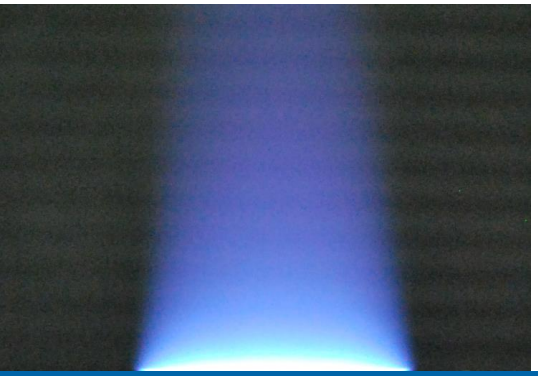
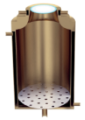
TECHNISCHE UNIVERSITÄT
BERGAKADEMIE FREIBERG
Die Ressourcenuniversität. Seit 1765.

Measurement of key values in combustion: The heat flux burner method to determine laminar burning velocities



Heat Flux Method



for accurate measurement of the laminar burning velocity
www.heatfluxburner.org

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Institute of Thermal Engineering, TU Bergakademie Freiberg

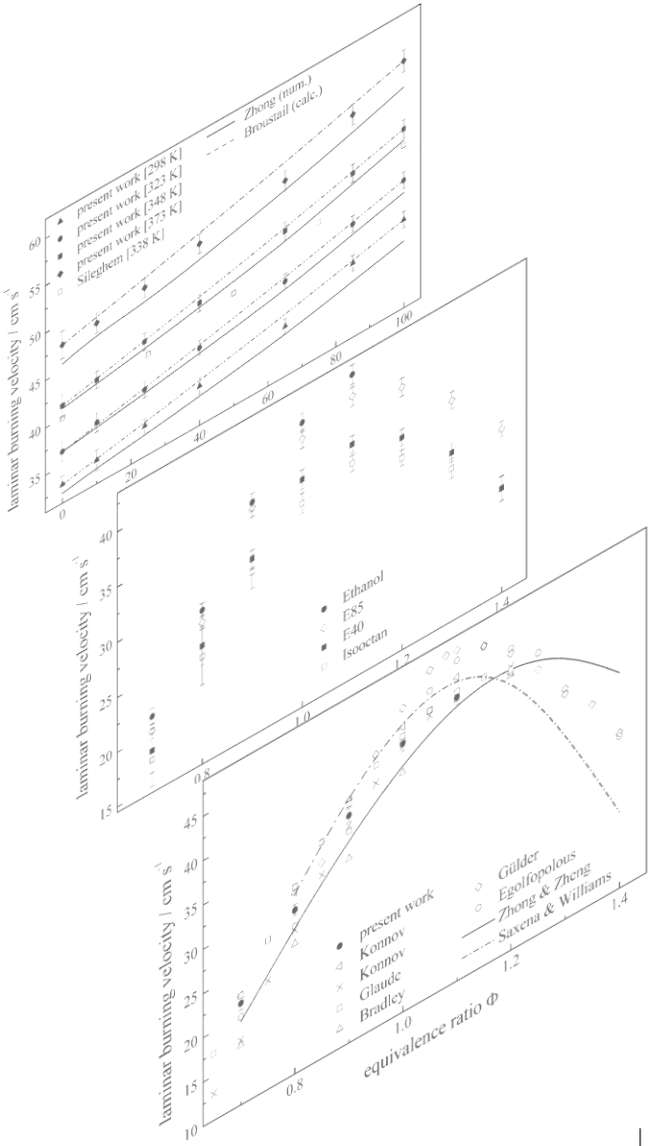
cost
EUROPEAN COOPERATION
IN SCIENCE AND TECHNOLOGY

