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The Effect of air inlet into Gas Turbine combustion chamber on flame stability and temperature distribution

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ABSTRACT

The combustion chamber is one of the very important parts of gas turbine power plants, the combustion chamber due to generate heating power demand to produce dynamic power. The main problems of combustion chamber are cracks and damages, caused by none stability of flame and none-homogenous temperatures distribution.

This study is focused on investigating experimentally the effect of secondary air swirl inlet into gas turbine combustion chamber on flame stability, and temperatures distributions. The combustor performed consists of two casing one inside the other, the outer casing proceeding in the flow direction of the secondary air. The inside casing is called flame tube, which provided with fifty-six (56) holes tangentially with an angle (45°). Two combustion chamber are made the first one has the holes with (5 mm in diameters) and the second one the holes with (10 mm in diameters) to introduce the secondary air. The combustion chamber provided with six small holes on one line at the top of the combustion chamber for entering the thermocouples to measure the temperature distribution .

The experimental results show a significant effect of secondary air swirl and swirl strength on flame stability, and temperatures distributions. On the other hand the low temperatures are recorded at the wall along the combustor, and a significant temperatures distributions at exit of the combustion chamber.

Also the secondary air swirl and swirl strength cause a reduction in the flame diameter and flame length, and the flame is turning around away from the flame tube wall and stable.

الخلاصـــــــــــــــــــة

تعتبر غرفة الاحتراق من أهم أجزاء التربينة الغازية وهى تستخدم لإنتاج الطاقة الحرارية المستخدمة في إنتاج القدرة الميكانيكية ، و من أهم المشاكل الموجودة في غرفة الاحتراق الشقوق والانهيارات وذلك بسبب عدم استقرارية اللهب والتوزيع الحراري الغير متجانس .

هذه الدراسة المعملية تهدف إلى التحقق من تأثير الهواء الثانوي الداخل إلى غرف الاحتراق بالتربينات الغازية على إستقرارية اللهب وتوزيع درجات الحرارة . حيث آن الغرفة تتكون من غلافان واحد بداخل الثاني ، الغلاف الخارجي يحوي الهواء الثانوي والداخلي يدعى غلاف اللهب وبهي 56 فتحة يدخل منها الهواء الثانوي التدويمي وهذه الفتحات مماسية بزاوية (45^o) حول اللهب على طول غرفة الاحتراق ، تم صنع اثنان من غرف الاحتراق الأولى ذات فتحات بقطر 5 مم والثانية بقطر 10 مم للدخول الدوامي للهواء الثانوي ، وتوجد 6 فتحات ما بين الغلافين وذلك لدخول مقياس الحرارة داخل غلاف اللهب .

النتائج المعملية التي تم الحصول عليها أوضحت إن تدويم الهواء الثانوي له تأثير كبير على استقرارية اللهب والتوزيع الجيد لدرجات الحرارة داخل الغرفة شدة التدويم تزيد من الاستقرارية للهب وتوزيع درجات الحرارة ومن ناحية أخرى انخفاض درجات الحرارة على السطح الداخلي وعند مخرج الغرفة يكون التوزيع الحراري بمعدل جيد ، وأيضا فإن الهواء الثاوي وشدة التدويم تسبب في نقصان قطر اللهب وطوله ويكون اللهب أكثر إستقرارية.

DEDICATION

To My parents, my wife my children, And all my colleagues and friends.

ACKNOWLEDGMENT

Firstly I have to thank Allah for helping me to complete this work. Also, I want to thank the **ENGINEERING ACADEMY, TAJOURA** for all aids and facilities supplied to achieve this work.. I would like also to thank **Dr. Mohammad Salah Zawia** who has made substantial suggestions for improvement.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF PHOTOS

LIST OF TABLES

Nomenclature

AFR	Air fuel ratio.
C_d	The orifice discharge coefficient.
D_{sw}	Swirl diameter (mm).
G_m	Angular momentum.
G_t	Axial trust.
L	Lent of flame tube(mm).
P	Static pressure(N/m^2).
R	Radius of flame tube (mm).
r	Distance from surface of flame tube to center (mm).
R_h	Hub radius(mm).
R_{sw}	Swirl radius(mm).
S_N	Swirl number.
T	Temperature(C^o).
U	Axial component of velocity (m/s).
V	Tangential component of velocity(mm).
w	Air mass flow rate (kg/s).
x	Distance from injector(mm).
ρ_a	Air density at orifice(kg/m^3).
Δ_p	Pressure drop across an orifice (N/m^2).
$\emptyset$	Swirl vane angle(^{o})

1. INTRODUCTION

1.1 General introduction :

The gas turbine is in many respects the simplest type of power apparatus available. It is completely self-contained requiring no boiler or external heat source as burns fuel and converts heat released into mechanical power within a single assembly. Therefore, the studies and investigations of gas turbine combustion characteristics are of a prime importance. It is very important to investigate ways of improving the combustion efficiency, flame stability and temperature distribution.

In a gas turbine unit there are a compressor, combustor (combustion chamber), and turbine. The combustion chamber is the most important part in gas turbine power plant; where the combustion process is performed.

The combustion chamber consists of at least three basic parts: a casing, flame tube, and fuel injection system. The casing must withstand the cycle pressures and may be a part of the structure of the gas turbine. It encloses a relatively thin-walled flame tube within which combustion takes place, and a fuel injection system. The flame stability, temperature distribution, and flow pattern play an important role in the performance of gas turbine combustor. Therefore, the studies and investigations of the combustion characteristics, (flame stability, temperature distribution,) and flow pattern in gas turbine combustor is of a prime importance.

The gas turbine combustor is divided into three zones, (i) Primary zone,(the purpose of the primary zone is to anchor the flame, provide sufficient time, and turbulence to achieve essentially complete combustion of the fuel), (ii) Secondary zone, (the secondary zone is the region that lies between the primary and dilution zones, it serves principally as an extension to the primary zone, provide increase residence time for complete combustion). (iii) Dilution zone, (provide an outlet stream with a mean temperature and a temperature distribution that are acceptable to the turbine).

Swirling is the most important parameter that controls both the flow pattern and combustion process in gas turbine combustors. Therefore, the effect of air inlet into combustor on flame stability, temperature distribution and combustion in gas turbine combustors to be investigated.

1.2 History of gas turbine combustion chambers :

The Sawyer combustion chamber shown in Fig. (1.1A) is the first gas turbine combustion chamber was built in 1939 [1]. It has the main characteristics seen in all later combustion chambers. Air swirl is used for rotating the primary air and stability of the flame. The gas turbine engine test with this combustion chamber is made by the famous Stodola in Jun 1939 [2].

Combustion found by Whittle [3] to be one of the major problems to be overcome in developing an experimental turbojet engine. Although Whittle's very first bench engines used a single combustor, ten separate combustors where soon adopted to facilitate combustion testing. Whittie's early combustors involved attempts at combustion with low dispersion fuel sprays, and with fuel vaporizers, as shown in Figs. (1.1B & 1.1C). The combustion chamber for the German Junker's Jumo 004 engine shown in Fig. (1.1D), the only German turbojet engine to reach mass production and extensive service use in World War II , and the BMW 003 used annular combustors as shown in Fig.(1.1E) [4]. The Soderderg combustion chamber shown in Fig.1.1F used two vortices in an elbow tube for flame stabilization [5]. The combustion chamber constructed by the famous Russian scientist. Zotiokov [6] shown in Fig.(1.1G) and has flows going in opposite direction.

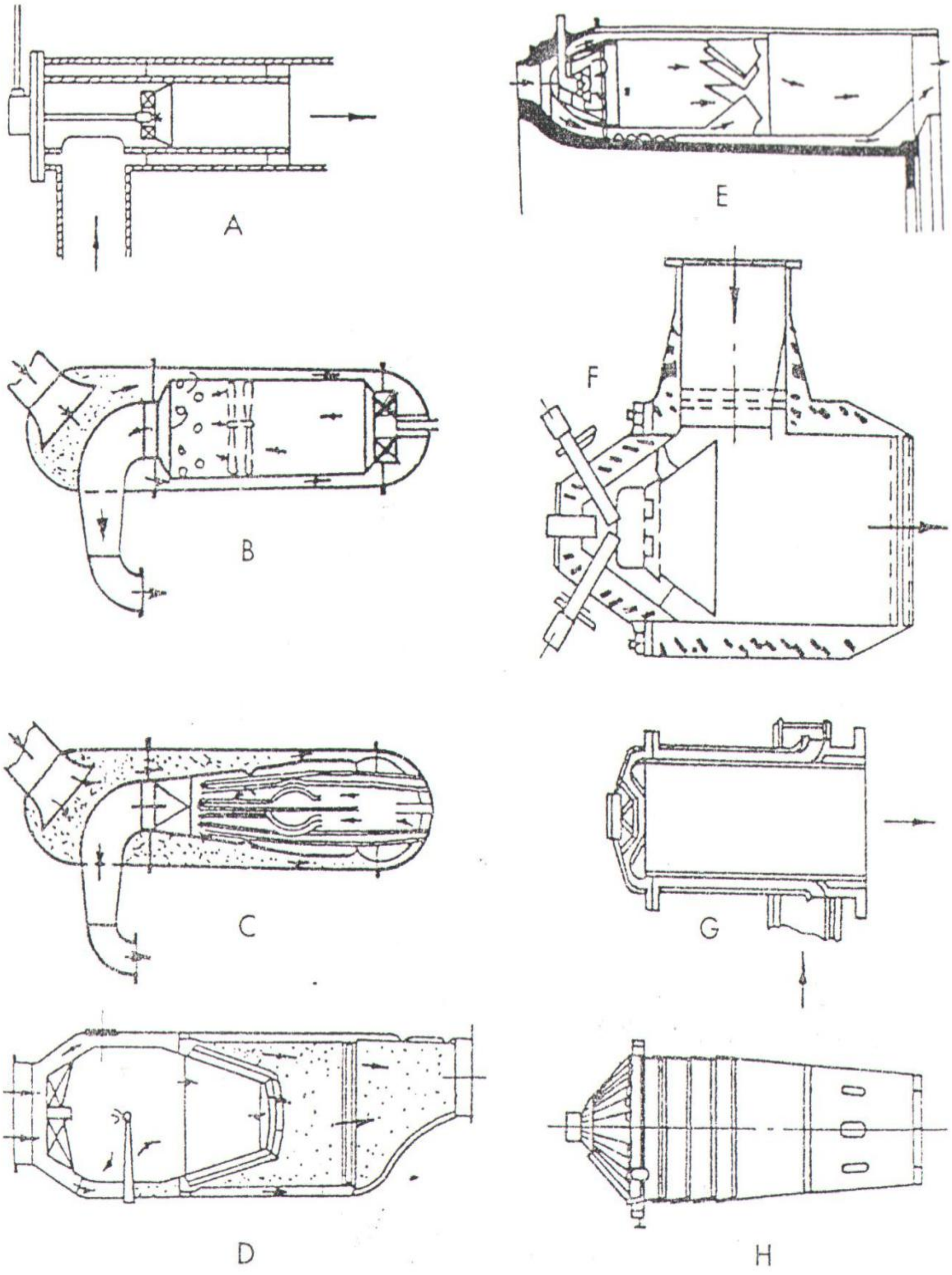


Fig (1.1) The main steps in the development of gas turbine combustor [20].

1.3 Type of Gas Turbine Power Plant:-

The gas turbine power plants can be classified mainly into two categories. These are :

1.3.1 *Open Cycle Gas Turbine Power Plant :-* The basic simple gas turbine engine is shown in (Figure 1.2)consists of a compressor, combustion chamber, and turbine. In the open cycle the atmospheric air is continuously compressed in the compressor and delivered to the combustion chamber at a high pressure where the fuel is burned with this compressed air. The hot gases from the combustion chamber pass out to the atmosphere after expanding through the turbine which converting the heat energy to useful work.

1.3.2 *Closed Cycle Gas Turbine Power Plant :-* In the closed gas turbine cycle is shown in (Figure 1.3), the working fluid (air or any other gas) circulates through its various component. Heat in this case, is supplied replaces the combustion chamber of the open cycle plant.

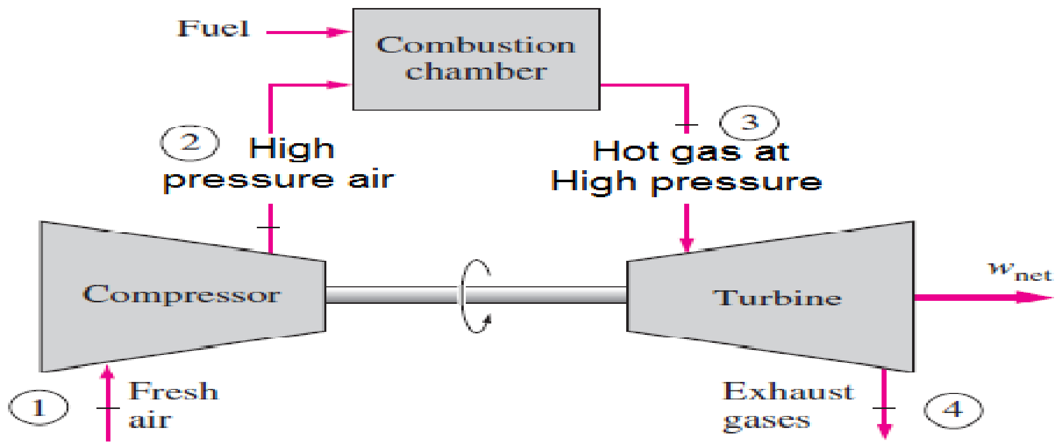


Fig 1.2 Open Cycle Gas Turbine Power

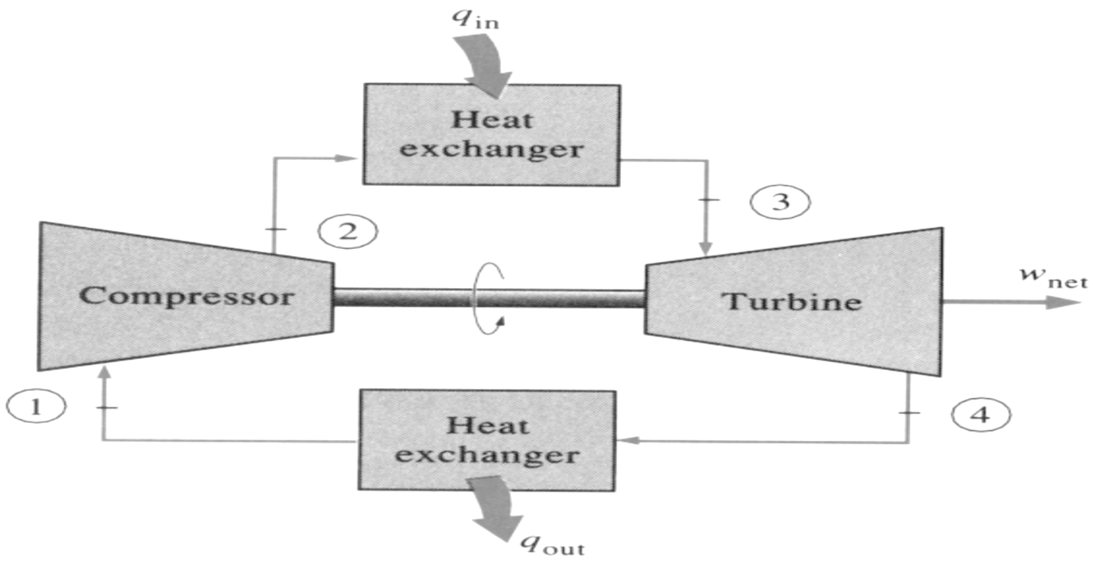


Fig 1.3 Close Cycle Gas Turbine Power Plant

1.4 Combustion systems requirements :-

A successful combustor design must satisfy many requirements and has been a challenge from the earliest gas turbines of Whittle and Von Ohain. The relative importance of each requirement varies with the application of the gas turbine, and

of course, some requirements are conflicting, requiring design compromises to be made. Most design requirements reflect concerns over engine costs, efficiency, and the environment. The basic design requirements can be classified as follows:

1- High combustion efficiency at all operating conditions.

2- Low levels of unburned hydrocarbons and carbon monoxide, low oxides of nitrogen at high power and no visible smoke. (Minimized pollutants and emissions.)

