

# EFFECT OF VARIOUS FUELS ON EXERGY ANALYSIS OF GAS TURBINE OF COMBINED CYCLE POWER PLANT

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**Abstract:** The demand of power is increasing day by day and fossil fuels are depleting at an enormous rate, which has made the power plants of specific interest with regards to not only efficiency but the use of various fuels. Most of the power plants are designed by the energetic performance criteria based on first law of thermodynamics only. The real useful energy loss cannot be justified by the first law of thermodynamics; because it does not differentiate between the quality and quantity of energy. Therefore, the present work is an attempt to analyse the exergy of the various components of gas turbine section of combined cycle Power Plant and determine major losses of available energy the exergy efficiency at each and every location. The fuels taken into consideration are CNG, Naphtha and light diesel oil (LDO). The performances of the system under these varying parameters for different fuels used for combustion were also investigated in order to determine the exergy and the effect of change of fuel up to the gas turbine section of combined cycle power plant.

## 1. INTRODUCTION

In power industry, various fuels are utilized in gas turbine power plant based upon several possible scenarios i.e. availability and costs. Every fuel which is employed to burn and generate the heat, comes with some constraints attached with its utilization. Though, constraints may be related to its byproducts (to be analyzed during greenhouse effect observations) or power production cost (to analyze the efficiency of power plant). In later point of view, the energetic and exergetic analysis are the way to analyze the efficiency of a particular components or overall plant. In this paper, various fuels are taken for the observation in Gas turbine power plant to acknowledge the energy and exergetic efficiency. The concerned fuels in present work are compressed natural gas commonly known as CNG, Naphtha and Light Diesel oil (LDO).

### CNG

CNG is mainly composed of Methane(CH<sub>4</sub>), produces lesser undesirable byproducts than the other conventional fuels. CNG is compressed form of natural gas when it is compressed to its 1% of the volume. This fuel is more often used in combustion chamber for gas turbine power generation. CNG, unlike gasoline and diesel does not depend on the crude oil prices. Source of production is definitely petroleum based but the way it is extracted or produced is quite different. In India, Natural gas fields exist in Assam, Gujarat, Krishna Godavari basin and Cauvery basin. Different gas extraction fields quote different prices because the pricing dominantly depends on the way it is extracted from the natural gas fields.

### Naphtha

Naphtha is an intermediate hydrocarbon mixture distilled from crude oil and natural gas condensates. It is considered a component between gasoline and kerosene. So, the availability and pricing of Naphtha is quite correlated with that of Crude oil. Naphtha refers to a mixture of Hydrocarbons which is a flammable liquid. It is made of paraffin, naphthene i.e. cyclic paraffins and aromatic hydrocarbons ranging from 5 carbon atoms to 12 carbon atoms. The initial boiling point (IBP) and final boiling point (FBP) are 35 °C and 200 °C respectively. It is categorized into two types because the distillation occurs in different stream. These are Light Naphtha and Heavy Naphtha. Light Naphtha contains its major parts of hydrocarbons with 5 to 6 carbons having IBP and FBP of 30 °C and 145 °C respectively, while Heavy Naphtha comprises of hydrocarbons with 7 to 12 carbons having IBP and FBP of 140 °C and 205 °C respectively.

### LDO

Light Diesel oil is liquid fuel for stationary gas turbine used in power generating stations. It comes with advantage of good storage and combustion properties. LDO is byproduct of crude oil distillation process while temperature maintained between 200 °C and 350 °C. It comprises of its 3/4<sup>th</sup> part of aliphatic hydrocarbons (C<sub>10</sub>H<sub>20</sub>-C<sub>15</sub>H<sub>28</sub>) and 1/4<sup>th</sup> part of aromatic hydrocarbons i.e. Benzene, Styrene. LDO has flash point of approximately 55 °C. This fuel is considered suitably great for atomization and combustion. That's why most of Gas turbines are well capable to handle this fuel without any significant modification. Minor concerns about emissions and thermal loading have to be taken care of.

## 2. EXERGETIC EVALUATION

Exergy is known as maximum available work obtained from a system when system is brought to dead state (state of environment) from a particular state while interacting only with environment. It will not be sufficient to elaborate without mentioning the reference environment state. Exergy analysis makes more sense as it takes conservation of mass, conservation of energy along with second law of thermodynamics while energy analysis takes only first law of thermodynamics, which is not sufficient to determine the true magnitude of losses and their locations. Hence, to improvise a system (here, refer to power plant based on Gas turbine), exergetic evaluation is a technique one must rely on.

