THERMODYNAMIC ANALYSIS OF NUCLEAR REACTOR ASSISTED GAS TURBINE POWER PLANT

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Abstract:

The demand for energy is increasing daily all over the globe. The fossil fuels are expected to be depleted in the near future. So there is a need for alternative sources of energy generation. Also , there is a need to improve the performance of already existing cycles and modify them. In this paper , the conventional gas turbine cycle which operates on Brayton cycle has been modified with the combustion chamber replaced by High Temperature Gas Cooled Reactor (HTGR) . Helium is used as the working fluid in a closed cycle Brayton cycle incorporating a Recuperator (Heat Exchanger). Analysis is carried out by varying the Gas Turbine Inlet Temperature (TIT).

Keywords: gas turbine, nuclear reactor, helium, turbine inlet temperature.

Introduction:

The development of economy of a nation is measured by the per capita energy consumption. Several types of power plants provide a viable source of power generation. These include thermal , hydroelectric, nuclear, gas turbine, diesel electric, wind based, geothermal, tidal , solar etc. Among these thermal power plants are used as base load plants whereas gas turbine are used as peak load plants. The base load plants take a long time to start and also for shut down whereas peak load plants are easily operated and closed in a shorter interval. Conventional closed cycle gas turbine power plant incorporates a compressor, a combustion chamber, a gas turbine and a heat exchanger. The HTGR based gas turbines replace the combustion chamber by a modular nuclear reactor with helium gas as the coolant. Other components of the reactor such as the fuel (Uranium) , moderator, control rods etc remain the same. The advantage of this of cycle is that higher turbine inlet temperatures (TIT) are achieved , resulting into higher thermal efficiency . The efficiency is increased in the range of 5 to 10 %. Also , another advantage is that environmental pollution is reduced as greenhouse gas emissions are reduced due to elimination of combustion chamber, which would have otherwise used fossil fuel.

LITERATURE REVIEW

B.J. Marsden et. al [1] studied advanced nuclear power plants and concluded that to remain competitive, future HTGRs (High Temperature Gas-cooled Reactors) will require a core and reflector design that is capable of operating reliably at very high temperatures , for extended lifetimes (approx 40 years) with the minimum generation of radioactivity . The present core designs are based on the use of high quality, semi-isotropic nuclear grade polycrystalline graphites . H Ohashi et. al [2] conducted a conceptual design of a 50 MW small-sized high temperature gas cooled reactor (HTGR) for multiple heat applications, named HTR50S,with the reactor outlet coolant temperature of 750° C and 900° C. It is first-of-a-kind of the commercial plant or a demonstration plant of a small-sized HTGR system to be deployed in developing countries in the 2020s. W Stanek et. al [3] stated conducted studies on coal combustion, which is responsible forincreasing the CO_2 emission. Simultaneously, concluded that the European trends toward sustainability and global warming mitigation will lead to significant changes in the structure of electricity generation in Poland. Due to the domestic energy policy the increase of renewable resources utilisation, as well as installation of first nuclear power units (3x1. 6 GWel), areplanned in the perspective of the year 2030. Z Kolenda et.al [4], stated that nuclear energy is one of the possibilities ensuring energy security, environmental protection, and high energy efficiency. Among many newest solutions, special attention is paid to the medium size high-temperature gas-cooled reactors (HTGR) with wide possible applications. YE Gorlinskii et. al [5] postulated that a floating nuclear heat-and-power plant utilizes atomic energy to supply heat and electricity in remote coastal territories. The danger for people and the environment together with cost-effectiveness will be the decisive factors in choosing such a plant as a source of energy. Validation is given for the need to develop the concept of human and environmental safety security for future, serially produced, floating nuclear heat and-power plants.

DESIGN CRITERION

The thermal efficiency and specific power output of a gas turbine power plant are dependent upon a)The compressor pressure ratio, b)The maximum and minimum gas temperatures in the cycle ,c)The compressor and turbine component efficiencies ,d)Effectiveness of the heat exchangers and coolers e)The thermodynamic constants of the gas such as specific heats, gas constants etc.

FOR HTGR CYCLE:

Helium has got several favorable thermal properties. It acts as a cooling medium for the reactor and also as a working medium in the gas turbine cycle. Thermal conductivity coefficient of helium is five times greater than that of air which commonly serves as a working medium in turbine cycles of combustion based gas turbine power plants [3]. Moreover, helium, being a perfect gas, does not undergo ionization, hence it is friendlier to the environment than other cooling media used for nuclear reactors.

