"I hereby declare that I have read this report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Thermal-Fluid)"

Signature : ....

Name of Supervisor : Mr. Juhari Bin Ab Razak

Date : 14.12.2005

JUHARI BIN AB RAZAK
Pensyarah
Fakulti Kejuruteraan Mekanikal
Kolej Universiti Teknikal Kebangsaan Malaysia
Karung Berkunci 1200
75450 Ayer Keroh, Melaka.

A STUDY ON ENTRY TEMPERATURES AND AERODYNAMICS LOADINGS FOR INCREASED PERFORMANCE OF GAS TURBINE

NAIM BIN SAIM

A report submitted in fulfillment of the
requirements for the award o the degree of
Bachelor of Mechanical Engineering (Thermal-Fluid)

Faculty of Mechanical Engineering
Kolej Universiti Teknikal Kebangsaan Malaysia

November 2005

I declare that this report entitled "A STUDY ON ENTRY TEMPERATURES AND AERODYNAMICS LOADINGS FOR INCREASED PERFORMANCE OF GAS TURBINE" is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :..........................

Name : Naim Bin Saim

Date : 14.12.2005

Dedicate to both my beloved father and mother and my loving family.

ACKNOWLEDGEMENT

Alhamdulillah with His Mercy and Blessings, this study was finally completed. I would like to thank the following individuals for helping me in completing this project:

Mr. Juhari Bin Ab Razak as supervisor from the Faculty of Mechanical Engineering, Kolej Universiti Teknikal Kebangsaan Malaysia (KUTKM), for his constant guidance, inspiration, support and confidence towards completing this thesis. All lectures in Faculty of Mechanical Engineering for ideas and suggestions on this project.

My father Saim Bin Nawi and my mother Maimunah Binti Sujak, for their continuous support which in my studies at KUTKM.

All my friends, for their cooperation in completing this study successfully.

May Allah reward and bless all of them.

Finally the author is expressing his sincere gratitude to Allah once again who made the study to complete.

ABSTRACT

Gas turbine performance depends on the inlet temperature of high pressure turbine. This study is on how the inlet temperature can be improved while maintaining the outlet temperature, and if possible to decrease the outlet temperature to a certain degree. Educational gas turbine ET794 is used as a case study. Experimentally, the gas turbine efficiency is about 25.7 percent. It is also found that the outlet temperature will also increased when the inlet temperature is increased at the high pressure turbine. A proposed design involves regenerating the gas turbine system. Heat exchanger is used in this design. Air leaving the exhaust is reused in the system by flowing it into the heat exchanger. The outlet temperature from the compressor will be mixed with the outlet temperature from the exhaust in the heat exchanger to produce high temperature for burning process. Simulation of the proposed design is done using CFD software. The data from both initial system and proposed design are fed into the program. The results show some improvement on the gas turbine performance the thermal efficiency.

ABSTRAK

Prestasi turbin gas bergantung kepada suhu masukan pada bahagian turbin tekanan tinggi. Kajian ini mengkaji bagaimana suhu masukan boleh ditingkatkan sementara suhu keluaran adalah tetap dan jika berkemungkinan mengurangkan suhu keluaran kepada beberapa darjah. Turbin gas pembelajaran ET794 digunakan sebagai kajian kes. Secara eksperimen, kecekapan turbin gas adalah di antara 25.7 peratus. Suhu keluaran juga didapati meningkat apabila suhu masukan ditingkatkan pada sistem turbin tekanan tinggi. Rekabentuk yang dicadangkan melibatkan penjanaan semula di dalam sistem turbin gas. Penukar haba digunakan di dalam rekabentuk ini. Udara yang keluar dari ekzos digunakan kembali di dalam sistem dengan menyalurkannya ke dalam penukar haba. Suhu keluaran dari pemampat akan bercampur dengan suhu keluaran dari ekzos di dalam penukar haba untuk menghasilkan suhu yang tinggi untuk digunakan di dalam pembakaran. Simulasi rekabentuk yang dicadangkan dijalankan dengan menggunakan perisian CFD. Data dari sistem asal dan rekabentuk cadangan dimasukkan ke dalam program. Keputusan menunjukkan tedapat sedikit peningkatan pada prestasi turbin gas iaitu kecekapan termal.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

