Technology Insight 3

SINTEF Energy Research's oxy-fuel combustion research facilities used in NEWEST-CCUS

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The role of SINTEF Energy Research within the NEWEST-CCUS project

The thermal engineering laboratories at SINTEF Energy Research are Norway's leading laboratories in the field of combustion, refrigeration, air conditioning and heat pump, low-temperature and bio processes, Carbon Capture and Storage (CCS) and processing. The Bioenergy Laboratories support research and development related to thermochemical conversion of biomass, waste and by-product into renewable energy, biofuels, and carbon carriers. As part of SINTEF Energy Research's focus on CCS, oxy-fuel combustion has been studied for more than 20 years with particular attention to experimental activities, where permanent infrastructures which form part of the European Carbon Dioxide Capture and Storage Laboratory Infrastructure (ECCSEL) have been built. The NEWEST-CCUS project is at the crossing of bioenergy and CCS and therefore combines expertise and infrastructure developed in parallel.

The role of the experimental activities in NEWEST-CCUS performed at SINTEF Energy Research is to bring new knowledge on the use of waste as fuel in oxy-fuel combustion technology as an effective means of capturing carbon dioxide (CO_2). Because of the innovative nature of this combustion method, fundamental studies are necessary using well-controlled laboratory-scale reactors described in this Technology Insight. The experimental data collected is further used for developing models targeted at oxy-fuel combustion for the design of a first-of-a-kind, large-scale oxy-grate furnace and its CFD simulation.

PYROPT reactor: the Pyrolysis and Carbonisation Facility

The Pyrolysis and Carbonisation Facility was built in 2017 and is one out of two reactors used for the NEWEST-CCUS project in Norway. It is located at SINTEF's laboratories at Gløshaugen Campus in Trondheim and is a lab-scale, batch-mode reactor, which can be handled by one person (cf. Figure 1). The flexibility of this reactor makes it possible to thermally convert almost any dry biomass into biochar, condensate, and gas by heating biomass in an oxygen deficient environment, such as N_2, CO_2 or CO. Other materials, such as dry sewage sludge, municipal solid waste (MSW) and plastics, have also been applied.

Figure 1 The Pyrolysis and Carbonisation reactor

Figure 2, below, shows a schematic drawing of the pyrolysis reactor. The split-furnace reactor is equipped with three 1600-watt, semi-embedded FeCrAl thermal elements, positioned vertically alongside the furnace wall. These provide heating temperatures up to 1200°C and a broad range of heating rates. Biomass is heated in an enclosed steel or ceramic tube inside the furnace and only gas can flow in and out. Purge gas, such as CO_2, can be applied for oxy-fuel conditions. From the reactor tube, gas flows through a cooling unit, where some of the gases condense into a liquid. The condensate can then be collected for further analysis. The temperature and volume of non-condensable gases is measured instantaneously through a gas meter. Two filters remove downstream particles and dust. With the additional use of an online gas analyser, complete mass and energy balances of the entire process can be performed, with losses down to only 3%. Enhanced process understanding is achieved through insertion pressure gauges and thermocouples throughout the system. Online data logging and a separate control cabinet facilitates the handling of the reactor.

