THERMODYNAMIC ANALYSIS OF GAS TURBINE

BY

AHMAD NURAIZAT BIN SULAIMAN

MECHANICAL ENGINEERING

11427

Dissertation submitted in partial fulfillment of
the requirements for the
Bachelor of Engineering (Hons)
(Mechanical Engineering)
MAY 2012

UNIVERSITI TEKNOLOGI PETRONAS

BANDAR SERI ISKANDAR

31750 TRONOH

PERAK DARUL RIDZUAN

CERTIFICATION OF APPROVAL

Thermodynamic Analysis of Gas Turbine

By

Ahmad Nuraizat Bin Sulaiman

A project dissertation submitted to the

Mechanical Engineering Programme

University Teknologi PETRONAS

In partial fulfilment of the requirement for the

BACHELOR OF ENGINEERING (Hons) OF

(MECHANICAL ENGINEERING)

Approved by,

....

(Dr Aklilu Tesfamichael Baheta)

UNIVERSITY TEKNOLOGI PETRONAS

TRONOH, PERAK

MAY 2012

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgment, and that the original work contained herein have not been undertaken or done by unspecified source or persons.

....

AHMAD NURAIZAT BIN SULAIMAN
890422-03-6159

ACKNOWLEDGEMENT

First and foremost I would like to express my highest gratitude to the Allah S.W.T, which has been guiding and supporting me throughout my entire life in general and during taking this project in specific.

I would like to express my humble gratitude toward my FYP supervisor, Dr Aklilu Tesfamichael Baheta for his continuous belief in my ability to conduct this project successfully. His continuous supports and advices to me in completing the FYP project are very crucial. Without his firm and strict judgments, this project would be nowhere until today. I appreciate his effort and time to assist me in doing the reports and giving me assistance in doing simulation work.

Then I would like to express my warm gratitude towards my friends that are doing the same FYP project discipline with me. Their help and support mean a lot to me to complete this project. I would also like to express my thankfulness towards my parents, my family and all the lecturers in UTP for contribution to what I have today. Last but not least, special thank to PETRONAS for giving me the opportunity to study in University Teknologi PETRONAS (UTP) and completed my first degree in Mechanical Engineering.

Thank you.

ABSTRACT

This project is intended to do analysis of a gas turbine engine performance. The gas turbine operating conditions (pressure ratio, turbine inlet and exhaust temperatures, fuel to air ratio, isentropic compressor and turbine efficiencies and ambient temperature) affect the turbine performance. The performance indicators are thermal efficiency, compressor work, power output, specific fuel consumption and heat rate. This project will focus on the effect of ambient temperature, turbine inlet temperature, air to fuel ratio and compression ratio on the efficiency and output power of the turbine. The gas turbine basic components were modelled based on thermodynamics principle. The developed components models were integrated using conservation of mass and energy balance. In solving mathematical equation of every component, Microsoft Office Excel software was used. The simulation result could be use to suggest the optimum cycle operating condition.

LIST OF FIGURES

LIST OF TABLE

TABLE OF CONTENTS

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Gas turbine power plants consist of four components which are compressor, combustion chamber, turbine and generator. A schematic diagram for simple gas turbine is shown in Figure 1.1. Air is drawn by the compressor and delivered to the combustion chamber. Combustion occurs in combustion chamber with the mix of fuel and air then produces flue gas. High temperature flue gas is leaving the combustion chamber, entering turbine inlet and expands in the turbine which produces work by turning turbine blade. The corresponding thermodynamic cycle that is used to model the gas turbine working principle is Brayton cycle and it’s shown in Figure 1.2.

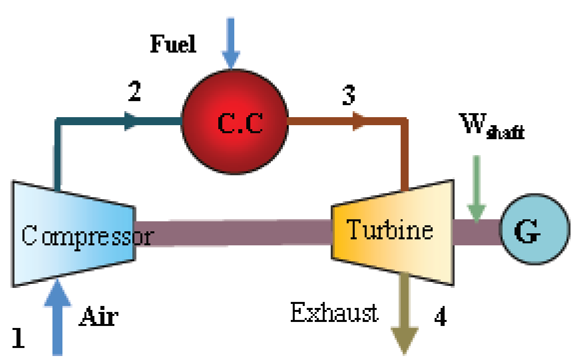


Figure 1.1: Schematic diagram for simple gas turbine

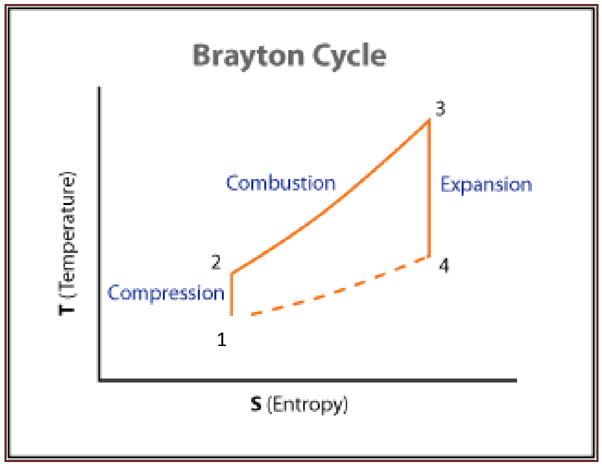


Figure 1.2: Brayton Cycle

Efficient compression of large volume of air is essential for a successful gas turbine power plant. This has been achieved in two types of compressors, the axial flow compressor and the centrifugal or radial flow compressors. Most power plant compressor design is to obtain the most air through a given diameter compressor with a minimum number of stages while retaining relatively high efficiency and aerodynamic stability over the operating range. The ideal processes and actual processes are represented in full line and dashed line, respectively, on the T-S diagram Figure 1.3. These parameters in terms of temperature are defined as (Al-Sayed, 2008):

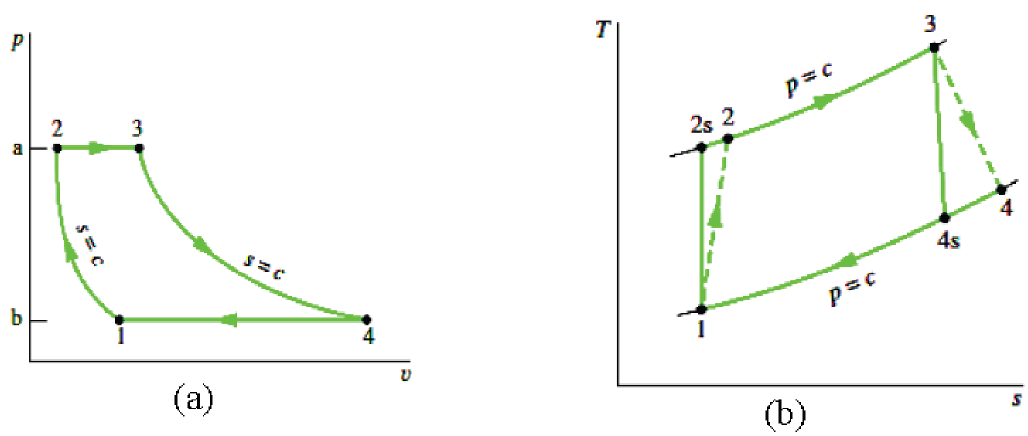


Figure 1.3: (a) P-V diagram and (b) T-S diagram for gas turbine

Figure 1.4 shows the example of gas turbine, Siemens Gas Turbine (SGT-750). The SGT 750 is a twin shaft gas turbine with a free power turbine and it can be employed both for power generation and as a mechanical drive. This gas turbine attains an efficiency level of 40% and has a capacity of 37 megawatts (MW). Gas turbine plant layout is shown in Figure 1.5 based on the Siemens SGT-750 Manual (Anders, 2010).