C_p	Constant pressure specific heat, kJ/kg.k
h_{exit}	Exit specific enthalpy, kJ/kg
h_{inlet}	Inlet specific enthalpy, kJ/kg
P	Pressure, kPa
q_{in}	Heat transfer input per unit mass, kJ/kg
q_{out}	Heat transfer output per unit mass, kJ/kg
S	Specific entropy, kJ/kg.K
T	Temperature, ^{o}C or K
υ	Specific volume, m^3/kg
w_{in}	Work input per unit mass, kJ/kg
w_{net}	Net work per unit mass, kJ/kg
w_{out}	Work output per unit mass, kJ/kg
η_{th}	Thermal efficiency

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.0 Introduction

A turbine is any kind of spinning device that uses the action of a fluid to produce work. It has a compressor to draw in and compress gas (most usually air); a combustor (or burner) to add fuel to heat the compressed air; and a turbine to extract power from the hot air flow. The gas turbine is an internal combustion process [Lee, 2000].

In industry, a turbine or gas turbine is used to generate power for industrial consumption. Typical fluids are air, wind, water, steam and helium. The efficiency of gas turbine depends on the air, temperature, fluid and fuel.

The result from the literature review implemented, the problem occur is on how to improve the gas turbine performance with increasing the inlet temperature at higher pressure turbine.

1.1 Focus

The focus of this study is at the cooling system of gas turbine. The component to be emphasis is the exhaust gas turbocharger to increase gas turbine performance. Temperatures will be observed at inlet and outlet high pressure turbine to derive the performance.

1.2 Objective

The main objectives are to analyze the cooling system performance in increasing the gas turbine efficiency and to simulate the analysis in Computer Fluid Dynamic (CFD) software. The experimental data will be compared with the simulation data.

1.3 Scope

The scopes of this study are to analyze the entry temperature and the effect of aerodynamics loadings. The important areas of this investigation include the internal and external cooling schemes efficiency.

Data from inlet and outlet temperatures are collected from high pressure turbine. They are then compared with data derived from the simulation in CFD.

1.4 Methodology of Research

In order to solve the objectives the following methodologies are undertaken. Firstly, the gas turbine efficiency is to be improved.

Generally, performance of gas turbine can be defined from Brayton cycle equation. This equation is used for gas turbine only where both the compression and expansion processes take place in rotating machinery. In this project, Brayton cycle with regeneration will be used as a case study to increase the efficiency and performance. The thermal efficiency is increased because exhaust gas is now used to preheat the air entering the combustion chamber.

Secondly, the gas turbine is simulated in CFD software. Both experiments are simulated to check the validity of the data derived from the simulation.

Thirdly, the data are compared to proof the increase of the turbine performance.

1.5 Outline Thesis

Chapter 2 discusses the literature review of gas turbine, its performance and efficiency, and its various components. A review on Brayton cycle is also discussed.

Chapter 3 discusses about method used to solve the problem such as CFD software. The entry temperature and aerodynamic loading of the turbine need to be considering in order increasing the efficiency of the turbine.

Chapter 4 discusses about the analysis result from experiment and simulation implementation. Initial data from experiment, initial simulation and final simulation data, graph T-s and schematic diagram gas turbine cycle can be derived and thermal efficiency will be obtained. The analysis is also involving the changes of gas turbine system to regeneration system.

Chapter 5 discusses about overall summaries project. This project has achieved the objectives and successfully improved the performance. In the other hand, the suggestion and recommendation suitable to continue detail research and improve the study to be more accurate and perfect.

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

High pressure turbine is the important part to investigate. From the literature review, temperature inlet and outlet at this part will be affected at the performance of gas turbine and this part is related to each other.

2.1 Gas Turbine History

The turbine is called "gas turbine" because of the frequent usage of gas as its fuel. A gas turbine has a compressor to draw in and compress gas (most usually gas), a combustor to add fuel to heat the air flow. The gas turbine is an internal combustion (IC) engine employing a continuous combustion process to complete the gas turbine cycle [Lee, 2000].

