High Intensity Low Emission Burners- Insights through Experiments and Computations

Sudarshan Kumar, P.J. Paul and H.S. Mukunda

Combustion, Gasification and Propulsion Laboratory

Department of Aerospace Engineering

Indian Institute of Science

Bangalore-560 012 (INDIA)

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- Introduction
- Previous Work
- Present Work
- Experiments and computations
- Results and Discussion
- Conclusions

Introduction

- Aim of a combustion engineer is to develop a system with
  - a) High Efficiency
  - b) Low emissions

Which needs

Basic research and its application to a practical problem, knowledge of theory and practice in both directions.

Different methods for Reducing emissions

Flame cooling

Staging

Exhaust gas Recirculation

Reburning and so on

Our main focus will be on

Recirculation of the combustion products into the fresh incoming air and fuel. This leads to

1. Decrease in the concentrations.
2. Increase in the temperature of reactants.

Which results in

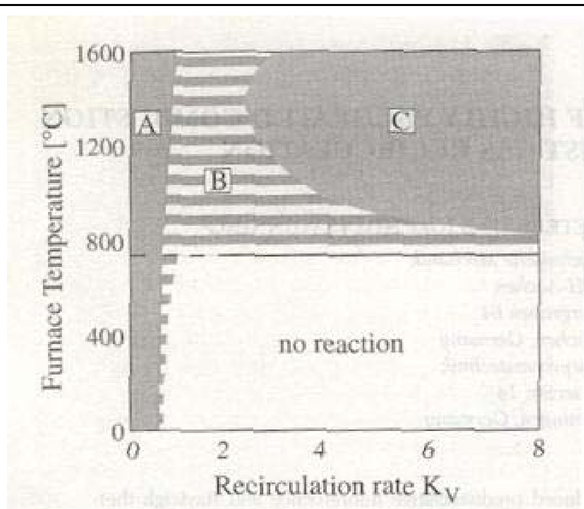
1. Reduced reaction rates due to very low reactant concentrations.
2. Reduced peak temperature.
3. Reduced NOx emissions.
4. Low temperature gradients
5. Low heat release rate(density, heat release per unit volume)

Previous Work:

Various configurations are studied for the aerodynamic, thermal and chemical characteristics. The configurations studied are

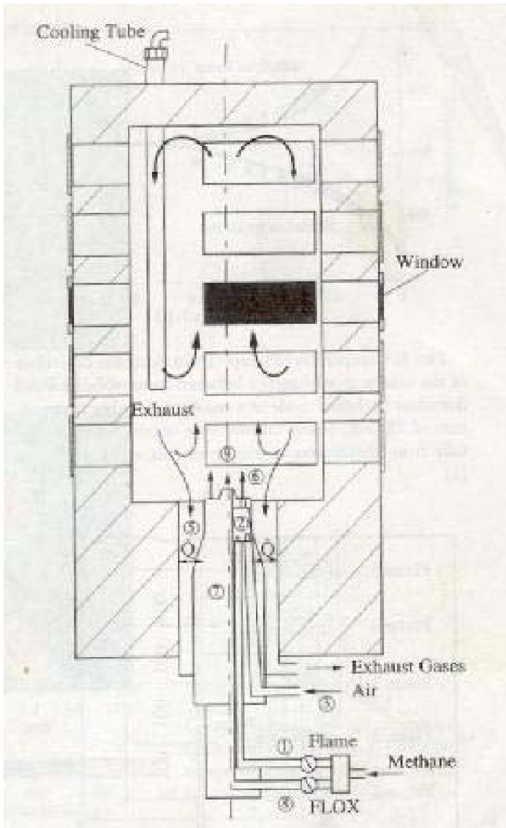
1. Starting work by Wunning et. al.
2. Opposed flow geometry
3. Regenerative and recuperative Burners

Recirculation rate Vs. Flame Stability:



