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Comparison of New concept Engine Based On Micro Gas Turbine with XU7/L3 Internal Combustion Engine

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In this study, a new micro gas turbine engine is presented. The effect of inlet air cooling on the performance of the micro gas turbine engine by changing the parameters such as the temperature difference between the inlet air temperature (IAT) based on ISA (International Society of Automation) standard and turbine inlet temperature (TIT) has been investigated. then, an Optimization is done base on the Genetic Algorithm with two separate objectives, SNOx minimization, and Thermal efficiency maximization, separately. The thermal efficiency and specific consumption of the optimized cycle based on the thermal efficiency are compared with the XU7/L3 internal combustion engine to produce the output power of 64.57 KW. Results show by adding a cooling system to the micro gas turbines to cool the inlet air with the coefficient performance of 2 and 4 increased the thermal efficiency by about 11.37% rather than base micro gas turbine engine Eventually, the proposed micro gas turbine engine is more efficient than the XU7/L3 internal combustion engine. so It can be understood that micro GT is one of the best substitutes for the internal combustion engine in the new vehicle age just by adding the cooling system.

1. Introduction

Plug-in hybrid system (PHEVs) and hybrid electric vehicles (HEVs) have been boosted as a feasible vehicle technology for the increasing demand for approachable and advanced fuel economy vehicles, environmentally, the manufacturer has taken into account parameters such as fuel economy, emissions, passenger comfort, and safety to improve the performance of PHEV, HEV, and fuel cell vehicles (FCV), in addition to HEV and PHEV the world of electric vehicles includes all-electric vehicles that use no longer internal combustion engines (ICE).

The substitution power has been supplied by a large battery pack. Although the challenges of electric vehicles are to attain small sizes, high efficiency, and low costs in power converters and electric machines, as well as in associated electronics,[1-3] to reduce the size of power generation engine, a study about the production of clean energy with Biogas plants to produce electric energy in ICE or a micro-gas turbine (MGT) was done to discover the benefits of using MGT in the operation of plants[4, 5].

Injection flow for ignition of the chamber will be influenced extraordinary in engine parameters such as rotors turn, specific fuel consumption,

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compressor pressure ratio, and inlet turbine temperature by using MGT.[6]

Huu et al.[7] investigated an MGT engine as an auxiliary power unit (APU) has been coupled with a prototype vehicle with a generator to aid for an extended-range hybrid electric vehicle (ER-HEV). so many studies studied the inspiration of some additional humidification or dehumidification instruments such as additive heat pumps, absorption chiller, and inlet fogging systems to enhance the performance of power plants or engines particularly for gas turbines (GT) plants or GT engines[8, 9].

Effects of the novel cooling for installation in GT system by using turbo-expander to enhance the GT performance which, located at Iranian refinery with two practical air-cooling methods to use in evaporative media or a mechanical chiller has been done by Farzaneh-Gord and Deymi-Dashtebayaz [10].

Barakat et al.[11] presented a new hybrid cooling system and compared it with other GT configurations inlet air-cooling systems. Their proposed system contains fogging cooling system and an earth-air heat exchanger.

Caposciutti et al.[12] explored to achieve zero-emission with four novels practically zero-emission of an automotive gas turbine propulsion (AGT) in turbines of PHEVs by using oxy-fuel combustion (i.e., methane in a nearly pure oxygen environment) as fuel, their consequences were decreasing emission of the system with this novel AGT [13].

Radchenko et al.[14] studied operating liquefied natural gas (LNG) as fuel in cold energy for a novel inlet air cooling system in refining power plant performance. They optimized developing design parameters for maximization of power plant performance improving power plant performance.

In addition, the supercritical fluid used as working fluid into the inlet fluid of the compressor or pump is substituted, respectively in the refrigeration cycle subsystem[15-17].

To optimize the HEV, a genetic algorithm (GA) was implemented by reflecting multiple constraints on the fuel consumption of the system considered [18, 19].

In this study, a gas microturbine was used instead of an internal combustion engine in a hybrid system. The performance and fuel consumption of the proposed system with an internal combustion engine hybrid engine have been investigated. Also, the effect of the inlet temperature on the gas turbine cycle on the performance has been inspected. an Optimization by Genetic algorithm has been done to minimize the emission of SNOx production and maximize the thermal efficiency of the proposed system.