Napoli, April 5-6, 2016
University Federico II

CM1404
SMARTCATs

Outline

1. Introduction
2. Burner and test rig
3. Results and discussion
4. Conclusion



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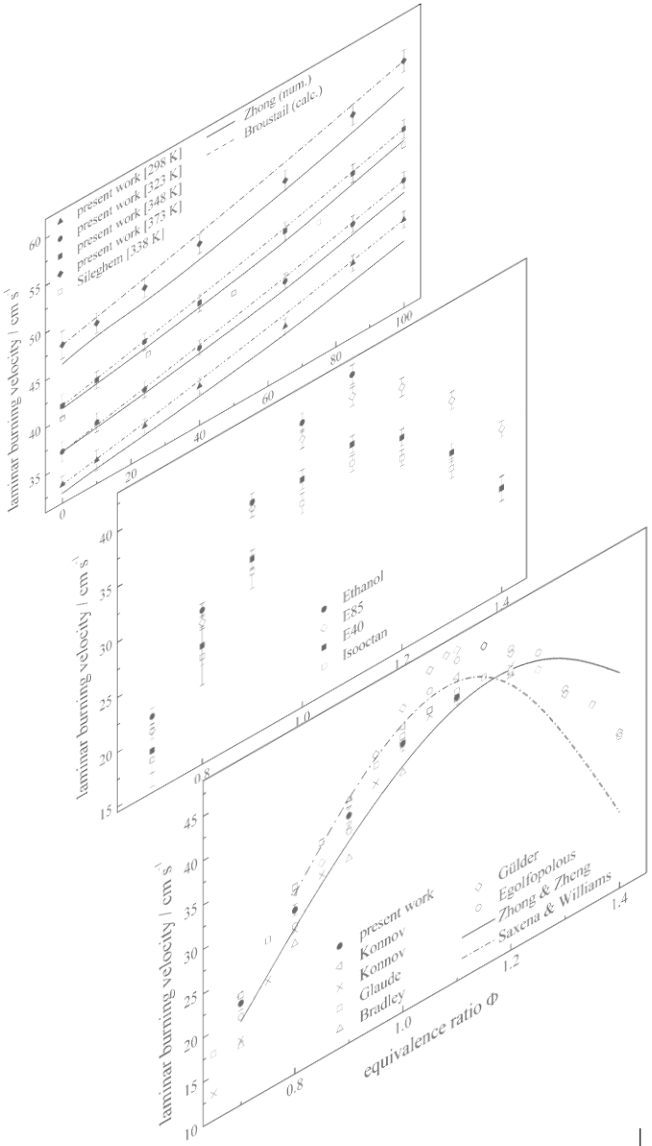
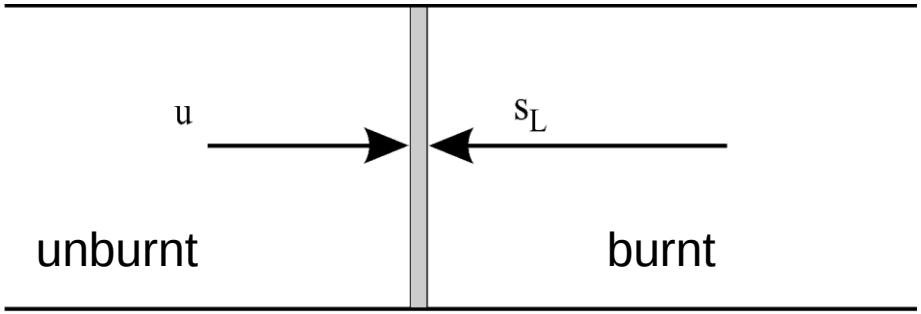
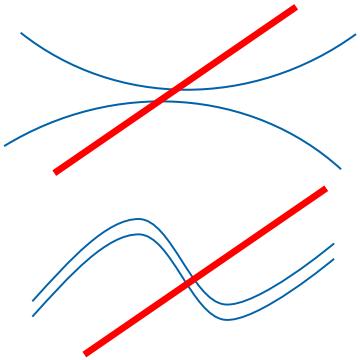


