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Thermodynamic analysis and performance improvement in natural gas based power plant: A comprehensive review

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Abstract

In the modern world, energy has become a basic necessity for every nation, and fossil fuels which are readily available and satisfy this need. As a result, research is being done in the energy sector to develop fuel-based energy conversion devices. The fuel consumption can be decreased while also maximizing the utilization of available energy. This study paper reviews the energy and exergy analysis of IC engines based on natural gas, which are investigated for performance enhancement by altering parameters. It is found that maximum energy is obtained at crankshaft speed of 2500 rpm, which are 29.78% and engine is VSG413 SI type with 95 octane gasolines. The test engine has 1.3 volumes, four strokes, four-cylinder, 45 kW maximum power capacity and 98 N-m maximum torque capacity. The maximum exergy efficiency is obtauned 59.76% and confirms that toluene RORC assembly is the best alternative for this natural gas engine. Engine rpm 1482 speed, a 120.2 L/min natural gas flow, 1.784 lambda, and 1758.77 kW of mechanical engine power. The exergy analysis reveals that the engine optimum speed is 1482 rpm, as the exergy efficiency has a maximum magnitude at this speed. In fact, this research demonstrates that choosing the ideal engine speed should not be done just based on the energy analysis. The amount of energy discarded by the cooling system increases at low speeds and is smaller as the speed rises. On the other hand, as the speed rises, the energy that heated gases lose increases. In the engine, irreversible processes such combustion, heat transmission, and friction depletes a sizeable portion of the fuel energy. Additionally, as engine speed rises, the sources of energy destruction like friction and heat transfer also increase.

Keywords: SI engine, energy analysis, exergy analysis, energy efficiency, exergy efficiency, irreversibility, performance

1. Introduction

Nawab Khwaja Ahsanullah started electrifying the nation's capital, Dhaka, in 1901, just 19 years after New York and 13 years after London. In 1948, East Pakistan formed an Electricity Directorate. A 132kV transmission line between Dhaka and Chittagong was commissioned in 1962 as part of the 40 MW Kaptai hydroelectric plant. Only 3% of the population in Bangladesh had access to electricity in 1971. In 2012 at 59.6%, it has increased. On the other hand, load shedding affects 79% of connected consumers, and low voltage supply affects 60% of users [1].

In FY 2018–19, there were 18,961 MW of total grid-based installed capacity, with 9,507 MW coming from the public sector, 8,294 MW from the private sector, and 1160 MW from India's cross-border power trade. The installed grid capacity was 19,630 MW in February 2020, with 9,740 MW coming from the public sector, 8,730 MW from the commercial sector, and 1,160 MW from India. When considering captive and renewable energy sources, Bangladesh has an installed capacity of 22,787 MW overall. The most energy was produced at 12,893 MW as of May 29th, 2019 [2].

It might be worthwhile to present the current state of the world's energy before moving on to our suggested ideal energy mix model for easier comprehension and comparison. Fig. 3 shows how the demand for current primary energy fuels in the power sector is increasing. The fossil fuel reserve as of 2017 and the reserve to production ratio [3].

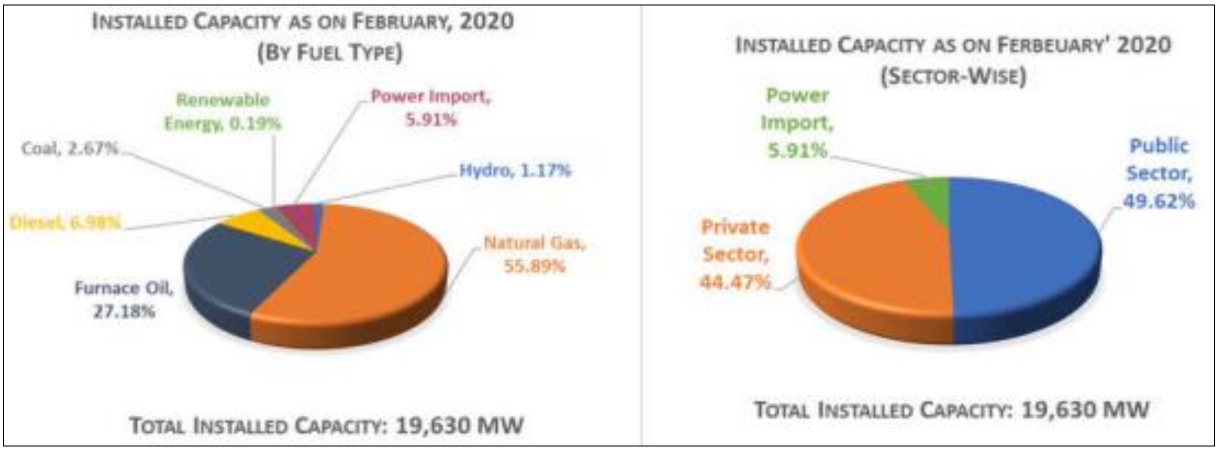

Fig 1: Total installed capacity by fuel type and sector wise of FY'2020 [2].

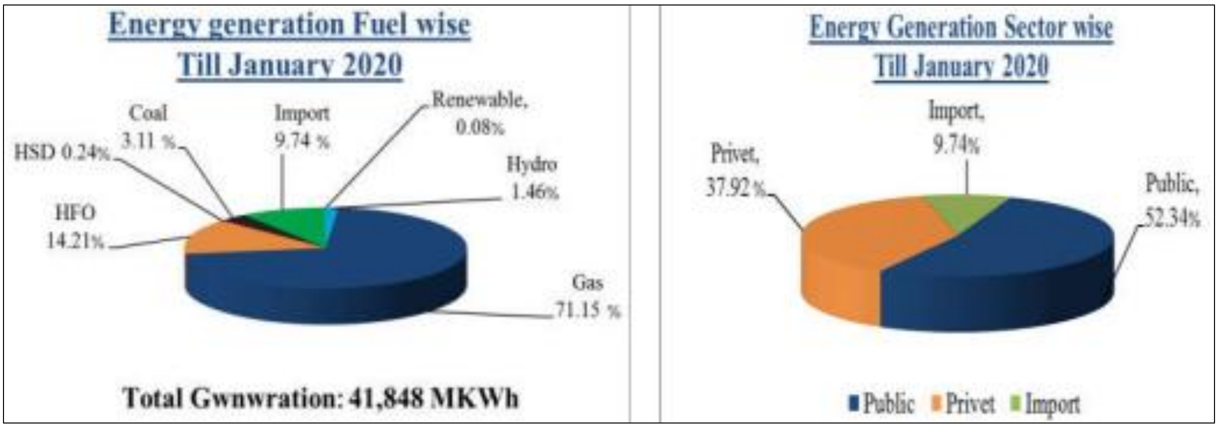

Fig 2: Total energy generation fuel type and sector wise of FY'2020 [2].

