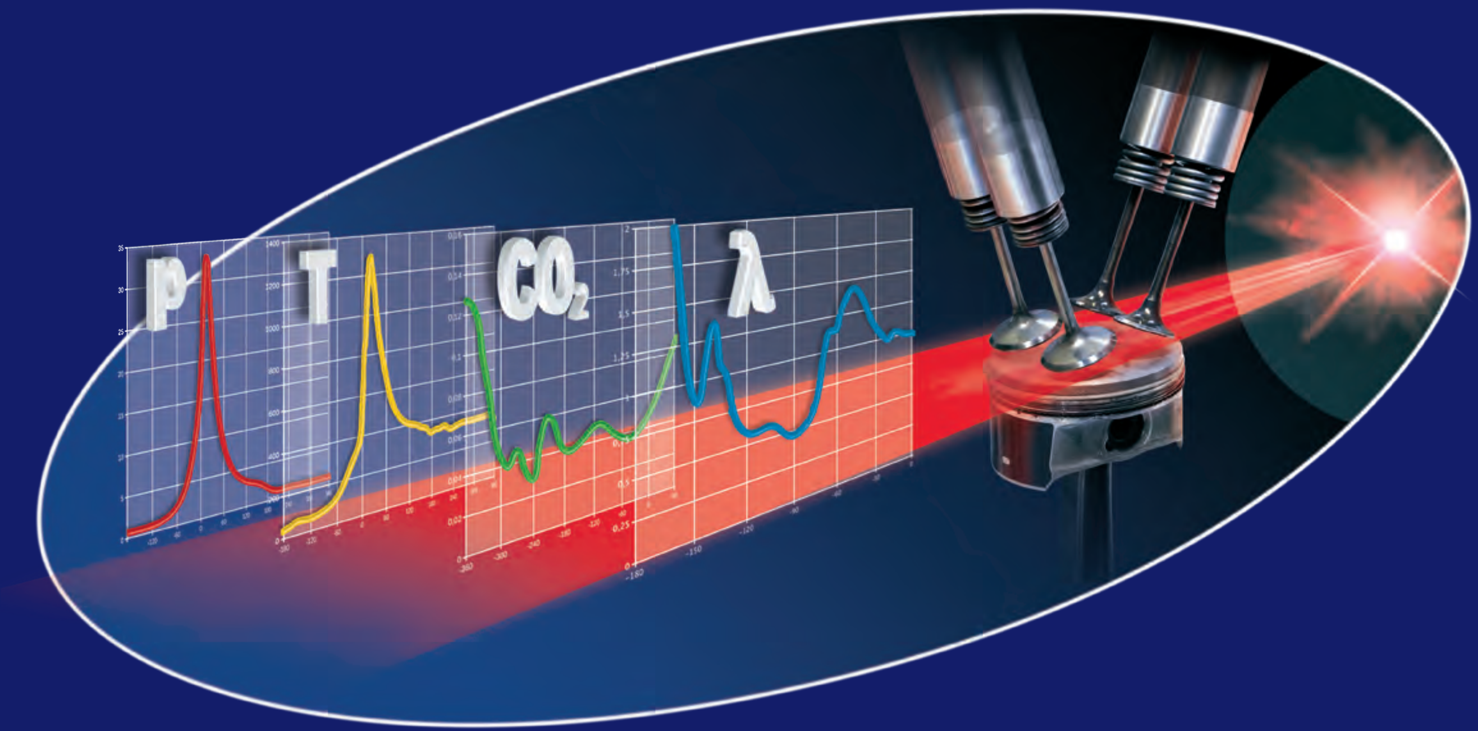


Internal Combustion Optical Sensor (ICOS)

Optical Engine Indication

LAVISION

FOCUS ON IMAGING

In-Cylinder Optical Indication

- air/fuel ratio
- exhaust gas concentration and EGR
- gas temperature

- analysis of highly dynamic engine conditions
- crank angle and cycle resolved
- no engine modification needed
- for spark ignition and compression ignition engines

