

# **Numerical Investigation of NO<sub>x</sub> and CO Formation in a 200 kW Swirl Burner**

**By**

**Eng. Abdallah Abdelaty Zaki Ahmed**

**A Thesis Submitted to the**

**Faculty of Engineering at Cairo University**

**In Partial Fulfillment of the Requirements for the Degree of**

**MASTER OF SCIENCE**

**In**

**MECHANICAL POWER ENGINEERING**

**FACULTY OF ENGINEERING, CAIRO UNIVERSITY**

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**Under Supervision of**

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**Title of Thesis: NUMERICAL INVESTIGATION OF NO<sub>x</sub> AND CO FORMATION IN A 200 kW SWIRL BURNER**

**Key Words:** Combustion, Swirl, NO<sub>x</sub> emissions, CO emissions, CFD.

**Summary:**

A CFD model of the Swirl Burner has been tested and evaluated using FLUENT. The Swirl Burner was modelled using a 2D structured grid consisting of about 45,000 cells with an average skewness of 0.04. Three turbulence models were tested on a cold flow with a flow rate equivalent to 200 kW. These were the k- $\epsilon$  model, the Realizable k- $\epsilon$  model and the Reynolds Stress Model (RSM). Based on an evaluation of the models ability to predict a central toroidal recirculation zone of this strong swirling flow ( $S>0.6$ ) and recommendations from literature, the RSM was chosen for further modelling of the reacting flow. With the RSM turbulence model, three different combustion models were tested. These models were the Eddy Dissipation model, the PDF-based Equilibrium model and the PDF-based Flamelet model. For the reaction models, the Eddy Dissipation model predicted peak flame temperatures higher than the adiabatic flame temperature for a propane-air mixture and was therefore dismissed. The Flamelet PDF model was chosen for the modelling of the swirl burner due to its ability to account for non-equilibrium chemistry. The decision of choosing the Flamelet PDF model was also based on recommendations found in literature.

Effect of swirl number, excess air factor, fuel dilution with N<sub>2</sub> and CO<sub>2</sub>, oxidizer preheating, and oxidizer composition on NO<sub>x</sub> and CO emissions at the combustion chamber exit were studied. Peak flame temperature is the dominating parameter, which controls NO<sub>x</sub> and CO Emissions. The higher flame temperature resulted, the higher NO<sub>x</sub> and CO emissions level formed.

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# Nomenclature

## Symbols and Quantities

$a$	Sonic speed
$C$	Constant
$c_p$	Constant pressure specific heat
$D$	Diffusion coefficient
$E$	Total Energy of fluid particle
$\vec{F}$	External Body Forces
$g$	Acceleration of gravity
$G_k$	Generation of turbulence kinetic energy due to mean velocity gradients
$G_b$	Generation of turbulence kinetic energy due to buoyancy
$h$	Enthalpy
$\vec{J}_i$	Diffusion flux of species $i$
$k$	Thermal conductivity
$M$	Mach number
$M_w$	Molecular Weight
$p$	Pressure
$Pr$	Prandtl number
$Q$	Volumetric flow rate
$R_i$	Rate of production of species $i$
$S$	Source term
$Sc$	Schmidt number
$T$	Temperature
$u_j$	Velocity magnitude in direction of $x_j$
$\vec{v}$	Velocity vector
$V$	Room volume
$Y_i$	Mass fraction of species $i$
$x, y, z$	Cartesian co-ordinate components

## Greek Letters

$\delta$	Boundary Layer thickness
	Differential
$\bar{\bar{\tau}}$	Stress tensor
$\sigma$	Turbulent Prandtl number
$\epsilon$	Turbulence dissipation rate
$\mu$	Dynamic viscosity
$\rho$	Density
$\nabla$	Gradient
$\beta$	Thermal expansion coefficient

## Superscripts and Subscripts

—	Mean property
'	Fluctuating component of any property
b	Buoyancy
i	Counter
ij	Indicates two different Cartesian coordinates
k	Turbulent kinetic energy
m	mass
p	point node property
t	Turbulent quantity
w	Wall property
$\mu$	Dynamic viscosity