2. Problem discussion

In the present study, a gas micro-turbine is used instead of XU7/L3 engine as an ICE which, was designed by Peugeot company with specifying intake and exhaust manifold maps, combustion chamber maps, piston map, and crankshaft map. The purposed cycle includes compressor, turbine, combustor, Generator with distinguished performance characteristics such as output power, specific fuel consumption, fuel mass flow rate, and rotational speed[20]. the performance parameters of the XU7/L3 engine shown in Table 1.

Table 1. XU7/L3 engine performance parameters.

Fuel type	Thermal efficiency (%)	Fuel mass flow rate(g/s)	Cost of fuel consumption in an hour of performance (American dollars)
Gasoline	۳۰,۵۹	۵,۰۵	۱۰,۱۶۲

The system proposed in this study the system components consists of a gas turbine (GT) for providing the torque power of the generator rotor. The generator couples with an electrical hybrid engine to connect with the compression refrigeration cycle to the inlet air temperature of the gas microturbine for the cooling system according to Figure 1.

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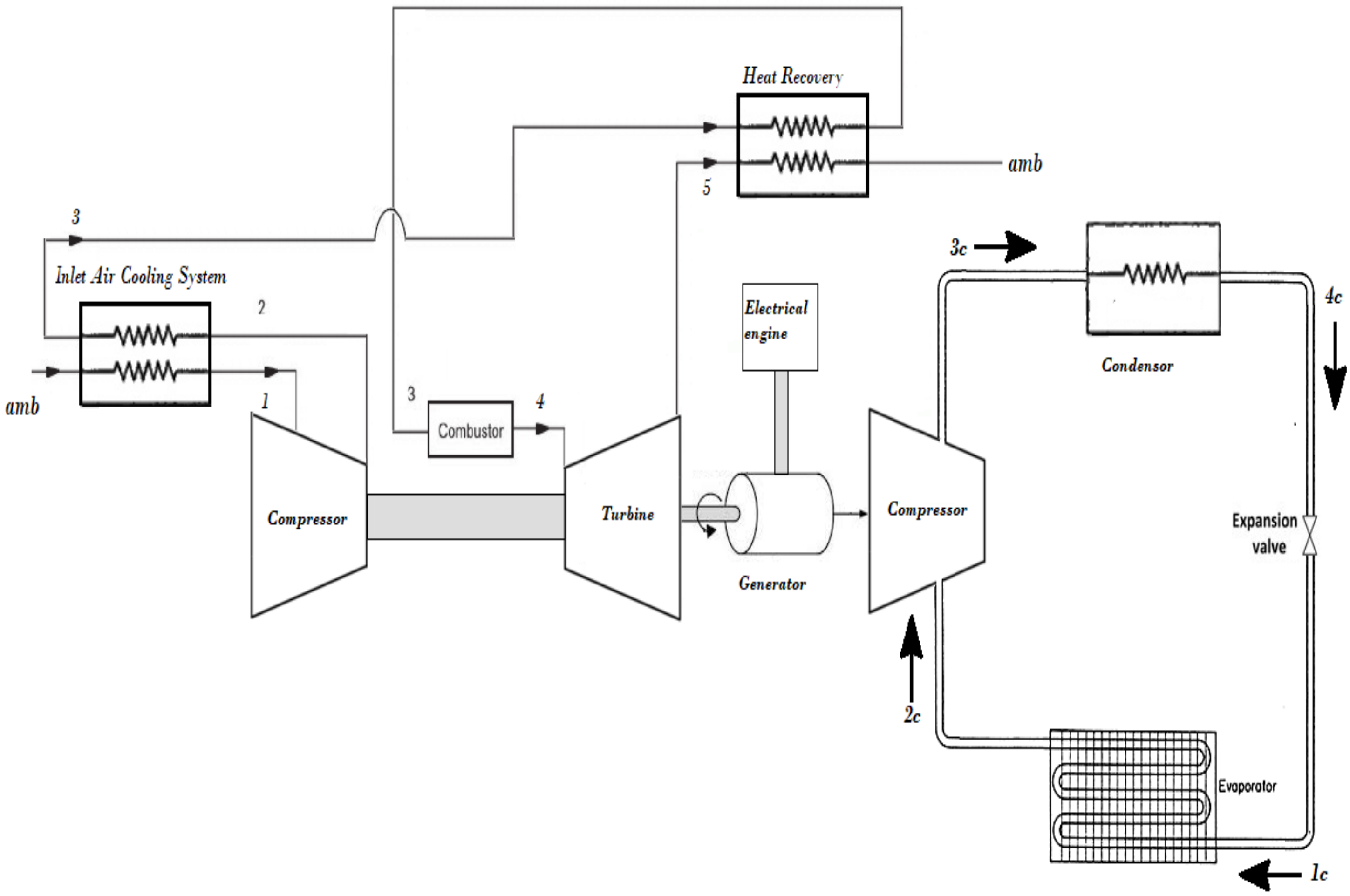