The first practical gas turbine is in 1939 was developed by Brown Boveri Company at Neuchatel, Switzerland to generate electricity. The first gas turbine powered airplane flight also took place in 1939 in Germany, using the gas turbine developed by Hans P. Von Ohain. In 1941, the 1930's invention and development of the aircraft gas turbine by Frank Whittle resulted in a similar British flight in 1941 in England [Lee, 2000].

2.2 Gas Turbine Application

In aviation applications gas turbine is usually called a jet engine and various other names depending on the particular engine configuration or application, such as jet turbine engine, turbojet, turbofan, fanjet and turboprop or prop jet (if it is used to drive a propeller) [Lee, 2000].

The role of gas turbine power plants in electrical energy production has been considerably increased in the last two to three decades. Various methods have been proposed to improve the performance of gas turbine cycles. In order to achieve higher efficiency and capacity in gas turbines, higher turbine inlet temperatures (1300°C and more) are used. Basically, application of such temperatures without turbine blade cooling is impossible. Therefore, analysis of gas turbine cycles without considering blade cooling in modeling will certainly not lead to a valid and correct result [Sarabchi, 2004].

Gas turbine is one of the prime movers for industrial plant and power generation. They are very complicated devices and maintenance cost is extremely high, particularly the large one driving a gas compressor. It is important to find ways of reducing maintenance costs and increasing the ability of the gas turbine. Mohd Saidi [2003] suggested preventive maintenance techniques to be used to minimize the problems [Mohd Saidi, 2003].

The output of the turbine is used to turn the compressor. The hot air flow leaving the turbine is then accelerated into the atmosphere through an exhaust nozzle to provide thrust or propulsion power. Thrust is generated both by air passing through the fan and through the gas generator itself. A turbojet does not have a fan and generates all of its thrust from air that passes through the gas generator. In non-aviation gas turbines, part of the turbine power is used to drive the compressor. Some of the principle advantages of the gas turbine are [Lee, 2000]:

i. Capability to produce large amounts of useful power for a relatively small size and weight.

ii. Its mechanical life is long and the corresponding maintenance cost is relatively low.

iii. It can be brought up to full-load conditions in minutes as contrasted to a steam turbine plant whose start up time is measured in hours.

iv. Natural gas is commonly used in land-based gas turbines while light distillate oils power aircraft gas turbines.

v. The gas turbine requires no coolant.

A simple gas turbine consists mainly of three components. There are two rotating machines and a heat addition device. However, more complex system is possible with the addition of auxiliary devices such as heat exchanger, intercooler and reheater. In order to understand the working principle and cycle arrangements one should first have some fundamental knowledge of rotating machines [Ganesan, 1999].

2.3 Gas Turbine Theory: Brayton Cycle

Brayton cycle was proposed by George Brayton around 1870. It's used for gas turbines only where both the compression and expansion processes take place in rotating machine [Cengel, 2002].

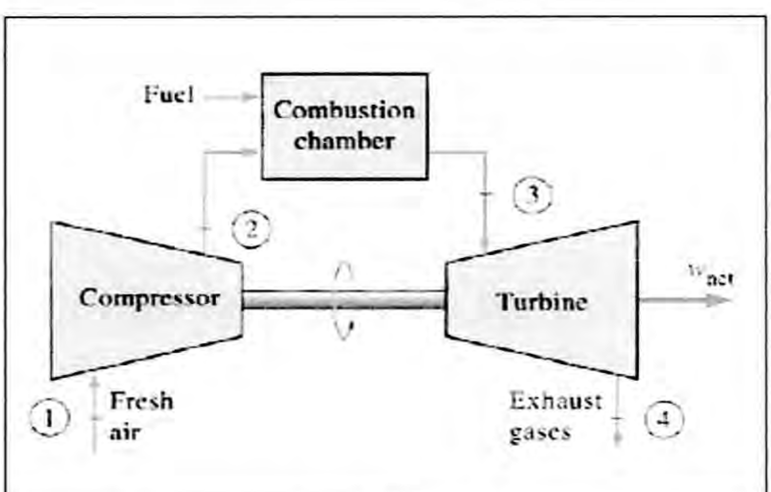

Figure 2.1 Open Cycle Gas Turbine [Source: Cengel, 2002]

In open cycle gas turbine (figure 2.1), fresh air at ambient conditions is drawn into the compressor, where its temperature and pressure are raised. The high pressure air proceeds into the combustion chamber, where the fuel is burned at constant pressure. The resulting high temperature gases then enter the turbine, where they expand to the atmospheric pressure, thus producing power. The exhaust gases leaving the turbine are thrown out [Cengel, 2002].