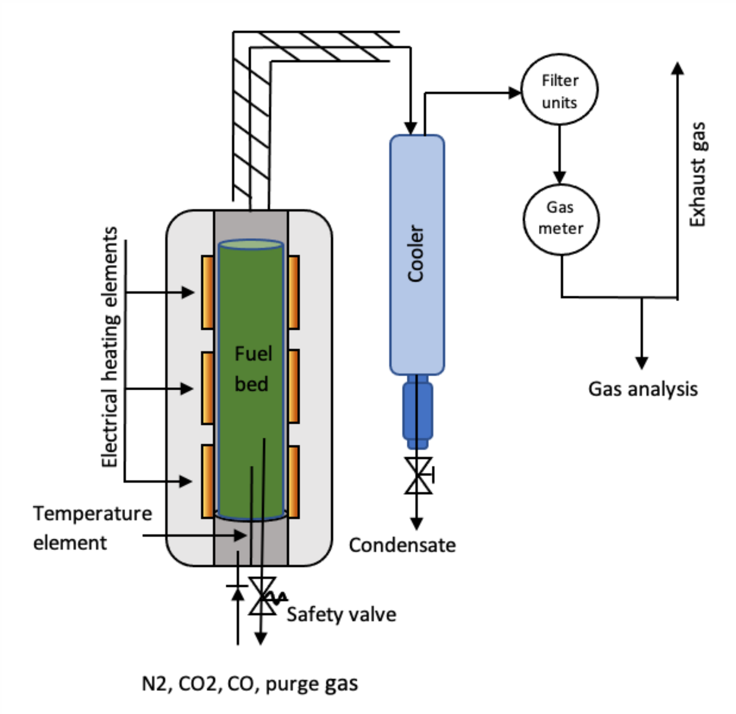

Figure 2 Schematic figure of the Pyrolysis and Carbonisation reactor

OXY-VTF reactor: the vertical tube furnace facility

The Oxy-VTF facility (an ECCSEL Research Infrastructure) is located at the SINTEF Energy lab in Blaklia, Trondheim, and is the second reactor used in the NEWEST-CCUS project in Norway. The reactor was built to study grate-like combustion of MSW, with a continuous feeding system and an integrated primary and secondary gas supply. It is particularly designed for the study of oxy-fuel combustion, with e.g. $O_2/CO_2/N_2$-mixtures as oxidisers. With online sampling and analysis of the flue gas, as well as temperature and pressure control, the vertical tube furnace provides the unique possibility of performing small-scale research on the oxy-fuel combustion of many materials and mixtures.

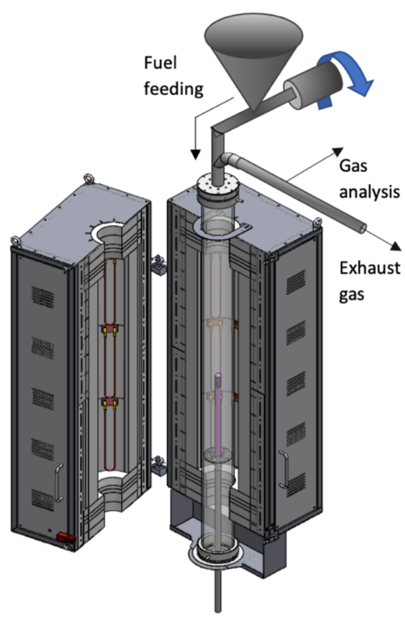

Figure 3 3D-drawing of the OXY-VTF reactor

The Oxy-VTF reactor is electrically heated, split-furnace, enclosing a ceramic tube where combustion takes place inside (cf. Figure 3). It is composed of three MoSi2- heating elements with a combined power of 18000VA, providing a maximum temperature of 1600°C and a broad range of heating rates. From the bottom, gas enters the tube and sets the desired atmospheric condition around a grate. The grate allows for build-up of a fuel bed and collection of ashes for further analysis. Turbulence enhancers are inserted inside the tube for optimal gas distribution. A screw feeder pushes the pelletised fuel (see *Fuel preparation facilities*) into the tube from the top of the reactor, providing continuous feeding and controlled feeding rates. Changes in fuel and fuel size can be adjusted for through adaptation and calibration of the feeder. An image of the furnace and screw feeder can be seen in Figure 4. From the combustion, gas and ash is produced. The gas is instantaneously sampled and measured by a gas analyser (see *Characterisation and analysis*), which is connected to the exhaust pipe. Ash can be collected after the experiment has ended. Process monitoring is otherwise achieved through several thermocouples and pressure gauges throughout the system. Ports are available for other connections, when needed. Secondary gas can be applied to enhance the combustion efficiency, turbulence and burn off.

