ISSN: 0974-5823 Vol. 6 No. 3 December, 2021

International Journal of Mechanical Engineering

Optimization of a Gas turbine using Regasified liquid Natural Gas

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Abstract - **The Project titled Optimization of a Gas Turbine using Regasified Liquid Natural Gas (RLNG) is to improvise the performance and to reduce the cost of electricity produced by the gas turbine. Gas Turbine uses Diesel/Naphtha as its fuel. They use two fuels because naphtha has higher calorific value in which when used at the starter it may cause backfire and damage the components of the turbine. This does not provide enough efficiency, leaks lot of Sulphur content as emission, fuel consumption is high, transportation is difficult, cost of electricity production using these fuels are high and it also need three stage filters for filtering the contaminants in which it requires huge amount of money and lot of space. So, An Alternative fuel is to be used in place of Diesel and Naphtha which should completely replace them in all aspects. An Alternative Fuel is RLNG-REGASIFIED LIQUID NATURAL GAS which is better than Diesel/Naphtha. It produces electricity at low cost and consumes less fuel for the production of same amount of electricity then that of Diesel/Naphtha. RLNG requires only one stage filter for removing contaminants because it is easy to separate dust particles in gaseous state. By using RLNG as an Alternative fuel the pollution can be controlled and it can also produce some good profit to the Company.**

Keywords - optimization, gas turbine, regasified liquid natural gas.

INTRODUCTION

A **gas turbine**, also called a **combustion turbine**, is a type of continuous and internal combustion engine. The main elements common to all gas turbine engines are:

- an upstream rotating gas compressor
- a combustor
- a downstream turbine on the same shaft as the compressor.

A fourth component is often used to increase efficiency (on turboprops and turbofans), to convert power into mechanical or electric form (on turboshafts and electric generators), or to achieve greater thrust-to-weight ratio (on afterburning engines).

The basic operation of the gas turbine is a Brayton cycle with air as the working fluid. Atmospheric air flows through the compressor that brings it to higher pressure. Energy is then added by spraying fuel into the air and igniting it so the combustion generates a high-temperature flow. This high-temperature high-pressure gas enters a turbine, where it expands down to the exhaust pressure, producing a shaft work output in the process. The turbine shaft work is used to drive the compressor; the energy that is not used for compressing the working fluid comes out in the exhaust gases that can be used to do external work, such as rotating a second, independent turbine (known as a power turbine) which can be connected to a fan, propeller, or electrical generator. The purpose of the gas turbine determines the design so that the most desirable split of energy between the thrust and the shaft work is achieved. The fourth step of the Brayton cycle (cooling of the working fluid) is omitted, as gas turbines are open systems that do not use the same air again.

RLNG

Regasification is a process of converting liquefied natural gas (LNG) at −162 °C (−260 °F) temperature back to natural gas at atmospheric temperature. LNG gasification plants can be located on land as well as on floating barges. Floating barge mounted plants have the advantage that they can be towed to new offshore locations for better usage in response to changes in the business environment. In a conventional regasification plant, LNG is heated by sea water to convert it to natural gas / methane gas. RLNG is being imported from foreign countries like Iran, Kuwait, Qatar etc.. This Natural Gas is being compressed to LNG in which the volume of gas is reduced by 600 times this done for reducing the volume while transportation. Then this LNG is regasified i.e., expanded back to gas. That's how RLNG is formed and consumed.

Table I.
RLNG Compositions

Components	Mol%
Methane	96.35
Ethane	1.88
Propane	0.38
Normal butane	0.10
Normal pentane	0.01
Hexane+	0.01
Nitrogen	1.00
Carbon dioxide	0.27
Sulphur	50 ppm
Heavy metals	<100 ppbwt

Table II
RLNG Specifications

Mass density	0.7452
Molecular weight	145 g/mol
C_p/C_v	1.305
Z factor	0.9885
Lower heating value	`193680 Kcal/Kg mol
Kinematic viscosity	3.103 cSt
Mass density	3.828 kg/m^3
Calorific value	12500 kcal/kg.k

PROCESS OF MAKING RLNG

Natural gas (predominantly methane, CH4, with some mixture of ethane, C2H6) that has been cooled down to liquid form for ease and safety of non-pressurized storage or transport. It takes up about 1/600th the volume of natural gas in the gaseous state (at standard conditions for temperature and pressure). It is odourless, colourless, non-toxic and non-corrosive. Hazards include flammability after vaporization into a gaseous state, freezing and asphyxia. The liquefaction process involves removal of certain components, such as dust, acid gases, helium, water, and heavy hydrocarbons, which could cause difficulty downstream. The natural gas is then condensed into a liquid at close to atmospheric pressure by cooling it to approximately −162 °C (−260 °F); maximum transport pressure is set at around 25 kPa (4 psi).