Introduction



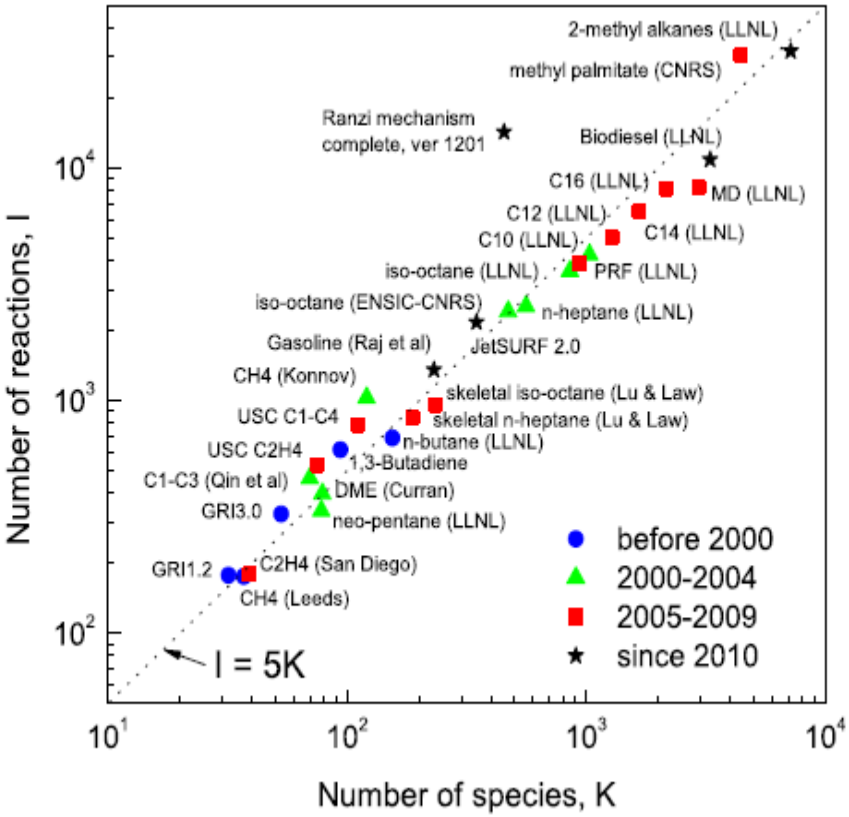
flame front

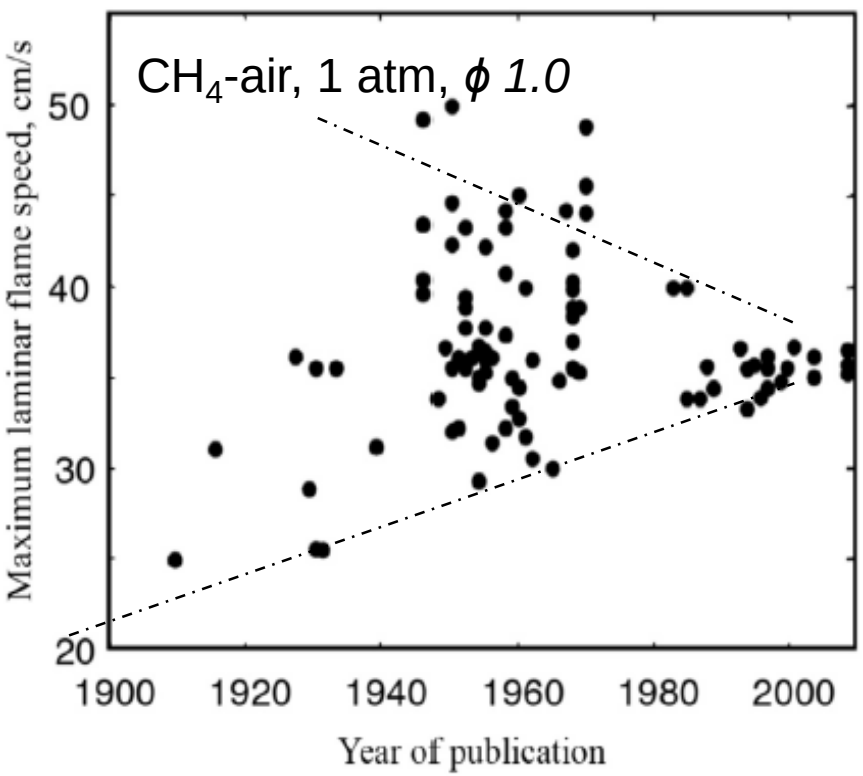


<u>laminar burning velocity / flame speed</u>

- propagation speed of a reactive flame front to the fresh reactant side in a stationary/resting fuel-oxidizer mixture.
- characteristics:
  - adiabatic
  - laminar
  - planar (unstretched and non-curvature)
- depending on T, p, λ, fuel, (oxidizer)

Introduction

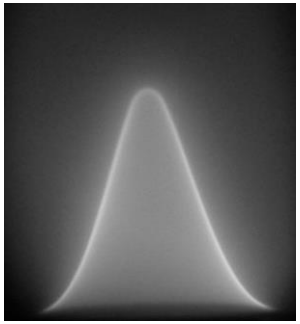




Egolfopoulos et al., Progress in Energy and Combustion Science 43 (2014) 36 - 67

Introduction

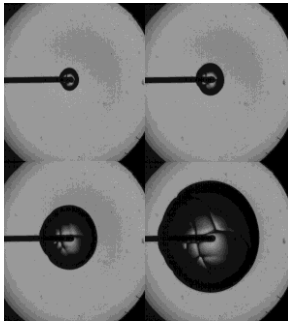
Several measuring techniques to determine the laminar burning velocity



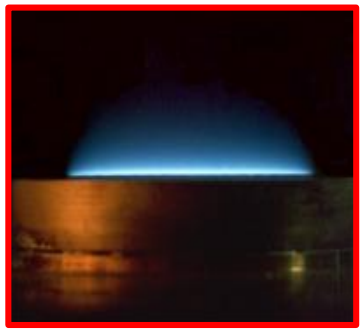
Bunsen method

Counterflow method

Flame tube method



Constant volume spherical flame method



Heat-Flux burner

Review paper by Egolfopoulos et al. 2014

Progress in Energy and Combustion Science 43 (2014) 36 - 67

The heat flux burner is a suitable burner for laminar flame research

Experiments ⟷ **Modeling**

- S_L
- Species Concentrations
- Flame Structure
- …

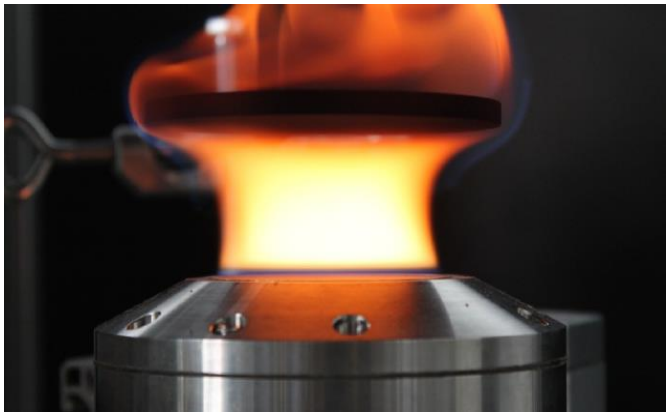
- Chemical Kinetics
- Flame Structure
- …

Introduction

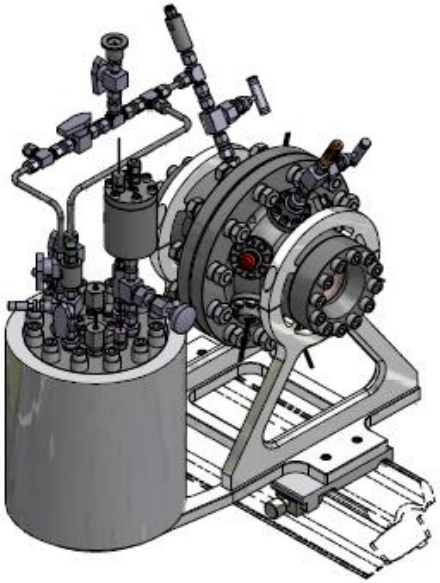
Flame diagnostics at TU Bergakademie Freiberg

Furthermore, a range of model burner systems are available:

- flat flame burner (McKenna and Heat-Flux burner)
- counter flow burner
- constant volume bomb chamber



Flat flame burner
(soot investigation)



Constant volume bomb chamber
(laminar burning velocity)
(gaseous and liquids fuels up to 20 bar)

Counter flame burner
(auto-ignition; extinction)