Table 1: Power generation plan from FY 2020 to 2041.

S. No.	Description	Year 2020	Year 2021	Year 2030	Year 2041
1.	Power generation capacity (MW)	22,787*	24,000	40,000	60,000
2.	Electricity demand (MW)	14,800	19,000	33,000	52,000
3.	Transmission line (Ckt. KM)	12,119	12,000	27,300	34,580
4.	Grid substation capacity (MVA)	44,340	46,450	1,20,000	2,61,000
5.	Distribution line (KM)	5,60,000	5,15,000	5,26,000	5,30,000
6.	Power generation per capita (KWh)	510	700	815	1475
7.	Access to electricity	96%	100%	100%	100%

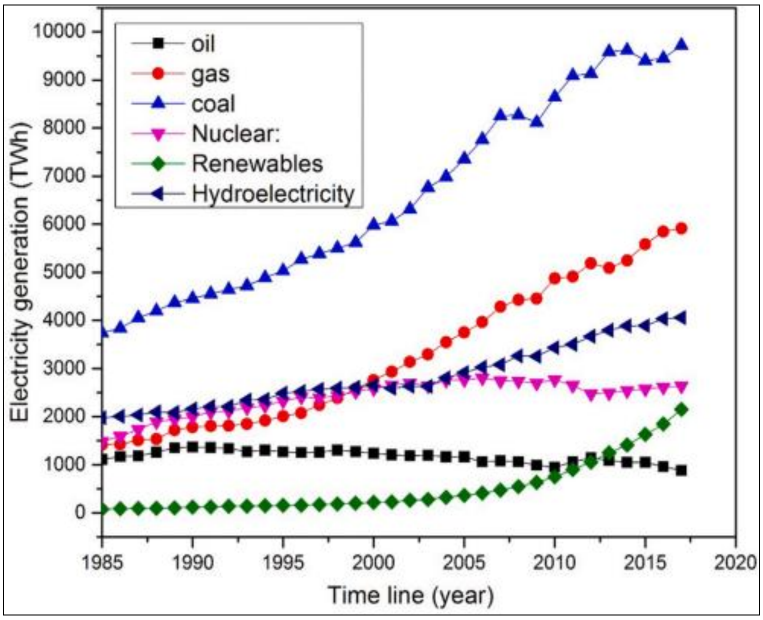

Fig 3: Primary energy in power sector by fuel types from 1985 to 2017

1.1 Natural Gas

Due to its high energy content, natural gas has been seen as a suitable primary source for the production of electricity. Compared to the combustion of coal and oil fuels, natural gas produces less carbon dioxide (CO_2). Presently, 23% of the world's electricity has come from natural gas, and the trend will continue to grow till 2041 [4]. Natural gas is used to generate 64% of the nation's electricity. However, only 12.88 TCF of natural gas is stored in 26 gas fields across the nation, significantly less than the necessary demand. The total daily capacity for gas production is 274 million standard cubic feet (MMSCFD). Whereas the current national gas demand is around 4221 MMSCFD [3].

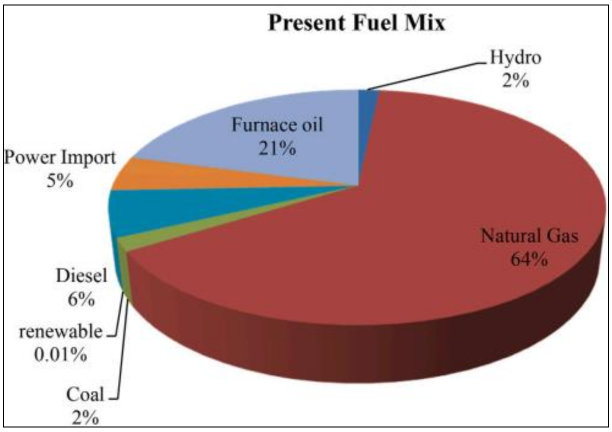

Fig 4: Present primary energy mix until August 2018 [3].

The majority (64%) of the natural gas, which is used to generate electricity by power plants and the captive power station, is used for this purpose, as shown by the sector-specific gas consumption pie chart in Fig. 5. Concurrently, domestic households, businesses, the production of fertilizer, and compressed natural gas (CNG) sectors use about 16.13%, 14.63%, 5.44%, and 4.81%, respectively. Bangladesh currently imports liquefied natural gas (LNG) to meet this requirement. The government-owned company Petrobangla and the American company Excelerate Energy have already agreed to establish the first Floating Storage and Re-Gasifying Unit (FSRU) of Bangladesh at Moheshkhali in the Chattogram district of Bangladesh for the import and processing of LNG [3].

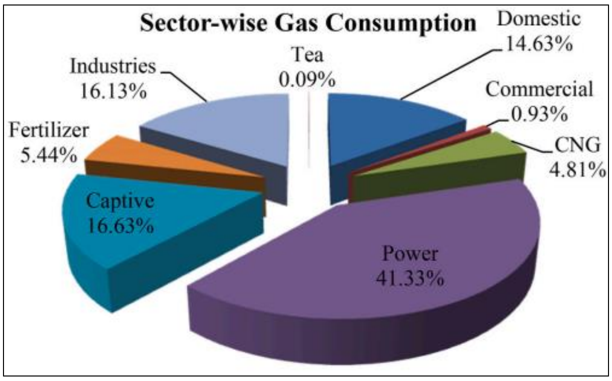

Fig 5: Natural gas consumption of Bangladesh in the FY 2015–16 [3].

The study by Bhatti *et al.* [5] deals with using data from experiments, analyze the energy and exergy of a four-stroke, variable compression ratio spark-ignition engine. The findings indicate that when the compression ratio raised from 6 to 10, the maximum power output 3.80 kW was attained at a compression ratio of 10 at 1800 rpm. At a compression ratio of 9 for 1200 rpm, it is discovered that the highest energy and exergy efficiencies are 28.55% and 27.35%, respectively. Entropy generation was discovered to be minimum for compression ratio 9, or 15.68 W/K at 1200 rpm, and maximal for compression ratio 7, or 36.47 W/K at 1800 rpm. According to the study's findings, with a compression ratio of 7 for 1800 rpm, there was a maximum amount of energy destroyed (10.87 kW).

Nieminen and Dincer [6] have compared the efficiency of hydrogen and gasoline spark-ignition engines in terms of exergy, and as a result, identified several variables that affect the transmission of input exergy. A. Ghareghani *et al.* [7] studied Effect of fuel on energy and energy balance in a dual-fuel Spark Ignition (SI) engine using a different fuel, such as CNG. The efficiency of CNG's first and second laws is discovered to be 5.4% and 3.18% higher than that of gasoline, respectively. Giani Bidini *et al.* [8] report Rankine cycle cogenerator, which runs as the bottoming cycle on the exhaust gases from the ICE, and a reciprocating internal combustion engine cogenerator, which serves as the topping cycle. Compared to exergetic efficiencies, which were 39.9%, electrical and energetic efficiencies were 35.1% and 44.9%, respectively.

