# ANALYSIS OF THE PERFORMANCE OF A COMBUSTION CHAMBER GAS TURBINE

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"I hereby the author, declare this report entitled "**ANALYSIS OF THE PERFORMANCE OF A COMBUSTION CHAMBER GAS TURBINE**" is my own except for quotations and summaries which have been duly acknowledged"

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

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# ABSTRACT

In this study, Turbine Gas, ET794 is used as the model to analyze the performance in the combustion chamber. The combustion process is of critical importance in a gas turbine cycle. It is because in this process the chemical energy of the fuel is converted to heat energy, which is later converted into work by the turbine. Therefore losses incurred in the combustion process will have a direct effect to the thermal efficiency of the cycle.There are three zones of combustion process: a) primary zone to provide the necessary high temperature or rapid combustion, b) secondary zone to complete the combustion. For high combustion efficiency, this air must be injected carefully at the right points in the process, c) tertiary or dilution zone the remaining air is mixed with the products of combustion to cool then down to the temperature required at inlet to the turbine. The combustion of Liquid Petroleum Gas LPG with air is occurred in the combustor. Industrial combustion that produces steam or electric power represents a crucial facility for overall plant operations. To make the combustion more efficient, less emission (cleaner) and less prone to tube rupture problems, it is important to understand the combustion and thermal flow behaviors inside the combustion chamber. This study performs a detailed simulation of combustion and thermal flow behaviors. The simulations are conducted using the commercial CFD package FLUENT. The 3-D design using species transport equations are solved for the combustion model.

# ABSTRAK

Dalam kajian ini, gas turbine ET794 di jadikan sebagai model untuk mencari pengurangan emisi didalam bekas pembakaran. Proses pembakaran merupakan bahagian penting dalam proses gas turnine. Ini adalah kerana, berlaku penukaran proses tenaga kimia kepada tenaga haba dalam bahan bakar. Tenaga haba kemudiannyya bertukar kepada tenaga yang mengerakkan turbin. Oleh yang demikian, pengurangan dalam proses pembakaran akan memberi kesan kecekapan haba dalam proses. Didalam bekas pembakaran terdapat tiga bahagian iaitu bahagian utama, bahagian kedua dan bahagian ketiga. Bahagian utama berfungsi untuk membekalkan suhu yang tinggi atau pembakaran yang cepat. Bahagian kedua untuk pembakaran lengkap. Untuk kecekapan pembakaran yang tinggi, udara mesti dimasukkan dengan berhati-hati ke tempat yang betul. Untuk bahagian pembakaran yang terakhir, baki udara dicampur dengan hasil pembakaran untuk menyejukkan suhu seperti mana yang diperlukan untuk dihantar ke turbin. Untuk mengetahui pengurangan emisi di dalam bekas pembakaran, terdapat 2 kaedah iaitu melalui experiment dan melalui simulation. Untuk psm ini, kaedah simulation di gunakan, Gas Turbine ET794 dijadikan model dimension untuk melukis lukisan gambit. Simulation yang di gunakan ialah CFD iaitu FLUENT untuk mencari sinarannya. Dan gas LPG digunakan sebagai bahan bakar utama. Ini kerana gas LPG ringan dan merupakan bahan bakar yang baik.

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# CHAPTER I

# INTRODUCTION

## 1.1 General Introduction

From the early days of engine technology, investors, researchers and scientists regarded the gas or combustion turbine as an ideal from of heat engine, because of its mechanically simple operation principle James Watt (1765). The development of the steam turbine is followed by De Laval / Sweden in 1883 and Charles Parsons / England in 1884, and the final goal was recognized as the combination of direct heating of the driving medium, that means direct use of the combustion gases with a nearly vibration free rotating turbo-engine.

First stationary gas turbine was successfully put in operation 1940. Today gas turbines operate with outputs of more than 150 Megawatts. The possibility of combining gas turbine with a steam cycle is becoming a recognized way of improving the economy of energy generation. Efficiencies of more 50% can be obtained, Korting AG, Bosch.