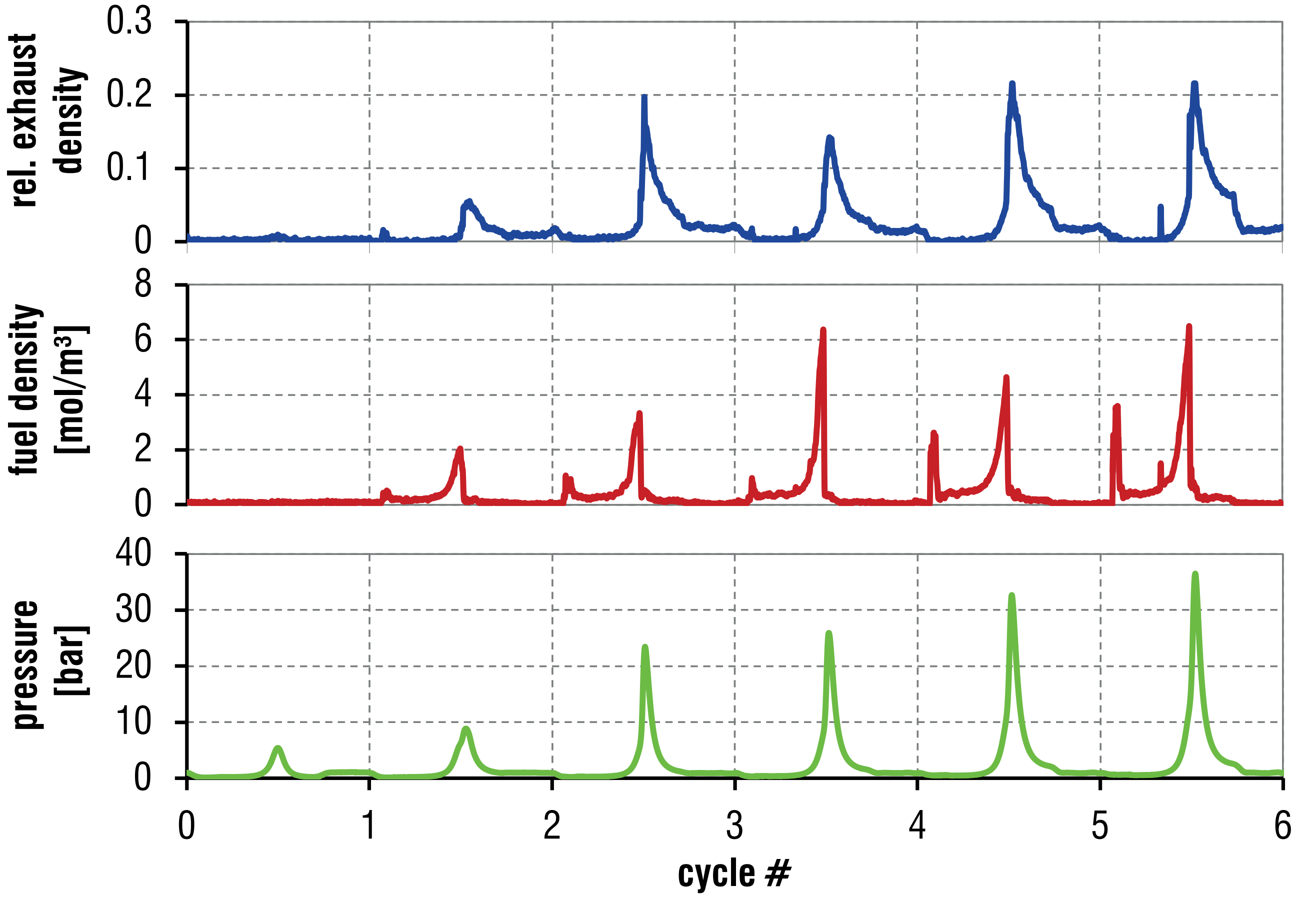
Optical engine indication synchronized with standard pressure indication allows a much more detailed characterization of the in-cylinder charge formation process.

Internal Combustion Optical Sensor

LaVision's **I**nternal **C**ombustion **O**ptical **S**ensors (**ICOS**) measure crank angle resolved air/fuel ratio, exhaust gas concentration and gas temperature locally at the spark plug, glow plug or at any other in-cylinder location using optical probes. The **ICOS** systems provide highly time resolved data of the relevant engine parameters at the tip of the probe. Single cycle parameter profiles as well as variations over many cycles are recorded.

Measurement Principle of Optical Engine Indication

The **ICOS** measurement systems are based on infrared absorption spectroscopy of the relevant molecules like water, CO_2 or hydrocarbons. The in-situ absorption technique is **instantaneous** and needs **no gas extraction**. A single probe can measure multiple parameters simultaneously.