Dinler, N., *et al.* [9] illustrated the studies on internal combustion engines frequently focus on the combustion. Increasing combustion efficiency is necessary to decrease air pollution from internal combustion engines and to improve engine performance. This study used numerical analysis to explore the impact of the air/fuel ratio. The flow and combustion of an in-cylinder engine were simulated using a model of an axis-symmetric internal combustion engine. Equations for combustion, momentum, turbulence, and transient continuity in two dimensions were all solved.

Alkidas [10] calculated the availability destruction based on test measures of braking power and heat produced in coolant and lubricant, identifying combustion and heat transfer as the primary sources of irreversibility. Ameri *et al.* [11] illustrated utilizing the findings from experimental test runs, energy and exergy analysis is used to assess an internal combustion engine's performance at steady-state conditions. Various engine speeds are used to determine the energy and exergy balances. According to the findings, as engine speed increases, energy and energy flow's heat rejection also rises. The energy efficiencies are slightly lower than the exergy efficiencies.

Rufino *et al.* [12] explained as fuel for a spark-ignition engine, gasoline and hydrous ethanol were used in experiments to collect experimental data for various operating circumstances. Finally, engine speed, engine load, and air-fuel ratio functions were used to assess first and second law efficiency.

M. K. Rath *et al.* [13] expressed the compression ignition (CI) engines using diesel and Karanja methyl ester mixes had their energy, exergy, mean gas temperature, and exhaust gas temperature analyzed. At various compression ratios while the engine is fully loaded and at varied engine loads. With an increase in compression ratio and load, it has been found that energy efficiency, mean gas temperature, and brake thermal efficiency all rise.

Aditya Kolakoti *et al.* [14] the studies are carried out for waste cooking oil biodiesel (WCOBD), waste palm oil biodiesel (WPFBD), and waste poultry fat biodiesel (WPFBD) at varied loads while maintaining a constant rpm of 1500. The results demonstrate that WCOBD outperforms the other two biodiesels due to its high exergetic efficiency (52.74%) and low exergetic destruction (3.74 kJ).

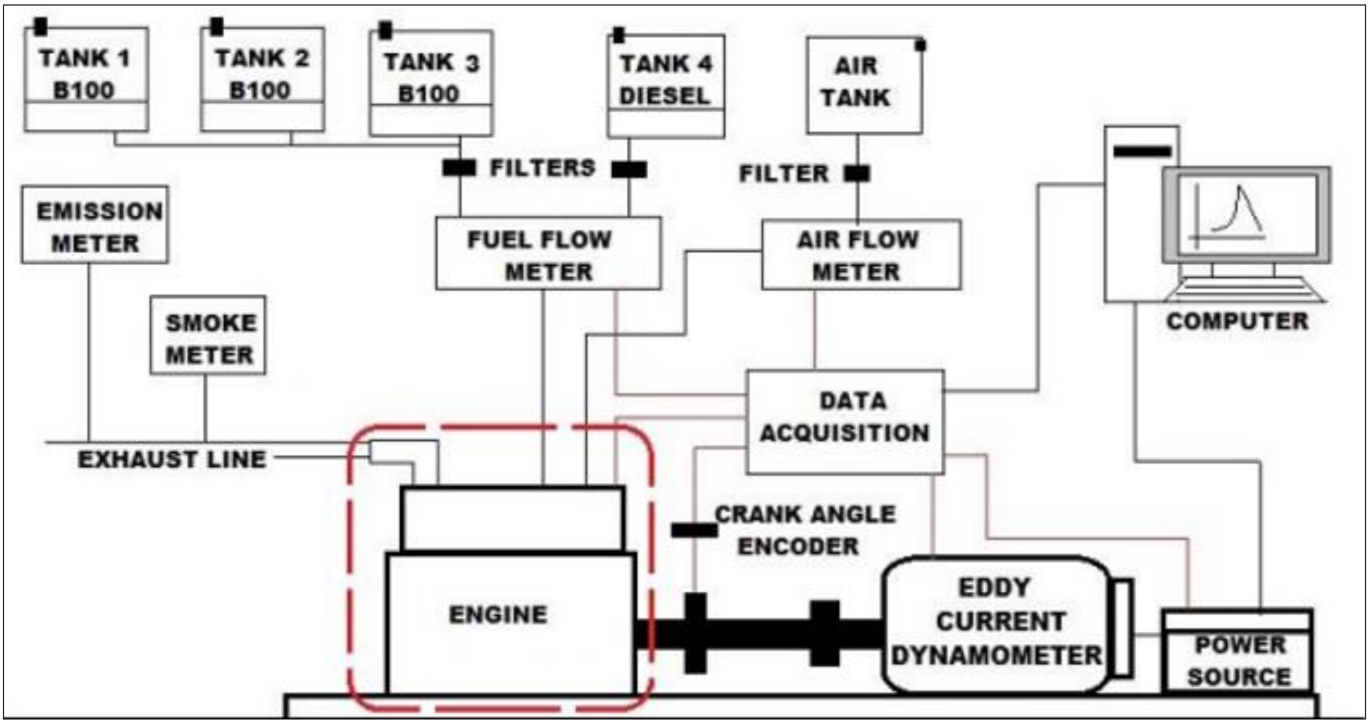

Fig 6: Experimental test rig and its components

Thibordin Sangsawang *et al.* [15] the experiments were carried out in a small single-cylinder diesel engine at full load condition using two different fuels; diesel and B50. The efficiency calculated from the first and second law of engine fuel with diesel was 44% and 31.26% respectively, while B50 was 32.90% and 30.15%. The irreversibility of the engine was 40.36% and 41.94% for diesel and B50.

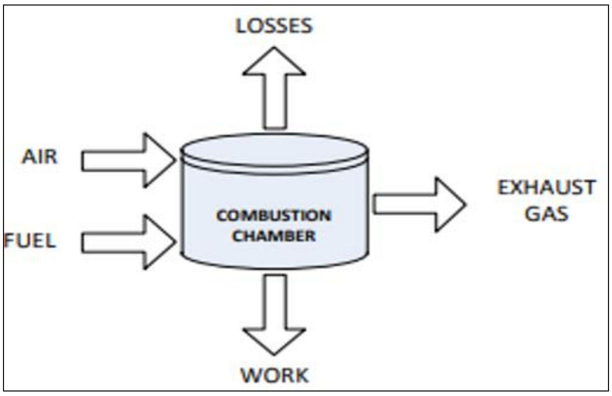

Fig 7: Schematic of an energy balance of the ID engine [15].