Figure 1. Schematic of the system with consideration of refrigeration cycle

The basic XU7/L3 engine characteristics parameters are used for comparison by variation of Rotational speed for this cycle pretend in table 2.[23]

Table 2. The performance characteristics of the XU7/L3 engine.[23]

	XU7 ENGINE							
Rotational speed (rpm)	1500	2000	2500	3000	3500	4000	4500	5000
Output power (kW)	19.68	26.67	37.40	44.10	51.08	57.54	61.89	64.57
BSFC (g/KWh)	235	236	240	238	250	262	275	282
Fuel mass flow rate (g/s)	1.28	1.74	2.49	2.91	3.54	4.18	4.72	5.05

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The governing power equation in this study has been defined in the following equations.

The net power of the purposed cycle calculated as, [21, 22]

$$W_{net} = m_T Cp\, TIT \left[1 - (r_T)^{\frac{1-\gamma}{\gamma}}\right] \eta_T - m_a Cp\, \mathrm{IAT} \left[\left(r_p\right)^{\frac{\gamma-1}{\gamma}} - 1\right] / \eta_C \qquad (1)$$

Where, m_T is the passing mass flow rate to the turbine, m_a is real air mass flow rate, TIT is turbine inlet temperature, IAT is inlet air temperature to the compressor, γ is heat capacity coefficient, r_p is the pressure ratio of compressor and r_T is the pressure ratio of the turbine, η_C is isentropic compressor efficiency and η_T is isentropic turbine efficiency.

the heat value of hot reservoir calculated as,

$$Q_h = m_a Cp\,(TIT - COT) \qquad (2)$$

Where, m_a is real air mass flow rates, Cp is the specified mean heat capacity, TIT(turbine inlet temperature) is the turbine inlet temperature is the turbine outlet flow and COT is the compressor outlet flow temperature.

In the following equation, FHV (fuel heat value) can be reached as a function of the heat transfer rate of the hot reservoir.

$$FHV = \frac{Q_h}{m_f . \eta_{co}} \qquad (3)$$

Where, η_{co} is the thermal combustor efficiency and Q_h is the heat value of hot reservoir and m_f is fuel consumption mass flow rate.

JP10 is one of the Jet Propellant classifications considers as engine fuel instead of Gasoline, some of the input engine parameters are presented in Table 3.

Table 3. The inlet conditions of the system.

Parameter	description	Value	Unit
IAT	Inlet air temperature	293	(K)
P_1	Inlet pressure	101.3	(kPa)
m_a	Real air mass flow rate	0.45	(Kg/s)
r_p	Compression ratio	4.44	-
TIT	Inlet air temperature	1182	(K)
FHV	Fuel heat value	42.075	(MJ/Kg)

Where, P_1 is the inlet pressure of the compressor.

Thermodynamics properties of the output condition of the gas turbine engine are obtained in Table 4.

Table 4. output condition of the gas turbine engine.

Parameter	description	Value	Unit
Wnet	Power output	66.8	(KW)
η	Thermal efficiency	18.46%	-
m_f	Fuel mass flow rate	8.59	(g/s)
$BSFC$	Specific fuel consumption	463.5	(g/KWh)
$SNOx$	nitrate oxide emission index coefficient	0.092	(g/kg_{fuel})

Brake-specific fuel consumption (BSFC) calculated as,

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$$BSFC = \frac{m_f}{W_{net}} \quad (4)$$

Which, m_f is fuel consumption mass flow rate and W_{net} is net power.

the η_{th} is the thermal efficiency of the engine, which is defined as follows.

$$\eta_{th} = \frac{W_{net}}{Q_h} \quad (5)$$

The nitrate oxide emission index coefficient (SNOx) calculated certainly as follow,

$$SNOx = \left(\frac{P_2}{2965}\right)^{0.4} e^{\left(\frac{T_2-826}{194}+\frac{6.29-\beta}{53.2}\right)} \quad (6)$$

Where, P_2 is the departure pressure of the compressor, T_2 is the departure temperature of the compressor and β is the friction of water-air in the departure of the compressor to the pure air compressor exhaust.

The heat transfer rate of the cooling reservoir calculated as,

$$Q_c = m_a Cp\, \Delta T_c \quad (7)$$

Where, m_a is the air mass flow rate through the engine. In the refrigeration cycle.

