2nd INITIATE WORKSHOP: “CCU MODELLING APPROACH FROM MICRO TO MACRO ASSESSMENT”

Detailed Model of a CO_2 Capture Process: Definition of a Capture Process Characteristics and Performance

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Presentation Outlines:

1. C4U project and research group
2. Carbon capture technologies
3. Case study: (Base case for C4U project)
4. Process modelling specification
6. Techno-economic performance evaluation

C4U project and research Group:

C^{4}U project:

Funded by the **European Union H2020 programme**, the C^{4}U project spans demonstration of efficient solid based CO_2 capture technologies for optimal integration into an iron and steel plant and detailed consideration of the safety, environmental, societal, policy and business aspects for successful incorporation into **the North Sea Port** CCUS industrial cluster in **Belgium** and the **Netherlands**.

C^{4}U Work packages:

Carried out in 8 Work Packages (WPs). WPs 1-6 deal with technical development, scientific, business, societal readiness and public policy activities, whilst WP 7-8 are concerned with project dissemination, exploitation and management.

WP3:

The aim of this WP is the design of the C^{4}U capture technologies at industrial scale and the assessment of the energy and costs of the integrated process in the steelwork plant operation.

Our team at University of Manchester:

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Carbon Capture technologies:

Capture Technology

Critical Challenges

- Parasitic load
- Cost-effective oxygen production
- Application to existing plant
- Scale up
- etc.

Post-Combustion

- Chemical/Physical Solvent
- Membrane
- Chemical/Physical Sorbent

Pre-Combustion

- Chemical/Physical Solvent
- Membrane
- Chemical/Physical Sorbent

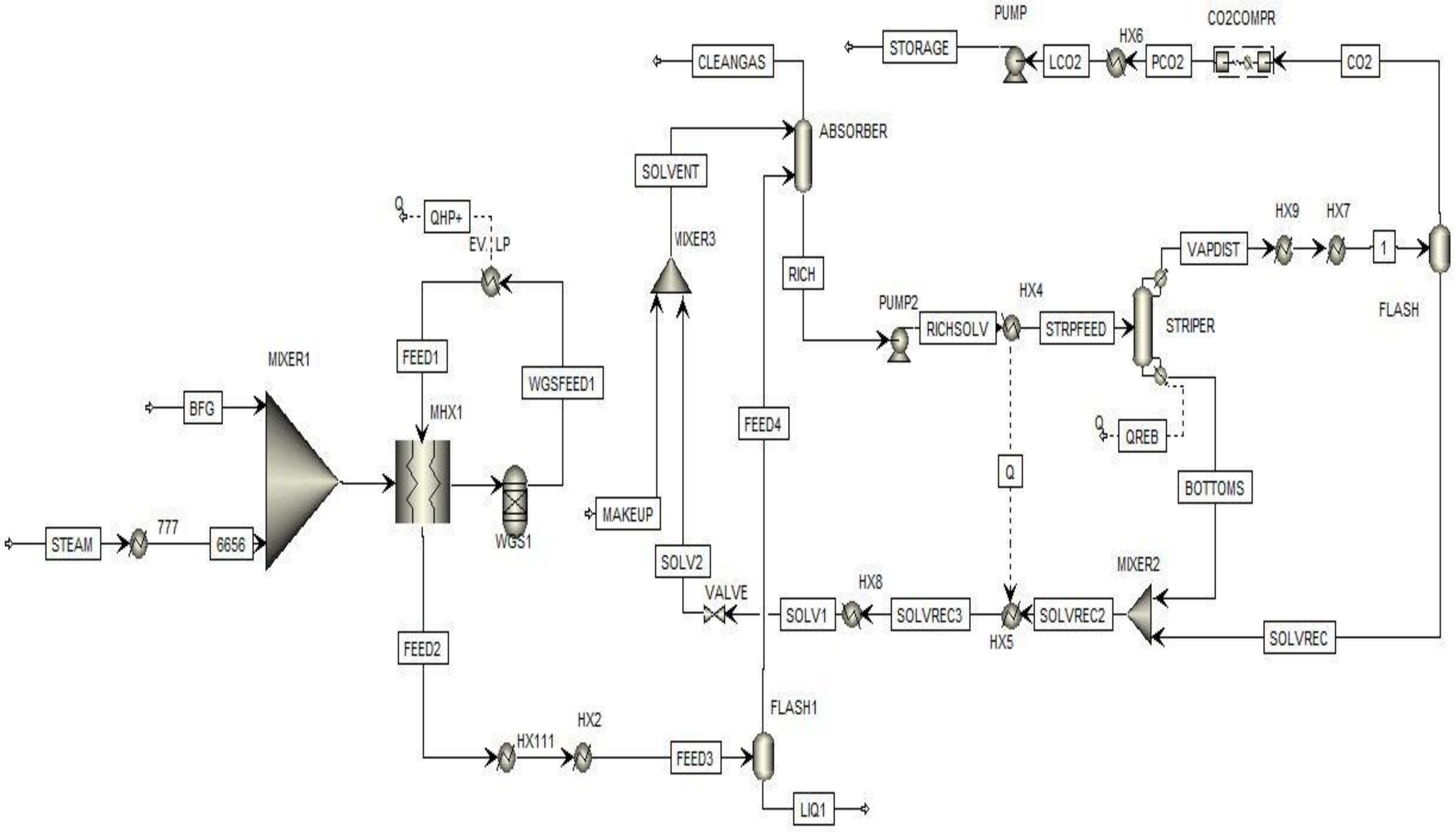
Oxy-Combustion

- Oxy-fuel with recirculation
- Oxygen transport membrane
- Chemical Looping

Amine solvent-based carbon capture is one of the mature technology that can be deployed to existing plants

Our recent visit to the pilot scale amine solvent-based carbon capture plant at Translational Energy Research Centre (TERC) at Sheffield

Case Study: Base case for C4U project



BFG decarbonisation with WGS and MDEA*

Process description:

- Aspen plus software is used for process simulation.
- The *ELECNRTL* equation of state and *equilibrium* calculation type are considered for simulation.
- MDEA is used as solvent.
- ~4 Mt/year BFG is considered for this simulation.
- Steam at 3 bar and 145 degree is provided.
- One stage WGS is implemented at 300 degree.
- Absorber works at 40 degree and 2 bar.
- Regeneration stage works at 90 degree and 6 bar.
- Captured CO_2 is liquefied at 78 bar and 25 degree and pressurised up to 110 bar for storage.