Total Exergy of a system is defined as exergy obtained from Heat and work processes. Though, the process comprises both the heat and work transfer are common in formulation of any power plant problem. Here on, it can be written as

$$\Delta \dot{E}_{system} = \Delta \dot{E}_{heat} - \Delta \dot{E}_{work} \quad (1)$$

$\Delta \dot{E}_{heat}$ : It is the exergy (rate) linked with heat transfer rate  $\dot{Q}$ , presumption of uniform temperature distribution in thermal energy reservoir. It is given by:

$$\Delta \dot{E}_{heat} = \left(1 - \frac{T_0}{T}\right) \dot{Q} \quad (2)$$

$\Delta \dot{E}_{work}$  : Work, itself is measure of available energy i.e. exergy is every aspect. So exergy transfer can be written as work transfer to which it corresponds

$$\Delta \dot{E}_{work} = W + \int P_0 dV \quad (3)$$

Putting equations (2) and (3) in equation (1):

$$\Delta \dot{E}_{system} = \left(1 - \frac{T_0}{T}\right) \dot{Q} - (W + \int P_0 dV) \quad (4)$$

$$\Delta \dot{E}_{system} = (\dot{Q} - T_0 \int dS) - (W - \int P_0 dV) \quad (5)$$

According to first law of thermodynamics:

$$\Delta E = Q - W \quad (6)$$

After eliminating Q and W, equations (5) yields to:

$$\Delta \dot{E}_{system} = \Delta E - T_0 \int dS + \int P_0 dV \quad (7)$$

Expanding it by considering macro form of energies:

$$\Delta \dot{E}_{system} = \Delta U - T_0 \int dS + \int P_0 dV + m \frac{1}{2} v^2 + mgz \quad (8)$$

Integrating above equation between the state point and dead state:

$$\dot{E} = U - U_0 - T_0(S - S_0) + P_0(V - V_0) + m \frac{1}{2} v^2 + mgz \quad (9)$$

The total exergy of system comprises of its 4 components known as:

1. Kinetic Exergy: It is the exergy of a system due to its velocity with respect to a reference point of environment. It is same as kinetic energy.
2. Potential Exergy: Potential exergy is associated with potential energy which is determined with respect to datum level of the environment. It must also include force generated by the pressure effects of environment components.
3. Physical Exergy: Physical exergy is a part of total exergy due its temperature and pressure points of both state of the system and environment.
4. Chemical exergy: Part of exergy due its chemical composition i.e. mixture of various substances and it is brought to dead state from environment state by involving exchange of substances only with environment.

### 3. MATHEMATICAL MODELLING

Here, the system taken into consideration is Gas turbine power plant which consists of compressor, combustor and gas turbine unit as its main components. The component wise evaluation gives more appropriate data about losses and their location so that system can be improved significantly.

