CLEEN
Cluster for Energy and Environment

ccsp
Carbon Capture and Storage Program

D331: Hot test rig design – Chemical looping combustion in PDU (Process Development Unit)

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Background and motivation

- The main objective, originally set out in the research plan of CCSP, was to develop technologies and concepts for CCS deployment leading to industry pilots and demonstrations by the end of the program.
- After the first two funding periods, the research had advanced to the stage that a hot test rig for chemical looping combustion could be designed in FP3.
  - Unfortunately, the needed investment was close to 1 M€, which was too expensive for inclusion in the program and the plans had to be abandoned.
- At the end of FP4 new opportunity raised:
  - 200 kW dual fluidized bed (DFB) gasifier (at that time under construction and now just commissioned at Bioruukki) could be modified with relatively little expenses to work as a CLC process development unit (PDU) for low-ash fuels.
- This would enable CCSP to reach its original targets for enabling piloting of CO_2 capture technologies.

Bio-Energy CCS (BECCS) – Justification

- The IPCC[1] states that “CDR (Carbon Dioxide Removal) technologies such as BECCS (Bio-Energy CCS) are fundamental to many scenarios that achieve low-CO_2eq concentrations”. Moreover, “BECCS features prominently in long-run mitigation scenarios for two reasons:
  1. The potential for negative emissions may allow shifting emissions in time; and
  2. In scenarios, negative emissions from BECCS compensate for residual emissions in other sectors (most importantly transport) in the second half of the 21st century.”
- Further, a recent major study identifies CCS and bioenergy as the two most valuable technologies for achieving climate policy objectives (more important than energy efficiency improvements, nuclear power, solar power and wind power), motivated by their combined ability to produce very significant negative emissions via BECCS[2]. So it is clear that the value and necessity of BECCS to achieve climate goals cannot be disputed.

1) Climate Change 2014: Mitigation of Climate Change. *Intergovernmental Panel on Climate Change*, 2014.
2) Kriegler, E,. et al. The role of technology for achieving climate policy objectives: Overview of the EMF 27 study on global technology and climate policy strategies. Climate Change 123, 353-367 (2014).

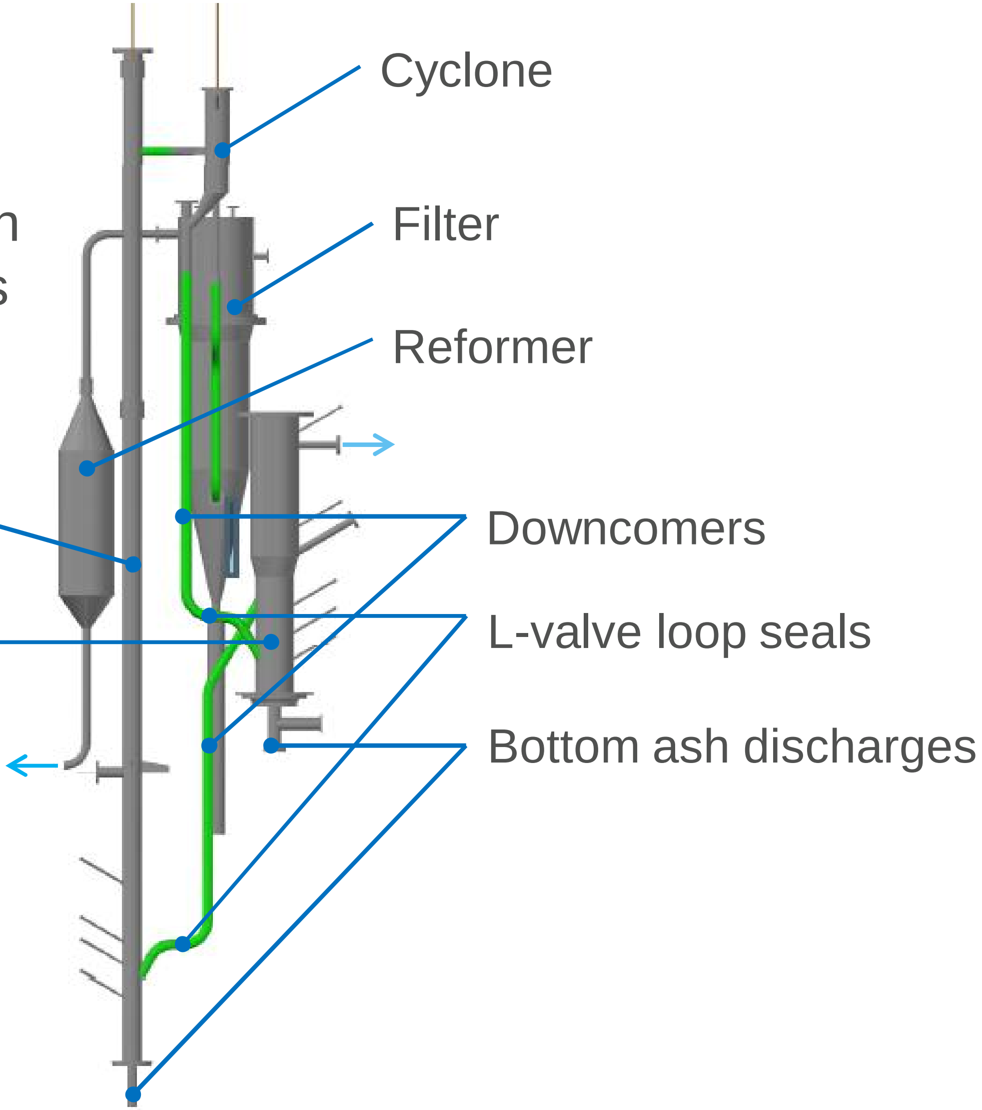
Why Bio-CLC?

