



ECN

Energy research Centre of the Netherlands

LAB-SCALE COMBUSTION/GASIFICATION SIMULATOR (LCS)

- APPLICATION AND FEATURES -
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Info

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Description of the ECN Lab-scale Combustion Simulator

General description

The ECN lab-scale combustion simulator (LCS) is a flexible facility for the characterisation of solid fuel behaviour under typical pulverised fuel fired furnace and gasifier conditions. The facility comprises a drop tube reactor together with a primary/secondary gas burner to simulate a flame/flue/syngas environment in which the conversion behaviour of fuel particles can be studied in the function of time. An adequate simulation of heating rate, gas temperatures and composition can thus be obtained independent of the test fuel. The approach is specifically suited to study secondary fuels under primary fuel conditions.

Fuels may be characterised in terms of:

convertible (organic) matter

- time & particle size dependent conversion, including burnout (C-in-ash, LOI)
- volatile matter yield under high heating rates
- fate of nitrogen, NO_x formation
- char reactivity (in combination with thermogravimetric analysis)

inconvertible (inorganic or ash forming) matter

- slagging of near-burner zones or waterwalls
- fouling of heat exchanging surfaces in boiler convective areas
- fly ash composition and quality
- fine particle formation and emission, including related trace elements

An impression of the LCS rig is presented in Figure 1.

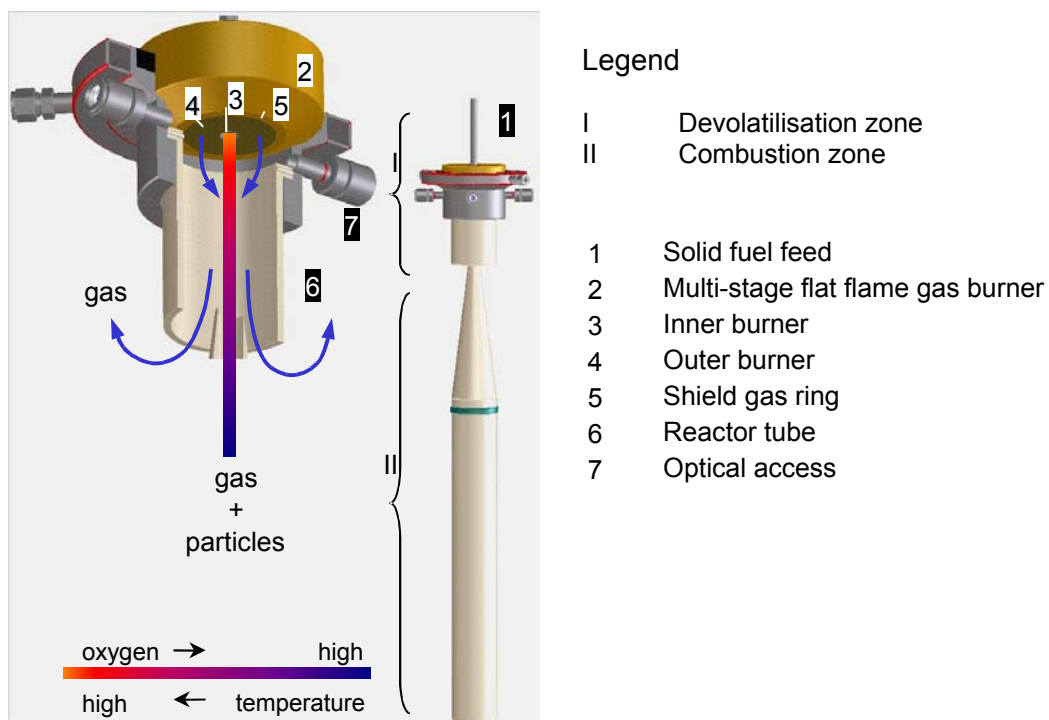


Figure 1 Staged flat flame gas burner and reactor (drop) tube in ECN combustion simulator

Detailed description

The LCS consists basically of a drop tube reactor with an integrated, premixed and multi-stage flat flame gas burner. The staged gas burner accommodates high initial heating rates and temperatures and provides the possibility to simulate air staging as in low-NO_x burners and also the presence of specific combustion products such as, e.g., SO₂. The facility is also very well suited for oxy-fuel firing simulation.

