INCREASING OF OPERATIONAL STABILITY IN LOW NO_X GT COMBUSTORS BY RADICALS INJECTION

Y. Levy, A. Gany, Y. Goldman, V.Erenburg,
V. Sherbaum, V. Ovcharenko, L. Rosentsvit
Faculty of Aerospace Engineering, Technion, Israel Institute of Technology

B. Chudnovsky, A.Herszage, A. Talanker,
Israel Electric Company

GENERAL DESCRIPTION OF THE PROBLEM

- Necessity of NO_x reduction in GT stimulates research for new combustion methods.

- Lean combustion is a combustion method where low combustion temperatures is used. It enables to lower NO_x formation.

- Lowering temperature reduces the reaction rate of the hydrocarbon–oxygen reactions and the associated heat release. This deteriorates combustion stability.

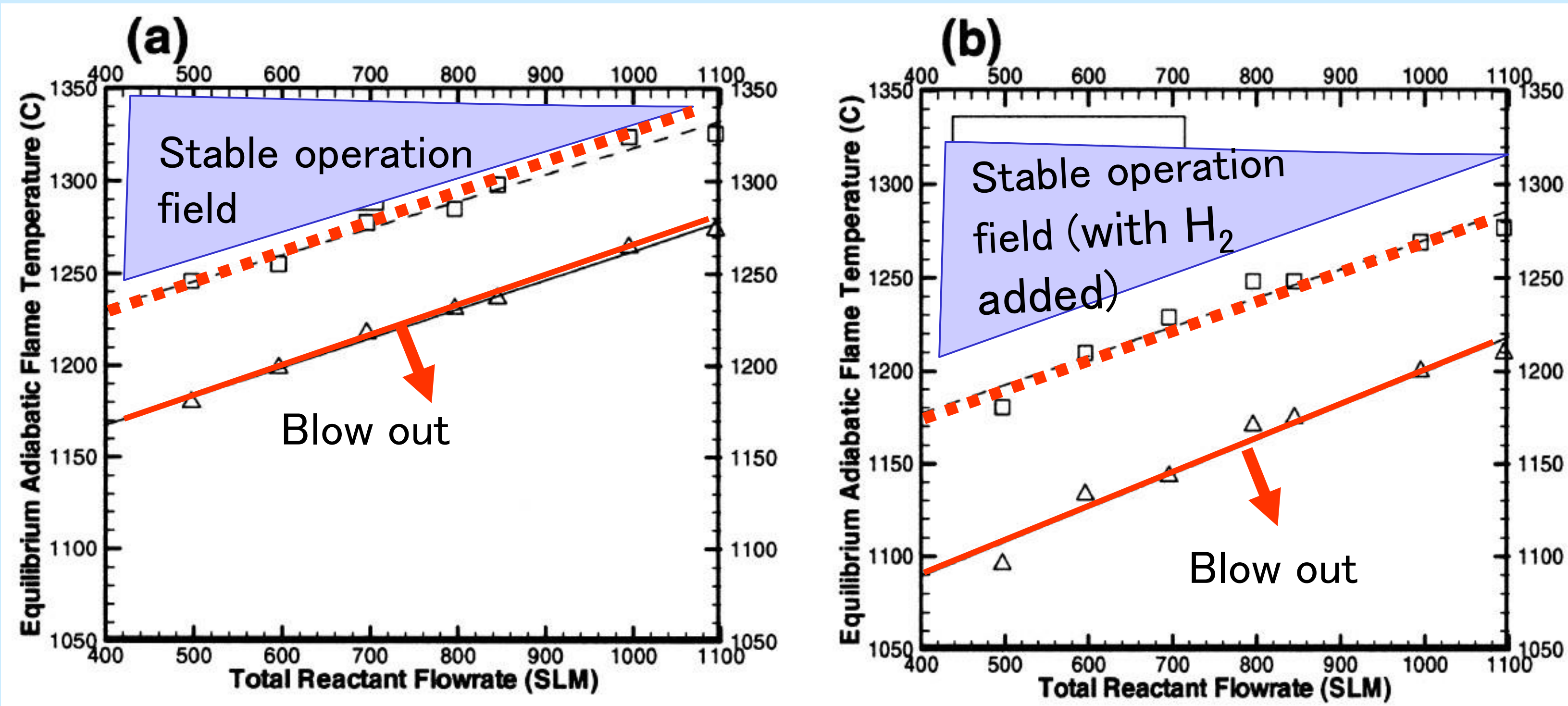
- Combustion instability may cause severe damage to turbine.

·The objective: To investigate the possibility to enhance the combustion stability limit for lean premixed operation mode by injection of radicals.

·How did we try to achieve this objective?

Methodology

- The study is based on the assumption that there is a correlation between the starting point of unstable operation and lean blow out of the premixed fuel and air flame. Such correlation was observed in earlier studies.



(According to: Schefer R.W., Wichsall D.M., Agrawal A.K., 2002)

Methodology (cont.)

- We assumed that if we will be able to decrease the lower limit of the blow out temperature, the lower limit of temperature, which leads to instability, will reduced.

- The effect of radicals on combustion stability was studied.

- Radicals were produced through combustion of rich fuel-air mixture inside a pilot combustor as source of radicals.

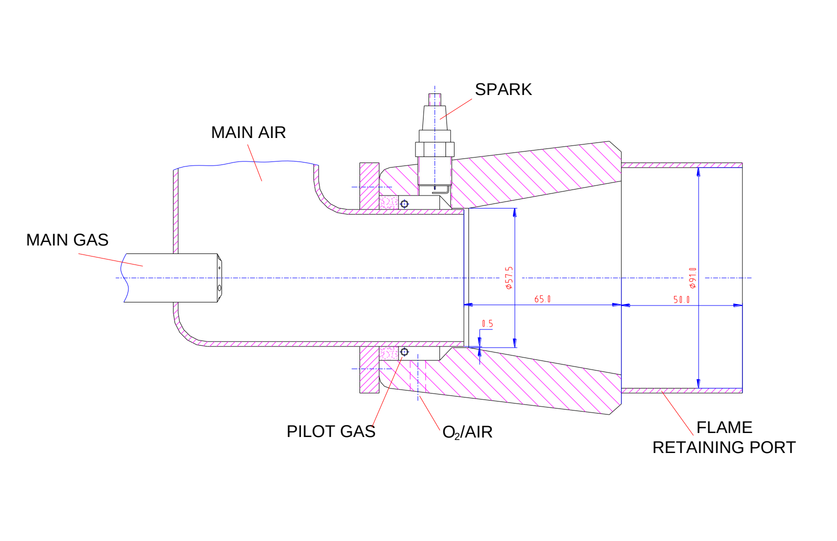
- Tests were carried out under atmospheric pressure.

