# Optical Measurements
# Techniques and Applications
# $2^{nd}$ Edition

## Eds: F. Mayinger, O. Feldmann

## CD to the book

next

# Optical Measurements
# Techniques and Applications

The present CD-Rom is added to the book in order to demonstrate the capabilities of the optical measuring techniques presented in the book.

By combining the different measuring techniques with modern video or even high-speed video recording devices, additional information can be obtained from the recorded time series.

This CD contains examples of the combination of image forming optical measuring techniques and the high speed cinematography.

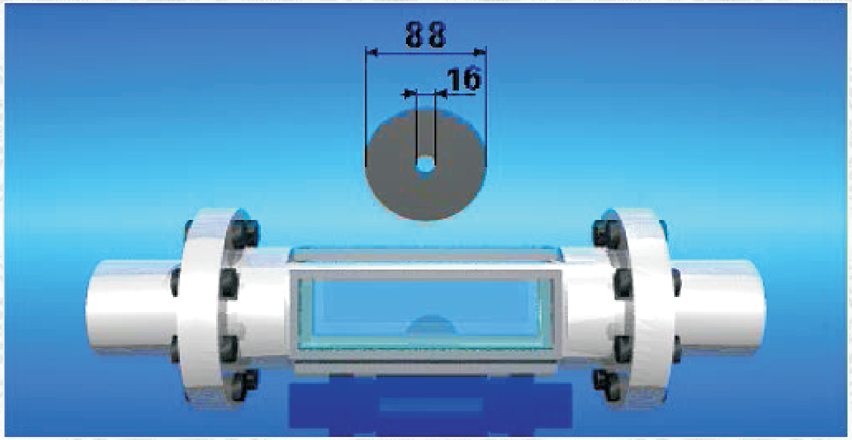
# Contents of the CD

# Premixed Turbulent Combustion

# High-speed Schlieren Cinematography

- ➡ Influence of obstacles on flame propagation (1)
- ➡ Influence of obstacles on flame propagation (2)
- ➡ Influence of obstacles on flame propagation (3)
- ➡ Influence of counter-flow on flame propagation

# Influence of a plate on the flame propagation




The film shows the propagation of a premixed hydrogen-air flame, which is influenced by a an obstacle in the path of the flame. The combustion process is visualized by means of a Schlieren-setup in combination with a high-speed video-camera. The test section and the optical setup is also shown in the film.

Due to the increasing turbulence behind the obstacle, an enhanced mixing of the burned and the unburned gas takes place which results in a significant flame acceleration and an increasing pressure release.

The experiments were performed in the frame of safety research, the obstacle substitutes a wall between two closed rooms with a central window opening.

# Influence of a plate on the flame propagation


The film shows the propagation of a premixed hydrogen-air flame, which is influenced by a an obstacle in the path of the flame.
Due to the increasing turbulence behind the obstacle, an enhanced mixing of the burned and the unburned gas takes place which results in a flame acceleration.
The combustion process is visualized by means of a Schlieren-setup in combination with a high-speed video-camera.
The experiments were performed in the frame of safety research, the obstacle substitutes a wall in a building.

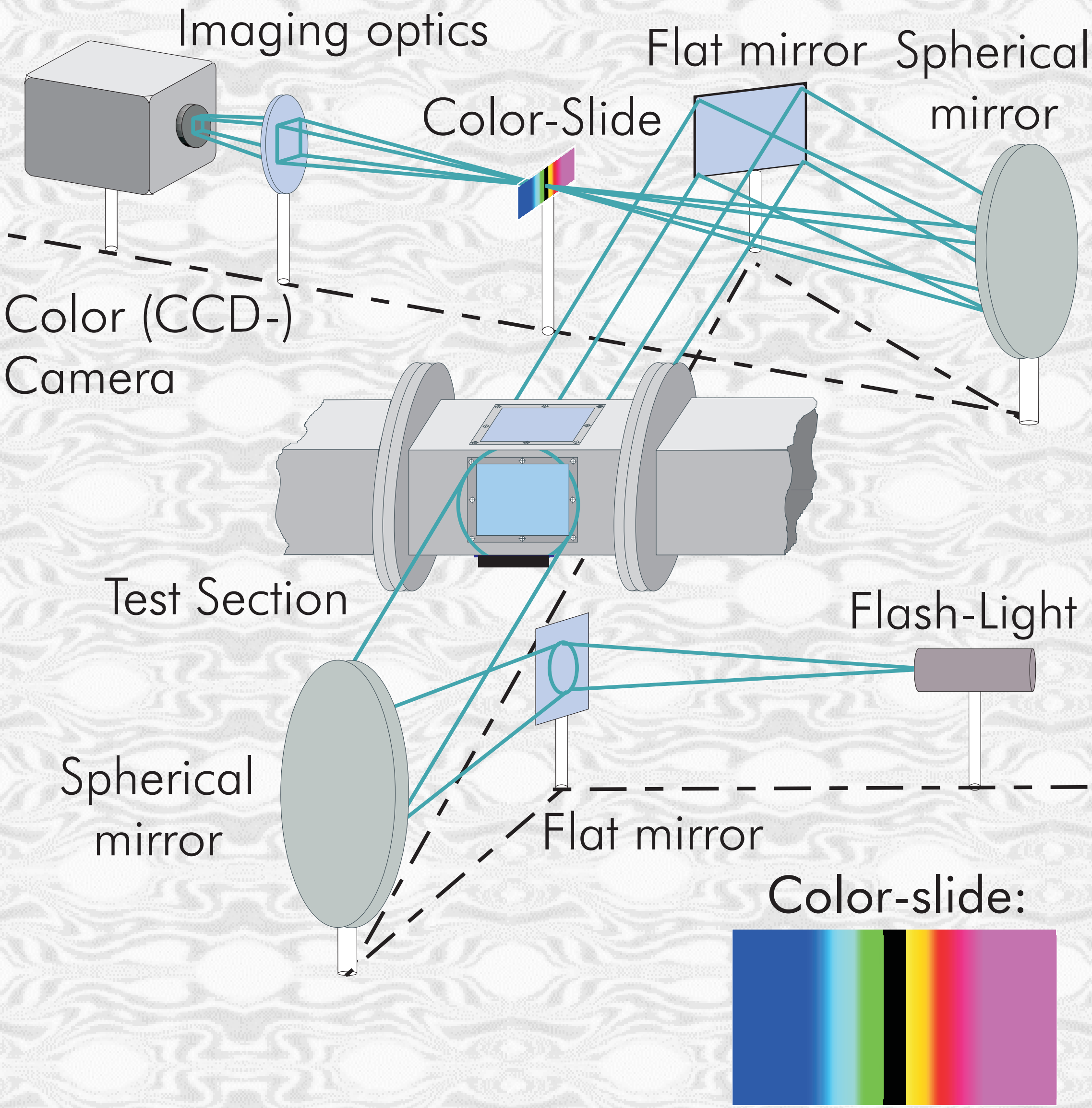
# Influence of tube-obstacle on the flame propagation

A horizontal cylinder substituts a tube inside a building in the path of a laminar burning premixed flame. The obstcle induced turbulence leads to the transition from a laminar to a turbulent combustion process. This results in a higher flame velocity and increasing pressure release.
The experiments were performed within the frame of hydrogen risk mitigation. The film was recorded with a high-speed schlieren video-camera.