The flat flame gas burner consists of two concentric sub-burners *viz.* a primary, inner burner (~1 cm ID) and a secondary, outer burner (~6 cm ID). A tertiary nitrogen flow is applied to create suitable mixing profiles and for thermal protection of the reactor tube. Fuel particles are fed through the inner burner and are rapidly heated (>10⁵ °C/s) to the high temperature level of, e.g., a coal flame (1400-1600 °C). The fuel particles are fed by means of a commercial rotating brush/ram feeder. The fuel is brought into a cylinder and a piston presses the powder against a rapidly rotating brush. The particles are dispersed by the brush and transported into the reactor pneumatically. Typically, low particle feed rates of 1-5 g/h are used in order to control the gaseous environment of each particle by means of the imposed gas burner conditions. For low-NO_x operation, this implies that heating and devolatilisation of the fuel particles takes place in an oxygen-deficient zone (indicated as I in Figure 1) provided by the primary, inner burner, whereas subsequent char combustion takes place in a zone with excess oxygen (indicated as II in Figure 1). The transition from oxygen-lean to oxygen-rich takes place and is completed in zone I by diffusion. The resulting gas/particle flow is then sucked into a 76 mm ID alumina reactor tube for complete oxidation of the fuel. The tube is surrounded by three 3.4 kW each electrically heated zones equipped with Kanthal Super 1800 elements with a maximum element temperature of 1700 °C. The temperature of each zone is independently controlled by a Eurotherm controller and two S-type thermocouples. A typical temperature/residence time profile is shown in Figure 2, below.

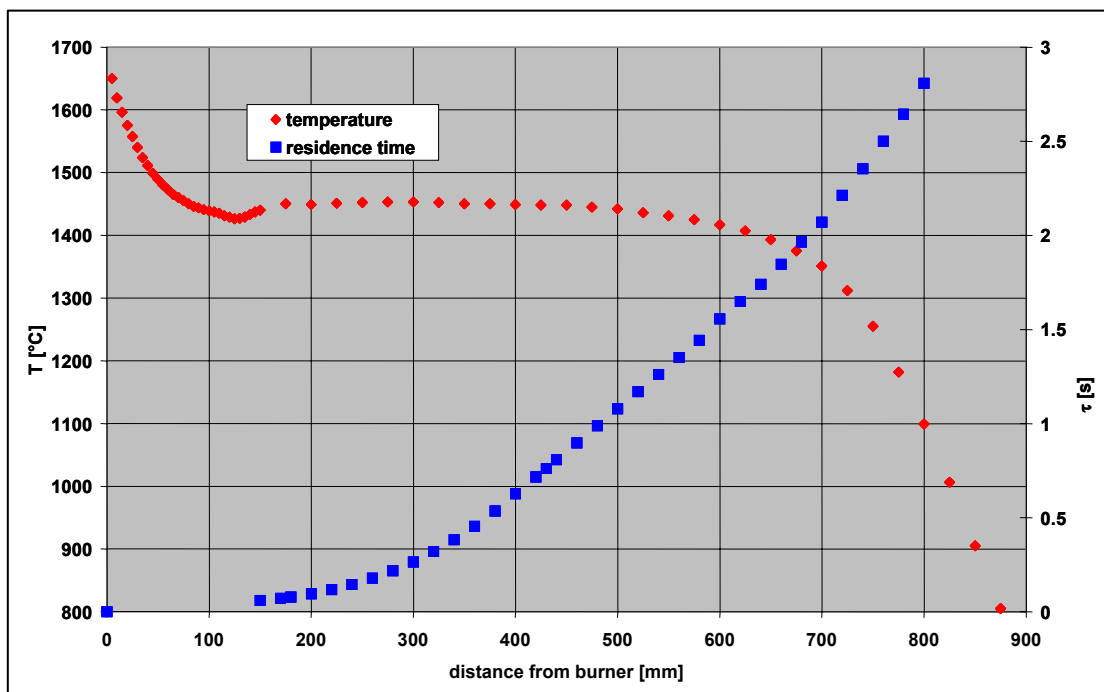


Figure 2 Typical LCS temperature/residence time profile under combustion mode

In the gasification mode the open reactor system is replaced by a double-walled sealed one. This allows to perform the tests with explosive/corrosive/toxic syngas conditions. The achievable residence time are much like those under regular combustion conditions while at the same time much higher flame temperatures can be obtained (>2250°C).