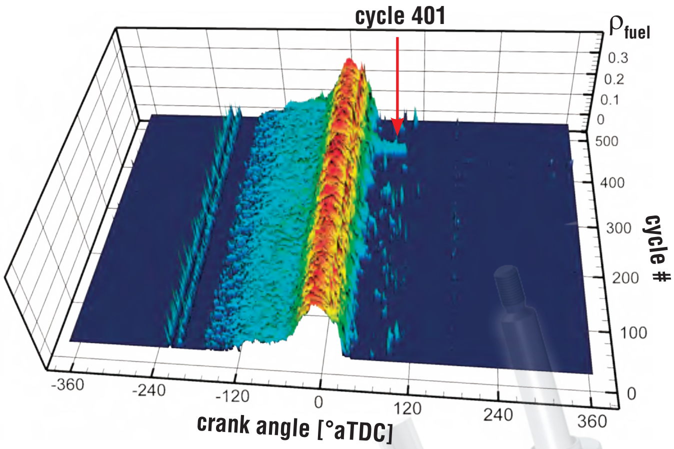


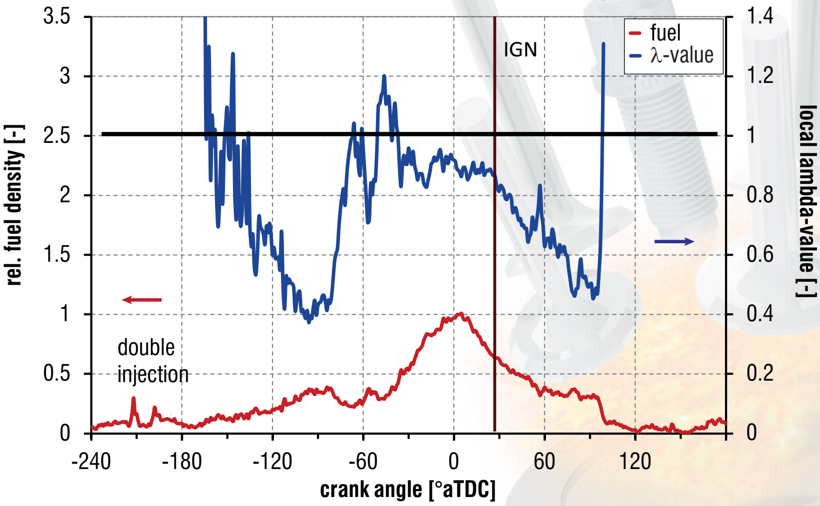
Tip-in of an engine from coasting to load operation measured with ICOS system. The crank angle resolved fuel and exhaust density profiles together with cylinder pressure are shown for six consecutive engine cycles.

Cycle-to-Cycle Variations

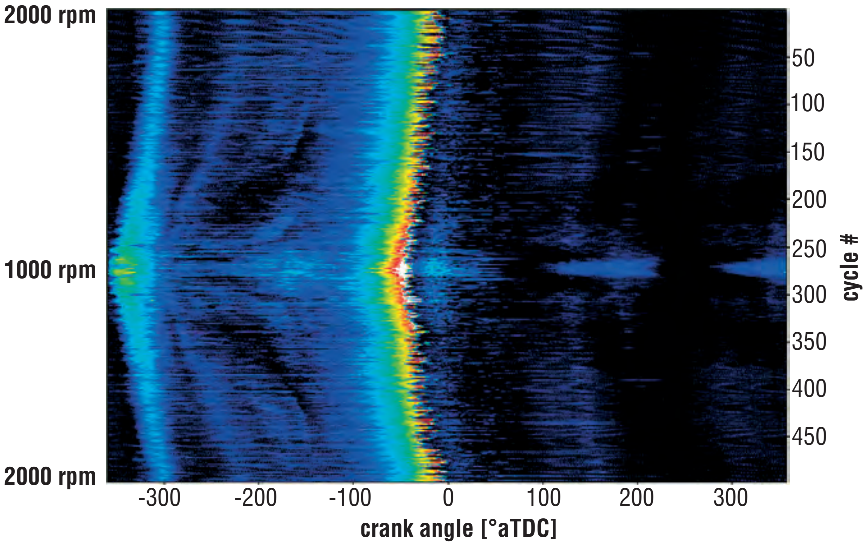
The **ICOS-Fuel** system offers the possibility to examine hundreds of consecutive cycles with crank angle resolution to analyze stability and combustion effects. In the upper diagram the fuel density profiles of a catalytic converter heating point recorded at the spark plug is shown over 500 consecutive cycles. After the dual injection (-200 and -180 °CA aTDC), the fuel density rises during compression to TDC and decreases again due to the beginning of expansion afterwards. When ignition takes place at 30 to 40 °CA aTDC, the fuel disappears.

Abnormal combustion in individual cycles is resolved such as the delayed ignition in the marked cycle 401. The drop in the fuel density at 100 °CA aTDC marks the appearance of the flame front locally at the probe tip. The timing is significantly later than the ignition point. For this individual cycle, the fuel density and the corresponding λ-value curve are also shown in the bottom diagram. The λ-value curve is calculated from the fuel density using a thermodynamic model.





Transient Conditions - Speed Change



The diagram shows the transient behavior of the local fuel density over 500 consecutive engine cycles. Each line represents one engine cycle, the fuel density is color coded. The engine speed was at first slowed down from 2000 rpm to 1000 rpm and after releasing the break the speed returned to 2000 rpm. During the breaking the injection and the ignition timings were shifted forward in the cycle by the engine electronics. The amount of injected fuel rises due to the increased load during breaking.

