Numerical Investigation of NOx 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

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Title of Thesis: NUMERICAL INVESTIGATION OF NOx AND CO FORMATION IN A 200 kW SWIRL BURNER

Key Words: Combustion, Swirl, NOx 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-ε model, the Realizable k-ε 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_2 and CO_2, oxidizer preheating, and oxidizer composition on NO_x and CO emissions at the combustion chamber exit were studied. Peak flame temperature is the dominating parameter, which controls NOx and CO Emissions. The higher flame temperature resulted, the higher NOx 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
Mw	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

δ	Boundary Layer thickness
	Differential
$\bar{\bar{\tau}}$	Stress tensor
σ	Turbulent Prandtl number
ε	Turbulence dissipation rate
μ	Dynamic viscosity
ρ	Density
∇	Gradient
β	Thermal expansion coefficient

Superscripts and Subscripts

$\bar{\ }$	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
μ	Dynamic viscosity