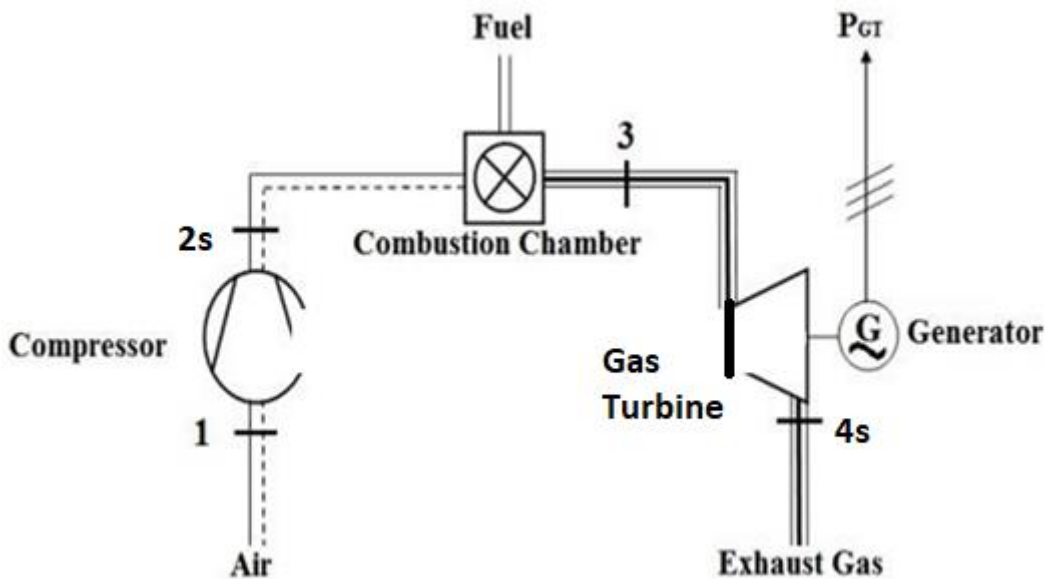


Figure1: Schematic representation of Gas turbine power plant

Gas turbine power plant work on the concept of Brayton cycle. Here, unlike ideal conditions, in this consideration the isentropic efficiency of compressor and gas turbine taken as 85% and combustion chamber efficiency is taken as 90%. The following T-S (Temperature- Entropy) diagram shows the various processes and state points of components.

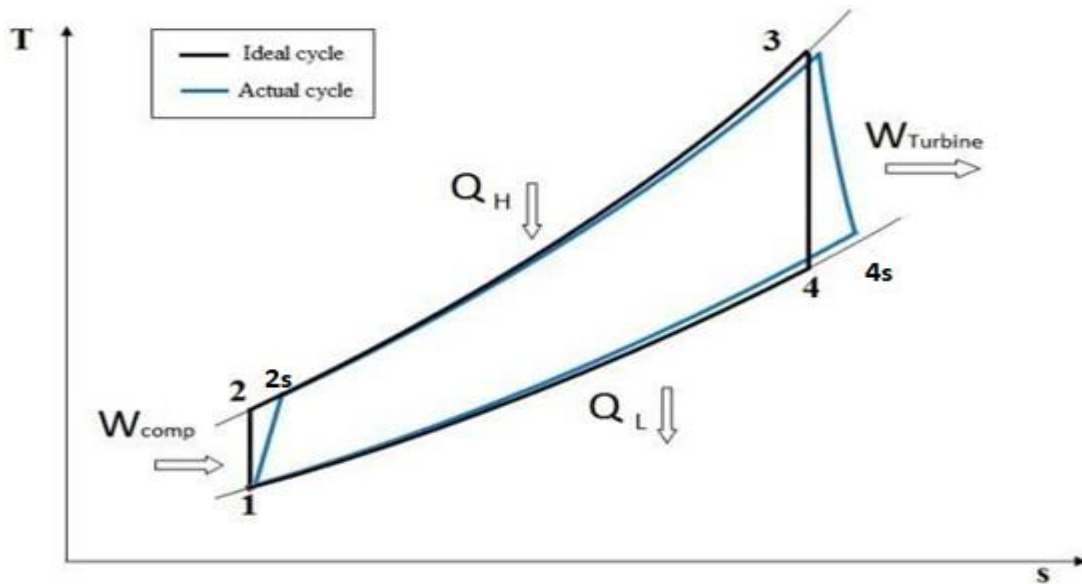


Figure 2: Brayton cycle with ideal and actual states.

The following formulation is taken as base for analysis of gas turbine power plant:

### 1. Compressor

$$X_1 + W_c = X_{2s} + \Delta X_{dest.} \quad (10)$$

$$\Delta X_{dest.} = X_1 + W_c - X_{2s} \quad (11)$$

$$\eta_{exer.} = \frac{X_{2s} - X_1}{W_c} \quad (12)$$

Where,

$$X_1 = \dot{m}_a [h_1 - h_0 - T_0 (s_1 - s_0)] \quad (13)$$

$$X_2 = \dot{m}_a [h_{2s} - h_0 - T_0 (s_{2s} - s_0)] \quad (14)$$

### 2. Combustion Chamber

$$X_{2s} + X_f = X_3 + X_{cc} \quad (15)$$

$$X_f = X_{ph} + X_{ch} \quad (16)$$

$$X_{ph} = \dot{m}_a [h_f - h_0 - T_0 (s_f - s_0)] \quad (17)$$

$$X_{ch} = \dot{m}_f e_{ch} \quad (18)$$

For fuel with composition  $C_xH_y$ , the value of  $\Omega$  is determined from following expression,

$$\Omega = 1.033 + 0.0169 \frac{y}{x} - \frac{0.0698}{x} \quad (19)$$

For CNG, the main component is Methane ( $CH_4$ ) so  $X=1$ ,  $Y=4$ , then,

$$\Omega = 1.06$$

$$X_f = \dot{m}_f (1.06 * LCV) \quad (20)$$

LCV: It is known as Lower calorific value; Lower calorific value means the total quantity of heat liberated from combustion of unit mass or unit volume of given fuel when side products are allowed to escape. Fuels taken into consideration are CNG, Naphtha and Light diesel oil (LDO) having the LCV of 43500 kJ/kg, 44900 kJ/kg and 42680 kJ/kg respectively.

