Accelerating CCS Technologies

NEWEST-CCUS

Technology Insight 2

IFK's oxy-fuel fluidised bed research facilities at the University of Stuttgart

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The IFK at the University of Stuttgart

The University of Stuttgart (USTUTT) is one of Germany's nine leading technical universities (TU9), with highly ranked programmes in civil, mechanical, industrial and electrical engineering. More than 25,000 students are enrolled in the courses offered by 160-degree programmes.

The University has over 5000 employees, including 283 full professors, who work in 150 institutes, 10 faculties and in central institutions. Research at USTUTT is strengthened through interdisciplinary networks of cooperation with other research institutions and industry in order to continue to expand the cutting-edge position in these fields.

The Institute of Combustion and Power Plant Technology (IFK) has more than 50 years' expertise in energy research and holds considerable experience in the thermal utilisation of gaseous, liquid and solid fuels, such as coals, biomass and solid recovered fuels. For all commercially available combustion and gasification systems (i.e. fixed bed, pulverized fuel, fluidised bed systems and gaseous and liquid fuel boilers), experimental facilities are available with capacities ranging from 5 kW to 500 kW.

The IFK's oxy-fuel fluidised bed research facilities

At USTUTT a range of experimental facilities are available for multiple process investigations, from small laboratory up to pilot scale. In NEWEST-CCUS, pre-tests will be carried out at USTUTT's 20 kW_{th} electrically heated bubbling fluidised bed (BFB) facility. The main industrial validation experiments will use the 200 kW_{th} pilot scale test rig for circulating fluidised bed (CFB) oxy-fuel combustion.

The 20 kW_{th} bubbling fluidised bed (ELWIRA) facility

The so-called ELWIRA facility is a 20 kW_{th} reactor that consists of an electrically heated BFB (see Figure 1). It is equipped with volumetric dosing systems for solid fuels, as well as additives and sorbents. The gas path of the test rig is equipped with two cyclones (primary and protective) and a candle filter. It offers ports for gas measurement at various locations. The facility is equipped with thermocouples and pressure sensors along all gas and solid lines to characterise the operating conditions and perform analyses of the processes applied.

Moreover, sampling ports for gas and solid sample extraction are available at various locations within the plant. The facility is especially designed for flexible operation as the electrical heating allows setting the process temperature to the value of interest. This facility will be used for the pre-testing of fuels in WP3 to support the pilot-scale experiments.

Table 1. Characteristics of the IFK's experimental facilities to be used in NEWEST-CCUS

	20 kW_{th} facility	**200 kW_{th} facility**
Fluidisation regime	Bubbling	Circulating
Temperature	up to 950 °C	850-950 °C
Height	3.5 m	10 m
Thermal input	up to 20 kW_{th}	100-330 kW_{th}

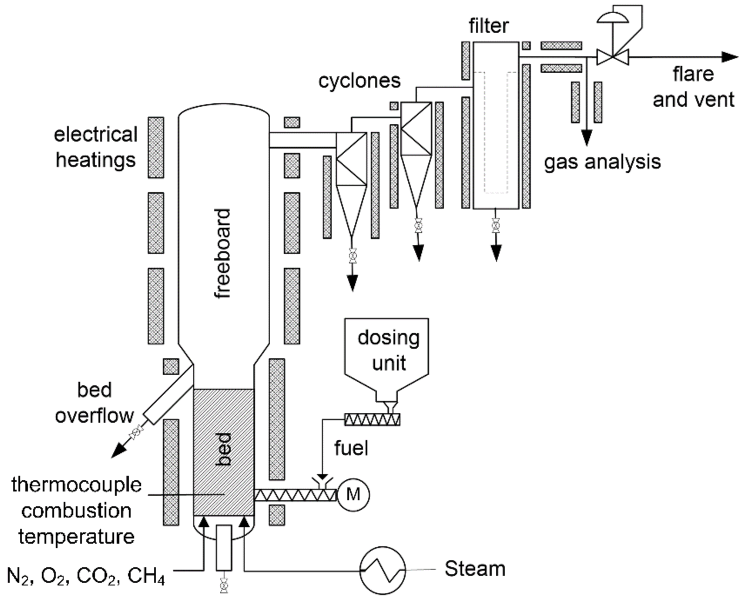

Figure 1. Schematic of the 20 kW_{th} bubbling fluidised bed facility (ELWIRA)

