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M. Sc. Christian Wondra

Determination of flammability limits and laminar flame velocity of biogenic synthesis gases

14TH SEPTEMBER 2021, KARLSRUHE

Overview on this presentation

1. Motivation

2. The Project „KonditorGas“

3. Laminar flame velocity and flammability limit

4. Construction of the test rig

Project KonditorGas - Overview

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Title of the Doctoral Project:	„KonditorGas“
Doctoral Student:	Christian Wondra
Project Partners:	DBFZ Leipzig E-Flox GmbH TesTneT GmbH
University:	Friedrich-Alexander University Erlangen-Nürnberg
University Supervisor:	Prof. Dr.-Ing. Jürgen Karl
Funding :	BMWi, PTJ — Bundesministerium für Wirtschaft und Energie; Projektträger Jülich Forschungszentrum Jülich
Duration:	09/2020 – 08/2023

Motivation – Industrial Process Heat

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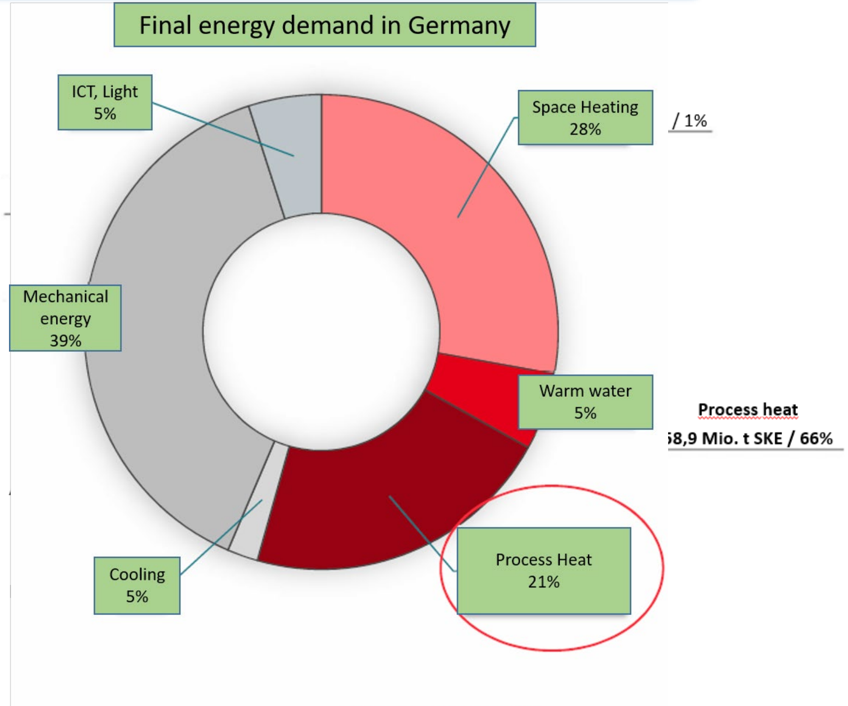
Handelsblatt

Industrie: Der heimliche Energiefresser: Grüne Lösungen für Prozesswärme gesucht

„Wenn wir wirklich wollen, dass die Energiewende funktioniert, müssen wir die Industrie auf CO2-neutrale Prozesswärme umstellen", sagt ...

12.08.2020



Daten: BMWi-Energiedaten 1/2018

- Process heat largest final energy consumer in industry
- 1/5 final energy consumption in Germany is required for process heat
- Renewable concepts important for achieving climate targets
- CO_2-tax since 2021
  →economic factor

Motivation – Energy sources for process heat

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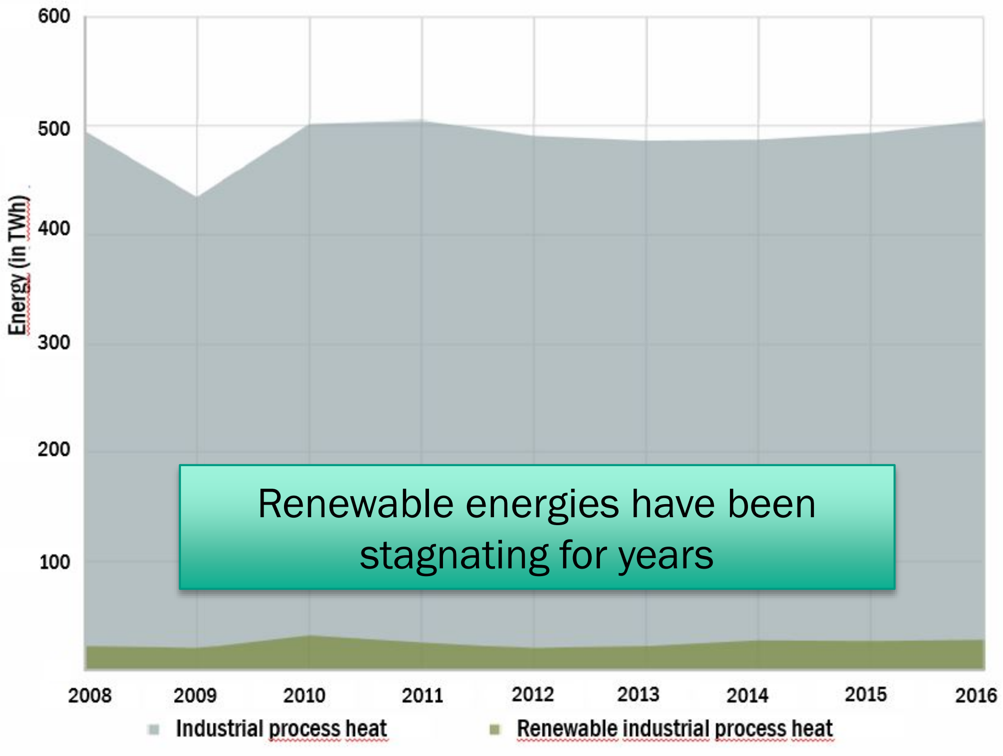