References

A. Grosch, V. Beushausen, O. Thiele, and R. Grzeszik, “Crank angle resolved determination of fuel concentration and air/fuel ratio in a SI-internal combustion engine using a modified optical spark plug”, SAE Technical Papers (2007), Nr. 2007-01-0644

S. Liebsch, A. Zboralski, J. Maass, M. Guenther, et al., “Cold Start Simulation and Test on DISI Engines Utilizing a Multi-Zone Vaporization Approach“, SAE Technical Paper 2012-01-0402, 2012

air/fuel ratio - lambda value - transients
investigation of highly dynamic engine conditions
verification of injection strategies and systems

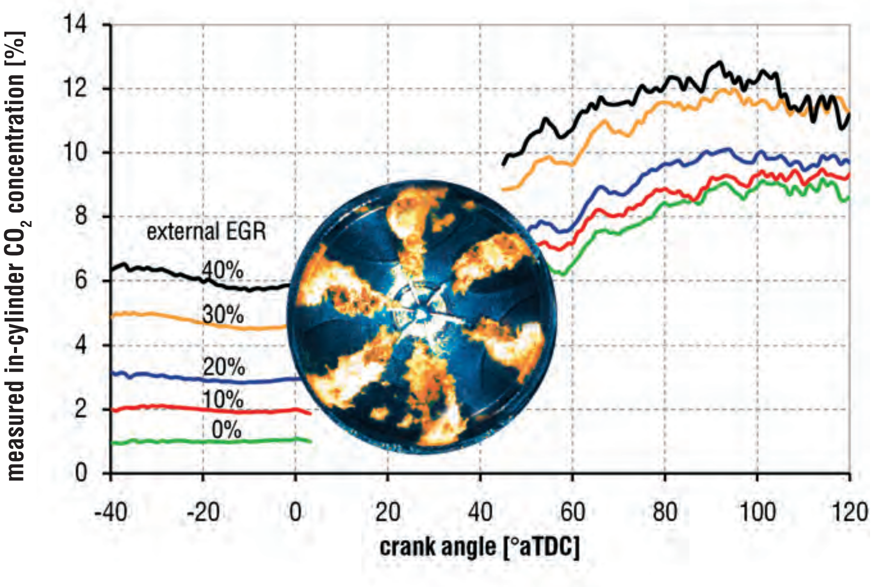
The ignitibility quality of in-cylinder charge cannot be determined by pressure indication alone. Additional optical engine indication of fuel density and local air/fuel ratio at the spark plug position reveals a quantification of the ignitibility of the mixture at the exact ignition position.

The crank angle resolved measurement of the fuel density distinguishes the **ICOS**-**Fuel** system from other techniques, like gas extraction. In contrast to conventional Flame Ionization Detectors (FIDs) **ICOS** measures directly inside the cylinder without any time delay. Variations within many consecutive cycles can be visualized in real-time. In combination with the cylinder pressure the local air/fuel ratio (λ-value) is derived from the fuel concentration. Taking advantage of these capabilities, investigations and comparisons of injection strategies and systems are carried out in great detail.

Specifications

Measuring principle	IR absorption
Indicated quantities	fuel density, air/fuel ratio
Measurement error	< 2%
Sampling rate	30 kHz
Data acquisition	crank angle resolved multiple cycles

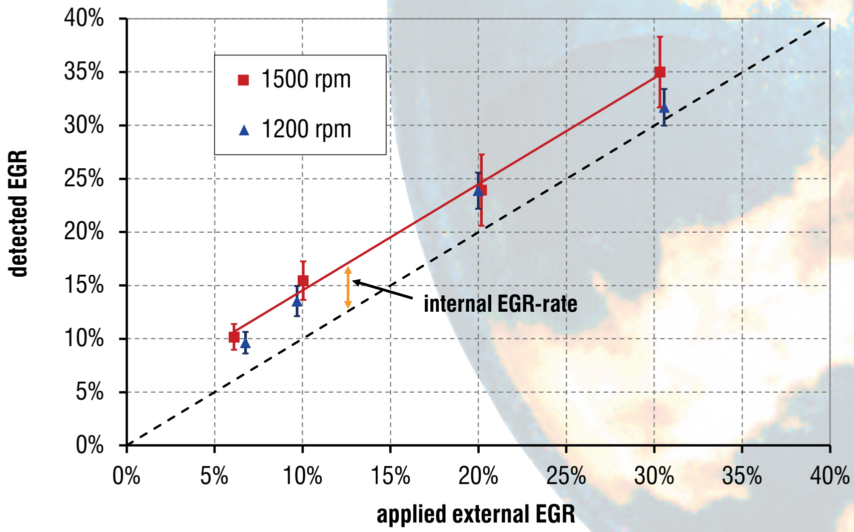
Variation of external EGR



For in-cylinder CO_2 measurements the **ICOS** probe was placed into a glow plug adapter of a Diesel engine. The diagram shows the different in-cylinder CO_2-concentrations for changing applied external EGR rates. The absolute amount of CO_2 in the cylinder is determined with crank angle resolution over single cycles.