The 200 kW_{th} dual fluidised bed (MAGNUS) facility

The so-called 200 kW_{th} MAGNUS pilot facility has three fluidised bed reactors, which are connected by a solid flow transport system. In the NEWEST-CCUS project only one of the reactors will be used for the oxy-fuel validation tests. Figure 2 shows a schematic of the installation that will be used.

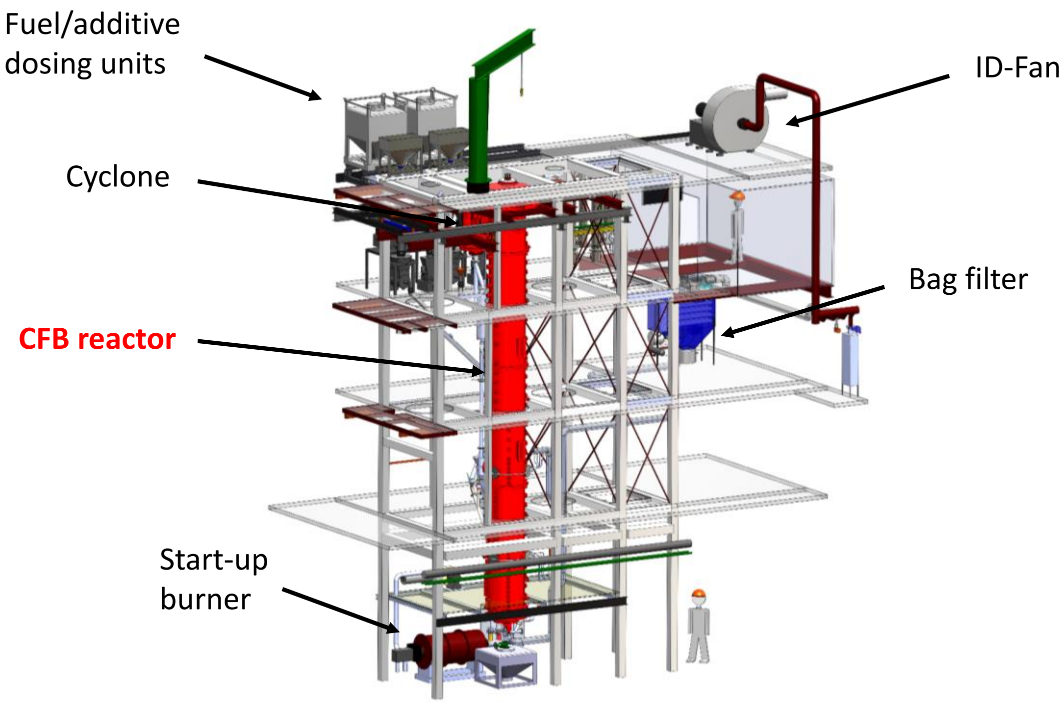

Figure 2. Construction schematic of the 200 kW_{th} CFB facility to be used in NEWEST-CCUS

The 200 kW_{th} facility is constructed for process validation in industrially relevant conditions. It is designed with a high degree of flexibility to enable operation in a wide range of conditions of economic and scientific interest. Its special design involving multiple reactors allows for switching between different configurations of interconnection of the gas and solid flows, hence giving the possibility to investigate several processes on one single facility (e.g. combustion, gasification, solid looping processes). For the oxy-fuel combustion process the facility will be operated in CFB mode. Figure 3 shows a schematic of the facility configuration as foreseen in the NEWEST-CCUS experiments.