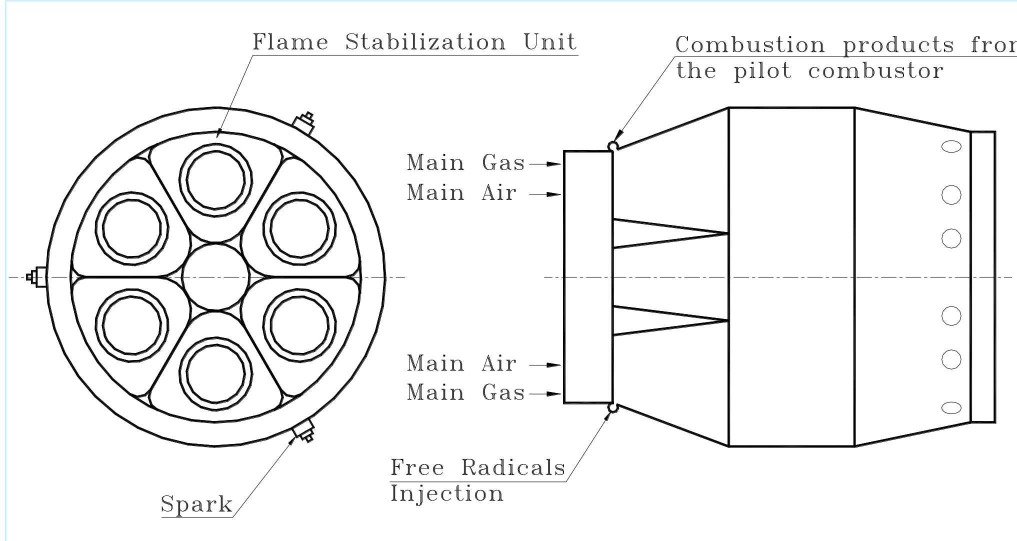
Methodology (cont.)

- CFD simulations were performed to obtain :
- 1) a detailed description of the combustion process;
- 2) test combustor design;
- 3) for the CHEMKIN simulations.

- The CHEMKIN simulations were carried out for conditions as in industrial GT combustor.

Concept of industrial gas turbine combustor

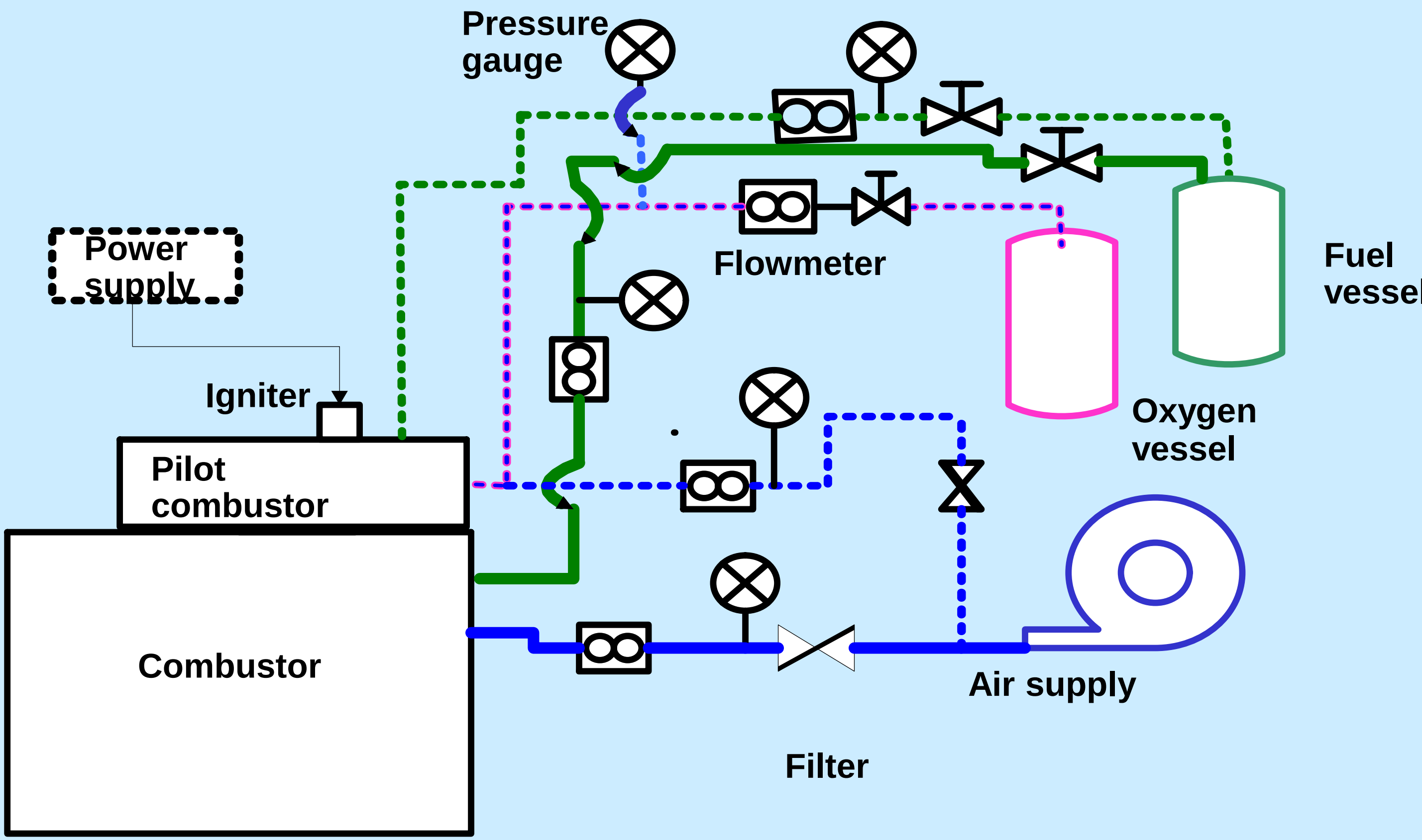




Experimental burner unit.