3- Low pressure drop. Three to four percent is common.

4- Combustion must be stable under all operating conditions.

5- Consistently reliable ignition must be attained at very low temperatures, and at high altitudes (for aircraft).

6- Smooth combustion, with no pulsations or rough burning.

7- A low temperature variation for good turbine life requirements.

8- Useful life (thousands of hours), particularly for industrial use.

9- Multi-fuel use. Characteristically natural gas and diesel fuel are used for industrial applications and kerosene for aircraft.

10- Length and diameter compatible with engine envelope (outside dimensions).

11- Designed for minimum cost, repair and maintenance.

12- Minimum weight (for aircraft applications).

(Therefore, the studies and investigations of gas turbine combustion characteristics are of a prime importance. It is very important to investigate ways of improving the combustion efficiency, flame stability and temperature distribution.)

1.5 Combustion parameters in Gas Turbine Combustors :-

A number of parameters play vital role in the combustion process such as type of gas turbine combustors, Main sections of gas turbine combustors, fuel for gas turbines, method of introducing the fuel into the combustors, method of mixing the fuel with air, and air to fuel ratio. These parameters are discussed below.

1.5.1 Types of gas turbine combustion chambers. [7]

There are 3 types of combustion chambers are in today :-

(a) tubular combustion chambers:

In this case some tubular flame tubes are arranged aound engine center line. Every flame tube is contained in an outer case. The several flame tubes are interconnected so as to operate in the same conditions of pressure, as seen in (Figure 1.4).

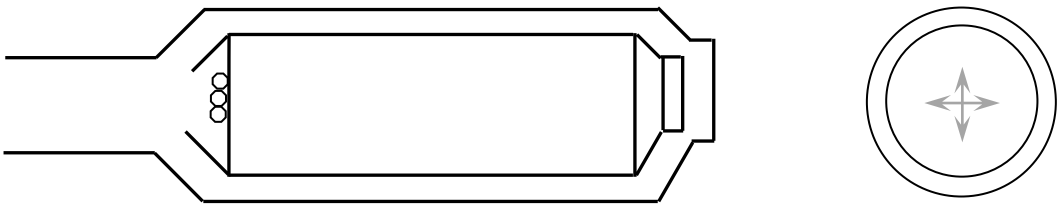


Figure 1.4 Tubular combustor. [7]

(b) tube-annular combustion chamber:

It consists of several flame tubes that are fitted in a single casing. The air flow is similar to the tubular chambers This configuration joins the advantage of maintenance easiness of the tubular chambers with the compactness of annular chambers, as seen in (Figure 1.5).

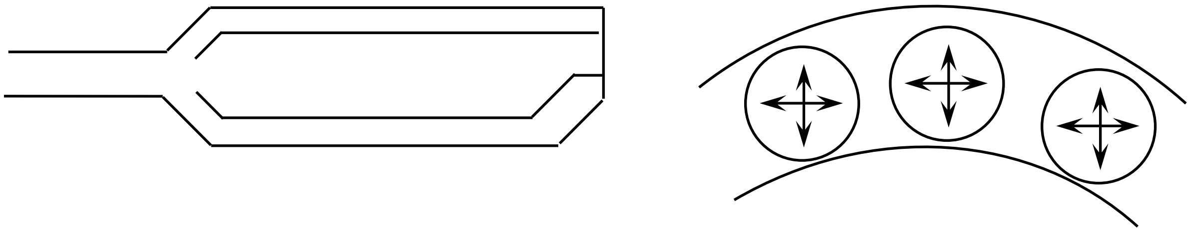


Figure 1.5 Tubo annular combustor. [7]

(c) annular combustion chambers:

This type of combustor consists of a single flame tube with annulus form that is contained in a inner and an outer casings. The main advantage of this combustion chamber is that on same performances it is shorter than a tubular chamber or tube-annular with a remarkable saving of weight and cost of the losses of Production. The pressure leaks in this combustion chamber are lower with respect regarding the previous one with remarkable benefits on the engine thermodynamic cycle, as seen in (Figure 1.6).

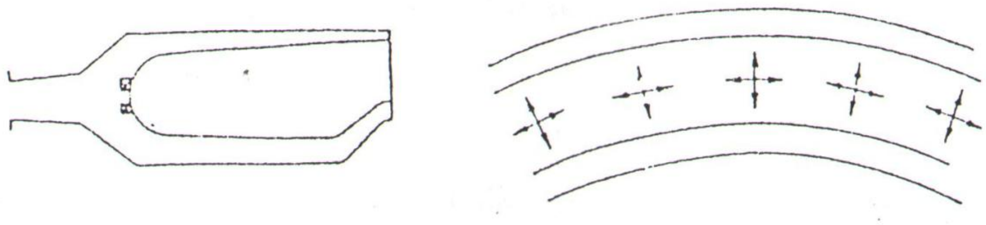


Fig 1.6. The annular combustion chamber. [7]

1.5.2 Main sections of gas turbine combustors :

The gas turbine combustor is divided into four sections as illustrated in Figure (1.7).

Diffuser :- The function of the diffuser is to reduce the velocity of the combustor air inlet to a value at which the combustor pressure loss is acceptable but also to recover as much of the dynamic pressure as possible, as well as present the liner with a smooth and stable flow.

Primary zone :- The purpose of the primary zone is to anchor the flame, provide sufficient time, temperature, and turbulence to achieve essentially complete combustion of the fuel. An essential feature is the toroidal flow reversal that is created and maintained by air entering trough swirl vanes located around the fuel injector and through a single row of holes in the wall of the liner. This flow reversal ensures that some of the hot gases produced during combustion are recirculated back into the primary zone to mix with the incoming air and fuel.

Secondary or intermediate zone:- The secondary zone is the region that lies between the primary and dilution zones. At low combustion pressures the rate of chemical reaction is slow, and the combustion is far from complete at exit from the primary zone, under these conditions the intermediate zone serves principally as an extension to the primary zone, provide increase residence time for combustion to proceed to completion. At high temperature prevailing in the primary zone, dissociation of carbon dioxide to carbon monoxide and oxygen occurs and to a lesser extent, dissociation of water vapor to hydrogen and oxygen. Lowering the flame temperature, by injecting prudent amounts of air into the secondary zone, inhibits dissociation and allows the combustion of carbon monoxide and hydrogen to proceed to completion upstream of the dilution zone.

Third zone:- The role of the dilution zone is provide an outlet stream with a mean temperature and a temperature distribution that are acceptable to the turbine. The dilution air is introduced through one or more rows of holes in the air liner walls.

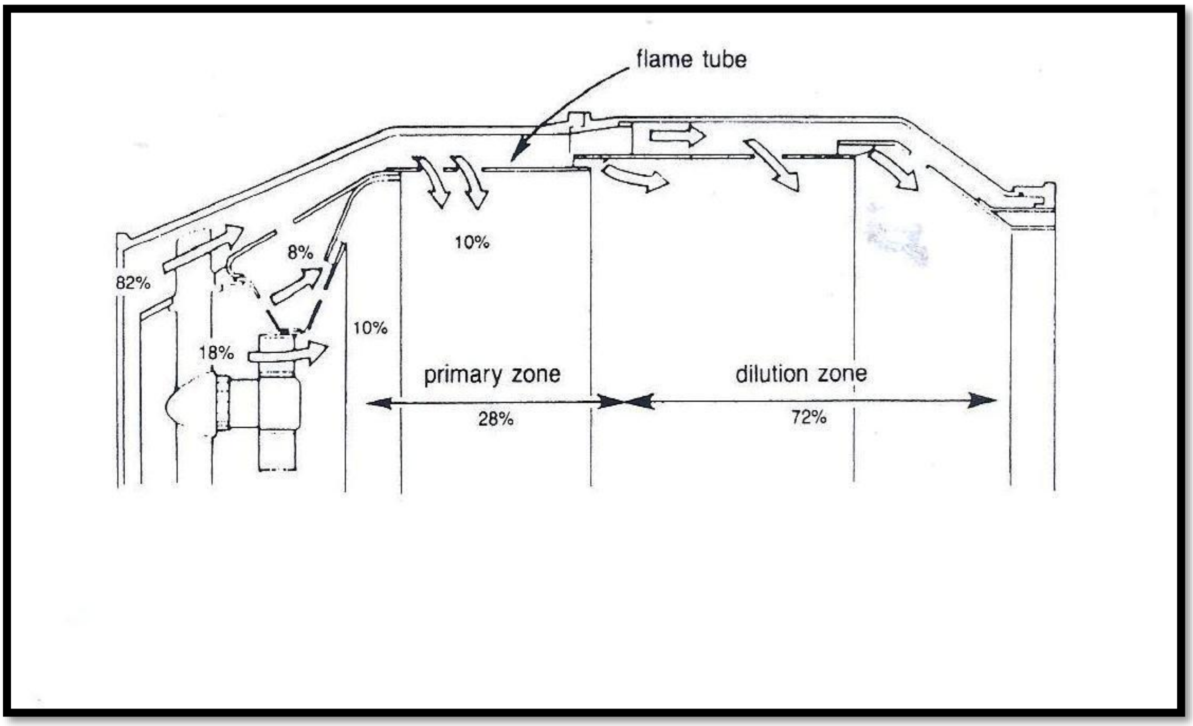


Fig1. 7. Air distribution in a typical combustor . [7]

1.5.3 fuel for gas turbines:

Natural gas is the ideal fuel for gas turbines, but this is not available everywhere. Blast furnace and producer gas may also be used for these plants. However, liquid fuels of petroleum origin, such as, distillate oils or residual oils are most commonly used for gas turbine power plants. The essential qualities of these fuels include proper volatility, viscosity and calorific value. At the same time, the fuel should be free from any content of moisture and suspended impurities that may clog the small passages of the nozzles and damage valves and plungers of the fuel pump.

However, liquid fuels of petroleum origin, such distillate oils or residual oils are most commonly used for gas turbine plants.

Residual oils burns with less ease than distillate oils and the heaters are often used to start the unit from cold, after which the residual oils are red into the combustor.

Pre-heating of residual oils may be necessary in cold climates.

Use of solid fuel, such as coal in pulverized form in gas turbines presents several difficulties, most of which have been only partially overcome. Some practical applications of solid fuel burning in turbine combustors have been made commercially available in recent years. In one of such design finely crushed coal is used instead of pulverized while the gas is released centrally at the opposite end. In another design, a regenerator is used to transfer the heat to air, the combustion chamber being located on the outlet of the turbine, and the combustion is carried out in the turbine exhaust stream. The advantage is that the turbine handles only clean air. [20]

1.5.4 Method of introducing liquid fuel to gas turbine combustors

Fuel is introduced to the combustor by one of two distinct methods. The most common is the injection of a fine atomized spray into the recalculating airstream through spray nozzles. The second method is based on the pre-vaporizing method. The fuel is sprayed from feed tubes into vaporizing tubes which are positioned inside the flame tube. The fuel vaporizes before passing into the flame tube. The primary airflow passes down the vaporizing tubes with the fuel and also through holes in the flame tube entry section which provide fans of air to sweep the flame rearwards. The fuel atomization process plays a major role in many aspects of combustion performance. The atomization characteristics of importance to combustion performance include mean drop size distribution, attenuation, cone angle, and penetration.

1.6 Combustion stability :

An important property of a combustion chamber is combustion stability. To have combustion stability, the flame must remain stable at varying fuel mixtures, inlet temperatures turbulence levels, flow speeds and so on. If it does not, things can go wrong. To simplify the idea combustion stability, we usually only consider the mixture. the combustion stability depends on the range of the air fuel ratio at which the flame remins stable. If the flame extinction due to too much fuel, we have rich extinction (upper limit of combustion ULC) . similarly, if there is too little fuel, we have weak extinction (lower limit of combustion LLC) .the two limits mainly depend on the mass flow of air passing through the combustion chamber. Flames have trouble surviving at high flow velocities. high flow velocity is , of course, linked to a high mass flow . so too high, flow velocities/mass flows are not good .On the hand, If the flow velocity is too low, the flame will move upstream. This is called flashback. It is not very good either. So, we do not want a low flow velocity either.

1.7 Flow Pattern in Gas Turbine Combustors:

The airflow pattern in the primary-zone plays a very important role in performance, combustion and temperature distribution. The creations of toroidal flow reversal that entrains and recirculates a portion of the hot combustion products are commonly employed to enhance the mixing quality of incoming air and fuel. These highly vortices are continually refreshed by air admitted through holes pierced in liner walls, supplemented in most cases by air flowing through swirlers and flare-cooling slots, and by air employed in atomization. One of the most effective ways of inducing flow recirculation in the primary zone is to fit a swirler in the dome around the fuel injector. Vortex breakdown is a well-known phenomenon in swirling flow. It causes recirculation in the core region when the amount of rotation important to the flow is high as shown in Fig1.8. This type of recirculation provides better mixing than is normally obtained by other means such as bluff bodies, because of the swirl component produces strong shear regions, high turbulence and rapid mixing rates. The typical profiles of axial and swirl velocity components in strongly swirling flow pattern is shown in Fig 1.9. These characteristics of swirling flow have been recognized and been used in many practical combustion devices to control the stability and intensity of combustion and the size and shape of the flame region [7].

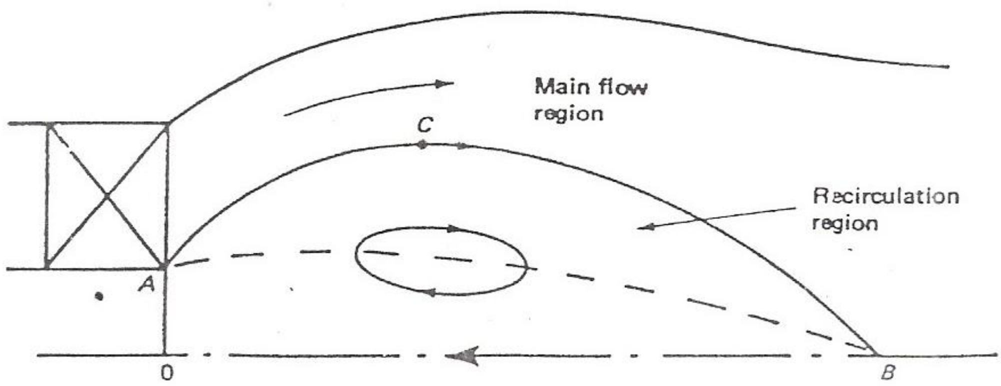


Fig 1.8 Recirculation region in a free swirling flow filed. [7]

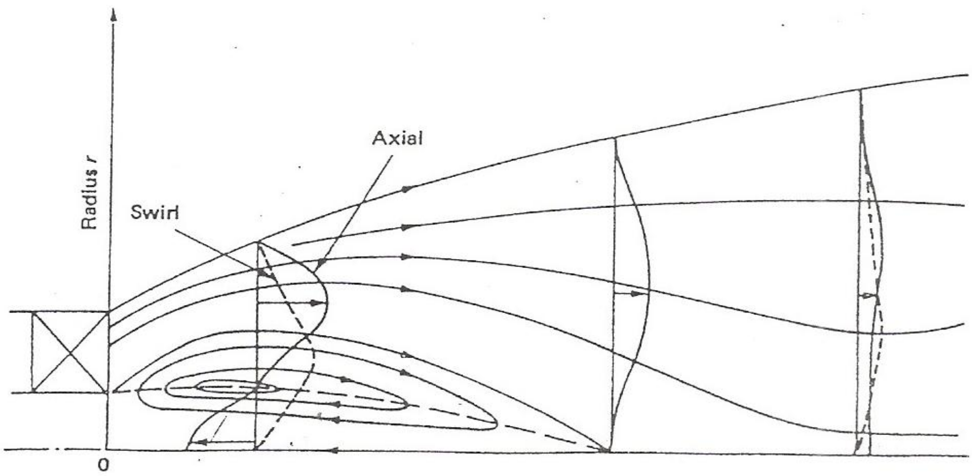


Fig 1.9 The typical profiles of axial and swirl velocity components in strongly swirling flow pattern.