# Influence of counter-flow on the flame propagation

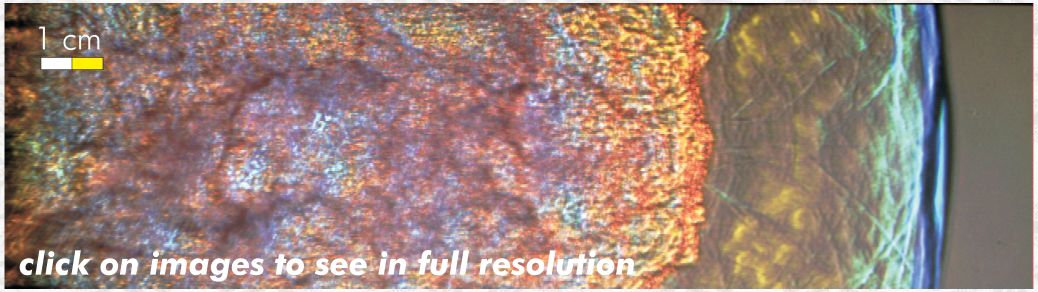

A premixed hydrogen air flame is burning against a turbulent flow field. By means of Schlieren-setup in combination with a high-speed vido-camera the integral flame structure and the flame velocity were analyzed.
The investigations of the influence of tubulent mixing processes on the flame propagation were performed within the frame of hydrogen risk mitigation.

# Experimental Setup for Color-Schlieren Records

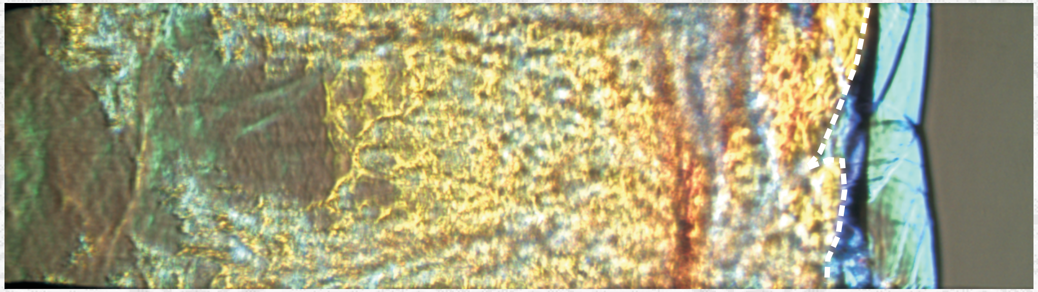



The Color-Schlieren Technique is similar to the classical Schlieren Technique. The main difference is that a color-slide replaces the knife-edge. Therefore, an unique color is assigned to each deflected light beam. The given slide can be used, if only horizontal gradients are of interest. The side of the slide corresponds to either a decreasing or an increasing density-gradient. The distance of the respective color to the focus (located on the black bar) is a measure for the strength of the gradient.

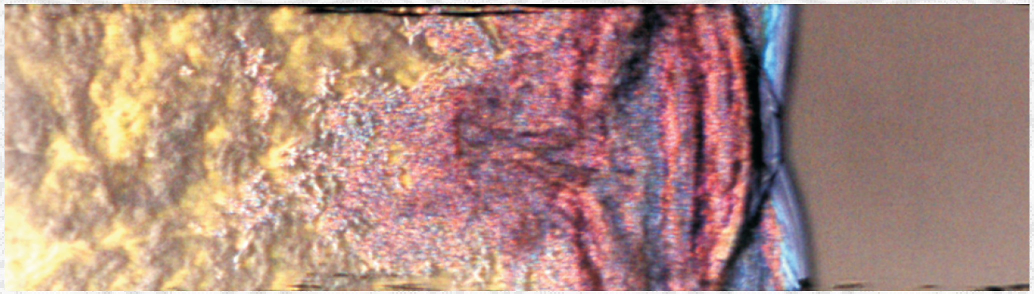
# Deflagration and Detonation in Premixed Hydrogen-Air Mixtures




Fast Deflagration, $u_{Flame}$ = 800 m/s, 18 vol. % $H_2$



Quasidetonation, $u_{Flame}$ = 1450 m/s, 18.5 vol. % $H_2$



Detonation, $u_{Flame}$ = 1650 m/s, 19 vol. % $H_2$

The Color-Schlieren Technique (Setup: here) facilitates to visualize density gradients.

The images show the propagation of fast flames in an explosion-tube, which is filled with a premixed hydrogen-air mixture.

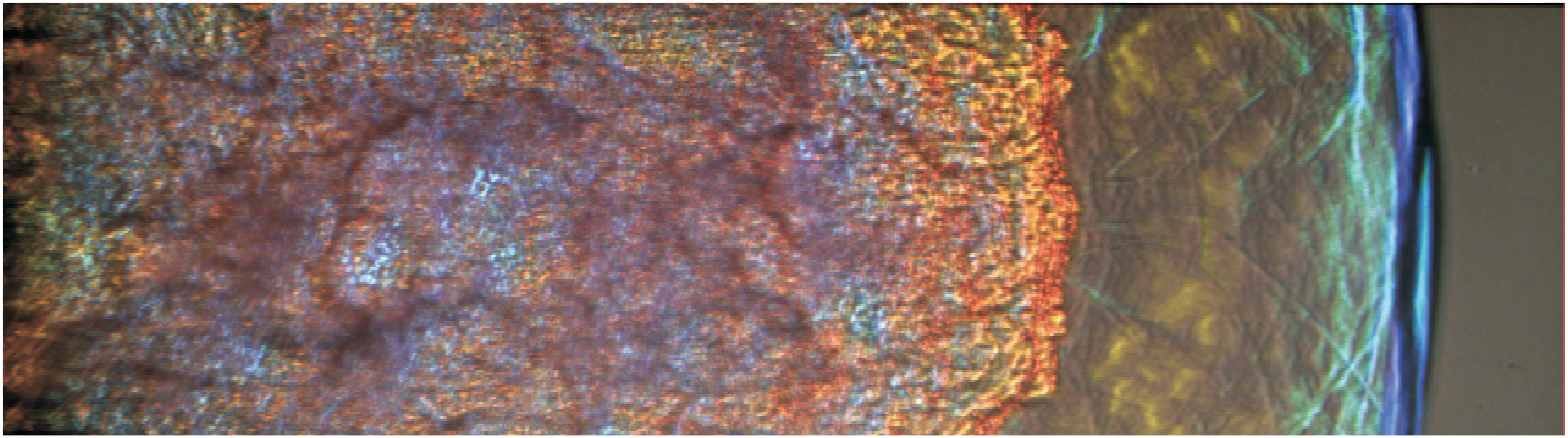
These fast combustion waves consist of a leading shock-front and a flame-front.