Hamburg Institut, Kurzgutachten zur Dekarbonisierung der Prozesswärme, 2018.

- Renewables contribute only 5 % to supply
- Main energy source is (natural) gas

- Substitution of natural gas by biogenic synthesis gases from the gasification of biomass
- Adaptation of the process chains for industry possible with little effort

Aim of the project: Complete process chain for direct utilization of biogenic synthesis gases

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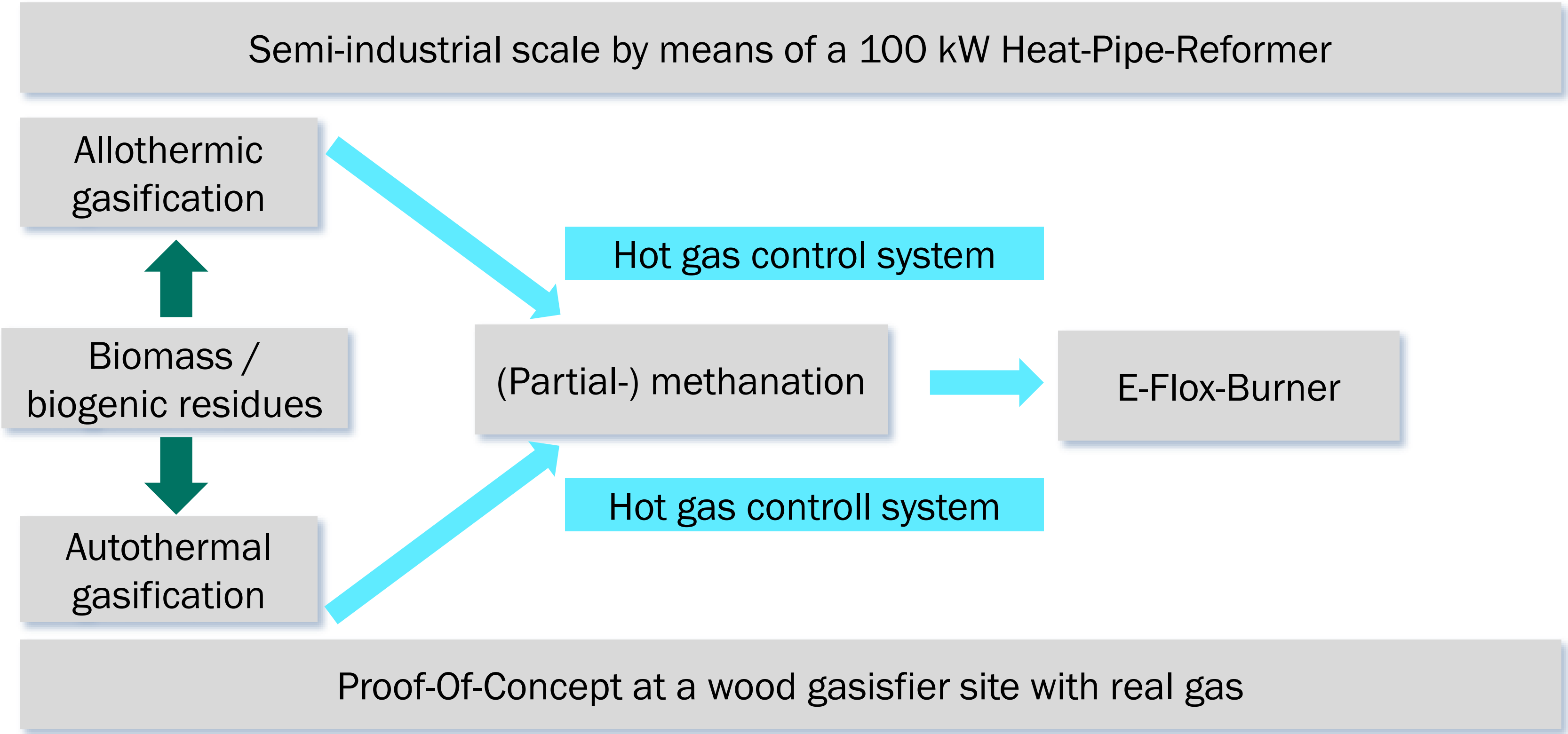
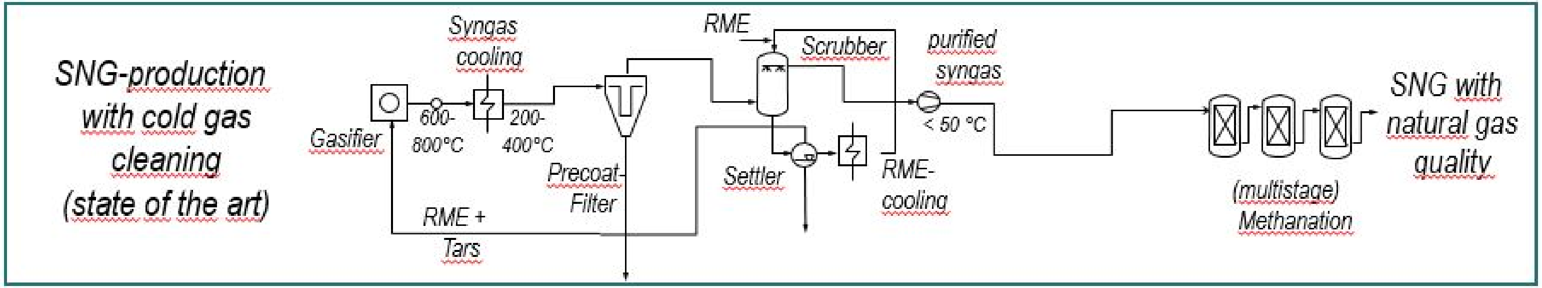
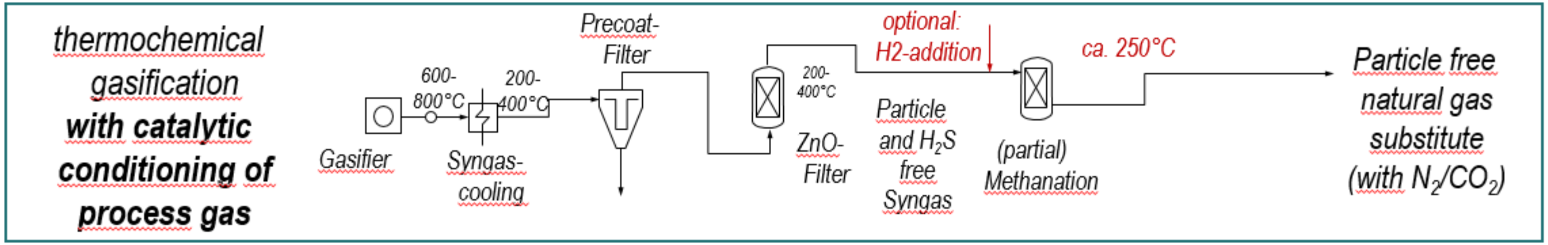


