# Atomization vs. Vaporization of Fuel in Micro Gas Turbines

*Daniel Kutikov and Prof. Yeshayahou Levy*

*Faculty of Aerospace Eng.*

*Technion, Haifa*

# Impact of fuel delivery system

| Causes | | Effects |
|---|---|---|
| Atomization | → | Ignition |
| Fuel distribution | → | Flame stability |
| Evaporation | → | Combustion efficiency |
| Mixing | | |

Difficulties in small-scale jet engine:

- ➔ Low ignition energy
- ➔ Small combustor volume
- ➔ Simplicity of the atomizer/vaporizer

# Existing models for combustion of liquid fuel

- Semi-empirical droplet sizing models for a single atomizer
- Evaporation models for droplets

➔ Need for integration of processes and models

- CFD involving two-phase flow and evaporation, combustion chemistry, heat transfer

➔ Heavy numerical calculations

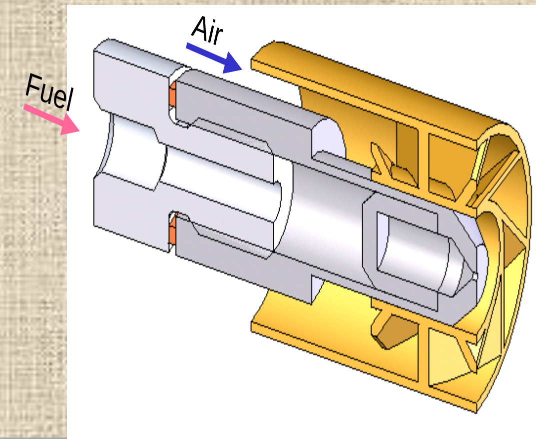
# Objectives

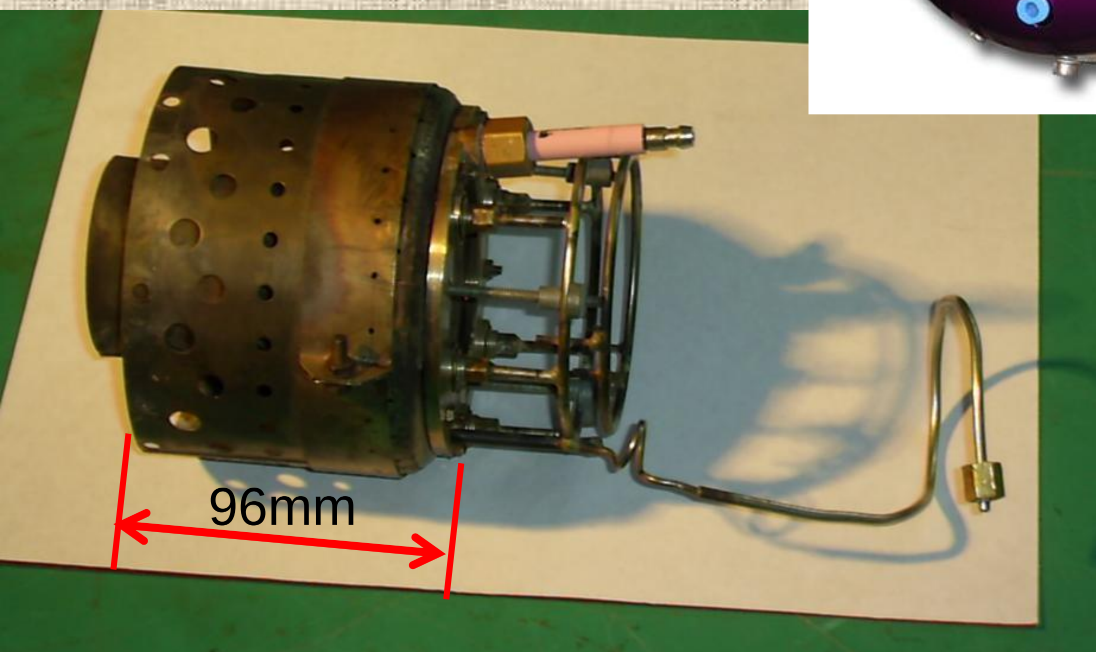
Comparison: Atomizers vs. Vaporizers for Micro Gas Turbines

- Ignition system
- Stable operational envelope
- Combustion Efficiencies

# Research method

- Small-scale combustor
- Comparison of fuel supply only, not a combustor upgrade




# Research method (cont.)

Measurements:

- Air & fuel flows
- Combustor outlet temperature at 4 points
- Combustion gas concentrations at 4 points

Evaluations:

- Stable operational envelope
- Combustion Efficiency
- Chemical efficiency

# Research method (cont.)

## Combustion efficiencies – definitions:

Combustion Efficiency, $\eta(T) = \dfrac{\text{Enthalpy rise through combustor}}{\text{Chemical energy of liquid fuel}}$