$$\Delta X_{dest.} = X_{2s} + X_f - X_3 \quad (21)$$

$$\eta_{exer.} = \frac{X_3}{X_{2s} + X_f} \quad (22)$$

### 3. Gas Turbine

$$\Delta X_{dest.} = X_3 - X_{4s} - X_T \quad (23)$$

$$\eta_{exer.} = \frac{W_{GT}}{X_3 - X_{4s}} \quad (24)$$

## 4. RESULTS AND DISCUSSION

To analyze the nature of each fuel on various components in operation, fuels are added in combustion chamber to burn with air and generate heat. Fuel comes to combustion chamber at the unit mass flow rate (in kg/s). To fluctuate Air fuel ratio (AFR), the mass flow rate (in kg/s) of air is varied from intake through compressor. So the change in performance of compressor because of variation in AFR is evident but fuel is added in combustion chamber so there will be no effect of various fuels on the performance of compressor. Hence forth, exergetic analysis outcomes of combustion chamber and gas turbine are shown in figures.

Combustion Chamber results

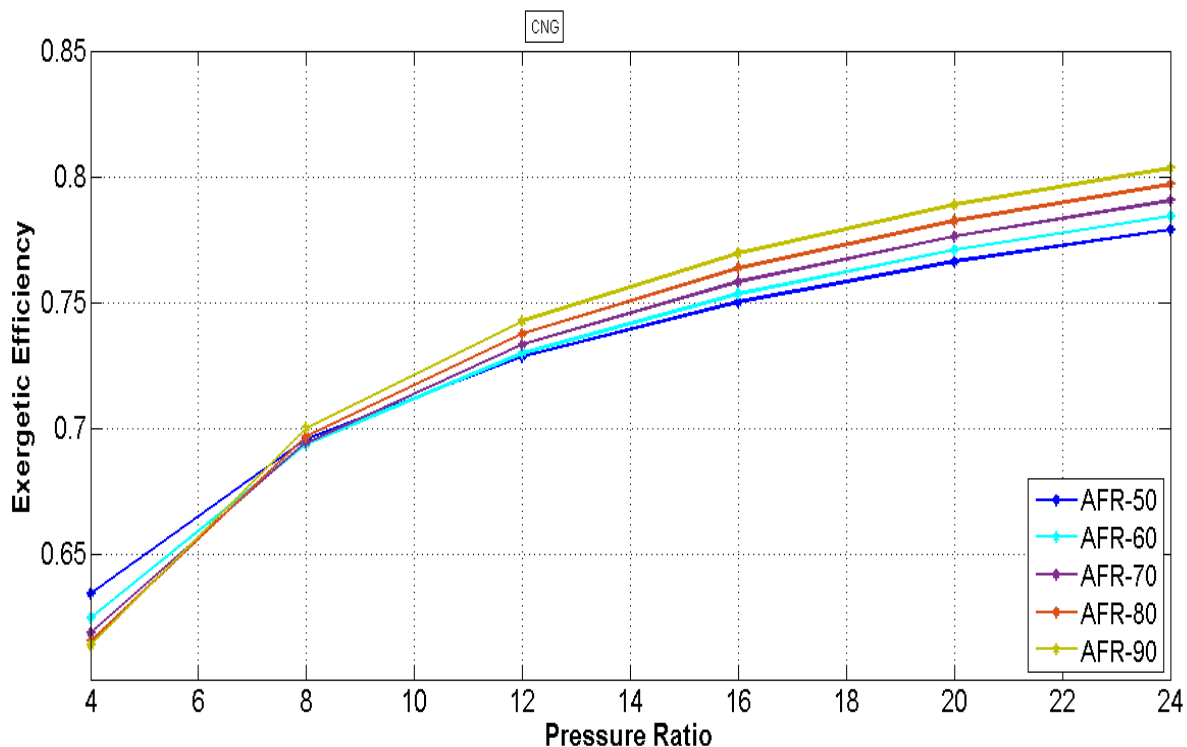


Figure 3: Variation of Exergetic efficiency of Combustion Chamber on CNG Fuel vs. Pressure ratio