Industrial low-NO_x burner conditions are simulated based on the notion that, after entering a furnace, fuel particles are rapidly heated in an environment resulting from volatile matter combustion (gas containing CO, CO₂, H₂O, N₂ and little to no O₂). To create a similar environment in the LCS, The primary, inner burner is fed with a sub- or near-stoichiometric CH₄/O₂ mixture. The secondary, outer burner is then fired with an excess of oxygen to obtain a flue gas containing 3-4 % oxygen. In order to enable simulation of deep-staging conditions, with a strongly reducing near-burner zone and a tertiary air feed, the installation has been recently equipped with an additional air inlet in the reactor tube. This feature allows for the introduction of a gas stream (oxygen/air or a gas mixture containing other reactive components), into the part of the reactor where char burnout takes place, in a way that does not influence adversely the aerodynamics of the installation (Figure 3).

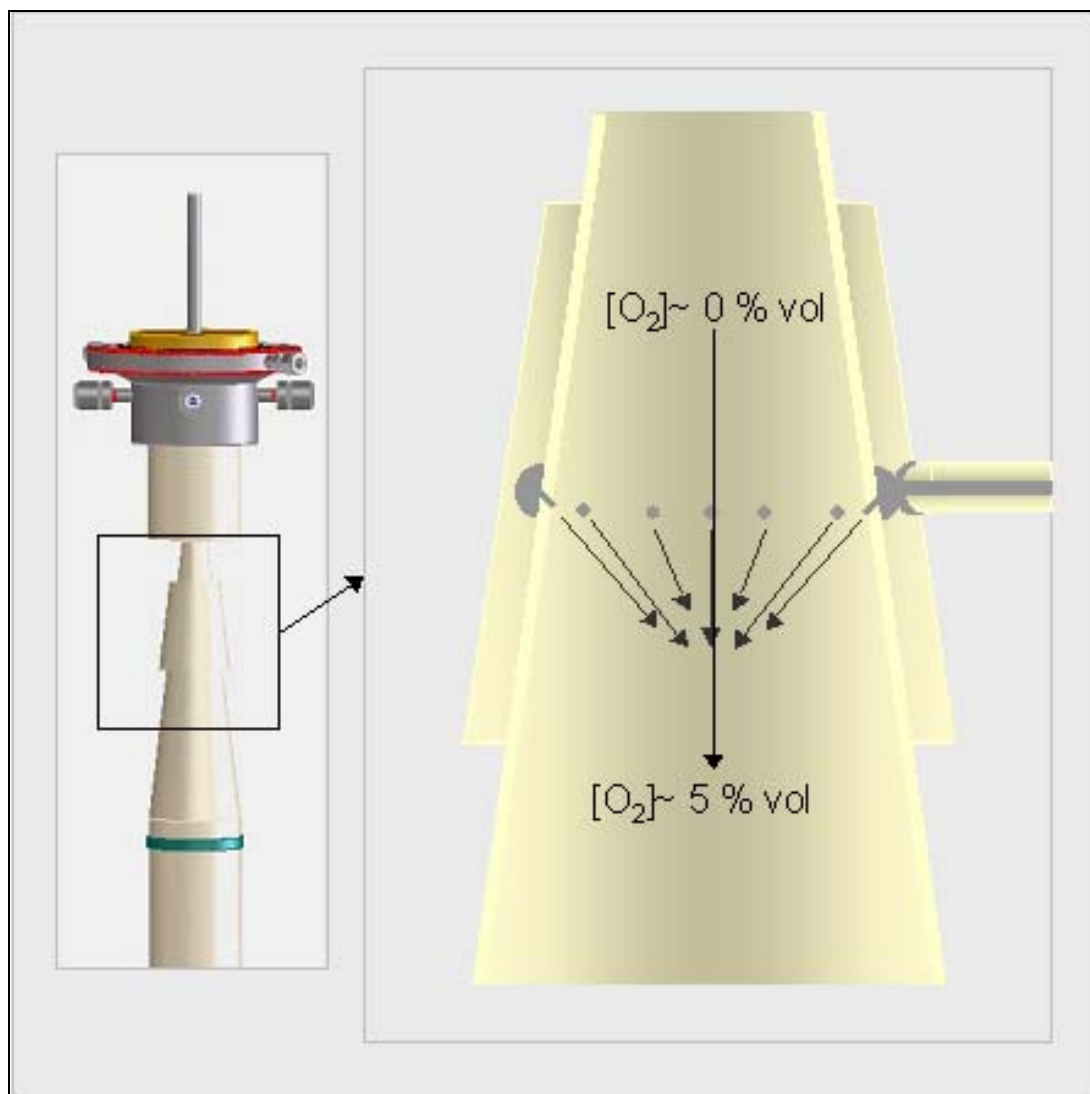


Figure 3 Schematics of the LCS OFA simulation facility

Sampling

Whole particle samples can be obtained at residence times between 10 and 3000, with a vertically adjustable, oil-cooled probe to prevent water condensation. A photograph of the tip of the probe is shown in Figure 4. The particles are rapidly cooled (a nitrogen/helium quench may be used at the tip of the probe) and are collected by either a cyclone ($d_{50}=3 \mu\text{m}$), a back-up filter or - if fractionated samples are required - a cascade impactor.