Gas turbines are rapidly becoming the choice for current and future power generation systems because they offer efficient fuel conversion, reduced cost of electricity, low installation and maintenance cost, can be put in service with minimum of delay time, occupy less room than other plants for the same capacity, and the ability to consume wide range of hydrocarbon fuels (Nag, 2008). Their exhaust gases are relatively less pollutant to the environment and can be used for preheating air before entering the combustion chamber, or for district heating as in combined heat and power plants (Wang and Chiou, 2002).

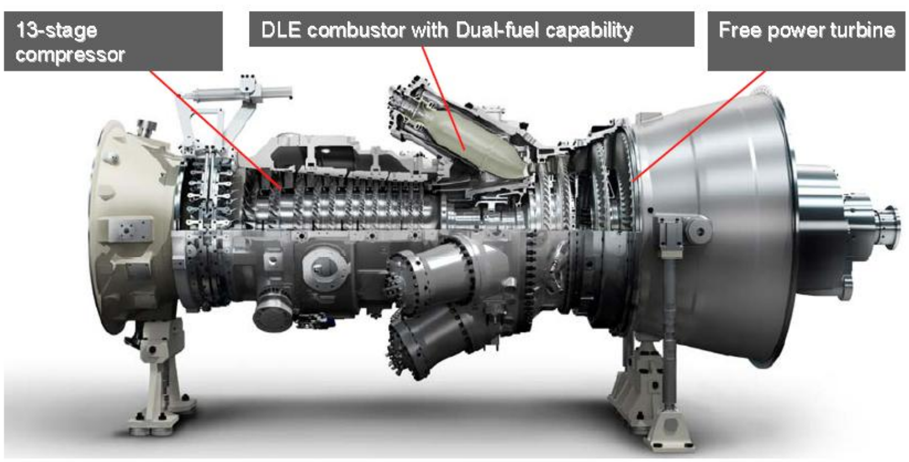


Figure 1.4: Siemens (SGT-750) Gas Turbine

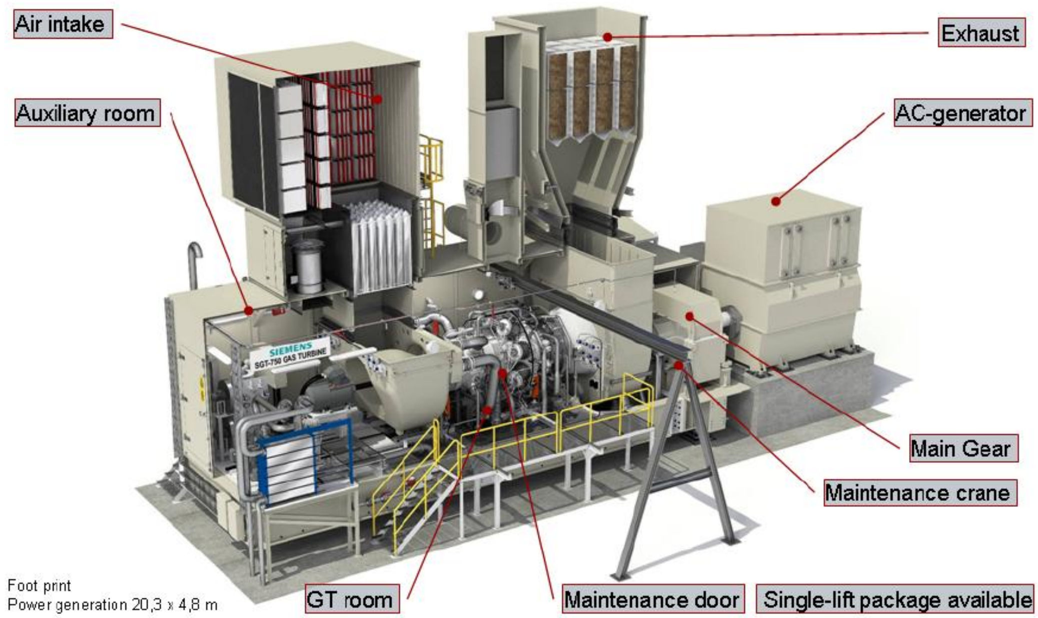


Figure 1.5: Gas Turbine Plant Layout

1.2 PROBLEM STATEMENT

A study from Taniquchi and Miyamae in 2000 reveals that, until mid seventies, mostly gas turbine suffered because of low efficiency and poor reliability. This limited the use of gas turbines to fulfill peak power demand. Based on recent study, performance of the gas turbine is closely related to the behavior of its operating conditions. Ambient temperature of air is draw by the compressor might influence the power output of the gas turbine. Power rating of a gas turbine may drop by as much as 20% to 30%, with respect to international standard organization (ISO) design condition, when ambient temperature reaches among 35^0C to 45^0C. Most gas turbines typically produce 30% higher electric output when the ambient air temperature is 15^0C compared to 45^0C (Mahmood and Mahdi, 2009).

Then higher turbine inlet temperature will produce more output power and increase efficiency of gas turbine. Higher turbine inlet temperature is still limited by turbine blade cooling requirement and metallurgical improvements (Horlock et al., 2003). Recently, General Electric (GE) manufactured a gas turbine used a turbine inlet temperature of 1425^0C and produced up to 282 MW while achieving a thermal efficiency of 39.5% in the simple cycle mode (Cengal and Boles, 2008).

1.3 OBJECTIVE

1) Develop thermodynamics model of each components.
2) Study the performance of gas turbine with respect to its operating condition.
3) Suggest the optimum operating condition for maximum thermal efficiency.

1.4 SCOPE OF STUDY

This project mainly focuses:

1) Simple gas turbine.
2) Steady state conditions.
3) The effect of ambient temperature on the gas turbine performance.
4) The effect of turbine inlet temperature on the gas turbine performance.
5) The effect of fuel to air ratio on the gas turbine performance.
6) The effect of compression ratio on the gas turbine performance.

1.5 RELEVANCY OF PROJECT

Up till today, world energy demand keep increasing in developed country including Malaysia because of rapid development and heavy industry. Worldwide energy consumption will grow over 59% at year 2020 (Department of Energy US, 2000). Current gas turbines for power generation cover the range from 1 MW to 250 MW per unit. Large units can be combined with steam turbines in blocks and can providing base load power stations with capacities of up to 2500 MW with thermal efficiencies of 55 % or more (H.I.H Saravanamuttoo). Gas turbine is widely used in power generation and various industries and it makes sense to study on gas turbine for further improve its performance by manipulating operating conditions.

Intensively study was carried over past decade and yield positive outcome which contribute to the more usage of gas turbine in industries.

1) Increase compressor pressure ratio.

2) Advanced combustion technique.

3) Improved technology of material (single-crystal material and high performance alloy).