Todays gas turbine where the generator units used for power generation are operated gas turbine units without heat recovery to supply base or peak-loads, or they are incorporated in a combined gas and steam plant, where the energy contained in the exhaust gases is partly reused to generated steam. The steam is used to drive a steam turbine and as a heat source for district heating and / or process steam. Thus the efficiency of the entire plant is considerably increased.

## 1.2 Operating Practices and Conditions

In combustion experiments, especially for high-pressure test, measurements are usually difficult to conduct. Visualization is in most cases limited to two-dimensional image and sensors can obtain data at several points. Recent progress in numerical simulation techniques has proven that Computer Fluid Dynamic (CFD) methods like FLUENT can contribute to combustion research in various ways. To understand dynamics in combustor system, it has been shown that the numerical approach based on FLUENT techniques is effective, although several models are required in the formulation (J.Shinjo *et.al* , 2001)

Here, the numerical studies of practical-scale gas turbine combustor systems are done to investigate dynamics and mechanisms of unstable combustion in combustor systems. The numerical methods are based on FLUENT techniques and the flame let model. The target combustion is a swirl-stabilized combustor and flame holder type model combustor installed at ET794 Functional Gas Turbine Model. Details of these combustors are described in the next section (PSM II)

## 1.3 Gas Turbine General Principle

In principle gas turbines are simple combustion engines. Air is drawn in compressed, heated by combustion and expanded through a turbine. Air is compressed passing rows rotating and stationary vanes. At the end of the compressor, before reaching the combustion chamber, the air has been heated by compression.

The combustion chamber is the heart of the engine; here the combustible mixture of compressed air and fuel is burnt. The continuous hot-gas stream reaches more; its volume is more than doubled by the combustion. It expends in a four stage turbine transferring its energy to the turbine shaft.

The power generated in the turbine is used to drive the compressor and the coupled generator. The electric power output is made available at the generator terminals. The remaining heat in the turbine low-pressure exhaust gas can be recovered in subsequent processes, e.g. for power generation and cogeneration of heating or process steam.

The generator is designed to act also as a motor in order to be able to start up the gas turbine because the turbine can only deliver power to drive its compressor when a certain shaft speed has been attained. If a gas turbine power plant is required to run in isolation (island operation), a diesel-engine generator is provided to produce the power to start up the gas turbine independently of any external electrical power system. (Siemens 2001)

## 1.4 Combustion Description

The investigated combustion chamber is coupled with a diffusion flame type gas turbine located at the ET794 Functional Gas Turbine Model. The combustor works at a pressure level of about 1 MPa, permits the dual fuel operation (liquid and gaseous) and fits on a small size gas turbine, which has a performance of 1kW net electrical power. The diffusion flame combustion process is based on chemical reactions, which occur due to fuel injection and mixing in figure 1.1. Crossover tubes are built in, to allow flame propagation between the liners. Figure 1.2 shown Main components of conventional combustor.