Internal EGR

The correlation between the applied external EGR rate and the measured EGR rate for two different engine speeds in a truck Diesel engine is demonstrated here. The error bars show the EGR fluctuations over 100 cycles.
The offset between the measured and applied EGR-values (dashed line) is the internal EGR rate at a given condition. The results show a higher standard deviation of the EGR rate at higher engine speeds. The amount of internal EGR rate changes with engine speed and applied external EGR rate, proving the strong influence of these engine parameters on the internal flow management.



Reference
R. Vanhaelst,O. Thiele, T. Berg, B. Hahne, H.-P. Stellet, F. Wildhagen, W. Hentschel, C. Jördens, J. Czajka, K. Wislocki,
“Development of an in-cylinder-optical infrared sensor for the determination of EGR and residual gas rates inside SI and diesel engines”,
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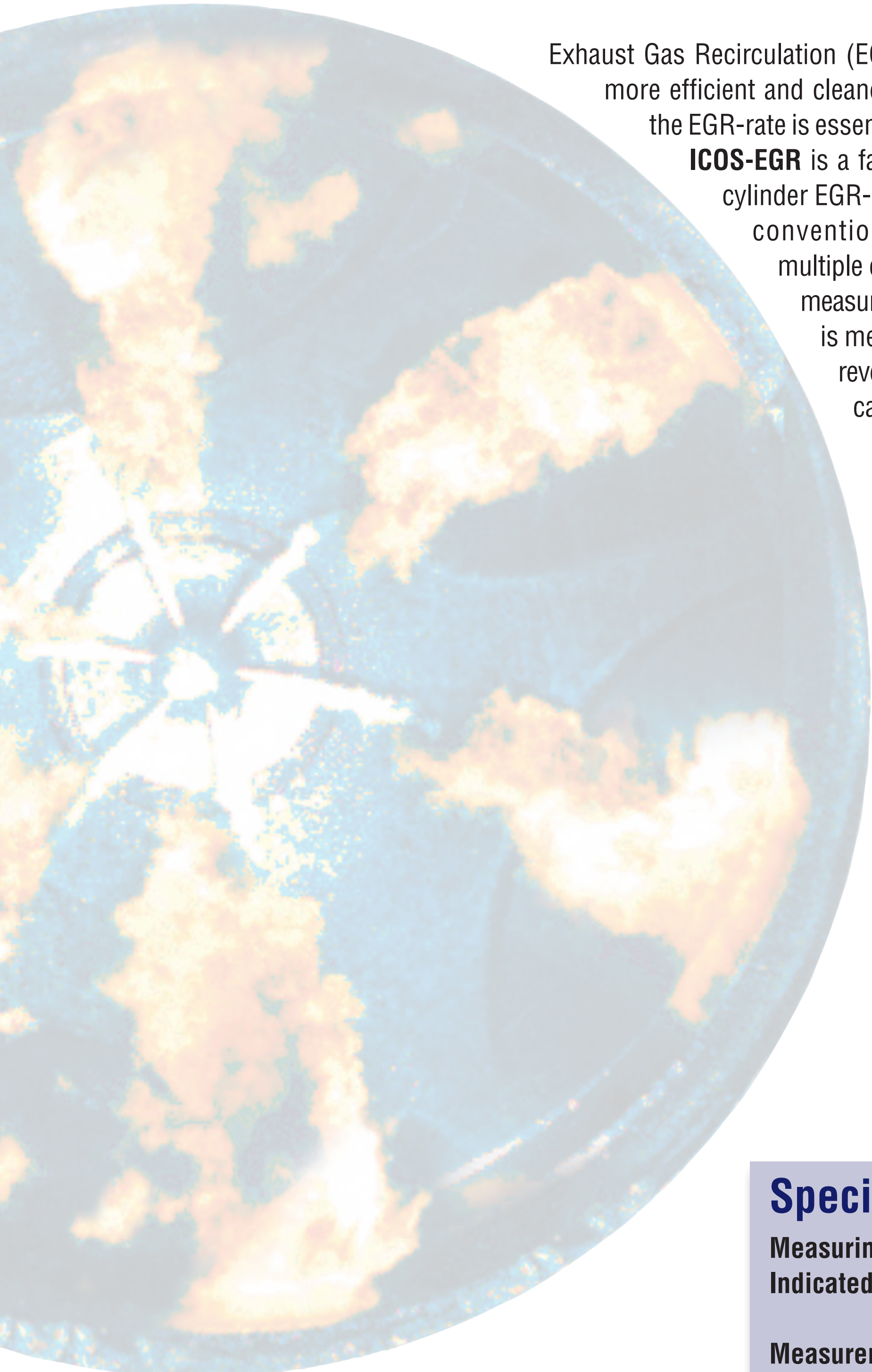
internal and external EGR-rates
analysis of EGR-stability
synchronous multi cylinder measurements