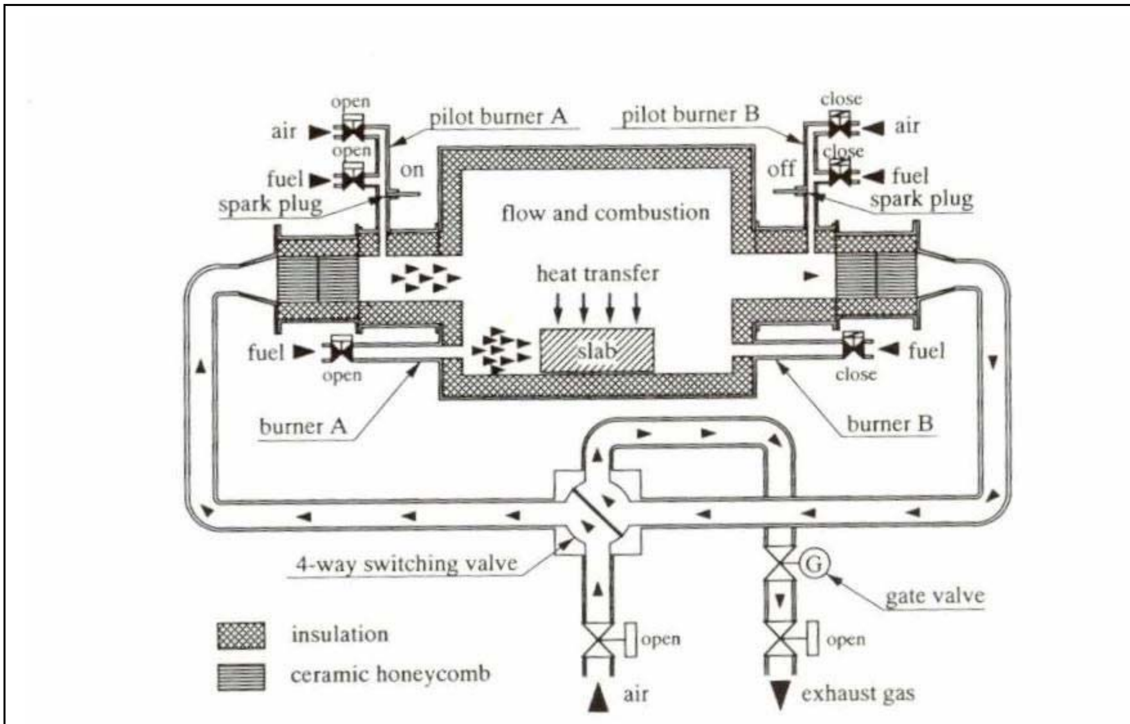
a. For burner stabilized flames, the recirculation rate is limited to 0.3.
b. For the intermediate rates, the flame will lift off and finally blow out for temperatures below fuel ignition.
c. For very high recirculation rates again the combustion becomes stable.

Reverse flow furnace:



- Plessings et al, Ozdemir et al., Coelho et al. have measured the peak temperature, peak NO_x in ppm, instantaneous temperature and OH radical fields.
- The peak temperature measured is below 1650 K and NOx emissions are app. 10 ppm and EINOx is ~17 g/kg of fuel.
- The heat release density is ~320 kW/m^3.

Regenerative and Recuperative Burner:

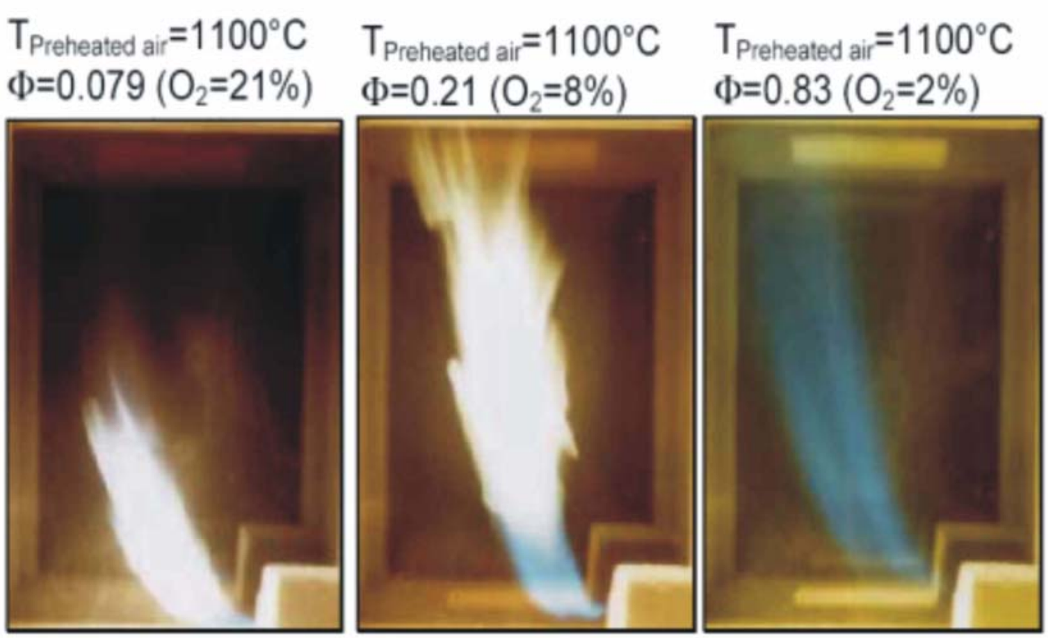


- Regenerators are used to preheat the incoming air to high temperatures.
- The firing cycle time is varied between 20-50 s.
- The heat release density is ~23 kW/m^3.(Weber et. al.)
- Two factors decided to get more insight in to the combustion process.

a. Mixing Factor = $\frac{kg(O_{2,} reacted)}{kg(O2, reacted) + kg(O_{2,} needed)}$

b. Degree of Oxidation = $\frac{(kg(O_2)/kg(fuel))_{flamepoint}}{(kg(O_2)/kg(fuel))_{stoichiometric}}$

- Plots of degree of oxidation and mixing factor are similar, thus indicating that to a leading order the combustion is mixing controlled.
- Boltz et. al. studied various flame characteristics like flame size, colour with change in air preheat temperature and Oxygen concentration.

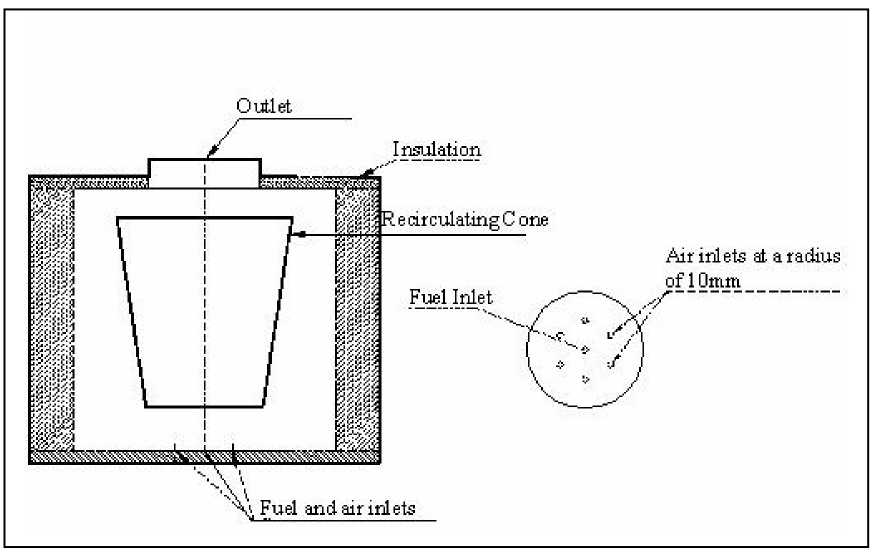


Propane flame photographs with combustion air temperature of 1100°C and O_2 conc. (from left to right) of 21%, 8% and 2% (Nitrogen as the dilution gas).