- *Bio-CLC could be profitable also without CCS.*
  - It is expected that high-temperature corrosion problems can be significantly reduced in Bio-CLC as compared to conventional biomass. This is because heat will be extracted mainly in the exothermic air reactor, in which there will be no alkali compounds present and very little fly ash. This should allow the use of improved steam data compared to conventional biomass combustion and improved efficiency for power generation.
  - ➢ Hence implementation of Bio-CLC could in fact be economically feasible already before there is an infrastructure for CO_2 transport and storage available.
- *Bio-CLC could be demonstrated in large scale at low economic risk.*
  - A demonstration plant could be designed so that it would be possible to operate it also as an ordinary CFB boiler. This means that, after the demonstration period, the unit could be operated in CFB mode if its performance in CLC mode is unsatisfactory.
  - ➢ This would reduce the economic risk of such a venture greatly, if there is need for a utility on the demonstration site.

Introduction

- The main target is to modify VTT’s dual fluidized bed (DFB) gasifier applicable for chemical looping combustion (CLC) and demonstrate the *i*G-CLC (*in situ* gasification CLC) with solid biomass as fuel
- The main parts of the DFB-CLC PDU (Process Development Unit) are circulating fluidised bed (CFB) air reactor interconnected with bubbling fluidized bed (BFB) fuel reactor.
- Several modifications are required to convert the gasifier to CLC test rig, but the costs and efforts of these are still reasonable.

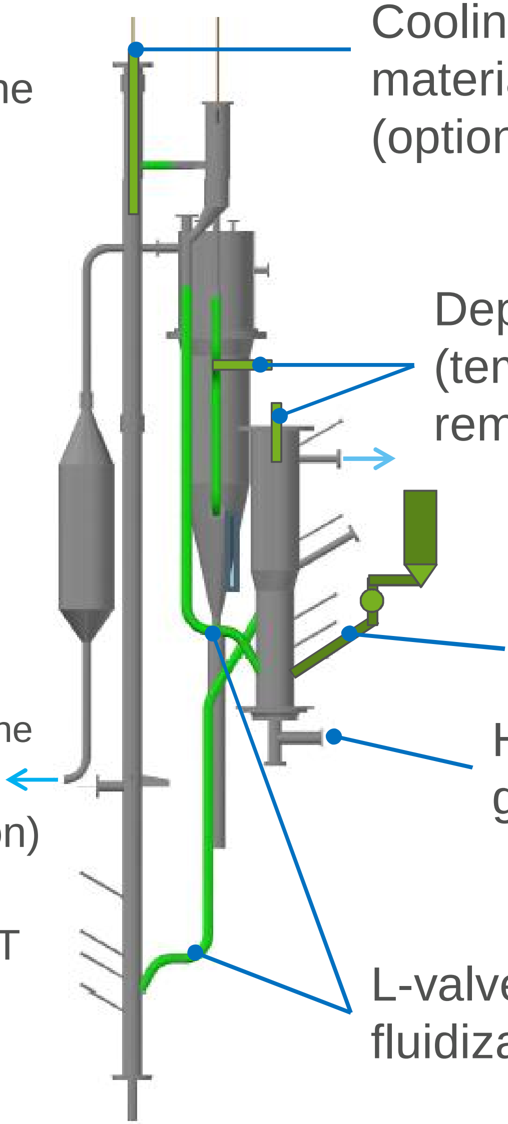
Existing Dual Fluidized Bed (DFB) gasifier