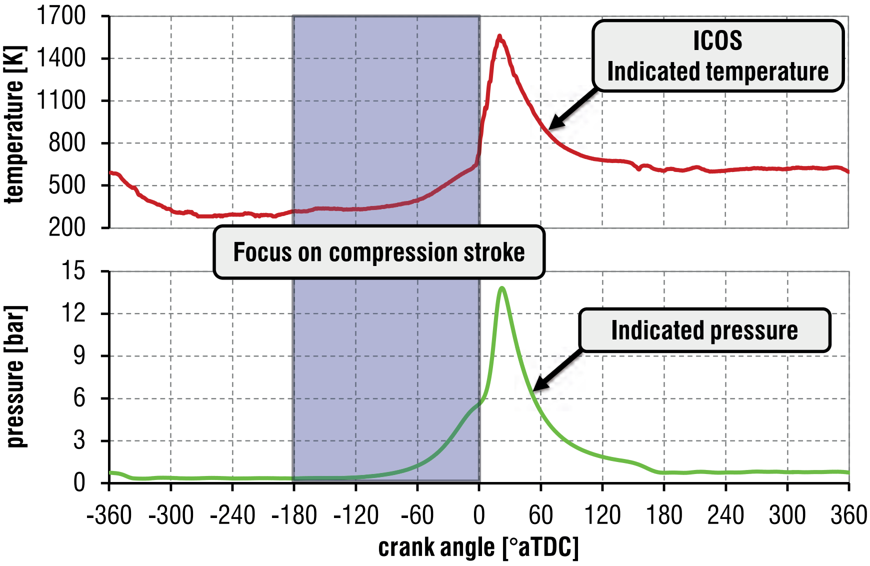


Exhaust Gas Recirculation (EGR) is part of the strategy for the development of more efficient and cleaner IC-engines. The fast cycle resolved detection of the EGR-rate is essential to evaluate stable engine conditions. LaVision´s **ICOS-EGR** is a fast optical indication system for measuring the in-cylinder EGR-rate based on the detection of CO_2 and water. While conventional gas sampling probes need averaging over multiple cycles, the **ICOS** system allows single cycle resolved measurements. The EGR distribution over multiple cylinders is measured with a multi-probe **ICOS** system. This setup reveals differences in the CO_2 loading among cylinders caused by the intake flow management.

Specifications

Measuring principle	IR absorption
Indicated quantities	CO_2 concentration, exhaust gas recirculation rate (EGR)
Measurement error	< 0.2 vol% CO_2 (5-30 bar)
Sampling rate	30 kHz
Data acquisition	crank angle resolved multiple cycles

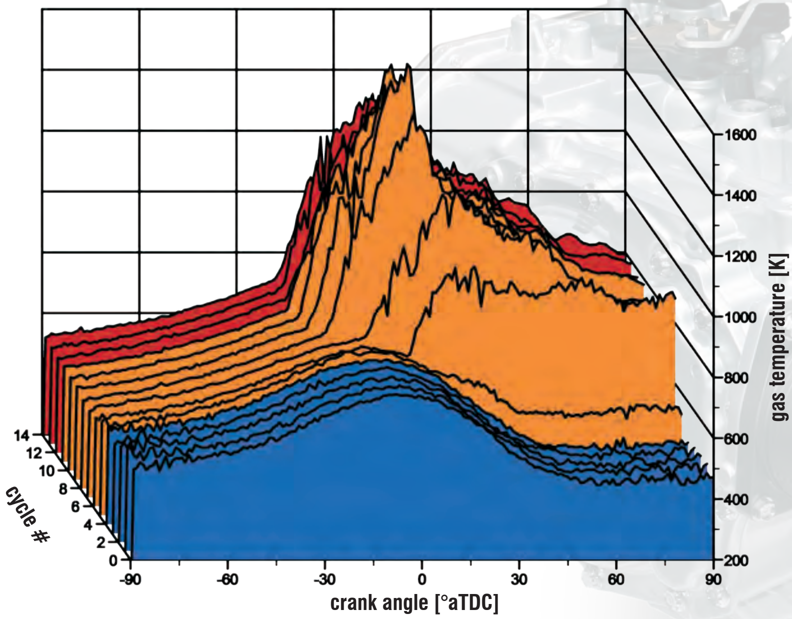
Temperature during Compression



Indicated in-cylinder gas temperature in a fired 4-stroke DISI engine is shown in the top diagram, the simultaneously recorded pressure is shown in the bottom diagram. The local gas temperature is determined at the spark plug position using a standard **ICOS** spark plug probe. Cross cylinder line-of-sight probes are also available to measure integral cross-cylinder temperatures.