SNG production: State of the art vs. Catalytic conditioning

State of the art: SNG with natural gas quality



Aim of the project: Simplification of gas purification and methanation, resulting in technical and economic simplification of the process chain



Gasification: Different gas quality and inert gas content

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Allothermal process chain:

- 5 kW fluidized bed gasifier
- Steam as gasification medium

H_2	CO	CO_2	CH_4	Tars
Vol %	Vol %	Vol %	Vol %	mg/m³
47,4	14,6	27,5	10,5	5000

Autothermal process chain:

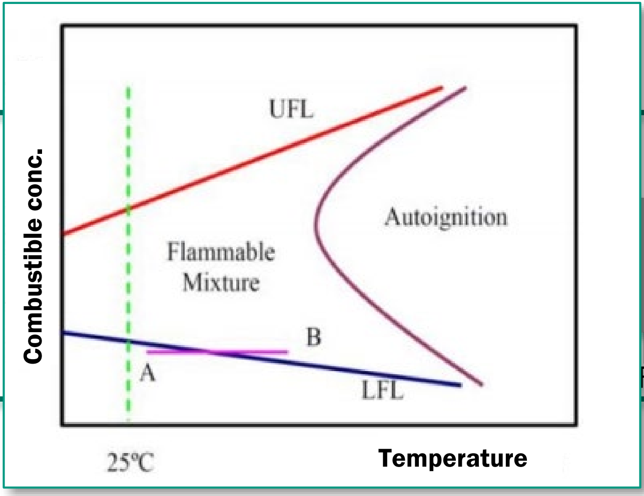
- 10 kW fixed bed gasifier (Spanner RE)
- Air as gasification medium

H_2	CO	CO_2	CH_4	N_2	Tars
Vol %	Vol %	Vol %	Vol %	Vol %	mg/m³
19,5	22,6	11,1	1,9	43,7	193

Due to the simplification of the process, the fuel gas contains higher concentrations of inert gases, which influence parameters such as flammability limits and flame velocities.