At subsonic fast deflagrations, shock and flame are decoupled, whereas at detonations the reaction zone is coupled to the shock wave.

# Fast Deflagration

Flame velocity: 800 m/s

Mixture composition 18.5 vol. % $H_2$



Flame-Front

Shock-front

Gradient-strength

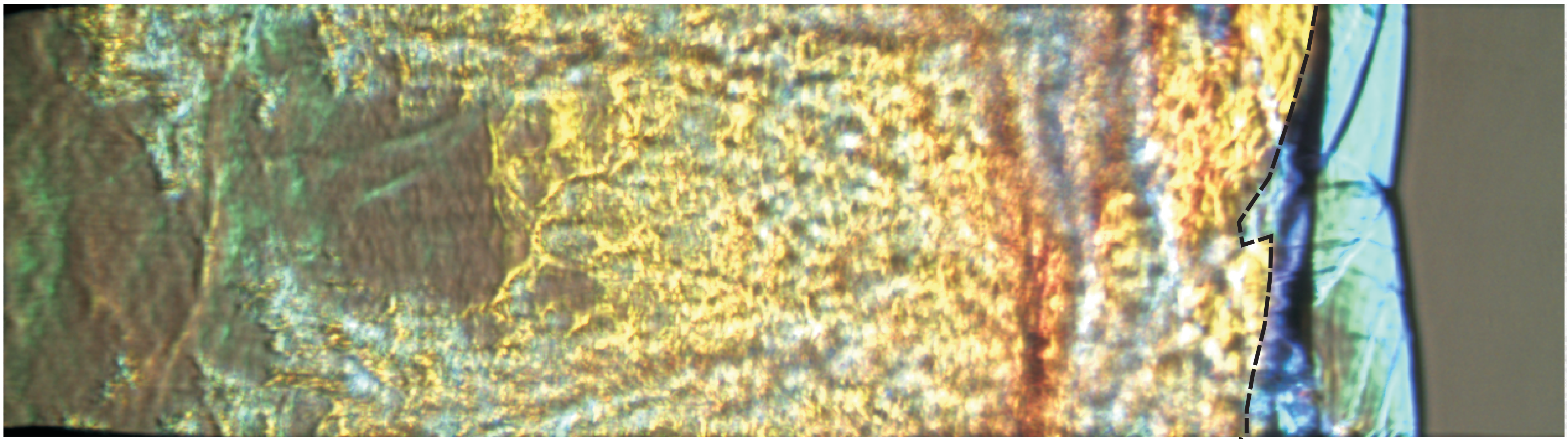
decreasing density ← 0 → increasing density