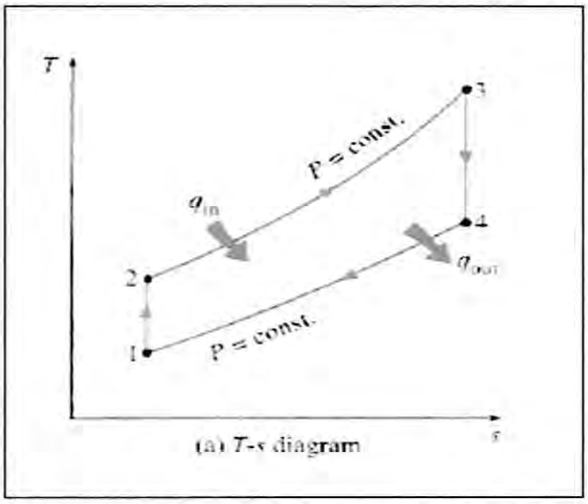

Figure 2.2 T-s Diagram for Open Cycle Gas Turbine [Source: Cengel, 2002]

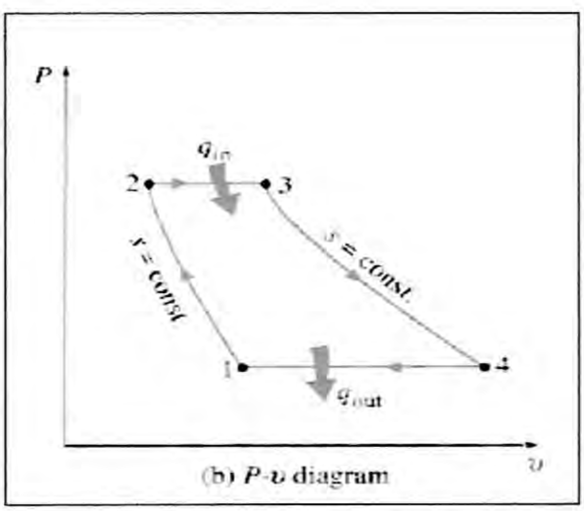

Figure 2.3 P-υ Diagram for Open Cycle Gas Turbine [Source: Cengel, 2002]

From the gas turbine cycle, the T-s and P-υ diagram are shown in figure 2.2 and 2.3. And then, the energy balance for a steady flow process can be expressed.

$$\left(q_{in} - q_{out}\right) + \left(W_{in} - W_{out}\right) = h_{exit} - h_{inlet} \tag{2-1}$$

Therefore, heat transfers to and from the working fluid are;

$$q_{in} = h_3 - h_2 = C_p\left(T_3 - T_2\right) \tag{2-2}$$

$$q_{out} = h_4 - h_1 = C_p\left(T_4 - T_1\right) \tag{2-3}$$

Then, the thermal efficiency of the ideal Brayton cycle under the cold air standard assumption becomes;

$$\eta_{th,Brayton} = \frac{W_{net}}{q_{in}} = 1 - \frac{q_{out}}{q_{in}} = 1 - \frac{C_p\left(T_4 - T_1\right)}{C_p\left(T_3 - T_2\right)} = 1 - \frac{T_1\left(\frac{T_4}{T_1 - 1}\right)}{T_2\left(\frac{T_3}{T_2 - 1}\right)} \tag{2-4}$$

2.4 Gas Turbine Theory: Brayton Cycle with Regeneration

The leaving temperature of turbine exhaust gas is often considerably higher than the temperature of the air leaving the compressor. Therefore, the air of high pressure leaving the compressor can be heated by transferring heat to it from the hot gases in a counter-flow heat exchanger [Cengel, 2002].