Turbine’s combustor with its 6 burners

Combustor with radicals injection (schematic)



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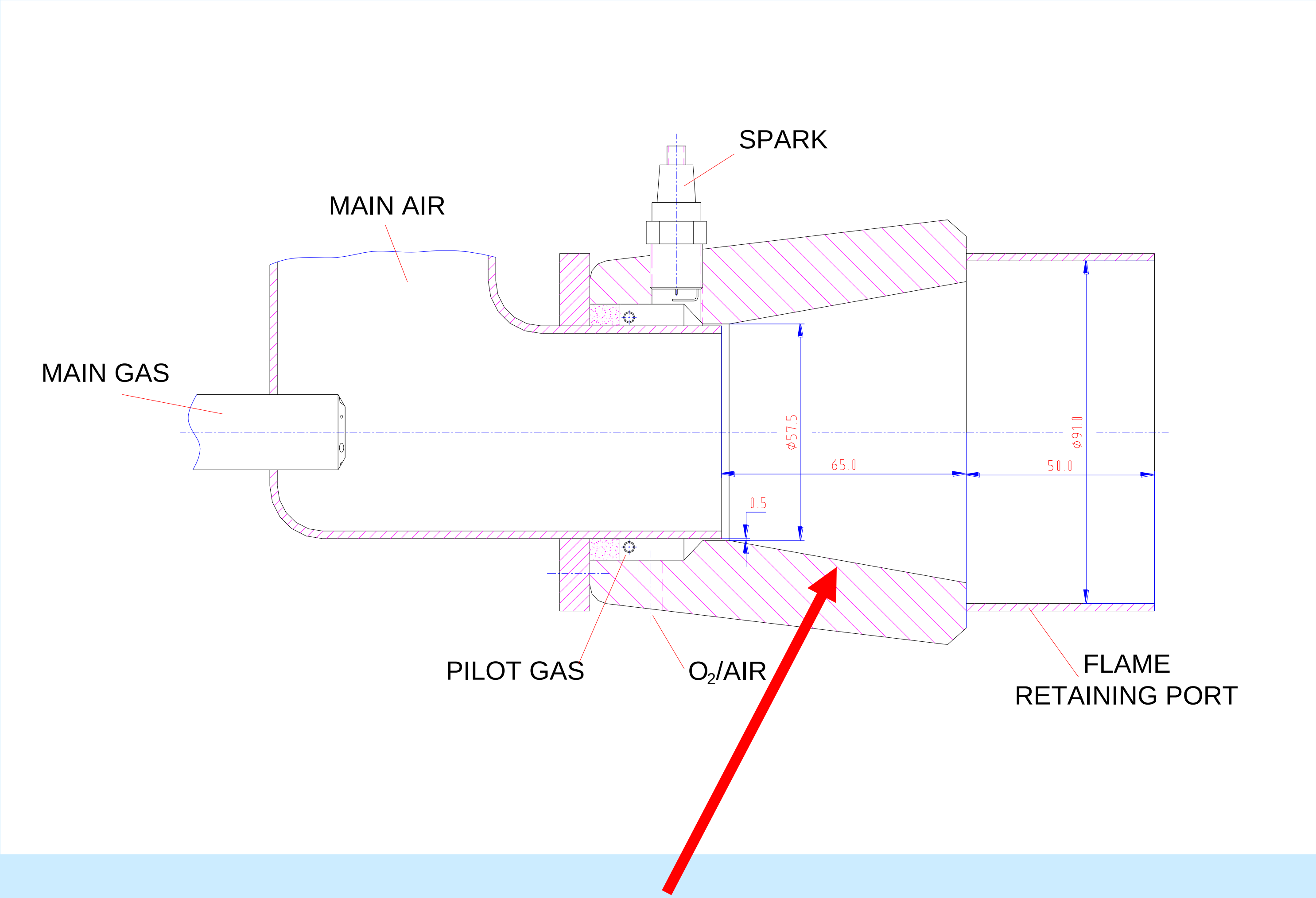
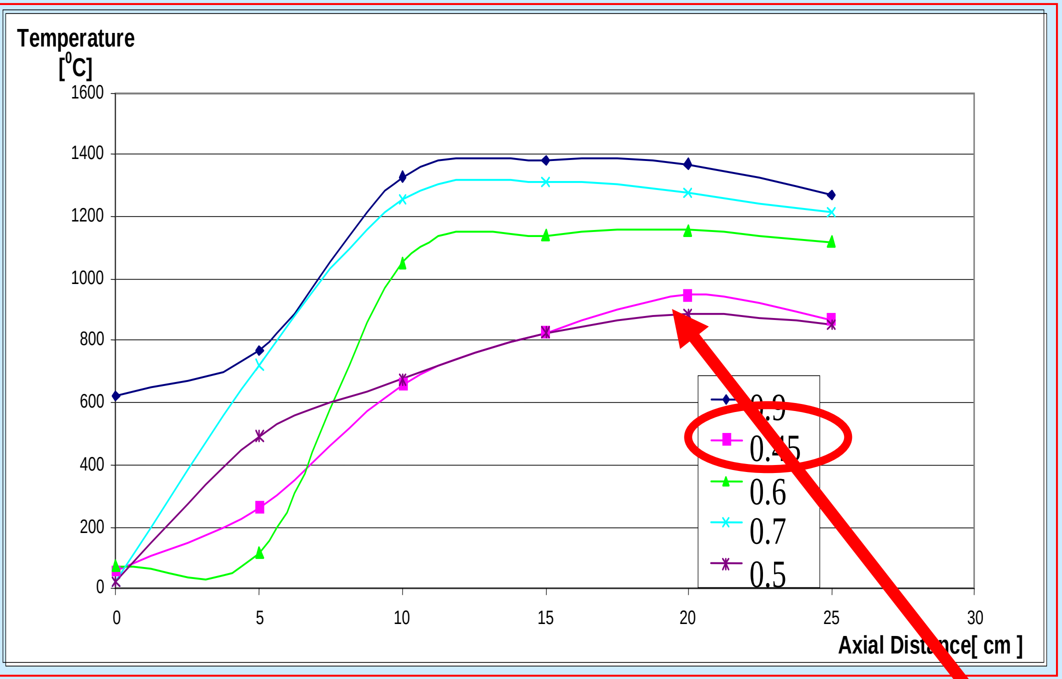
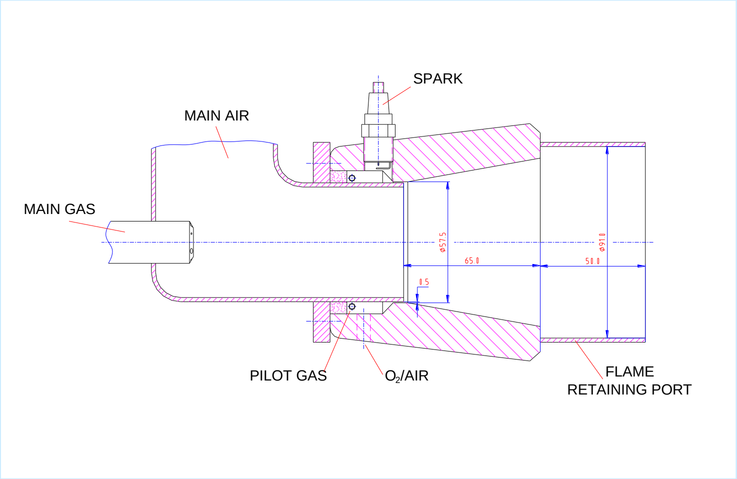
Experimental set-up (schematic)



