International Journal on Recent Technologies in Mechanical and Electrical Engineering
ISSN: 2349-7947 Volume: 9 Issue: 2
***Article Received:** 25 March 2022 **Revised:** 12 May 2022 **Accepted:** 20 May 2022*

A Review of Using Natural Gas in Internal Combustion Engines

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Abstract:-
Due to its increasing emissions from combustion of fuels in the internal combustion engines and increasing world concern on global warming problem. It's a significant issue to use alternative fuels that would be safe for people and the environment. In this article, the previous research's concern on using natural gas is discussed. This research presents the precious studies on the benefits of using natural gas fuel in spark ignition, diesel, and agricultural engines. In addition to modeling focusing on engine parts loads to identify fuel-burning influence. Also presents a former discipline on using hydrogen enrichment to improve fuel efficiency and shows characteristics of using dual fuel in internal combustion engines. The difference between lean combustion and exhaust gas recirculation strategies and produces a comparison between natural gas/methanol and natural gas/gasoline in a dual-fuel engine are reviewed. In addition the comparative study between gasoline and natural gas with a direct injection strategy is presented. Also, this article focus on using natural gas as a fuel with reactive controlled compression ignition (RCCI). It can concluded that using the natural gas fuel is one of the perfect solutions to reduce hydrocarbons emissions and increase the thermal efficiency of fuel combustion and reduce the cost of energy production.

Keywords:- Internal combustion engines – Natural gas – Knock onset - Hydrogen - Combustion – Emissions – Performance – Diesel engine – Water injection.

1. Introduction:

Many researchers studied the benefits of using natural gas fuel as an alternative fuel for internal combustion engines. (Abdullah and Anwar, n.d.) [1], selected a process called sample design with a random sampling method and taken in different locations in Kurdistan in Iraq which led to some results, that fossil fuels used in internal combustion energy had detrimental consequences for the environment including low air quality, dangerous waste production natural gas has low carbon content as compared to oil and low anti-knocking properties. Many countries used CNG as the main fuel for internal combustion engines and this led to low No, HC, and CO emissions. Also, (Ah and V, 2019) [2] studied the use of compressed natural gas as a fuel for internal combustion engines on both motor transport and agricultural machinery. Results of tests taken from other researchers. The analysis focused on the conclusion about the quality of gas supplied as a fuel for locomotive agricultural engines. From the analysis results, It was observed that the best environmental, economic, and technical performance of the engine is achieved with high explosion resistance in Greenwich and any fuel for gas engines must have the limits set by the CNG standard.

The researcher methodology application in this article focused on cylinders, exhaust manifold, and turbocharger turbine sections and the model was validated by actual operating data with an error limited to 5% which enables a thermal characterization of jenbacher JMS 612Gs – N based on the model. The analysis is based on considering the output electric power, the volumetric efficiency, the effective efficiency, the exhaust gas temperature, the turbine mass flow, and the specific fuel consumption under nominal operating conditions which is 1.16 bar gas pressure, 65-C cooling water temperature 35-C average ambient temperature and 1500 rpm resulting this mean value model is taken from typical measurements in this type of engine as the volumetric natural gas condition, lambada, and rpm. According to the phenomenological-based semi-physical. model made for a 2 MW gas engine, a relationship is denoted between variables which be studied. The most

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important relationships studied are those between all the temperatures of the exhaust line with effective and electric power generated this enables us to know the efficiency of using the power generated from natural gas combustion and this will open the door to future studies. It is recommended to establish models and equations to predict the time and exhaust gas emissions that result from natural gas combustion (Ochoa et al., 2019) [3].

The source of pollution is mainly petrochemicals, the researcher in this article studies the control of petrochemicals which are used as a fuel in internal combustion engines by implementation of hydrogen fuel in the transportation field. This study have been established under a wide range of hydrogen percentages (0 – 50 % in volume) in CNG fuel, EGR rates (0 – 26 %) , spark timings (14-42◦CA BTDC) and loads (25%, 50% & 75%) at stoichiometric operating condition. And have been further studied with the enrichment of hydrogen fractions in CNG fuel, regulation of EGR ratios, and spark timings at low, half, and high loads. The results are that the smaller H2/EGR ratio (HCNG50&EGR = 10%) is good for low load conditions and medium H2/EGR ratio (HCNG50&EGR = 14%) is good for half load conditions and the high H2/ EGR ratio (HCNG50&EGR = 26%) is good for high load conditions. (Rao et al., 2021)[4].

The influence of using hydrogen adding on the combustion of fuel is studied in (Duan et al., 2020) [5]. The researcher establishes his study on five conditions or cases to study variations of hydrogen energy from cycle to cycle, resulting in the mean effective pressure of the engine chosen decreased while increasing the hydrogen content in fuel. Also decreases the coefficient of variation of the peak combustion pressure (PCP) from 8.75% to 2.82% with a 27.68% hydrogen energy share.