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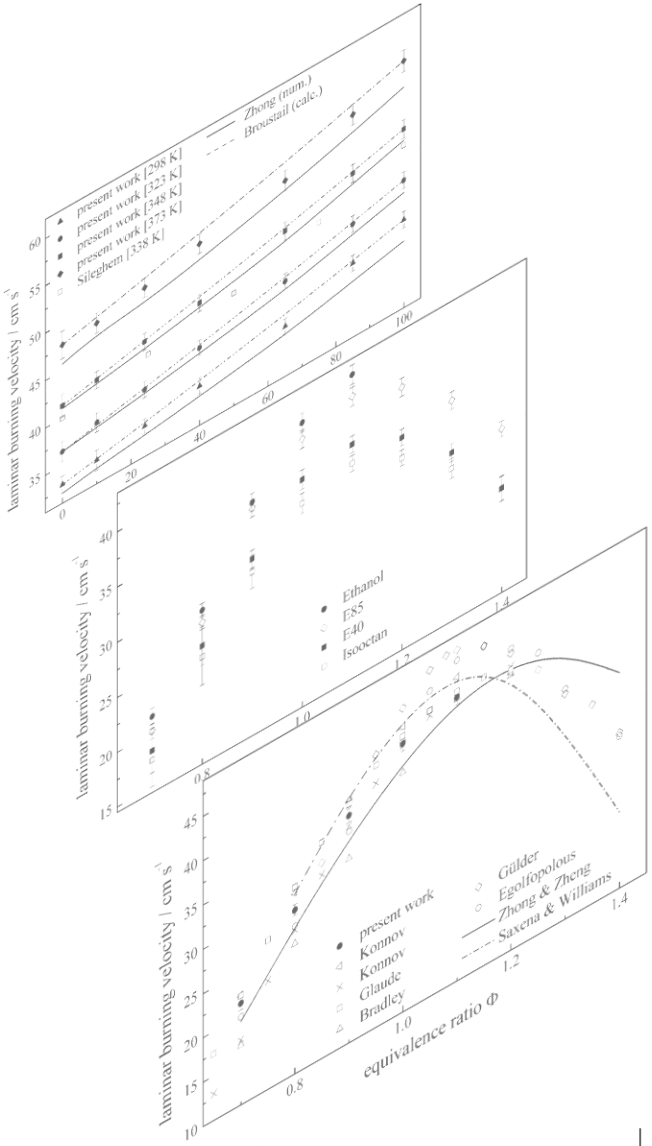
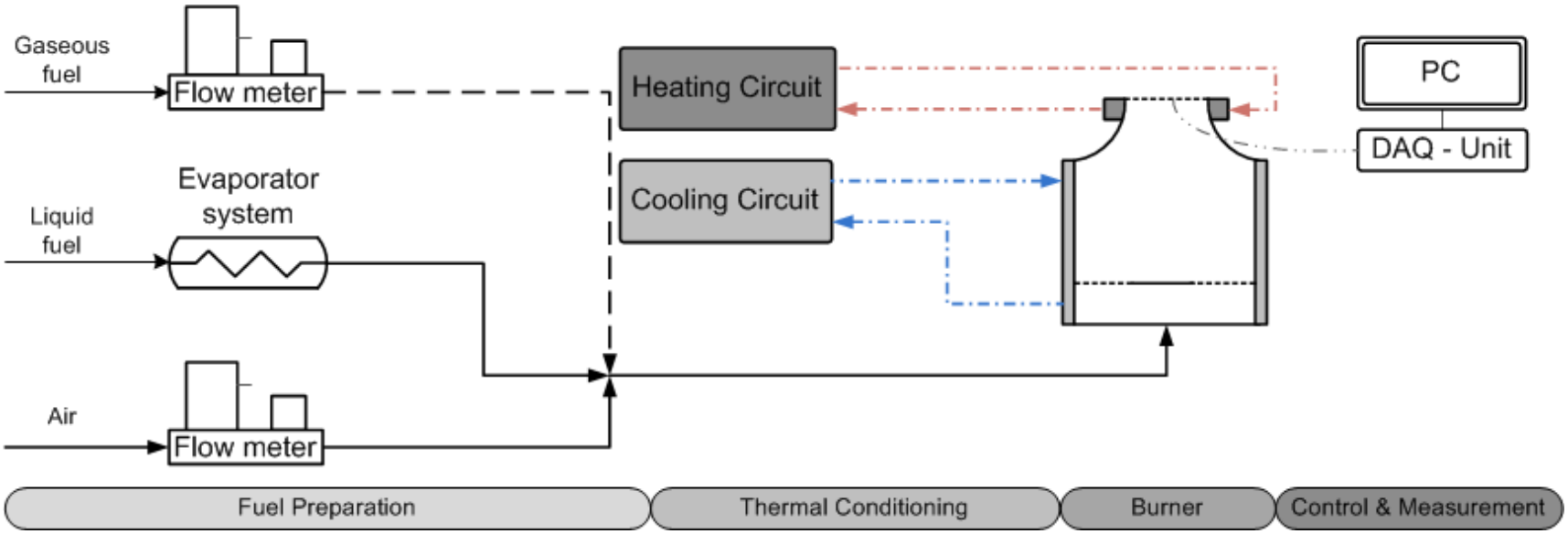


Burner and test rig



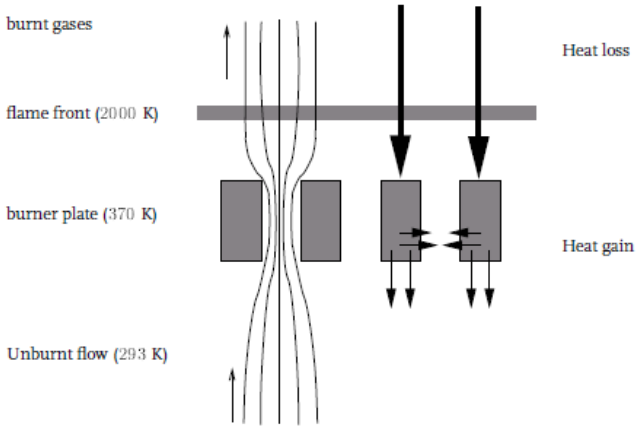
Eindhoven (TUE)
- thermocouple: type E
- temperature difference: 60 K
- effective burner plate-Ø: 30 mm

