_{f1} = natural evaporation rate of vapour-liquid interface within the high-temperature liquid in the boundary stratum scheme.

G_{f2} = evaporation liquid rate as a result of the vapour-liquid two-phase heat exchange on vapour- the liquid interface.

2.2.5 Simulation Environment-Based Modeling

The SRK- equation of state (EOS) and the PR were the basis for the fluid packages definition for the simulation model as follows:

$$P = \frac{RT}{v-b} - \frac{a(T)}{v(v+b)} \quad \ldots(23)$$

$$a(T) = 0.42747\frac{R^2T_c^2}{P_C}\alpha(T)$$

$$b = 0.0867\frac{RT_C}{P_C}$$

For all pure substances, this equation was modified by Soave in a straightforward outline for $\alpha \equiv \alpha(T_r, \omega)$ looking at the improvement of the theory of the acentric factor of Pitzer [16]. There were several evaluations by Soave on the best model for the prediction of vapour pressure from his improvements of the initial SRK EOS. After test-running some substances it was discovered that his adjustment significantly enhanced vapour pressure predictions. Where $\alpha(T)$ is extrapolated for the supercritical temperatures?

2.2.6 Robinson-Peng Method

Peng and Robinson 1978 recommended an all-inclusive method for characterizing and analyzing light and heavy hydrocarbon fractions using EOS. In terms of the molar volume, V_m, Peng and Robinson imagined the following two constant cubic EOS.

$$P = \frac{RT}{v_m - b} - \frac{a(T)}{v_m(v_m+b) + b(v_m-b)} \quad \ldots(24)$$

$$a(T) = 0.45724 \frac{(R\ T)^2}{P_C}$$

$$b = 0.07780 \frac{RT_C}{P_C}$$

The generalized expression for the temperature-dependent parameter is given by

$$a(T) = a(T_C)a(T) \quad \ldots(25)$$

$$a(T) = \left\{1 + m\left[1 - \frac{\sqrt{T}}{T_C}\right] - \right\}^2 \quad \ldots(26)$$

With:
$m = 0.3746 + 1.5423\omega - 0.2699\omega^2$

By evaluating the vapour-pressure calculation of quite a few substances using SRK EOS and PR EOS with experimental data, the results are not always the same [8]. The enthalpies for some pure substances were also compared, PR-EOS and SRK EOS both equations generated enthalpy values of about the same reliability.

3.0 Results and Discussion

The feed gas composition of methane of percentage in different scenarios is long-established to be 84.5%, 89.63%, 90.28%, 92.21%, and 95.44%, from different LNG sources as shown in Table 4.1 and Table 4.2 respectively and for the simulation proper the standard of methane composition is set at 100%. In line with the IMO recommended standard for IGC conditions on cryogenic tank design consideration parameters configuration for ambient temperature ought to be 20ºC to 25ºC, 30ºC to 35ºC and 40 ºC to 45ºC in that order depending on region. Hence the ambient temperature consideration for this simulation is set at 20ºC to 25ºC as starting points.