After Transportation, the LNG is regasified in which it is used as the fuel for the gas turbine and other equipment's inside the Company.

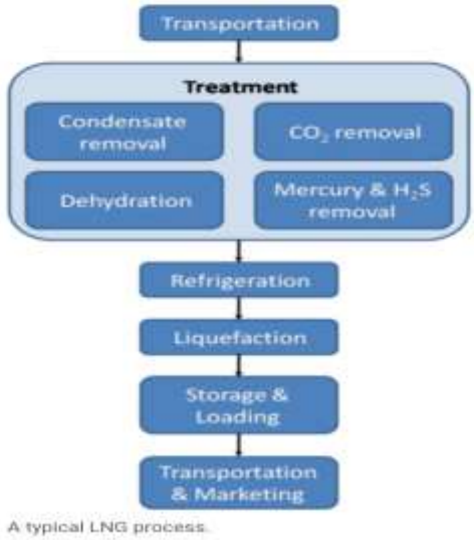

Figure.1
A Typical LNG Process

RLNG DISTRIBUTION NETWORK

A part of HP RLNG (corresponding to a quantity of 2.6 MMSCMD) is transferred to Heater 1 (E-201 A/B) which is located in CDU Ill to cater to the consumption of GT 1 to 5 (0.68 MMSCMD), HGUs (Pt-205 and Pt-214) (1.0 MMSCMD), Boiler 5 (0.1 MMSCMD), Boiler 6 (0.21 MMSCMD) and Ref I / II / I LEB-DHDS (0.61 MMSCMD). In this heater, RLNG is heated from 0-15 °C to 40-45 °C. This heating is essential to match the RLNG temperature with the already existing fuel temperature in the respective consumption points. The heater outlet is split into four streams -one stream to GT-1, 2 and 3 (0.41 MMSCMD), one stream to GT-4 and 5 (0.27 MMSCMD), one stream to HGUs (1.0 MMSCMD) and the last stream to Ref I / II / LEB-DHDS (0.61 MMSCMD).

The stream to Ref I / II / LEB - DHDS (0.61 MMSCMD) is further heated in another heater (E-204A/B/C) to increase the temperature of RLNG from 40 - 45 °C to 60 °C as the pressure of this RLNG stream has to be reduced to 5 kg/cm2g to facilitate floating of RLNG with FG header. During pressure reduction, the temperature is expected to decrease by around 15 - 20 °C and hence it is essential to increase the temperature of RLNG to 60 °C to facilitate floating of RLNG with FG header.

The heater (E-204 A/B/C) outlet is routed through PRS 2 to reduce the pressure of RLNG to 5 kg/cm2g. The PRS 2 outlet at 5 kg/cm2g and 40 °C is then split into three streams; one stream (0.1 MMSCMD) is routed to a new KOD in Boiler-5 (900-C-203), another stream (0.21 MMSCMD) is routed to an existing KOD in Boiler-6 (021-C-03-01) and the third stream (0.61 MMSCMD) is routed to a new KOO in Ref I (900-C-201).

Another part of HP RLNG (corresponding to a quantity of 0.64 MMSCMD) from R&D receiving station is sent to Heater 2 (E-202 A/B) located in CDU Ill, where the HP RLNG is heated from 0-15 °C to 60 °C. The heated HP RLNG is sent through PRS 1 where the pressure is reduced to 5kg/cm2g (and temperature drops to 40 °C). This LP RLNG is then routed to Ref Ill FG mix drum from where the mixture of

RLNG and FG is distributed to the Ref Ill furnaces (0.46 MMSCMD) and DCU (0.18 MMSCMD).

The third part of HP RLNG (corresponding to a quantity of 0.74 MMSCMD) is sent to Heater-3(E-203 A/B) located in Cogen where the temperature of RLNG is increased from 0 - 15 °C to 60°C. The heated HP RLNG is sent through PRS 3 where the pressure of RLNG is reduced to 5kg/cm2 g (and temperature drops to 40 °C). This LP RLNG is then routed to a new KOD in Cogen from where the RLNG is further distributed to Cogen Boilers 1 - 4.