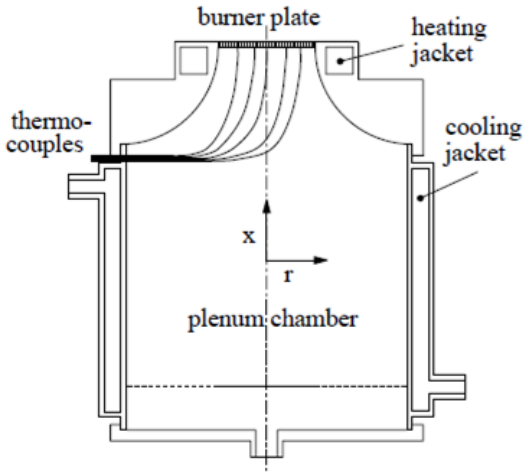
Lund (LU)
- thermocouple: type T
- temperature difference: 70 K (298 K) / 50 K (318 K)
- effective burner plate-Ø: 29,3 mm
- evaporation system with carrier gas / coriolis-MFC for liquid fuels

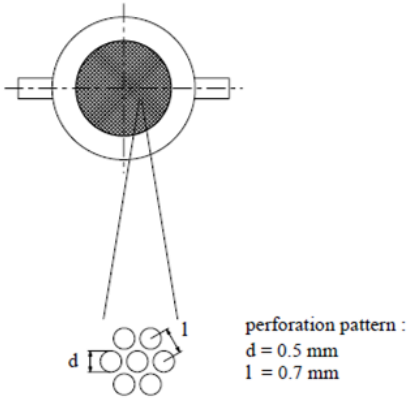
Öl-Wärme-Institut (OWI)
- thermocouple: type E
- temperature difference: 75 K
- effective burner plate-Ø: 29,3 mm
- evaporation with porous matrix and pump

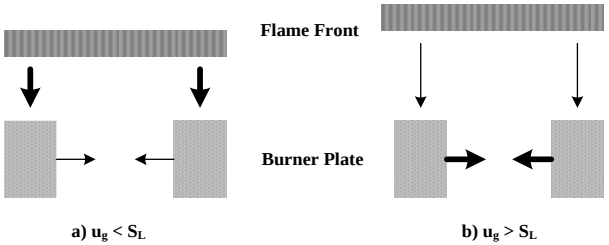
Bergakademie Freiberg (TUBAF)
- thermocouple: type E
- temperature difference: 70 K
- effective burner plate-Ø: 29,3 mm
- adapted direct evaporator system / coriolis-MFC for liquid fuels

Burner and test rig









<u>measuring principle</u>

- measuring radial temperature profile within the burner plate.
- stabilization of a quasi-adiabatic flame on top of the burner plate.
- heat flux between flame / burner plate and burner plate / fuel-oxidizer mixture must be equalized.
- $u_g < S_L$ → positive heat flux → burner plate achieve higher temperature compared to heating circuit
- $u_g > S_L$ → negative heat flux → burner plate achieve lower temperature compared to heating circuit

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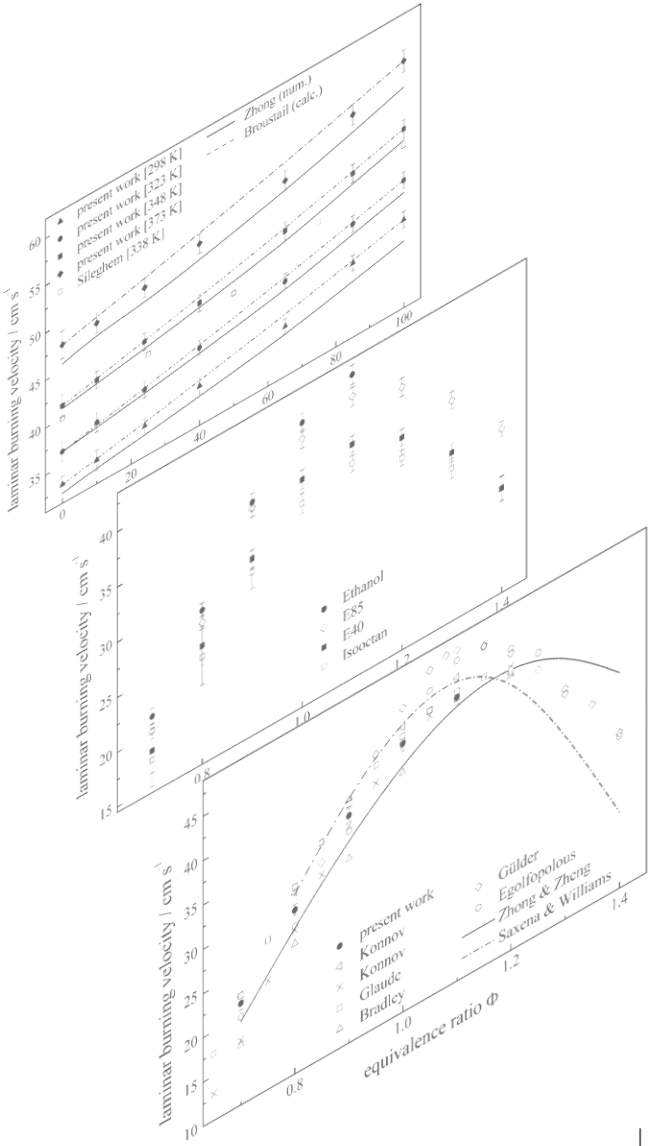
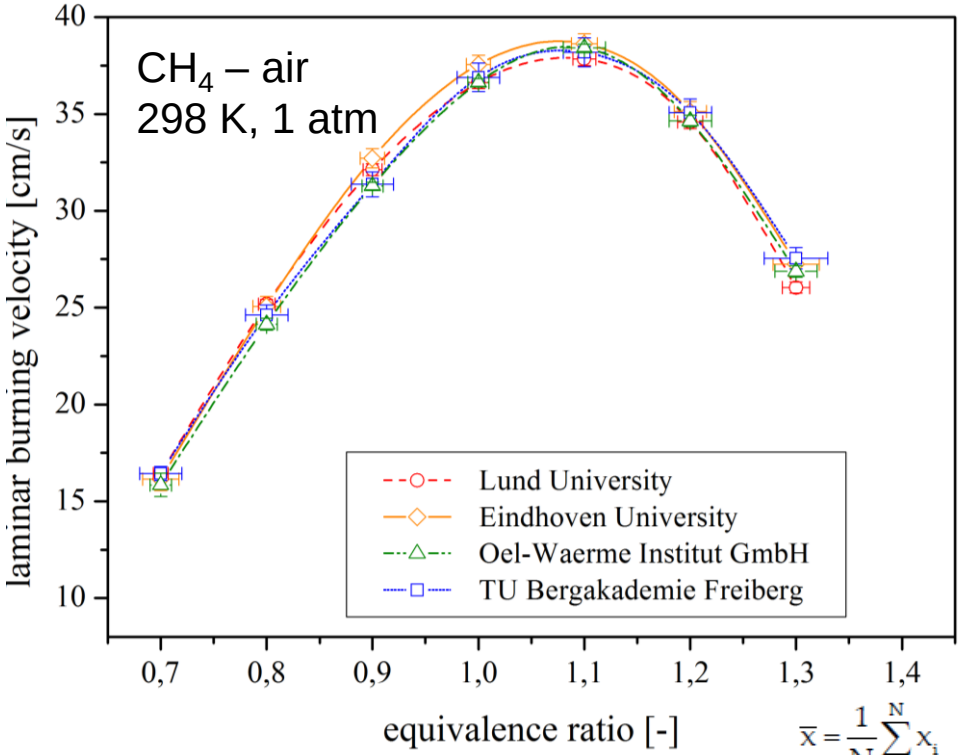