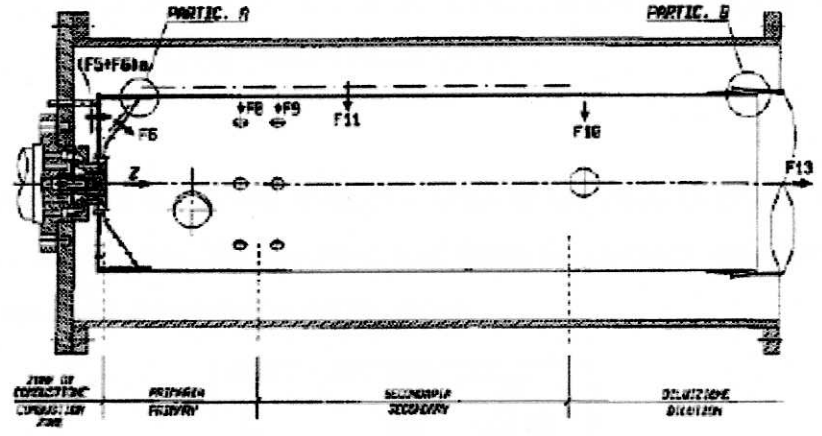

Figure 1.1: Reverse-flow combustion system

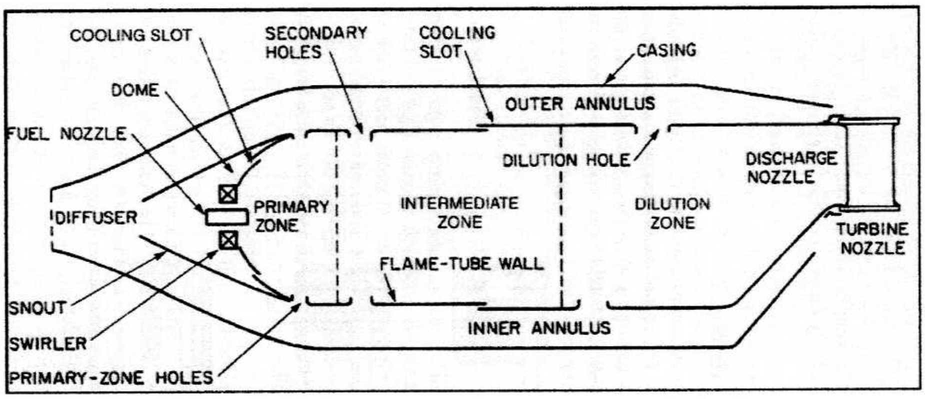

Figure 1.2: Main components of conventional combustor

A scheme of the axial swirler device used with the 8 holes fuel injector (F3) is reported in Figure 2. This injector was used for natural gas and propane rich mixture tests without any modifications (at here we use Liquefied Petroleum Gas LPG as fuel, and for this experiment assume propane (75%) as main gas).

The flame is stabilized by a combination of swirler air (F4) and the formation of recirculation zones. While operating with the present configuration two regions of recirculation are formed: a central recirculation created by the primary (F8) and secondary (F9) zone holes and an outer recirculation attached to the dome wall, created by the air flow trough the dome cooling louvers (F6).

The dilution air is entering through 4 holes of the chamber (F10). The air inlet (F11) consists of more than 300 louvers to cool down the chamber wall shown in figure 1.3. The exhaust gases flow into the (F13) section.

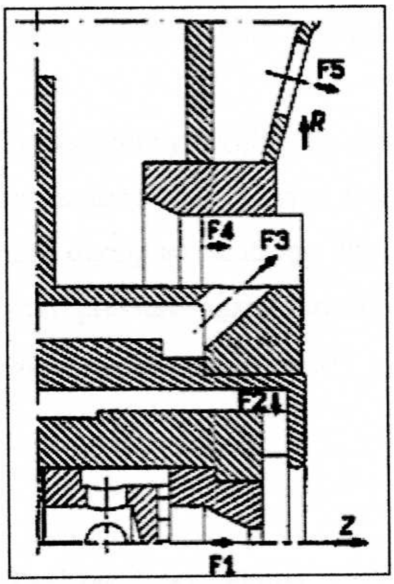

Figure 1.3: Axial swirler device

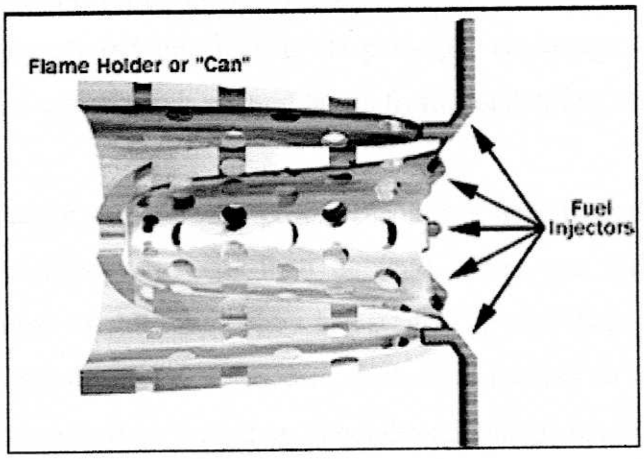

Figure 1.4: Louvers to cool down the chamber wall

## 1.5 Performance

The ideal gas turbine process normally applied, named "Joule-Brayton-Process" is defined by two isentropic and two isobaric changes of state. It begins at ambient conditions and an isentropic compression on the fluid (air). That means that the change of state of the fluid is made at constant entropy, i.e. free of any friction and free of any heat transfer across the boundaries of the machine. At the end of this ideal compression both, pressure and temperature are increased but entropy remained the same.