4) New coating and cooling scheme.

Gas Turbine can be use in several different modes in critical industries such as power generation, oil and gas, process plants, transport, and smaller industries.

CHAPTER 2

LITERATURE REVIEW

2.1 LITERATURE REVIEW

Until mid seventies, mostly gas turbine suffered because of low efficiency and poor reliability. This limited the use of gas turbines to fulfill peak power demand and as a standby power unit (Taniquchi and Miyamae. 2000). During hot season which is high atmospheric temperature, the performance for gas turbine to achieved peak power level was drop and cause significant reduction in its net power output. Gas turbine are the constant volume machine which mean at a given shaft speed, the will always move the same volume of air. In gas turbine, since the air in combustor is taken directly from environment, their performance is strongly affected by ambient temperature (Mahmoudi et al., 2009).

Power rating of a gas turbine may drop by as much as 20% to 30%, with respect to international standard organization (ISO) design condition, when ambient temperature reaches among 35^{0}C to 45^{0}C. Most gas turbines typically produce 30% higher electric output when the ambient air temperature is 15^{0}C compared to 45^{0}C. But the cost of installing gas turbine or combined cycle plant rated at temperature of 45^{0}C is 20% - 30%

higher than that rated at 15^{0}C (Mahmood and Mahdi, 2009). Figure below show the effect of ambient temperature on the performance of the gas turbine.

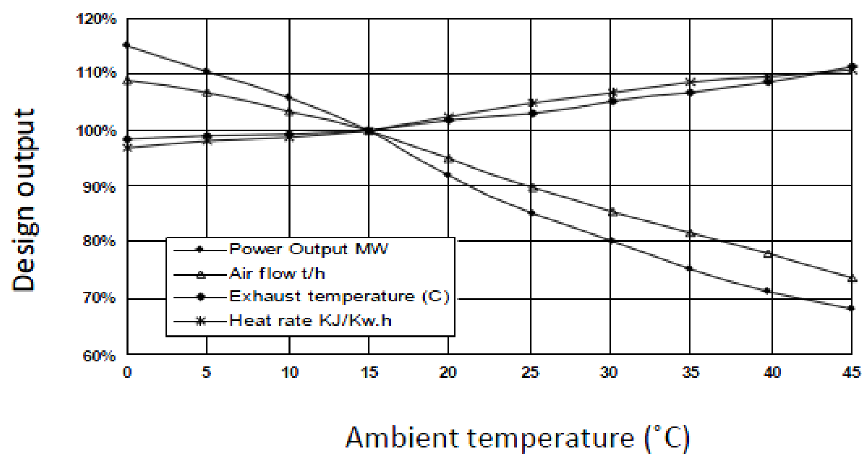


Figure 2.1: Effect of ambient temperature on a gas turbine (Saravanamuttoo et al., 2009)

Several studies conducted by experts, identified that, one way of to control ambient temperature is by using air cooler at the compressor inlet (Sadrameli and Goswami, 2007). The air cooling system serves to raise the turbine performance to peak power levels during the warmer months when the high atmospheric temperature cause the turbine to work at the off design conditions, with reduced power output (Kakaras et al., 2004). Gas turbine performance is sensible to the ambient condition. During high ambient temperature, less air can be compressed by the compressor and the compressor was operated at off design condition. With the insufficient air entering combustor, temperature at the turbine inlet will be low and reduced the power output from the gas turbine. Additionally, the compression works increase because the limited volumes of air increase in proportionality to the intake air temperature (Xiaojun et al., 2010).

Many researchers focusing on three different methods to improve power output of gas turbine cycles. Inlet air cooling and intercooling are two important methods but evaporative cooling with or without pre-compressed air and refrigeration cooling also attract their attention. Somehow, gas turbine intake cooling may cause a small decrease in efficiency because a lot of fuel is needed to bring compressor exhaust gas equal to the same gas turbine entry temperature.

Modern gas turbine technology has extensively used compressor intercooling and high turbine inlet temperature to achieve higher net power and increased thermal efficiency (Thamir K. Ibrahim and M.M. rahman, 2010). Looking for both of these solutions will leads to additional investment cost, but higher turbine inlet temperature are still limited by turbine blade cooling requirement and metallurgical improvements (Horlock et al., 2003). Recently, General Electric (GE) manufactured a gas turbine used a turbine inlet temperature of 1425^0C and produced up to 282 MW while achieving a thermal efficiency of 39.5% in the simple cycle mode (Cengal and Boles, 2008).

2.2 THERMODYNAMIC MODELLING OF GAS TURBINE

The first practical success was obtained by the Societe Anonyme des Turbomoteurs (French Company), which built a gas turbine in 1905. This engine, the first constant pressure gas turbine to run under its own power, had an efficiency of 3% which is used into the engine with multistage centrifugal compressor (20 stages or more) having a pressure ratio of 4 and compressor efficiency not more than 60% as well as the maximum gas temperature was about 393^0C.

However there was an elapse of many years, until in 1939, a Brown Boveri (BBC) unit for emergency electrical-power supply was put into operation in Neuchatel, Switzerland (Figure 7). The power output was 4000 kW and efficiency of 18%. The turbine with inlet temperature 550°C was provided 15,400 kW at 3000 rpm (Zurcher et al., 1988).

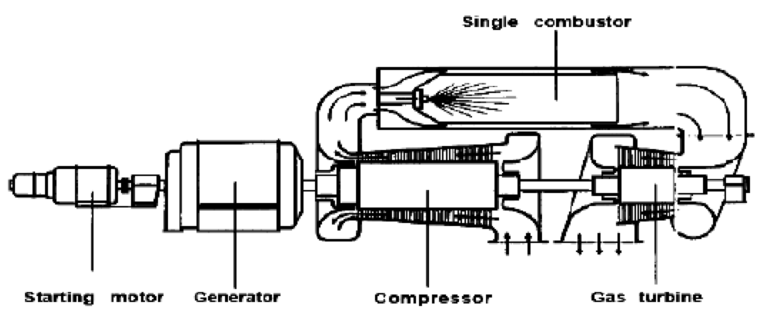


Figure 2.2: World's First Industrial Gas Turbines with Single Combustor (Zurcher et al., 1988).

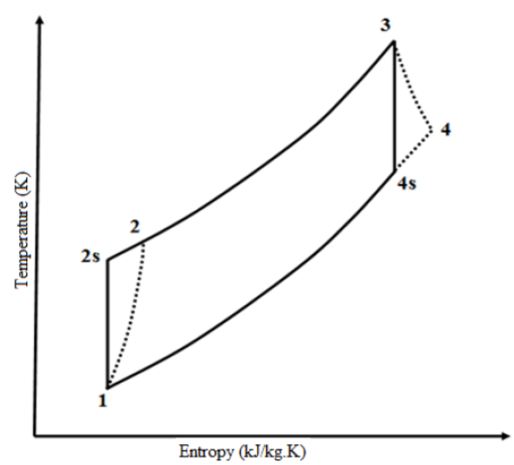


Figure 2.3: Temperature and Entropy Diagram for Gas Turbine

It is assumed that the compressor efficiency and the turbine efficiency are represented η_c and η_t respectively. The ideal and actual processes on the temperature-entropy diagram are represented in full and dashed line respectively as shown in (Figure 8) (Al-Sayed, 2008).