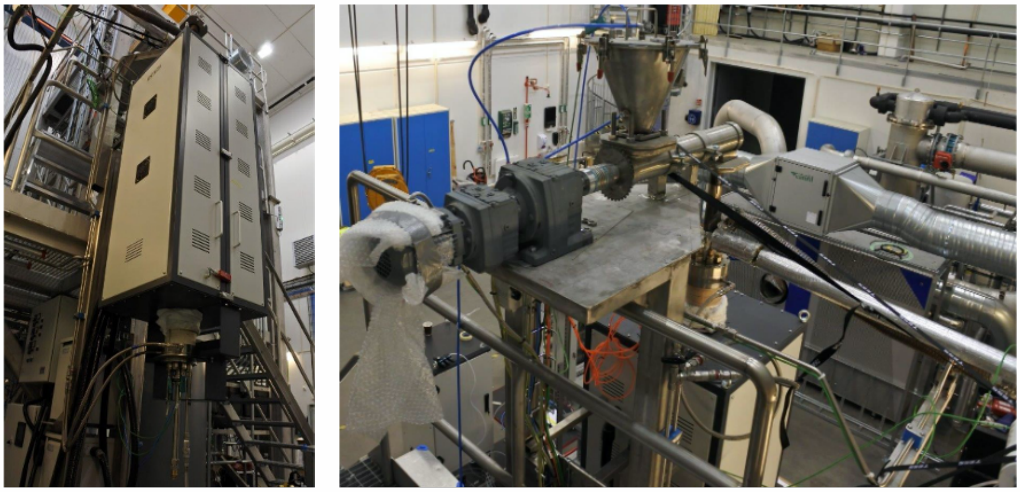

Figure 4 Images of the screw feeder (left) and OXY-VTF reactor furnace (right)

Fuel preparation facilities

The fuel preparation facilities at SINTEF Energy provide equipment for milling, grinding, sieving and pelletising almost any kind of solid fuel, including larger wood chips and plastics. The equipment varies from large-scale machines, which can process several kilos a day, to tabletop equipment for smaller sample sizes. MSW pellets are made in the large-scale machines seen in Figure 5, by milling and pelletising raw wood, paper, cardboard and plastics.

Figure 5 Fuel preparation facility showing the tabletop equipment for milling and sieving to the left and the large-scale mill and pellet-press machine to the right

In addition to reactor and fuel preparation facilities, SINTEF Energy laboratories have analytical instruments for the study and characterisation of solids, gas and liquids. These include instruments such as TGAs, TGA/DSCs, TGA/FTIRs, DSCs, different gas analysers, an ash melting microscope and equipment for standardised, proximate analyses of different fuels and char. Gas analysis can be done by e.g. gas chromatography, infrared gas analysers or paramagnetic gas analysers, depending on the properties of the gas and flow. SINTEF Energy laboratories provide fast, accurate and online gas analysis for most combustion facilities, including both stationary and mobile equipment, which can be easily implemented into the oxy-fuel combustion facilities. Table 1 lists the analytical techniques that can be used with the reactors, and their most relevant properties.

Table 1 Analytical techniques used in the NEWEST-CCUS project

Gas analysis technique	Gas detection	Other properties	P&C reactor	OXY-VTF reactor
FTIR	NOx, SOx, CO_2, CO, H_2O, CH_4, C+ and others	Wet gas, high flow, organic, inorganic, qualitative, quantitative		X
GC	N_2, H_2, CO, CH_4, CO, O_2, ethene, ethane, acetylene	Dry gas, low flow, mobile, organic, qualitative, quantitative	X	
IR and Paramagnetic	O_2, CO, CO_2	High flow, mobile		X

TGA/DSC was applied in the thermal, kinetic and compositional study of the MSW pellets and for validation of the degradation process occurring in the pyrolysis and OXY-VTF facility. Samples were heated under desired atmospheric conditions and the vaporisation of components resulted in a mass change over time. A broad range of gases, gas flows and heating rates can be applied and implementation of an FTIR allows for additional characterisation of the volatile compounds (see equipment in Figure 6). For further characterisation of fuel and char components, proximate analysis can be performed in a muffle oven, according to ASTM standards. The ash melting microscope can be applied in the study of ashes, providing heating temperatures up to 1600°C and a broad range of heating and frame rates.

Figure 6 Characterisation equipment at SINTEF Energy laboratories (left) and the ash melting microscope (right)

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