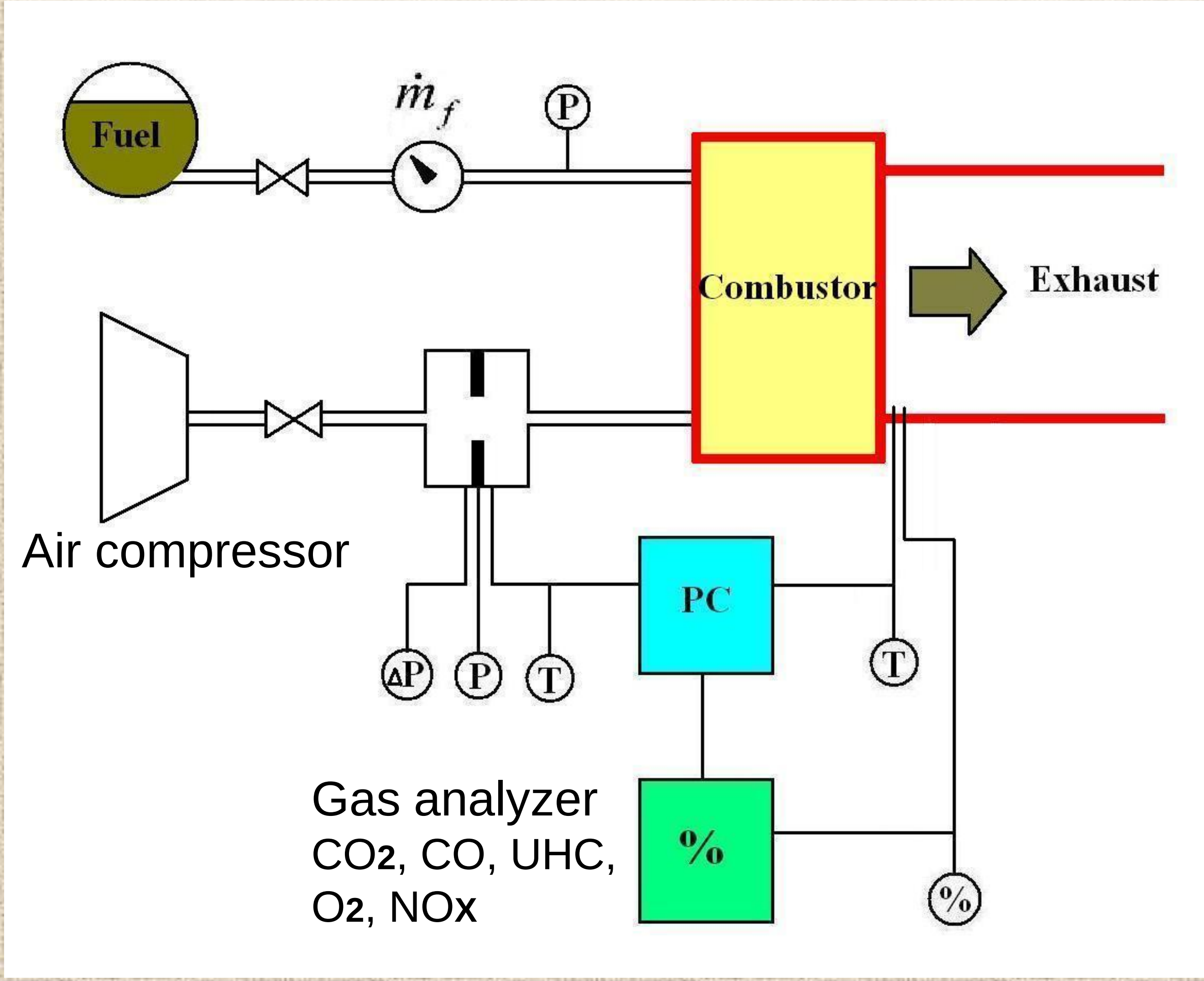
Chemical efficiency, $\eta(Ch) = \mathbf{1} - \dfrac{\text{Chemical energy of fuel remain in exhaust gases}}{\text{Chemical energy of vaporized liquid fuel}}$

$$\eta_{b,T} = \frac{(1+f)T_{04}C_{Pg} - T_{03}C_{Pin}}{Q_R f}$$

$$\eta_{b,ch} = 1 - \frac{0.5[CO] + 1.3[CH_4]}{[CO_2] + [CO] + [CH_4]}$$

UHC ➔ $CH_4$

# Experiment setup



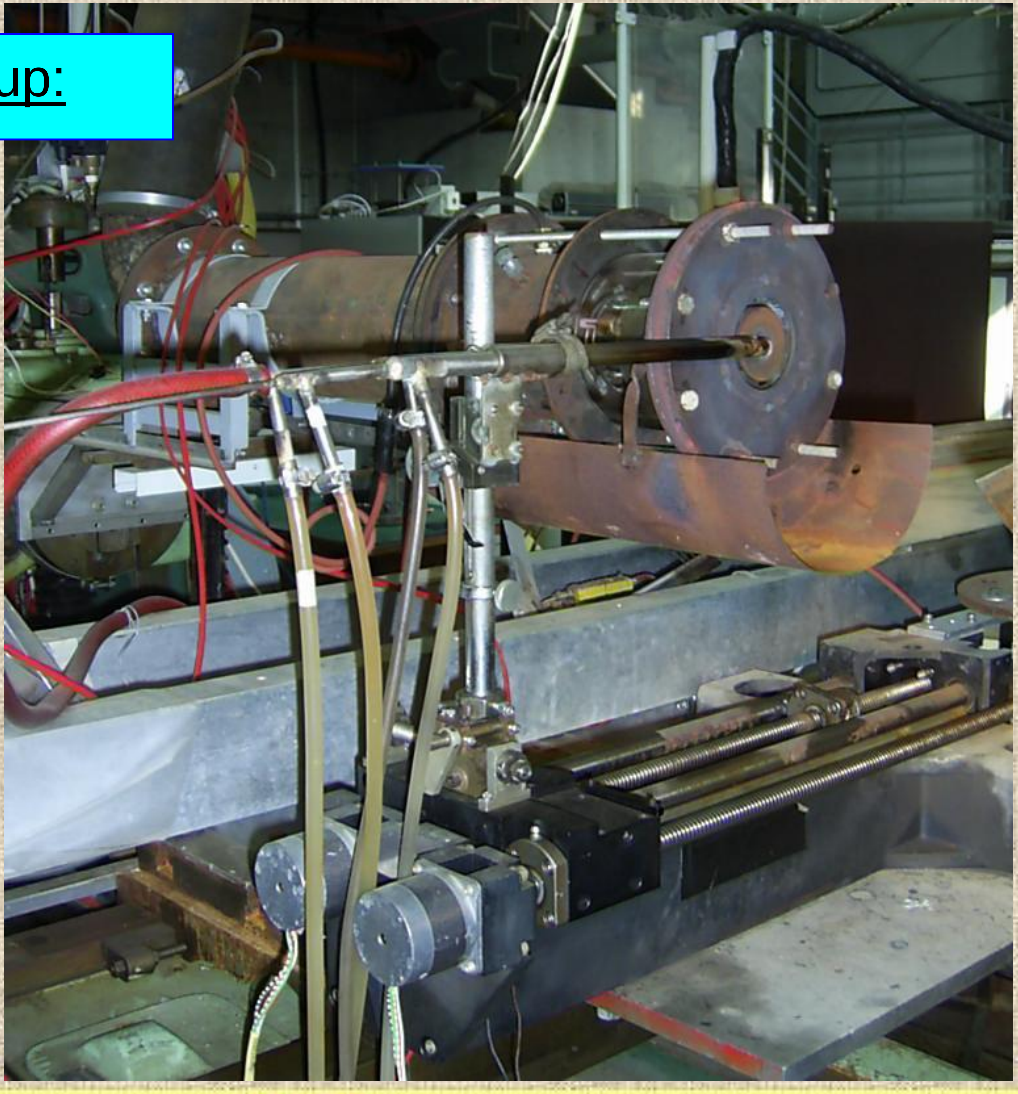
# Experiment setup (cont.)