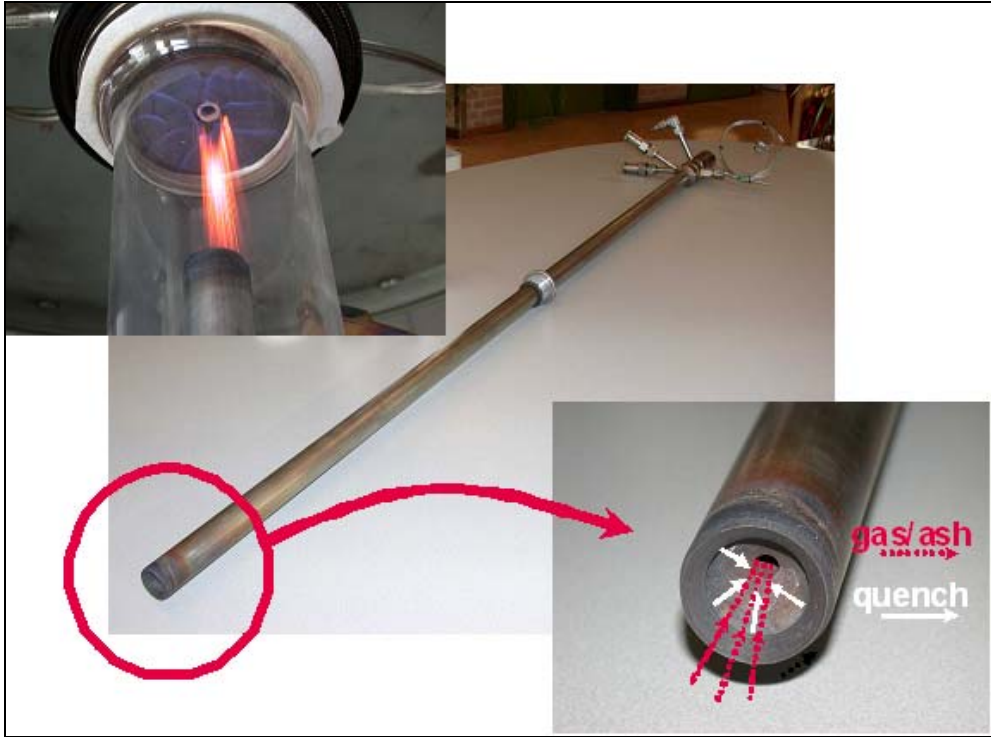


Figure 4 Photographs of the oil-cooled, quenched gas/ash sampling probe

For slagging or fouling tests a specialised deposition probe is used, shown in Figure 5. Different coupons can be attached to the probe head to simulate different deposition surfaces in terms of material and surface structure.