1.7.1 Swirler types:

There are two main types of swirlers widely used in combustors: axial and radial swirlers as shown figs 1.10A and 1.10B. Each kind of swirler can be fitted with flat vans or curved vans. However, the flat-vane swirlers are still preferred for many combustion chambers applications for some reasons such as: (i) Easy manufacturing (ii) The exit velocity profile is less peaked and is less biased radially outboard than that of corresponding curved-vane swirlers (iii) It can be made large enough to pass the required air mass flow (iv) It is clear that curved-vane swirlers more efficient aerodynamically than flat-vane swirlers because they allow the incoming axial flow to turn gradually. For these reasons flat-vanes still preferred for many combustor applications [8].

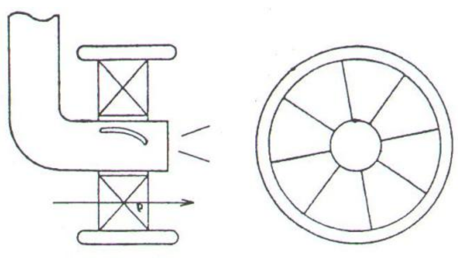


Fig 1.10A Axial Swirler [20].

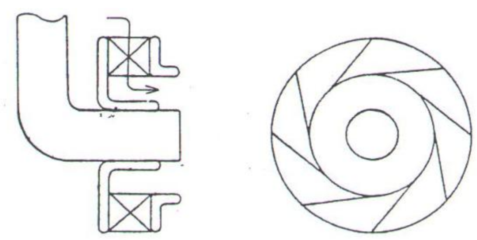


Fig 1.10B Radial Swirler [20].

1.7.2 Swirl number

Swirl number (S_N) is a non-dimensional criterion to characterize the amount of rotation to the axial flow:

$$S_N=2G_m/G_t\,D_{sw} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 1.1$$

Where G_m = axial flux of angular momentum

G_t = axial thrust

These can be written as

$$G_t = \int_0^{Dsw/2} 2\pi r U^2 \rho dr + \int_0^{Dsw/2} 2\pi r p dr \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 1.2$$

$$G_m = \int_0^{Dsw/2} 2\pi r W r \rho U dr \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 1.3$$

Where, U, W, and p are the axial and tangential components of the velocity and static pressure respectively in any section of the jet. The swirl number for various types of swirl with constant vane angle can be calculated by the expression:

$$S_N=2/3\{[1-(R_h/R_{sw})^3]/[1-(R_h/R_{sw})^2]\} \tan \text{Ø} \quad \ldots\ldots\ \ldots\ldots\ldots \quad 1.4$$

Where R_h, R_{sw}, Ø as shown in the Figs (1.11A and 1.11B).

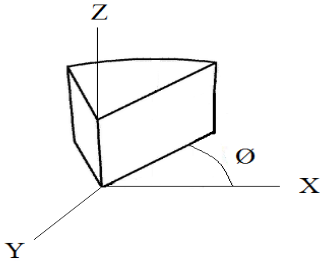


Fig 1.11A Swirl vane angle [20].

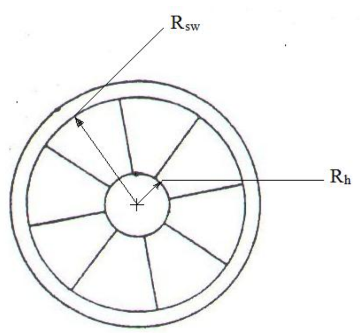


Fig 1.11B Swirler Radiuses [20].

1.8 Research Objective:

The objective of the research is to study and investigate the effect of the method of introducing the secondary air into gas turbine combustion chamber on flame stability, and temperature distribution using a test rig fig (3.1). In general, different combustors to be used in the study with different swirl intensity air inlet. first combustor with different hole diameters, second inlet angle (the holes angle).

Literature review

Combustion reactions are present in many industrial for the manufacture of products, and also in the direct generation of thermal, electrical, or mechanical energy. The modern design of technical combustion systems, must take into account there essential factor, the heat and mass transfer, optimization of combustion efficiency and represent an economic an reliable tool for facilitating combustion system design. Flam structure and stability and pollutant emissions strongly depend on aerodynamic and mixing characteristic of the fuel and combustion air jets during the last twenty-five years, a significant part of this efforts aimed mainly at the development of multidimensional mathematical models for different equipment, such as boilers, reactors, steam generator, and burners. These models serve as tools that reproduce physical experiments through equivalent numerical experiments. The technology of the combustion model can have many forms, but few have the capacity to realistically represent combustion processes.

An efficient operation of combustion chambers depended on the knowledge of the oxidation reactions and heat transfer between the combustion products and the chamber walls, which requires a detailed analysis of the governing mechanism. A number of combustion modeling methodologies are now available, but only a few are able to account the process in its entirety.

The non-reacting fluid flow fields generated by multi-swirler arrays with two different port configurations are investigated experimentally by Cai et al [9]. These two cases include a co-swirling array, where all swirlers act in the same direction, and a counter-swirling array, where all swirlers alternate between clockwise and counter-clockwise rotations.

The results show that the considered flow field has a very complicated structure, especially for the flow structures before 33 mm downstream. In this region, a high turbulent flow structure exists, due to the agitation of the air jets and the interaction between adjacent swirling flows. In comparison, the flow field generated by a co-swirler array deforms rapidly and at an axial distance far from the array behaves similar to the flow generated by a single swirler. Meanwhile, the counter-swirler array retains the individual swirler characteristics across a longer distance due to the amplifying interactions between adjoining swirlers, and the individually generated flow structures unify into a single counter-rotational flow at an axial distance far from the array.

Mahmood et al [10], studied the effects of inlet flow conditions and rotational speed on the flow and heat transfer in such a system, using a simplified computational model for 3D steady, incompressible turbulent flow. Computed results are compared with measurements of tangential velocity and Nusselt number made in a complementary experimental study.

The results show that there are significant mixing losses near the inlet nozzles, resulting in a reduced “effective” pre-swirl ratio at inlet. The computed tangential velocity distributions suggest free-vortex-type behavior for the flow between the pre-swirl nozzle radius and that of the receiver holes. There is mainly good agreement between the computed and measured velocities, although the measured values are generally lower than the computed values and follow free-vortex behavior less closely. There is less good agreement between computed and measured values of Nusselt number, although the correct trends are obtained for the effects of the main flow parameters.

Huang and Yang [11], they studied the unsteady flame dynamics in a lean-premixed swirl-stabilized combustor, with attention focused on the transition of flame structure from a stable to an unstable state. It was found that the inlet temperature and equivalence ratio are the two most important variables determining the stability characteristics of the combustor. A slight increase in the inlet mixture temperature across the stability boundary leads to a sudden increase in acoustic flow oscillation. One major factor contributing to this phenomenon is that as the inlet mixture temperature increases, the flame, which is originally anchored in the center recirculation zone, penetrates into the corner recirculation zone and flashes back, due to the increased flame speed. As a consequence, the flame is stabilized by both the corner and the center of re-circulating flows and exhibits a compact enveloped configuration. The flame flaps dynamically and drives flow oscillations through its influence on unsteady heat release. The results improve the understanding of the mechanisms of initiation and sustenance of combustion instabilities in gas-turbine engines with lean-premixed combustion .

The effect of inlet swirl on the flow development and combustion dynamics in a lean-premixed, swirl-stabilized combustor is numerically investigated by Hung and Yang [12]. Large Eddy Simulation (LES) Technique along with a level-set flamelet library approach is used.

The study show that when the inlet swirl number exceeds a critical value, a vortex breakdown induced, central toroidal recirculation zone is established in the downstream region. The computed flow pattern and acoustic properties agree well with those experimentally observed, although no velocity field measurements are available for comparison purposes. The swirl strength has enormous effects on the flow development and flame dynamics in the combustion chamber. When the inlet swirl-number increases, the central recirculation zone due to the vortex breakdown moves upstream and eventually overrides the wake recirculation zone. Excessive swirl may cause the central recirculating flow to penetrate into the inlet annulus and lead to the occurrence of flame flashback. A higher swirl number tends to increase the turbulence intensity, and consequently the flame speed. As a result, the flame surface area is reduced. The net heat release, however, remains almost unchanged because of the enhanced flame speed. Transverse acoustic oscillations often prevail under the effects of strong swirling flows, whereas longitudinal modes dominate the wave motions in cases with weak swirl.

Jian et al [13] conducted experimental studies to investigate the turbulent reacting flow in a swirl combustor with staged air injection.

The air injected into the combustor is composed of the primary swirling jet and the secondary non-swirling jet. A three dimension-laser particle dynamic analyzer (PDA) was employed to measure the instantaneous gas velocity. The probability density functions (PDF) for the instantaneous gas axial and tangential velocities at each measuring location. The measurement by the PDA show that, the probability density function for the gas axial velocity is close to a Gaussian distribution, the gas tangential velocity in the upstream region and the downstream region are approximately a Gaussian distribution, the fluctuating gas axial velocity and the absolute magnitude of the axial-tangential Reynolds shear stress are relatively high near the central axis and low near the wall. The fluctuating gas axial and tangential velocities remain strong in the downstream.

Wang et al [14] A comprehensive study on confined swirling flows in an operational gas-turbine injector was performed by means of large-eddy simulations. The formulation was based on the Favre-filtered conservation equations and a modified Smagorinsky treatment of subgrid-scale motions. The model was then numerically solved by means of a preconditioned density-based finite-volume approach. Calculated mean velocities and turbulence properties show good agreement with experimental data obtained from the laser-Doppler velocimetry measurements. Various aspects of the swirling flow development (such as the central recirculating flow, recessing vortex core and Kelvin–Helmholtz instability) were explored in detail. Both co- and counter-rotating configurations were considered, and the effects of swirl direction on flow characteristics were examined. The flow evolution inside the injector is dictated mainly by the air delivered through the primary swirler. The impact of the secondary swirler appears to be limited.

Dener Silva et al [15] The focus of the present work is a new configuration of Low-NOx combustor with especial application for gas turbine. For the concept proposed, the unfavorable combustion conditions for NOx formation are reached through the dynamic control of reactants mixing process into the double-stage combustor. In the first stage swirling air and gas fuel are injected and a sooting flame is observed in a region close to the flows interaction. From the first to the second stage, the combustor diameter increases and a pre-mixed lean combustion is stabilized into an intense recirculation zone. However, depending on the operational parameters, some acoustic oscillations happen for the lean combustion in the secondary chamber. Therefore, the present work is concerned about the influence of these operational parameters on the acoustic instabilities (equivalence ratio, fuel jet Reynolds number, swirler blades angle and primary chamber length/diameter ratio (L/D).

The results show that increasing the swirler blades angle and reducing the fuel jet Reynolds number, the combustion oscillations can be attenuated. In addition, higher L/D ratios (maximum investigated here was 3) presented good results for instabilities attenuation. In spite of the difficulties to understand the complex phenomena of combustion instabilities, this work presents some recommendation to control the oscillations in this type of combustors.

The stability characteristics of a premixed, swirl-stabilized flame are studied by Schefer [16] to determine the effects of hydrogen addition on flame stability under fuel-lean conditions. The burner configuration consisted of a center body with an annular, premixed methane/air jet. Swirl was introduced to the flow using 45-degree swirl vanes. The combustion occurred within an air-cooled quartz chamber at atmospheric pressure. The results, using methane/hydrogen fuel mixtures, showed that the addition of up to 41% hydrogen significantly extended the lean burning limit. Planar Laser-Induced Fluorescence (PLIF) measurements of the OH radical were applied to study the behavior of the OH mole fraction near the lean stability limit. The results showed that as the lean stability limit was approached the overall OH mole fraction decreased, the flame width decreased and length increased, and the high OH region took on a more intermittent, shredded appearance. For operating conditions near the lean stability limit, the addition of a moderate amount of hydrogen to the methane/air mixture resulted in a significant increase in the OH concentration and a more robust appearing flame.

Eldrainy et al [17] The central recirculation zone (CRZ) in a swirl stabilized gas turbine combustor has a dominant effect on the fuel air mixing process and flame stability. Most of state of the art swirlers share one disadvantage; the fixed swirl number for the same swirler configuration. Thus, in a mathematical sense, Reynolds number becomes the sole parameter for controlling the flow characteristics inside the combustor.

The result, at low load operation, the generated swirl is more likely to become feeble affecting the flame stabilization and mixing process. This paper introduces a new swirler concept which overcomes the mentioned weakness of the modern configurations. The new swirler introduces air tangentially and axially to the combustor through tangential vanes and an axial vanez respectively. Therefore, it provides different swirl numbers for the same configuration by regulating the ratio between the axial and tangential flow momenta. The swirler aerodynamic performance was investigated using four CFD simulations in order to demonstrate the impact of tangential to axial flow rate ratio on the CRZ. It was found that the length of the CRZ is directly proportional to the tangential to axial air flow rate ratio.

The effects of flame cooling and residence time on NO_x and CO emission in a can type gas turbine combustor is investigated experimentally by Zawia, [18]. The flame cooling and residence time are obtained by introducing the secondary air tangentially through four slots at the upstream of the combustor around the flame (secondary air swirl). The flame temperature and residence time are varied by changing the cross section area of the slots (increasing the swirl intensity). Measurement of the emission concentrations and the temperature distributions have been undertaken for diesel fuel at an overall air /fuel ratio of (78:1). A significant effect of swirl intensity of the secondary air on both flame temperature and flame dimensions has been recorded. Results of this study indicate that the flame cooling and residence time have great effect on emission characteristics in the gas turbine combustor under investigation.

As a result of this experimental study the following conclusions are obtained.

1- The flame is affected by secondary air swirl intensity. The increase of swirl intensity causes a considerable reduction in temperature of the flame and increase the residence time.

2- An average reduction of 65% in NO_x emission at outlet has been obtained by changing the total slots area from 6000 to 4000 mm^2. The concentration of CO is zero at the outlet of the combustor.

Furuhata et al [19], they presented a low NO_x spray combustor for kerosene-fueled micro gas turbine based on an upward swirl concept to investigate the effect of combustion air temperature on combustion characteristics experimentally. The upward swirler is fitted between the primary and secondary combustion zones. The combustion air is introduced into the casing and flows between the secondary combustion tube and the casing (heat exchange zone), then the air is ejected into the primary combustion zone through the swirler. The study shows that the preheated combustion air temperature can be raised by increasing lengths of the secondary combustion tube and the casing simultaneously, the axial velocity of combustion gas toward the combustor exit in the primary combustion zone is increased, also the species concentrations (CO and NO_x) in the primary combustion zone are increased with the increase of combustion air temperature.

Qubbaj [21] presented a numerical simulation of a turbulent natural gas jet diffusion flame at a Reynolds number of 9000 in a swirling air stream. The numerical computations are carried out using the commercially available software package CFDRC. The instantaneous chemistry model is used as the reaction model. The thermal composition, flow (velocity), as well as stream function fields for both the baseline and air-swirling flames are numerically simulated in the near-burner region, where most of the mixing and reactions occur. The results are useful to interpret the effects of swirl in enhancing the mixing rates in the combustion zone as well as in stabilizing the flame. The results showed the generation of two recirculating regimes induced by the swirling air stream, which account for such effects.

EXPERMINTAL WORK

Gas turbine combustion chamber must satisfy a wide range of requirements such as complete combustion of fuel, minimum pressure losses, flame stability and good distribution of the temperatures inside and outlet of the combustor.

In this study an experimental test rig is made to study and investigate the effect of secondary air entranced (with swirling through a number of holes made with an angle of (45^o) tangentially) into gas turbine combustion chamber on flame stability, and temperatures distributions.

3.1 Test Rig :

The gas turbine test rig is constructed as shown in the Figs.(3.1 , 3.2 & 3.3) and photo (3.1) which consist of : (i) Combustion chamber, (ii) Burning unit, (iii) Secondary air supply system, (iv) Instrumentation and the fuel tank provided with fuel level indicator.