The compressor compression ratio (r_p) can be defined as (Al- Sayed, 2008):

$$r_p = \frac{p_2}{p_1} \tag{2.1}$$

Where, P_1 and P_2 are inlet and outlet compressor air pressure respectively.

The isentropic efficiency for compressor and turbine are in the range of 85 – 90% (Rahman et al., 2011) is expressed as:

$$\eta_C = \frac{T_{2s} - T_1}{T_2 - T_1} \tag{2.2}$$

Where, T_1 and T_2 are compressor inlet and outlet air temperature and T_{2s} is compressor isentropic outlet temperature.

The final temperature of compressor is calculated using equation below

$$T_2 = T_1 \, r_p^{\frac{K-1}{K\eta pc}} \tag{2.3}$$

K=1.4

η_{pc} $(Polytropic\ Efficiency\ of\ Compressor)$ = *0.88*

The work of the compressor (W_c) when blade cooling is not taken into account can be calculated as;

$$W_c = \dot{m}\, C_{pa} T_1 (r_p^{\frac{K-1}{K\eta pc}} - 1) \tag{2.4}$$

Where, c_{pa} is the specific heat of air which can be fitted by equation (2.5) for the range of 2000K <T< 800K (R) and η_m is the mechanical efficiency of the compressor and turbine (Rahman et al., 2011);

$$C_{pa} = 1.0189\times10^{3} - 0.13784T_a + 1.9843\times10^{-4}T_a^2 + 4.2399\times10^{-7}T_a^3 - 3.7632\times10^{-10}T_a^4 \tag{2.5}$$

Where, $T_a = (T_2 + T_1)/2$ is in Kelvin

The specific heat of flue gas (C_{pg}) is given by (Naradasu et al., 2007);

$$C_{pg} = 1.8083 - 2.3127\times10^{-3}T + 4.045\times10^{-6}T^2 - 1.7363\times10^{-9}T^3 \tag{2.6}$$

From the energy balance in the combustion chamber is expressed as;

$$\dot{m}_a C_{pa} T_2 + \dot{m}_f \times LHV + \dot{m}_f C_{pf} T_f = (\dot{m}_a + \dot{m}_f) C_{pg} \times TIT \tag{2.7}$$

$\dot{m}_f$ = *fuel mass flow rate (kg/s)* C_{pf} = *specific heat of fuel*

$\dot{m}_a$ = *air mass flow rate (kg/s)* T_f = *Temperature of Fuel*

LHV = Low Heating Value

T_3 = *TIT = Turbine Inlet Temperature*

After manipulating equation (2.8), the fuel to air ratio (f) is expressed as

$$f = \frac{\dot{m}_f}{\dot{m}_a} = \frac{C_{pg} \times TIT - C_{pa} T_2}{LHV - C_{pg} \times TIT} \tag{2.8}$$

LHV (Methane) = 50.05 MJ/kg

The exhaust gases temperature from gas turbine is given by equation (2.9)

$$T_4 = \frac{T_3}{r_p^{\frac{K-1}{K\eta p}}} \tag{2.9}$$

η_{pt} $(Polytropic\ Effeciency\ Of\ Turbine)$ = *0.89*

The shaft work of the turbine (W_t) is given by equation (2.10)

$$W_t = C_{pg}\ (T_3 - T_4) \tag{2.10}$$

The net work of the turbine is calculated from the equation;

$$W_{net} = W_t - W_C \tag{2.11}$$

The output power from the turbine (P) is expressed;

$$P = \dot{m}_a \times W_{net} \tag{2.12}$$

The specific fuel consumption (SFC) is determined by equation (2.13)

$$SFC = \frac{3600\ f}{W_{net}} \tag{2.13}$$

The heat supply is also express as;

$$Q_{add} = \dot{m} f \eta_{comb} LHV \qquad (2.14)$$

η_{comb} = 0.9

The gas turbine efficiency (η_{th}) can be determined by equation below

$$\eta_{th} = \frac{W_{net}}{Q_{add}} \qquad (2.15)$$

The heat rate (HR) is the consumed heat to generate unit energy of electricity can be expressed as (Saravanamuttoo et al., 2009);