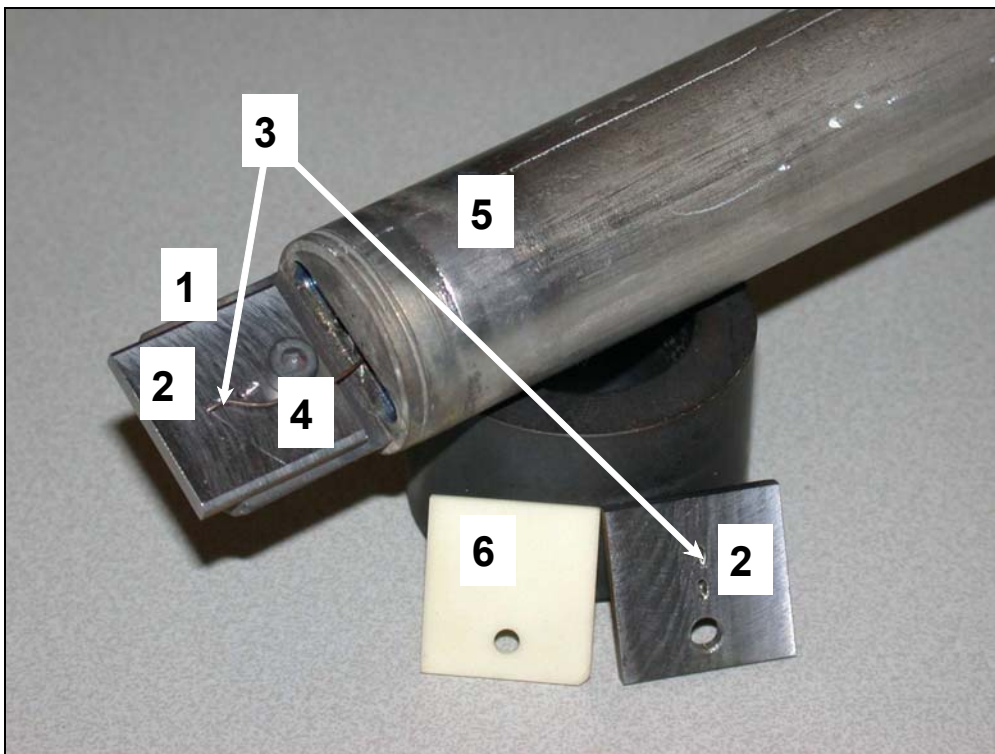


Figure 5 Photograph of the oil-cooled, vertical deposition probe for slagging/fouling investigations
 1. cooling body 2. metal deposit coupon 3. thermocouple channels 4. thermocouple
 5. probe body 6. ceramic deposit coupon (uncooled)

The coupons may be either uncooled (ceramics) or cooled (metal surfaces), in the latter case the surface temperature is continuously monitored. Sampling at different gas temperatures or residence times is accommodated by means of a vertical probe transport mechanism. The coupons can be removed for further testing (e.g., corrosion) and chemical or microscopic analysis of the deposit.

Fouling studies can also be carried out by means of a recently-developed horizontal deposition probe, which can be placed at a fixed distance from the burner. The facility (shown in Figure 5) is to mimic the gas/particle flow around a single boiler tube. It consists of a ring-shaped quadruple heat-flux sensor and a detachable deposition substrate. While the sensor yields on-line data on the influence of the deposit on the effective heat flux through the tube wall, the tubular substrate is used to collect samples for off-line deposit morphology studies (by means of visual/electron microscopy, also in combination with EDX analyses).