Guillermo Valencia *et al.* [16] explained the energy and exergy evaluations of three ORC-WHR systems with thermal oil coupling. Cyclohexane, toluene, and acetone are simulated as ORC working fluids in three different ORC configurations: a straightforward ORC (SORC), an ORC with a recuperator (RORC), and an ORC with double pressure (DORC). By achieving a net power output of 146.25 kW, an overall conversion efficiency of 11.58%, an ORC thermal efficiency of 28.4%, and a specific fuel consumption reduction of 7.67% at 1482 rpm engine speed, 120.2 L/min natural gas flow, 1.784 lambda, and 1758.77 kW of mechanical engine power, RORC with toluene improves the operational performance.

Fig 8: Jenbacher JMS-612 GS-N.L natural gas engine [16].

Jianqin Fu *et al.* [17] illustrated the waste heat energy mostly concentrates on cooling water at low speeds and low loads; Exhaust gas energy is greater than cooling water energy at high speeds and high loads, both in terms of quantity and exergy percentage and efficiency; meanwhile, cooling water exergy efficiency is highest at low speeds and low loads. Theoretically, the use of waste heat recovery, the gasoline engine's total fuel economy can be increased by almost a factor of two, with a maximum improvement of 60%.

A. Kumar *et al.* [18] expressed the 250 MW coal-fired sub-critical power plant, the exergetic efficiency and the exergy destruction phenomenon are computed. The estimated value for the calculated plant's overall energy efficiency is 34.75%. In addition, it appears from the results that the steam generator, which has a capacity of 490.76 MW

(93.07%), is where the majority of the energy is lost. The condenser contributes significantly to the heat loss ratio in a comparative analysis of the heat loss ratio with respect to changing plant load.

Adeel Arshad *et al.* [19] presented a basic overview of the theoretical and experimental elements of thermodynamics analysis for commonly used fuel cells (FCs). The FC converts fuel (often hydrogen) chemical energy directly into electrical energy, producing heat and liquid water as waste products. The solid oxide fuel cell (SOFC), molten carbonate fuel cell (MCFC), and proton exchange membrane fuel cell (PEMFC) electrochemical processes and thermodynamic models are discussed in the second section.

N.K. Das *et al.* [3] illustrated a comprehensive analysis of the current energy situation was provided, accounting for the many energy resources that are now available, while also suggesting the optimum energy solution for Bangladesh's sustainable development. According to our estimation, the ideal energy mix for Bangladesh would be 25% coal, 25% natural gas, and 35% renewable energy.

The literature review shows that several researchers studied the internal combustion chamber’s fuel performance in terms of energy, exergy rates, irreversibility, exergy destruction, and efficiency, first and second law of thermodynamics, mechanical parameters as well as the scenario of natural gas with composition of Bangladesh.

2 Energy and exergy in engines

2.1 Energy

Empirical knowledge defines energy as a physical quantity and a thermodynamic condition. Basically, there are many different types of energy, including magnetic, chemical, mechanical, and electrical energy. In the words of Richard Feynman, "It is crucial to understand that in modern physics, we have no idea what energy is. We lack a visual representation of energy arriving in discrete amounts of little blobs". However, the greatest revolution occurred when man discovered how to convert energy from one form to another. Engine is the device responsible for converting energy [20].

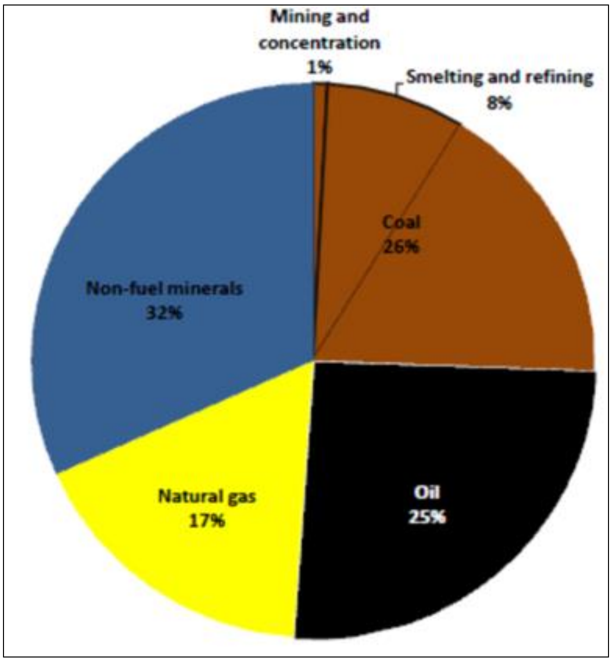

Fig 9: Energy distribution of Natural gas [20].

2.2 Exergy

Exergy is defined as the maximum theoretically feasible useful work produced while a system interacts with an equilibrium state. Exergy is typically not conserved as energy but rather destroyed inside the system. It is a significant characteristic of the system and is dependent on both the condition of the system and the characteristics of the environment. There are two parts of availability of the exergy as (i) The thermo-mechanical availability and (ii) The chemical availability [22].

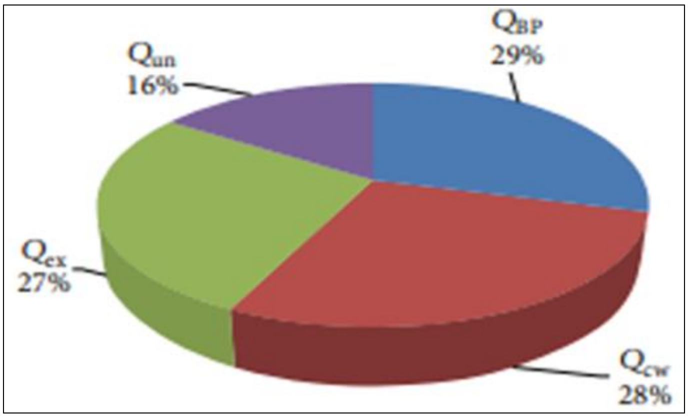

Figure 10: Exergy distribution of Natural gas [21].

An analysis of a system's performance that is based on the first rule of thermodynamics is known as an energy-based performance analysis. There are additional losses at each level, so only a portion of the energy is actually available. An analysis of a system's performance that uses the second law of thermodynamics and goes beyond an energy-based analysis is known as an exergy-based performance analysis [20]. A machine that converts one form of energy into another is called an engine. In a heat engine, thermal energy is thus changed into mechanical energy. In general, there are two types of heat engines: Engines that burn fuel internally (IC Engines) and outside (EC Engines) [23]. In an internal combustion engine, a component, such as pistons, turbine blades, or a nozzle, is subjected to direct force as a result of the expansion of the high-temperature and-pressure gases created by combustion. This force propels the part over a distance, producing mechanical energy that is used to power the engine [24].