$$HR = \frac{3600}{\eta_{th}} \qquad (2.16)$$

CHAPTER 3

METHODOLOGY

3.1 RESEARCH METHODOLOGY

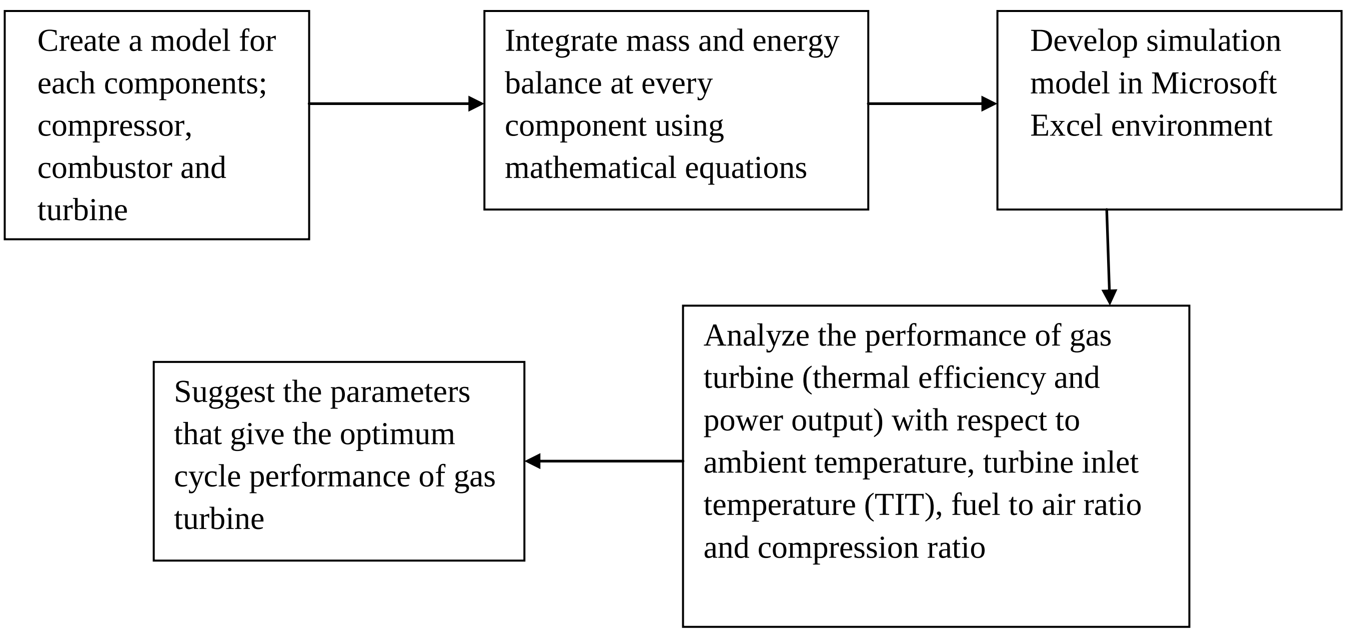


Figure 3.1: Research Methodology for thermodynamics analysis of gas turbine

3.2 SIMULATION FLOW CHART

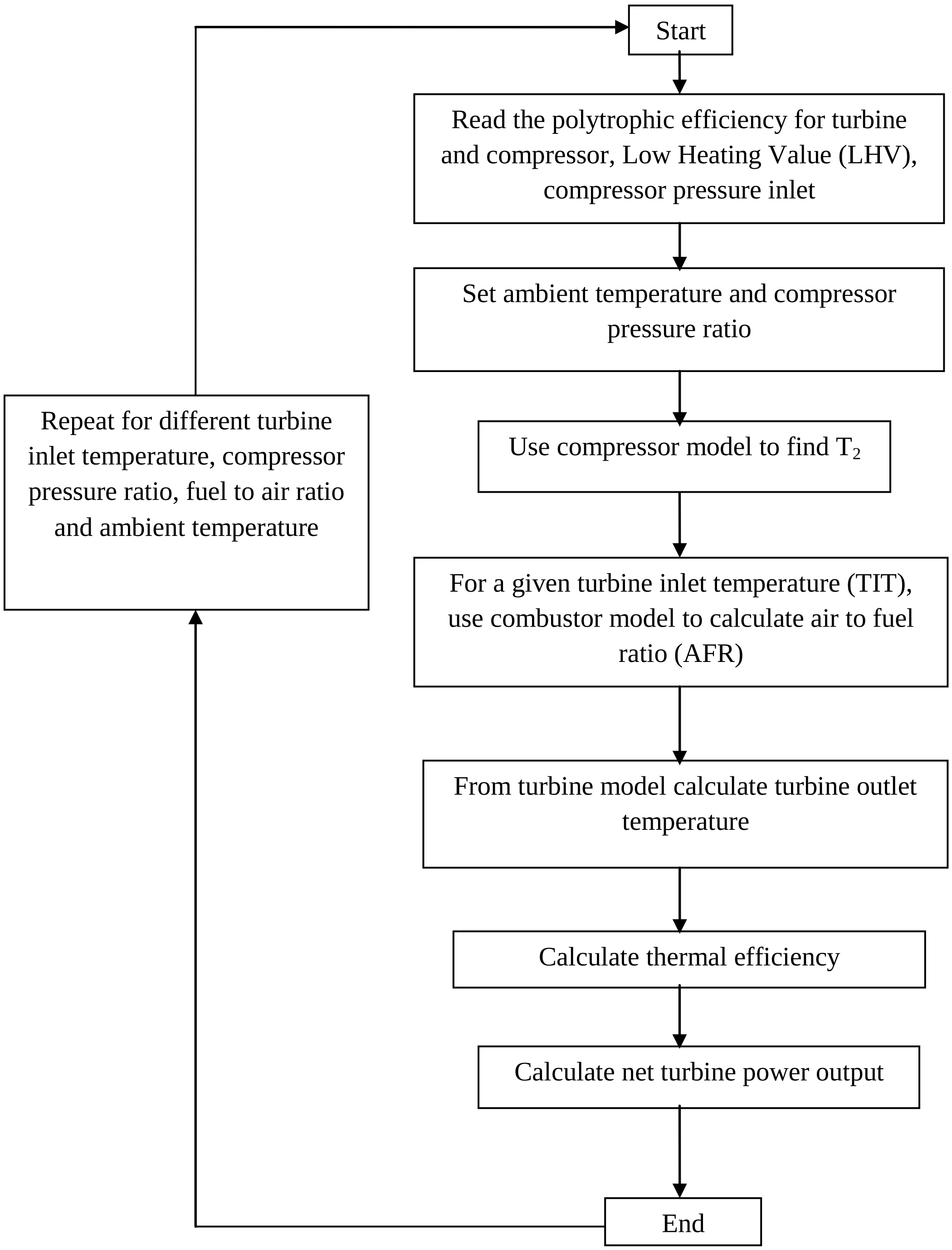


Figure 3.2: Simulation Flow Chart in Microsoft Excel

3.3 PROJECT ACTIVITIES

Final Year Project I

1) Review previous study that are relevant with the problem statement and with what approach they use to overcome the problem.
2) Identify studies that are relevant to the proposed title.
3) Narrow down the area of study to comply with technical knowledge and time constraint.
4) Identify operating conditions of gas turbine and mathematical equations to be use for analysis.

Final Year Project II

1) Develop simulation model.
2) Do analysis on gas turbine performance (thermal efficiency and power output) with respect to the selected operating conditions (ambient temperature, turbine inlet temperature, fuel to air ratio and compression ratio).
3) Display result from the analysis using graph and discuss.
4) Suggest parameters that give optimum cycle performance of gas turbine.

3.4 GANTT CHART

No.	Details/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of project topic							Mid Semester Break							
2	Preliminary research work														
3	Submission of Extended Proposal														
4	Proposal Defense														
5	Project Work Continue														
6	Submission of Interim Draft Report														
7	Submission of Interim Report														

Table 3.1: Gantt Chart (FYP I)

No	Detail/Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14	15
1	**Project Work Continues (Simulation Model in Microsoft Excel)**								MID-SEMESTER BREAK								
2	**Submission of Progress Report**																
3	**Project Work Continues (Performance Analysis)**																
4	**Pre-EDX**																
5	**Submission of Draft Report**																
6	**Submission od Dissertation (Soft Bound)**																
7	**Submission of Technical Paper**																
8	**Oral Presentation**																
9	**Submission of Project Dissertation (Hard Bound)**																

Table 3.2: Gantt Chart (FYP II)