Cone angle and measurement probes position were obtained from CFD simulation (described later)

TEMPERATURE AT COMBUSTOR AXIS VS. AXIAL DISTANCE





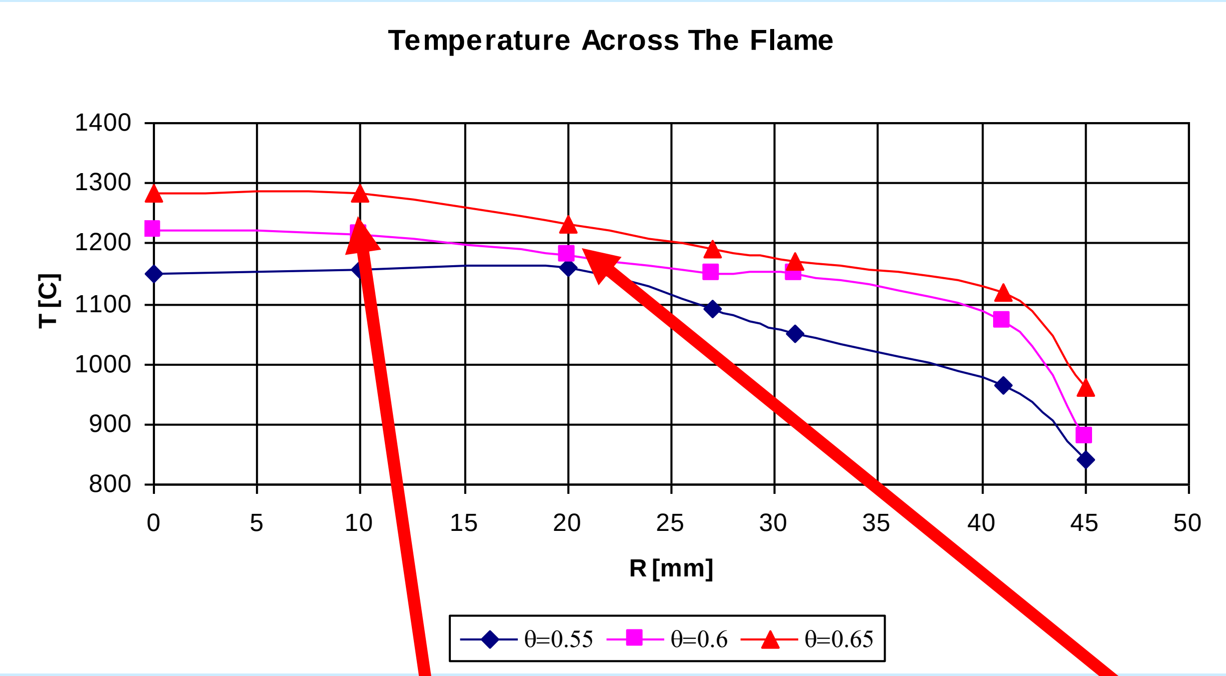
Eq. ratio ϕ definition:

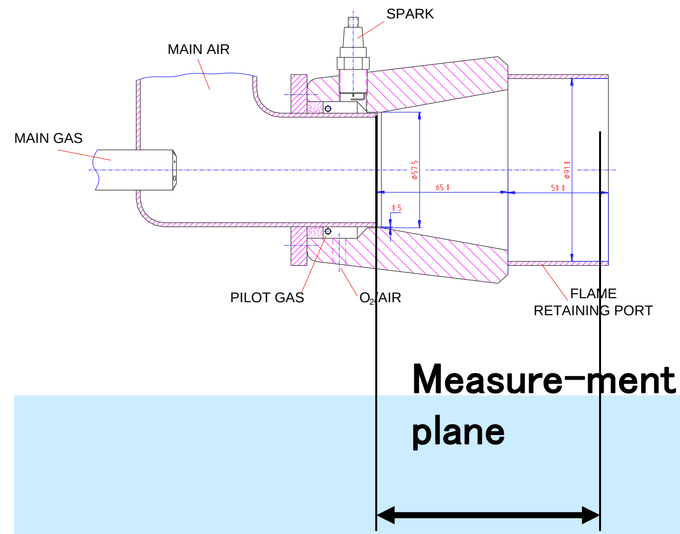
$\varphi = FAR_{act} / FAR_{stoich}$

- Pilot combustor: ϕ_1=1.5, fuel fraction = 5% of main combustor.
- For low global eq. ratio, ϕ_0, maximum temperature is achieved at downstream of the pilot combustor.
- This means that lean mixture requires longer reaction time.
- Typical lower limit in GT is 0.52 –0.55; present value = 0.45

Test Results

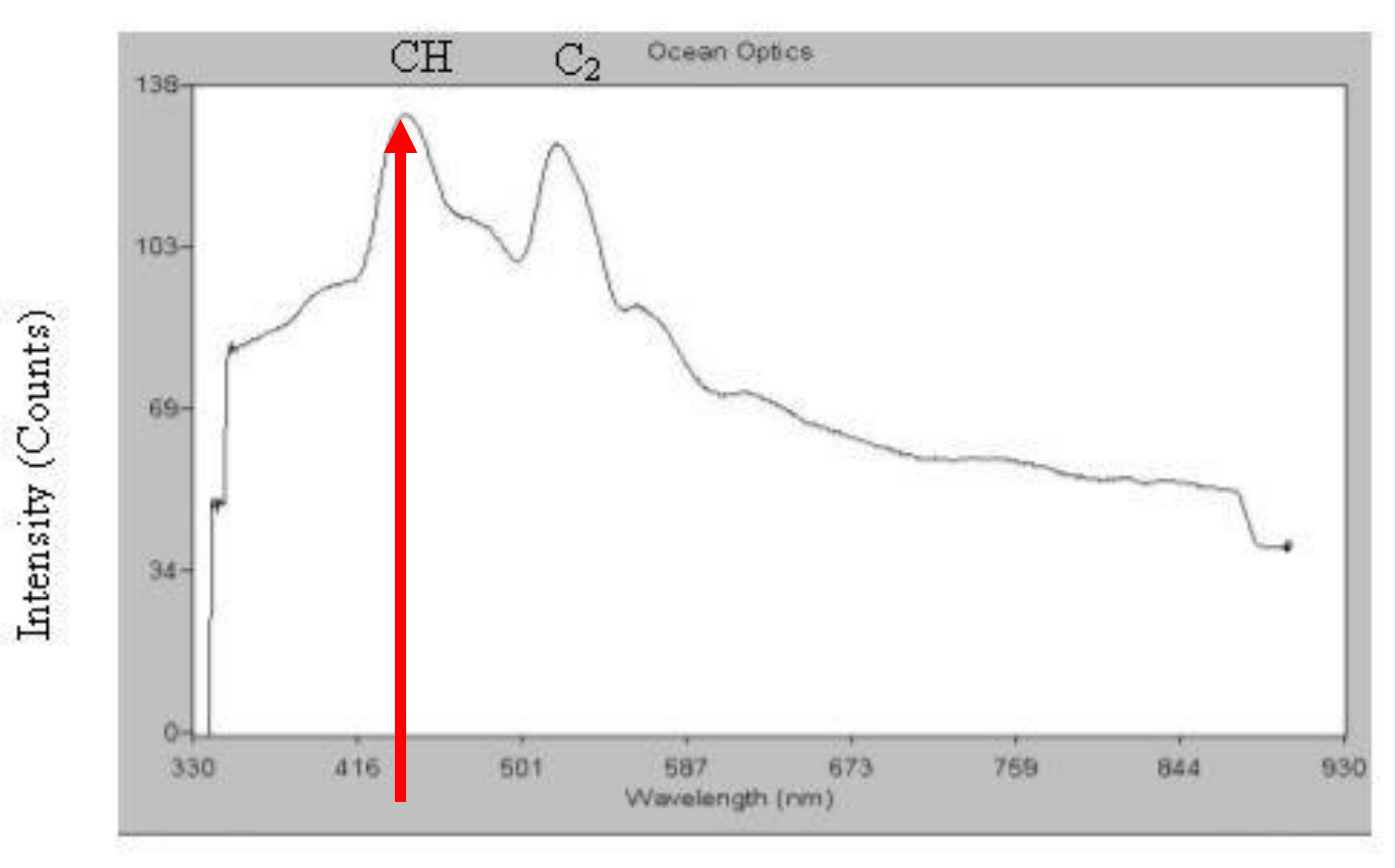
Temperature across the flame, 130 mm downstream of pilot burner exit