*MORE DETAILS AVAILABLE AT: N. Khallaghi S, Z. Abbas, G. Manzolini, E De. Coninck VS. Techno-economic assessment of Blast furnace gas pre-combustion decarbonisation integrated with the power generation. Energy Convers Manag 2022;148:148–62. https://doi.org/10.1016/j.enconman.2022.115252.

Process modelling specification

Assumptions and initial inputs to simulate the capture plant configurations

Parameter	Value
MDEA CO_2 absorption process	
MDEA/water content in the lean solvent (%wt)	25/72
Absorber stage number	15
Stripper stage number	20
Steam condition at the reboiler (bar)	6.0
Pinch point ΔT in the regenerative heat exchanger (°C)	10.0
Pump hydraulic/mech efficiency (%)	75/95
Heat Exchangers	
Minimum ΔT gas-gas heat exchanger (°C)	25
Minimum ΔT gas-liquid heat exchanger (°C)	10
Minimum ΔT liquid-liquid heat exchanger (°C)	10
Turbomachines	
Expander isentropic efficiency (%)	93
Expander delivery pressure, (bar)	1.015
CO_2 compression train	
Number of stages	2
Intercoolers temperature (°C)	40
Intercoolers pressure drops (% of P_{inlet})	5
Isentropic efficiency, (%)	80
Mechanical efficiency (%)	95
CO_2 delivery pressure (bar)	110
CO_2 delivery temperature (°C)	25

Aspen plus components used in the process modelling

Unit	Aspen Plus ID	Description
Condenser	Flash2	Pressure change=0, Duty=0
Cooler	Heater	
Heat exchanger(s)	HeatX, MHeatX	
Combustor	RGibbs	
Turbine, Compressor	Compr, MCompr	
Expander	Compr	
Absorber	RadFrac	15 stages, standard convergence
Regenerator	RadFrac	20 stages, partial vapour condenser, Standard convergence, Reflux ratio=0.6 mole , Boil up ratio= 0.1 mole
WGS	RGibbs	
Pump	Pump	
Valve	Valve2	

BFG composition and specification

Parameter	Value
Temperature (̊C)	35
Pressure (bara)	3
Composition (%mol)	
CO_2	22.2
CO	22.7
C_2H_4	0.2
H_2	2.4
N_2	53.5
S compounds	*Not considered*
Lower heating value (MJ/kg)[a]	2.35

Techno-economic performance evaluation

Important parameters to consider for performance evaluation

- Temperature/pressure required for integration
- Heat requirement for steam generation
- CO_2 capture rate
- CO_2 purity for transportation/storage
- CO_2 compression stage power requirement
- Heat duty for regeneration

Techno-economic performance evaluation

	Unit	no capture	Enhanced
Thermal input (BFG LHV)	[MW]	294.67	294.67
Thermal output (decarbonised fuel LHV)	[MW]	294.67	266.80
CO_2 flow rate for storage (kg/s)	[kg/s]	-	65.8
Reboiler heat duty	[MW]	-	91.4
Required heat for WGS	[MW]	-	66.5
CO_2 capture efficiency	[%]	-	83.8
Electricity requirements	[MW]	-	33.62
CO_2 purity for storage	[%]	-	98.1
Cold gas efficiency	[%]	100.0%	90.5%
Overall energy efficiency	[%]	100.0%	56.7%
CO_2 specific emissions	[kg_{CO2}/GJ_{LHV}]	267.1	51.19
SPECCA	[MJ_{LHV}/kg_{CO2}]	-	3.54
MDEA unit	[M€]	-	56.65
WGS reactors+ Heat exchangers	[M€]	-	12.36
Gas expander	[M€]	-	2.80
CO_2 compressor units	[M€]	-	19.98
Pumps	[M€]	-	0.02
Total Equipment Cost	[M€]	-	91.81
Total Direct Plant Cost	[M€]	-	187.29
Total Plant Cost	[M€]	-	247.69
Annua5lised Plant Cost	[M€/y]	-	28.24
Fuel Cost	[M€/y]	43.49	43.49
variable, heat and electricity	[M€/y]	-	27.78
Fixed O&M	[M€/y]	-	12.38
Total Annualised cost	[M€/y]	43.49	111.9
CO_2 capture cost	[$€/t_{CO2}$]	-	44.35

- 65.8 kg/s CO_2 flow rate and 266.8 MW thermal output results in specific emission of 51.19 $kg_{CO2}/GH_{LHV.}$
- Electricity requirement of 33.6 MW is mainly dictated by the power requirement for CO_2 compression stage.
- MDEA capture unit with more than 56 M€ plays the main role in total equipment cost.
- It is assumed that 43.5 M€/y is spent for fuel cost. However, considering that the BFG is available free of charge by the steel plant is another option that didn't consider in this evaluations.
- The economic evaluation here is for illustration of capture unit-only integration to steelmaking plant.

Thank You!
Any Question?