Where,m_a and ΔT_c is difference temperature between of inlet and outlet of the refrigeration cycle.

COP (coefficient of performance) in the refrigeration cycle defined as follows,

$$COP = \frac{Q_c}{\dot{W}_{net}} \quad (8)$$

The relative humidity calculated as,

$$\emptyset = \frac{P_{H2O}}{P^*{}_{H2O}} \quad (9)$$

Where, P_{H2O} is the partial pressure of water vapor in mixture and $P^*{}_{H2O}$ the equilibrium vapor pressure of water at a determined temperature.

The genetic Algorithm method for a numerical random search follows the simplified flow of natural evolution.

The algorithm operates on a population of responses and goes to exertion.

Taking the principle of survival of the best, and evolution, to make better answers and more appropriate. The Genetic algorithm is the optimization methods differ, which is the most important the differences are the genetic algorithm with coding parameters, not with the only parameters, the algorithm.

genetic with a population of points, not a point,

Genetic algorithm of probability rules instead of commands in math. In addition to this genetic algorithm derivative and other information-related information is not just a cost function that is the process of progress of the algorithm make it clear. By using the algorithm Genetic can be obtained as a suitable solution for the problem.[23-25]

3. Results &discussion

3.1. Parametric analysis of a micro turboshaft engine

In the parametric analysis of the micro turboshaft engine, thermal efficiency and output power were investigated. Also, the effects of the inlet air temperature on the real inlet air flow rate air and SNOx were investigated. The output power, thermal efficiency, fuel consumption, and consumed fuel flow rate in terms of the turbine inlet temperature as the inlet temperature of the turbine increased, the turbine input enthalpy is increased which can increase the output power of the cycle. As the turbine inlet temperature increases, fuel consumption increases. By increasing the intake temperature, special fuel consumption is reduced. The thermal efficiency increases by increasing the inlet temperature of the turbine. which are illustrated in Figure 2a.

In the following, the effect of inlet air cooling on the performance of the proposed system is investigated. Figure 2b. shows the effect of inlet temperature change on air mass flow rate, fuel consumption, BSFC, output power, and thermal efficiency.

By decreasing air temperature, the incoming air density increased and was followed by the real flow of incoming air to the engine, and air mass flow rate increases. The output power is increased as the intensity of the turbine power is higher than the intensity of the power consumption. Also, the

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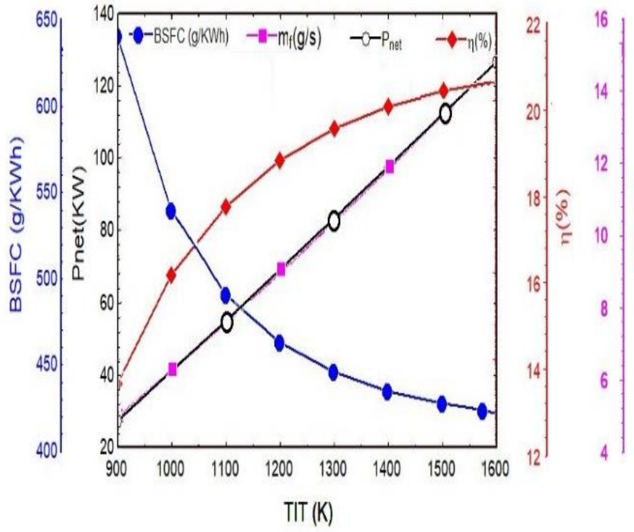
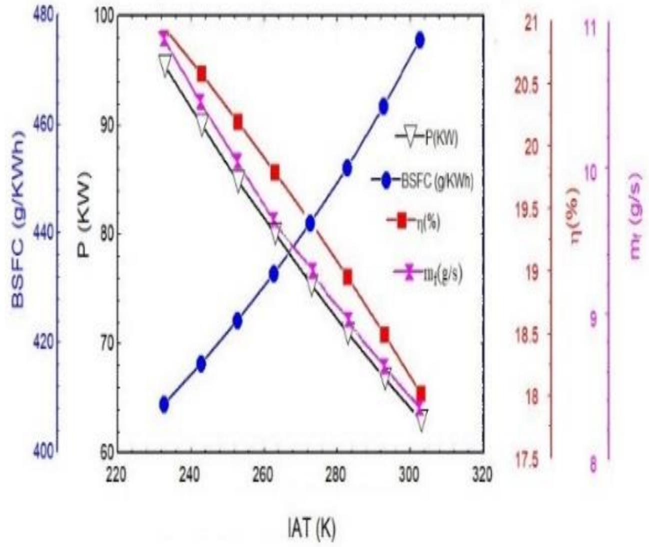
heating rate is increased because of the decrease in the input temperature of the incoming air inlet. The fuel consumption is reduced by reducing the temperature of the input air. Also, due to the decrease in the temperature of the increase the intensity of the output power is higher than the intensity of the increase in the heat transfer rate, which decreases the thermal efficiency of the engine. As the inlet air temperature increases, the amount of SNox produced also increases shows in figure 3.



a)



b)

Figure 2. effects of the system performance parameters by variation a) TIT b) IAT.