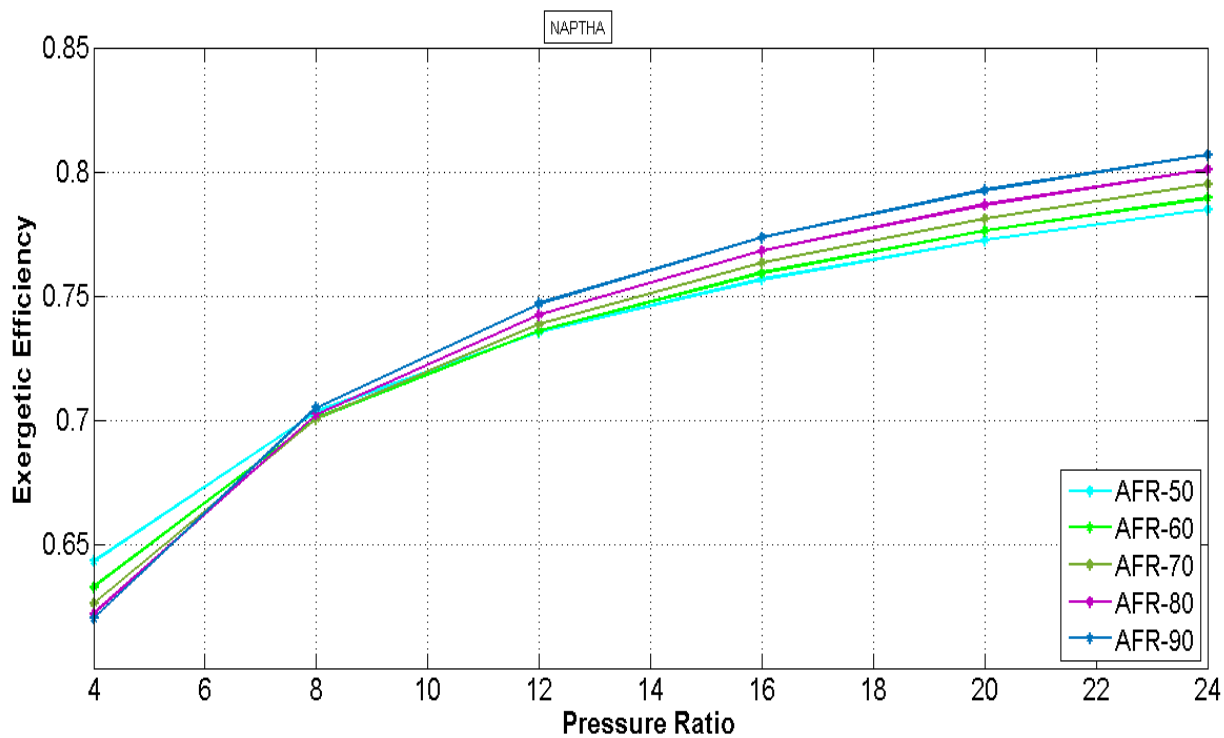


Figure 4: Variation of Exergetic efficiency of Combustion Chamber on Naphtha Fuel vs. Pressure ratio