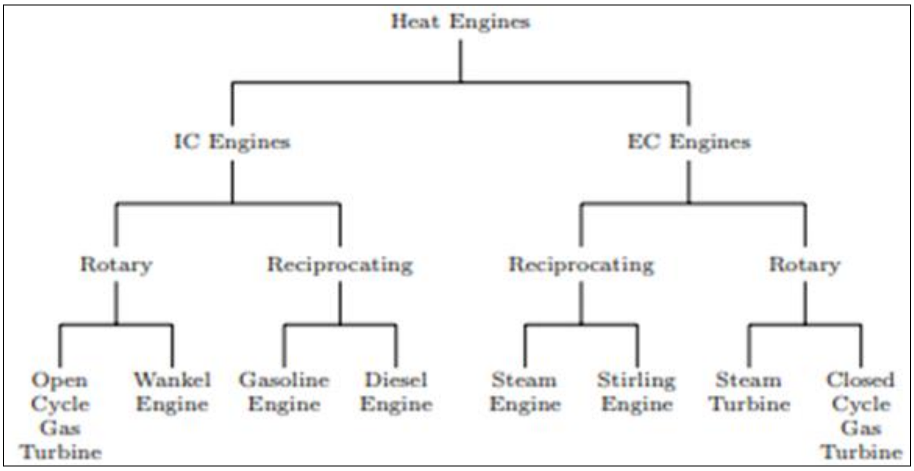

Fig 11: Classification of heat Engine [23].

Table 2: Specification of the engine model W20V34SG following.

S. No.	Description	Value	Unit
1	Cylinder bore	340	mm
2	Piston stroke	400	mm
3	Cylinder output	450	Kw/Cylinder
4	Engine speed	750	rpm
5	Piston speed	10	m/s
6	Cylinder no’s	20	No’s
7	Air/fuel ratio	11:1	-
8	Engine efficiency	44.4	Percentage, %
9	Engine weight	76.4	Ton
10	Fuel type	NG	-
11	Brake mean effective pressure	19.8	Bar
12	Max mechanical power output	9000	Kw

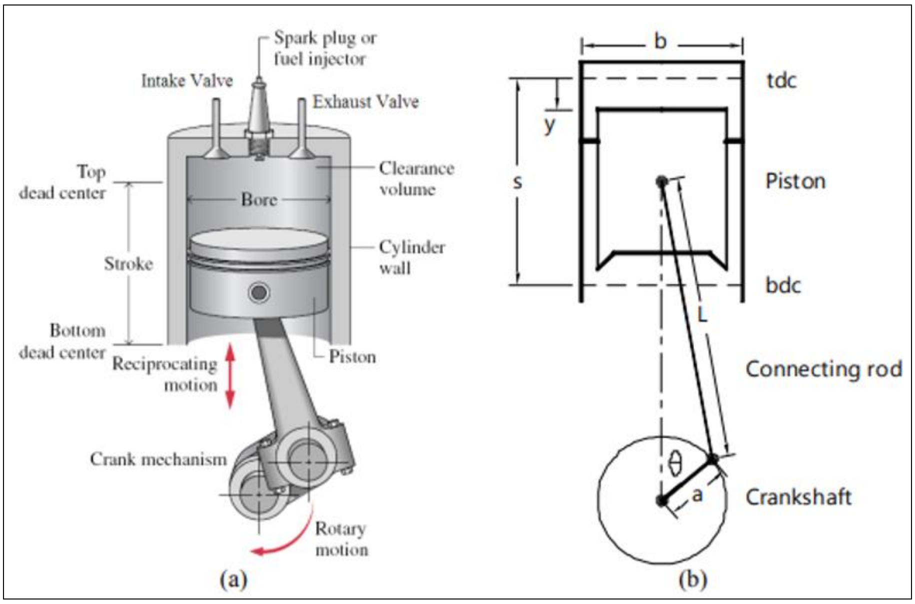

Fig 12: (a) Engine terminology, (b) Piston-Cylinder Geometry [25].