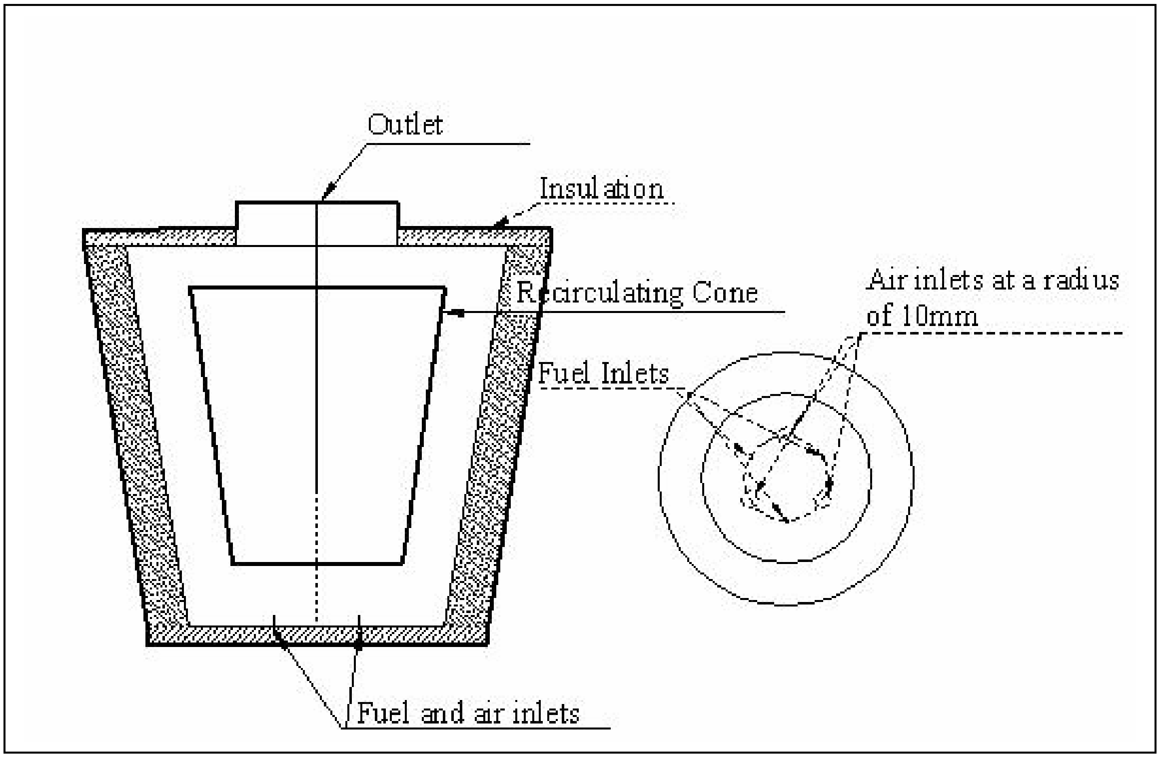
- **The following points are worth noting from the previous work**.
  1. The heat release density of the burners is very low i.e. ranging from 23 kW/m^3 to 320 kW/m^3.
  2. A reverse flow geometry and a cyclic regenerative burner are used for the experiments.
  3. No detailed study of the recirculation rates.
- **This necessitates the addressing of the following questions.**
  1. The fuel jet behavior in a high temperature low oxidizer concentration medium which occurs their during mild combustion.
  2. Study of the mechanisms responsible for extinction in mild combustion mode.
  3. Optimisation of recirculation rates for maximum efficiency.
  4. Enhancement of the limits of mild combustion i.e. using reactants at atmospheric temperature.

Present work:

The main aim is to conceptualize a configuration to attain mild combustion with low pollutant and noise emissions while using reactants at atmospheric temperature.