Transient Temperatures during Tip-in

The in-cylinder gas temperature was measured in a near production SI engine using a spark plug probe. The diagram shows the transient behaviour of the temperature during a tip-in (load change) operation for 15 engine cycles. The engine is coasting over the first 5 cycles. After this the accelerator pedal is pushed down resulting in a load step and transient firing behaviour over 7 cycles. The combustion process then stabilizes in the following cycles. The shown temperature profiles are averaged over 10 repeated tip-ins.



- **temperature indication during mixture formation**
- **effect of EGR-rate**
- **validation of simulation models**
- **supercharging, downsizing, HCCI**

The knowledge of the gas temperature during the mixture formation is becoming increasingly interesting for the development of combustion processes. The high demand on lowering emissions in internal combustion engines has also led to the increased employment of Exhaust Gas Recirculation (EGR). Particularly when using high internal EGR rates, the gas temperature can only be determined directly in-cylinder with a fast in-situ measurement. LaVision's **ICOS-Temperature** system indicates the in-cylinder temperature at crank angle resolution over hundreds of consecutive cycles. This ultra-fast (23 kHz) sensor system is based on infrared absorption spectroscopy of water molecules. A variety of probes allow local in-cylinder (e.g. at the glow plug location) or integral cross cylinder temperature measurements. The results give valuable information of the behavior of the in-cylinder temperature during the compression stroke, and how it is influenced by varying operating conditions.

Specifications

Measuring principle	IR absorption of water molecules
Indicated quantity	gas temperature
Measurement error	< 20 K @ 3 vol% H_2O (273 K-900 K)
Sampling rate	23 kHz
Data acquisition	crank angle resolved multiple cycles

ICOS Sensor Probes

M12 spark plug probe

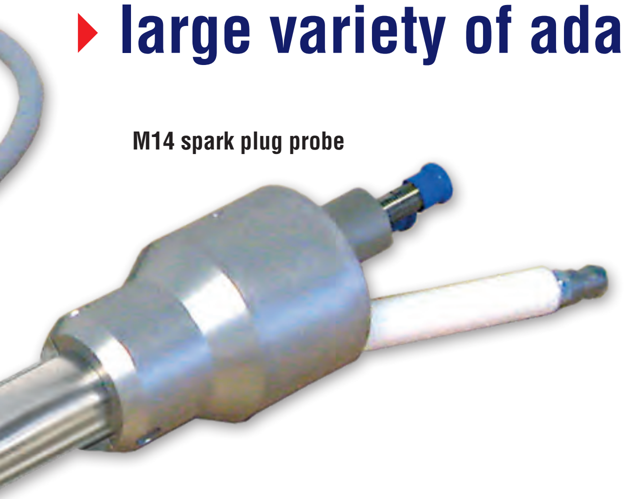
M12 combination probe, simultaneous fuel / EGR and temperature measurements

M5 probe

Probe Adapters

LaVision provides a variety of adapters to install our in-cylinder probes into your engine, for example, glow plug adapters for use in Diesel engines, as illustrated in the picture. We have experience in designing custom adapters for almost any application.

integrated spark plug probes
non-firing probes for flexible choice of location
integral line-of-sight probes
large variety of adapters to suit different applications


M14 spark plug probe

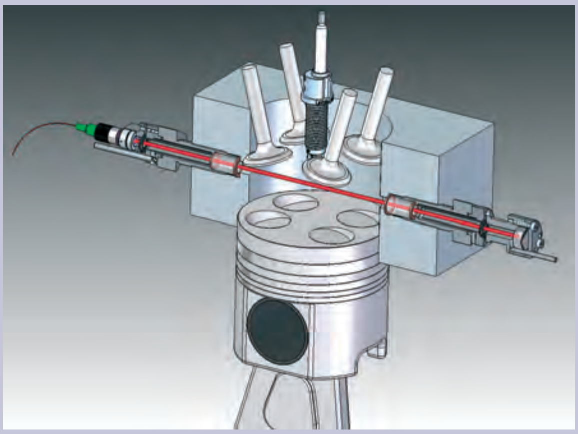
Cooled probe

Firing and non-firing sensor probes are available for the **ICOS** systems. The in-cylinder probes can be installed in almost any engine with no modification required. This is applicable for research test engines up to near production engines with limited optical access. For example, the spark plug probe directly replaces the standard spark plug in SI engines while maintaining full firing capability.

A single probe can measure air/fuel ratio and exhaust gas simultaneously. With the combination probe it is possible to additionally measure gas temperature at the same time. Multiple probes can be installed to measure in different cylinders simultaneously.