back

# Quasidetonation

Flame velocity: 1450 m/s

Mixture composition 18.5 vol. % $H_2$



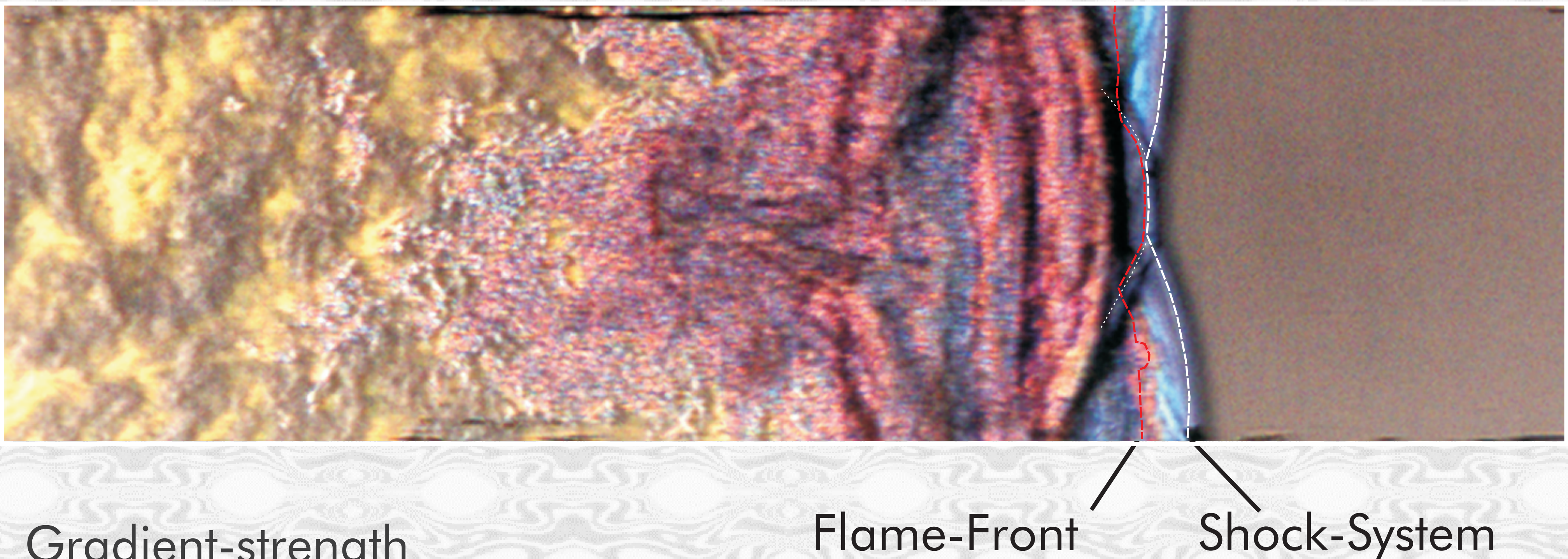


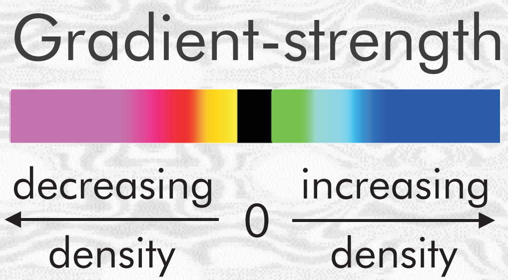
back

# Detonation

Flame velocity: 1650 m/s

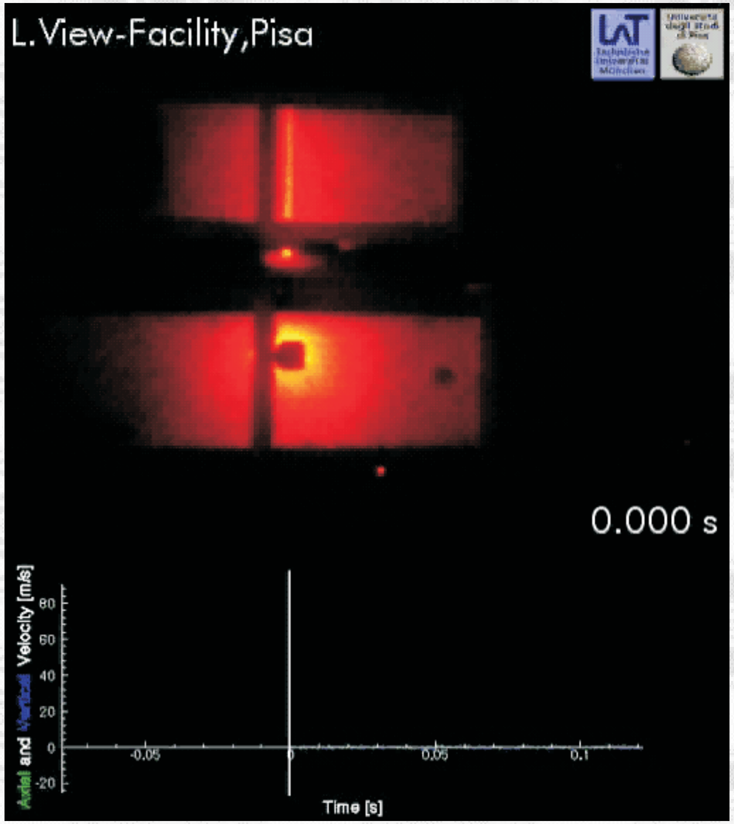
Mixture composition 19 vol. % $H_2$




back

# Influence of the flame propagation on flow velocities in adjacent chambers




In this experiment, the flame acceleration in a closed confinement is investigated. The chamber has a length of 3m and a cross section of 700x700mm. By means of a 45° mirror above the chamber the combustion process is observed from both the front and the top side simultaneously. The confinement is separated by a wall with a central opening of 100mm. Both parts are initially filled with the same lean hydrogen mixture.

The flame acceleration due to the influence of the wall opening is measured by means of a high speed video camera. The flow velocity as well as the turbulence intensity is determined in one position in the left chamber by means of a LDV-system.

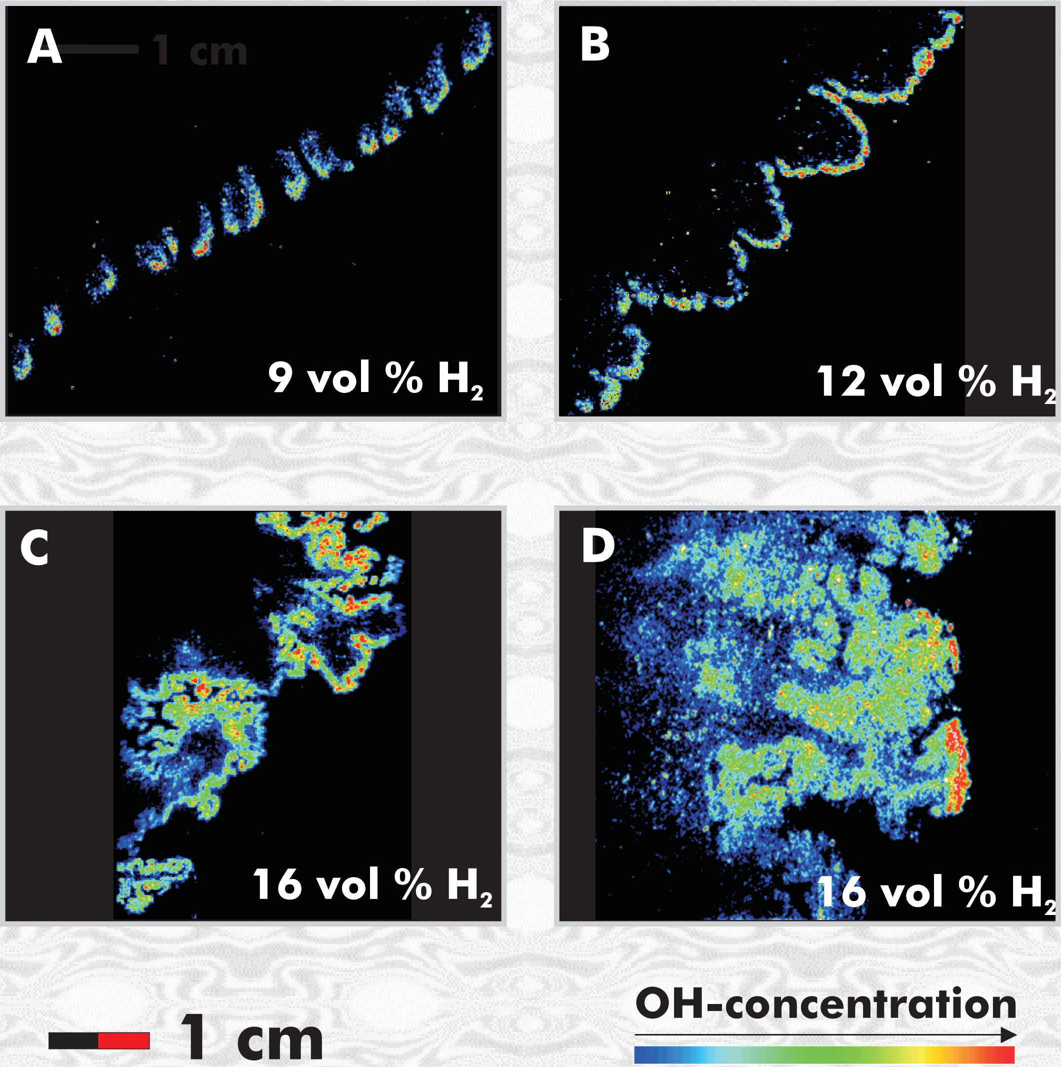
# Planar Laser-induced Predissociation Fluorescence