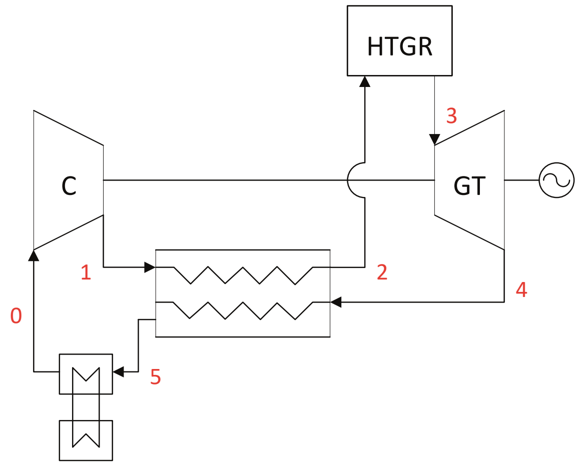


Fig.1: Schematic Diagram : C – compressor, HTGR – high-temperature reactor, GT – gas turbine.

FORMULA USED:

- $\dot{W}_C = \frac{C_{Phe}\, T_1 [r_c^{\frac{\gamma-1}{\gamma}} - 1]}{\eta_c}$
- $\dot{W}_T = C_{Phe} T_3 \eta_T \left[1 - r_e^{\frac{1-\gamma}{\gamma}}\right]$
- $Q_d = C_{Phe} [T_3 - T_2]$
- Back work ratio = $\frac{Wc}{Wth}$
- Work ratio = $\frac{Wt - Wc}{Wt}$
- $\eta_{GT} = \frac{Wt - Wc}{Qd}$

- **ASSUMPTIONS:**
- Equipment's are analyzed as control volumes at steady state and are adiabatic.
- Specific heat of He remains constant.
- There is no pressure drop for flow through heat exchangers.
- Kinetic and potential effects are negligible.

- **CALCULATIONS:**
- W_t = 1653.7KJ/Kg
- W_c = 802.8KJ/Kg
- Q_d = 2258.3KJ/Kg
- Back work ratio = $\frac{Wc}{Wt}$ = 0.485
- Cycle work ratio = $\frac{Wt - Wc}{Wt}$ = 0.514
- Thermal efficiency = $\frac{Wt - Wc}{Q_d}$ = 0.377 = 37.7 %

RESULTS

Table 1 Results of C++ program

1	T0	T1	T2	T3	T4s	T4	h3	h4	h1	h0	h2	Qd	Wt	Wc	ηth	Wnet	Bwr	Cwr
2	299.2	455.58	720	1050	756.9816	786.2835	5449.5	4080.811	2355.4	1552.6	3736.8	1712.7	1368.689	802.8	0.330407	565.89	0.586547	0.413453
3	299.2	455.58	735	1075	775.005	805.0045	5579.25	4177.973	2355.4	1552.6	3814.65	1764.6	1401.277	802.8	0.339157	598.48	0.572906	0.427094
4	299.2	455.58	750	1100	793.0284	823.7255	5709	4275.136	2355.4	1552.6	3892.5	1816.5	1433.864	802.8	0.347407	631.06	0.559886	0.440114
5	299.2	455.58	765	1125	811.0517	842.4466	5838.75	4372.298	2355.4	1552.6	3970.35	1868.4	1466.452	802.8	0.355198	663.65	0.547444	0.452556
6	299.2	455.58	780	1150	829.0751	861.1676	5968.5	4469.46	2355.4	1552.6	4048.2	1920.3	1499.04	802.8	0.362568	696.24	0.535543	0.464457
7	299.2	455.58	795	1175	847.0985	879.8886	6098.25	4566.622	2355.4	1552.6	4126.05	1972.2	1531.628	802.8	0.369551	728.83	0.524148	0.475852
8	299.2	455.58	810	1200	865.1219	898.6097	6228	4663.784	2355.4	1552.6	4203.9	2024.1	1564.216	802.8	0.376175	761.42	0.513228	0.486772
9	299.2	455.58	825	1225	883.1452	917.3307	6357.75	4760.946	2355.4	1552.6	4281.75	2076	1596.804	802.8	0.382468	794.00	0.502754	0.497246
10	299.2	455.58	840	1250	901.1686	936.0517	6487.5	4858.109	2355.4	1552.6	4359.6	2127.9	1629.391	802.8	0.388454	826.59	0.492699	0.507301
11	299.2	455.58	855	1275	919.192	954.7728	6617.25	4955.271	2355.4	1552.6	4437.45	2179.8	1661.979	802.8	0.394155	859.18	0.483039	0.516961
12	299.2	455.58	870	1300	937.2153	973.4938	6747	5052.433	2355.4	1552.6	4515.3	2231.7	1694.567	802.8	0.399591	891.77	0.473749	0.526251
13	299.2	455.58	885	1325	955.2387	992.2148	6876.75	5149.595	2355.4	1552.6	4593.15	2283.6	1727.155	802.8	0.40478	924.35	0.464811	0.535189
14	299.2	455.58	900	1350	973.2621	1010.936	7006.5	5246.757	2355.4	1552.6	4671	2335.5	1759.743	802.8	0.409738	956.94	0.456203	0.543797