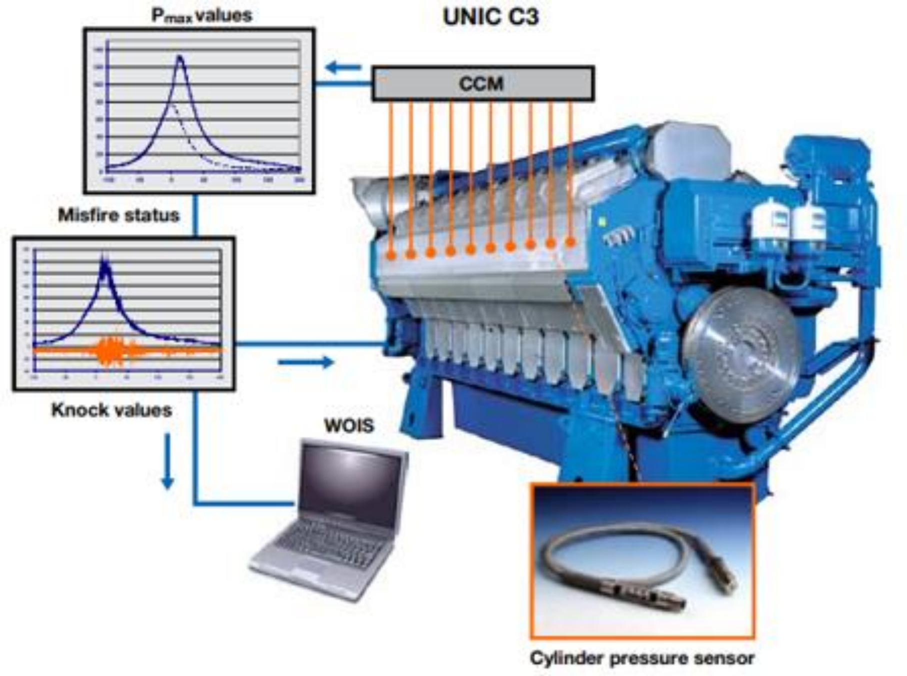

Fig 13: Wartsila Engine model with WOIS Monitor

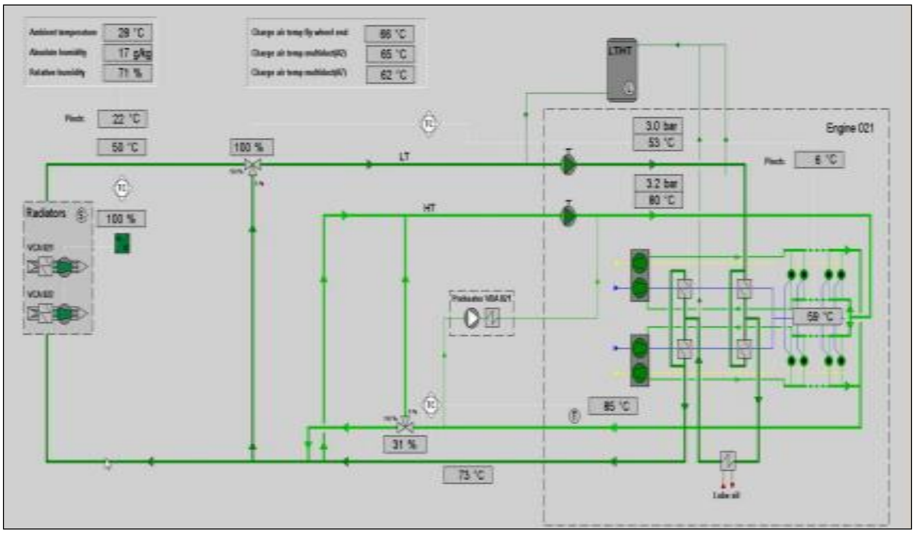

Fig 14: Wartsila engine cooling system

Table 3: Fuel Composition and supply condition for the engine.

S. No.	Components	Chemical Composition/ Units	Range (mole %)
1	Methane	CH_4	70-90
2	Ethane	C_2H_6	0-0.20
3	Propane	C_3H_8	0-0.20
4	Butane	C_4H_{10}	0-0.20
5	Oxygen	O_2	0-0.02
6	Carbon dioxide	CO_2	0-0.80
7	Nitrogen	N_2	0-0.50
8	Hydrogen sulphide	H_2S	0-0.50
9	Inert gases	He, Ni, Ar, Xe	Trace
10	Uncorrected Vol. ratio	L/s	110-140
11	Base Volume	10265	M^3
12	Mechanical Volume	86525	M^3

Table 4: Standard air parameters (P_o= 101.325 kPa and T_o = 298 K).

S. No.	Air components	Chemical composition	Mole fraction (%)
1	Nitrogen	N_2	75.67
2	Oxygen	O_2	20.35
3	Water	H_2O	3.03

4	Carbon dioxide	CO_2	0.0345
5	Carbon mooxide	CO	0.0007
6	Sulphure dioxide	SO_2	0.0002
7	Hydrogen	H_2	0.00005
8	Others	-	0.91455

2.3 Performance Parameters of SI Engines

Due to population increase and economic development, there is a rising need for energy worldwide, along with a need to reduce emissions and pollution. High energy prices, in addition to these other reasons, are encouraging us to use energy resources sustainably [26]. The first combustion models were developed by using a closed system with a single zone and a time-dependent volume to apply the first law of thermodynamics [27]. Exergy, also known as availability, is the portion of energy that can perform work in a particular setting. A system's capacity to perform work in a particular environment is determined by exergy, which is dependent on FLT and SLT [28]. Exergy analysis is applied to engineering systems and is highly helpful since it offers quantitative data on exergy losses and irreversibilities in the system. This allows for the quantification of thermodynamic efficiency, the identification of areas with low efficiency, and the improvement of process design and operation [29]. The compression, combustion, and expansion processes of SI engines can be seen as a control mass application because the fuel and air combination is well mixed at the start of the simulation [30].

Table 5: Total generation of the plant for the month of August'2019.

Description	Month To Date (August'19)	Year To Date (July'19 to August'19)
Gross Generation, MWh	7822.52	15179.08
Auxiliary Consumption MWh	136.16	276.88
Total Export, MWh	7686.36	14902.20
Total Import, MWh	1.80	3.96
Availability Factor (%)	95.06	91.83
Plant Factor (%)	76.53	74.18
Net Heat Rate, kj/kWh	8444.98	8448.14
PPA Heat Rate kj/kWh	9411	9411
Water Consumption, ml^3	166	345.00

3 Thermodynamic analyses

Energy is a fundamental concept in thermodynamics and one of the most important components of engineering analysis. Additionally, system losses caused by process changes such as load variations and changes in pilot fuel quality must be evaluated.

3.1 Energy Analysis

The energy input (Qin) in any IC engine is contained in its fuel.

This amount of input energy is then converted into other forms. In an engine, the input chemical energy of fuel is usually converted to the following forms.

a) Useful work output or shaft energy (Pshaft).
b) Energy transferred to cooling water (Qcw).
c) Energy transferred to the exhaust gases (Qeg).
d) Uncounted losses (Quncounted) due to friction, radiation, heat transfer to surroundings, operating auxiliary equipment, etc.

The amount of each of these energies stated above evaluated on the basis of the first law of thermodynamics is now described.

The input energy (Qin) to the engine is the amount of fuel energy content in the supplied fuel and it is given by,

For energy input, $Qin = [(M'd /3600)*LHVd]$ kW

The energy converted to shaft output,

$$Pshaft = 2 * \Pi * N * W * r; \text{ kW}$$

The heat loss from the engine block to the cooling water is given by

$$Qcw = [M'we * Cpw * (T2-T1))]; \text{ kW}$$

The energy wasted in form of exhaust gas losses is evaluated by,

$$Qeg = [M'eg * Cpeg * (T5-To)]; \text{ kW}$$

Where, the physical property of the exhaust gas (the value of Cpeg) can be determined from the energy balance of flows passing through the calorimeter as follows:

$$Cpeg = [M'wc * Cpw * (T4-T3)] / [M'eg * (T5-T6)] \text{ Kj/Kg k}$$

and

$$M'eg = M'a + M'd \text{ (for diesel)}$$

$$M'eg = [M'a + M'pd + M'g] \text{ (for dual fuel)}$$

e) The amount of the uncounted losses is determined by performing an energy balance and is given by, Quncounted

$$= [Qin - (Pshaft + Qcw + Qeg)] \text{ kW}$$

Energy efficiency η_1 is ratio of useful output to energy input and is given by:

Energy efficiency $\eta_1 = P_{shaft}/Q_{in}$ [20].

3.2 Exergy analysis

Exergy consists of two crucial components. The first is known as physical exergy, and the second is known as chemical exergy. The study gives little weight to the kinetic and potential components of exergy [11]. Availability is defined as the capacity to perform useful mechanical work. In an IC engine, the chemical fuel availability input (Ain) is transformed into different energy sources.

In an engine, the input fuel availability is converted into the following forms:

1. Useful work output or shaft availability (Ashaft).
2. Availability transferred to cooling water (Acw).
3. Availability transferred to the exhaust gases (Aeg).
4. Uncounted availability destructions (Adestoyed) due to friction, radiation, heat transfer to surroundings etc. From the second law of analysis, now we calculate all the availabilities transferred.