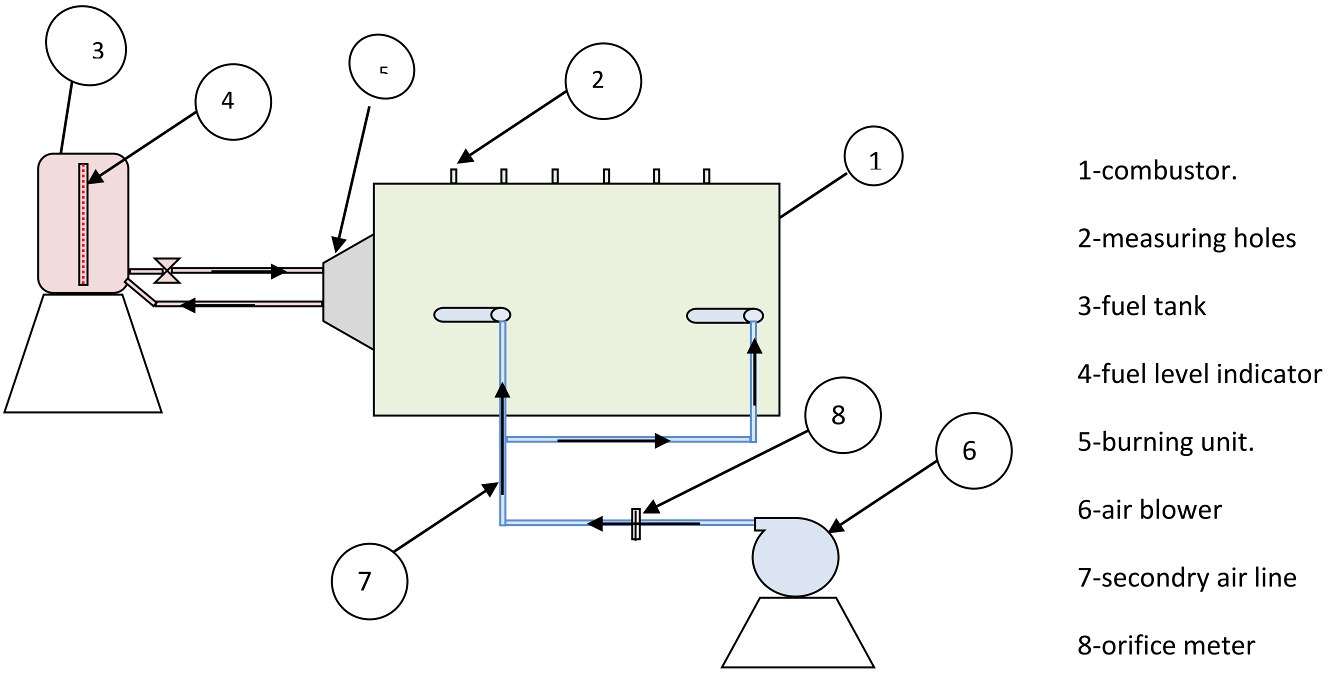


Fig 3.1 Schematic diagram of combustor test rig.

3.1.1Combustion chamber :

A can type gas turbine combustion chamber, where the combustor is performed it consists of two casing one inside the other, the outer casing proceeding in the flow direction of the secondary air. The inside casing is called flame tube, which provided with fifty-six (56) holes tangentially with an angle (45^o). Two combustion chamber are made the first one has the holes with (5mm in diameters) and the second one the holes with (10mm in diameters) to introduce the secondary air. The combustion chamber provided with six small holes on one line at the top of the combustion chamber for entering the thermocouples to measure the temperature distribution .

3.1.2 Burning unit :

The burning unit photo (3.2) consists of (i) Primary air system, which consists of air blower and swirl vane, (ii) Fuel system which consists of fuel pump and pressure jet fuel injector, (iii) Ignition system, (iv) Controller with characteristics as shown in table 3.1.

Table 3.1 characteristics of burning unit.

Burner	AZ 14 OIL/E (Italy)		
MIN.	Kw 82	kcal/h 70000	Kg/h 6.9
MAX.	Kw 175	kcal/h 1510000	Kg/h 14.8
220/140V	50Hz		

3.1.3 Secondary air supply system:

Large air blower connected to the combustion chamber by pipe system provided with orifice meter for measuring the flow rate.

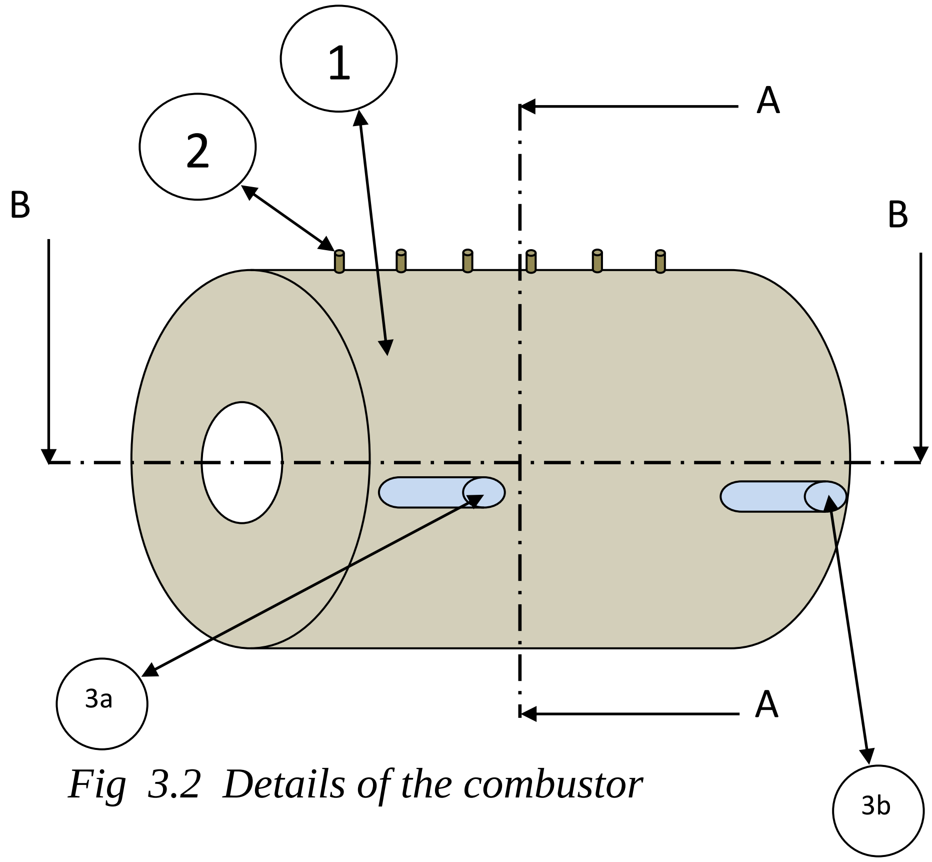


Fig 3.2 Details of the combustor

1-combustor.

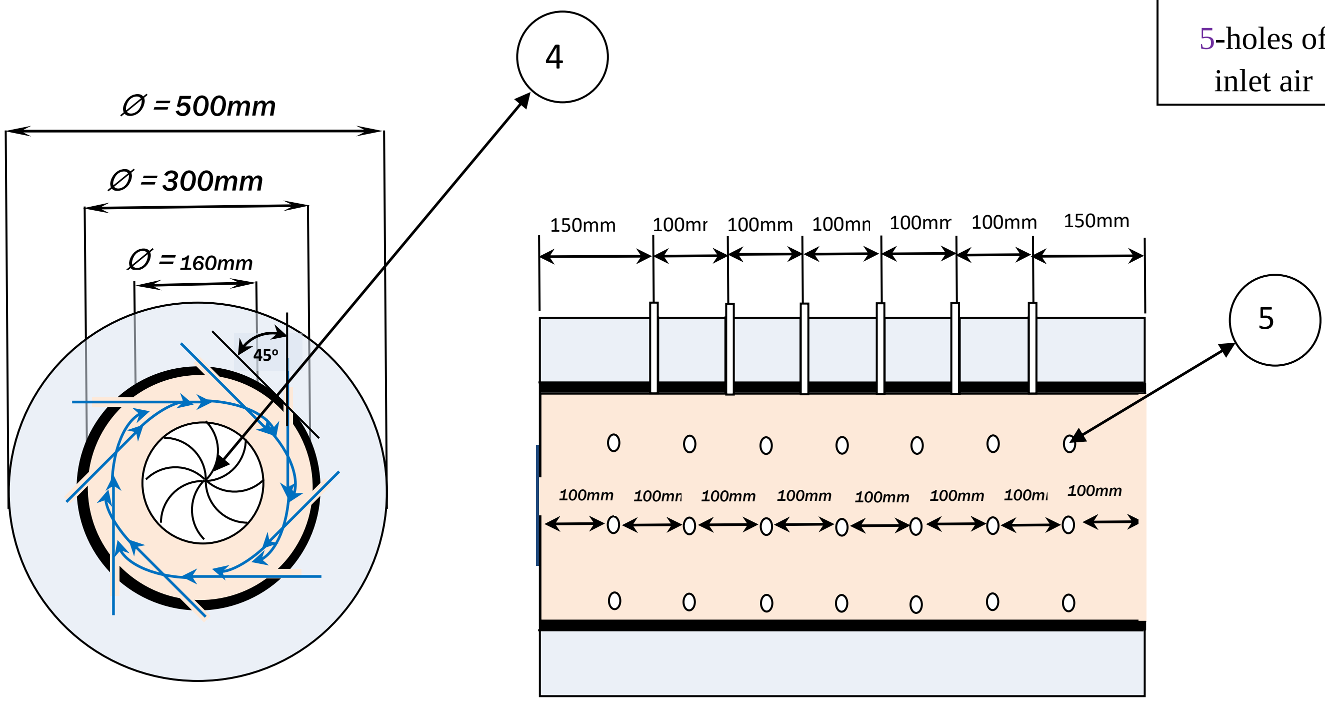
2-hole of measuring

3a-inlet of secondary air from back.

3b-inlet of secondary air from front.

4-primary air swirl

5-holes of inlet air



Section A-A

Section B-B

Fig 3.3 Arrangements and cases details of the secondary air entry

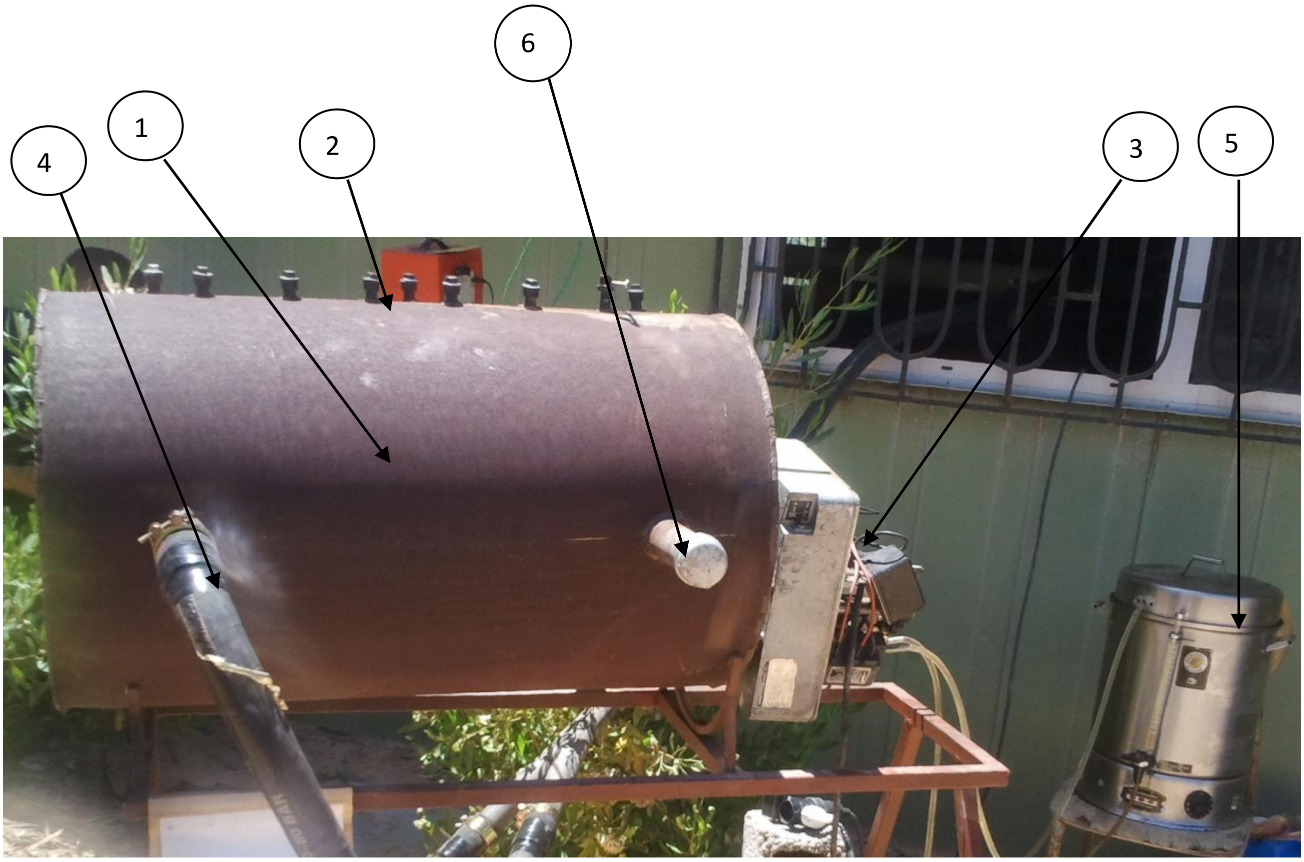


Photo 3.1 Combustion chamber.

1.combustion. 2.measuring holes.
3.burning unit. 4.entering of air at front.
5-fuel tank. 6- entering of air at back.

1. Air blower.
2. Fuel Pump.
3. Controller.
4.Ignition system.

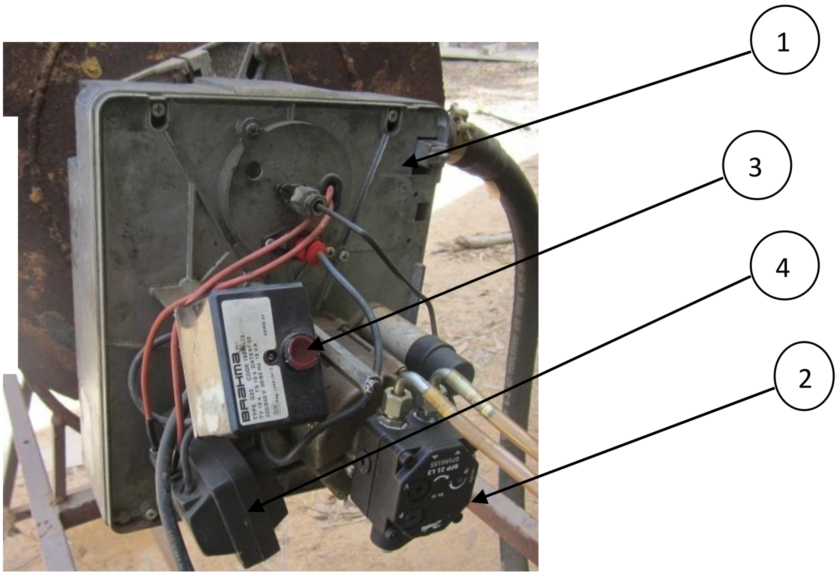


Photo 3.2 Burning Unit

3.1.4 Instrumentation:

The digital thermometer is used to measure temperature distribution in radial and axial directions of the test rig. For each hole six readings at different radial distances from the wall to the center of combustor are recorded using K type thermo-cable photo (3.3) .