Now heat is added to the fluid by burning the fuel in the compressed fluid. Thus, entropy and temperature are increased but pressure remains unchanged. Here after the hot fluid (flue gas) is expanded during an isentropic change of pressure and temperature. The fluid is now at ambient pressure again but at elevated entropy and elevated temperature (Zorner. W.,1995).

## 1.6 Advantage of Gas Turbine Power Plants

A gas turbine power plant can deliver electric power to the grid within only a few minutes after being started up. This is its principal advantage compared to a steam turbine power plant which needs several hours from standstill to full load.

For this reason, gas turbine power plants are able to fulfill the special power generation task of supplying peak-load demand. Their gas turbines and generators remain idle for most of the time. They are started up and connected to the grid only when a peak demand for electricity occurs, such as at midday in winter. Such peaks are mostly of short duration. It is, therefore, generally advantageous to keep a number of gas turbine power plant for standby duty because they require lower capital investment and occupy less space than other types of thermal power plant.

## 1.7 Objectives and scope of this study

The objective of this research is to study the performance of a combustion chamber using Computational Fluid Dynamic (CFD) software. This is done by:

i) Understanding the work concept of gas turbine combustion chamber.
ii) Familiarizing and applying the usage of Gambit Software for simulation purpose
iii) Familiarizing with Fluent software for simulation process.
iv) Simulate the model of gas turbine combustion chamber to do
    a) Analysis in combustion condition
    b) Gas concentration analysis

This report composed of 7 chapters. Chapter I is the introduction of the history gas turbine, thermodynamic principles for gas turbines at power plant, and advantage of gas turbine power plant.

Chapter II includes the literature reviews on previous researchers on combustion chamber gas turbine as reaction and $NO_X$ formation in gas turbine combustor use of computational fluid dynamics (CFD) and include the gas turbine theory.

Chapter III describes the description of the two-shaft gas turbine (ET794) in Kolej Universiti Teknikal Kebangsaan Malaysia including the process occurs flow in combustion chamber.

Chapter IV will show the modeling two-shaft gas turbine (ET794) of the combustion chamber for simulate model.

Chapter V is the discussion of the simulation results including the analysis of cold flow, combustion flow and gas concentration analysis in the combustor.

Chapter VII is the summarization of the whole research with recommendation to the existing combustor.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Introduction

The combustion process is of critical importance in a gas turbine cycle. It is because in this process the chemical energy of the fuel is converted to heat energy, which is later converted into work by the turbine. Therefore losses incurred in the combustion process will have a direct effect to the thermal efficiency of the cycle.

In the gas turbine combustion system initially a mixing of fuel and air under conditions in which the resulting flame is self-sustaining should be accomplished first. Further, the chemical reaction should be complete. Thus, the combustion design involves the formation of turbulent zones, with the complication of both aerodynamics and thermo chemical effects (V.Ganesam, 2001).

## 2.2 Combustion in the Gas Turbine

In evaluating the combustor performance and efficiency, many parameters had been taken into account referring to some previous literatures from various researchers. Due to the air pollutant problem and emitted product gases released, this issue had been rise since many years ago. Many modern techniques have been applied in reducing the emission from combustion chamber. A secondary reduction technique which is less costly have been used by many researchers until now as one of the ways in reducing emission while giving the priority in combustor performance and efficiency . Many previous researchers came out with different way by analyzing the changes of some combustion parameters to the combustor performance.