Gas analyzer:

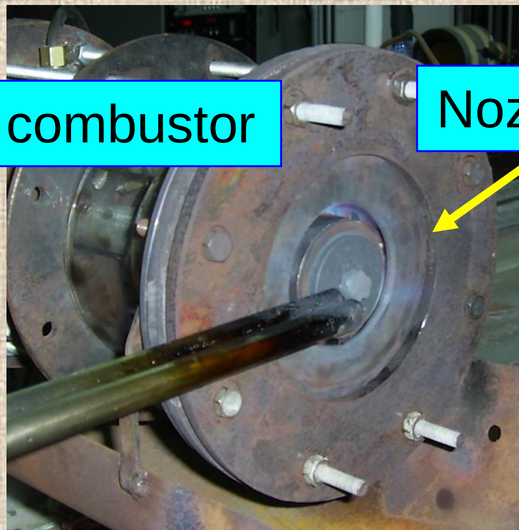
$CO_2$, CO, UHC, $NO_x$, $O_2$

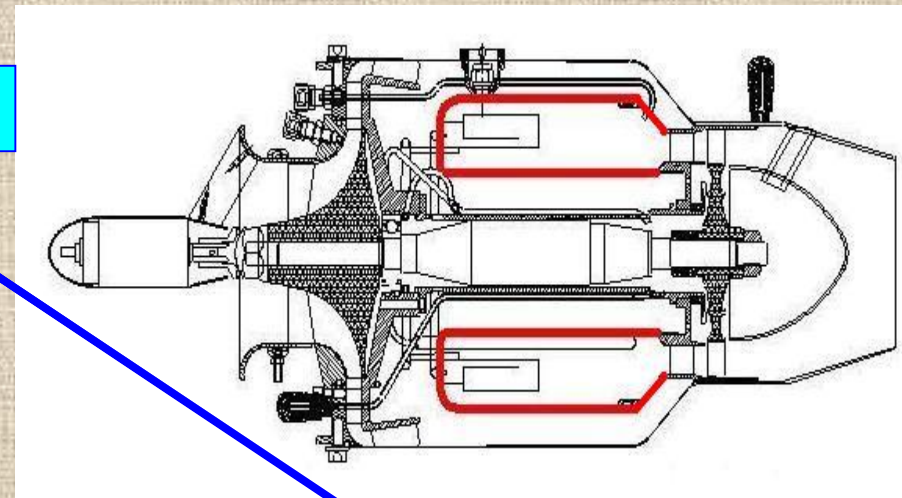
# Experiment setup (cont.)

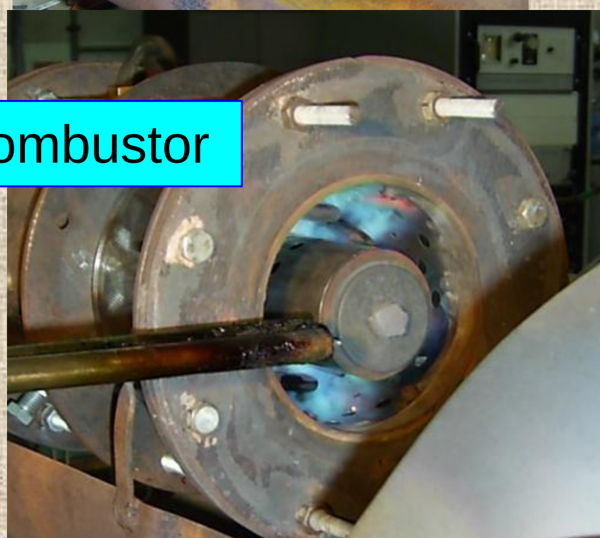
Combustor setup:

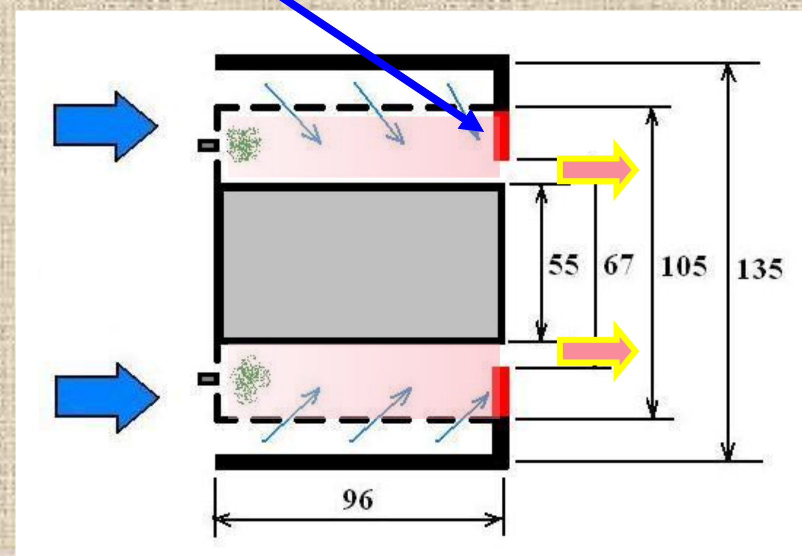


# Experiment setup (cont.)

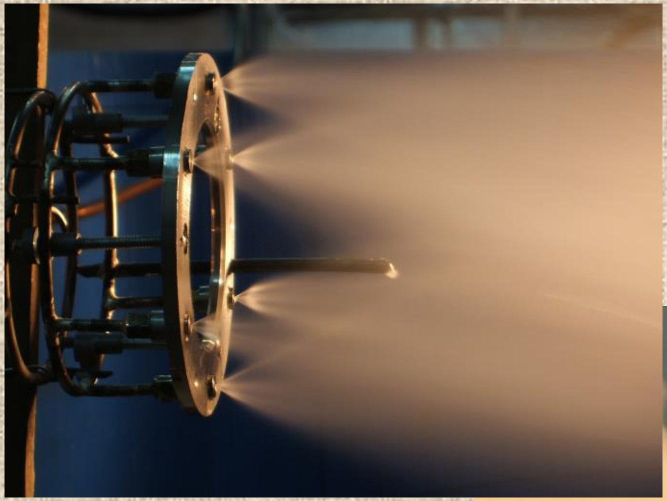


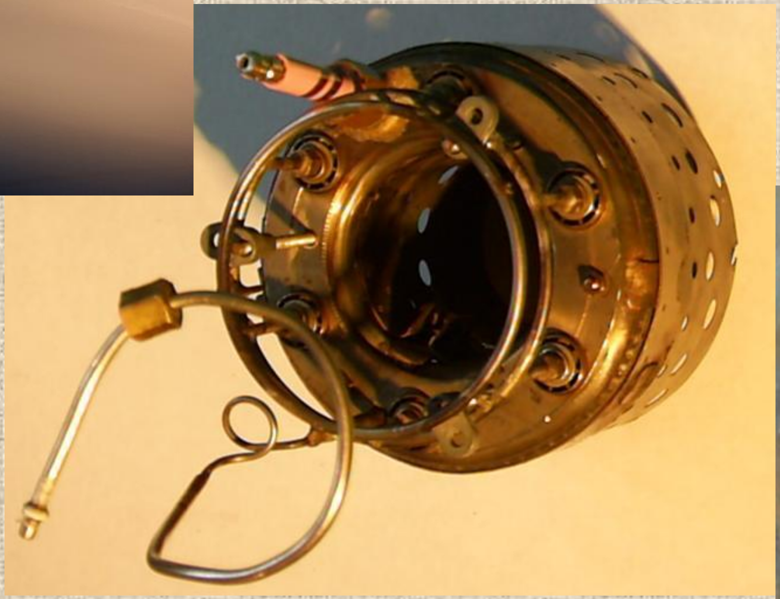