3.1 Liquefied Natural Gas (LNG) Feed Characterization

The data on the physical properties of various Liquefied Natural Gas characterization was collected from different gas companies and each of the collected samples was analyzed concerning each products composition, Methane component mole fraction percentages, the advanced caloric value ((20^0C (-3.98bar), (25^0C, (^{0}C, 1.01bar)) and ((30^0C, 6.01bar) in that order, Average molecular weight (kg/k.mol), density (kg/m^3(n)), Specific Gravity (relative density), minor calorific value, higher specific energy KJ/Kg, boiling point at atmospheric pressure and the Wobbe Index which in this case is looked upon as the measure of the value of heat contribution to LNG in any application, the Wobbe index is a derivative of a standard of measure from the equation of orifice flow. The Wobbe index is considered an advanced calorific value, constantly centred on volume, divided by the square root of the equivalent relative density. The heat input of different LNG compositions is the same if they have a Wobbe index and are used under the same gas pressure. The LNG characterization of five varieties of gases namely Greenville, Ras-Laffan, Das-Island and Standard as shown in Tables 1,2,3 and 4 respectively are the values for each gas density and specific gravity (relative density) 0.6107 Kg/m^3, and 0.7897 (Kg/m^3 (n)) correspondingly for NLNG, while for Greenville LNG 461.8 Kg/m^3, Ras-Laffan LNG 461.8 Kg/m^3, Das-Island 456.8 Kg/m^3, and finally for the standard LNG density value is set at 459.4 Kg/m^3. The Boiling point at atmospheric pressure for Greenville and NLNG is set at -162^0C while the rest has -160.8^0C and the higher specific energy 54.414 KJ/Kg in that order. Advanced and minor calorific values are 4.321 MJ/m^3 (n), 12.00 kWh/m^3 (n) and 39.05 MJ/m^3(n), 10.85 kWh/m^3 (n) correspondingly and the Wobbe Index (on Hs) 55.30 MJ/m^3 (n) 15.36 kWh/m^3 (n), while the n represents at normal condition. The Greenville LNG chemical and physical properties values were used in this work.

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Table 1: Liquefied Natural Gas Characterization

Components		Mole %
Methane	CH4	92.215%
Ethane	C2H6	4.841%
Propane	n-C3H8	2.111%
Butane	n-C3H10	0.360%
Iso-butane	i-C3H10	0.381%
Pentane	n-C5H12	0.018%
Iso-Pentane	i-C5H12	0.003%
Nitrogen	N_2	0.000%
Molecular Weight (kg/k mol)		17.646
Density (Kg/m^3(n))		0.7897
Specific Gravity (Relative Density)		0.6107
Units of Measure	MJ/m^3(n)	kWh/m^3(n)
Advanced Calorific Value	4.321	12.00
Minor Calorific Value	39.05	10.85
Wobbe Index (on Hs)	55.30	15.36

Table 2: Critical LNG Physical and Chemical Properties [15]

Chemical names	Boiling Point	Melting Point	Molecular Weight	Vapor Pressure	Vapor Density (Air=1)	Gas Density Kg/m3 @20°C
Methane	-162 °C	182.5 °C	16.04	46700 hPa @ -82.5 °C	0.56	0.668 @15°
Ethane	-88.7°C	-183 - -20°C	30.06	600 - 39000 hPa @ 20 °C	1.05	1.282 @15°
Propane	-42.1°C	-183 - -20 °C	44.09	600 - 39000 hPa @ 20 °C	1.55	1.99 @15°
Iso-butane	-11.7 °C	-255 °C	58.12	2100 hPa @ 20 °C	2.06	2.51 @15°
N-butane	-0.5 °C	-138.3 °C	58.12	2200 hPa @ 20 °C	2.11	2.52 @15°
Nitrogen	-196 °C	-210 °C	28.01	Above critical temp.	0.97	1.165

Table 3: Methane Critical Properties [4]

	Atmospheric Boiling Point (°C)	Liquid SG [15°C/15°C]	Gas SG [Air = 1]	Flammability Limits [Vol. % in Air]
Methane	-161.5	(0.30) apparent	0.554	5.0/15.0

Table 4: Cryogenic tank dynamics [5]

Dynamics	Model Details	Vessel Volume [m^3]	2.89
Specs	Initialize From Products	Vessel Diameter [m^3]	0.25

Holdup	Dry Start up	Length [m]	0.59
Strip Chart	Initialize from User	Liq. Volume Percent [%]	75.0
Heat Exchanger	Lag Rxn Temperature	Liq. Percent Level [%]	75.0
Dynamic	Feed Delta P [KPa] (0.00)	Level Calculator	Hori Cylinder
Specifications	Vessel Pressure [KPa] (101.3)	Fraction Calculator	Levels & Nozzles