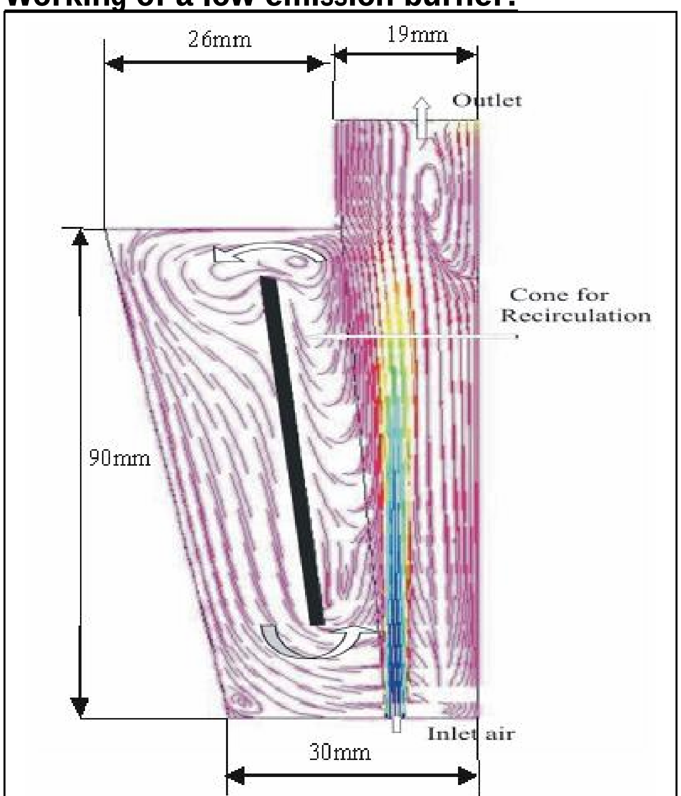


A proposed cylindrical configuration for moderately high recirculation



Modified conical configuration for moderately high recirculation rate and larger heat release rates

Working of a low emission burner:



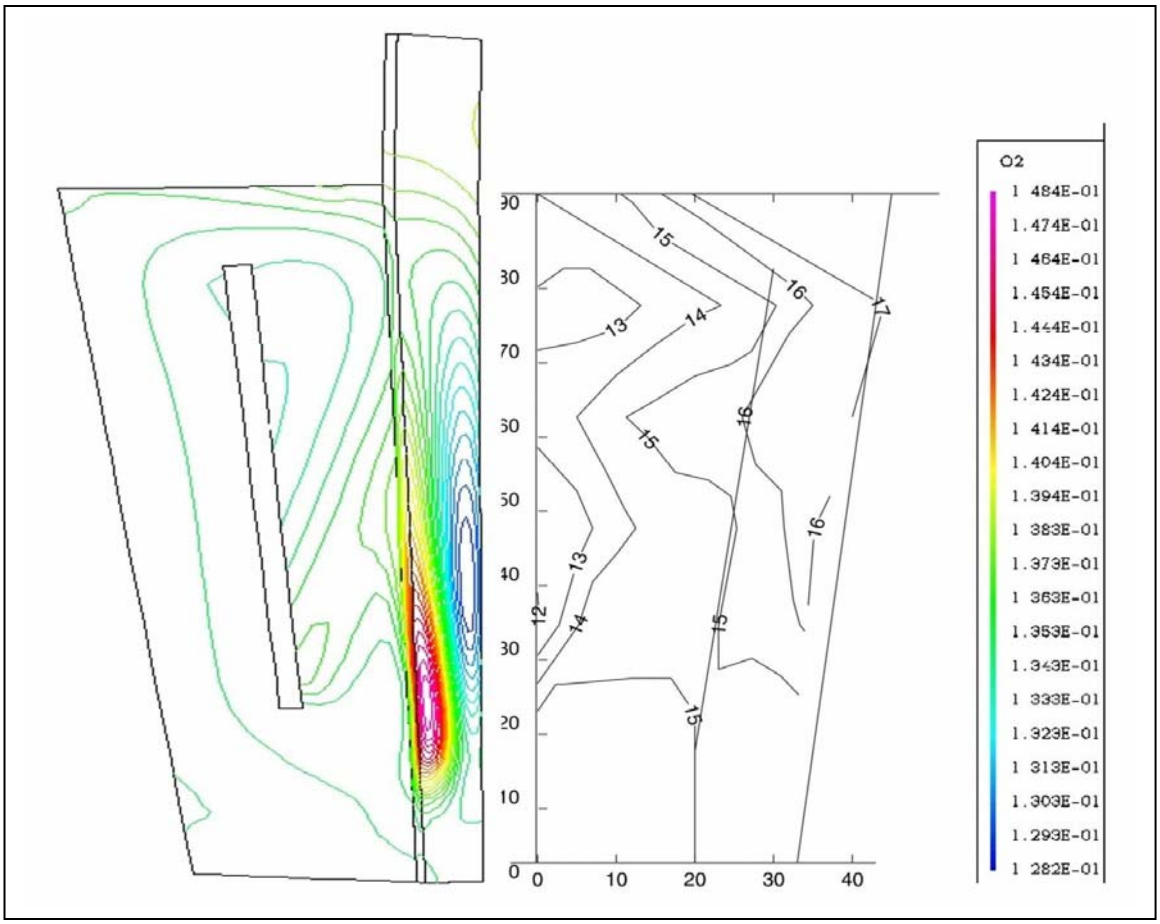
1. The recirculation rates can be varied up to 150% depending upon the size of the outlet and inner cone dimensions.
2. The peak temperature obtained is ~1700 K.
3. The NO_x emissions are 12 ppm.
4. The heat release density is ~5 MW/m^3.