➡ Deflagrations in Hydrogen-Air Mixtures

➡ Detonations in Hydrogen-Air Mixtures

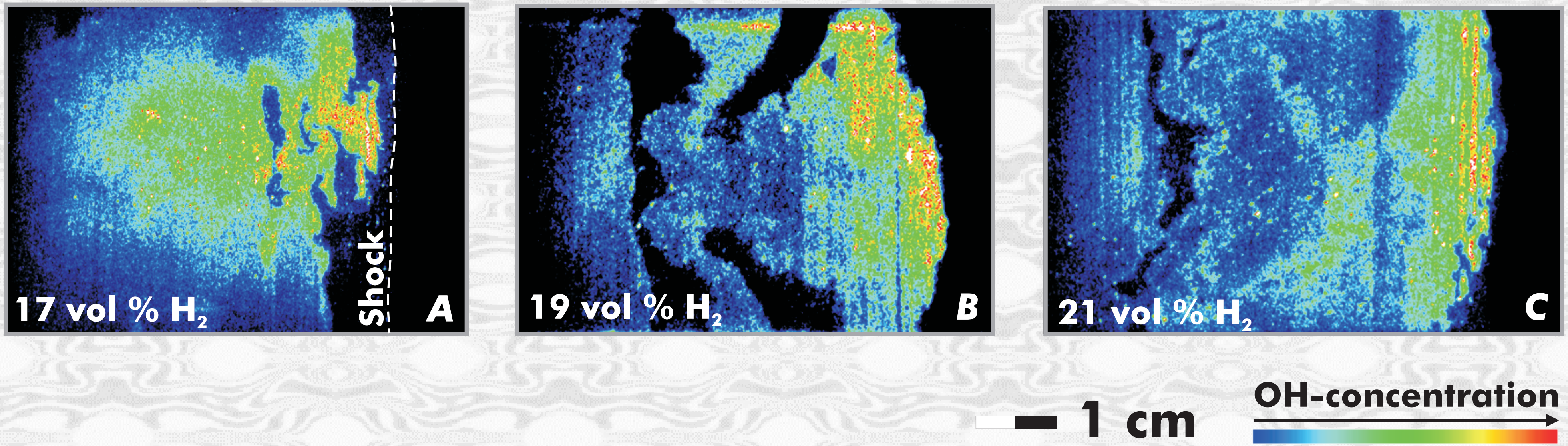
➡ Jet-Ignition in Hydrogen-Air and Methane-Air Mixtures