. For low global φ_0, maximum temperature is achieved at intermediate radius, whereas for high φ_0 it is closer to the combustor axis.

Test Results



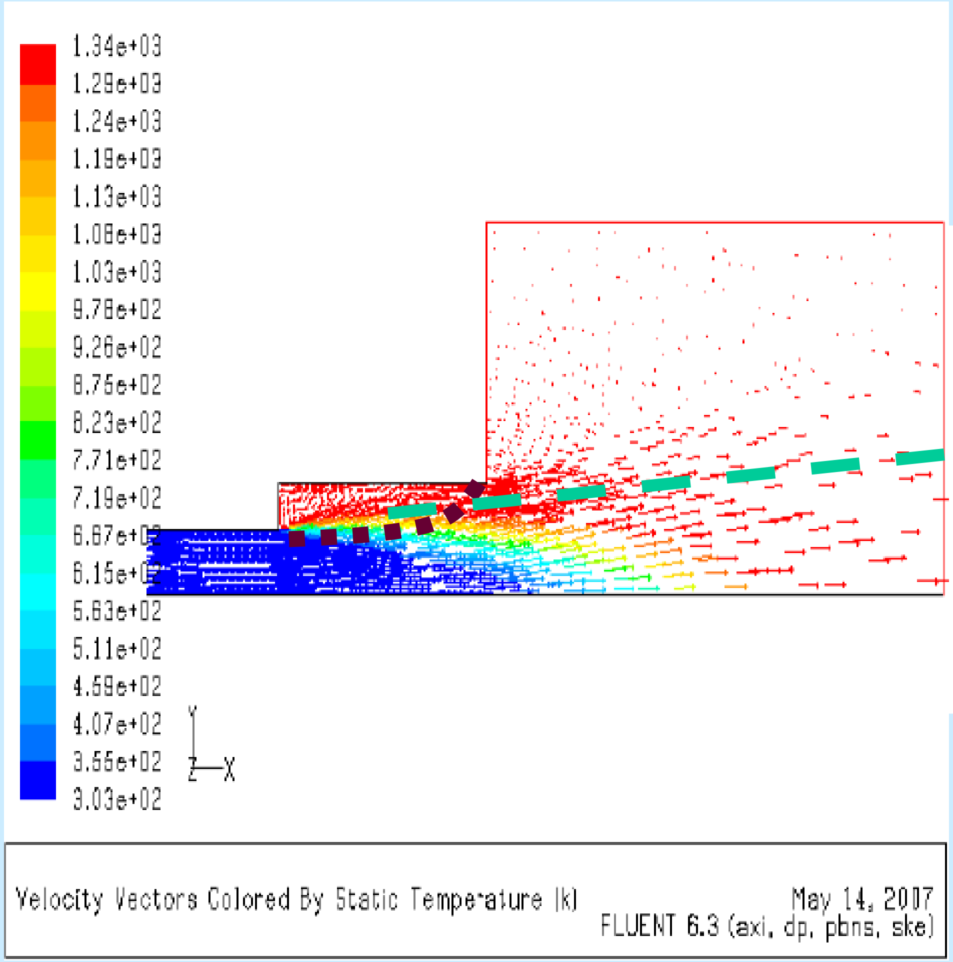
The presence of radicals was recorded by spectrometer

Emission spectrum for a premixed hydrocarbon fuel.

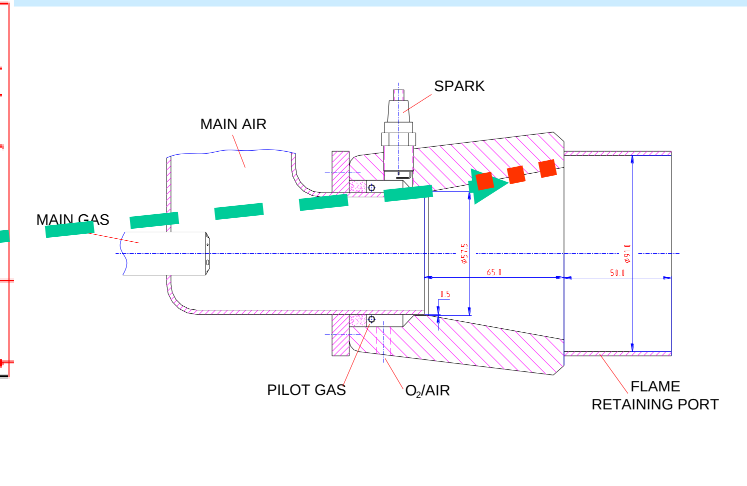
Summary of experimental results

·The experimental study showed that using a pilot combustor with high equivalence ratio can help to stabilize the combustion process in the main combustor. This allows to operate at reduced global temperatures. Thus, it presents a potential method to lower NO_x.