The increasing of Brayton cycle thermal efficiency is the result of regeneration since the portion of energy of the exhaust gases that is normally rejected to the surroundings is now used to preheat the air entering the combustion chamber. This, in turn, decreases the heat input (thus fuel) requirements for the same net work output. However, when the turbine exhaust temperature is higher than the compressor exit temperature, the use of a regenerator is recommended. Otherwise, efficiency is decreasing because heat will flow in the reverse direction (to the exhaust gases). This situation is encountered in gas turbine engines operating at very high pressure ratios [Cengel, 2002].

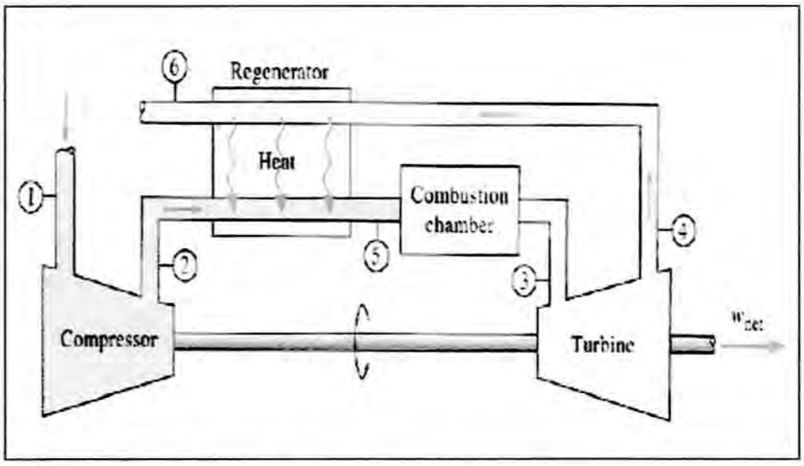

Figure 2.4 Gas Turbine Regeneration System [Source: Cengel, 2002]

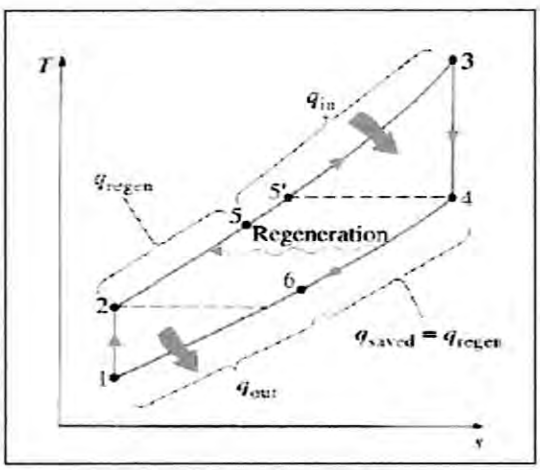

Figure 2.5 T-s Diagram for Regeneration System Gas Turbine [Source: Cengel, 2002]

In figure 2.4 and 2.5, the highest temperature occurring within the regenerator is T_4, the temperature of the exhaust gas leaving the turbine and entering the regenerator. Air normally leaves the regenerator at a lower temperature T_5. In the limiting case, the air will exit the regenerator at the inlet temperature of the exhaust gases T_4.

2.5 Gas Turbine Components

There are five important components of gas turbine. The components are:

i. Inlet
ii. Compressor
iii. Combustor
iv. Turbine
v. Exhaust nozzle

2.5.1 Inlet

The velocity of entering air is reduced by an inlet to make sure the suitable level for the compressor. It is reduced by compression process which increases the air pressure. Inlet operation and design are described in terms of efficiency of the compression process, the external drag of the inlet, and mass flow into the inlet depend on the air entering the duct whether it is subsonic or supersonic [Saravanamutto, 2001].

2.5.2 Compressor

The function of the compressor is to increase the pressure of the incoming air. This is for combustion process and the power extraction process after combustion can be carried out more efficiently. The volume of the air is reduced by increasing the pressure of the air, means that the combustion of the fuel or air mixture will occur in smaller volume [Walsh, 2004].

2.5.3 Combustor (Main Burner)

A combustor is used to burn mixture of fuel or air and to deliver the resulting gases to the turbine at a uniform temperature. The gas temperature must not exceed the allowable structural temperature of the turbine. Less than one-half of the total volume of the air entering the burner mixes with the fuel and burns. The rest of the