Results and discussion

Laminar burning velocity of methane



$$\bar{x} = \frac{1}{N}\sum_{i=1}^{N} x_i$$

$$MD = \frac{1}{N}\sum_{i=1}^{N} \left| x_i - \bar{x} \right|$$

$$\sigma = \frac{1}{N}\sqrt{Var(x)}$$

Table 1 – Mean values of measured burning velocities for methane/air mixtures at 298 K

φ	Mean value, cm/s	Mean deviation, cm/s	Standard deviation, cm/s
0.7	16,2	0,2	0,2
0.8	24,8	0,4	0,2
0.9	31,9	0,5	0,3
1	36,9	0,3	0,3
1.1	38,3	0,3	0,4
1.2	34,9	0,2	0,4
1.3	26,9	0,5	0,4

Table 2 – Average differences between the results of different labs for methane/air mixtures at 298 K

	Average difference [cm/s]		
	TUBAF	OWI	TUE
LU	0,6	0,6	0,6
TUBAF	-	0,4	0,5
OWI	-	-	0,7

S. Voss, E. Volkov, F. Rau, V.A. Alekseev, A.A. Konnov, R. Haas-Wittmüß, R.T.E. Hermanns, L.P.H. de Goey

Results and discussion

Laminar burning velocity of ethanol

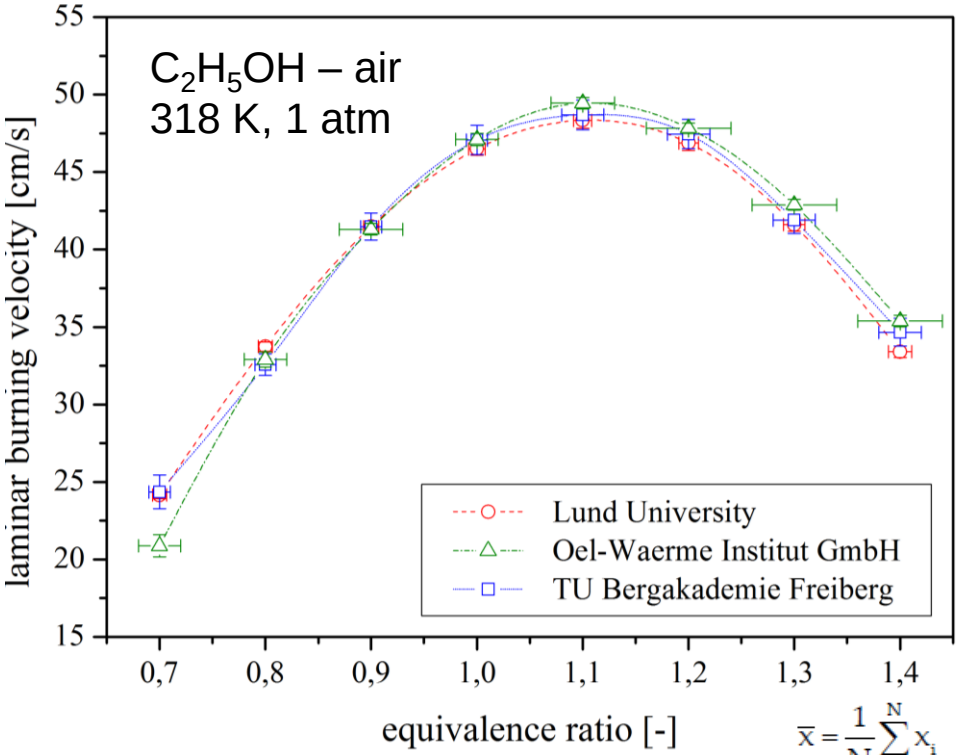


Table 3 – Mean values of measured burning velocities for ethanol/air mixtures at 318 K