A C++ program is written for different parameters such as thermal efficiency, work ratio, back work ratio. The results are shown as given below :

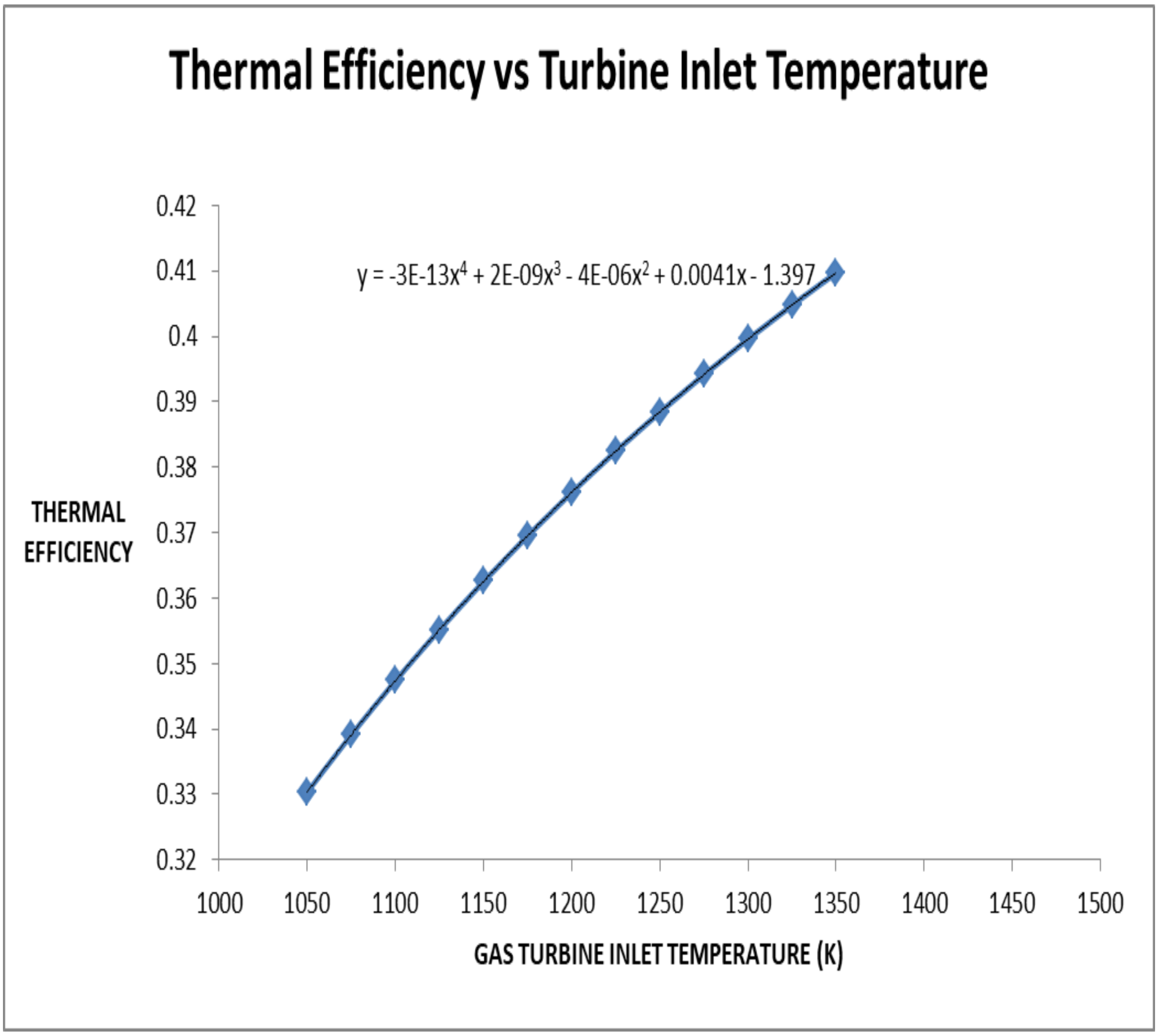
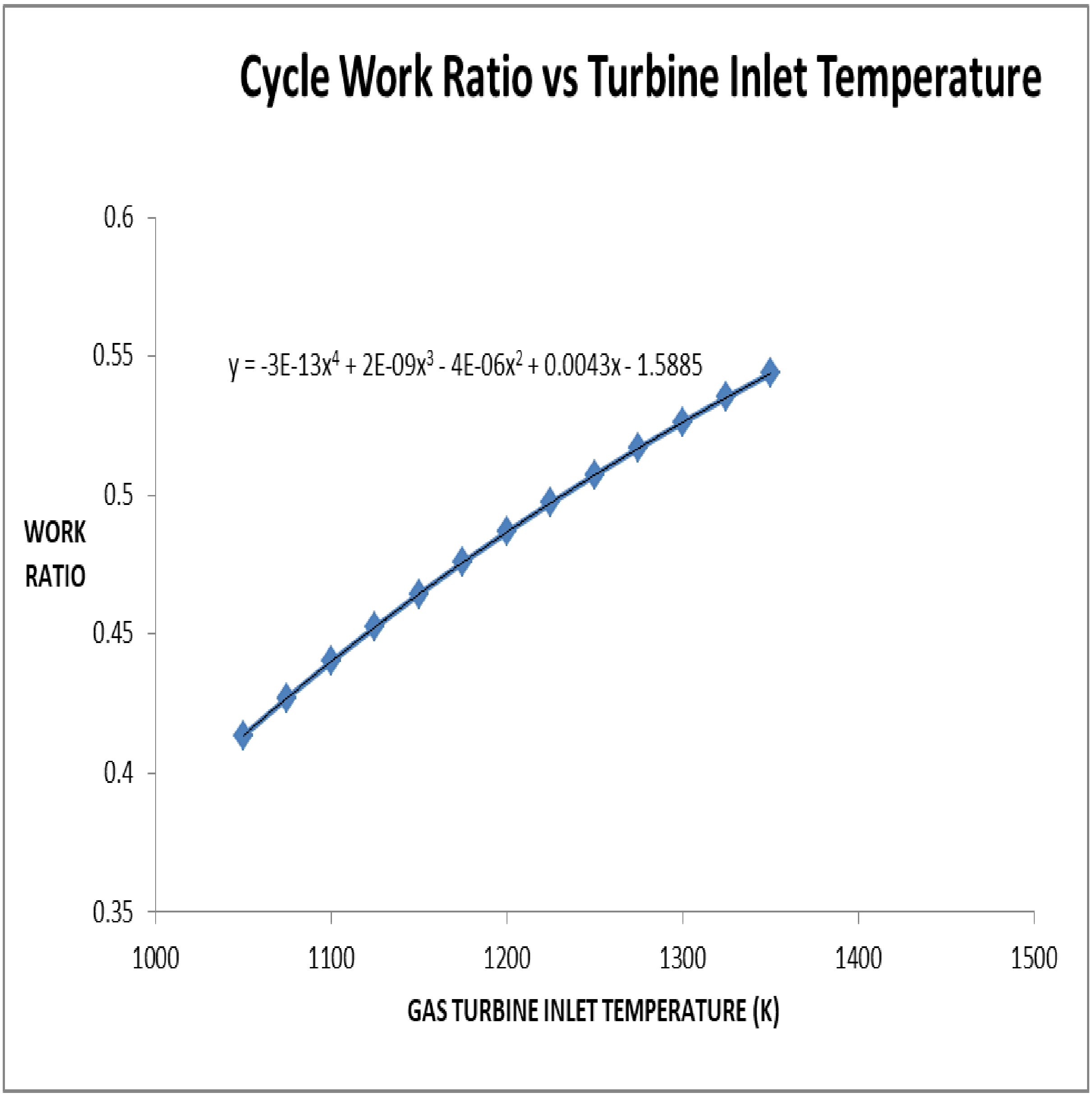