This comparative article studies the use of natural gas / hydrous ethanol dual-fuel combustion in a spark ignition with an adjusted compression ratio. A special intake valve opening technique to enable internal exhaust gas recirculation [IEGR]. The article results were that the use of dual-fuel improves the efficiency of fuel conversion compared to CNG without hydrogen ethanol because of less unburnt hydrocarbon (HCS) and carbon monoxide (CO) and NOx emissions increased in the case of dual fuel compared to CNG case (da Costa et al., 2019) [6].

A comparison between lean combustion and exhaust gas recirculation in an engine fuel with HCNG was conducted by (Park et al., 2017) [7]. This comparative research was established in an engine with 1260 rpm, 50% of maximum load (575 Nm) at maximum brake torque for both cases. Results were that thermal efficiencies with stoichiometric combustion with lower EGR than those in lean combustion case led to more pumping loss and lower combustion speed. Emissions in the lean combustion case are less than in the stoichiometric combustion case at low combustion speed. The lowest NOx emissions were in the lean combustion case. (Giménez et al., 2021) [8], focused on the turbulent speed of premixed combustion in an internal combustion engine using hydrogen, natural gas, and intermediate mixtures of fuels. This study was established with several air-fuel ratios and different speeds of engine combustion speed calculated by the aid of two zones diagnoses of the thermodynamic model in addition to a geometric model with the use of spherical flame front hypothesis diagnosis of combustion that results from measuring pressure in the engine and provides the values of average speed of turbulent combustion over the entire surface of the front of the flame. The result of this article is that the flame front position affects the value of combustion speed in an internal combustion engine.

A stoichiometric natural gas combustion in addition to recirculation of the exhaust of the gas and a three-way catalytic (TWC) device is examined by (Chen et al., 2020) [9]. The study was established according to increase the world's attention to the global warming and emissions resulting from hydrocarbon combustion. The researcher found that injection of water is a good way to limit the thermal load, in addition, to reducing the emission of NOx and knock onset. The result was that with the use of injection of water we can decrease the velocity of natural gas combustion and this will limit the peak pressure in the cylinder in addition to the peak rate of released heat and temperature of combustion.

The researchers in this article established his study on a Rankine cycle which is an organic one in an engine fueled with natural gas to study if electricity can be generated by the use of the engine with exhaust gas recovering. Results were that the pressure of evaporation affects deeply the elimination of exergy. (Ochoa et al., 2020) [10]. (Chen et al., 2021) [11] provided a comparison of combustion between natural gas – methanol fuel and natural gas – gasoline fuel. The engine conditions taken were (n = 1600 rpm and 0.387 MPa mean effective pressure. Results were that gasoline and methanol increase the rate of burning of natural gas and this leads to increasing peak pressure in the cylinder and the rate of heat released. Brake thermal efficiency increased by 0.8 % for natural gas – methanol fuel. Monoxide emission from engines with natural gas fuel can be

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decreased by methanol and gasoline enrichment. (Kar et al., 2021) [12] Established his study using an engine that is spark ignition using either direct injection gasoline or direct injection natural gas. Three cases or conditions have taken: lean burn, stoichiometric operation with the use of recirculation of exhaust gas, and stoichiometric operation of engine without using external dilution. At high loads, direct injection compressed natural gas (DI CNG) provides high efficiency compared to gasoline direct injection (GDI). (DI CNG) achieves maximum brake torque without producing Knock. (DI CNG) efficiently was lower than (GDI) for equal EGR rate in both cases and produces higher gasoline velocity of burning. CO_2 emissions of stoichiometric (GDI) were 16-19% more than stoichiometric (DI CNG). Using lean burn and EGR strategies increased emissions of CO_2 compared to the stoichiometric case without using the dilution strategy.
(Lopatin, 2020) [13] studies a diesel engine fueled with natural gas with diesel fuel enrichment that produces better mixture formation and combustion. The researcher also made a comparative study on the difference between operating diesel engines on natural gas and diesel fuel.

Table 1. Results of studies of combustion process parameters diesel engine 4F 11.0/12.5 at Θinj=23° and rated mode (n=2200 min-1, pe=0.64 MPa). (Lopatin, 2020)

	Indicators				
Fuel	Tmax K	Pmax Mpa	λ degree of pressure	(dp/dφ)max MPa/deg Rigidity of combustion process	Φinj deg
Diesel	2190	8.1	1.9	0.59	22.5
NG	3010 increase of (37.4%)	8.5 increase of (4.9%)	2 increase of (5.3%)	0.69 increase of (17%)	30 increase of (33.3%)

Table 2. Results of studies of combustion process parameters diesel engine 4F 11.0/12.5 at Θinj=23° and rated mode (n=1700 min-1, pe=0.69 MPa). (Lopatin, 2020) [13]

	Indicators				
Fuel	**T** Temperature Maximum,(K)	**P** Pressure Maximum(MPa)	**λ** The degree of Pressure	The Rigidity of Combustion Process **(dp/dφ)**max MPa/deg	Φinj (deg) Injection angle corresponding to the ignition delay period
Diesel	2210	8.6	2	0.64	20
NG	3050 Increase of (38 %)	11 Increase of (27.9 %)	2.6 Increase of (30%)	0.83 Increase of (29.7 %)	22 Increase of (10 %)