φ	Mean value, cm/s	Mean deviation, cm/s	Standard deviation, cm/s
0.7	23,1	1,5	1,9
0.8	33,1	0,4	0,6
0.9	41,4	0,1	0,1
1.0	46,9	0,3	0,3
1.1	48,8	0,4	0,6
1.2	47,4	0,3	0,5
1.3	42,1	0,5	0,7
1.4	34,5	0,7	1,0

Table 4 – Average differences between the results of different labs for ethanol/air mixtures at 318 K

	Average difference [cm/s]	
	TUBAF	OWI
LU	0,6	1,3
TUBAF	-	0,9

$$\bar{x} = \frac{1}{N}\sum_{i=1}^{N} x_i$$

$$MD = \frac{1}{N}\sum_{i=1}^{N} \left| x_i - \bar{x} \right|$$

$$\sigma = \frac{1}{N}\sqrt{Var(x)}$$

S. Voss, E. Volkov, F. Rau, V.A. Alekseev, A.A. Konnov, R. Haas-Wittmüß, R.T.E. Hermanns, L.P.H. de Goey

Results and discussion

Laminar burning velocity of methanol

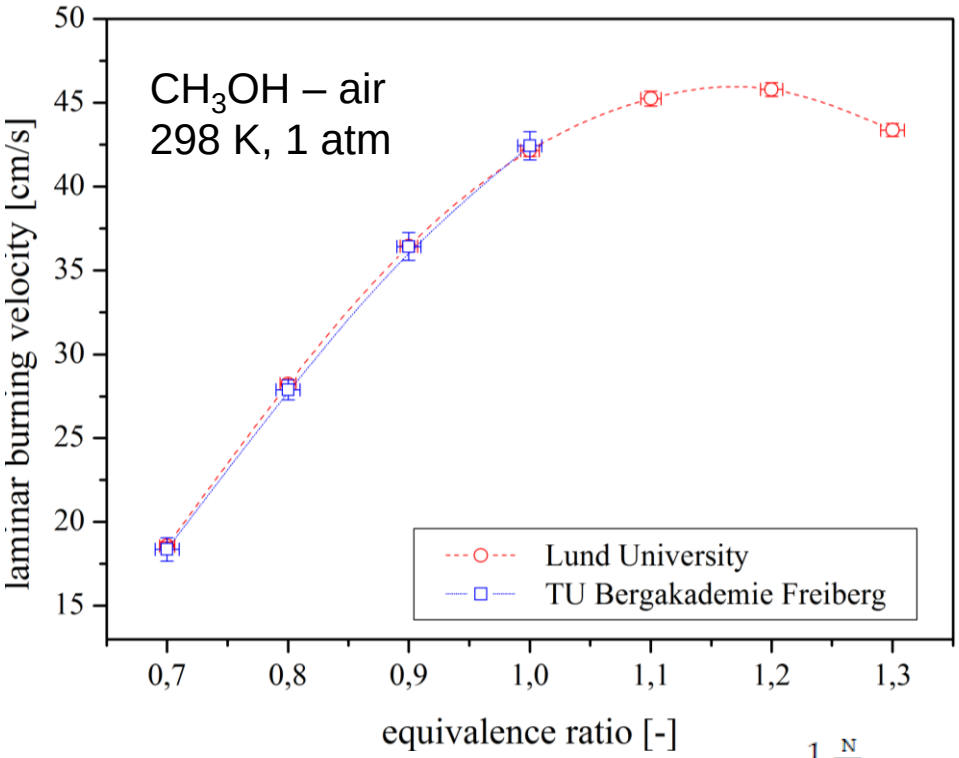


Table 5 – Mean values of measured burning velocities for methanol/air mixtures at 298 K

φ	Mean value, cm/s	Mean deviation, cm/s
0.7	18,5	0,1
0.8	28,1	0,2
0.9	36,4	0,0
1.0	42,3	0,1