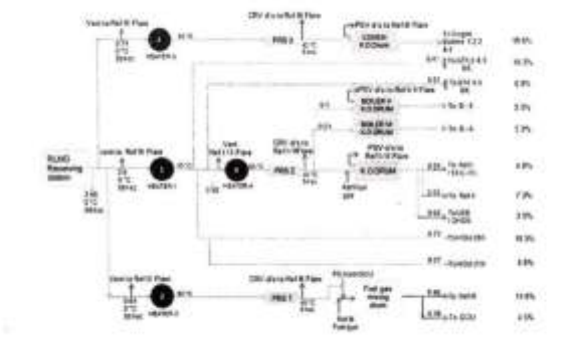

Figure.2
RLNG Distribution Network

OPTIMIZATION OF GAS TURBINE

The Gas Turbine operating parameters like pressure is measured using instruments like pressure transmitter and bourdon pressure gauge, flow measurement by mass flowmeters and temperature measurement by using temperature gauge and temperature transmitter with probe for both Diesel/Naphtha and RLNG.

Table III.
INITIAL AND OPTIMIZED CONDITIONS

PARAMETERS	**DIESEL/ NAPHTHA**	**RLNG**
Compressor inlet temperature	33^{O}C	32^{O}C
Compressor outlet temperature	277^{O}C	279^{O}C
Compressor inlet pressure	1.013 bar	1.013 bar
Compressor outlet pressure	7.8 bar	8.1 bar
Liquid/RLNG mass flow	6.840 TPH	6 TPH
VHP steam flow	40 TPH	41 TPH
IP steam flow	6 TPH	6.2 TPH
Heat rate	3555 kcal/kwhr	3571 kcal/kwhr
Combustion chamber outlet temperature	1097^{O}C	1110^{O}C

Table IV
OBSERVATION TABLE

	Compressor Inlet Temperature ^{O}C	**Compressor Outlet Temperature ^{O}C**	**Compressor Inlet Pressure bar**	**Compressor Outlet Pressure Bar**	**Liquid/ RLNG Mass flow TPH**	**VHP Steam flow TPH**	**IP Steam flow TPH**	**Heat rate kcal/kwhr**	**Combustion Chamber Outlet Temperature ^{O}C**
DIESEL/ NAPHTHA	32	275	1.013	7.75	6.84	40	6	3553	1094
	33	276	1.013	7.75	6.84	40	6	3557	1096
	33	277	1.013	7.8	6.84	40	6	3556	1095
	33	278	1.013	7.8	6.84	40	6	3554	1099
	34	279	1.013	7.8	6.84	40	6	3556	1101
AVERAGE	**33**	**277**	**1.013**	**7.8**	**6.84**	**40**	**6**	**3555**	**1097**
(RLNG)	32	278	1.013	8.05	6	41	6.2	3570	1109
	32	279	1.013	8.05	6	41	6.2	3572	1111
	32	281	1.013	8.05	6	41	6.2	3571	1112
	32	279	1.013	8.1	6	41	6.2	3570	1110
	32	278	1.013	8.1	6	41	6.2	3571	1108
AVERAGE	**32**	**279**	**1.013**	**8.1**	**6**	**41**	**6.2**	**3571**	**1110**

CALCULATIONS

A. THERMAL EFFICIENCY CALCULATION FOR DISESEL/NAPTHA

From observation table
Work done by turbine $W_T = 2.5\ W_C$
Compressor inlet temperature (T_1) =33ºC = 306 K
Compressor inlet pressure (P_1) = 1.013 bar
Compressor outlet pressure (P_2) = 7.8 bar
Generator efficiency = 0.981
Gearbox efficiency = 0.985
Specific heat ratio (γ) for air =1.4

To find thermal efficiency, parameters required are

I. Combustion chamber exit temperature (T_3)
II. Gas turbine exit temperature (T_4)

Thermal efficiency is given by

$$\frac{\text{Workdone (W)net}}{\text{Heat supplied (Qs)}}$$

η Thermal =
η Thermal = W_T - W_C / Q_A
W_T = Turbine Work
W_C = compressor Work

The process takes places in Brayton cycle are:

I. Process 1-2 : Reversible adiabatic process (Isentropic compression)
II. Process 2-3 : Constant pressure heat addition
III. Process 3-4 : Reversible adiabatic process (isentropic expansion)