1. Chemical availability of fuel or input availability

Ain= [1.0338 * M´d* LHVd] Kw.
Apd= (1.0338 *M´pd* LHVpd) Kw.
Ag = (.95 * M´g* LHVg) kW; 2).
Shaft availability Ashaft = Brake power output (kW).

2. Availability transferred to cooling water

(Acw): Acw = {Qcw - [(M´we /3600) *Cpw* To * ln (T2/T1)]} kW

3. Availability transferred to the exhaust gases

Aeg= {Qeg + [M´eg/3600 * To *(Cpeg * ln (To/T5) –Regln (Po/Pego))]} kW

4. Destroyed availability: Adestroyed= [Ain– (Ashaft+ Ashaft+ Aeg)] kW

The exergy efficiency (η_{II}) is the ratio of total availability recovered from the system to the total availability input into the system. The recovered availability includes Ashaft, Aeg and Acw.
Therefore,
η_{II}= (Availability recovered/Availability input)
η_{II}= 1 – (Adestroyed /Ain) [20].

4 Results and Discussion

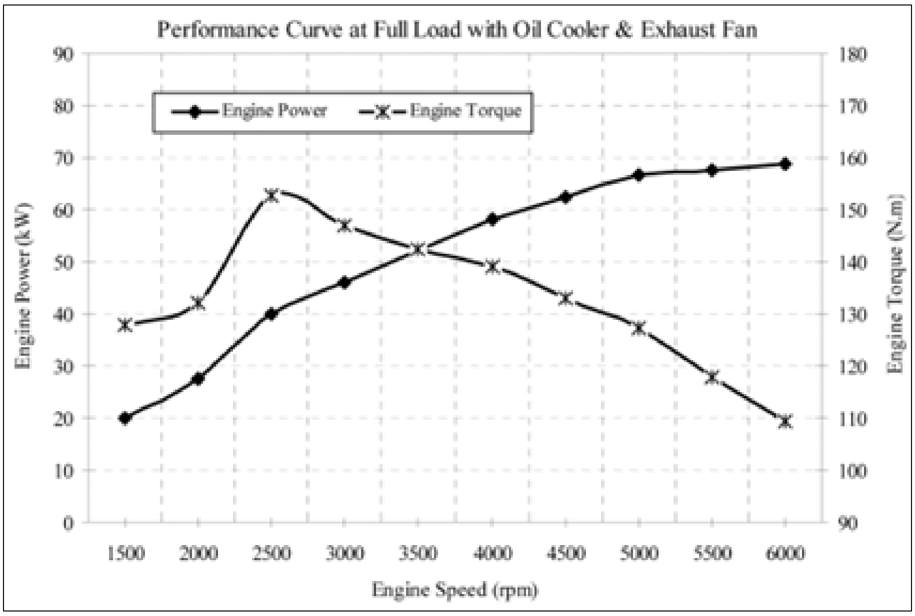

Fig 15: Engine power and engine torque vs. engine speed

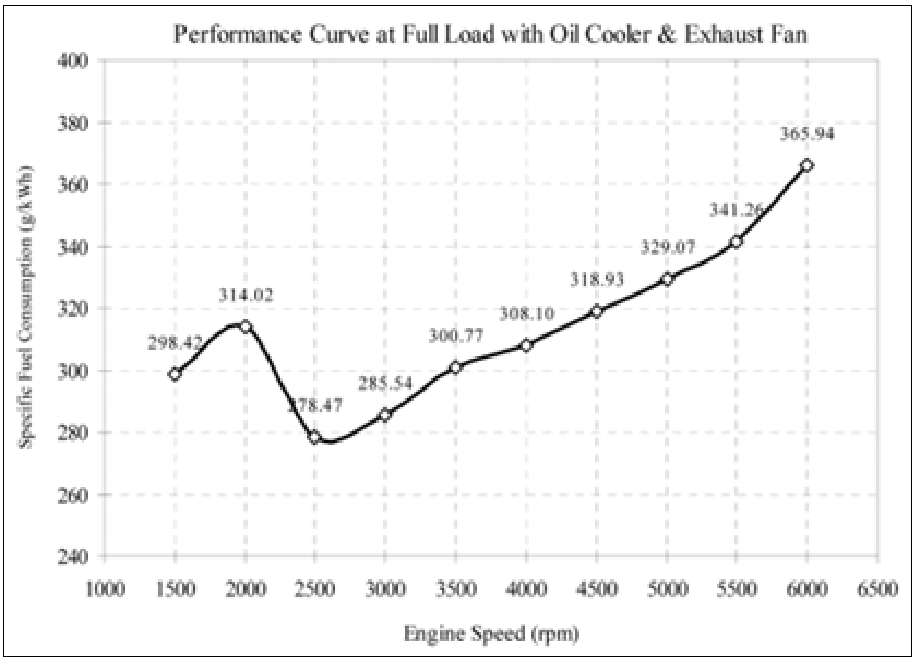

Fig 16: Specific fuel consumption vs. engine speed

Figure 15 demonstrates the power and torque curve vs. the engine speed. It shows that the engine power increases with speed. However, the torque increases to a maximum point at 2500 rpm and decreases after this point. The maximum power and torque produced using gasoline fuel (95-RON) is 68.65 kW and 152.75 Nm at 6000 and 2500 rpm, respectively. Figure 16 shows the specific fuel consumption curve vs. the engine speed. The specific fuel consumption reduces to a minimum at 2500 rpm, which is exactly the same speed for the maximum torque point. The curves show that the specific fuel consumption at full load condition and low speed (2000 rpm) is high. It should be emphasized that the specific fuel consumption increases from 1500 rpm up to 2000 rpm. However, it decreases to a minimum point at 2500 rpm and it increases furthermore with an increase in the speed. The specific fuel consumption generally increases if the speed increases. For two different engine speeds, namely 2500 rpm and 3000 rpm, the specific fuel consumptions are 278.47g/kW−1 h−1 and 285.54 g/kW−1 h−1, respectively [11].