# Experiment setup (cont.)

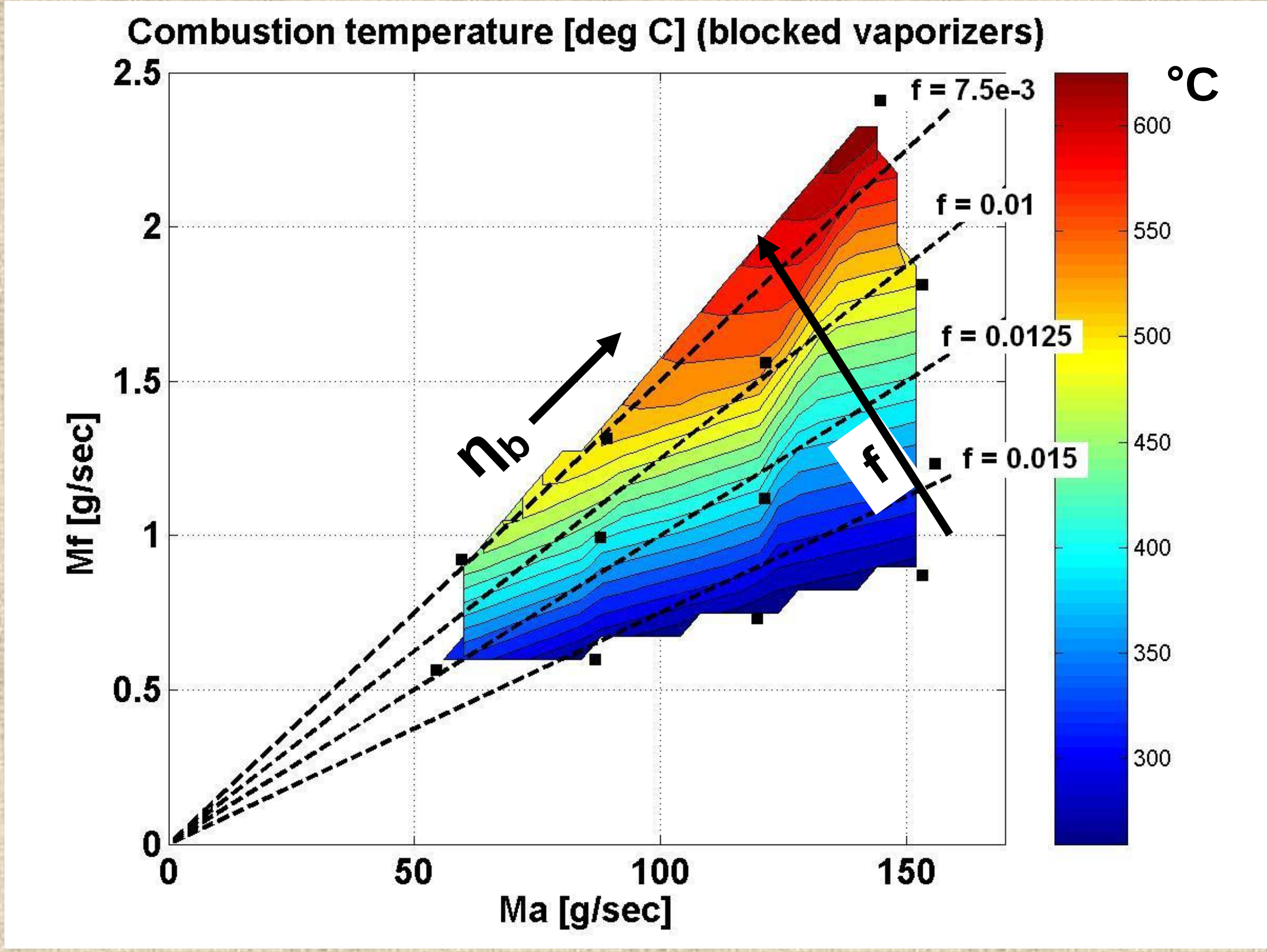




# Results

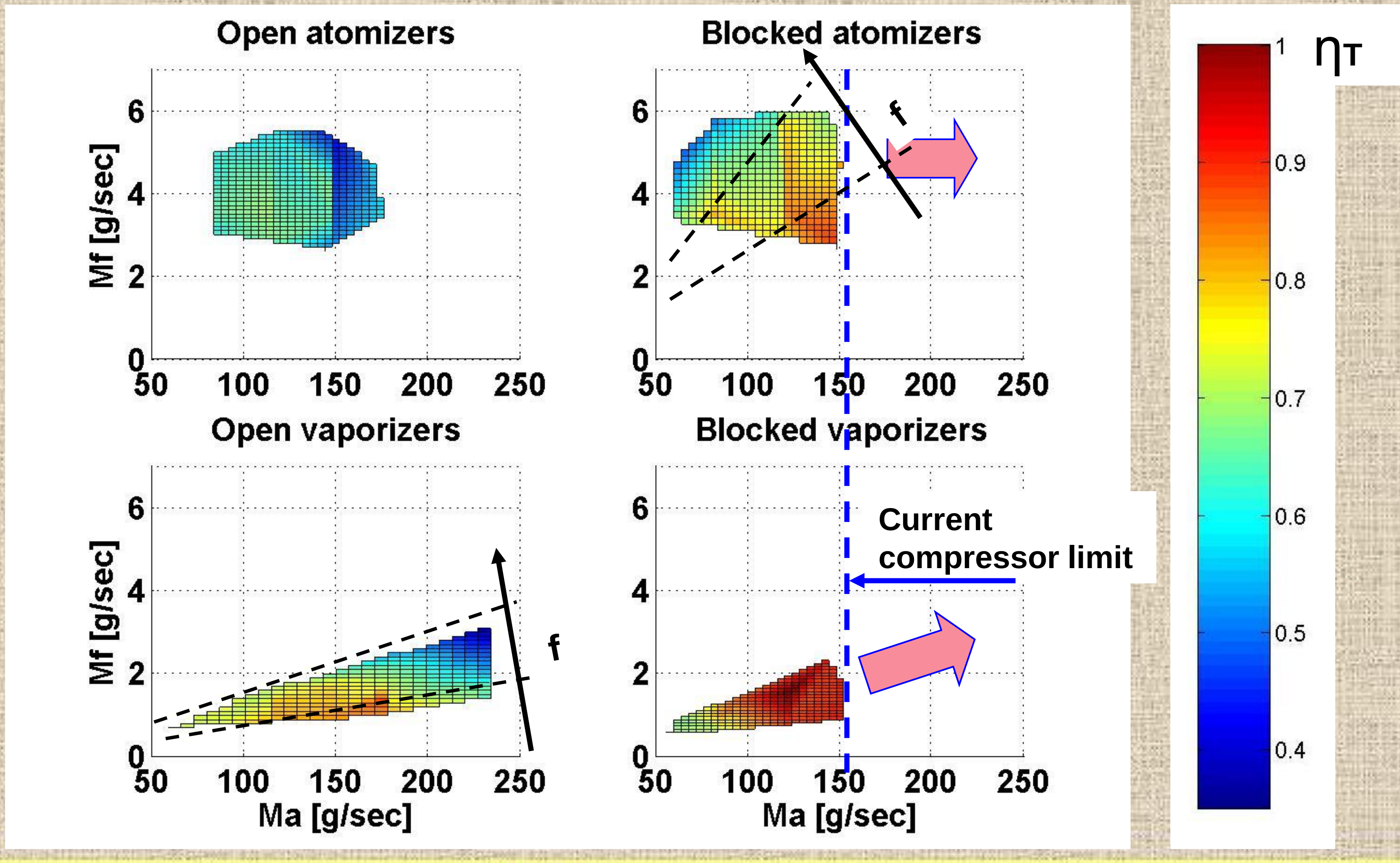
*Exit temperature for different air and fuel mass flow rates*