The article focused on the benefits of using NG – Diesel fuel in an internal combustion engine with reactivity controlled compression ignition (RCCI) strategy, this will increase the brake thermal efficiency (BTE) and produce low PM and NOx emissions. But also more unburnt Hydrocarbon (HC) and carbon monoxide (CO) emissions also produce a low temperature of exhaust gas (EGT). models established in this article enable the researcher to predict brake-specific fuel consumption (

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BSFC), CO, NOx, and HC with errors 0.6, 1.5, 0.1, and 0.1 g/kwh; exhaust gas temperature (EGT) with 2.6-C error and 0.001 g/kwh error of pm. (Ansari et al., 2018) [14].

In this article, the researcher studied the recirculation of exhaust gas (CO, H2, unreformed hydrocarbons,…etc). this study was established with the use of reformed fuel and exhaust gas catalytic equipment. Extra CO and HC emissions results from the REGR (reformed exhaust gas recirculation) engine due to valve overlap period leakage and the incomplete combustion of the reformate added. the result of this article is that (1) CH4 leaking and CH4 which is unburnt in the cylinder will decrease if reformate addition (Rref) increases. (2) the increase of (Rref) CO results from partially oxidizing of CH4. Remains without change while increasing CO emissions from unburnt reformate and CO leakage. (3) While the mass of CH4 and CO leaking increases, the mass of CH4 and CO unburnt decreases.

(Long et al., 2018) [15] Used computational fluid dynamic (CFD) and experiments to study the influence of timing of diesel injection on engine combustion fueled with (diesel – natural gas) dual fuel and the performance of emissions under four load cases. Results produced that timing of diesel injection leads to the peak pressure increasing in addition to increasing thermal efficiency and missions of NOx for all cases, the timing of diesel injection decreases methane which it has not burned and decreases CO2 emissions at low, medium, and high level of speed.

Yousefi et al., 2019) [16] studied the increase of emissions from fuel combustion in internal combustion engines. The researcher used recirculation of exhaust gas (EGR) and lean-burn in a spark-ignition engine fueled with natural gas to overcome these emissions. Rate of natural gas combustion decreased in EGR, lean, and ultra-lean cases. The researcher established a model which is simulated on the two-zone combustion principle of modeling with the use of data collected from experiments. He takes several values of lambdas and EGR and to predict the performance he simulated twin-spark plugs. This study proved that using twin-spark plugs increases combustion rate to the maximum in ultra-lean mixture cases compared to lean cases. (Li et al., 2022) [17] presented a study on using natural gas as a fuel in diesel engines by adding a gas injector in the intake manifold and replacing the diesel injector with a spark plug in its place. Results showed a comparison between converted and conventional engines which presents the numerical and experimental simulation of flame propagation in engine. Results proved that the combustion of fuel in engines fueled with diesel converted to lean natural gas spark ignition operation should reduce the fuel burning rate in the squish region.

Due to increasing exhaust emissions from fuel combustion in the transportation field. Scientists do their bests to develop a combustion strategy that would decrease exhaust emissions and increase thermal efficiency value. In this article, the researcher establishes his study by using two different types of fuels as a dual-fuel in the engine. This would reduce oxides of nitrogen and improve the efficiency of fuel burning. Different shapes and several compression ratios are tested to produce the optimal setting of hardware for (NG-diesel) dual-fuel burning with the use of converting diesel engine into NG-diesel dual-fuel engine. Results proved that emission was reduced by 13% maximum than the diesel-fueled engine [18] (Liu & Dumitrescu, 2019). Also, (n.d.) [19] studied how to reduce soot content in exhaust gases of the diesel engine of a tractor which is smoke type by using alternative fuel compressed natural gas (CNG). The researcher focused on the effect of the engine gaseous fuel on the combustion process and soot content in the cylinder and exhaust gases. Results proved that combustion of natural gas in turbocharged diesel engine increases the calorific value of fuel and combustion rate of air-fuel mixture but increases the rigidity of combustion process and loads on parts of the engine. (Likhanov & Rossokhin, 2020) [20].

Conclusion:-

Natural gas can be perfectly used as an alternative fuel for internal combustion engines. Pollution which results from the combustion of petrochemicals can be controlled with the implementation of hydrogen fuel in the transportation sector due to the property of the carbon-free structure. Water injection in internal combustion engines overcomes thermal load, NOx emissions, and Knock onset. The possibility of waste heat recovery to generate electricity from an organic Rankine cycle integrated into a natural gas engine can be achieved to improve the energetic, economic, and environmental performance of the system. Methanol addition to the natural gas is better than gasoline as it increases BTE and decreases harmful emissions.

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Forming a mixture of natural gas with an additional portion of diesel fuel can make a new fuel with distinctive features for the combustion process in the engine.

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Article Received: *25 March 2022* ***Revised:*** *12 May 2022* ***Accepted:*** *20 May 2022*

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