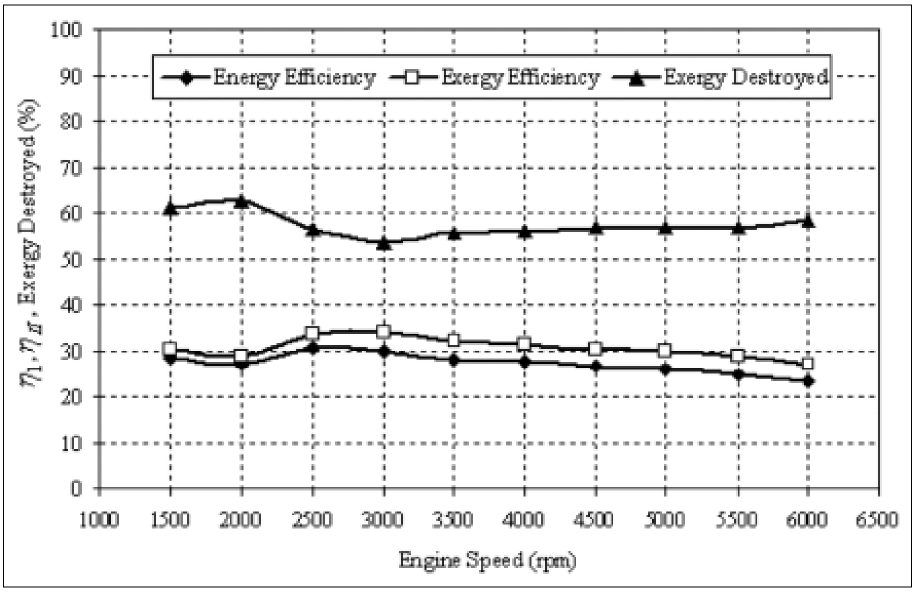

Fig 17: Energy efficiency, exergy efficiency and exergy destroyed vs. engine speed

Figure 17 shows that the energy efficiency has a maximum point at a speed of 2500 rpm whereas the exergy efficiency has a maximum point at a speed of 3000 rpm. It is obvious that the energy analysis reveals that both 2500 rpm and 3000 rpm are the optimum speeds as the efficiency curve is almost flat at those speeds. The exergy efficiencies are 5.83-14.05% higher than the corresponding energy efficiencies because a higher amount of fuel exergy compared with the fuel energy is supplied to the engine [11].

5. Summary

Table 6: Energy and Exergy Efficiency with major observation.

Author Name [Reference]	Condition	Major Observation
N P Perez *et al.* [31]	Its maximum energy capacity is of 5 TR (17.4 kW), and its contribution to the system was approximately 3.62 kW.	If only power production is considered, it can be seen that the first law efficiency is 23.5% and the exergetic efficiency of the trigeneration system is determined to be 51.19%.
M. Razmara *et al.* [28]	Optimal exergy-based control of internal combustion engines. The ICE exergy model is based on the Second Law of Thermodynamics.	the exergy-based optimal control strategy leads to an average of 6.7% fuel saving and 8.3% exergy saving compared to commonly used FLT based combustion control.
G Valencia *et al.* [32]	Engine rpm 1482 speed, a 120.2 L/min natural gas flow, 1.784 lambda, and 1758.77 kW of mechanical engine power.	The energy efficiency 28.41% and exergy efficiency 59.76% confirm that toluene RORC assembly is the best alternative for this natural gas engine.
D Ganesh *et al.* [33]	Single cylinder constant speed of 1500 rpm at varying loads where the CNG is fumigated in the intake manifold at 110mm	The second law efficiency for CNG at equivalence ratio of 0.5 is 42% which is far more than the diesel efficiency 32%.
B Ozdalyan *et al.* [34]	The test engine is VSG413 SI type engine fuel with 95 oct gasoline. The test engine has 1.3 volume, four stroke, four-cylinder, 45 kW maximum power capacity and 98 N-m maximum torque capacity	It is found that maximum energy and exergy efficiencies are obtained at crankshaft speed of 2500 rpm, which are 29.78% and 27.77%, respectively.
M. Ameri *et al.* [11]	The exergy efficiency has a maximum point as the exergy destruction of combustion process reaches its min. point at the speed of 3000 rpm.	The exergy efficiencies are 5.83–14.05% higher than the corresponding energy efficiencies

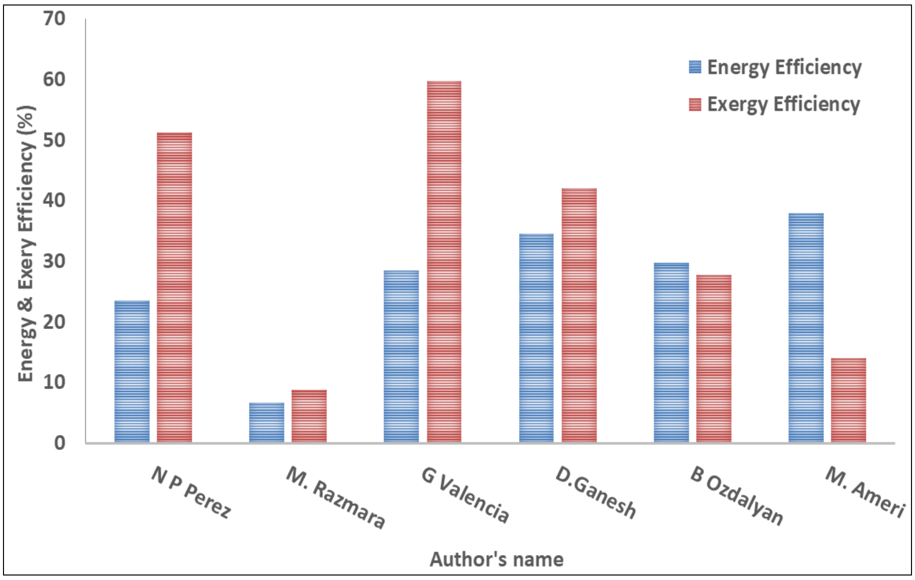

Fig 18: Energy and exergy efficiency with Author's name

6. Conclusion

In this paper, an internal combustion engine's analytical evaluation and experimental measurements are both presented. The following conclusions can be reached as a result of such analyses:

a) It is found that maximum energy is obtained at crankshaft speed of 2500 rpm, which are 29.78%. The test engine is VSG413 SI type engine fuel with 95 oct gasoline. The test engine has 1.3 volumes, four strokes, four-cylinder, 45 kW maximum power capacity and 98 N-m maximum torque capacity.
b) The maximum exergy efficiency is obtained 59.76% and confirms that toluene RORC assembly is the best alternative for this natural gas engine. Engine rpm 1482 speed, a 120.2 L/min natural gas flow, 1.784 lambda, and 1758.77 kW of mechanical engine power.
c) The exergy analysis reveals that the engine optimum speed is 1482 rpm, as the exergy efficiency has a maximum magnitude at this speed.
d) In fact, this research demonstrates that choosing the ideal engine speed should not be done just based on the energy analysis.
e) The amount of energy discarded by the cooling system increases at low speeds and is smaller as the speed rises. On the other hand, as the speed rises, the energy that heated gases lose increases.

In the engine, irreversible processes such combustion, heat transmission, and friction deplete a sizeable portion of the fuel energy. Additionally, as engine speed rises, the sources of energy destruction like friction and heat transfer also increase.

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