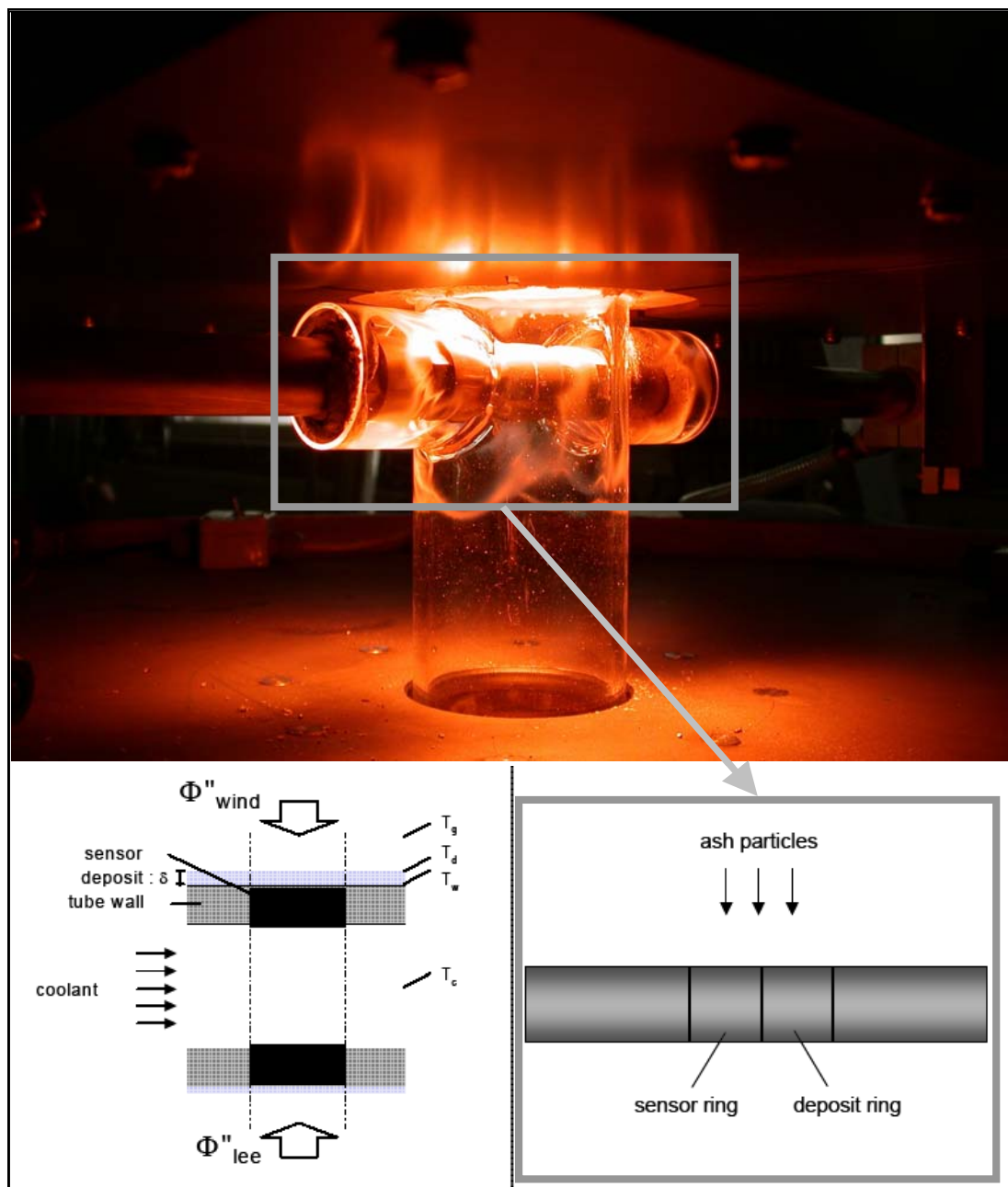


Figure 6 Photographs and schematics of the LCS heat flux/deposition probe

Conditions range and test procedure

As described earlier, in the LCS, the gas temperature is initially controlled by the flat flame gas burner and then by the electrical furnace. For the gas burner, fuel mixtures are composed in such a way that the calculated adiabatic flame temperature and the equilibrium composition of the combustion products from the flame match the target values. The inner burner can be supplied with a mixture of CH₄, O₂, N₂, H₂, CO, CO₂ and H₂S, the outer burner has a gas supply for CH₄, O₂, N₂, H₂ and CO. The gas supply provides a flexible selection of process conditions, ranging from staged combustion to gasification with strongly reducing conditions.

The calculated burner and furnace settings are validated by measuring the axial temperature and gas composition profiles. If necessary, the settings are further optimised. The said temperature profile is measured with a thin-wired S-type thermocouple. Using a 25 µm measuring wire, radiation losses are small and temperature readings are accurate within 25-50 °C. Calculated corrections are applied when exceeding 25 °C.

The residence time at which either ash particles or deposits are sampled is obtained by calculation, taking into account gas flow condition as well as particulate (fuel) fineness and density.

The gas composition (profile) is measured once to validate each new set the gas burner settings. Further, during each experiment gas composition is monitored to verify the performance of the burner. A variety of analyzers is applied in these on-line analyses. The bulk gas components CH₄, CO, CO₂, O₂ and H₂ are measured by means of a set of three ABB monitors, the components N₂, H₂S, SO₂ and COS are determined by means of gas chromatography and H₂O is determined gravimetrically using a P₂O₅ syringe. In addition, trace combustion products such as CO, NO_x and SO₂ can be continuously monitored at the reactor outlet by means of a sufficiently sensitive analyser.

Summary of features

Particle feed rate	1-5 g/h
Particle residence time	10-3000 ms
Particle heating rate	>10 ⁵ °C/s
Gas supply primary burner	CH ₄ , O ₂ , N ₂ , H ₂ , CO, CO ₂ , H ₂ S
Gas supply secondary burner	CH ₄ , O ₂ , N ₂ , H ₂ , CO
Operating pressure	0.1 Mpa
Reaction tube inner diameter	0.076 m
Reaction tube length	1.3 m
Max. electrical heating temperature	1700 °C
Probes for	<ul style="list-style-type: none">• (fractionated) ash particulate sampling• slagging/fouling• heat flux/fouling factor• gas temperature & composition

Fuels

Fuels investigated with the LCS rig include so far: coals, wood, torrefied wood, straw, dried sewage sludge, paper residue, eucalyptus, cocoa, chicken manure, MBM, olive residues, palm oil residues, S/RDF and a large variety of fuel blends.