3.2 Solutions to Cryogenic Tank Design and Dimensions

After ascertaining and establishing the feed gas properties, the design of the stored tank was the next step as shown in chapter three before embarking on the simulation proper, the design of the tank using Autodesk Inventor Exported into ANSYS (Multi-physics) using the space claim Reactor discretized into nodes and elements to determine the wall thickness and heat fluctuation, flux and distribution flow into the system. The tank is designed in a method that the required boil-off gas will be produced as expected concerning the insulation of the tank wall thickness and the appropriate dimension and materials as shown in Figure 3 the materials for the stored tank insulation for the heat flux effect were Glass Wool, this is due to the material quality and the capacity to regulate the flow of heat from the environment through the wall of the tank to the annulus and the first layer of the system. The tank B (1.3) is the inlet valve for the feed gas stream while the area labelled A (1:3) is the outlet valve for the passage of the produced boil-off gas to the valve connecting the compressor flow line. The interior part of the store is designed such that the volume of the LNG, the rate at which the feed gas is supplied and the extent to which the storage will last are momentous determinants of the prospective boil-off gas characteristics and performance. With the appropriate heat flux of 1.5 W/m^2. K and the temperature of 298K, the required boil-off will be produced and the actual result of the volume produced per second based on the volume of storage will be archived through simulation. The accurate material for insulation and coating and the design dimensions have been established. The tank inlet and outlet nozzles have been estimated and measured to the internal and external radii of 25.4 and 16.7. ANSYS R18.1 as utilized presents the accurate shape and size of the stored tank after the inventor analysis and the selection of internal and external insulation materials with appropriate annulus dimensions. The installed valves at the inlet steam and outlet stream would always be closed to prevent backflow, ensure that the vessel pressure is known at this point and also maintain a uniform temperature distribution for each of the tank nodes and elements to be calculated as shown in Figure 4: The computer-aided investigation of the fluent and estimated heat fluxes simulation would be resolved and the application of the Finite Element Analysis (FEA) to determine the pressure distribution of the cryogenic tanks as well as the thermal effect of atmospheric disturbances through computational fluid dynamics (CFD) simulated and obtained for further use [5]. Concerning the thickness of the stored tank insulation materials and the annulus, the increase in the thickness of insulation with glass wood material offers the needed heat flux as shown in Figure 3 of 0.1 within -162^{o}C LNG temperature. The thickness has a great impact on the heat flux into the system, the chart showed the thickness (M) insulation against flux (Joule and M2) of heat into the tank where the LNG is stored. The conditions of the system boundary bring about the detailed definition of the operating provision of the configuration and the entire system process. The material used for the tank design is one factor we used to determine some aspects of

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the condition. The temperature of the vaporized gas leaving the tank and the tank pressure build-up owning to the gas molecule expansion are other factors.

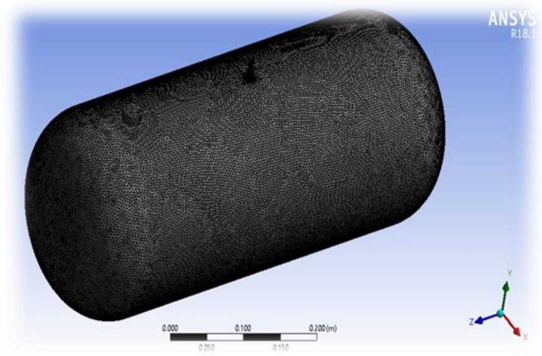

Figure 3: Solution to ANSYS Discretised, Meshing into Nodes and Elements

The evaporation and the combustion at the point of the engine, the engine tail gas releasing and outlet temperature, build-up of the pressure and flow rates are the prominent parameters that were recorded and made use of in the simulation and derived models from literature. An additional condition of operation entails the ambient temperature of the area or location of the vehicle containing LNG for combustion. The weight of the tank, the density of the LNG and the ambient condition jointly are required to determine the nearness of the fluid boil-off formation. The interesting aspect of the simulation was the consideration of the kind of heat transfer that is taking place between the surrounding and the stored tank which is the convective heat transfer coefficient. This heat transfer process was applied to act on the stored tank LNG as it was assumed that the vehicle conveying the product may be in static motion or may also be in motion to determine each level of gas vaporization. The overall interest of these is conducted to establish the spread of the heat flux for the duration of the mixing and integration of the liquid and gaseous phases of the LNG. At this point, the spread of heat flux or propagation is measured via the computer-aided engineering application in use. This is regulated in teams of the intensity of heat progression towards the stored tank's lower temperature region and the higher temperature fluid region which in this situation is the inner tank outer layer as against the core or centre region of the stored tank. The basic principle behind the determination of HTC in a cryogenic tank is the system wall-function-based model which is applied here through the treatment of kinetic energy turbulence, temperature, density, pressure and specific heat as shown in equation 27.