# Planar Laser-Induced Predissociation Fluorescence: OH-Radical Distribution of Deflagrations



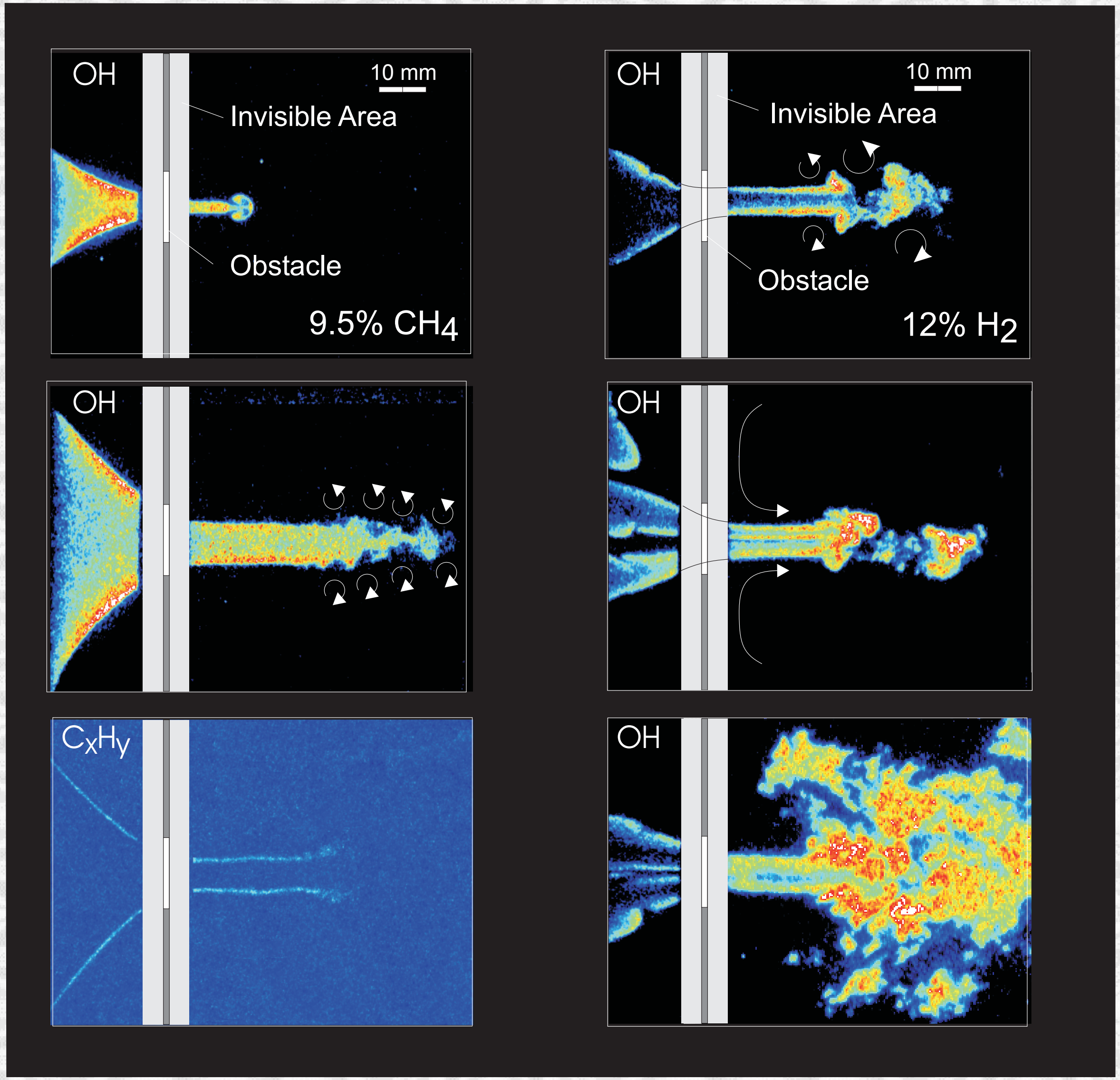

Intermediate species in a fuel-air reaction indicate the location of the reaction zone, such as e.g. the OH-radical in case of a hydrogen-air mixture. The images on the left show the reaction zones of propagating flames. The thickness of the reaction zone is an important parameter to classify premixed turbulent combustion processes.
A slowly propagating deflagration (v < 100 m/s) in a flow field with low turbulence is shown in Fig.s A-C.
Fig. D displays a fast-deflagrationin a highly turbulent flow field (800 m/s).

# Planar Laser-Induced Predissociation Fluorescence: OH-Radical Distribution of Detonations




Detonations are shock-induced combustion waves which propagate with supersonic speed (1500-2000 m/s). In contrast to the deflagrations (see here), a significant number of OH-radicals remain stable behind the reaction front. With this technique the proof could be furnished that at the detonation limit of the fuel-air mixture (Fig. A and B), pockets of unreacted gas are formed behind the reaction front. For richer mixtures (Fig. C) a nearly closed front was detected.

# Planar Laser-Induced Predissociation Fluorescence: Turbulent Jet-Ignition



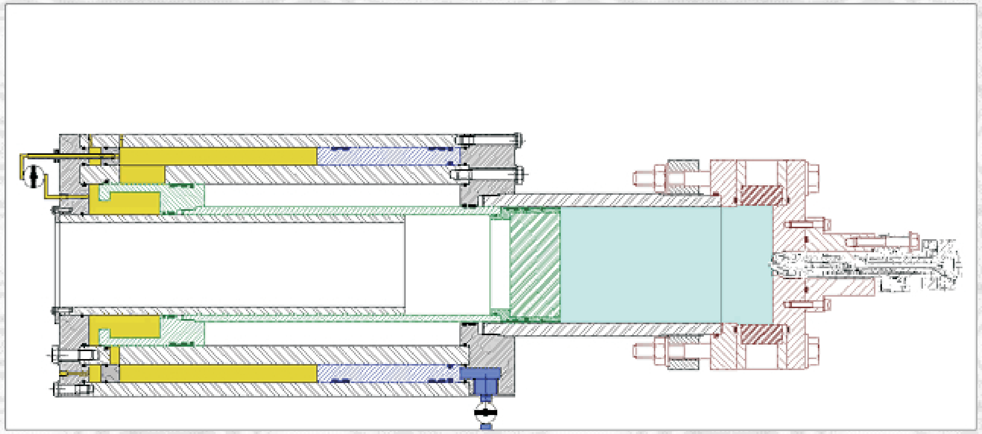

The jet-ignition in a hydrogen-air mixture is compared to one in a methane-air mixture. Both mixtures have almost the same laminar burning velocity. However, the combustion behavior and the reaction zones differ significantly.

In methane-air mixtures, the $C_xH_y$-radicals indicate the location of the reaction zone, since no radicals exist behind the front. The arrows symbolize the turbulent eddies of integral scale.

The images on the left correspond to the Schlieren series shown here.

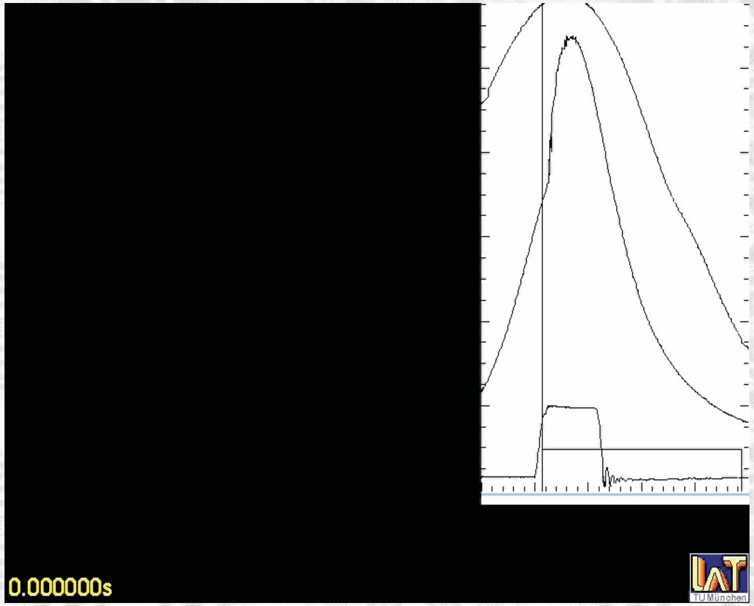
# Internal Combustion Engines

# Single Stroke Rapid Compression Machine: Setup



The rapid compression machine (RCM) was developed to investigate internal combustion processes of large bore diesel engines by means of optical measurement techniques. The RCM is completely optically accessible through the windows in both piston and walls of the combustion chamber. High speed video, Schlieren/Shadow technique, and laser-induced fluorescence were applied. During the experiments a single compression and expansion stroke takes place under realistic operating conditions. The machine is equipped with a second piston moving in counter-direction of the compression piston in order to establish complete mass balance. This prevents the machine from vibrating during the operation .

# Hydrogen Ship Diesel Engine: Standard 6 - Hole Nozzle

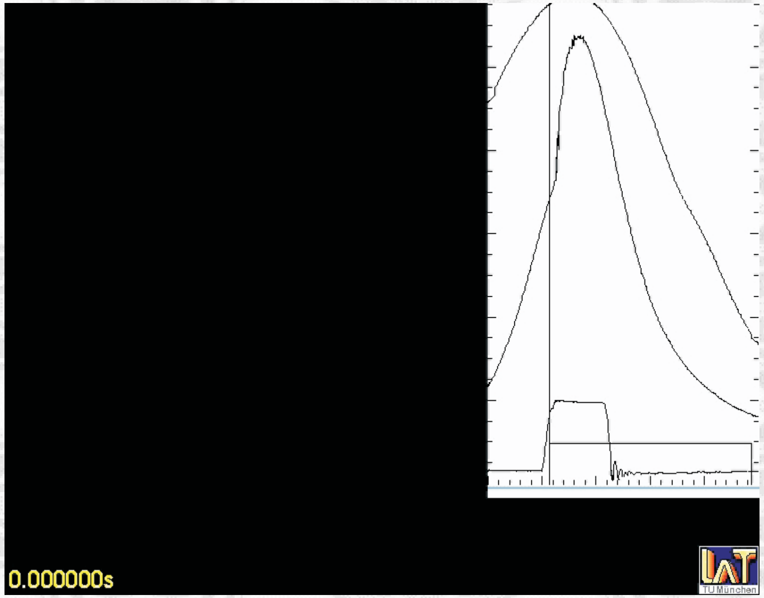



The focus of this research was the use of hydrogen as fuel for ship diesel engines with compression ignition. Simple 6- hole nozzles were investigated under different operating conditions in the first experiments (e.g. compression ratio, compression and pressure, swirl).