$$T_{04} = \frac{Q_R f + C_{Pin} T_{03}}{C_{Pg}(1 + f)}$$



# Results (cont.):

<u>*combustion efficiencies* η(T) *for different configurations*</u>



# Results (cont.)

Low efficiency:

- low inlet temperature
- low air pressure

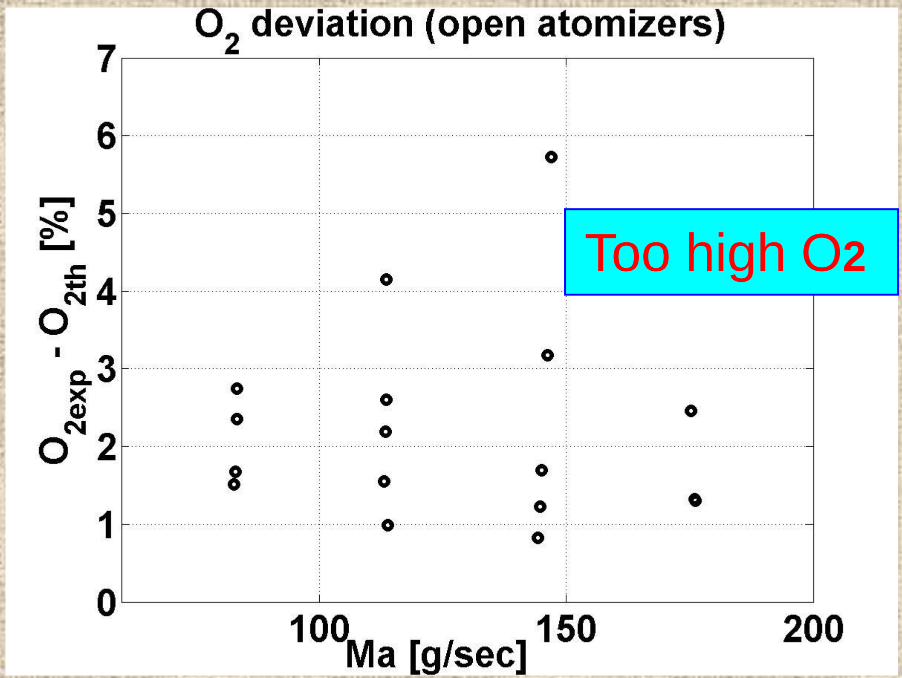
➔ Incomplete vaporization