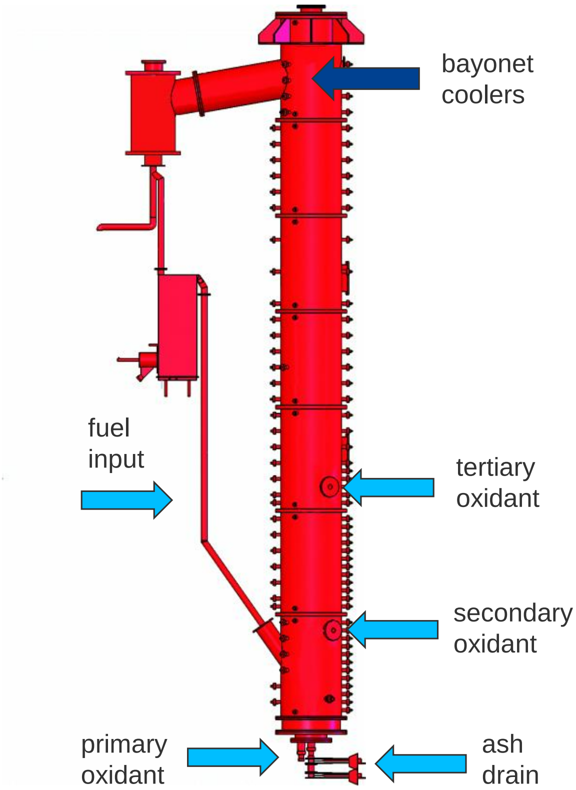

Figure 3. Schematic of the 200 kW_{th} CFB oxy-fuel reactor in the MAGNUS facility

The 200 kW_{th} circulating fluidised bed combustion reactor has a total height of 10 metres and an inner average diameter of 0.20 m. The riser and primary cyclone are refractory lined. The standpipe, the loop seal and the return leg are constructed of heat-resisting stainless steel.

The fluidisation gas (i.e. oxygen mixed with recirculated flue gas) is provided by a high-pressure blower. After the volume flow, temperature and pressure are measured, the gas stream is separated into primary, secondary and tertiary streams. The staging of the fluidisation gas can be set up via three pressure valves and is controlled by measuring the secondary and tertiary volume flows.

The primary oxidant addition enters the reactor through the windbox and a bubble cap distributer. Part of the primary gas may instead be added below the fuel downcomer pipe of the return leg to prevent blockage of difficult fuels in this leg. At 1.5 m over the grid, the secondary oxidant enters the combustion chamber through four nozzles. The tertiary oxidant is injected at 3.5 m. The diameter of the riser is increased with every gas staging to enable a homogeneous velocity distribution.

The combustion temperature in the reactor can be regulated by six water-cooled bayonet heat exchanger tubes. They can be inserted independently from the top of the riser. A maximum heat of up to 120 kW_{th} can be extracted here. In addition, the reactor mantle is also water cooled to ensure a descent surface temperature of the outer steel wall.

After the primary cyclone, the flue gas leaves the reactor and is led through a secondary cyclone to ensure an efficient solid separation before the gas cooler. Here, the gas is cooled down in four water cooled heat exchanger segments. The outlet temperature of the gas cooler is controlled not to exceed 250 °C. This is achieved by two valves, which regulate the bypass of one gas cooler segment.

After the gas cooler, a fraction of the flue gas is led to online gas measurement. The rest of the flue gas is filtered in a bag house filter. After a volume flow measurement of the total flue gas stream, the flue gas is then passed through the ID fan to the stack. A pressure control valve before the ID fan enables the regulation of the pressure in the reactor.

To monitor the facility's operation, there are numerous temperature and pressure sensors along the gas path. In the riser alone, 11 temperatures and 9 pressures are distributed over the reactor height. With this information, the mass of bed material and the actual velocities in the reactor can be evaluated to characterise the state of operation.

Table 2. Standard online gas analytics available at USTUTT.