$$h_{eff} = \frac{pC_p C_\mu^{1/4} K_P^{1/2}}{} \qquad \ldots(27)$$

In this case the C_p represents the specific heat capacity while the K_p indicates the turbulence Kinetic energy at point P, and T* is the pressure and temperature as defined in ANSYS FLUENT 6.3 as the basis for the computer application simulation of the FLUENT. Although this is basically for unconventional cases cum adiabatic system walls and also accessible simply when the fluid flow is turbulent and the energy equation is made possible or enabled.

3.3 Computational Fluid Dynamics Heat transfer

The solution to the CFD was achieved through the input data of the software heat transfer models. All the necessary assumption made in chapter three was the basis of obtaining the CFD result. The convective boundary heat transfer of 1.5 W/m^2 K and a free stream temperature of 298k for the stored tank wall zone material. With a flow direction moving from the z direction to the x direction and an air-fluid zone area and board solid zone casing. The entire process within the LNG vehicle configuration is a clear result of the temperature distribution of a convective heat transfer cum mesh, velocity vector and contours of temperature. The matching operating conditions were the first point of subjecting inlet feed temperature against the outlet temperature as a result of boundary condition determination, the pressure

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system upsurge, and specific gravity. The solution using a well-known CFD simulation environment model [5] was the core source of determining the temperature circulation impact and the heat flux distribution across the used material grid, the velocity vectors distribution and the temperature contours. With the application of these preliminary methods, all simulation result is ascertained to be true and free from errors. Also considering CADE's capability to compute and calculate conduction heat transfer via solids material, attached cum convective heat transfer in fluid of multiple phases. These are not only applicable to conductive and convective but also to couple boundary conduction of several material wall regions which detaches multiple cell zones of storage LNG tank system. The cryogenic tank containing LNG with 162^0C temperature and in an environment of ambient temperature of 77^0F with pressure of 1 bar and tank internal pressure of 2 bars owning to the LNG molecular expansion undergoing through heat flux input, the temperature distribution of a convective heat transfer cum mesh, vector and the mach contours is as shown in figure 4. The estimation and evaluation of the BOG rate is fundamental for developing an LNG process with a key interest in heat leakage. Several literature types of research scrutinized BOG rate basically in LNG workstations, maritime units and immobile containers. The assumptions or hypothesis has been only for surface evaporation of liquid cum BOG rate estimated as % of its initial volume.

$$BOR = \frac{Q*360*24}{\Delta H*V_{LNG*}\rho}*100 \qquad \ldots(28)$$

BOR indicates daily basis % of BOG (%/d), VLNG, volume of LNG in tanks in m^3, ρ = LNG density in kg/m^3, Q = heat exchange in W and ΔH = latent heat of evaporation in J/kg. Still, the BOR equation does not explain vapour increase within the tank internally and a detailed analysis of heat transfer to the tank. [22] Modelled mass transfer rate of LNG from liquid to the gaseous phase, and tied their model using ANSYS FLUENT they proved temperature and BOG characterization and foretell an entire rate of evaporation inside a motion and motionless LNG tanks, a similar approach was used to archive our heat transfer result as shown in Figure 4.

$$Mass - Transfer - Rate = \frac{r*VF_{l*}\rho_l(T_{l-}T_{sat})}{T_{sat}} \qquad \ldots(29)$$

r = under relaxation factor, VF_l = liquid volume fraction, ρ_l = liquid density, T_l = liquid temperature and T_{sat} = saturated temperature. This work uses equation 3.51 to model the absolute rate transfer of heat, mass and evaporation of a 12kg LNG cryogenic tank via UDF in ANSYS FLUENT.