Experimental Work:

Experiments are conducted on burner with following parameters.

1. Fuel flow rate 0.03-0.08 gm/sec
2. Air flow rate was maintained stoichiometric.
3. The corresponding sound level was between 85-90 dBs.
4. LPG is used as fuel.
5. The temperature and species concentrations viz. CH, CO, NO_x and O_2.
6. N_2 and O_2 are used as two different gases to determine the mixing in the configuration.

Experimental and computational results:



Computed and measured Oxygen contours in the burner

The contours show uniform mixing in the combustion volume for cold flow experiments

Temperature Profiles

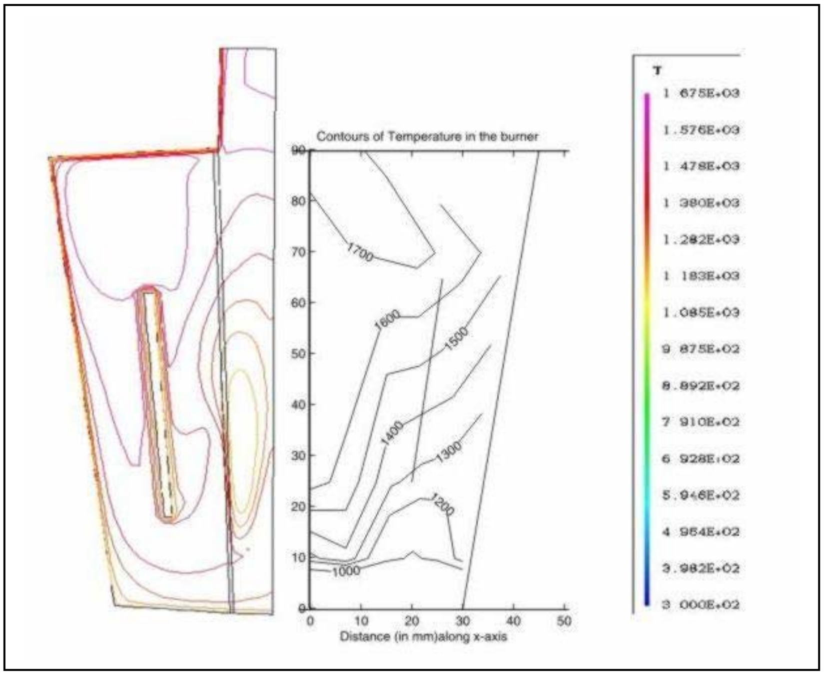


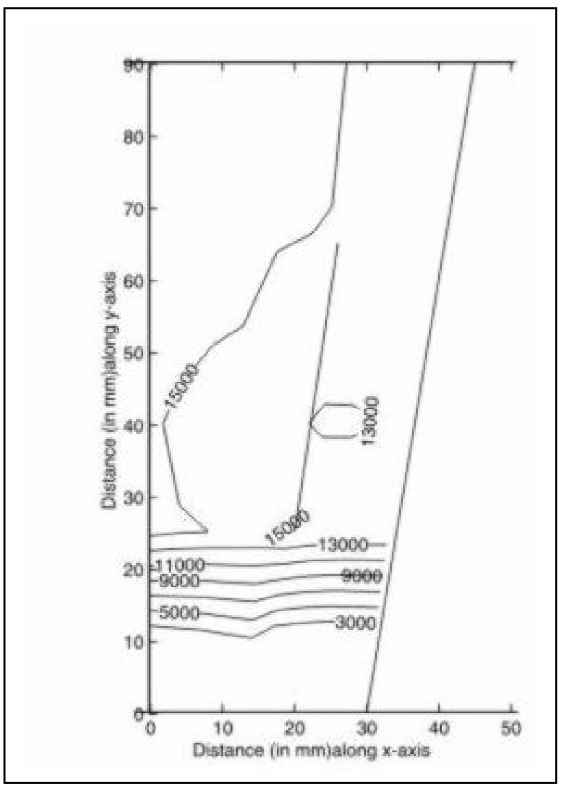
Fig. Measured and predicted temperature profiles