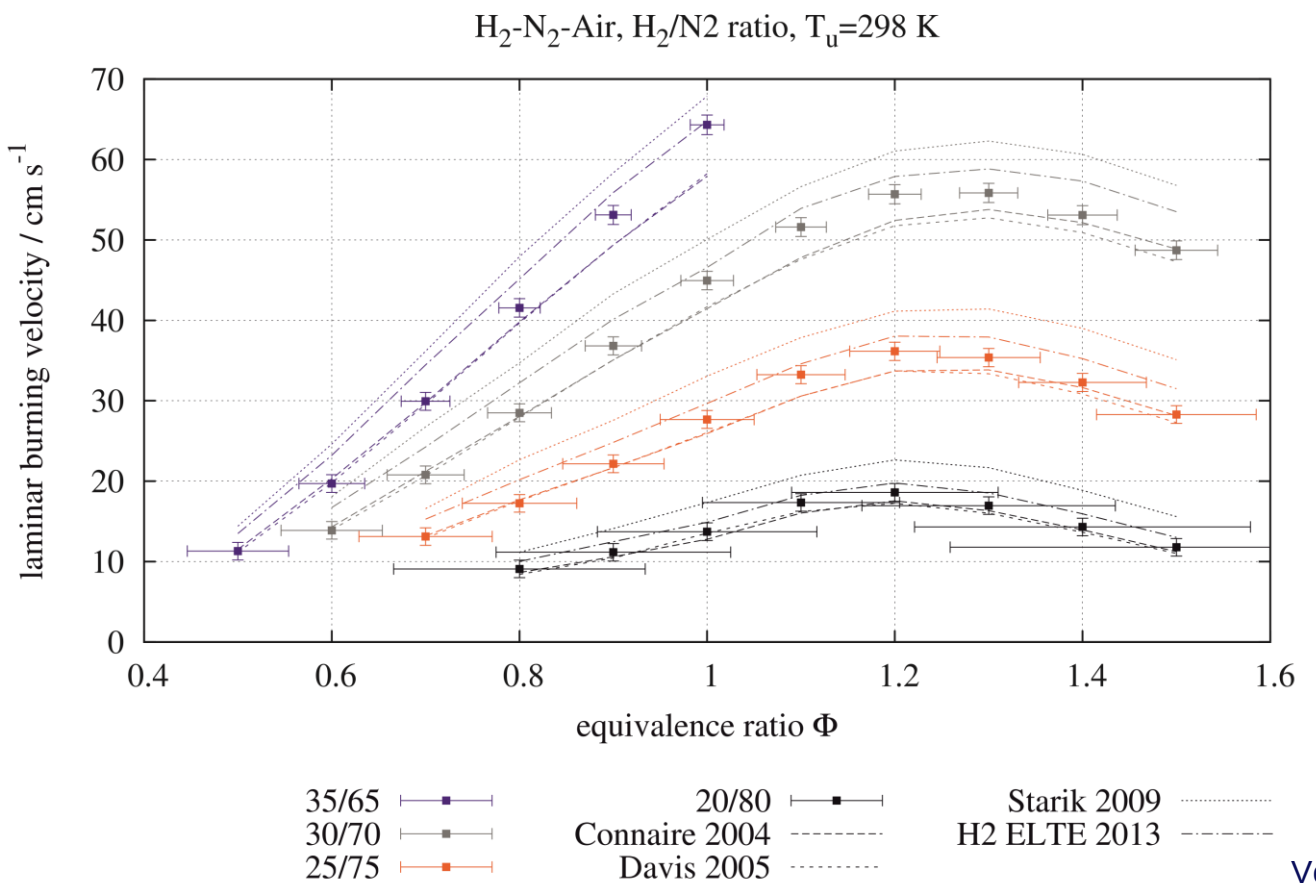
$$\bar{x} = \frac{1}{N}\sum_{i=1}^{N} x_i$$

$$MD = \frac{1}{N}\sum_{i=1}^{N} |x_i - \bar{x}|$$

S. Voss, E. Volkov, F. Rau, V.A. Alekseev, A.A. Konnov, R. Haas-Wittmüß, R.T.E. Hermanns, L.P.H. de Goey

Results and discussion

Laminar burning velocity of syngas



Voss et al., 2014,
doi: 10.1016/j.ijhydene.2014.09.093

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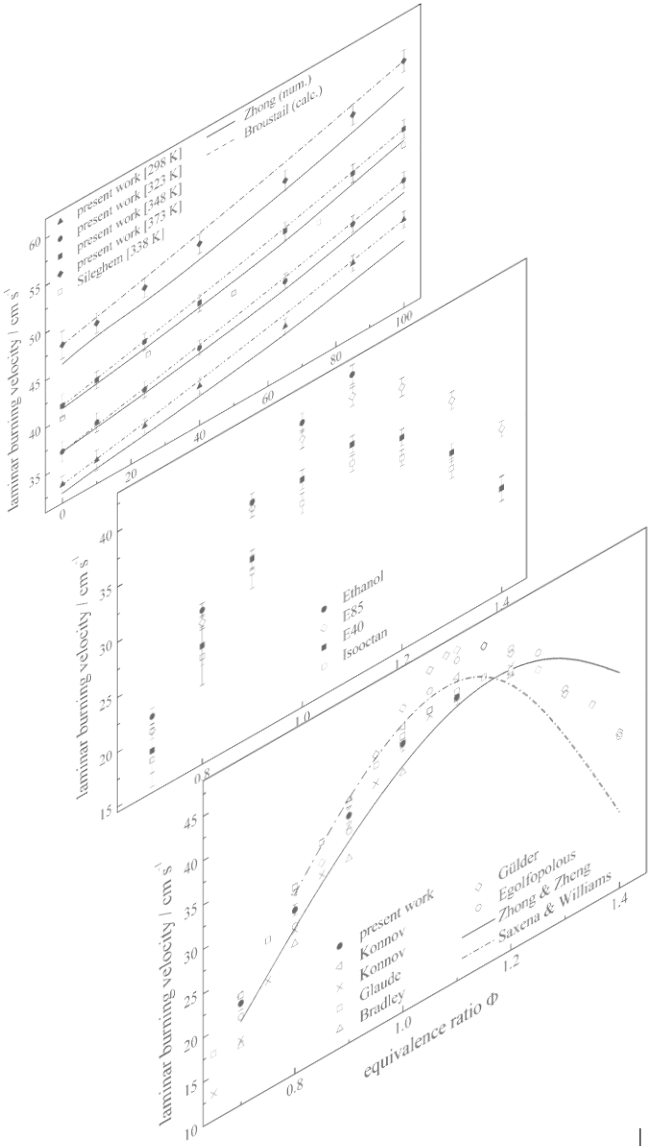

Conclusion

- The heat flux burner method has been used to measure the laminar burning velocity of different fuels:
  - methane-air mixtures
  - ethanol-air mixtures
  - methanol-air mixtures
  - syngas mixtures
- In this study the combined standard uncertainty of independent input quantities for the laminar burning velocity, the equivalence ratio is calculated. It is later expanded to a higher level of confidence so it results in an expanded standard uncertainty. The calculation of the uncertainties is based on the “Guide to the Expression of Uncertainty in Measurement” (GUM) from the “Joint Committee for Guides in Metrology” (JCGM).
- Standard deviations were over wide ranges < 0,7 cm/s.
- Heat-Flux burner in combination with a direct evaporizer, coriolis mass flow controller and hydraulic accumulator ensure high reproducibility and accuracy.

Network

Heat Flux Method

for accurate measurement of the laminar burning velocity

www.heatfluxburner.org

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Thank you for your attention

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