CFD Analysis

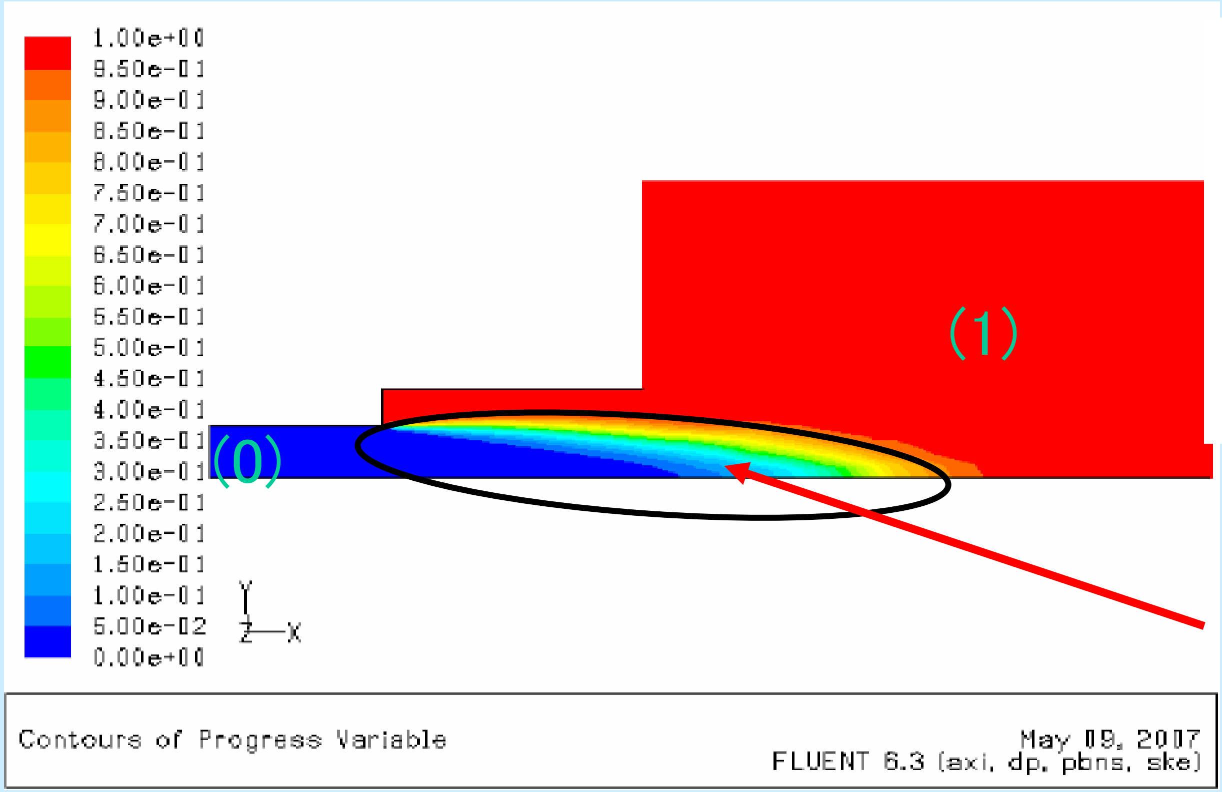


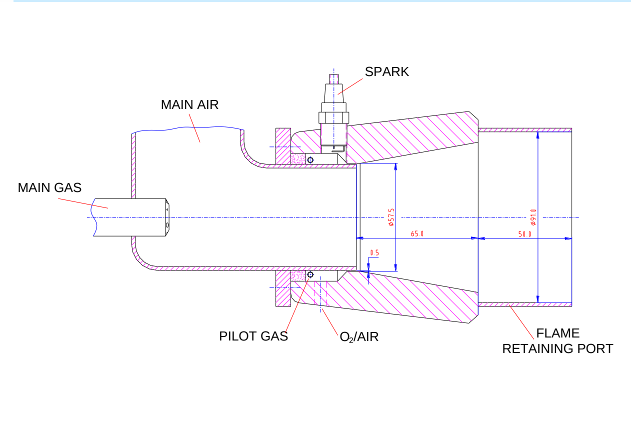
Cone angle was chosen according to inner boundary of the recirculation zone for different values of ϕ_0.