Theoretical background – Flammability limit of gas mixtures

- Describes the flammability of a gas mixture in air
- Important safety characteristic
- Lower (LFL) and upper (UFL) flammability limit

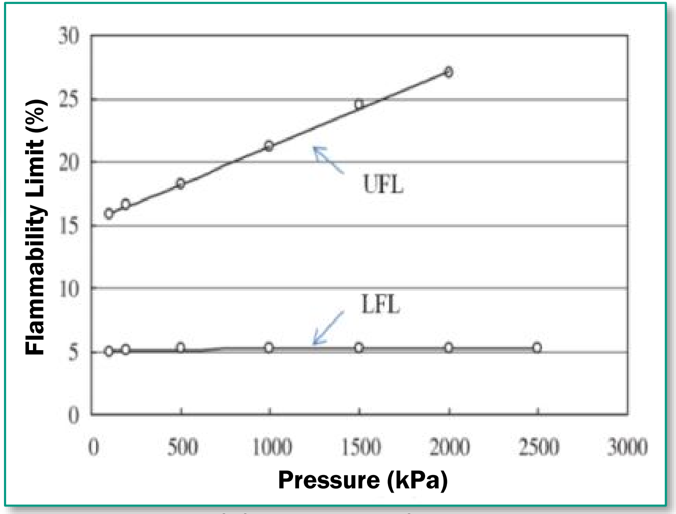


Zabetakis, M.G, Flammability Characteristics of Combustible Gases and Vapors

Depends on:
100 Vol%
- Temperature
- e
- s content

Too rich

FL



Azadboni et.al, Investigation of influencing parameters of LFL and UFL

Flamability limit – Influence of inert/neutral gas

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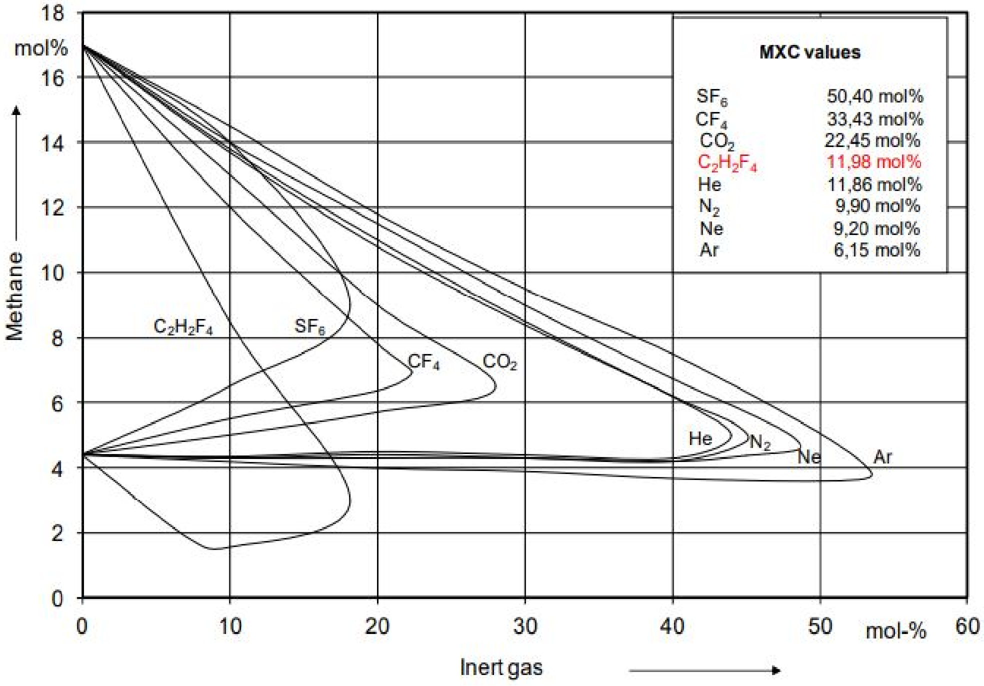
- Considerable effect on chemical reaction mechanism
- Dilution of the fuel gas mixture
- Inert gas with high thermal capacity reduce the flame temperature
- Also the thermal conductivity is a factor