IV. Process 4-1 : Constant pressure heat rejection

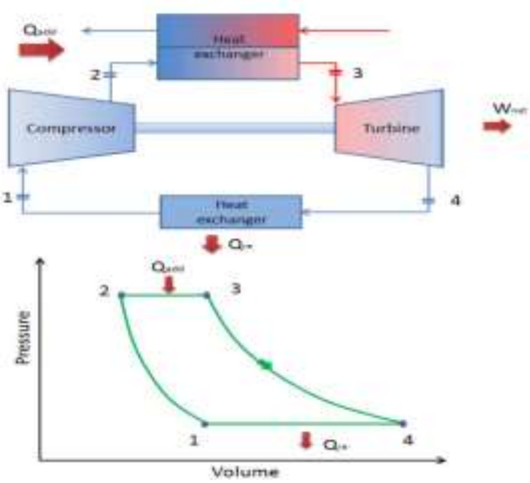

Figure.3
Gas Turbine Circuit Diagram and P-V Diagram.

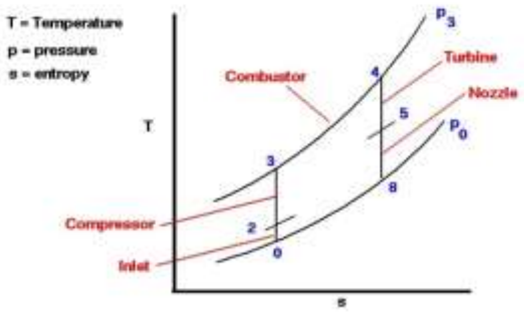

Figure.4
T-S Diagram

For process 1-2: Isentropic compression

$$\frac{T2}{T1} = \left(\frac{P2}{P1}\right)^{\frac{\gamma-1}{\gamma}}$$

$$T_2 = T_1 * \left(\frac{P2}{P1}\right)^{\frac{\gamma-1}{\gamma}}$$

$$T_2 = 306 * \left(\frac{7.8}{1.013}\right)^{\frac{1.4-1}{1.4}}$$

$T_2 = 306 * 7.6999^{0.2875}$

$\mathbf{T_2 = 548.264\ K}$

Similarly for process 3-4: Isentropic expansion

$$\frac{T3}{T4} = \left(\frac{P3}{P4}\right)^{\frac{\gamma-1}{\gamma}}$$

Pressure ratio (r_p) = $\frac{P2}{P1} = \frac{P3}{P4}$

So,

$$T_4 = \frac{T3}{rp^{\frac{\gamma-1}{\gamma}}} = \frac{T3}{7.6999^{0.2857}} = \frac{T3}{1.9717}$$

Using relation, $W_T = 2.5W_C$

$mC_P (T_3 – T_4) = 2.5\ mC_P (T_2 – T_1)$

$T_3 - \frac{T3}{1.7917} = 2.5 (548.264 – 306)$

$0.7917\ T_3 = 605.66*1.7917$

$\mathbf{T_3 = 1370.672\ K}$

So,

$$T_4 = \frac{T3}{1.7917}$$

$$T_4 = \frac{1370.672}{1.7917}$$

$\mathbf{T_4 = 765.0\ K}$

Thermal efficiency is given by

η Thermal $= W_T - W_C / Q_A$

$$= \frac{mCp(T3-T4)-mCp(T2-T1)}{mCp(T3-T2)}$$

$$= \frac{(T3-T4)-(T2-T1)}{(T3-T2)}$$

$$= \frac{(1370.672-765)-(548.264-306)}{1370.672-548.264}$$

= 363.408/822.408

= 0.44188

η Thermal **= 44.18%**

B. THERMAL EFFICIENCY CALCULATION FOR REGASIFIED LIQUID NATURAL GAS (RLNG)

Compressor inlet temperature (T_1) = 32ºC = 305 K
Compressor inlet pressure (P_1) =1.013 bar
Compressor outlet pressure(P_2) = 8.1 bar
Specific heat ratio (γ) for air =1.4