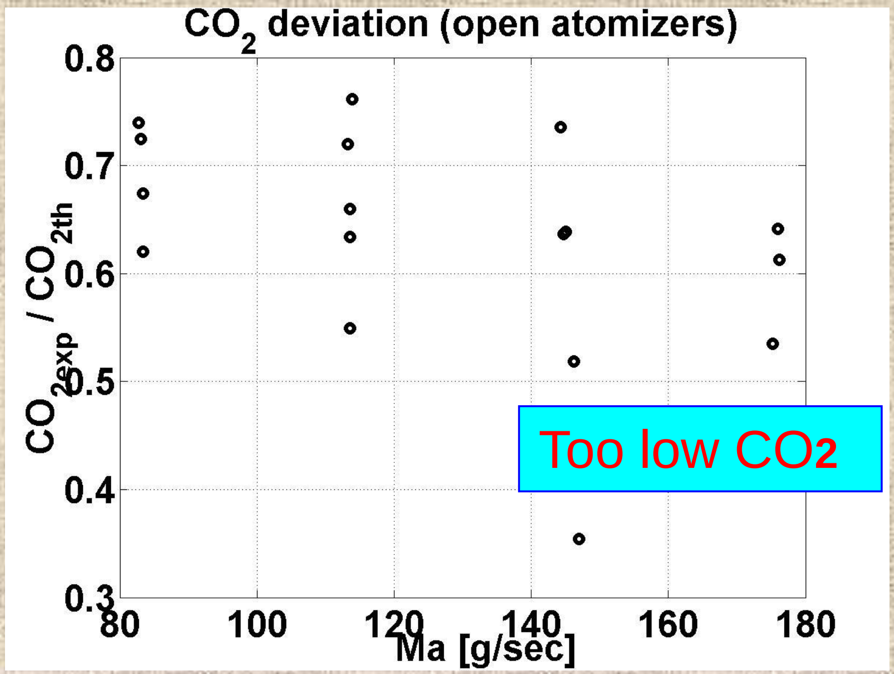
➔ Insufficient residence time

➔ Insufficient mixing

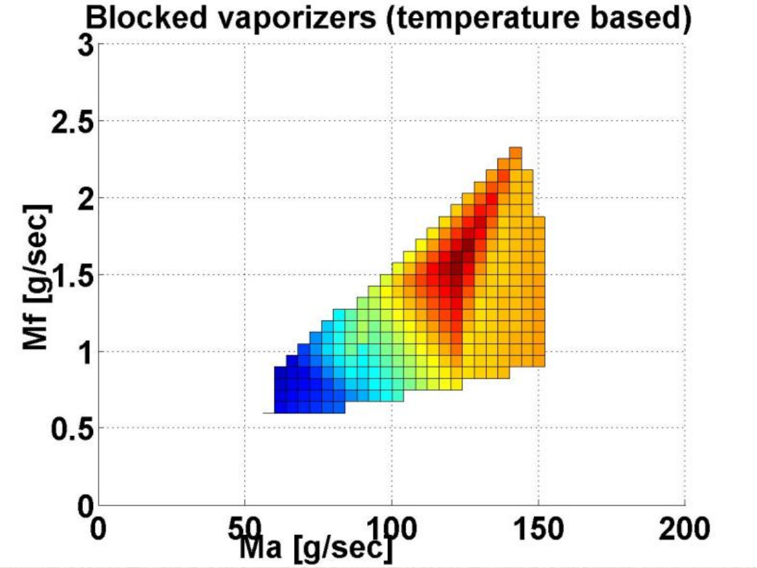
$\eta = F(t_R)$

$$t_R = \frac{\rho V}{\dot{m}} \approx 3ms$$

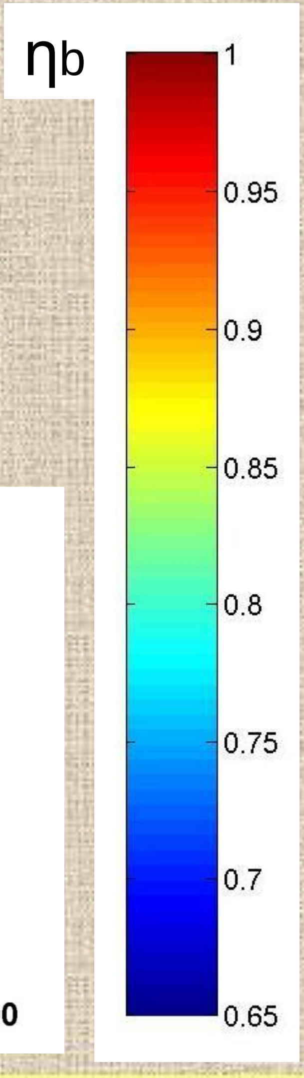


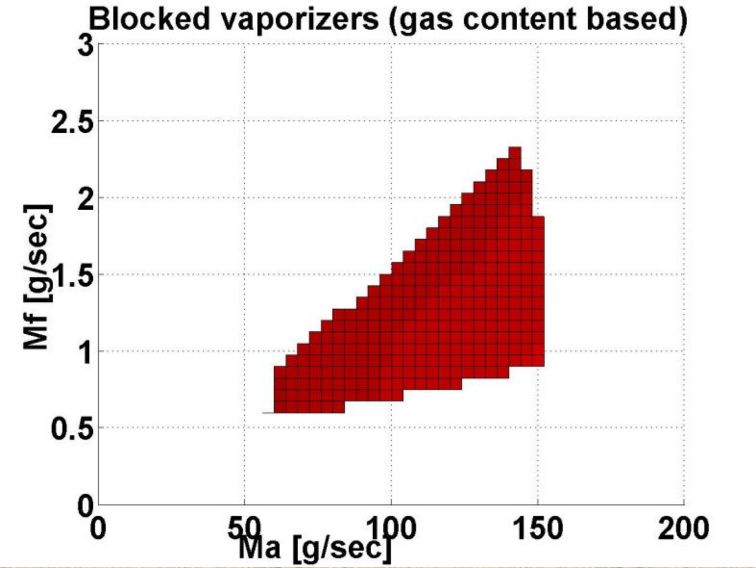
# Results (cont.)