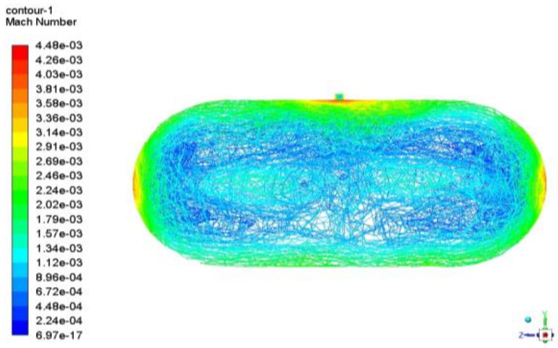

Figure 4: Temperature Distribution of Convective Heat Transfer Vector and contours

Looking at the occurrence of natural convection, we realized that the moment it takes place in a system such as this case the fluid in question gains heat and at this point the density of the fluid expanse with variation in its temperature. Hence the fluid flow is acted upon or stimulated by gravitational force performing on fluid density disparity and variation. The gravitational expression is applied to estimate the level flow cum the gradient of the pressure and that of the evaporation, therefore in teams of the body force, the most appropriate and prominent equations are re-written to suit in line with the momentum equation as shown in equation 30.

$$-\frac{\partial p}{\partial x}+pg \Rightarrow -\frac{\partial p'}{\partial x}+(p-p_0)g \qquad \ldots(30)$$

Where: $p' = p - p_0 gx$

The CFD natural convection simulation environment is based on the Boussinesq Model which is assumed the uniformity of the fluid density although it is only appropriate and applied for the body force expression cum momentum model alongside the path of gravity, therefore we have the equation expressed in this form as shown in equation 30;

$$(p-p_0)g = -p_0\beta(T-T_0)g \qquad \ldots(31)$$

This is majorly applicable as soon as density variations with the fluid stored in the tank are identified to be minute (i.e., little variation in T). It makes available a more rapid convergence for various natural-convection of fluid flows instead of relying only on the application of fluid density-dependent or as a purpose of temperature reliance. In the cause of this work, we identified that the constant fluid density hypothesis decreases the system's non-linearity and it is only suitable and applicable as at the time density disparity or variations are very minimal.

3.2 Result of Simulated Parameters

All the relevant parameters were well-defined at the preliminary stage of the simulation. The basic parameters such as the one that has to do with the influx of heat, the condition, properties, composition and the process flow specification were considered as stated in Table 5. At this point, the LNG vapour is produced at the surface or top of the fluid and it is fed to the compressor suction unit as the flow continues with a 1% increase as shown in the boil-off column. There is a little change in the temperature of the gas, because of this temperature change the initial pressure also increases concerning time. The compressor suction receives the evaporated gas at the top of the fluid and is controlled with a control element. From the result, no liquid is expected to be around the control volume unit. Based on the result archived from the simulated parameters no backflow was observed and the entire input data match our expected result such as that of the heat flux and temperature changes concerning time. The graphical plot of the heat interaction with the tank and the flow of the vapour respectively point towards the confirmation that LNG is one of the most transport fuels with high volume retention as illustrated in Figure 5. In this case, there is no re-liquefaction method as our major interest has been for the LNG to vaporize at a given time with control systems. The external heat flow was set at 2.250 kJ/h which influenced the BOG and also increased the pressure to be slightly high to 4.5 bars, towards the end of the process flow and against 1 bar starting point. BOG flows from the top of the internal configuration of the thermo-cool system with an optimal temperature and with an extremely low vapour fraction. The process is designed for automatic capacity control from 40% to 100% cum an utmost efficiency at 80 % of the ostensible vaporized capacity. In line with the IMO IGC specification for the design simulated parameters when considering an atmospheric temperature of 20ºC - 25 ºC and 32ºC and LNG temperature of 162ºC.