With increasing inert gas content the range between LFL and UFL is reduced



CHEMSAFE®, Database of evaluated safety characteristics

Theoretical background – Laminar flame velocity

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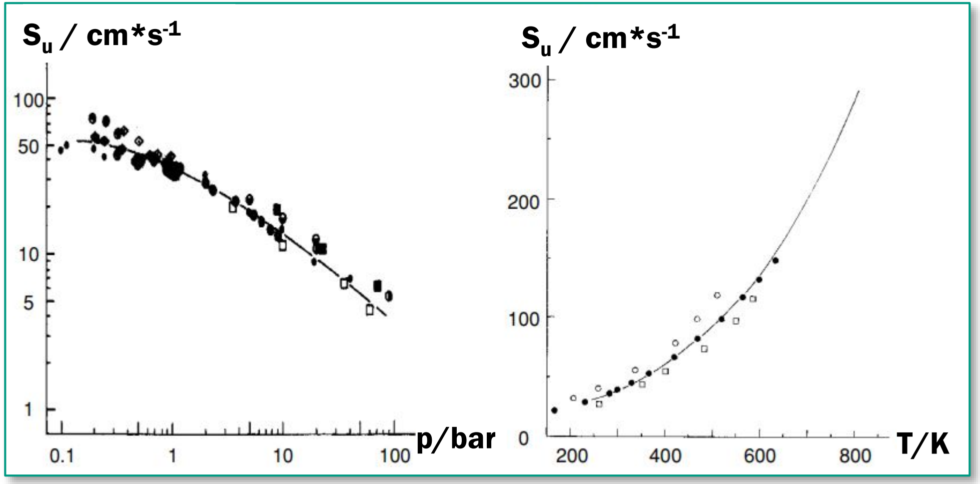
- Corresponds to the propagation velocity of the flame front in the direction of the fuel/air mixture flowing after it
- Flame speed describes reactivity of the fuel gas
- Depends on the fuel/air mixture
- Defined by Zeldovich et al. as

$$S_u = \sqrt{\frac{a}{A * e^{-\frac{E_A}{RT}}}}$$



Warnatz et al., Combustion

- Depending on temperature and pressure

Laminar flame velocity – Influence of gas composition

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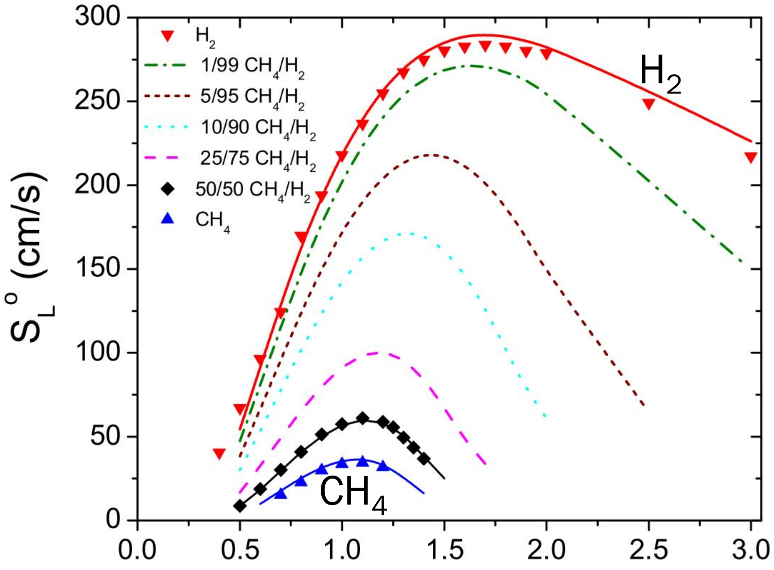
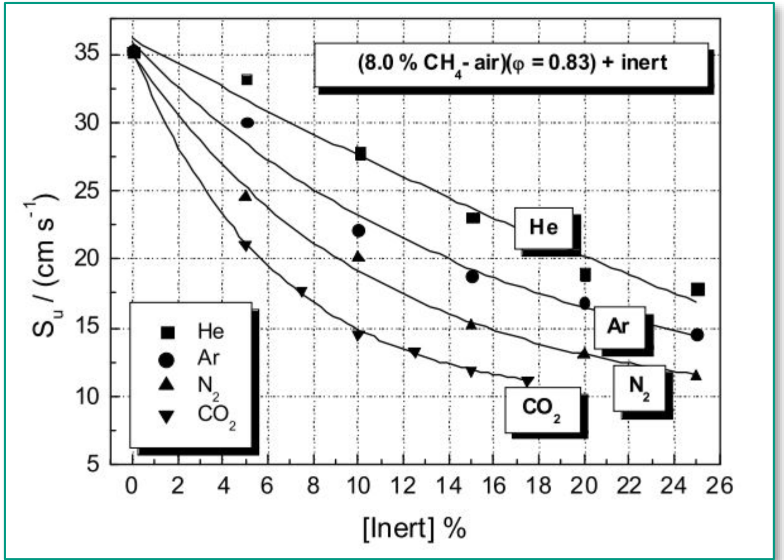
- H_2 has a considerably higher laminar flame velocity
- Depends on fuel-air equivalence ratio