Project milestone

Project work

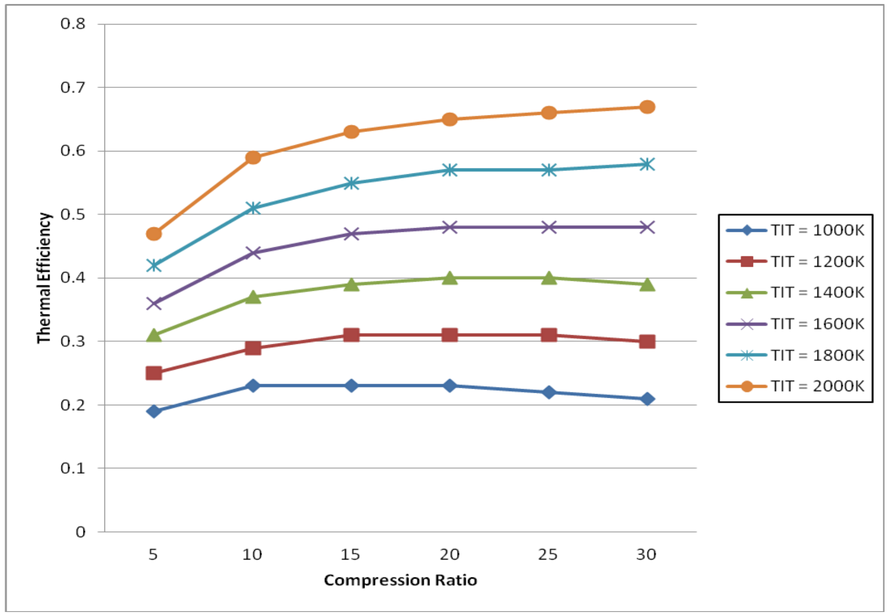
CHAPTER 4

RESULT AND DISCUSSION

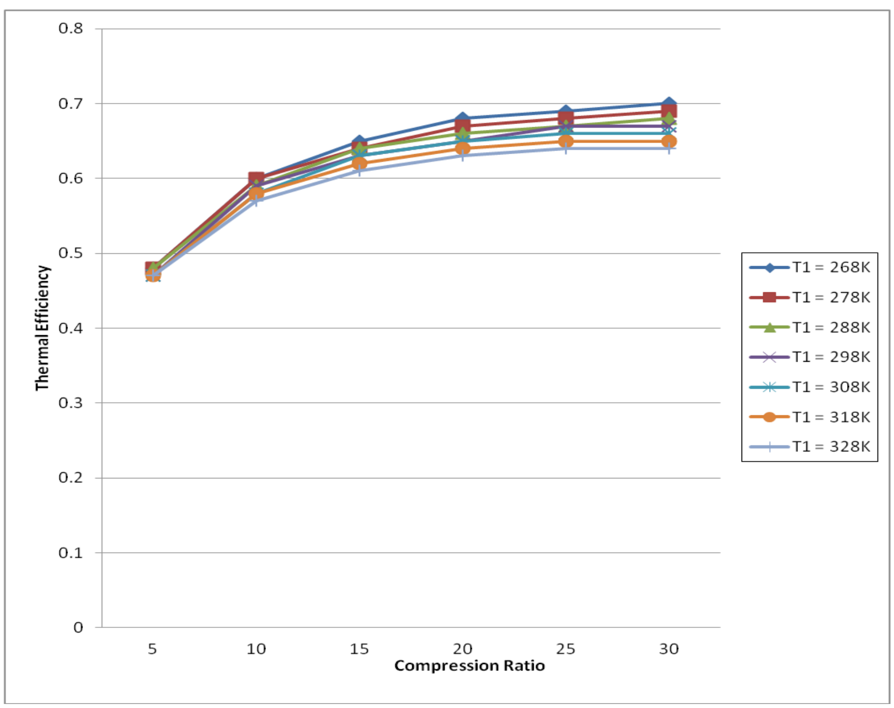
4.1 SIMULATION RESULT AND DISCUSSION

Figure 4.1 (a) presents a relation between the gas turbine cycle thermal efficiency versus compression ratios for different turbine inlet temperature (TIT). Based on the simulation result represented in graph, thermal efficiency increases with respect to the higher compression ratio and higher turbine inlet temperature (TIT). At lower compression ratio, the deviation of thermal efficiency is not significant but the variation at higher compression ratio is vital for thermal efficiency at different turbine inlet temperature (TIT). Furthermore, at lower turbine inlet temperature, the efficiency will be increase at one point, and then it will start dropping when the compression ratio increases. From the equation of work net of turbine, when turbine inlet temperature (TIT) increase work net of turbine also will increase hence it produce higher power output. So, thermal efficiency of the system will increase.

Figure 4.1 (b) presents a relation between the gas turbine cycle thermal efficiency versus compression ratio for different ambient temperature. Thermal efficiency increase with increase the compression ratio and decrease in ambient temperature. Thermal efficiency is affected by ambient temperature due to the change of air density. Lower ambient temperature leads to a higher air density and reduce work of the compressor. So, lower compressor work will tends to increase gas turbine power output and thermal efficiency will be increase. The increase of ambient temperature leads to decrease of the thermal efficiency.



(a) Turbine Inlet Temperature (TIT)



(b) Ambient Temperature

Figure 4.1: Variation of compression ratio, turbine inlet temperature (TIT) and ambient temperature on thermal efficiency

Figure 4.2 show the relationship between thermal efficiency and compression ratio at different fuel to air ratio. Thermal efficiency increase with increase the compression ratio and increase in fuel to air ratio (FAR). The variation of thermal efficiency for different fuel to air ratio (FAR) at low compression ratio is not much but at higher compression ratio the variation of thermal efficiency is greater. Higher fuel to air ratio (FAR) will tend to encourage combustion in combustion chamber then will produce higher temperature of flue gas that will be expand in turbine. Hence it will increase thermal efficiency of the gas turbine.

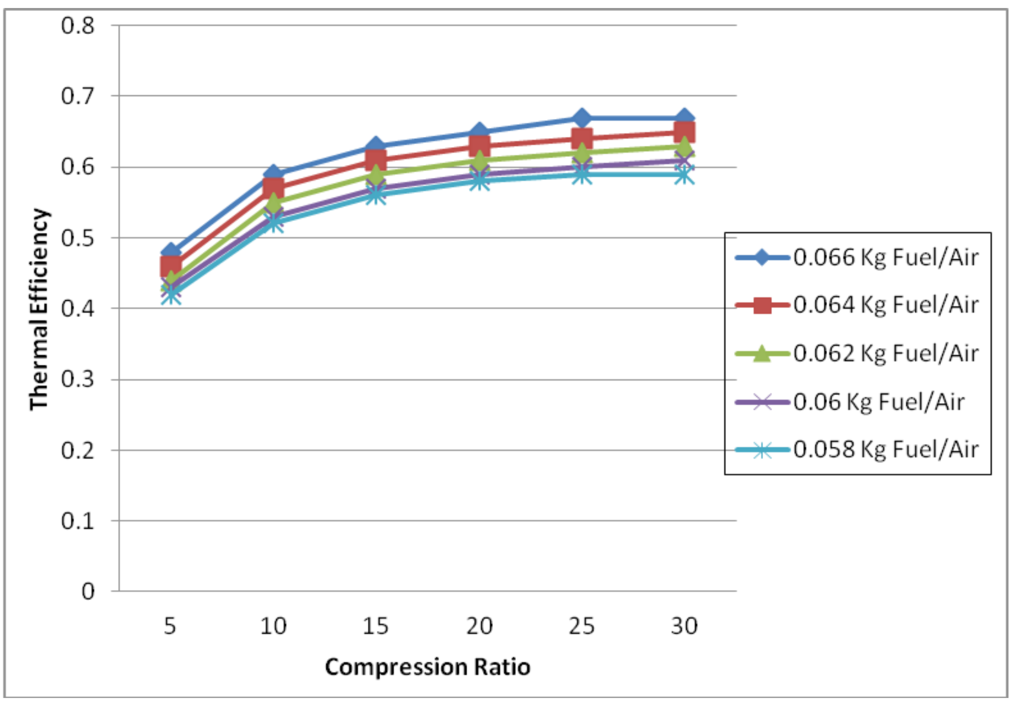


Figure 4.2: Variation of compression ratio and fuel to air ratio (FAR) on thermal efficiency

Figure 4.3 present the effect of compression ratio on compressor work. Compressor work increases with increase the compression ratio and the ambient temperature. Furthermore, at lower compression ratio for different ambient temperature, the variations of compressor work are not significance but at higher compression ratio, the variations of compressor work are more significance. Thermal efficiency is affected by ambient temperature due to the change of air density. Higher ambient temperature leads to a lower air density and increase work of the compressor. So, higher compressor work will tends to decrease gas turbine power output and thermal efficiency will also been decrease.