For process 1-2: Isentropic compression

$$\frac{T2}{T1} = \left(\frac{P2}{P1}\right)^{\frac{\gamma-1}{\gamma}}$$

$$T_2 = T_1 * \left(\frac{P2}{P1}\right)^{\frac{\gamma-1}{\gamma}}$$

$$T_2 = 305 * \left(\frac{8.1}{1.013}\right)^{\frac{1.4-1}{1.4}}$$

$T_2 = 305 * 7.99605^{0.2875}$

T_2 = 552.397 K

Similarly, for process 3-4: Isentropic expansion

$$\frac{T3}{T4} = \left(\frac{P3}{P4}\right)^{\frac{\gamma-1}{\gamma}}$$

Pressure ratio (r_p) = $\frac{P2}{P1} = \frac{P3}{P4}$

So,

$$\frac{T3}{T4} = \left(\frac{P2}{P1}\right)^{\frac{\gamma-1}{\gamma}}$$

$$\frac{T3}{T4} = \left(\frac{8.1}{1.013}\right)^{\frac{1.4-1}{1.4}}$$

$$T_4 = \frac{T3}{1.811}$$

Using relation, $W_T = 2.5W_C$

$mC_P (T_3 – T_4) = 2.5\ mC_P (T_2 – T_1)$

$T_3 - \frac{T3}{1.811} = 2.5\ (552.397 – 305)$

$0.811T_3 = 1120.089$

T_3 = 1381.122 K

So,

$$T_4 = \frac{T3}{1.811}$$

$$T_4 = \frac{1381.122}{1.811}$$

T_4 =762.629 K

Thermal efficiency is given by

η Thermal = W_T - W_C / Q_A

$$= \frac{mCp(T3-T4)-mCp(T2-T1)}{mCp\,(T3-T2)}$$

$$= \frac{(T3-T4)-(T2-T1)}{(T3-T2)}$$

$$= \frac{(1381.122-762.629)-(552.397-305)}{1381.122-552.397}$$

= 371.096 / 828.725

= 0.44779

η Thermal **= 44.78%**

C. FUEL COST AND POWER COST FOR NAPHTHA

Price of naphtha per metric ton = ₹36760
Naphtha mass flow for Kg/s = 1.9
For one hour
= 1.9*60*60
= 6840 kg/hr.
= 6.84 ton/hr.
So price of naphtha for one hour = 36760*6.84 = ₹251438.4
Since we are getting additional high pressure steam
Very high pressure steam (VHP) = 40 T/h
Intermediate pressure steam (IP) = 6 T/h

So, in total 46 T/h

Cost of steam per ton = ₹2300
Total cost of steam = 2300*46 = ₹ 105800

Since, this amount is an additional benefit; this is to be subtracted from the fuel cost
= ₹ 251438.4 - ₹ 105800
= ₹ 145638.4

Now,
Power produced for one hour = 20. 2 MW

Price of Naphtha for 1kw = $\frac{145638.4}{20.2*1000}$
= ₹7.21 per kw

Price of Naphtha for 1kw = ₹7.21 per kw

D. FUEL COST AND POWER COST FOR RLNG

Price of RLNG per metric ton = ₹36947
RLNG mass flow = 6 T/hr
So, the price of RLNG for one hour = 36947*6 = ₹ 221682

From additional high pressure steam

Very high-pressure steam (VHP) = 41 T/hr
Intermediate pressure (IP) steam = 65 T/hr
So, In total 47.5 T/hr

Cost of steam per ton = ₹2300
Total cost of steam = ₹ 47.2*2300
= ₹108560.

Since it is an additional benefit
= ₹221682 - ₹108560
= ₹113122.

Now,
Power produced for one hour =21 MW

Price of RLNG for 1kw = $\frac{113122}{21*1000}$ = ₹ 5.39 per kw

Price of RLNG for 1kw = ₹5.39 per kw

Therefore, by using RLNG we get ₹1.82 per kw as profit.

CONCLUSION

By Extensive Study of "**Optimization of a Gas Turbine using Regasified Liquid Natural Gas"** at CPCL-Manali were carried out and the following conclusions were arrived.

- The Overall Efficiency of a Gas Turbine is being improvised by **0.60%.**
- **Sulphur emission** from the exhaust of Gas Turbine is reduced.
- The Three Stage Filter is reduced to **one stage filter** i.e., for diesel/naphtha filter is set up to three stage like 25 micron,10 micron and 5 micron filter respectively. Whereas in case of RLNG only one filter (5 micron) is used to remove the contaminants.
- For Same amount of electricity produced, the consumption of **RLNG is less than that of Diesel/Naphtha**.
- A Profit of **₹1.82** is made, for the production of every 1kw.
- Since Diesel/Naphtha is found in Liquid state it has to atomized, whereas as RLNG doesn't require any.

FUTURE SCOPE OF WORK:

- Experiments should be conducted to test the longevity of Gas Turbine and other parts like flow divider, Three-way valve etc., when running with RLNG as the fuel.
- Modifications required on the gas turbine design itself should be studied for getting optimum performance from a RLNG.

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