AIN SHAMS UNIVERSITY

FACULTY OF ENGINEERING

# INVESTIGATION OF COMBUSTION UTILIZING NON-CIRCULAR PORTS

*By*

**Osama Ahmed Metwally Hassan Kashkousha**

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**A Thesis Submitted in Accordance with the Requirements for the Degree of Master of Science**

Under Supervision of

**Prof. Dr. Mahmoud Abd El-Rasheed Nosir**

Professor at the Mechanical Power Department

Faculty of Engineering

Ain Shams University

**Dr. Abd El-Aziz Morgan Abd El-Aziz**

Associate Professor at the Mechanical Power Department

Faculty of Engineering

Ain Shams University

**Dr. Mahmoud Mohamed Kamal**

Associate Professor at the Mechanical Power Department

Faculty of Engineering

Ain Shams University

**Cairo**

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## Examiner Committee

The undersigned certify that they have read and recommended to the faculty of engineering , Ain Shams University for acceptance a thesis entitled by **"Investigation of Combustion Utilizing Non – circular Ports"**, submitted by Osama Ahmed Metwally Hassan Kashkousha, in partial fulfillment of the requirements for the degree of Master of Science in Mechanical Power Engineering.

| | **Name** | **Signature** |
|---|---|---|
| 1. | **Prof. Dr. Hendawy Salem Mohamed**<br>Mechanical Power Department<br>Faculty of Engineering<br>Cairo University | |
| 2. | **Prof. Dr. Adel Abd El Malek El Ahwany**<br>Mechanical Power Department<br>Faculty of Engineering<br>Ain Shams University | Adel E |
| 3. | **Prof. Dr. Mahmoud Abd El-Rasheed**<br>Mechanical Power Department<br>Faculty of Engineering<br>Ain Shams University | M.A.A |
| 4. | **Dr. Mahmoud Mohamed Kamal**<br>Mechanical Power Department<br>Faculty of Engineering<br>Ain Shams University | M.M.Kamal |

# Statement

This dissertation is submitted to Ain Shams University in fulfillment of the requirements for the degree of Master of Science in Mechanical Engineering.

The work included in this thesis was made by the author during the period from October 2009 to January 2012 at the Mechanical Power Engineering Department, Ain Shams University.

No Part of this thesis has been submitted for degree or qualification at any other university or institute.

| | | |
|---|---|---|
| **Date** | : | 4-11-2012 |
| **Signature** | : | O. A. Kashkousha |
| **Name** | : | **Osama Ahmed Metwally Hassan Kashkousha** |

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# ABSTRACT

Combustion Control using Elliptic jets issued from elliptic nozzles has gained a lot of interest during the last four decades due to the obtained favorable aerodynamic features and enhanced mixing characteristics of two flowing streams of fluids than two dimensional jets issued from circular nozzles. These efforts were done in response to the increased demands for higher efficiency burners for various industrial applications.

Burner nozzle element was designed and equipped to the combustor rig to carry out the proposed investigation experimentally of the characteristics of diffusion flames for three elliptic burner nozzles of different aspect ratios; 1.6, 2, 3.3 respectively. Flame Temperature, turbulence Characteristics as well as emissions [CO, $NO_X$, UHC…] were measured and compared to those of diffusion flames issued from circular nozzles of equivalent cross section area.

Four burner nozzle configurations were investigated; single elliptic burner nozzle in circular co – flow, applied cross flow admissions on diffusion flames issued from elliptic burner nozzle, two concentric nozzles configurations using biased injection element [this configuration was applied for normal diffusion flames and for inversed diffusion flames].

Numerical simulations were performed for the four configurations to predict and estimate the expected experimental flame properties and predicting the optimized firing conditions when using burners equipped with elliptic nozzles.

It was found that a single elliptic burner nozzle of aspect ratio 3.3 produced the lowest carbon monoxide concentration level indicating more oxidation of carbon monoxide to carbon dioxide as a result of the enhanced air entrainment into the jet core. This occurred due to the effect of further increase of nozzle aspect ratio.

Retarding the cross flow reduced the CO concentrations as the premixing effect increased the rate of oxidation of CO into $CO_2$. The reduction of $NO_X$ concentrations was recorded due to the increased level of homogeneity and reduced local peak flame temperatures. These effects reduced the formation of $NO_X$ according to the Zeldovich Mechanism.

Favorable interaction zones resulted due to varying the modulating angle between the inner and outer nozzles in two concentric nozzles configuration.

Inversed diffusion flames issuing from elliptic nozzles had reduced CO concentrations due to the enhanced mixing and combustion rates upon increasing the number of active points in the unburned regions.

The peak turbulent kinetic energy was maximized at the major axis tips to pronounce increased jet entrainment by 478% in comparison to concentric circular jets. Increasing the aspect ratio from 1.6 to 3.3 nearly duplicated the peak turbulent kinetic energy and resulted in 9% increase in the combustion efficiency with 25% UHC reduction. As dominated by the peak turbulent energy merging, the optimum angular positioning of the two jets was $35^o$ for higher inner jet velocity. For lower inner jet velocity, the best angular positioning was 45 and $30^o$ for higher and lower inner aspect ratio, respectively. By introducing radially opposing air jets, the optimum angular positioning decreased to $25^o$ as the flame was shortened by about 43%. The multi-stage air cross-flow revealed more aerodynamic features. Using less number of stages and increasing the cross-flow admission distance to 20 cm at increased cross-flow percent to 70% minimized the average UHC and $No_x$ emissions. The optimum performance was thus found when lifted flame premixing features were coupled with the impinging cross-flow stabilizing effects

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# Nomenclature

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|---|---|
| A | Cross section Area [$m^2$] |
| $A_j$ | Junction Surface Cross section area [$m^2$] |
| $C_d$ | Coefficient of Discharge. |
| D | Equivalent Diameter [mm] |
| $D_a$ | Damköhler number, |
| E | Activation Energy [W] |
| $\triangle H$ | Pressure Head [m] |
| $l_k$ | Kolomogrov' s length scale |
| $l_d$ | Diffusive Layers length |
| $m^o$ | Mass Flow rate [kg/sec] |
| $\triangle P$ | Pressure Difference [bar] |
| Q | Mass Flux at particular location [kg/m $^2$ .s] |
| $Q_o$ | Mass Flux at nozzle exit with equivalent diameter [kg/m $^2$ .s] |
| $T_a$ | Activation Temperature [K] |
| $T_f$ | Flame Temperature [K] |
| $T_j$ | Junction Temperature [K] |
| $T_w$ | Wall Temperature [K] |
| U | Mean Axial Velocity at a particular location [m/s] |
| $U/U_o$ | Normalized Axial Velocity |
| $U_{Conv}$ | Convection Heat Transfer Coefficient [Watt/$m^2$.K] |
| $U_o$ | Mean Exit Velocity at a particular location [m/s] |
| x/D | Axial distance to Jet Diameter Ratio |