Simulations were carried out for atmospheric pressure

Velocity and temperature distributions inside the combustor



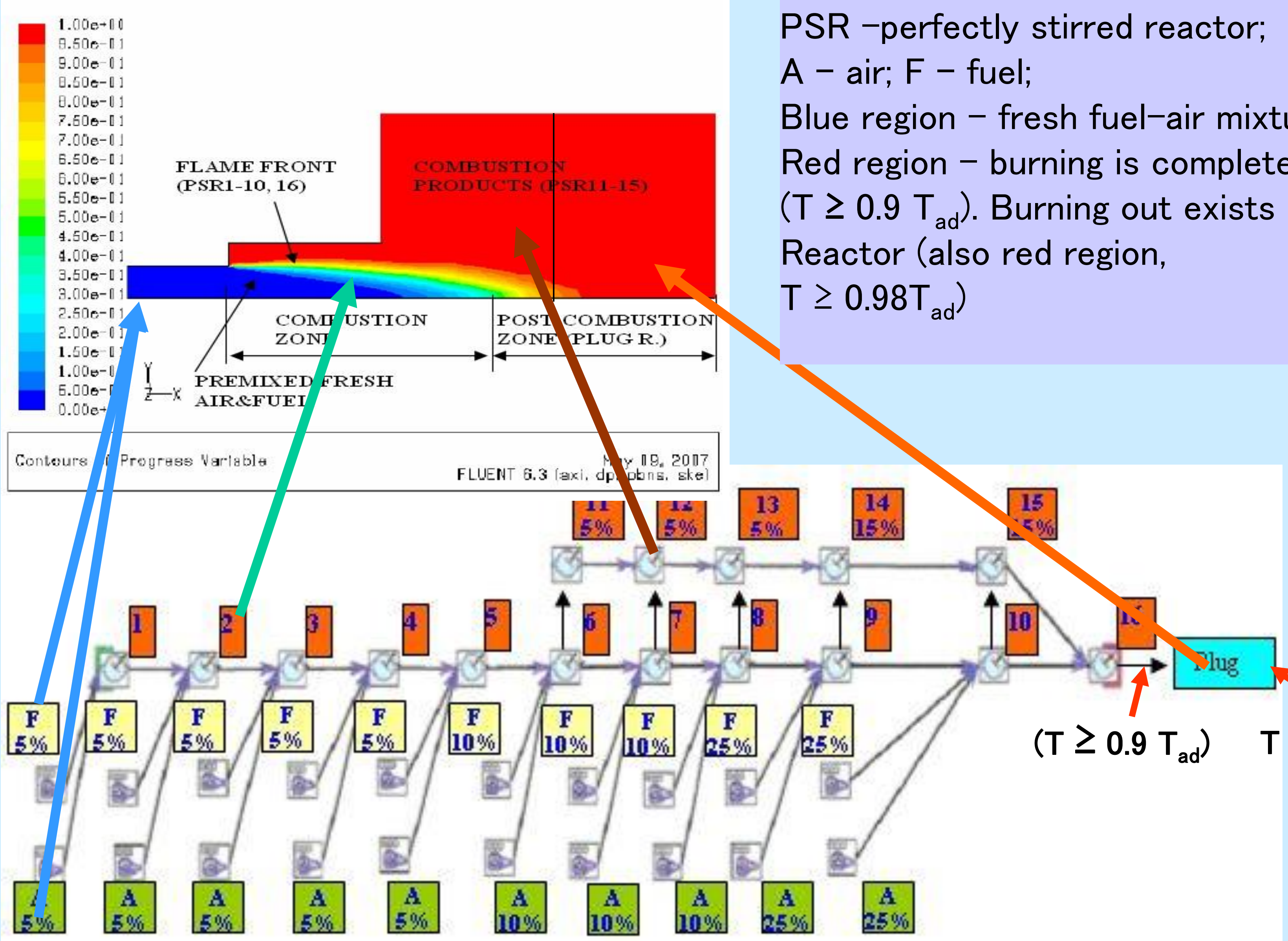


Burning region

Contours of "burning out" across the combustor length. Blue– unburned region (0),

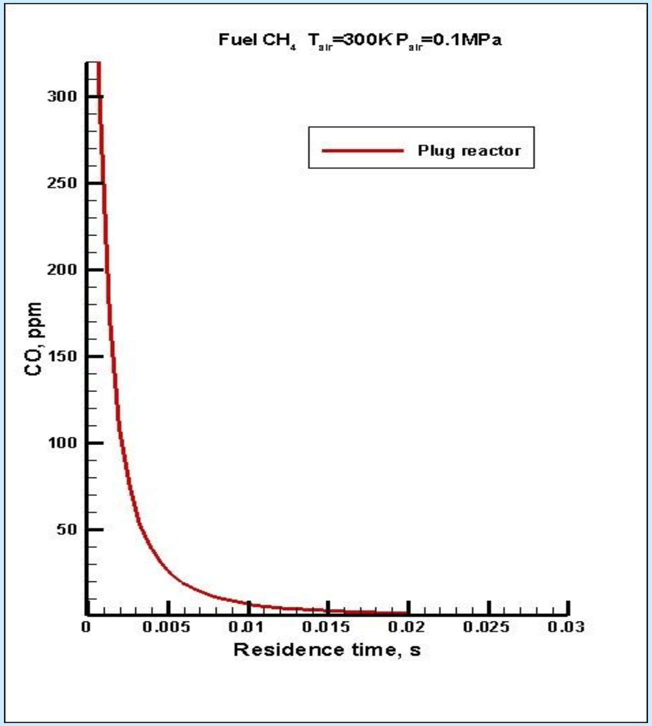
Red – complete reaction field (1).

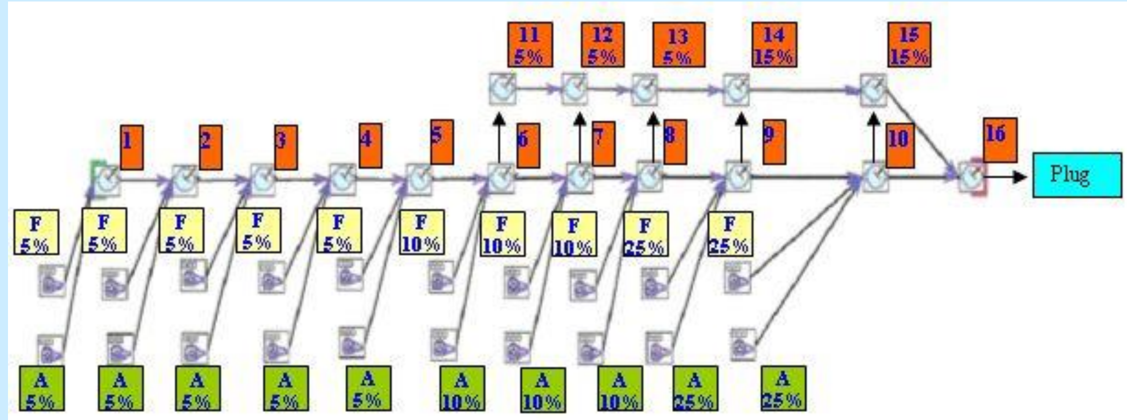
PSR – perfectly stirred reactor;
A – air; F – fuel;
Blue region – fresh fuel-air mixture;
Red region – burning is completed ($T \geq 0.9\ T_{ad}$). Burning out exists in Plug Reactor (also red region, $T \geq 0.98T_{ad}$)



(T ≥ 0.9 T_{ad})   T ≥ 0.98T_{ad})

CHEMKIN simulations: Link between CFD and CHEMKIN





CO evolution with time in a Plug Reactor

Simulation results of the “lean” combustion.
Conditions:
Tad=1472K; Φ_0 (R1–R16)=0.4962; Tair=300K;
Pair = 1atm τ = 20 ms

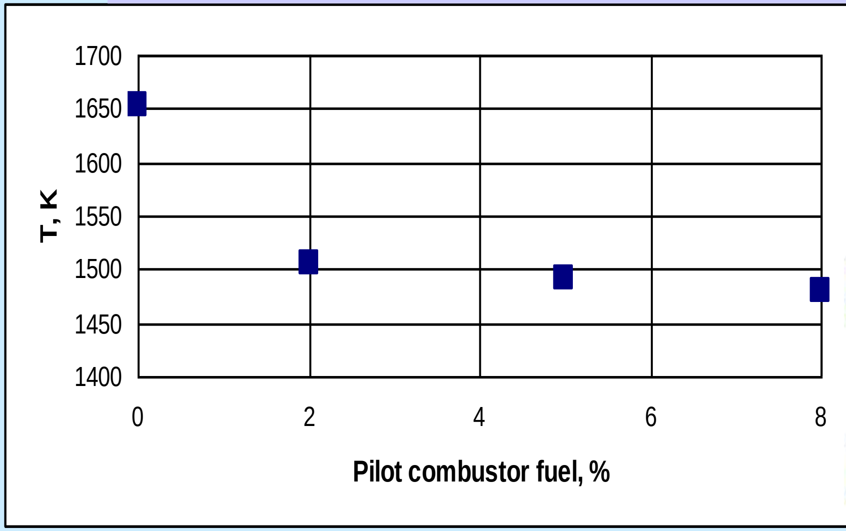
	Reactor 1	Reactor 16	Plug reactor
T,K	1360	1458	1466
CO, ppm	9299.0	666.0	0.8