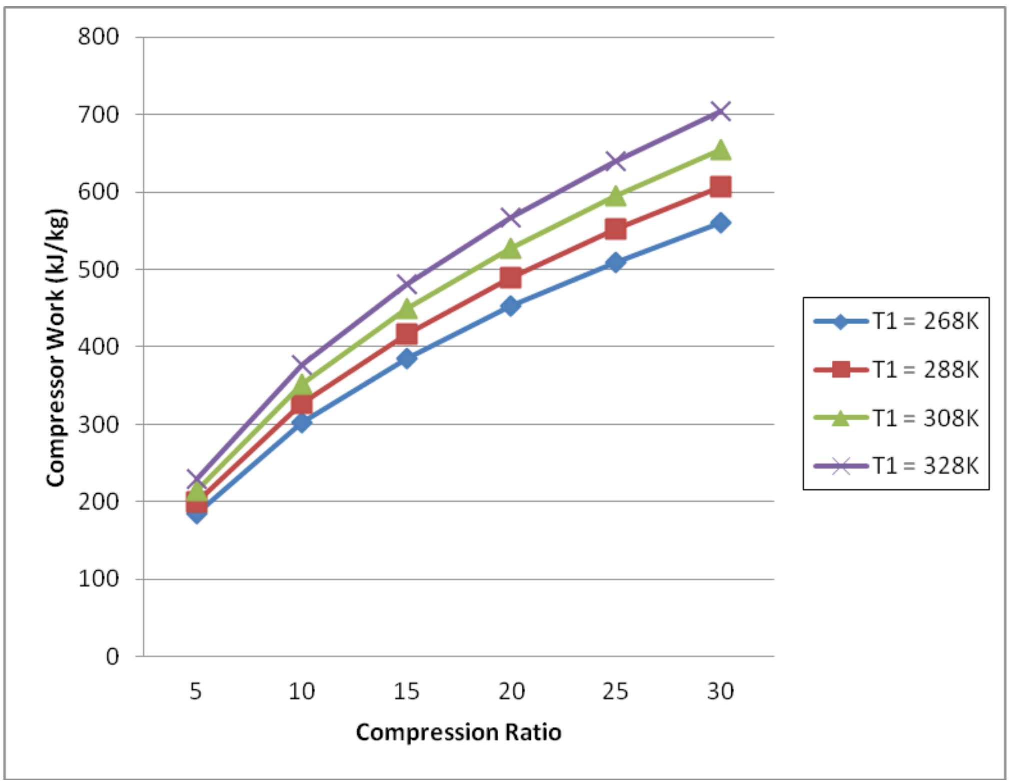


Figure 4.3: Effect of compression ratio and ambient temperature on compressor work

Figure 4.4 shows that the gas turbine thermal efficiency decreases when ambient temperature increase. This is because the air mass flow rate inlet to compressor increases with decrease of the ambient temperature. So the fuel mass flow rate will increase, since fuel to air ratio (FAR) is keep constant. The slope for decreasing is stiffer for higher fuel to air ratio (FAR).

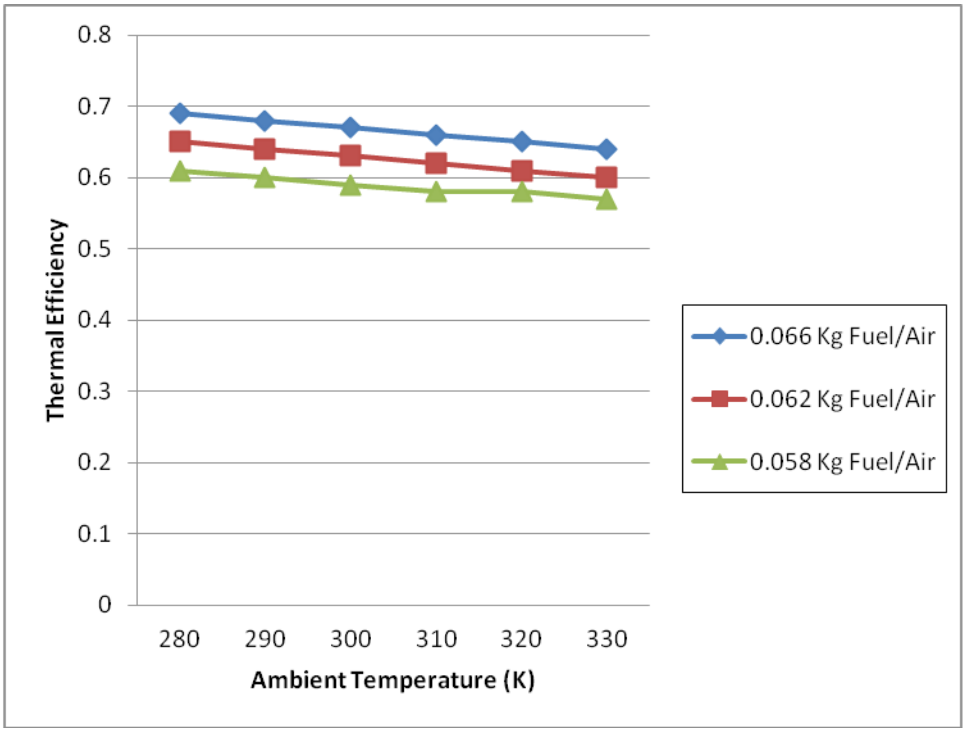


Figure 4.4: Effect of ambient temperature and fuel to air ratio (FAR) on thermal efficiency

Figure 4.5 presents the relationship between shaft powers of gas turbine with respect to ambient temperature at different fuel to air ratio (FAR). Power decrease with increase of ambient temperature and decrease in fuel to air ratio (FAR). At lower ambient temperature, the air draws by compressor is high in density and lower the compressor work. So, this will yield the higher gas turbine output power. The decreasing in term of output power is more significant with higher fuel to air ratio (FAR).

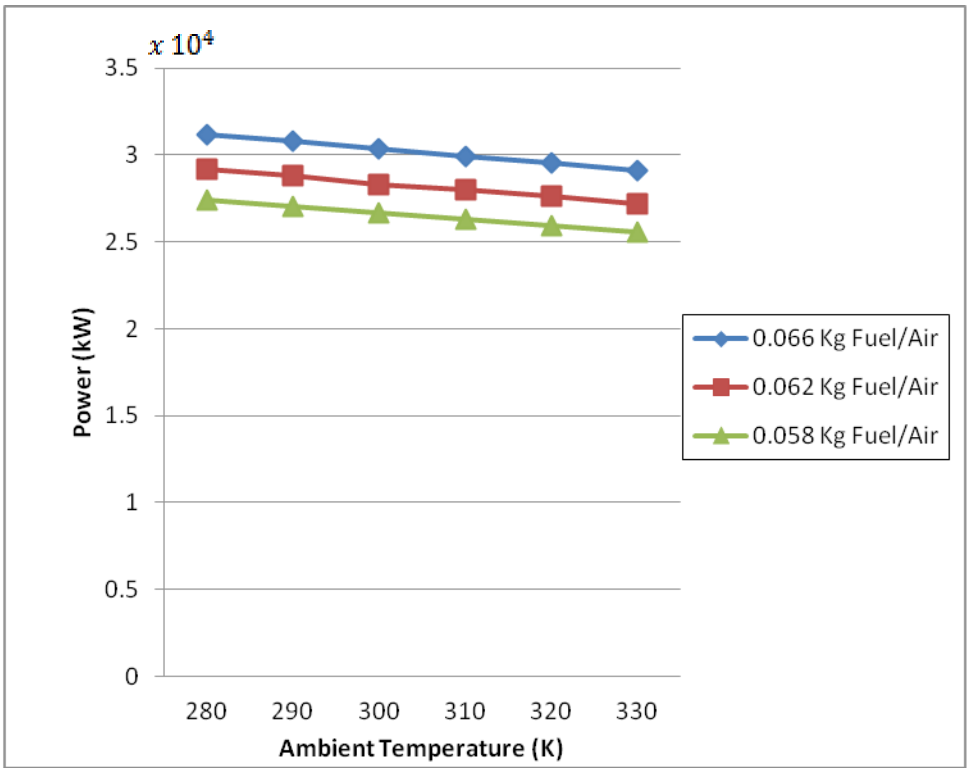


Figure 4.5: Effect of ambient temperature and fuel to air ratio (FAR) on power

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

Based on the performance analysis from the graph of the simulation result, there are two significant finding that affect performance of gas turbine