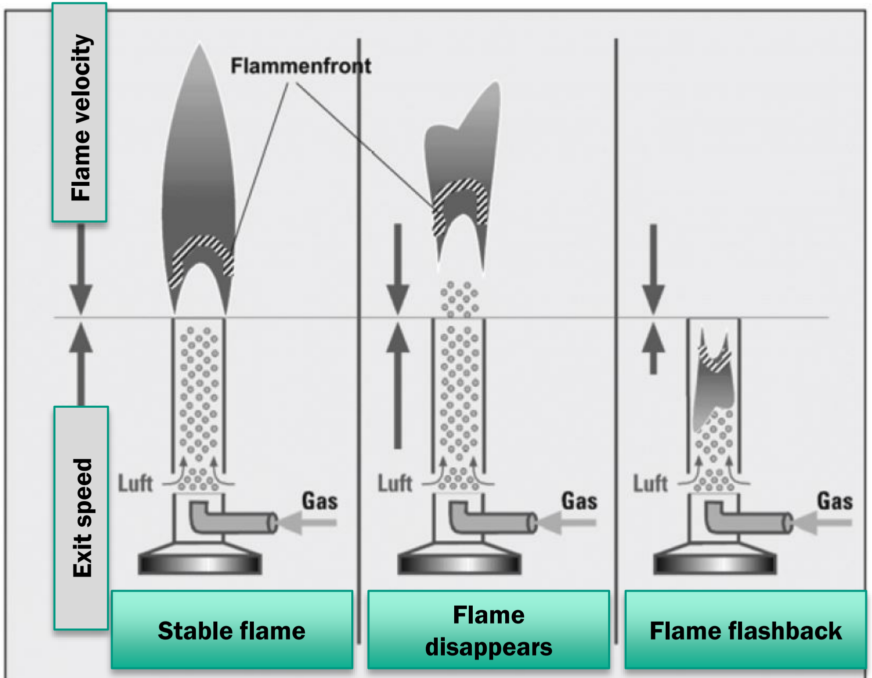
N. Donohoe et al., Ignition delay times, laminar flame speeds, and mechanism validation for natural gas/hydrogen blends at elevated pressures

- Neutral gas dilutes the mixtures and reduce the calorific value and reaction rate
- Flame velocity decreases with higher neutral gas content



M. Mitu et al., Inert gas influence on the laminar burning velocity of methane-air mixtures

Laminar flame velocity – Important parameter for burner technology



F. Joos: Technische Verbrennung

- For a stable flame, the exit speed of the fuel/air mixture must be equal to the flame velocity
- Safety risks if the exit speed is too low

  → **Flame flashback**

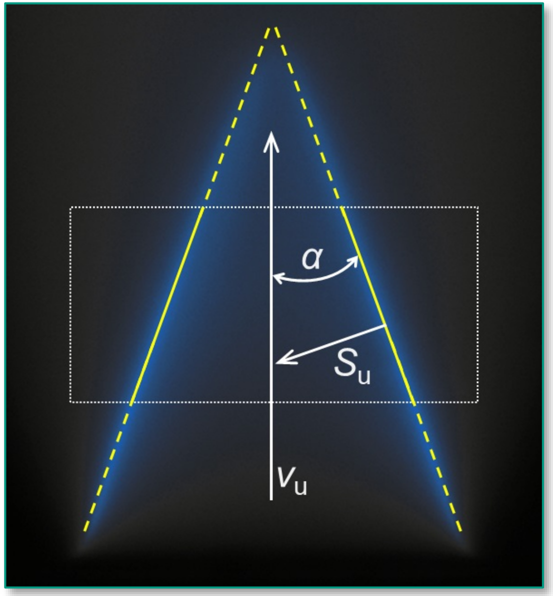
- Flame velocity too low

  → **no continuous flame and bad performance of the burning system**

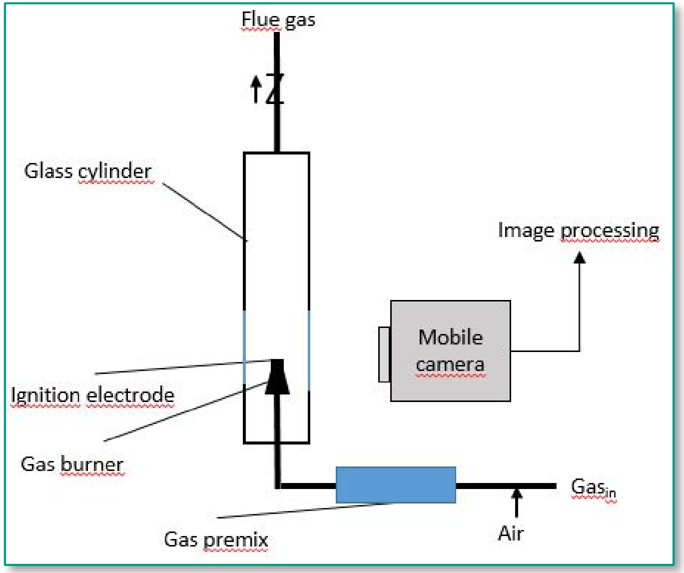
Test rig – Determination of the laminar flame velocity