Exemplified results

Conversion kinetics

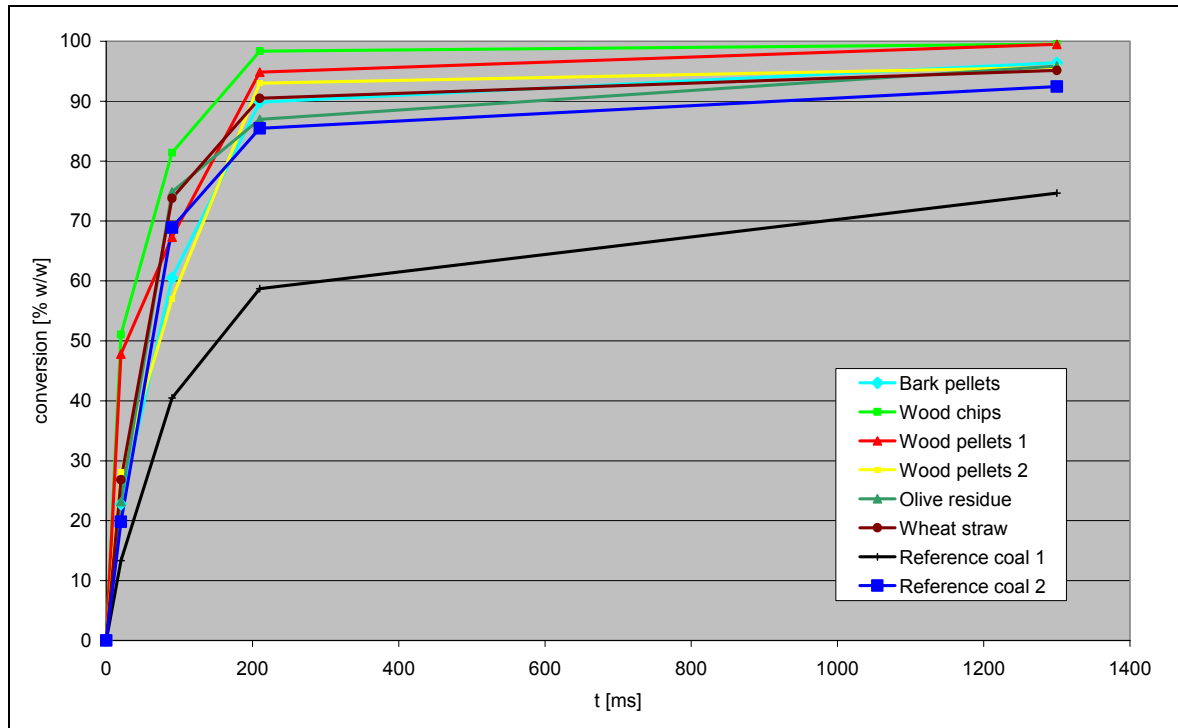


Figure 7 Graphical summary of a 4-point-kinetics study on a broad range of coal and biomass fuels at standard LowNOx combustion conditions