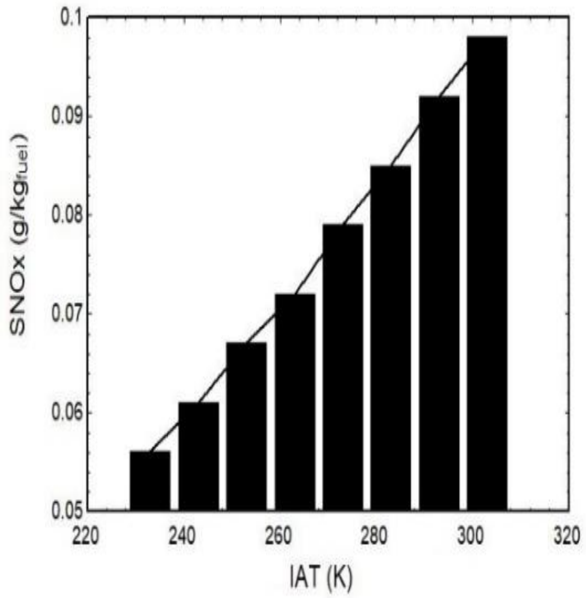


Figure 3. changing of SNOx according to the temperature of the inlet air temperature.

3.2. Optimization of micro turboshaft engine

Considering the importance of the efficiency of the proposed system and the number of pollutant emissions such as SNox, the proposed gas microturbine is

optimized based on two objective functions using a genetic algorithm. The design parameters and their range are presented in Table 5.

Table 5. Design parameters of optimization of micro turboshaft engine

Parameters	Lower bounds	Upper bounds
TIT (K)	900	1450
∅(%)	20	95
r_p	2	15
m_a(Kg/s)	0.1	1.5
IAT(K)	273	323

3.2.1. SNOx minimization.

In this segment, Due to the importance of environmental effects to the proposed system, which optimized based on minimizing the amount of Snox production. The constraints for the amount of output power and BFSC are considered, which

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are presented in Table 6. The optimal values of the design parameters and performance of the proposed system in the optimal state are presented in Tables 6 and 7.

Earlier, it has been discussed the SNOx is variable inlet air temperature also, it has effects on the net power and BSFC.

Table 6. The constraint of optimization for minimized SNOx

Parameters	Lower bound	Upper bound	Units
Wnet	64	80	KW
BSFC	200	282	g/KWh

Table 7. chosen design parameters for optimization in terms of minimization SNOx

Parameters	m_a(Kg /s)	$TIT(K)$	$IAT(K)$	r_p	∅(%)
Values	0.257	1384	273	8.515	87.16

3.2.1. Thermal efficiency maximization

In this section, the proposed system optimization based on the maximization of thermal efficiency is discussed. Constraints parameters as output power and BFSC are included in this optimization and are presented in Table 8.

Table 8. The constraint of optimization for maximized thermal efficiency

Parameters	m_a(Kg /s)	$TIT(K)$	$IAT(K)$	r_p	∅(%)
Values	0.234	1399	273	14.99	22.19

Investigating the effect of supplying the required power for the compression chiller of the inlet air cooling system from the micro-turboshaft engine generator.

The effect of the refrigeration cycle performance coefficient on the optimal state based on the objective function of thermal efficiency has been investigated. The ambient temperature, the input air mass flow considered 323 K, 0.263 kg /s respectively. in compression chiller system by the assumption of COP=2 and 4, the compression chiller power consumption with the value and 5.96 kW, 2.97 kW reflected, respectively. Comparison of fuel consumption for the optimized cycle is based on the maximum thermal efficiency of the input and with COP= 4, in figure 4. also, by presumptuous of COP=2 the design parameters are shown in figure 5. It can be realized that by increasing fuel consumption the net power linearly increasing and by chosen the net power of 64.57 KW to compare specific fuel consumption which, was decreased 11.38 % and 11.36 with COP=4 and COP=2, respectively.