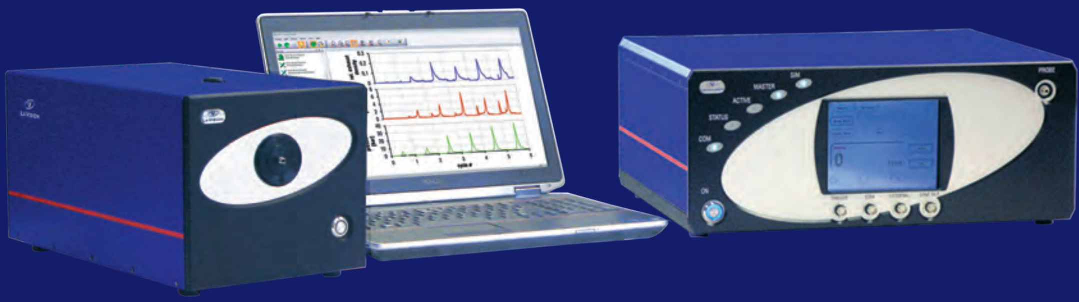
All probes have a small mirror on the tip to maintain the light absorption path and reflect the light back to the receiver. Measuring over several hours or days using the same mirror is realistic under standard engine operating conditions. The mirrors are exchangeable and supplied as a set of spare parts. Exchanging a mirror only takes a few minutes.

Integral Line-of-Sight Probe



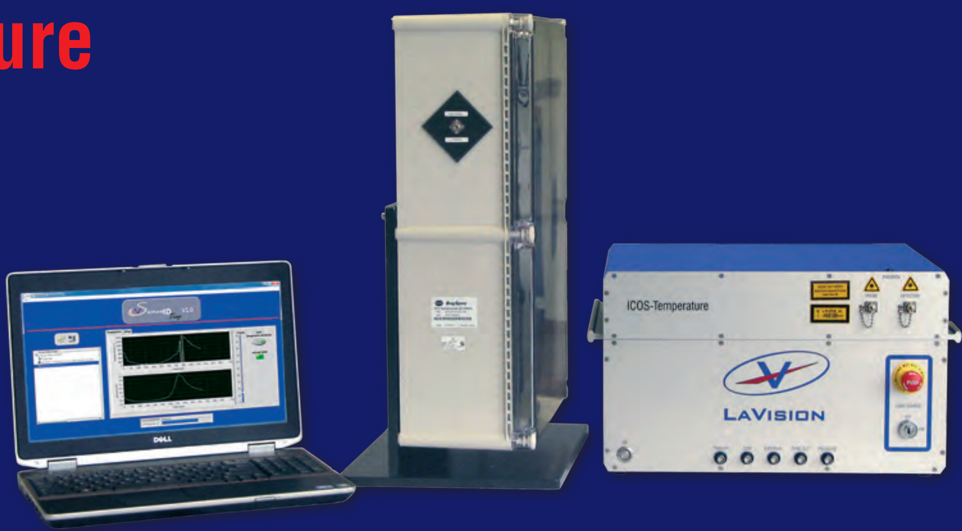
For certain investigations it is more relevant to obtain global parameters from inside the engine, for example when comparing measurement data to 1D-simulation results. LaVision offers customized line-of-sight probe solutions to measure spatially averaged parameters. The picture shows a schematic installation of a line-of-sight probe in an engine for cross-cylinder temperature measurements. The long absorption path of this configuration also results in a favorable signal to noise ratio without interfering with the combustion chamber geometry and gas flow.

ICOS-Fuel, -EGR, -TWIN



System	ICOS-Fuel, -EGR, -TWIN		ICOS-Temperature
Indicated quantities	Fuel density, air/fuel ratio	CO_2 concentration, EGR	Gas temperature
Acquisition rate	30 kHz		23 kHz
Measurement error	< 2%	< 0.2 vol% CO_2 (5-30 bar)	< 20 K @ 3 vol% H_2O (273 K-900 K)
Sensor probes	M12 / M14 spark plug, glow plug adapter, M5 indication probe, cooled indication probe, line-of-sight probe		
Applications	mixture preparation, stability of the combustion process		
	Direct injection Cold start Load changes Ignition behaviour	Cycle-resolved internal and external EGR Distribution over multiple cylinders Valve timing	Validation Supercharging EGR HCCI

ICOS-Temperature



LaVisionUK Ltd
2 Minton Place / Victoria Road
Bicester / Oxon / OX26 6QB / United Kingdom
E-Mail: sales@lavisionuk.com
www.lavisionUK.com
Phone: +44-(0)-870-997-6532
Fax: +44-(0)-870-762-6252

LaVision GmbH
Anna-Vandenhoeck-Ring 19
D-37081 Göttingen / Germany
E-Mail: info@lavision.com
www.lavision.com
Tel.: +49-(0)5 51-9004-0
Fax: +49-(0)551-9004-100

LaVision Inc.
211 W. Michigan Ave. / Suite 100
Ypsilanti, MI 48197 / USA
E-Mail: sales@lavisioninc.com
www.lavision.com
Phone: (734) 485 - 0913
Fax: (240) 465 - 4306