Fouling propensity

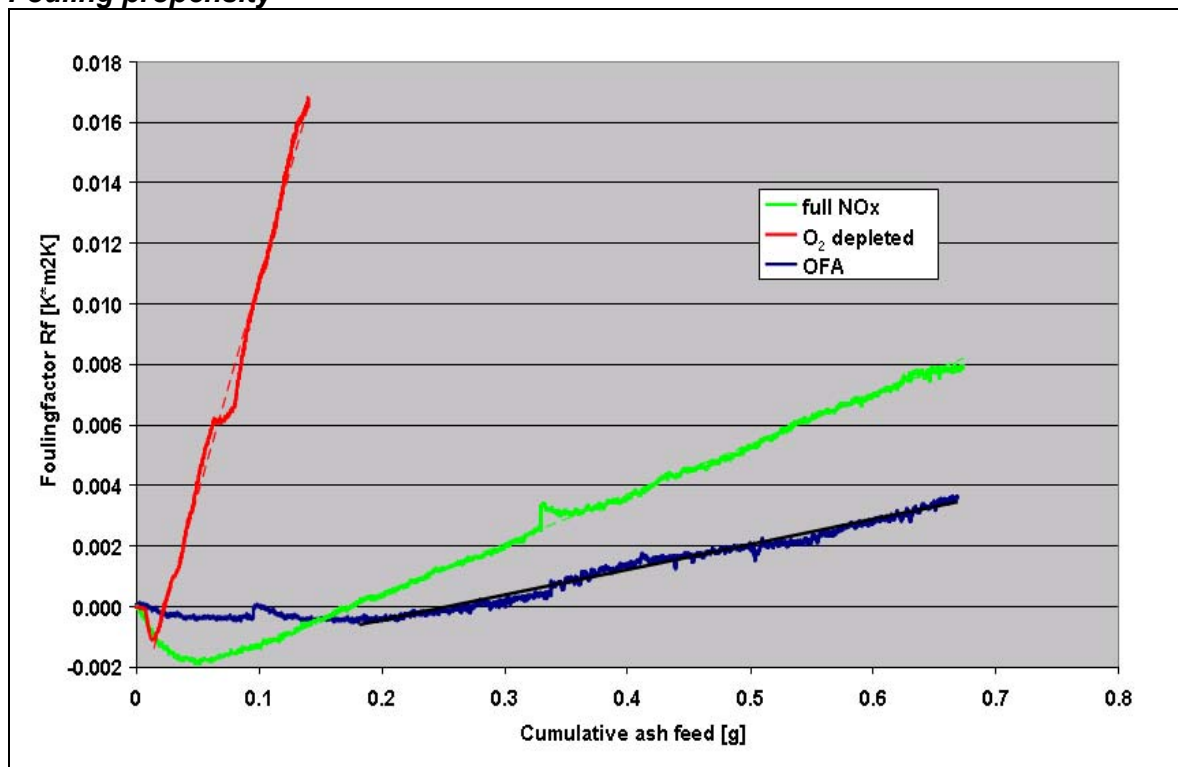


Figure 8 Fouling factors for a reference coal in the function of combustion conditions (unstaged "full NOx", deep-staged "OFA" and simulation of disturbed combustion "O₂ depleted")

NOx formation

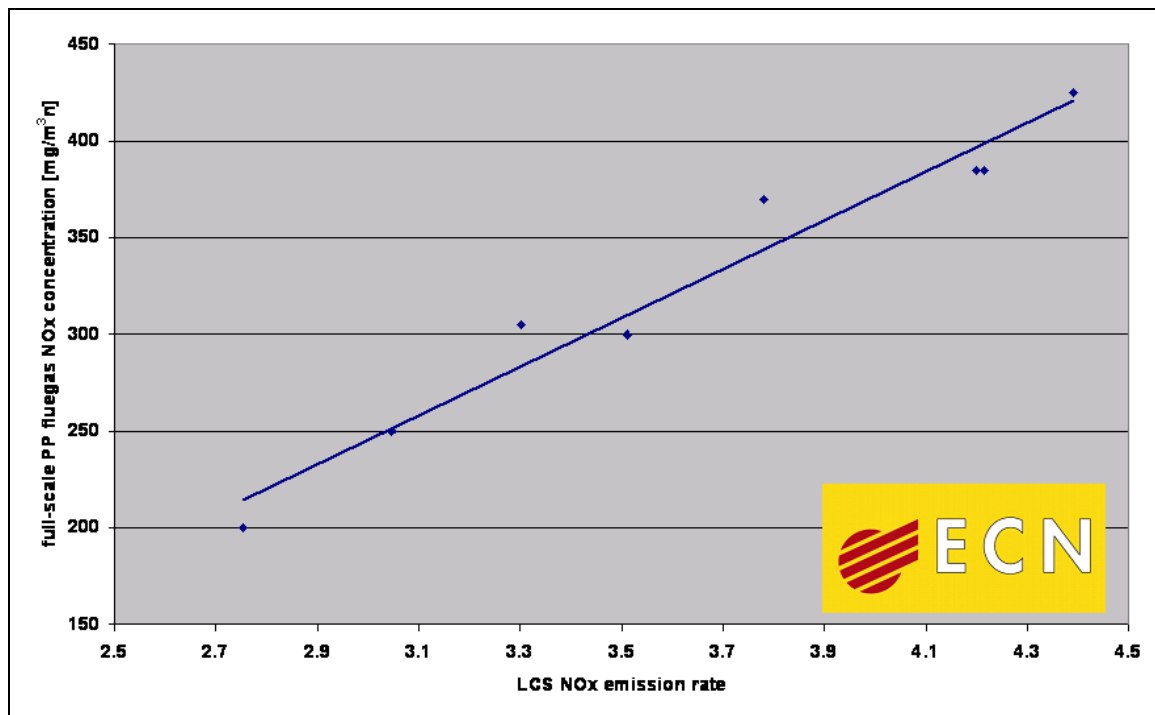


Figure 9 Lab-scale emissions rates vs measured full-scale PF boiler fluegas NOx concentrations for a set of 8 coals with nitrogen contents <1 to >2 % w/w.