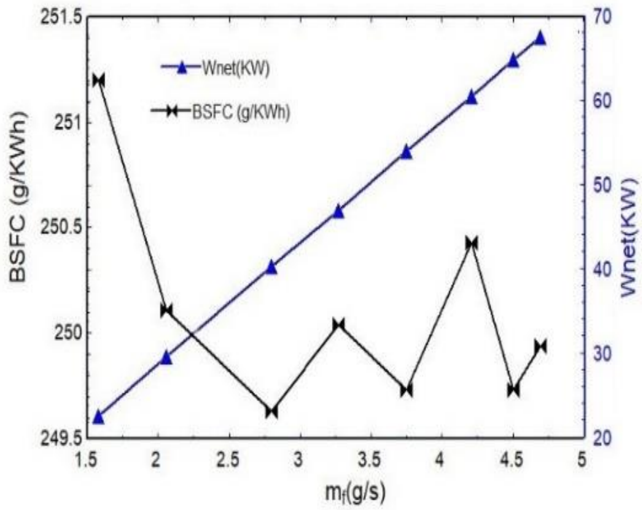

Figure 4. The comparison of fuel consumption mass flow rate with COP=4

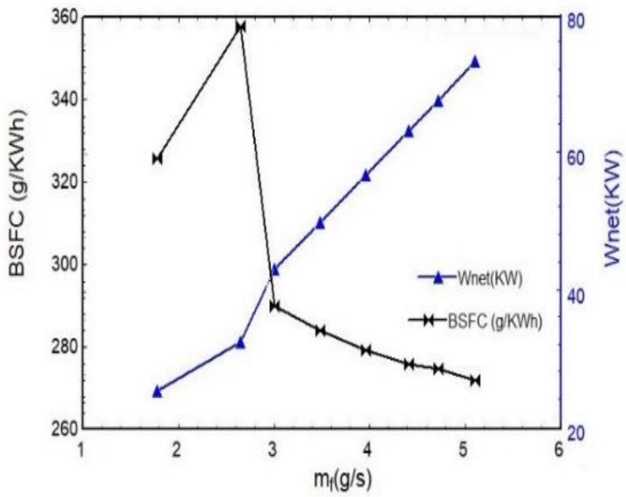

Figure 5. The comparison of fuel consumption mass flow rate with COP=2

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The different biofuel and liquid natural gas (LNG) thermodynamically and economically compared with each other.

The heat value of the study is shown in table 9.

Fuel name	Gasoline	Liquid natural gas	Ethanol	Diesel
Fuel Heat Values (MJ/Kg)	42.075	49.736	26.81	42.743
Price($/Kg)	0.559	1.348	0.489	0.697

Table 9. heat value of different fuels[٢٦].

Comparison of Performance and economy of fuel consumption of XU7/L3 of the optimized cycle according to thermal efficiency in return of power

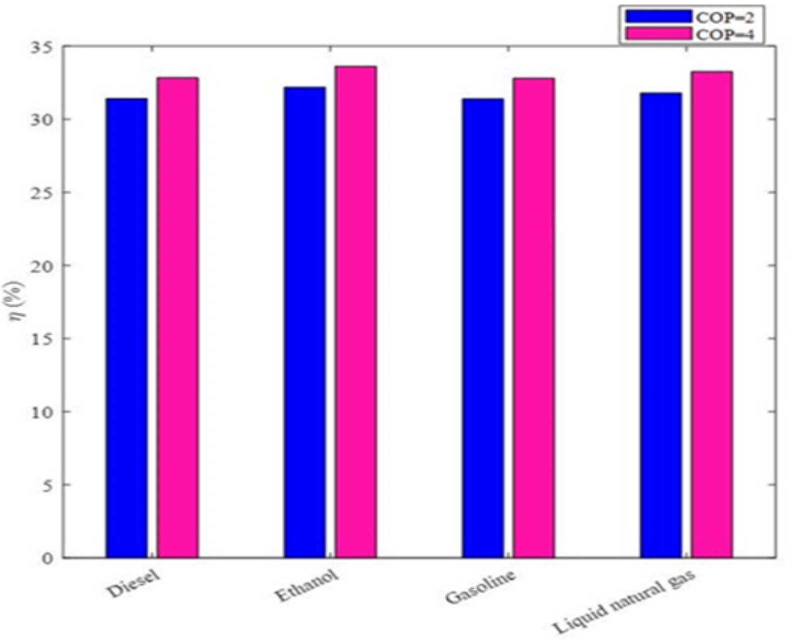
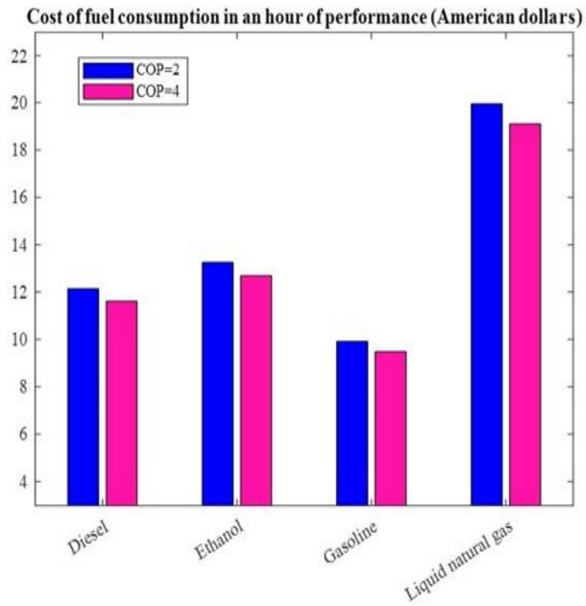