- Used for gasification research for synthesis gas applications
  - Gasifier (CFB)
    - Height 8 m
    - Diameter 0.10/15 m
  - Oxidizer (BFB)
    - Height 2.5 m
    - Diameter 0.32/0.42 m
    - Freeboard 0.35 m
  - Fuel power ~200 kW

Construction and modifications

- New fuel and oxygen carrier feeding line to fuel reactor (BFB)
  - Feeding level about the same as circulation material return
- Gas feeding modifications
  - Preheated H_2O and CO_2 lines into fuel reactor (BFB)
  - Preheated air to air reactor (CFB)
  - L-valve fluidization by N_2 (and CO_2)
  - Possibly other purge gas changes
- Deposition probes at the outlets of air and fuel reactor
  - Collection deposition sample to study the deposition rate and corrosion risk
- Modifications to flowsheet (for operation)
- Some new/modifications to measurements of gas composition, p, T and flow and other smaller instrumentation work



Cooling probe (circulation material temperature control) (optional)

Deposit probes (temperature controlled, removable test rings)

Fuel and oxygen carrier feeding lines

H_2O and CO_2 (preheated) gas feed lines

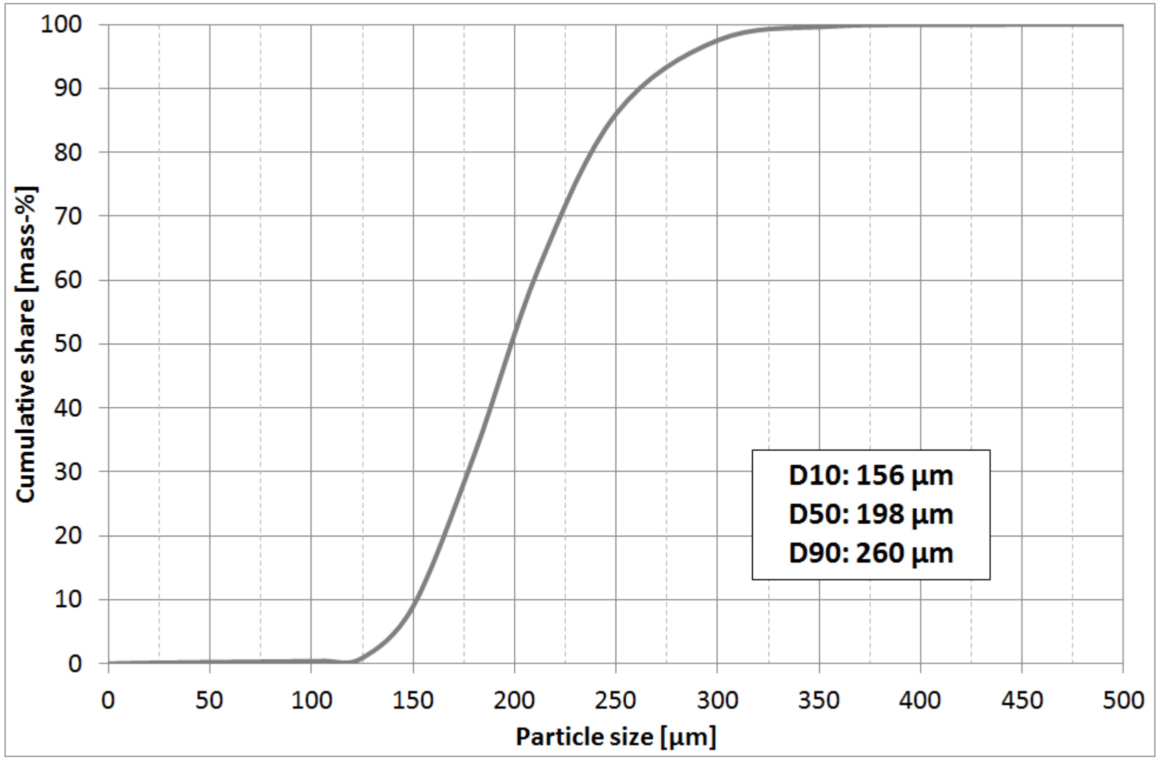
L-valves (loop seals) fluidization by N_2 and CO_2