- Optical measuring methode via angle methode

$$S_u = v_u * \sin \alpha$$



S. Richter, DLR-Institut für Verbrennungstechnik.



- Image processing with MatLab
- Mobile phone is used as a camera

Test rig – Determination of the flammability limit

- Integration in the same test rig

- Acording to DIN Norm there are two different methods

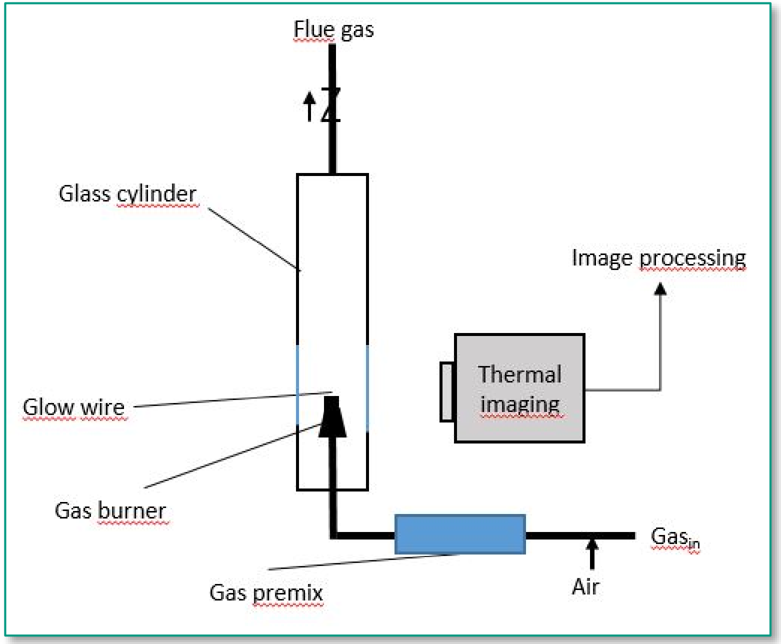
→ Both methods are not continous

- A modified tube methode is used

- Premixed gas flows over permanent ignition source

→ Flame formation or temperature changes are recorded

→ Validation of the new measurement methode with methane

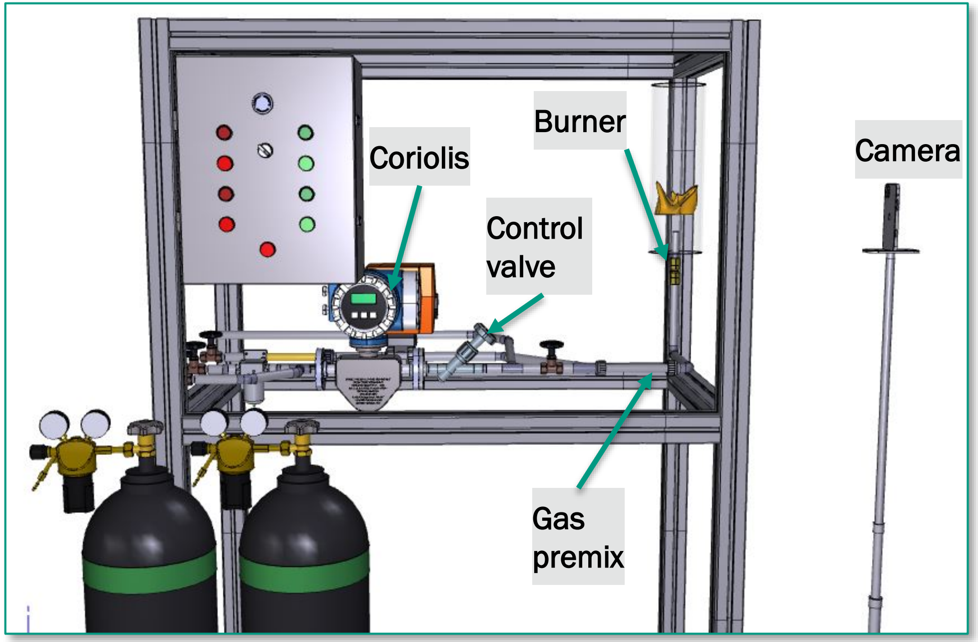


Construction of the test rig

- The syngas volume flow is controlled by a coriolis sensor proportional valve combination

- The pipe section and measuring instruments are trace heated and insulated to prevent tar condensation (T > 150 ° C)