Figure 6. Variation thermal efficiency in terms of different fuel in optimized cycle



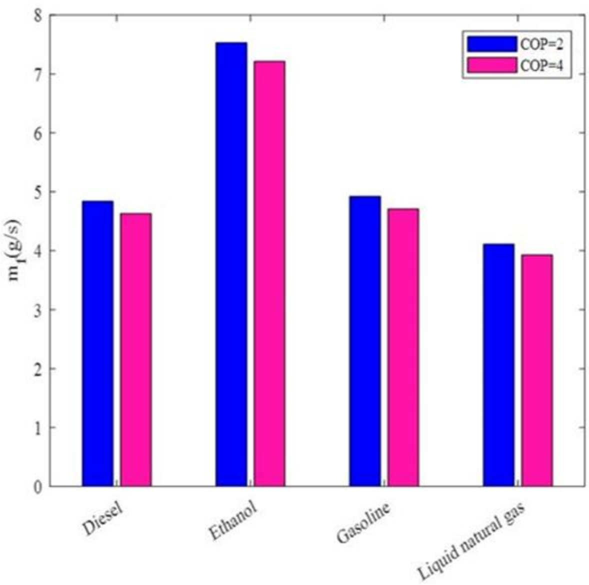


Figure 7. Variation mass flow rate in terms of different fuel in optimized cycle

Figure 8. Variation fuel cost per hour of performance in terms of different fuel in optimized cycle

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provision for refrigerating of the system with COP=2 in terms of the constant power output of 65 KW for different fuel for XU7/L3

As shown in fig6. Also, the economic comparison is shown in fig 7.

The results show in optimized cycle with the cooling system by variation of substitutional fuel suggestion that using of the ethanol as the fuel is the most efficient although the liquid natural gas (LNG) is the most reasonable fuel in this conceptional system, in addition, according to the fuel consumption mass flow rate by variation fuel shows that the ethanol conception is the most consumption fuel in the conceptional cycle, also LNG has the less consumption rather than others, consequently can prove that the LNG is better than the others