This type of nozzles was found to show large variations in ignition delay and energy release during combustion. Missfire was observed. Early injection of the hydrogen was required to ensure ignition. The result of such an operation mode was hard combustion, unstable operation and high emissions.

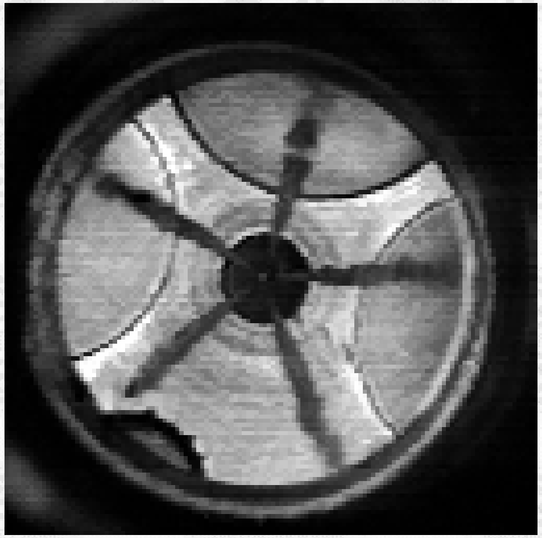
An ignition and combustion process is shown, injection timing and development of combustion pressure is also plotted.

# Hydrogen Ship Diesel Engine: Optimized 18 - Hole Nozzle



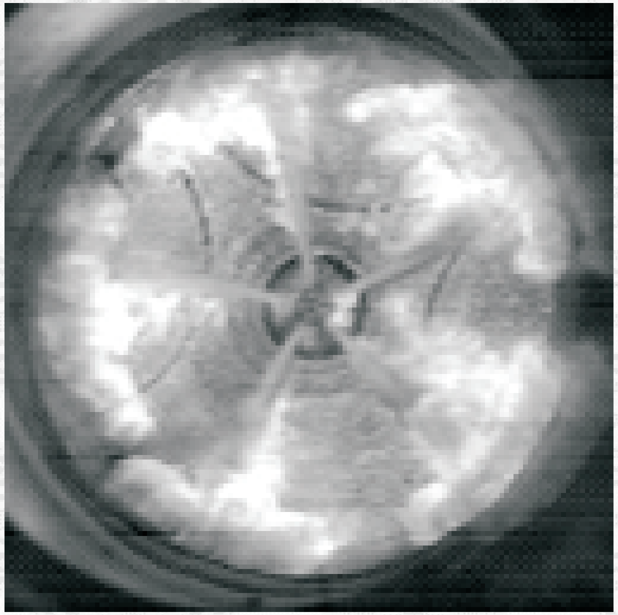

Compression ignition in large bore diesel engines with high pressure direct in-jection is achieved by high compression, temperatures of more than 1000 K, and specially designed nozzles .
Nozzles with a higher number of holes and a smaller bore diameter allow a very fast mixture formation in the vicinity of the nozzle and whith that good conditions for early ignition.
The homogeneous mixture around the nozzle allows a fast and stable flame propagation at the beginning of the combustion process. This leads to a smoother operation. The result of the optimization is shown in the video.

# Mixture formation



The picture shows a view through the piston bowl onto the cylinder head of a DI-diesel engine.
A certain amount of fuel is injected through the nozzle which is located in the center.
The following mixture process is determined by the fuel pressure / massflow and the cylinder pressure / temperature.
Due to the fast evaporation process of the fuel each configuration has its own characteristical penetration depth of the liquid phase. Beyond this depth, the injected fuel is completely evaporated. When this penetration depth exeeds the piston bowl radius, the liquid phase interacts with the piston bowl wall which is supposed to promote soot development.

# Combustion without Pre - Injection

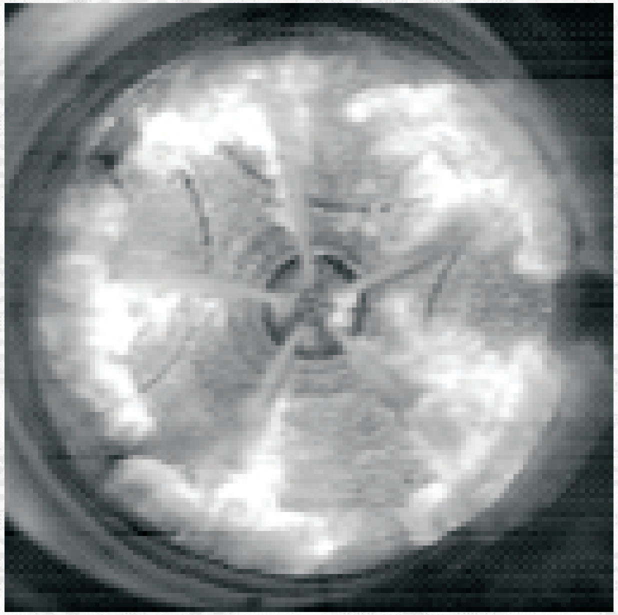


The conventional engine operation works with a single injection combined with a rotational in-cylinder air motion (swirl) which leads to an early ignition and a good fuel-air mixture.

Even if the swirl can not affect the liquid phase of the spray, it has a strong influence on the evaporated fuel located at the outer regions of the spray cone.

It is clearly visible that the first ignition takes place at the averted side of the swirl where a burnable fuel concentration is reached first. In every case there is a strong interaction between the ignited fuel-air mixture and the piston bowl wall, which is inevitable connected to increasing heat losses. This fact promotes soot development.