1) The compression ratios, ambient temperature, fuel to air ratio and turbine inlet temperature strongly influence the thermal efficiency of the gas turbine.

2) At higher turbine inlet temperature (TIT), compression ratio and lower ambient temperature (T1), thermal efficiency increase hence the output power of the gas turbine will be higher.

Studies on gas turbine are being carried out quite extensively to find suitable parameters that meet the highest possible thermal efficiency and also desire power output. This deals with wide area of interest including industrial applications and power generation unit.

This project was mainly about parametric analysis for gas turbine application. Simulation model was established in Microsoft Excel environment and analysis of the performance of gas turbine was placed once the simulation was done. At the end of this study, the combined parameters that give optimum gas turbine performance for a given conditions was suggested.

5.2 RECOMMENDATION

Due to the time limitation and limited access to the real operating data from installed gas turbine at plant, this project only focus on several operating parameter which are ambient temperature, turbine inlet temperature, fuel to air ratio and compression ratio. Then, the operating parameters were varied and the effect to the performance of gas turbine was studied.

For extended study, I am proposing that the other operating parameter such as efficiency of compressor and turbine also might be considered to determine the performance of the gas turbine. Beside, real operating data might be extracted from any plant that have gas turbine in service, so less assumption and more accurate result can be get from the study. Analysis on simple gas turbine might yield close to the ideal result but for further study, more advance gas turbine could be analyzing so that the result will be more reliable in the future.

Using other software like C++ or MATLAB to do analysis or develop friendly user interface software using visual basic to make the project usable for any parties. Developed software might be use by engineer in the plant to predict the performance of the gas turbine in their plant. It might reduce time consumption to anticipate gas turbine problem and save cost instead.

REFERENCES

1. Anders Hellberg (2010) SGT-750 – 37MW Gas Turbine, 19th Symposium of The Industrial Application of Gas Turbines Committee, Siemens Industrial Turbo machinery
2. Cengel, A.Y. and Boles, A.M. 2008. Thermodynamics an engineering approach. New York: McGraw-Hill.
3. Horlock JH (2003). Advance Gas Turbine Cycles. Elsevier Sci. Ltd., UK.
4. Ibrahim TK, Rahman MM, Alla AN (2010). Study on the effective parameter of gas turbine model with intercooled compression process. Sci. Res. Essays, 5(23): 3760-3770.
5. Kakaras E, Doukelis A, Karellas S (2004). Compressor intake-air cooling in gas turbine plants. Energy, 29: 2347-2358.
6. M.M Rahman, Thamir K. Rahman and Ahmed N. Abdalla (2011) Thermodynamic Performance Analysis of Gas Turbine Power Plant, International Journal of the Physical Sciences Vol. 6(14), pp. 3539-3550, 18 July, 2011 Available online at http://www.academicjournals.org/IJPS
7. Mahmood, F.G. and Mahdi, D.D. 2009. A new approach for enhancing performance of a gas turbine (Case study: Khangiran Refinery). Applied Energy, 86: 2750–2759.
8. Mahmoudi SM, Zare V, Ranjbar F, Farshi L (2009). Energy and exergy analysis of simple and regenerative gas turbines inlet air cooling using absorption refrigeration. J. Appl. Sci., 9(13): 2399-2407.
9. Nag, P.K. 2008. Power plant engineering. New Delhi: Tata McGraw-Hill Publishing Company Limited
10. Naradasu RK, Konijeti RK, Alluru VR (2007). Thermodynamic analysis of heat recovery steam generator in combined cycle power plant.Therm. Sci., 11(4): 143-156
11. Saravanamuttoo H, Rogers G, Cohen H, Straznicky P (2009). GasTurbine Theory. Prentice Hall, ISBN 978-0-13-222437-6

12. Sadrameli SM, Goswami DY (2007). Optimum operating conditions for a combined power and cooling thermodynamic cycle. Appl. Ener., 84: 254-265.
13. Taniquchi, H. and Miyamae, S. 2000. Power generation analysis for high temperature gas turbine in thermodynamic process. Journal of Propulsion and Power, 16: 557-561.
14. Wang, F.J. and Chiou, J.S. 2002. Performance improvement for a simple cycle gas turbine GENSET-a retrofitting example. Applied Thermal Engineering, 22: 1105–1115
15. Xiaojun S, Brian A, Defu C, Jianmin G (2010). Performance enhancement of conventional combined cycle power plant by inlet aircooling, inter-cooling and LNG cold energy utilization. Appl. Ther. Eng., 30: 2003-2010.
16. Zurcher U, Badoux JC, Mussard M (1988). The world's first industrial gas turbine set at Neuchatel. An International Historic Mechanical Engineering Significance of Landmark, September 2, Neuchatel Switzerland, ASME

APPENDIX: Simulation using Microsoft Excel

								T2 (K)			
T1 (K)	P1 (pa)	Kair	rp	Efficiency Comp	Kgas			914.171024		Efficiency Mech.	
303	101325	1.4	30	0.88	1.3					1	
								T4 (K)		TIT	
								671.171901		2000	2
Ta	Cpa (J/kgK	Cpg (J/kgK)	Wcomp (J/Kg	FAR	Efficeincy Comb.					LHV Methane (J/Kg)	
608.5855119	1052.453	1803.69077	643228.7996	0.056957587	0.9	0.0584				50050000	
										Efficiency Turbine	
			Wturb (J/Kg))	Wnet (J/kg)	Power	Mass Flow Fuel (kg/s)				0.89	
			2396794.972	1753566.172	30787227.43	1					
						Mass Flow Air (kg/s)					
			Qadd (J/Kg)	Efficiency Thermal		17.55692367					
			2630628	0.666596027							

	TIT = 1000K	TIT = 1200K	TIT = 1400K	TIT = 1600K	TIT = 1800K	TIT = 2000K
5	0.19	0.25	0.31	0.36	0.42	0.47
10	0.23	0.29	0.37	0.44	0.51	0.59
15	0.23	0.31	0.39	0.47	0.55	0.63
20	0.23	0.31	0.4	0.48	0.57	0.65
25	0.22	0.31	0.4	0.48	0.57	0.66
30	0.21	0.3	0.39	0.48	0.58	0.67