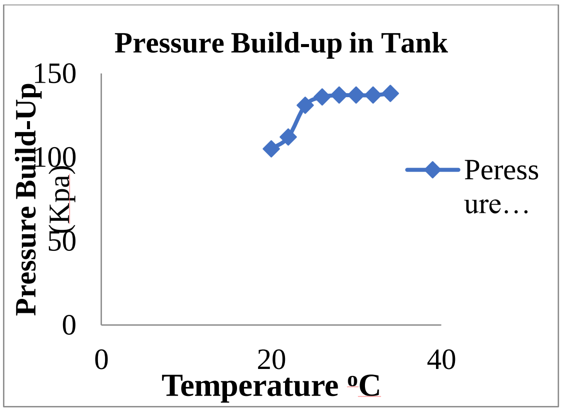

Figure 5: Graph of the build-up of pressure in the internal zone of the tank as a result of an increase in temperature, from 20^{0}C to 40^{0}C.

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The pressure increased from 101kpa to the point of 140kpa which means that pressure based on the temperature profile of the tank can be ascertained and controlled in under to prevent excessive pressure surge in the tank, as the temperature increased the pressure also increased, drop in the temperature as a result of heat flux is one of the factors used to determine the pressure build-up in the tank because based on this scenario can develop appropriate pressure gauges and safety materials to regulate the system pressure configuration. Other factors worth mentioning are the thickness of the wall tank, the material selection for the manufacturing of the tank, and the sizing, volume and density of the stored fluid in the tank. Fluid mechanics of the vapour process, LNG cryogenic tankers hold in a fluid that the density is reduced amount more than that of air and seawater at the point when the fluid evaporates and boil-off gas is formed. All the produced vapour as part of the initial assumption will always be formed at the surface of the LNG which retains its initial temperature of -162^{0}C and the moment the temperature is reduced to -152^{0}C which is -10^{0}C then we begin to observe a patch of the gas from the liquid phase and this is determined by a velocity which the attained based on the difference in pressure involving the atmospheric and the LNG tank pressure.

3.4 ANSYS CFD Result of LNG-Fuel Technology Re-gasification Process

As presented in Figure 6 the ANSYS fluent result of the internal re-gasification process of the LNG. The blue colour indicates the LNG with -152^{0}C as against the standard of -162^{0}C which means there is a drop in temperature of the gas at this point it is observed that the gas molecule will instantaneously expand to the point of boil-off formation. The yellow and Ors-blood colour with temperature ranges of 1-48^{0}C to -149C is part of the vaporized gas. The light green colour represents the vaporized LNG and with its temperature of -151^{0}C to -147^{0}C we can. The red colour shows the heat leak temperature which is from -147 to -146^{0}C, the mixture of the light green colour and the red colour will with a velocity mass flow to the compressor suction unit. On discussions based on control issues and concerns on the safety aspect of the LNG combustion heat process, within the S.I. engine, there are no technical difficulties in managing the LNG BOG fire or radiant heat as a result of the combustion because it is taking place in the engine cylinder piston, in other cases it is of great interest to the public health standard regulator and the authorities.

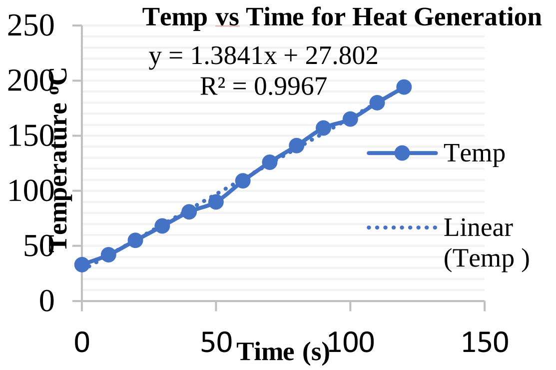

Figure 6: Increase in Temperature versus Time for Heat Generation

3.5 A numerical simulation using Finite Element Analysis (FEA) and ANSYS CFD.

The preliminary numerical simulation was conducted applying the Finite Element Analysis (FEA), design volume and the tank sizing of 20 litres while the tank heat flux as simulated for 5hr/day was 0.00157Kw/m^2 and the walls at 0.00448Kw/m^2 are presented in Figure 7 also the impact of the ambient heat flow (KJ/h) and the system mass flow rate of the LNG BOG generation (kg) plot is shown in Figure 7. The software calculated the heat leakage into the system with a temperature increase assumed per hour in a day was set at 1.3 W and pressure set at 1 bar at the initial stage. The LNG mass flow rates from the ANSYS primary Simulation result were recorded as 1.2%, -1.4% and 1.6% to 15% of the total LNG stored tank volume concerning the increase in the value of heat