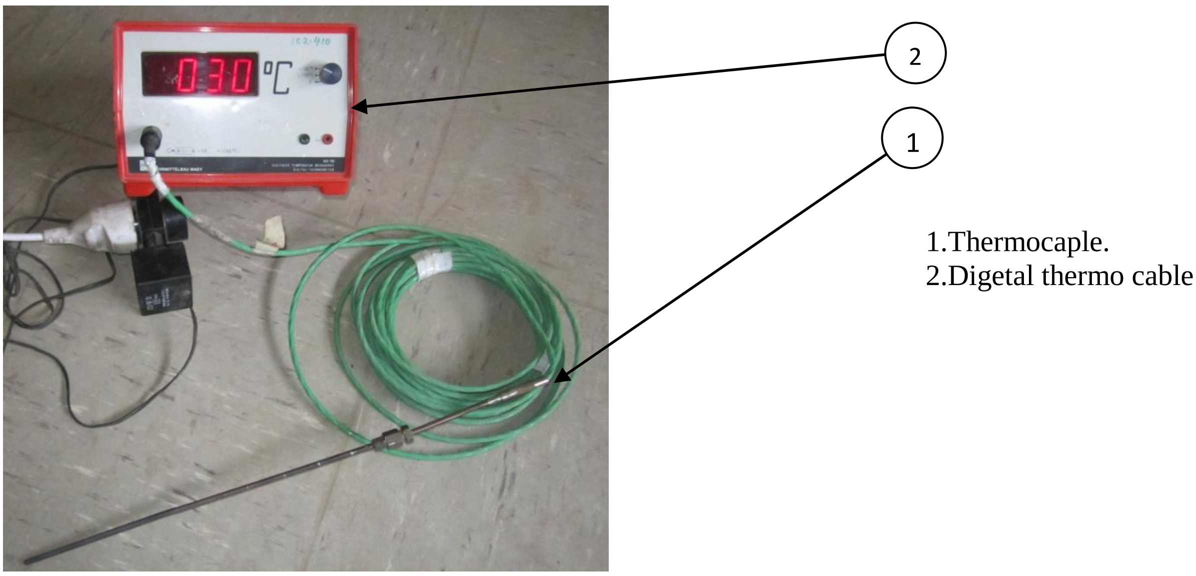


Photo 3.3 Temperature Measuring Instrumentation

3.2 Experimental Procedure :

A number of experiments are carried out in order to study and investigate the influence of secondary air swirl on flame stability and temperature distribution in a can type gas turbine combustor.

The air blowers are started to supply the primary and secondary air to the combustor. Vane type swirler is used for the primary air swirl. the secondary air swirl is provided by entering the secondary air through the holes made tangentially with an angle (45^o) around the combustor flame tube.

Two ways are used to introduce the secondary air between the flame tube and the outer casing of the combustor, (from the front and the back) of the combustor see fig (3.2 & 3.3) & photo (3.1).

The secondary air swirl intensity is changed by changing the diameters of the fifty-six (56) holes of secondary air entrance. Two diameters of holes (5mm &10mm) are used, case (A) & (B) .

Case (A) the diameter of each hole is (10 mm), and the velocity of the secondary air inlet through the hole is (3.11 m/s).

Case (B) the diameter of each hole is (5 mm), and the velocity of the secondary air inlet through the hole is (10.72 m/s).

The pressures and the mass flow rates of the primary air and the fuel are kept constant throughout the experimental work. The fuel flow rates are measured by taking the average of several readings of the flow from the fuel indicator with time .The combustion is kept for some time until the flame become stable. Then the Thermocouple is inserting through the six measuring holes at the top of the combustor starting with upstream one. Measurements of the temperatures are taken in a radial and axial direction of combustor. For each hole six readings at different radial distance (from the wall to the center line of combustor), Assuming the combustor is identical.

3.3 **Calculation of mass flow rate and inlet velocity of secondary air :-**

Secondary air mass flow rate:.....$(w) = \rho_a$ *orifice area*C_d*$(2*\Delta_{p/}\,\rho_a)^{1/2}$

Density of air:..........................$(\rho_a) = 1.22\ kg/m^3$

Orifice pressure drop:............$(\Delta_p) = (\rho_w) * g * h$

Discharge coefficient:...........$(C_d) = 0.163$

Secondary air mass flow rate (w_1) for holes diameter (**Ø = 5mm**):-

The pressure difference at the orifice meter (h_1=138 mm of water)

$$(w_1) = (1.22)*(\pi*0.02^2)*(0.163)*\{2*(1000*9.81*0.138)/1.22\}^{1/2}$$

$$(w_1) = 0.01177\ kg/s$$

Calculation velocity of air inlet into the hole :

Area of hole (A_1) = $\pi*(0.0025)^2 = 19.6*10^{-6}\ m^2$

Number of hole (n) = *(56)*

velocity of air inlet into the hole: (V_1) = $(w_1/n)/A$

$$(V_1) = (0.01177/56)/1.96*10^{-5}$$

$$= 10.72\ m/s$$

Secondary air mass flow rate (w_1) for holes diameter (Ø = 10mm):-

The pressure difference at the orifice meter (h_1=187 mm of water)

$$(w_2) = (1.22)*(\pi*0.02^2)*(0.163)*\{2*(1000*9.81*0.187)/1.22\}^{1/2}$$

$$(w_2) = 0.0137\ kg/s$$

Calculation velocity of air inlet into the hole :

Area of hole (A_2)= $\pi*(0.005)^2 = 78.5*10^{-6}\ m^2$

Number of hole (n) = *(56)*

velocity of air inlet into the hole (V_2) = $(w_1/n)/A$

$$(V_2) = (0.0137/56)/1.96*10^{-5}$$

$$= 3.11\ m/s$$

- Calculate of swirl number use equation number

$$S_N = 2/3\ \{[1-(R_h / R_{sw})^3] / [1-(R_h / R_{sw})^2]\} * \tan\emptyset$$

$$S_N = 2/3\ \{[1-(12.5 / 40)^3] / [1-(12.5 / 40)^2]\} * \tan 60$$

$$S_N = 0.6666 * \{0.9695 / 0.9023\} * \tan 60$$

$$S_N = 1.24$$

RESULTS AND DESCUSSION

4.1 Introduction :

The results of the experimental studies of the effect of the secondary air swirl and swirl intensity on the temperatures distributions, and flam stability in a can type combustion chamber are presented in this chapter.

The experiments are taken under the same conditions such as constant primary air to fuel ratio, same mass flow rate of secondary air, and concurrent swirl flow, (primary and secondary swirl in the same direction). But the swirl intensity is changed by changing the inlet velocity of the secondary air into the combustion chamber flame tube through the holes which are made with different diameter, with an angle (45^o) tangentially. Two cases are investigated.

Case (A) the diameter of each hole is (10 mm), and the velocity of the secondary air inlet through the hole is (3.11 m/s).

Case (B) the diameter of each hole is (5 mm), and the velocity of the secondary air inlet through the hole is (10.72 m/s).

The studies also include two ways are used to introduce the secondary air between the flame tube and the outer casing of the combustor, (from the front and the back) of the combustor see fig (3.2 & 3.3) .

4.2 Temperature distribution :

The results of the temperatures distribution is the radial and axial directions inside the combustion chamber for all cases are shown in tables (4.1 to 4.8) and plotted in figs (4.1 to 4.8).

Also the comparison of the temperatures distribution between all cases are shown in tables (4.9 to 4.16) and plotted in fig (4.9 to 4.16).

Figures (4.1 to 4.4) show the temperatures distribution in the radial and axial direction for case (A), for the secondary air inlet from the front and back of the combustor. From the figs (4.1 & 4.2) it can be seen that the temperature at the wall of the combustor flame tube are low, and it increase in the direction to the center line of the combustor. While the maximum temperature are recorded in the flame region where (r/R from 0.6 to 1) at (x/L=0.313 & x/L=0.438). But there are a large difference between the temperatures at upstream where (x/L=0.313 to 0.563) specially for the back entry of the secondary air, That mains the inlet of the secondary air from the front of the combustor is better than from the back.

The temperatures distribution in the radial and axial direction for case (B) are shown in tables (4.5 to 4.8) and plotted in figs (4,5 to 4.8). The results show that the temperatures near the wall the combustor flame tube are low, and high in the region of the flame [as in case (A)] at (r/R from 0.6 to 1) and (x/L from 0.313 to outlet). But the difference between the temperature are very small i.e (homogeneous , good distribution).

Figures (4.9 to 4.12) Shown the comparison of the temperatures distribution in the radial direction (from the wall of the flame tube to the center line of the combustion at the outlet) and the comparison of the temperatures distribution in the axial direction (from upstream to downstream of the combustor at the wall of the flame tube), for the two cases with inlet of the secondary air from the front and back of the combustor.

From the figs (4.9 & 4.10) The results that the radial temperatures distribution at outlet are nearly the same, But a little lower, and more uniform when the inlet of the secondary air between the flame tube and the casing of the combustor from the front of the combustor.

Figures (4.11 & 4.12) Show the axial temperatures distribution at the wall when the inlet of the secondary air between the flame tube and the casing of the combustor from front are higher except at the outlet and more uniform.

Figures (4.13 to 4.16) Show the effect of secondary air swirl intensity on the temperatures distribution in the axial direction from upstream to downstream at the wall of the flame tube (r/R=0), and the temperature distribution in the radial direction from the wall of the flame tube to the combustor center line at outlet, with the inlet of the secondary air from front and back, for the two cases (A & B).

From figs. (4.13 – 4.14) it can be seen that at the inlet of the secondary air from front the temperatures distribution along combustion chamber are nearly uniform but when the inlet of the secondary air from back the temperatures are increase in the direction to the outlet. Also it can be seen that the temperatures at the wall of the flame tube for high swirl intensity case(B) are lower than case(A).

But figs (4.15 – 4.16) Show there is no change in the temperatures distribution at the outlet of the combustion chamber for the two cases (A & B).

4.3 Flame stability :-

The flame structure (shape, diameter, length) is shown in photos (4.1 to 4.3). Photo (4.1) Shows the flame with primary air swirl only, it can be seen that the flame fill the combustor flame tube, and along the combustor length .

The effect of secondary air swirl on the flame is shown in photos (4.2 & 4.3), case (A) & (B). The photo (4.2) for case (A) shown a reduction of the flame diameter and flame length, and the flame is turning around away from the flame tube wall and stable.

The photo (4.3) for case (B) show the flame more stable, smaller in diameter, and shorter.

Table 4.1 Temperature distribution in Radial direction in the combustion chamber, for case (A) (Secondary Air inlet from front).

r(mm)	*r/R*	*Temperature(C^O)at measuring holes*					
0	0	365	470	482	490	443	434
30	0.2	376	505	582	667	771	755
60	0.4	452	753	807	838	897	834
90	0.6	650	888	882	890	884	832
120	0.8	738	1075	991	920	893	856
150	1	754	1095	1043	983	930	883

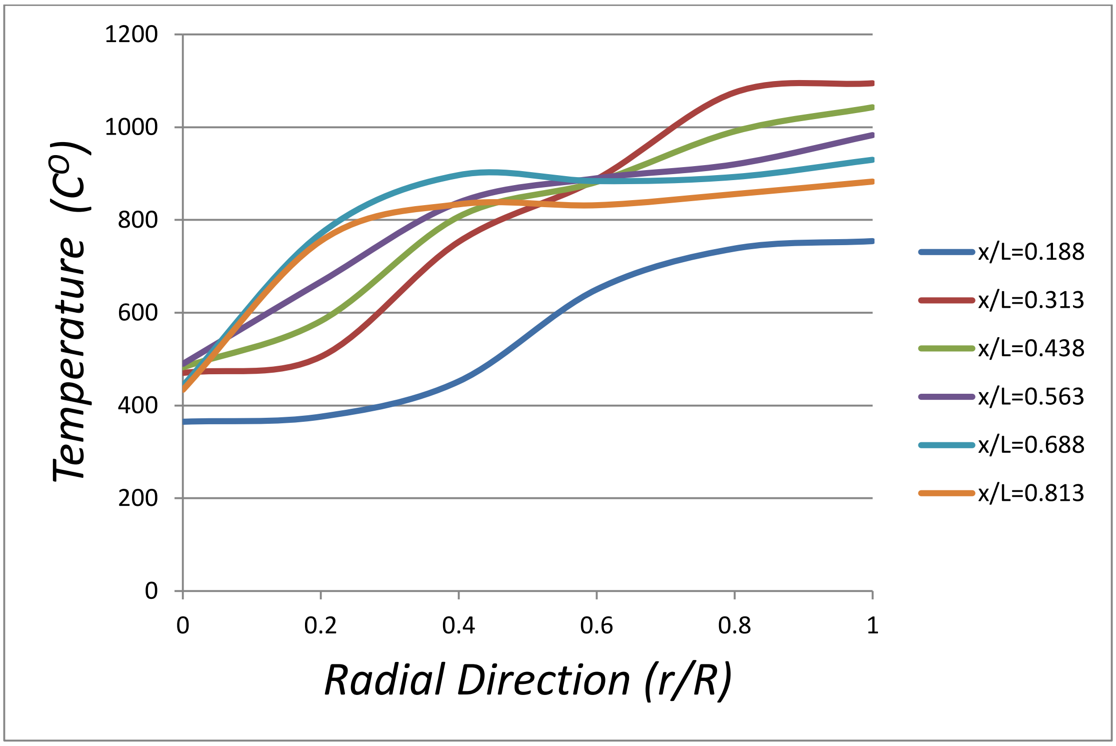


Fig 4.1 Temperature distribution in Radial direction in the combustion chamber, for case (A) (Secondary Air inlet from front).

Table 4.2 Temperature distribution in Radial direction in the combustion chamber, for case (A) (Secondary Air inlet from back).

r(mm)	r/R	Temperature(C^O)at measuring holes					
0	0	227	337	382	451	452	453
30	0.2	233	358	417	571	722	788
60	0.4	246	578	626	765	848	875
90	0.6	331	800	801	808	834	875
120	0.8	611	1030	942	876	841	897
150	1	712	1061	992	954	895	910

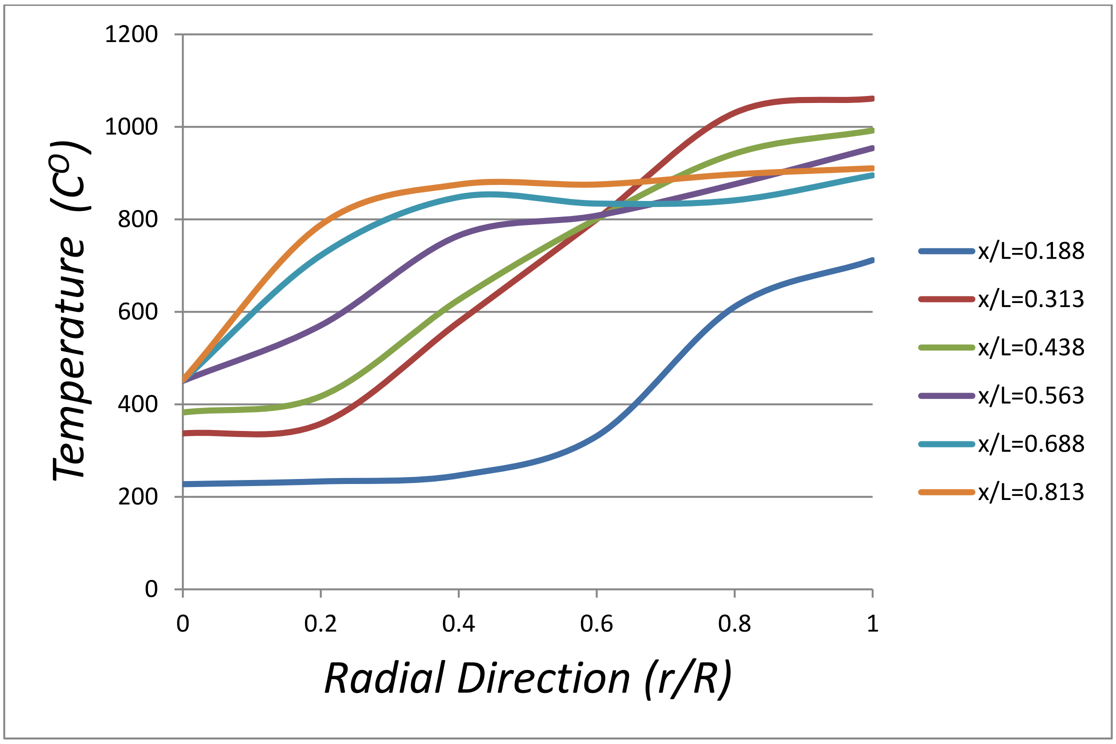


Fig 4.2 Temperature distribution in Radial direction in the combustion chamber, for case (A) (Secondary Air inlet from back).

Table 4.3 Temperature distribution in axial direction in the combustion chamber, for case (A) (Secondary Air inlet from front).