- For safety reasons N_2 can evacuate the whole test rig



Summary and outlook

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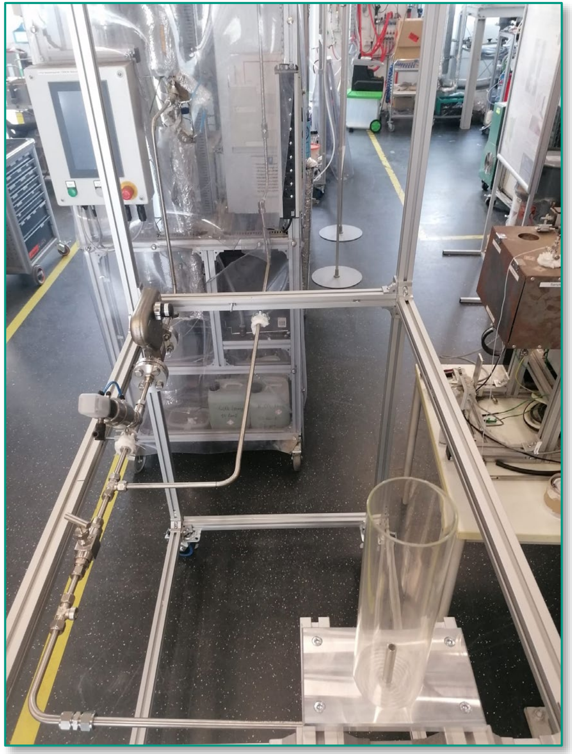
- Industrial process heat needs novel concepts to substitute fossil fuels
- Catalytically conditioned Syngas can be substitute natural gas and be used in modified burner systems
- The flame velocity is a decisive factor for the design and performance of the burner
- The higher inert gas and hydrogen content of the syngas can be influence the flame velocity as well as the flammability limits
- The test rig is used to determine the parameters for real wood gases and to investigate correlations with the performance of the burner



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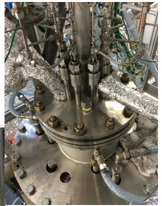
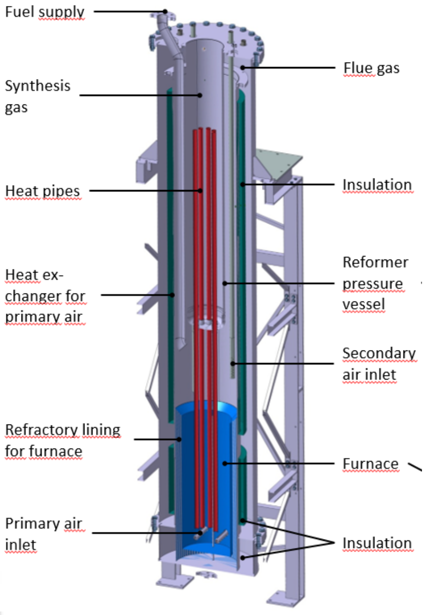
Proof of concept – Allothermic steam gasification

- 100 kW Heat-Pipe-Reformer
- Construction of the whole process chain at EVT
- Heat input into the reformer through 8 high-temperature sodium heat pipes
- Demonstration on a semi-industrial scale





FLOX Technology – FlameLess OXidation

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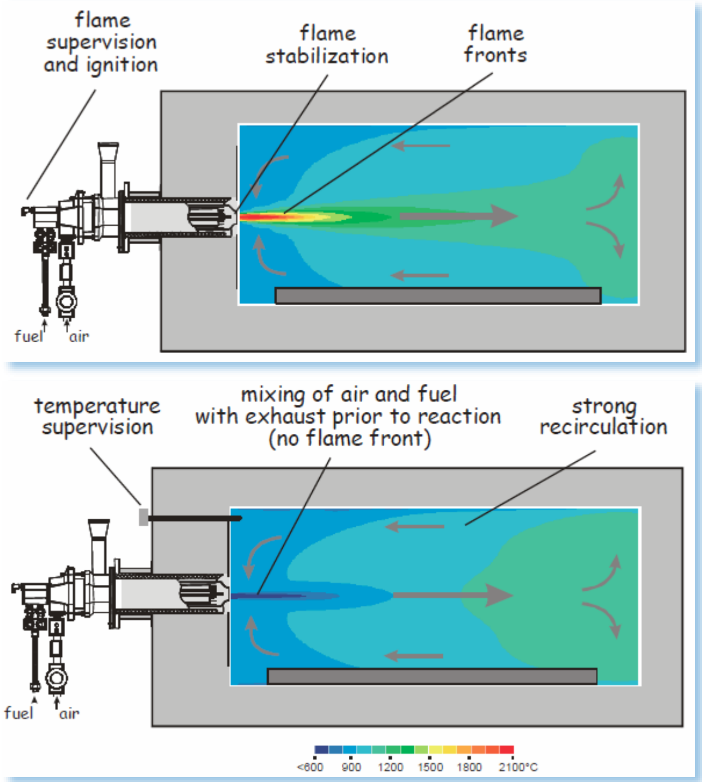

Advantages FLOX-Technology:

1. Oxidation in the combustion chamber volume instead of at the flame boundary
2. Uniform temperature distribution
3. Low thermal NOx
4. Excess air can be reduced
5. Fuel composition can vary
6. Weak gases can be used

Challenges of the FLOX-Technology:

- Only works at high temperatures (>800 ° C)
- Flame operation necessary when starting
- Until now natural gas is necessary for flame operation