Main targets

- Operation of bio-CLC PDU
  - with Fe-based oxygen carrier (ilmenite delivered by Titania A/S, Norway)
  - with 1-2 solid fuels (wood based and peat)
- Focus on optimization of operational parameters – not in oxygen carrier development
  - Solid material inventories and mass flow control
  - Oxygen carrier and fuel conversions
    - Calculation of needed carbon stripper and oxygen polishing process units
  - Temperature levels
  - Oxygen carrier durability, make-up flow
  - Deposition characterization
    - possibility for higher steam values due to low corrosion risk environment for heat exchangers (air reactor side)
- Generation of validation/verification data for reactor models (LUT)

Properties of oxygen carrier

Particle size distribution (wet Malvern) and composition (XRF) of ilmenite



Element	w-%
Ti	27.4
P	0.004
S	0.026
Cr	0.051
Fe	35.9
Si	0.76
V	0.11
Ca	0.15
Mg	2.23
Al	0.34
Mn	0.23
K	0.017
Na	0.052
Zn	0.012
Ni	0.018
Cu	0.0068
Co	0.012
Sr	0.0034
Zr	0.017
Nb	0.0045
Pb	<0.0001
SUM	67.3

Oxide	w-%
TiO_2	45.7
P_2O_5	0.010
SO_3	0.065
Cr_2O_3	0.074
Fe_2O_3	51.3
SiO_2	1.63
V_2O_3	0.16
CaO	0.21
MgO	3.69
Al_2O_3	0.64
MnO	0.30
K_2O	0.020
Na_2O	0.070
ZnO	0.015
NiO	0.022
CuO	0.0085
CoO	0.016
SrO	0.0040
ZrO_2	0.023
Nb_2O_5	0.0064
PbO	<0.0001
SUM	103.9

Estimations of some process parameters

(based on preliminary mass balance calculations)

Fuel reactor

Fuel type	-	spruce bark
OC type		Fe2O3-Fe3O4
OC inventory	kg	28.7
Fuel mass flow	kg/h	4.6
Fuel power	kW	21
Fluid. velocity	m/s	0.5
Temperature	ºC	900-915
OC/fuel-ratio	-	1.3

Air reactor

OC inventory	kg	119
Fluid. velocity	m/s	5.7
Temperature	ºC	900-950
Solids circulation	kg/s	0.10
Air factor (λ)	-	1.5

Schedule and status of bio-CLC-PDU at Bioruukki

1. Preliminary process calculations as base for construction works 01-06/2015
   - Ilmenite as oxygen carrier (delivered by Titania A/S)
   - Wood pellets as fuel
2. Detailed design work 08-11/2015
   - Fuel feeding system
   - Deposition probes at the outlet of fuel and air reactors
   - Gas piping and preheating modifications
   - Solids sampling from both reactors and circulation materials
3. Construction works 11/2015 – 01/2016
4. Cold test runs 01/2016
5. Commissioning and tuning test runs 02-03/2016
6. Actual test runs 04-05/2016
7. Reporting 06/2016