The experimentally obtained temperature is ~1750K.

The computed temperature is ~1700K.

The plots indicate very low temperature gradients in the upper half of the burner.

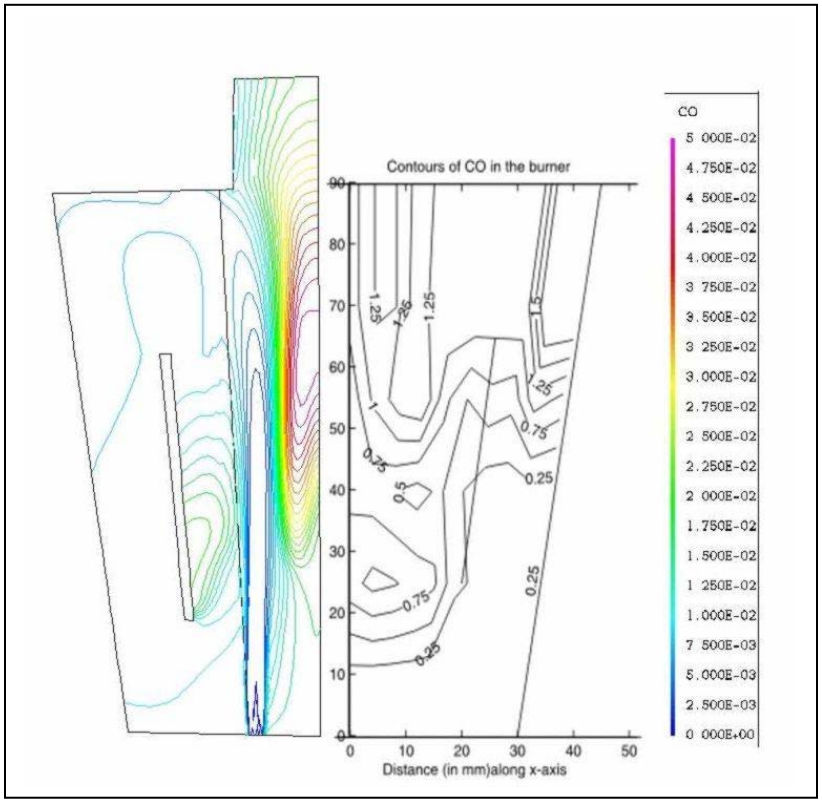
CH concentration plots:



- The figure shows the CH concentration plots. Which approximates the reaction zone.
- The plot indicates that the reaction takes place over the entire upper region in the burner.