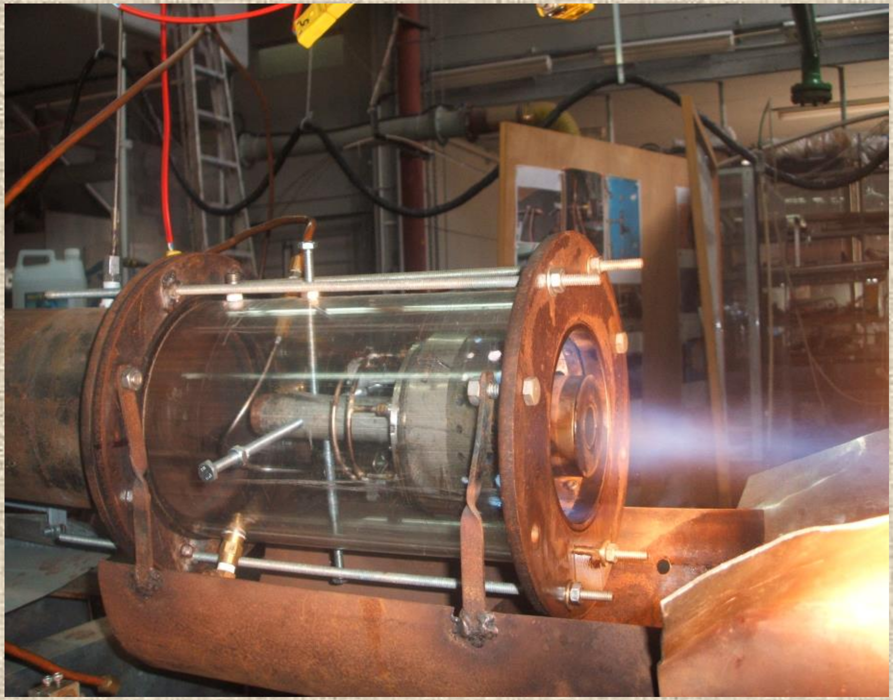

$$\eta_{b,T} < \eta_{b,ch}$$



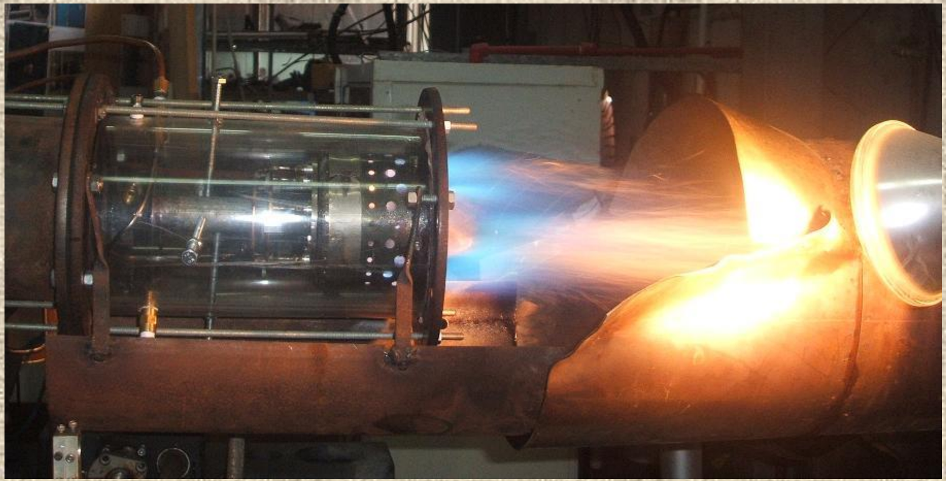

Differences mainly due to unvaporized liquid fuel



Low equivalence ratio: almost complete combustion



High equivalence ratio: incomplete combustion



# Conclusions

Atomizers

- ✓ Wider stable operational range
  (wider fuel supply ranges: 3 – 6g/sec vs. 0.5 – 2g/sec)
- ✓ Higher fuel flow rates & temperatures at the max efficiency points
  (4g/sec vs. 1g/sec & 1300K vs. 800K)
- ✓ Simple ignition (electric plug)
- ✓ Faster transient response
- X Larger combustor volume required (for evaporation & mixing)
- X Higher fuel pressure requirement

Vaporizers

- ✓ Higher efficiency due to longer vaporized fuel flow path
  ($\eta$=0.9 vs. 0.75) (higher combustion pressure would give higher efficiencies)
- X Complicated ignition (additional gas ignition system required)
- X Slower transient response (thermal inertia & fuel evaporation time)

# Conclusions (Cont.)

## General

- Combustion efficiency increases with pressure
- Unvaporized fuel affect efficiency values, hence should be accounted for ($\eta$(Ch) vs. $\eta$(T))
- Direct retrofitting of atomizers instead of vaporizes widen operational envelope but reduces combustion efficiencies
- New designs that can account for the larger volume required by atomizer may benefit from its advantages

# Questions?

$$\left(\frac{a+d+e}{x}\right)C_xH_y \quad +0.79N_2 \quad +0.21O_2 \quad \Rightarrow$$

$$\Rightarrow \quad aCO_2 \quad +0.79N_2 \quad +bH_2O \quad +cO_2 \quad +dCO \quad +eCH_4 \quad +fH_2$$

$$\eta_b = 1 - \frac{dQ_{R,CO} + eQ_{R,CH4} + fQ_{R,H2}}{\left(\frac{a+d+e}{x}\right)Q_R}$$

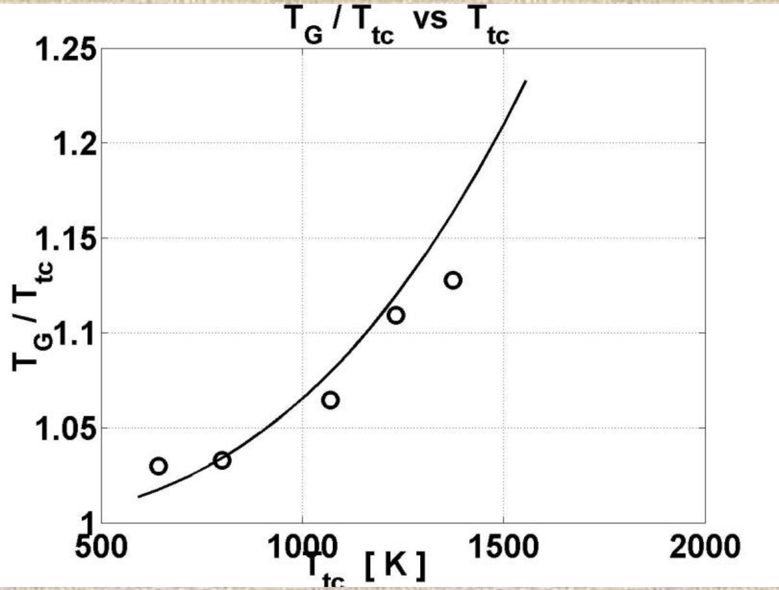
# Experiment setup (cont.)

Compensation of the radiative heat losses from TC:

$$T_g = T_{TC} + \frac{\varepsilon \sigma F \left(2T_{TC}^4 - T_\infty^4 - T_t^4\right)}{h}$$

$$h = \frac{k_g}{D} Nu_D \quad V = \sqrt{2C_{Pg} T_{app} \left(1 - P_a / P_C\right)^{(\gamma-1)/\gamma}}$$

The model was validated by comparison of shielded and unshielded thermocouples



# Results (cont.)

Low efficiency: high UHC values