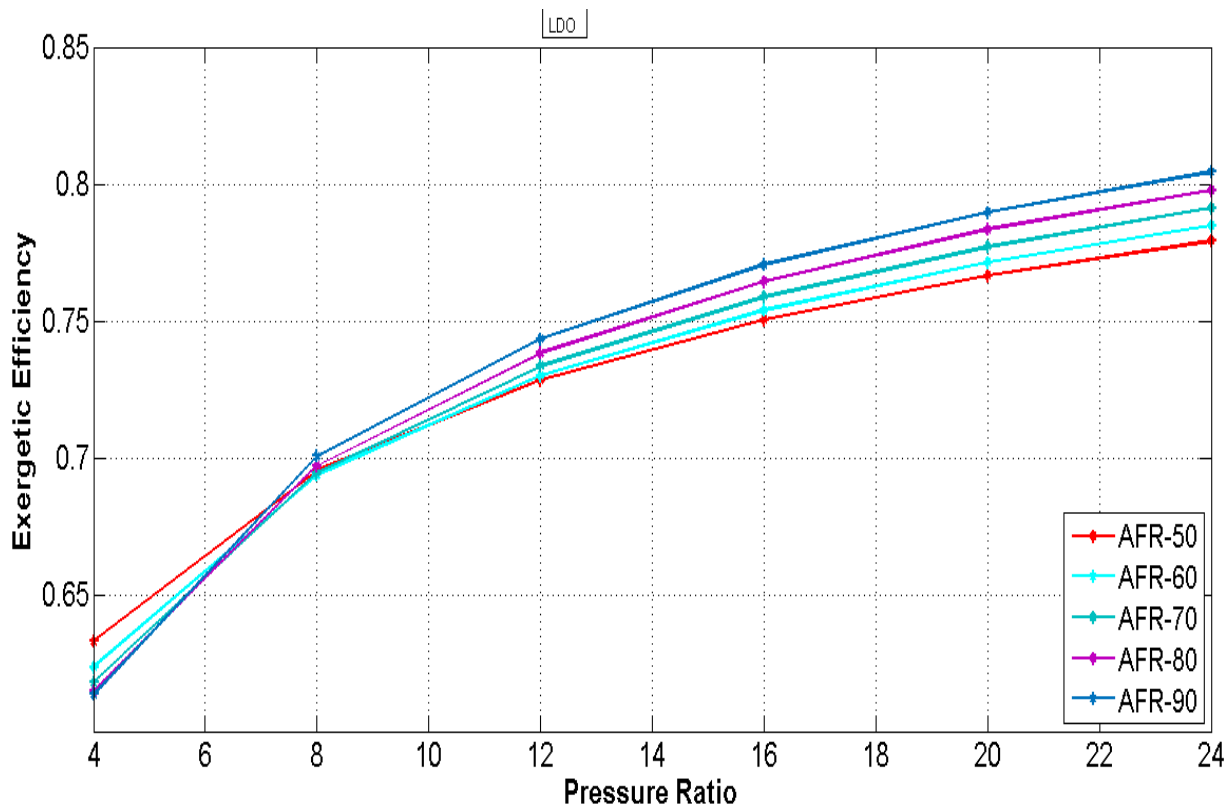


Figure 5: Variation of Exergetic efficiency of Combustion Chamber on LDO Fuel vs. Pressure ratio

Figure 3,4 and 5 depict the variation of exergetic efficiency of combustion chamber on fuel CNG, Naphtha and LDO respectively as a function of pressure ratio. Pressure ratio has been changed from 4 to 24. The variation has been observed on a domain of Air fuel ratios ranging from 50 to 90 in a step of 10. As pressure ratio increases exergetic efficiency is increasing and it is found that at air fuel ratio is 90, it increases more rapidly in comparison of lower air fuel ratio. At air fuel ratio 50, exergetic efficiency increases at lower rate as compared to higher air fuel ratios because as the air fuel ratio decrease temperature will increase and therefore exergy destruction will also increase. More the AFR results in rapid increase in exergetic efficiency.