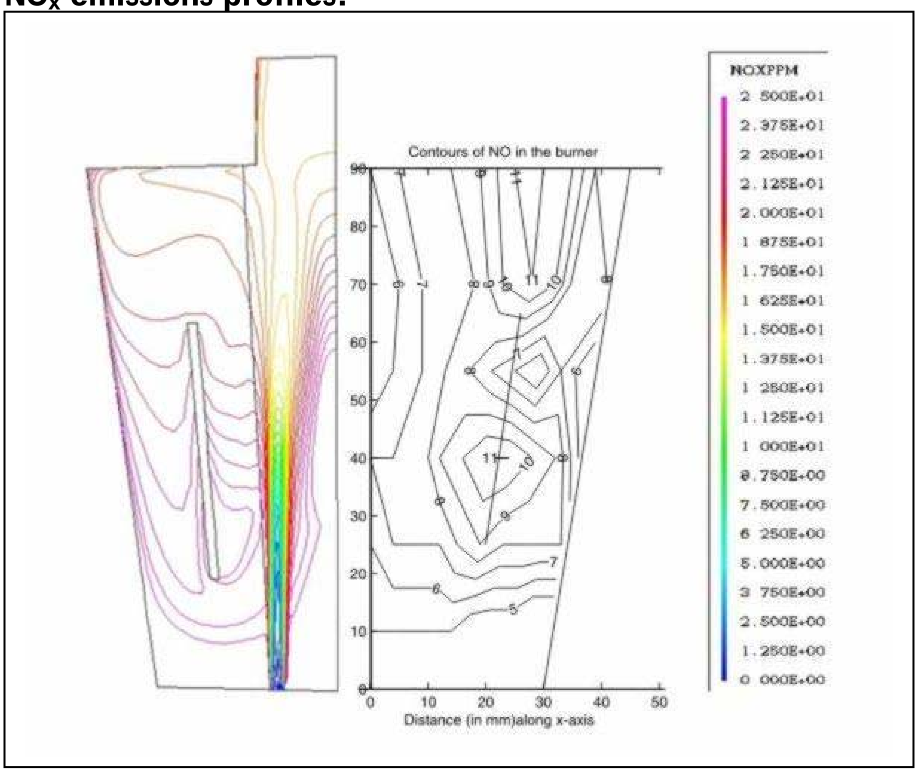
Measured CH concentration plots for the burner

CO concentration profiles:



- The CO emissions at the exhaust are ~1.5-1.7% by volume.
- CO is present in apprec-iable amounts all over the combustion region.
- There is further need to bring CO emissions down.

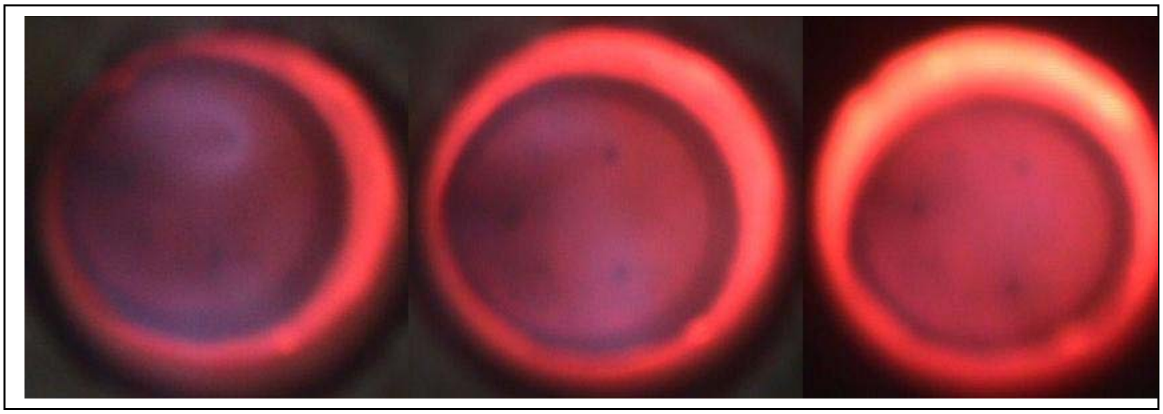
NO_x emissions profiles:



The average NOx emissions at the exhaust are ~12 ppm.

EINOx ≈21 g/kg of fuel

Burner stabilized flame: The highly turbulent flame is seen in picture.



- The photographs shows top view of the reaction zone. (the photograph is taken with a simple digital camera.)
- Red hot walls surrounding the reaction zone are seen. The fuel used is LPG (a mixture of Propane and Butane).
- The air inlets at the bottom are clearly visible.

Conclusions

1. Accomplishment of a combustion mode similar to mild combustion by using reactants at atmospheric temperature.
2. Ultra low NO_x emissions ~12 ppm which corresponds to EI_{NOx} ~26 gm/kg of the fuel.
3. Recirculation rates can be adjusted by two parameters.
    - Varying the inner cone dimensions.
    - Varying the outlet area.
4. The peak temperatures obtained are ~1750 K.
5. The CO emissions are ~1.5% by volume. Excess air probably will help to bring down the CO emissions.