X(mm)	x/L	*Temperature(C^O)at measuring holes*					
150	0.188	365	376	452	650	738	754
250	0.313	470	505	753	888	1075	1095
350	0.438	482	582	807	882	991	1043
450	0.563	490	667	838	890	920	983
550	0.688	443	771	897	884	893	930
650	0.813	434	755	834	832	856	883

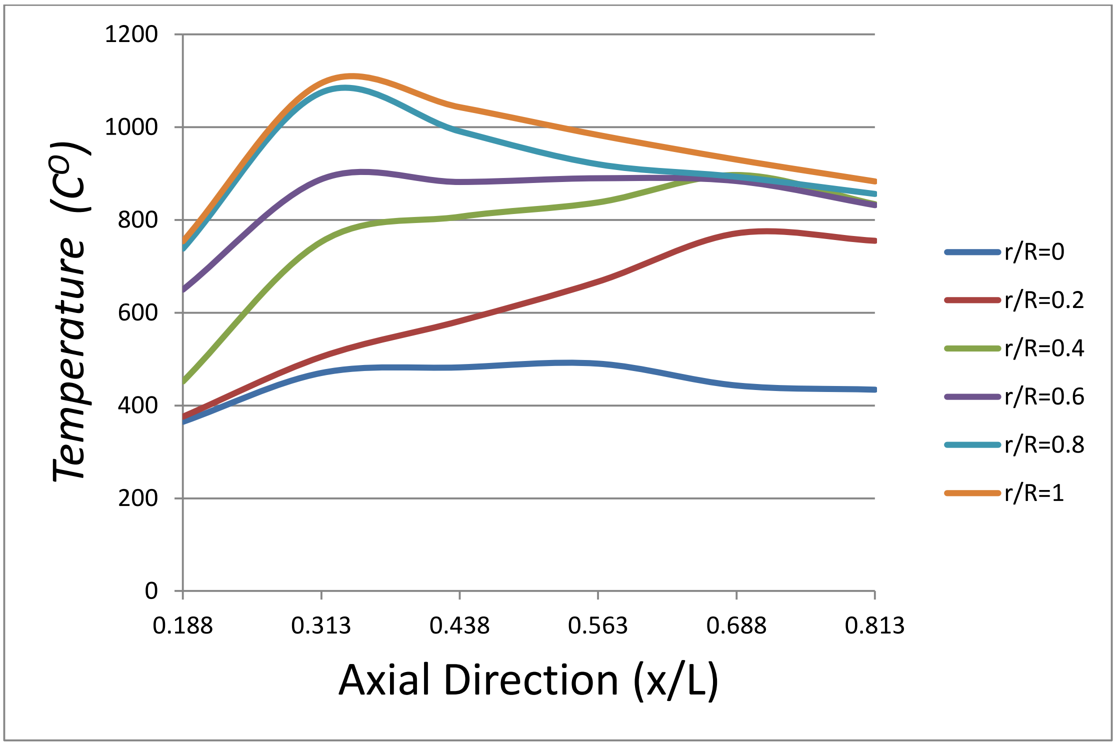


Fig 4.3 Temperature distribution in axial direction in the combustion chamber, for case (A) (Secondary Air inlet from front).

Table 4.4 Temperature distribution in axial direction in the combustion chamber, for case (A) (Secondary Air inlet from back).

X(mm)	*x/L*	*Temperature(C^O)at measuring holes*					
150	0.188	227	233	246	331	611	712
250	0.313	337	358	578	800	1030	1061
350	0.438	382	417	626	801	942	992
450	0.563	451	571	765	808	876	954
550	0.688	452	722	848	834	841	895
650	0.813	453	788	875	875	897	910

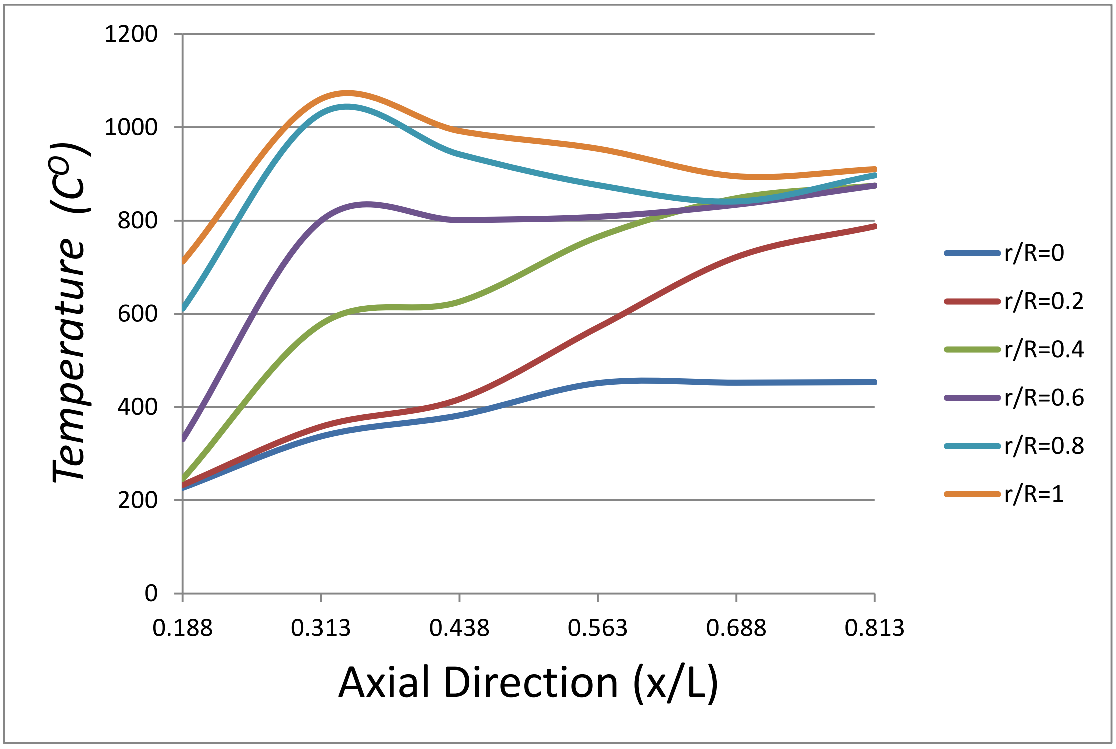


Fig 4.4 Temperature distribution in axial direction in the combustion chamber, for case (A) (Secondary Air inlet from back).

Table 4.5 Temperature distribution in radial direction in the combustion chamber, for case (B) (Secondary Air inlet from front).

r(mm)	*r/R*	*Temperature(C^O)at measuring holes*					
0	*0*	*326*	*392*	*423*	*433*	*421*	*411*
30	*0.2*	*351*	*443*	*534*	*632*	*688*	*765*
60	*0.4*	*568*	*963*	*940*	*909*	*872*	*8132*
90	*0.6*	*792*	*1032*	*939*	*909*	*879*	*843*
120	*0.8*	*844*	*1075*	*1003*	*931*	*909*	*872*
150	*1*	*864*	*1033*	*1009*	*962*	*923*	*887*

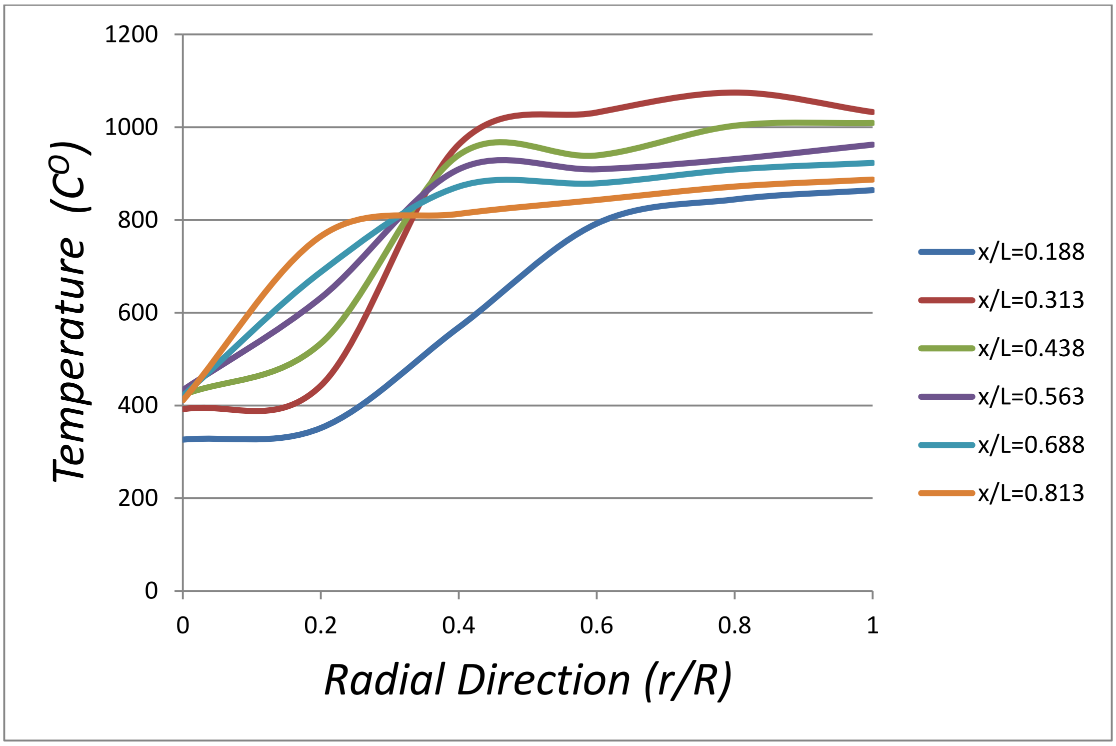


Fig 4.5 Temperature distribution in radial direction in the combustion chamber, for case (B) (Secondary Air inlet from front).

Table 4.6 Temperature distribution in radial direction in the combustion chamber, for case (B) (Secondary Air inlet from back).

r(mm)	*r/R*	*Temperature(C^O)at measuring holes*					
0	*0*	*211*	*267*	*331*	*366*	*412*	*443*
30	*0.2*	*221*	*302*	*405*	*491*	*624*	*743*
60	*0.4*	*479*	*932*	*918*	*894*	*866*	*831*
90	*0.6*	*779*	*1021*	*941*	*919*	*905*	*883*
120	*0.8*	*814*	*1096*	*999*	*956*	*931*	*909*
150	*1*	*948*	*1033*	*1030*	*989*	*972*	*966*

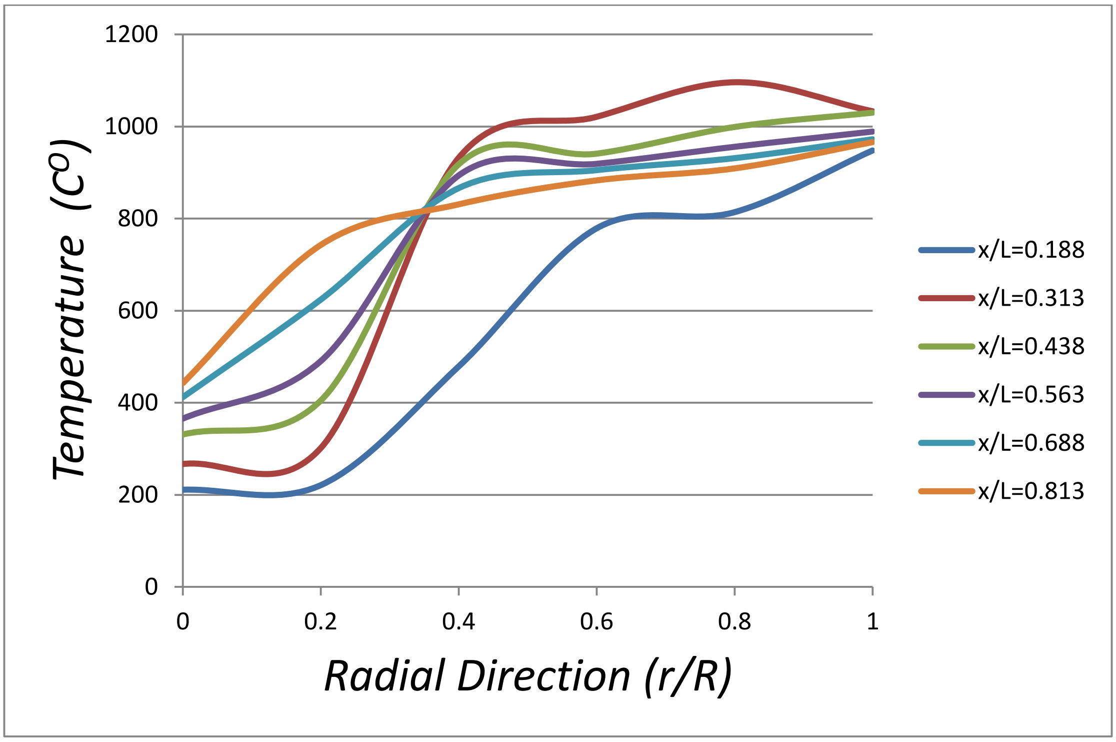


Fig 4.6 Temperature distribution in radial direction in the combustion chamber, for case (B) (Secondary Air inlet from back).

Table 4.7 Temperature distribution in axial direction in the combustion chamber, for case (B) (Secondary Air inlet from front).

X(mm)	*x/L*	*Temperature(C^O)at measuring holes*					
150	*0.188*	326	351	568	792	844	864
250	*0.313*	392	443	963	1032	1075	1033
350	*0.438*	423	534	940	939	1003	1009
450	*0.563*	433	632	909	909	931	962
550	*0.688*	421	688	872	879	909	923
650	*0.813*	411	765	813	843	872	887

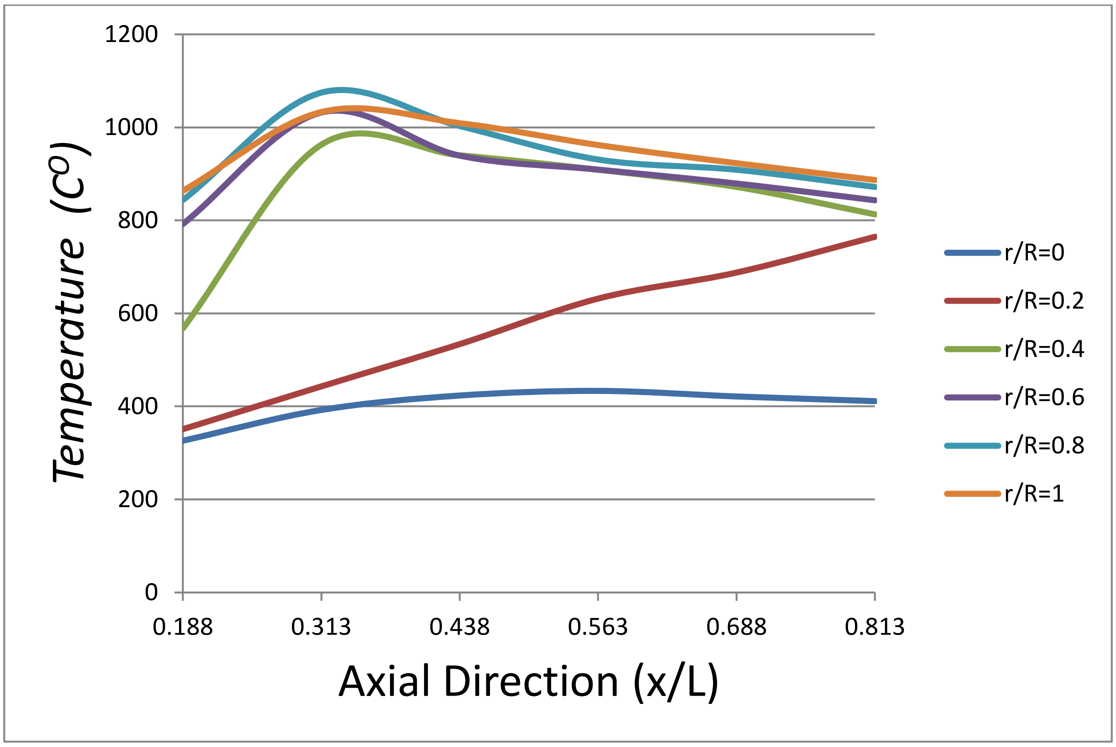


Fig 4.7 Temperature distribution in axial direction in the combustion chamber, for case (B) (Secondary Air inlet from front).

Table 4.8 Temperature distribution in axial direction in the combustion chamber, for case (B) (Secondary Air inlet from back).