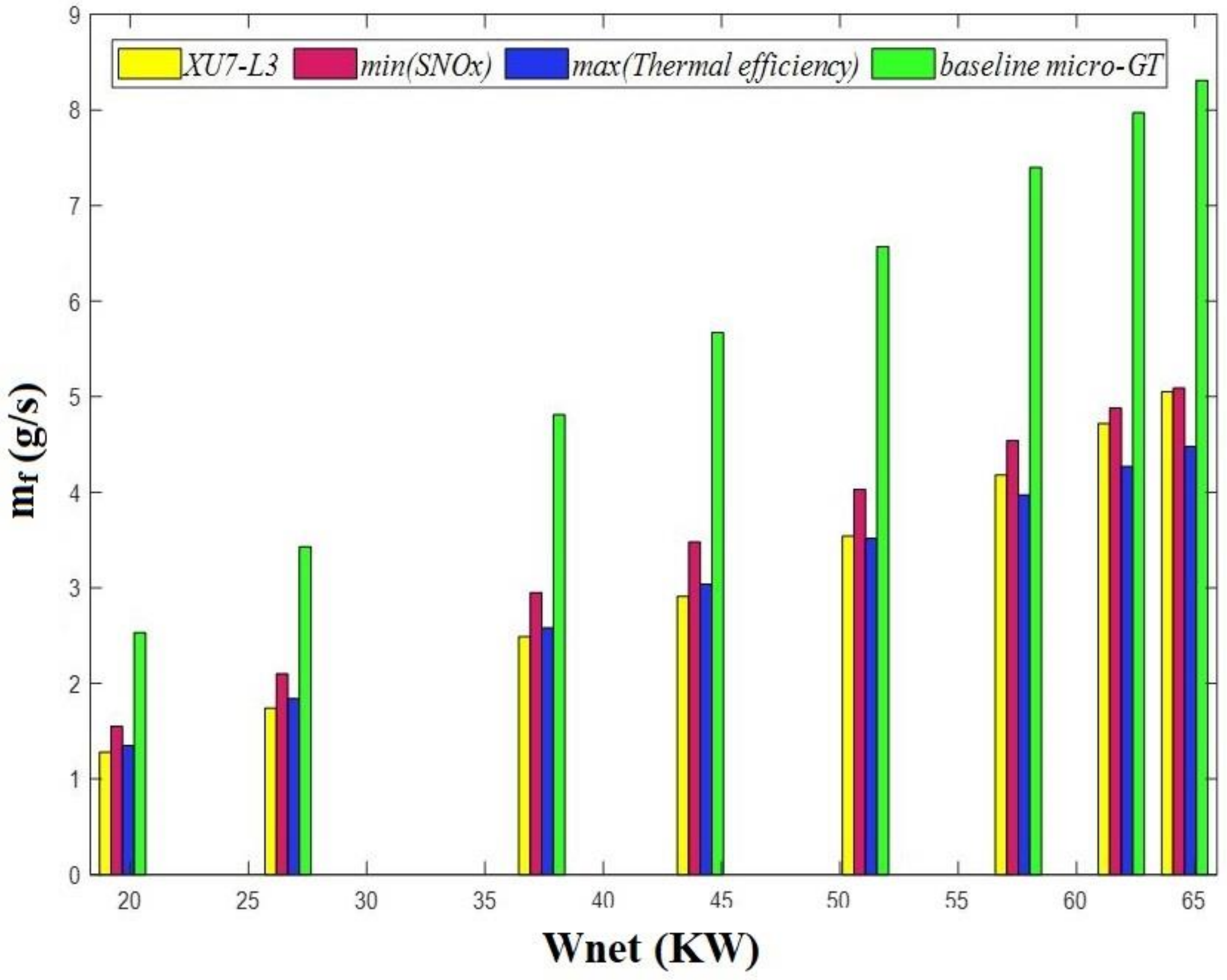

Figure 9. Comparison of XU7/L3 with the optimized engine by variation power output

In XU7/L3 and Gas turbine baseline engine fuel consumption without optimization has been compared with an optimized engine based on SNOx minimization cycle, Thermal efficiency maximization cycle in terms of Power output in units of KW shown in fig 9.the consequences disclosed that the fuel mass flow rate linearly changed with the power output and baseline micro gas turbine is the most powerful concept in this section. also, the optimized cycle bases on the more power output of 50 KW has less consumption rather than the basic XU/7 engine. Finally, It can be known that micro GT is one of the best substitutes for the internal combustion

the engine in near future.

4. Conclusions

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In this study, a hypothetical diesel engine cycle (XU7/L3) was compared with a micro-turboshaft. It has been considering as a purposed cycle. The effects of turbine inlet air temperature (IAT) and inlet air temperature were studied for the primary purposed cycle. Increasing the TIT and IAT effect on thermal efficiency, fuel mass flow

rate, specific fuel consumption, and output power. The TIT effect increased the thermal efficiency, the fuel mass flow rate, and output power, but it decreased the specific fuel consumption.

The IAT effect decreased the thermal efficiency, the fuel mass flow rate, and output power, nevertheless it increased the specific fuel consumption.

The optimization approach is performed on the primary purposed cycle. it has been optimized with two objective functions by the Genetic Algorithm, the minimization of SNOx and the maximization of thermal efficiency, separately.

It has been known that the optimized cycle base on thermal efficiency maximization in the more power out of 50 KW has less fuel consumption than the XU7/L3

A cooling system was added to the optimized cycle to increase the thermal efficiency in terms of 64.57 output power.

The compression chiller system with the coefficient of performance of 2 and 4 consider.

By changing the fuel suggestion in this conceptional system, the liquid natural gas fuel was the better fuel in this concept cause of less consumption.

The thermal efficiency increased meanly 11.37% and fuel consumption decreased an average of 2% in the optimized cycle with the cooling system.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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