Kulshreshtha and Digvijay (2005) had carry out the combustion chamber of gas turbine unit is one of the most critical components to be designed and reveals that much work is available pertaining to design and performance of combustion chamber. This is particularly true for small capacity units. Hence there is a need for experimental optimization of combustion chamber in small capacity range. The present work aims at the experimental optimization of liner wall configuration. Four different types of combustion chambers with primary zone equivalence ratios of 0.5, 0.7, 0.9 and 1.1 are designed, developed and experimented based on which an optimal configuration is recommended. It is worth to mention that the present work clearly focuses the combustion chamber with equivalence ratio in primary zone as 0.9 as the optimal combustion chamber.

Raja Saripalli and Ting Wang (2005) had cary out Industrial boilers that produce steam or electric power represent a crucial facility for verall plant operations. To make the boiler more efficient, less emission (cleaner) and less prone to tube rupture problems, it is important to understand the combustion and thermal flow behaviors inside the boiler. This study performs a detailed simulation of combustion and thermal flow behaviors inside an industrial boiler. The simulations are conducted using the commercial CFD package FLUENT. The 3-D Navier-Stokes equations and five species transport equations are solved with the eddy-breakup combustion model. The simulations are conducted in three stages. In the first stage, the entire boiler is simulated without considering the steam tubes. In the second stage, a complete intensive calculation is conducted to compute the flow and heat transfer across about 496 tubes. In the third stage, the results of the saturator/superheater sections are used to calculate the thermal flow in the chimney. The results provide insight into the detailed thermal-flow and combustion in the boiler and showing possible reasons for superheater tube rupture. The exhaust gas temperature is consistent with the actual results from the infrared thermograph inspection.

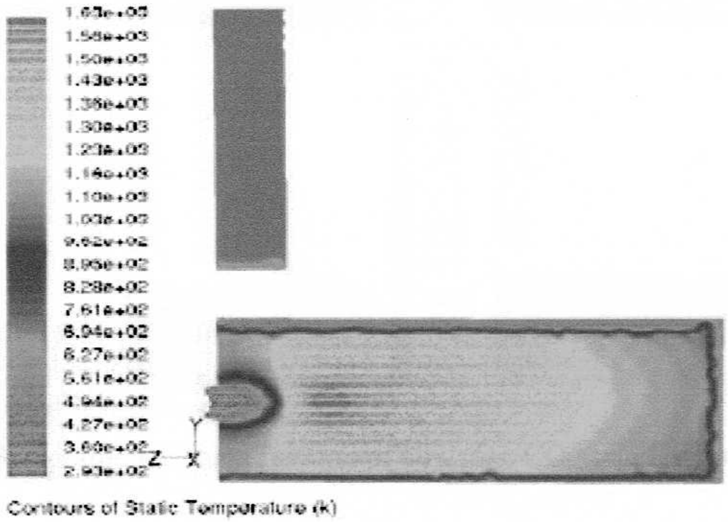

Figure 2.1: Contours of static temperature on the vertical plane at x=0

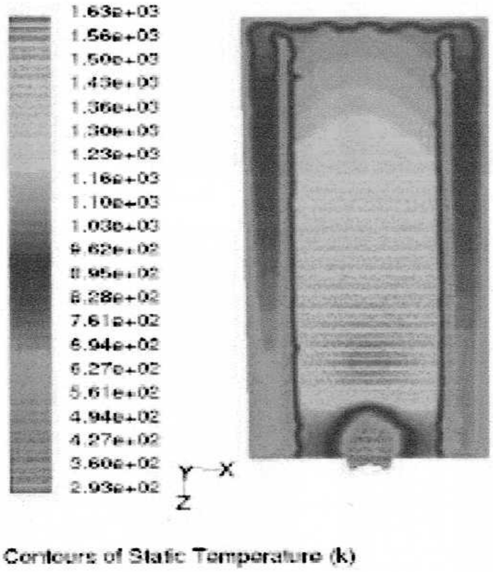

Figure 2.2: Contours of static temperature on the horizontal plane at y=0