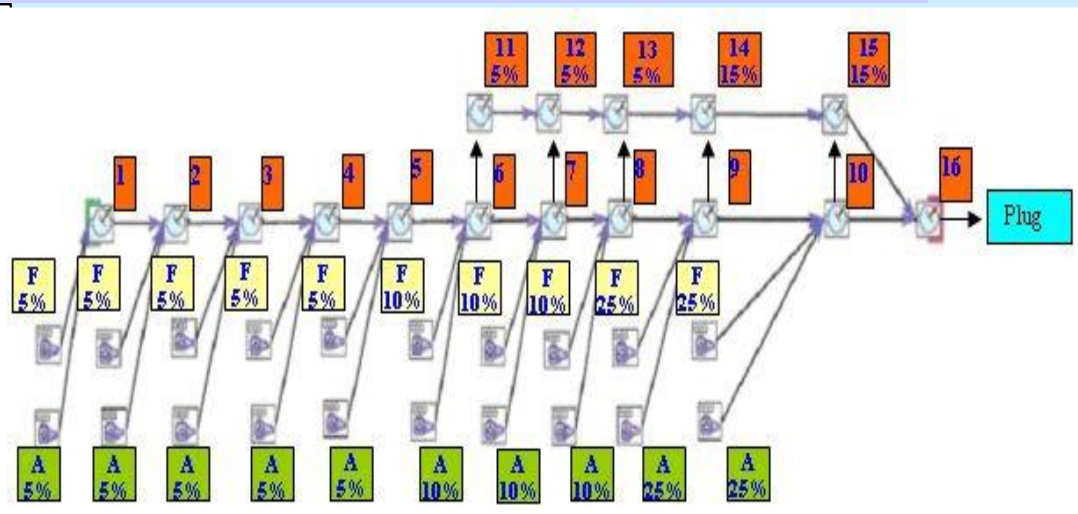
SIMULATION RESULTS ARE IN SATISFACTORY AGREEMENT WITH EXPERIMENTS.

CHEMKIN simulations results (Atmospheric pressure)

Effect of fuel fraction on combustion temperature
(Elevated pressure)

- The same combustion model was used for elevated pressure.

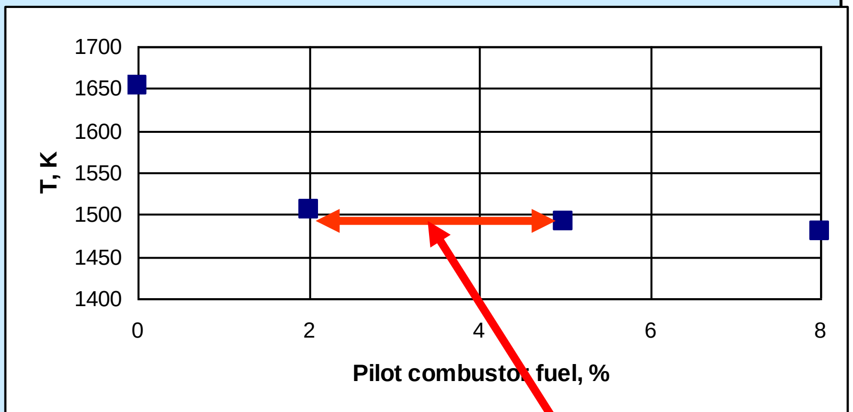


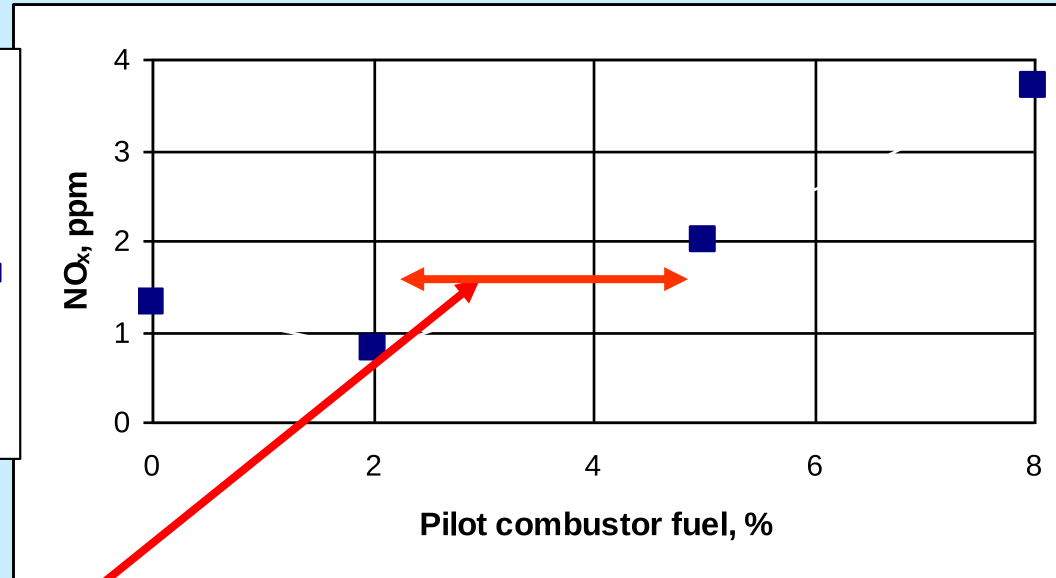


- Effect of fuel fraction of pilot combustor on the lower limit of temperature which provides stable combustion at $\Phi_1 = 1.5$.
- Lower limit of global equivalence ratio, Φ_0, reduces with increasing fuel fraction at the pilot combustor, hence combustion temperature decreases.

Elevated pressure

Optimal fuel fraction of pilot combustor for minimum NO_x emission (ϕ_1=1.5, ϕ_0=variable)





- Effect of fuel fraction at pilot combustor on NO_x emission (for lower limit of temperature).
- There is an optimal fuel fraction at pilot combustor where NO_x achieve their minimum.

CONCLUSIONS

- It was found that radicals can help to stabilize the combustion process at lean equivalence ratios.

- Radicals' injection allows operation at lower temperatures which reduces the NO_x emission and pollution.

- The CHEMKIN model was built according to CFD simulations.

- Distribution of air and fuel flow rates between the PSR reactors and Plug reactor in the CHEMKIN model enables to describe and model the combustion process.

CONCLUSIONS (cont.)

·CHEMKIN simulations confirm that the use of the pilot combustor with high equivalence ratio creates better conditions for stable combustion.

·These results are in satisfactory agreement with experimental data. They can serve as a base for lean premixed industrial combustor simulation and design.

·Further investigations for reducing of the temperature limit of stable combustion should include improvement of the combustion model by taking into account flow recirculation, heat losses, and preliminary mixture heating within the combustor.

THANK YOU FOR YOUR ATTENTION