**Gas Turbine results**

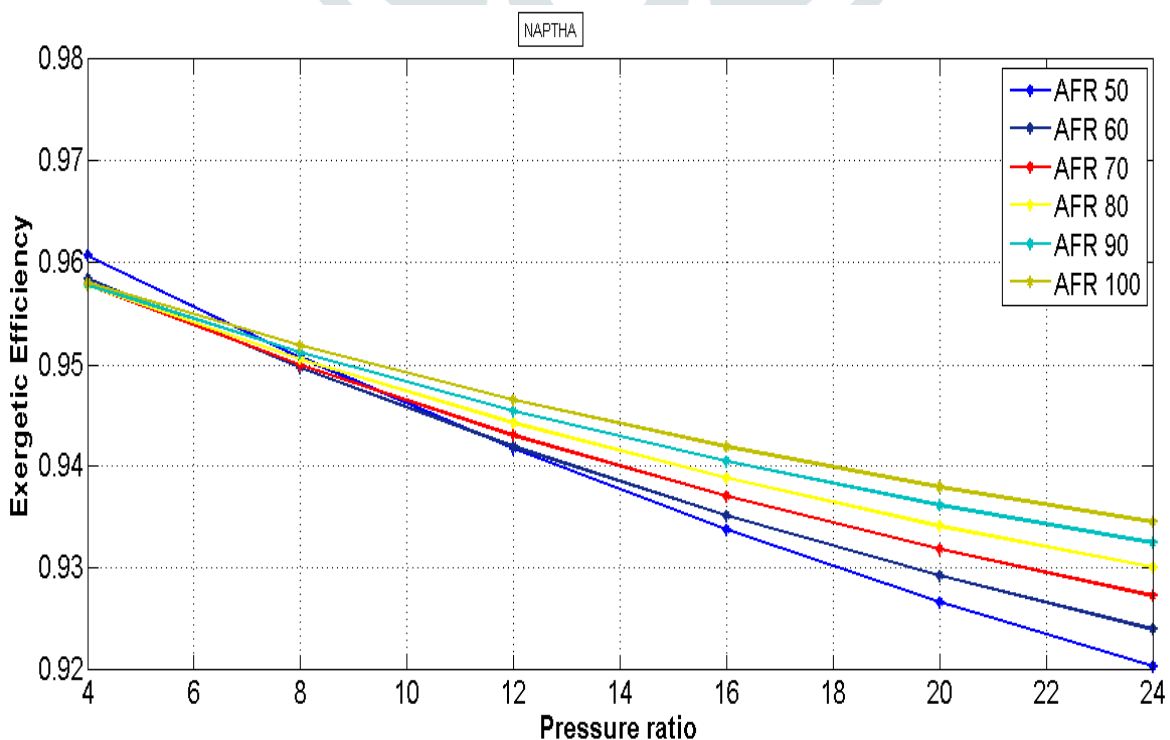


Figure 6: Variation of Exergetic efficiency of Gas Turbine on CNG Fuel vs. Pressure ratio

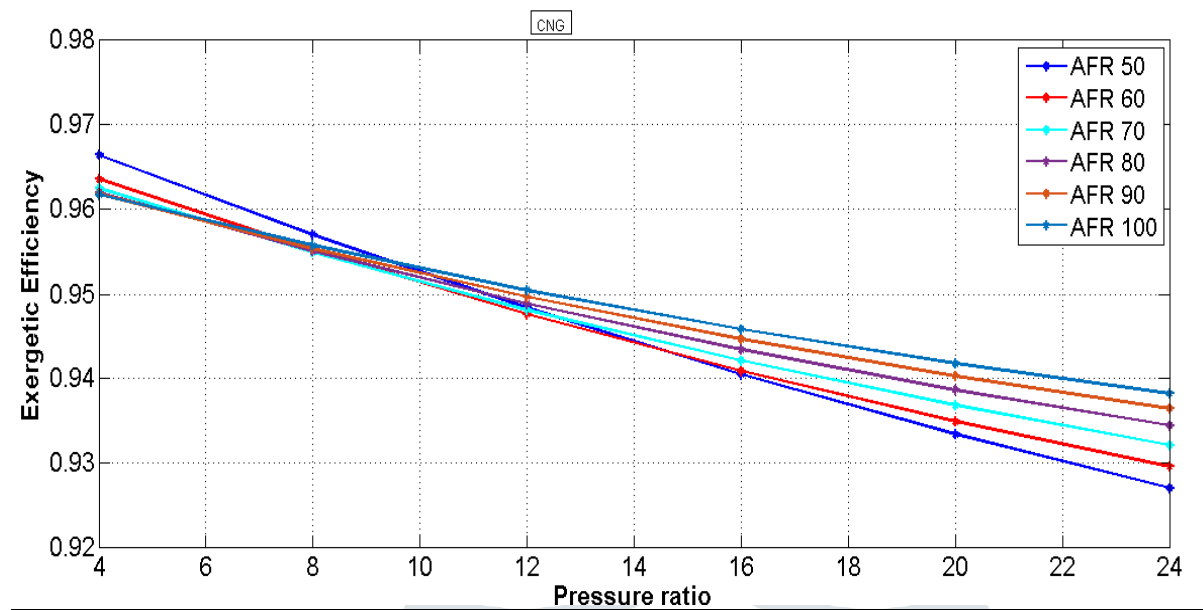


Figure 7: Variation of Exergetic efficiency of Gas Turbine on Naphtha Fuel vs. Pressure ratio