X(mm)	*x/L*	*Temperature(C^O)at measuring holes*					
150	0.188	211	221	479	779	814	948
250	0.313	267	302	932	1021	1096	1033
350	0.438	331	405	918	941	999	1030
450	0.563	366	491	894	919	956	989
550	0.688	412	624	866	905	931	972
650	0.813	443	743	831	883	909	966

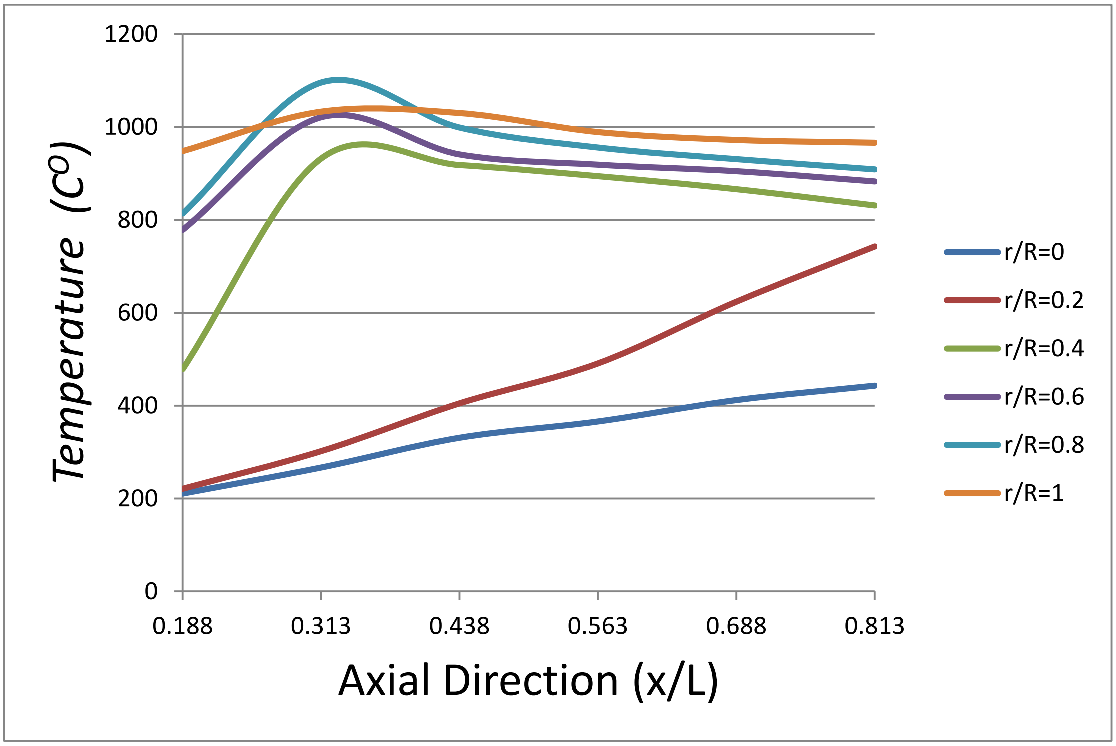


Fig 4.8 Temperature distribution in axial direction in the combustion chamber, for case (B) (Secondary Air inlet from back).

Table 4.9 Comparison of the temperature distribution in radial direction at the outlet combustion chamber, for case (A)
(Inlet secondary air from front and back).

From front		*From back*	
r/R	*Temperature(C^O)*	*r/R*	*Temperature(C^O)*
0	*434*	*0*	*453*
0.2	*755*	*0.2*	*788*
0.4	*834*	*0.4*	*875*
0.6	*832*	*0.6*	*875*
0.8	*856*	*0.8*	*897*
1	*883*	*1*	*910*

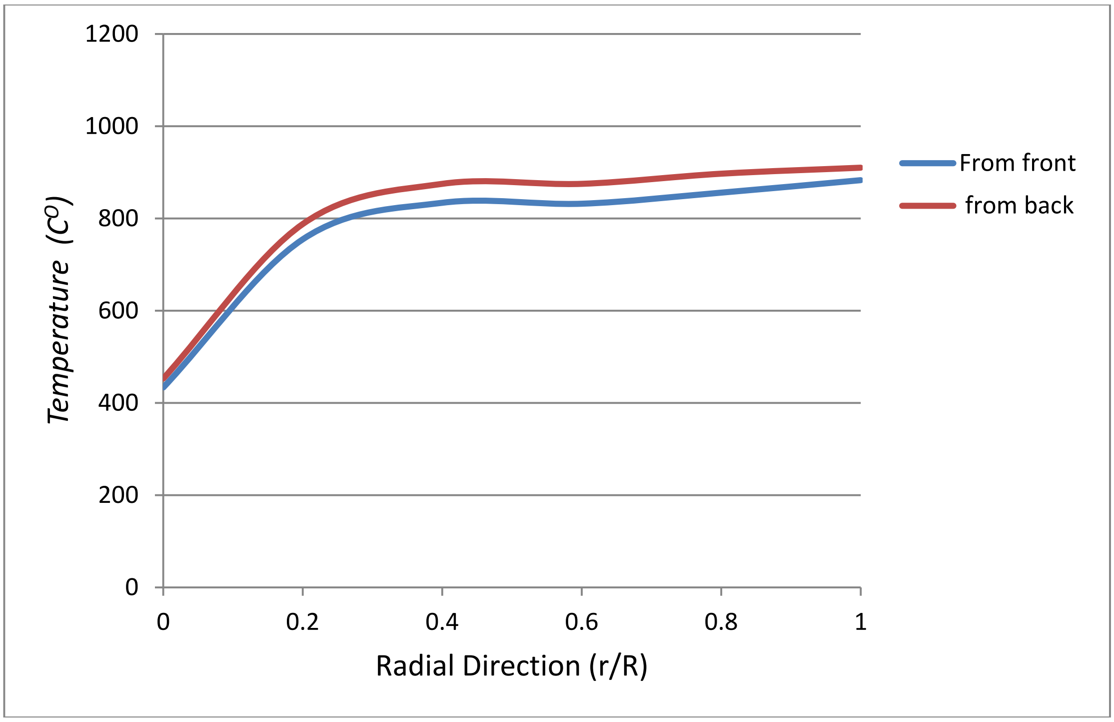


Fig 4.9 Comparison of the temperature distribution in radial direction at the outlet combustion chamber, for case (A)
(Inlet secondary air from front and back).

Table 4.10 Comparison of the temperature distribution in radial direction at the outlet combustion chamber, for case (B) (Secondary air Inlet from front and back).

From front		*From back*	
r/R	*Temperature(C^O)*	*r/R*	*Temperature(C^O)*
0	*411*	*0*	*443*
0.2	*765*	*0.2*	*743*
0.4	*813*	*0.4*	*831*
0.6	*843*	*0.6*	*883*
0.8	*872*	*0.8*	*909*
1	*887*	*1*	*966*

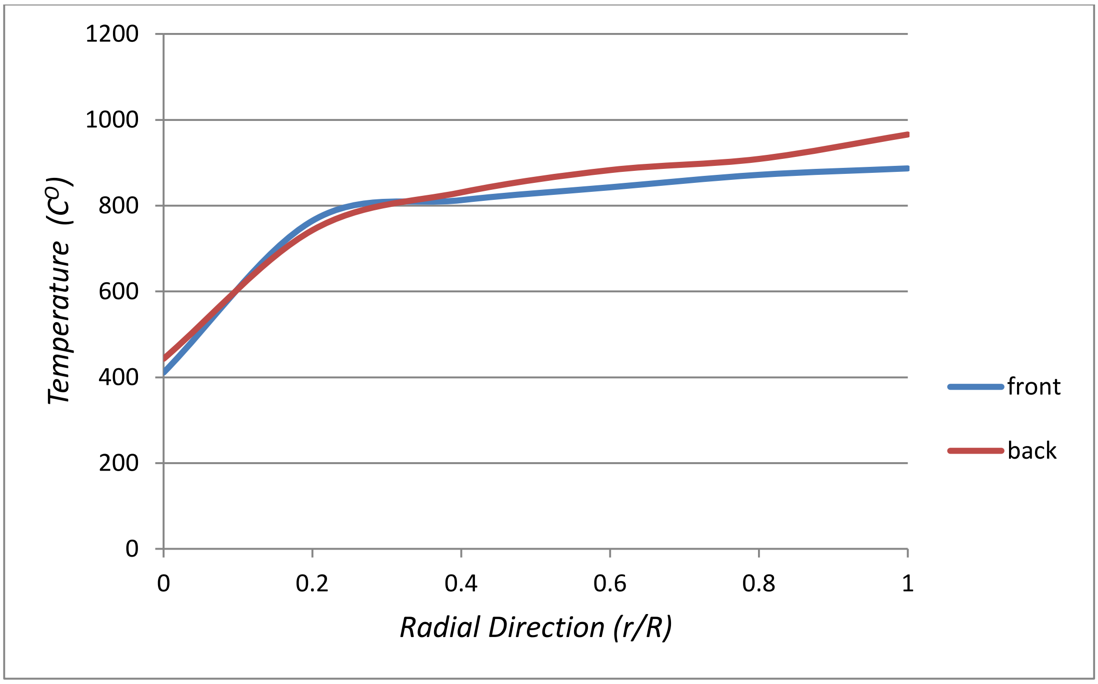


Fig 4.10 Comparison of the temperature distribution in radial direction at the outlet combustion chamber, for case (B) (Secondary air Inlet from front and back).

'*Table 4.11* Comparison of the temperature distribution in axial direction
at the wall (r/R=0) combustion chamber, for case (A)
(Inlet secondary air from front and back).

From front		*From back*	
x/L	*Temperature(C^O)*	*x/L*	*Temperature(C^O)*
0.188	365	0.188	*227*
0.313	470	0.313	*337*
0.438	482	0.438	*382*
0.563	490	0.563	*451*
0.688	443	0.688	*452*
0.813	434	0.813	*453*

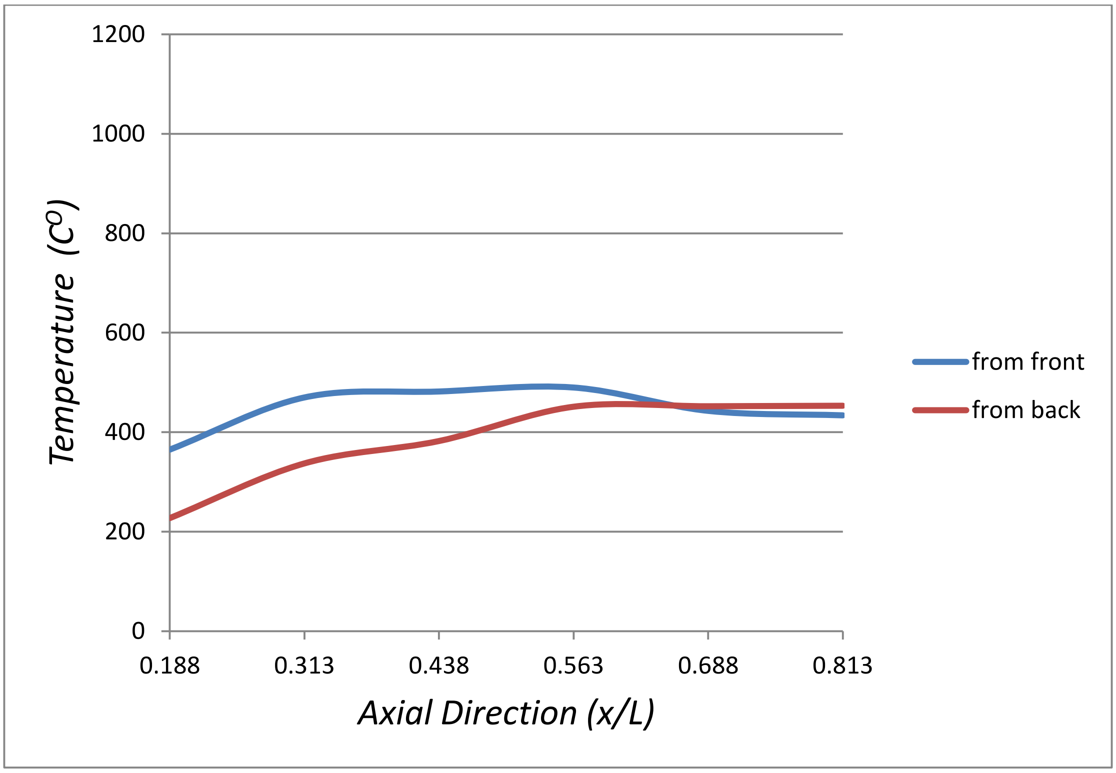


Fig 4.11 Comparison of the temperature distribution in axial direction
at the wall (r/R=0) combustion chamber, for case (A)
(Inlet secondary air from front and back).

Table 4.12 Comparison of the temperature distribution in axial direction at the wall (r/R=0) combustion chamber, for case (B) (Inlet secondary air from front and back).

From front		*From back*	
x/L	*Temperature(C^O)*	*x/L*	*Temperature(C^O)*
0.188	326	0.188	*211*
0.313	392	0.313	*267*
0.438	423	0.438	*331*
0.563	433	0.563	*366*
0.688	421	0.688	*412*
0.813	411	0.813	*443*

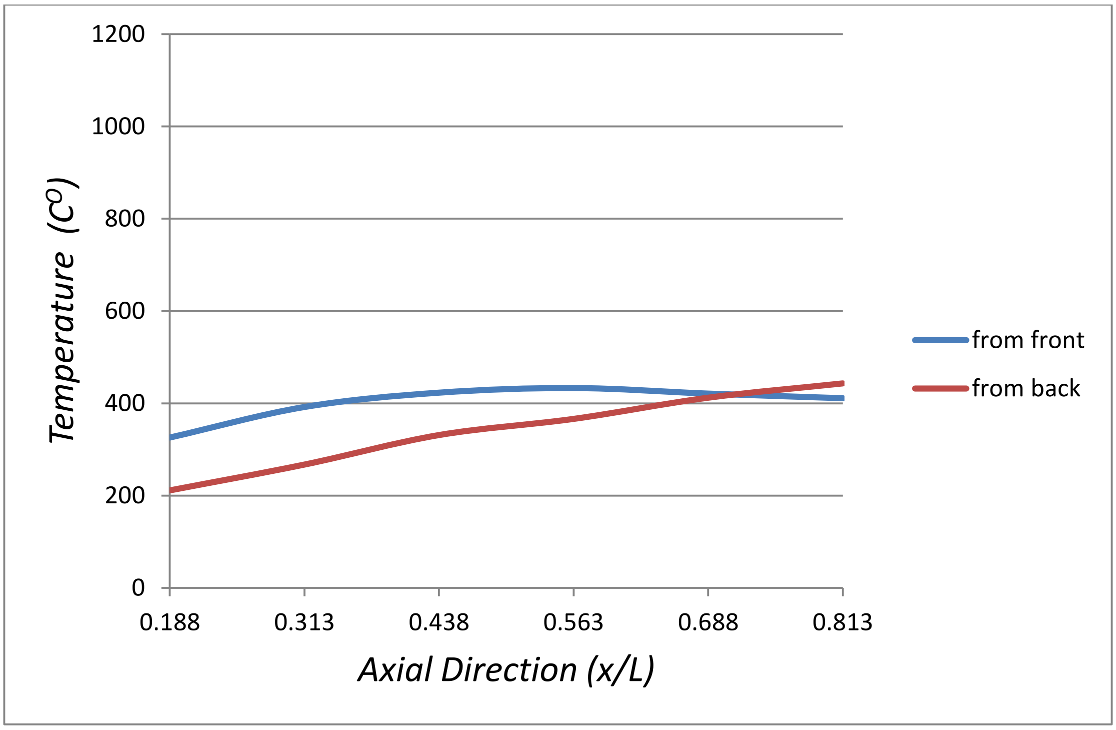


Fig 4.12 Comparison of the temperature distribution in axial direction at the wall (r/R=0) combustion chamber, for case (B) (Inlet secondary air from front and back).

Table 4.13 Comparison of the temperature distribution in axial direction at the wall (r/R=0) combustion chamber, for case (A & B) (Inlet secondary air from front).