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flux into the system at different simulations and time taken by the tank to absorb the heat. The results as estimated using ANSYS indicated that in LNG cryogenic tank BOG generation as presented in Figure 4.15 the Ambient Heat (KJ/h) and Mass Flow Rate of LNG Boil-off gas production (kg) based on the plot results are 0.0187%, 0.0551% and 0.09262% correspondingly. The result of the outlet velocity was recorded at 0.867m/s and the LNG temperature were initialized at -155^{o}C, while the tank pressure equals 1.2 bar. Now taking a whole view of the entire result, we could say that a drop in ambient temperature automatically results in to drop in the BOG production and the more time taken in the storage tank. On the other hand, the increase in temperature of the surroundings leads to an increase in the rate of BOG formation and the fast pressure surge would be observed.

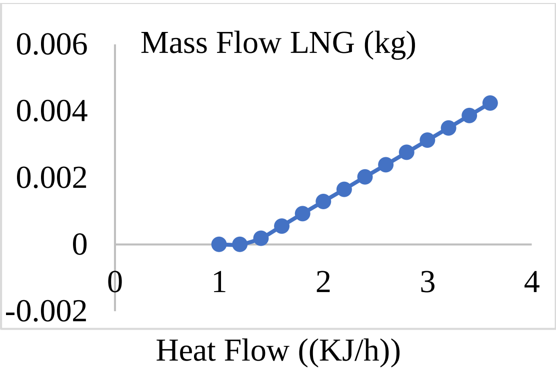

Figure 7: Ambient Heat (KJ/h) Vs. Mass Flow Rate of LNG BOG Production (kg) plot

Through the CAE software, the verification was made possible based on the input simulation data, FEA using the CFD Mesh and the fluent computation model established and presented in this thesis, 25 litres LNG storage cryogenic tank and the volume that contained (0.4) was observed to be adequate appropriate. After a series of test running with various tank sizing, volume, temperature, pressure and material selection it was discovered that as the heat flow continues to increase from 1 ((KJ/h)) to 4 ((KJ/h)), the mass flow rates of LNG Boil-off gas production at different percentage increase in the heat flux resulted into 0.012kg/s to 0.043kg/s as presented in figure 8 which the ambient heat (KJ/h) in opposition to the mass flow rate of the LNG Boil-off gas production (kg) plot. The anticipated chemical analysis and the thermodynamic variables of the rate of evaporation of the BOG generation were reasonable as projected with high and appropriate performance efficiency with the capacity to be supplied as fuel for combustion within the spark-ignition or internal combustion engine system.

3.6 Conclusion

The Thermodynamic effect of utilizing LNG-fuel technology Simulation and verification, FEA via the CFD Mesh and fluent calculation model of the Boil-off gas produced was moderate with high efficiency for fuel for internal or spark-ignition engine. With high economic and environmental advantages beyond the earlier proposal of CNG as an alternative to PMS and AGO. LNG fuel based on technical factuality holds the potential to empower the transportation sector around the world. The most up-to-date forecasting of the LNG market is that in the subsequent fifteen years to come, the international LNG trade will grow in multiple propulsion, in line with the coexisting, concurrent and simultaneous amplified overhead cost in spending in long-drawn-out LNG cargo fleets conveyors and with the new-fangled production facilities being initiated in recent times. However, there are serious indications that there would be a need for strong international legislation and the need for world leaders to put an end to natural gas flaring in line with the mandate to sustain the international environment from dangerous gas pollution.

Competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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