Measurement principle	Gas species
NDIR	CO, CO_2, SO_2, NO_x
FTIR	Non-standard IR-active gases (e.g. HCl)
Paramagnetic	O_2
Impact jet	Moisture (e.g. steam content in flue syngas)

For fluidised bed combustion, different fuels, sorbents and inert material are fed continuously into the reactor. Therefore, the facility is provided with four screw feeders: two units for fuel and two units for sorbent or inert material (e.g. limestone, sand, etc.). All dosing units are operated gravimetrically. The dosed material is inserted into the return leg. It then falls together with the recirculated solids into the combustion chamber. The facility is operated from a PLC system. All data (online gas measurements, temperatures, pressures and gas flows) are continuously logged and actuators, such as valves, blowers, mass flow controllers, are set through the system operator.

The gas measurements of the combustion flue gas in the experimental facility are conducted between the gas cooler and the bag filter. All continuous gas measurements are carried out cold and dry. The ABB EL 3020 is used for the measurement of CO_2, CO, O_2 and SO_2 (see Table 2 above). NO_x is measured with Ecophysics CLD 844. To sustain an exact gas measurement and to log possible deviations throughout the experimental campaign, the gas analysers are usually calibrated at the beginning of the experimental week and checked every 24 hours with an appropriate test gas.

A well-equipped laboratory for fuel, ash and sorbent characterisation as well as liquid and gas sample analysis is available at USTUTT. Apart from different mills, crushers and other equipment for fuel and sample preparation, a range of online gas analysers is at our disposal. Particularly interesting for the SRF oxy-fuel tests in NEWEST-CCUS is the FTIR analyser for small and pilot-scale tests.

The role of USTUTT within the NEWEST-CCUS project

USTUTT has an established, internationally renowned competence through various national and European research projects on oxy-fuel circulating fluidised bed operation (ADECOS-ZWSF [national German BMWi]; RECAL [EU-RFCS]); calcium looping which also requires oxy-fuel CFB combustion (CATS [industrial: EnBW]; FLEXICAL [EU-RFCS]; CEMCAP [Horizon2020]); and oxy-fuel combustion (Relcom, OxyBURNER, OXYMOD, etc.)). In the RECOMBIO project (EU-FP7) and in the ongoing project NuCA (national German BMWi), USTUTT and REMONDIS have been working on the production, characterisation and combustion/gasification of solid recovered fuels.

USTUTT's main role in NEWEST-CCUS is pilot plant demonstration of CO_2 capture using an oxy-fuel CFB for solid recovered fuels combustion. CO_2 capture from circulating fluidised bed combustion (e.g. oxy-fuel CFB combustion) is an industrially available technique for hard coal. In NEWEST-CCUS, the oxy-fuel CFB process is adapted for solid recovered fuel combustion to achieve higher efficiency than conventional grate-fired boilers. The external fluidised bed cooler is less exposed to high impurity concentrations that cause pipe corrosion in the superheated part of the boiler so that associated problems can be mitigated and steam temperatures – and, by extension, efficiency – increased.

USTUTT aims to demonstrate CO_2 capture from solid recovered fuel via oxy-fuel CFB combustion, assess the impact of the fuel on key process properties – such as flue gas quality, ash quality and corrosion – and determine the efficiency of an oxy-fuel CFB combustion CO_2 capture plant. Industrial solid recovered fuel produced by automatic waste sorting in Germany will be used for all experiments. Limestone provided by LHOIST will be the sorbent for dry desulphurisation.

Expected results

By applying fluidised bed technologies for solid recovered fuel oxy-fuel combustion, USTUTT aims to:

- Develop guidelines for the selection of robust, fuel-flexible technologies resistant to the impurities of municipal solid waste.
- Increase flexibility of the waste incineration process and maximum ash recycling with oxy-fuel capture technology.
- Demonstrate oxy-fuel combustion in circulating fluidised bed with solid recovered fuel at TRL 6.

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