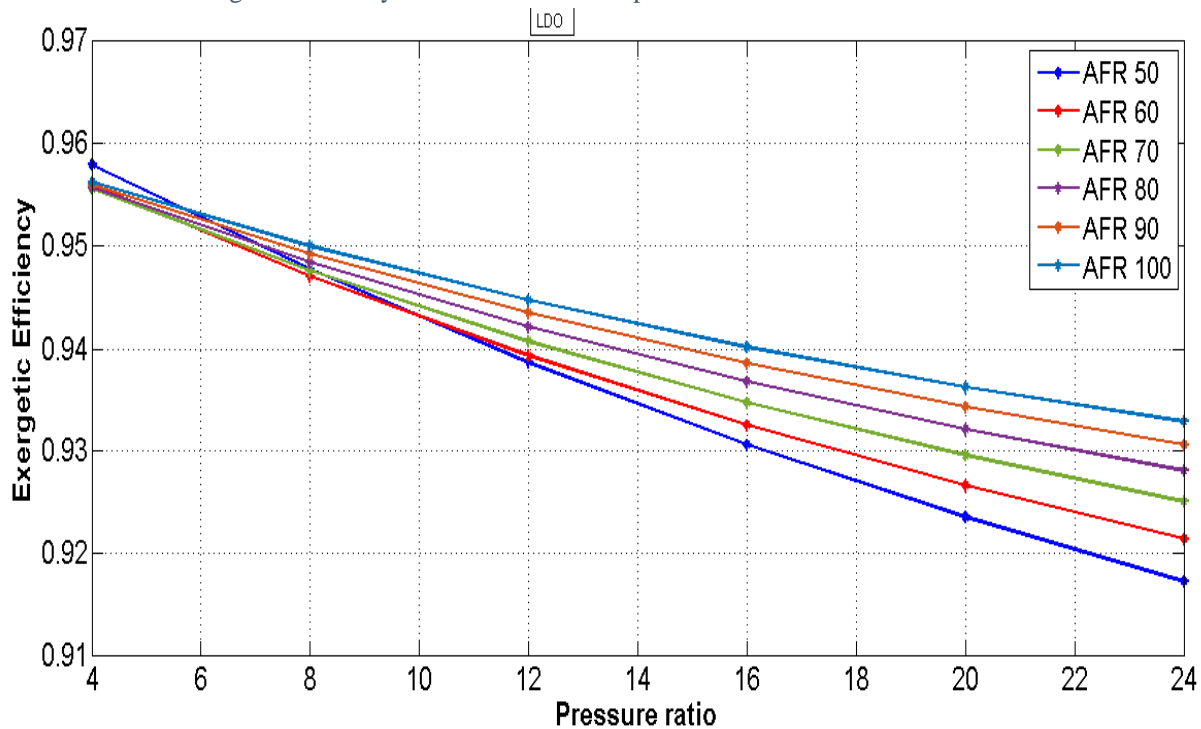


Figure 8: Variation of Exergetic efficiency of Gas Turbine on LDO Fuel vs. Pressure ratio

Figure 6, 7 and 8 show the exergetic efficiency of gas turbine on the fuel CNG, Naphtha and LDO respectively as the function of pressure ratio. The pressure ratio is being varied from 4 to 24 in the step of 4. Curves have been obtained on various Air Fuel ratios as shown in figure. As the pressure ratio increase turbine inlet temperature will increase and hence exergy destruction also increases therefore exergetic efficiency decreases. Because of same effect of AFR on turbine inlet temperature makes the higher AFR curve falls rapidly. Exergetic efficiency is maximum at AFR 100 and minimum at AFR 50.

## 5. CONCLUSION

The exergy evaluation of Gas turbine power plant was carried out to distinguish the location and amount of losses in entire system. All three fuels have shown different characteristics on different components of Gas cycle. The deciding parameter is taken as exergetic efficiency of each component while changing the fuel while observations have been made over a range of pressure ratios.

In combustion chamber, highest exergetic efficiency is achieved when NAPHTHA is being used as a fuel but on higher pressure ratios. Exergetic efficiency keeps on decreasing as the air fuel ratio increases. In gas turbine section, highest exergetic efficiency is obtained at lower air fuel ratios and at lower pressure ratios too. As the pressure ratio increases, higher AFR curves falls rapidly. Highest exergetic efficiency has reached on fuel CNG, when observed quantitatively.

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