# Combustion with Pre - Injection



Modern high-pressure injection technologies (Common Rail) equipped with fast piezo-electrical injectors offer the possibility of time-independant, multiple injections.

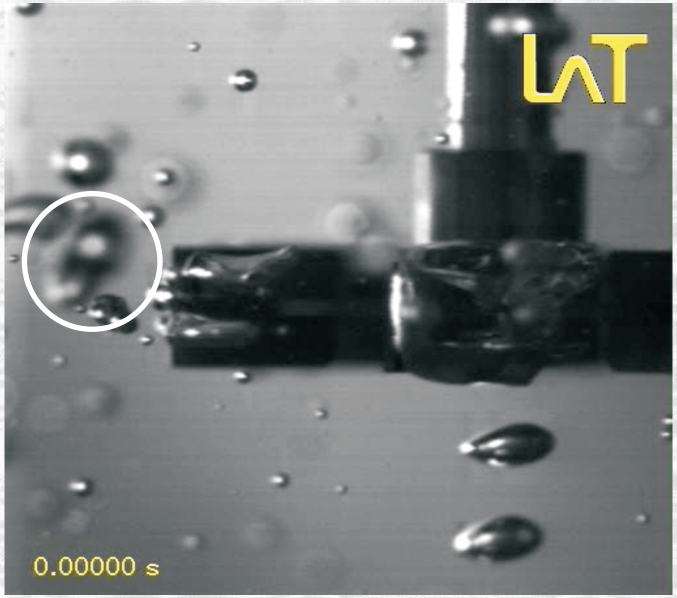
The strategy of using a tiny amount of pre-injected fuel immediately followed by the main-injection emerged to deliver best combustion and emission results.

The evaporated and ignited pre-injection rises the pressure and chiefly the temperature in the piston bowl. As a result the essentially shortened ignition delay of the main injection leads to a smooth pressure rise and a lower maximum temperature during the combustion process due to less premixed flames. The emission of $NO_x$ appears reduced.

# Bubble Dispersion in Aerated Stirred Vessels

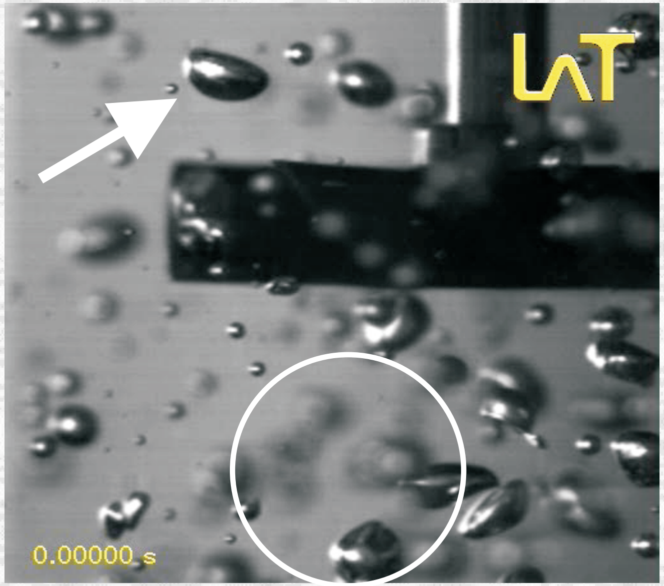
- Rushton-Turbine
- Pitched Blade Turbine (downward pumping)

# Bubble disintegeration by a Rushton Turbine



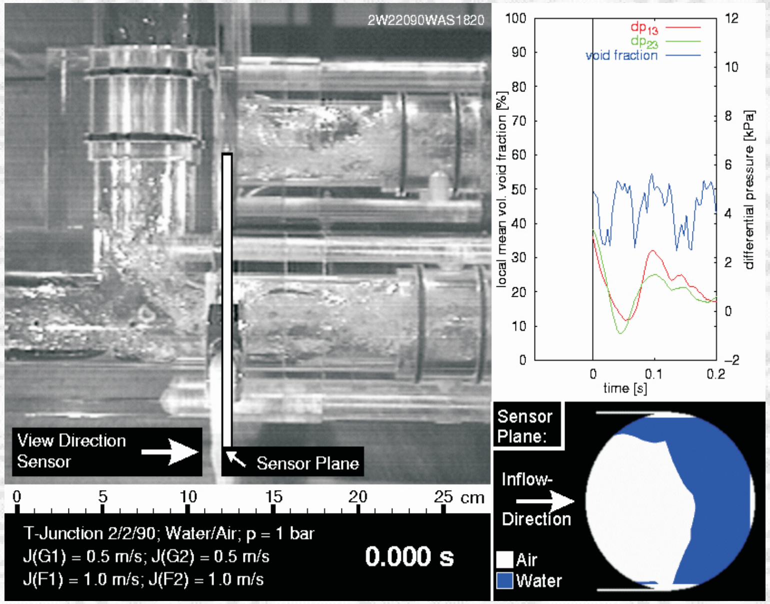

High speed videos were recorded to investigate the mechanisms of bubble disintegration in aerated stirred vessels.
The location, where the bubbles are disintegrated when a Rushton-Turbine is applied is marked in the image (white circle).
The number of the bubbles that are generated by disintegrating one instable bubble and the distribution of their sizes was derived from the video series.
Combined with the results from evaluated short-time holograms, which deliver the number of the bubbles in the entire vessel an their size distribution, valuable information on the residence time distribution and the hold-up of the air in an aerated stirred vessel at a given operating point was gained.

# Bubble disintegeration by a Pitched Blade Turbine




When a pitched blade turbine is applied at the same energy input as a Rushton-Turbine, both the flow-field and the bubble size distribution are completely different.
Again, the location, where the bubbles are disintegrated is marked (white circle).
An instable bubble is disintegrated in less but bigger bubbles. Bigger bubbles (white arrow) can be kept in the vessel due to the higher flow velocity of the liquid. Therefore, the residence time distribution of the bubbles is narrower when compared to the Rushton-Turbine.
The video sequences and the results from the holographic analysis led to an improved model to describe the dispersion characteristics of aerated stirred vessels.

# Flow through T-Junctions




The pressure loss of a two-phase flow through pipe fittings, such as combining T-junctions, is characterized by the void fraction and the flow regime down-stream the junction.

The high-speed recordings show the pressure drop and the local void fraction, measured by means of a wire-mesh sensor.

This sensor consists of 224 reading points and can scan cross-sectional images of the flow at a speed of up to 1200 Hz. From these pictures the size and the position of the constriction zone could be detected which is crucial to develop of new pressure loss models.