Fig. 2: Thermal Efficiency vs Turbine Inlet Temperature

Fig. 3: Turbine Inlet Temperature vs Cycle Work Ratio



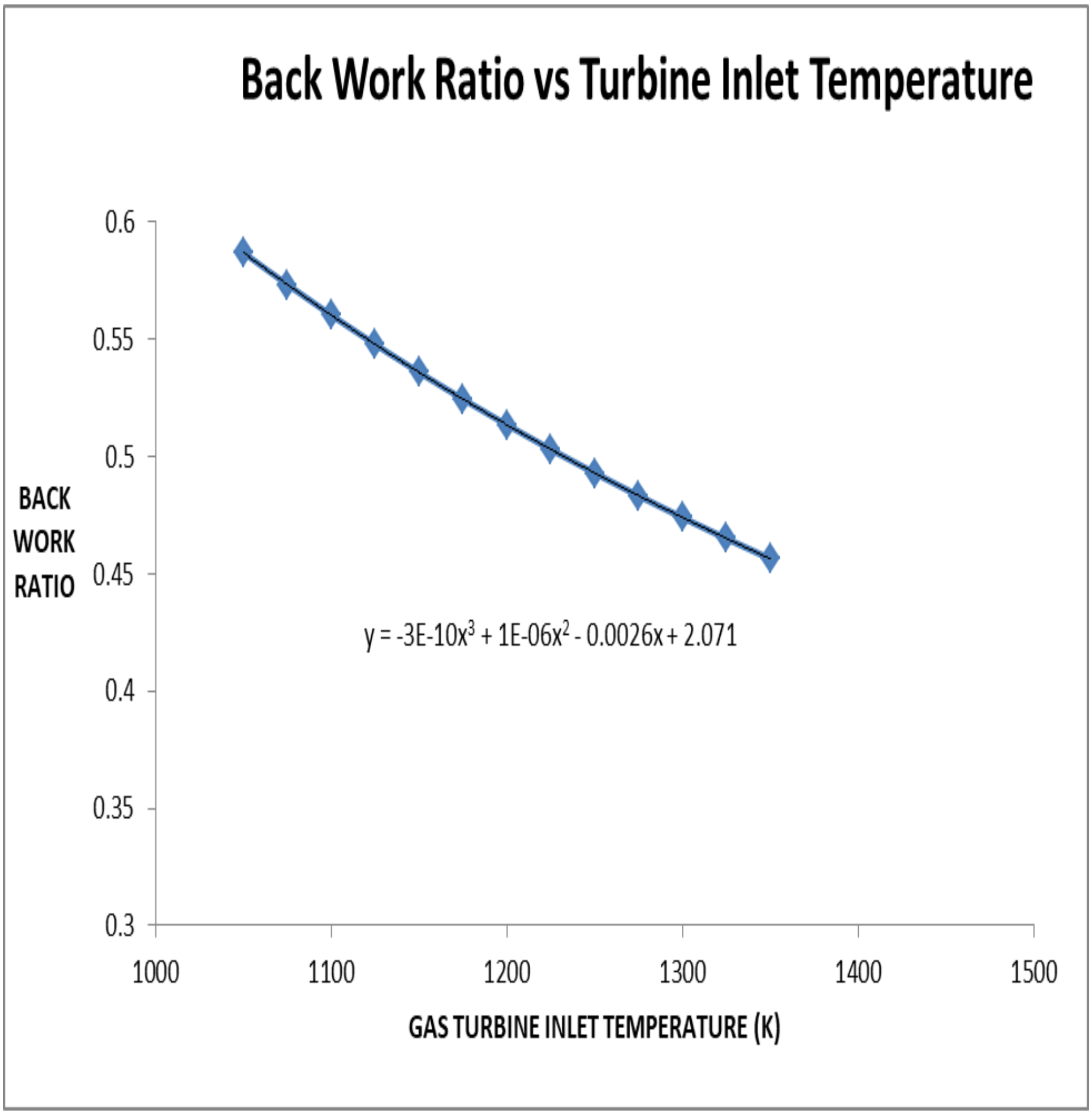


Fig. 4: Back Work Ratio vs Turbine Inlet Temperature

Conclusions:

It is observed that as the Turbine Inlet Temperature Increases , the thermal efficiency increases upto 41% (Fig.2) .

The cycle work ratio increases (Fig. 3)

The back work ratio decreases (Fig. 4.)

It can be concluded that the Turbine Inlet Temperature greatly influences the performance of the gas turbine. The thermal efficiency is enhanced by 5% to 10 % by incorporating a High Temperature Gas Cooled reactor (HTGR) instead of a conventional combustion chamber.

ACKNOWLEDGEMENT:

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