Case (A)		Case (B)	
x/L	*Temperature(C^O)*	*x/L*	*Temperature(C^O)*
0.188	365	0.188	326
0.313	470	0.313	392
0.438	482	0.438	423
0.563	490	0.563	433
0.688	443	0.688	421
0.813	434	0.813	411

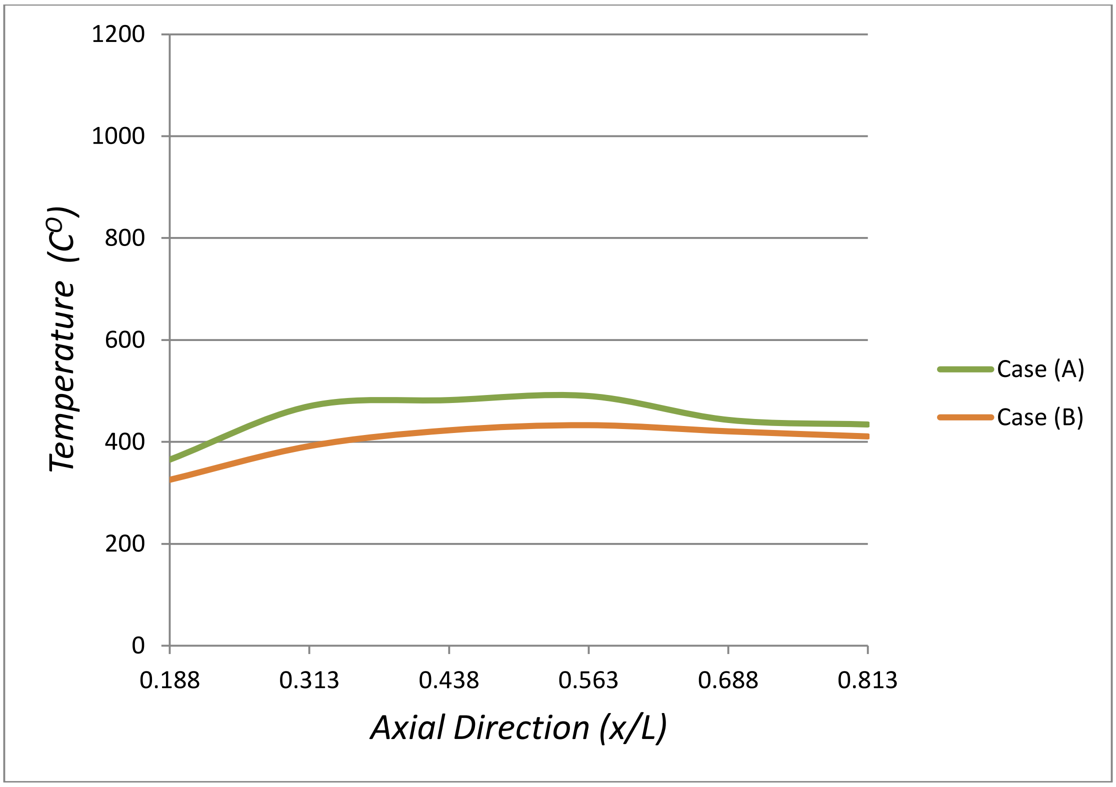


Fig 4.13 Comparison of the temperature distribution in axial direction at the wall (r/R=0) combustion chamber, for case (A & B) (Inlet secondary air from front).

Table 4.14 Comparison of the temperature distribution in axial direction at the wall (r/R=0) combustion chamber, for case (A & B) (Inlet secondary air from back).

Case (A)		Case (B)	
x/L	*Temperature(C^O)*	*x/L*	*Temperature(C^O)*
0.188	227	0.188	*211*
0.313	337	0.313	*267*
0.438	382	0.438	*331*
0.563	451	0.563	*366*
0.688	452	0.688	*412*
0.813	453	0.813	*443*

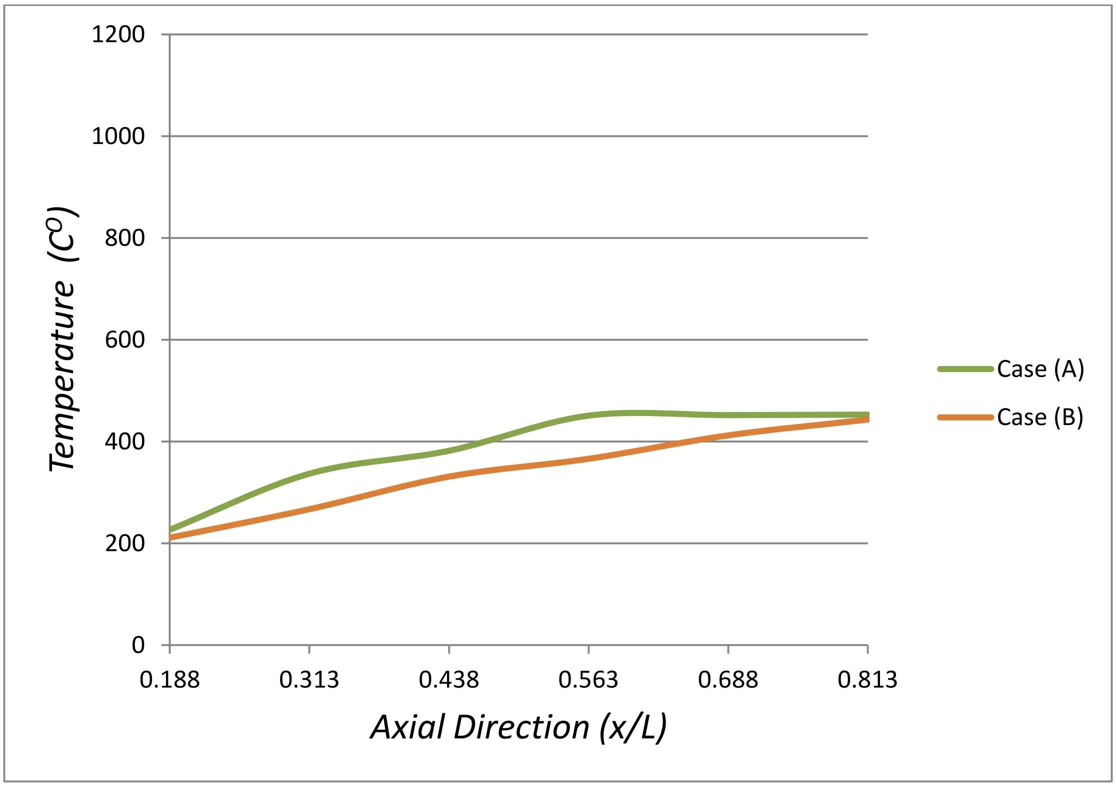


Fig 4.14 Comparison of the temperature distribution in axial direction at the wall (r/R=0) combustion chamber, for case (A & B) (Inlet secondary air from back).

Table 4.15 Comparison of the temperature distribution in radial direction at the outlet combustion chamber, for case (A & B) (Inlet secondary air from front).

Case (A)		Case (B)	
r/R	*Temperature(C^O)*	*r/R*	*Temperature(C^O)*
0	411	*0*	434
0.2	765	*0.2*	755
0.4	813	*0.4*	834
0.6	843	*0.6*	832
0.8	872	*0.8*	856
1	887	*1*	883

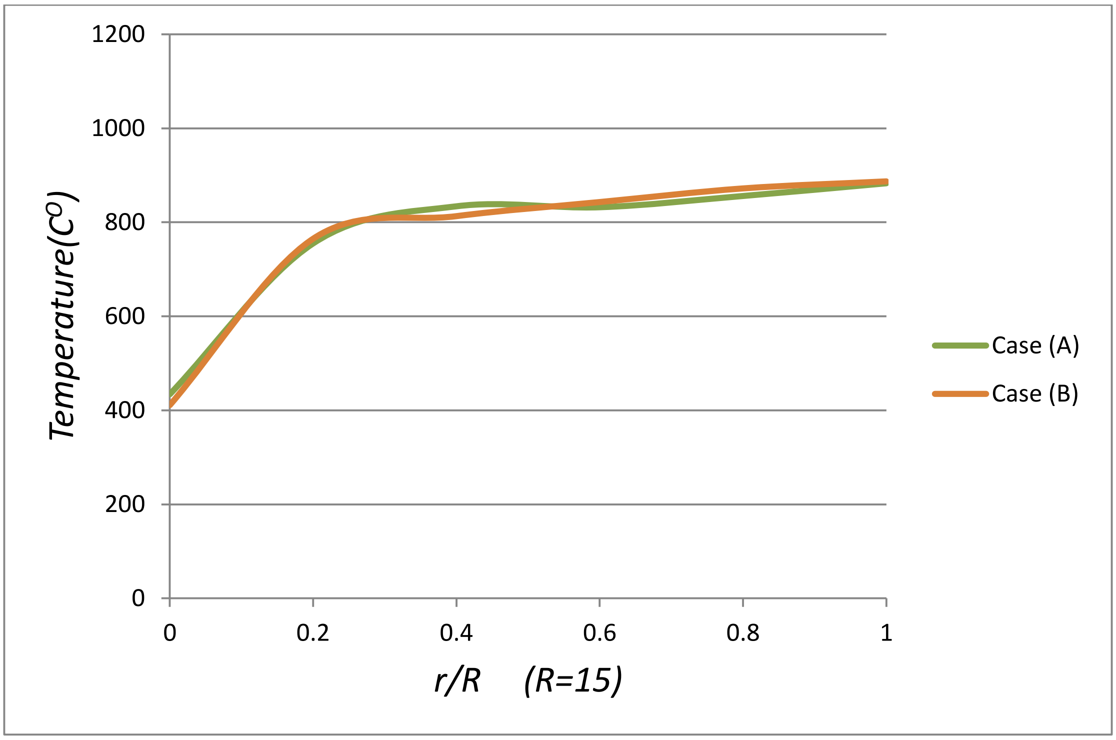


Fig 4.15 Comparison of the temperature distribution in radial direction at the outlet combustion chamber, for case (A & B) (Inlet secondary air from front).

Table 4.16 Comparison of the temperature distribution in radial direction at the outlet combustion chamber, for case (A & B) (Inlet secondary air from back).

Case (A)		Case (B)	
r/R	*Temperature(C^O)*	*r/R*	*Temperature(C^O)*
0	*443*	*0*	453
0.2	*743*	*0.2*	788
0.4	*831*	*0.4*	875
0.6	*883*	*0.6*	875
0.8	*909*	*0.8*	897
1	*966*	*1*	910

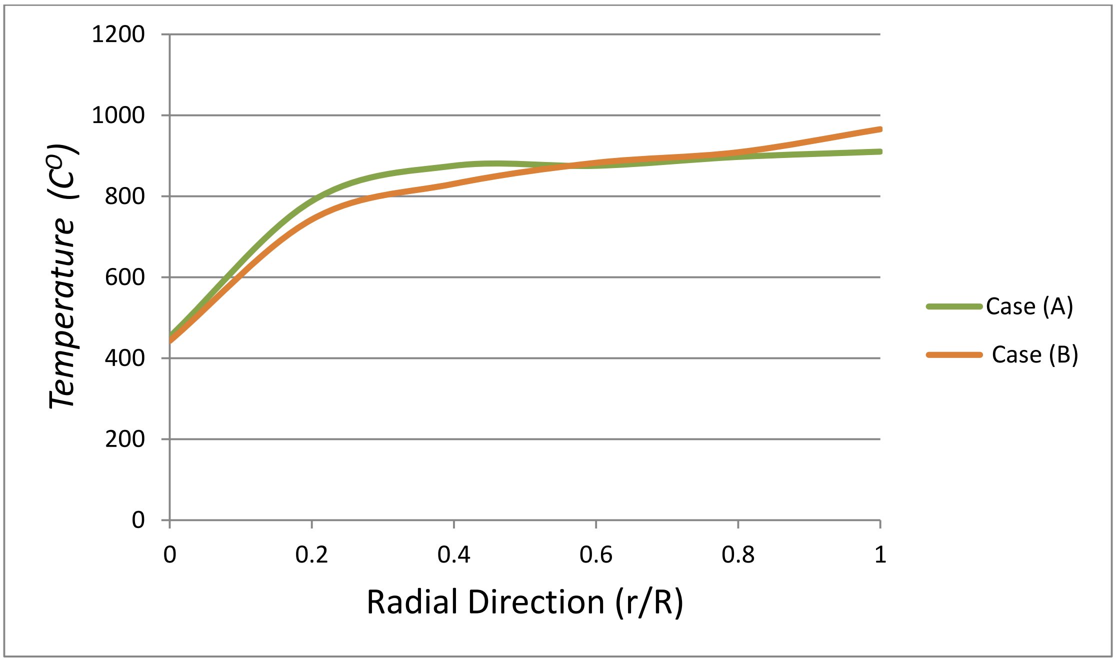


Fig 4.16 Comparison of the temperature distribution in radial direction at the outlet combustion chamber, for case (A & B) (Inlet secondary air from back).

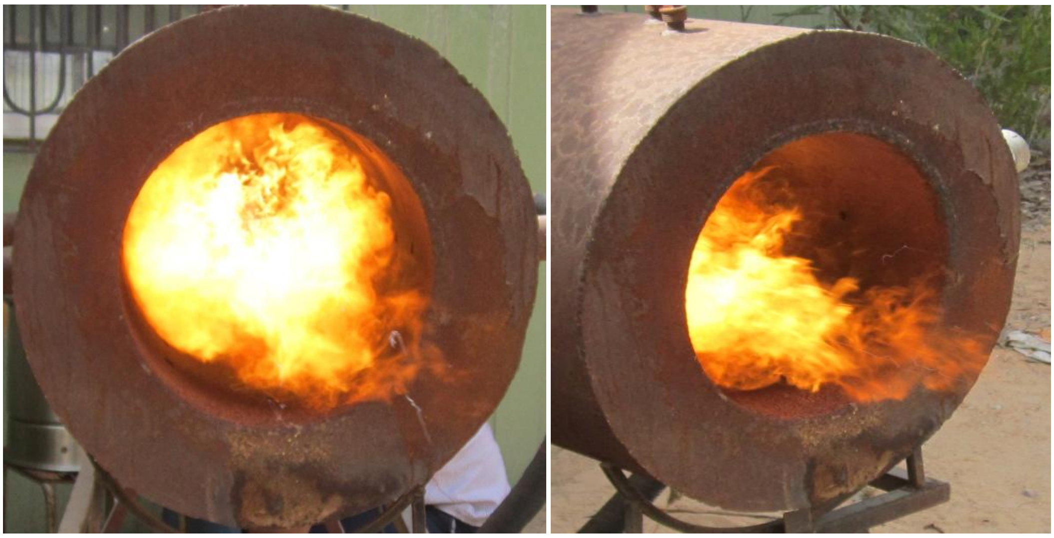


Photo. (4.1) With primary air swirl only

Photo. (4.2) With primary air and secondary swirl (Case A)

Photo. (4.3) With primary air and secondary swirl (Case B)

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions:-

The conclusions obtained from the experimental results summarized as the following:-

1- The temperatures distribution at the wall of the combustor flame tube for cases (A & B), When the secondary air inlet from the front of the combustor are better than from the back.

2- The temperatures for case (A) (Low secondary air swirl) near the wall of the combustor flame tube are low, and very high in the region of the flame. But the difference between the temperatures are very large at upstream (x/L=0.313 to x/L=0.563).

3- The temperatures for case (B) (High secondary air swirl) near the flame tube wall are lower, and the temperatures distribution all over the combustor are good.

4- The temperatures distribution at outlet are nearly the same for case (A & B), But a little lower, and more uniform when the inlet of the secondary air between the flame tube and casing of the combustor from front of the combustor.

5- The flame with primary air swirl only is filling the combustor flame tube, and along the combustor length.

6- The flame with secondary air swirl case (A) there is a reduction in the flame diameter and flame length, and the flame is turning around away from the flame tube wall and stable.

7- For case (B) the flame more stable, smaller in diameter, and shorter.

8- The increase of secondary air swirl gives more time for the fuel droplet inside the flame reign to burring completely.

9- Increasing of the swirl strength decreases the flame diameter and length that refer to reduce the size of the combustion chamber to become smaller and cheaper.

5.1 Recommendations :-

Through this experimental research we recommend more work on the diameters of the hole of the secondary entry and its angles.

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