Industry CCS Workshop

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Process Evaluations and Simulations of CO_2 Capture from Steel Plant Flue Gases

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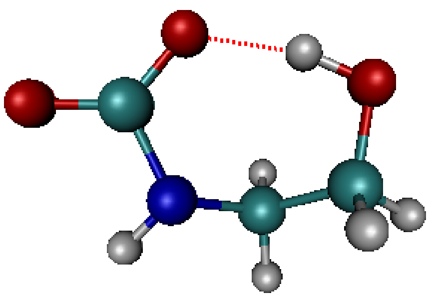
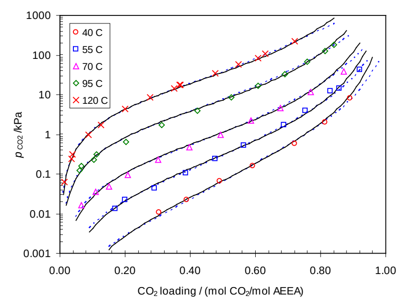
Outline

- SINTEF: Who we are
- Project objectives
- General process design and basis for simulation
  - CO2SIM simulation software
- Second Pass simulations (separate absorbers, combined desorbers at power plant)
  - Conventional MEA plant
  - Energy saving solvent and process configuration
- CO2 removal from an Oxygen blast furnace (OBF) stream
- Summary and conclusions

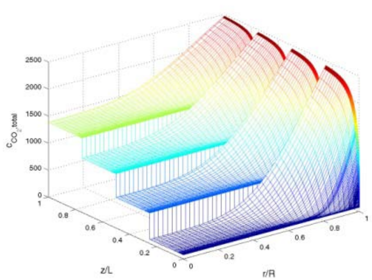
SINTEF CO2 capture group

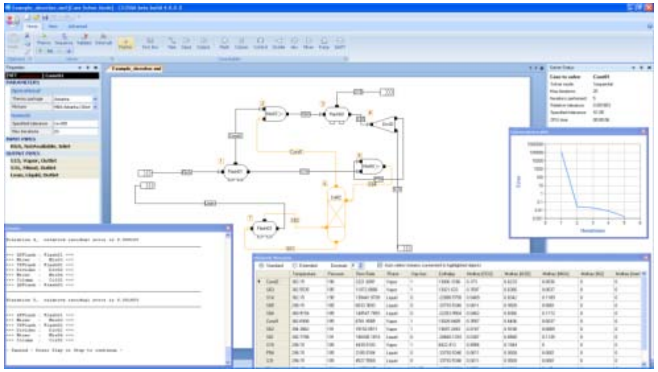
- The CO2 capture group at SINTEF/NTNU is one of the worlds largest research groups within absorption technology
- Laboratories and equipment for solvent characterization from bench to pilot scale
- In house molecular simulation models, thermodynamic models and complete process simulator (CO2SIM)

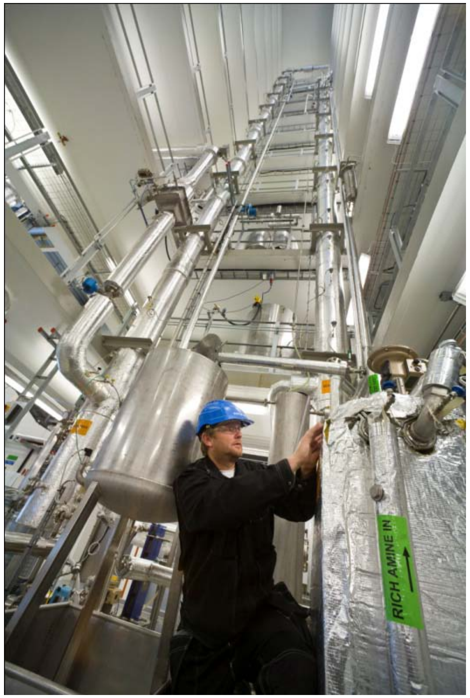




People:
CO_2 capture processes
20 researchers
NTNU Department of Chemical Engineering
18 PhD students and post doc







Project description

The overall project is headed by Swerea Mefos for IEA GHG,

"Techno-Economic Assessment of Carbon capture from an Integrated Steel plant"

SINTEF was to perform detailed simulations of solvent based CO2 capture processes on various flue gases present in a conventional steel plant as well as oxygen blast furnace (OBF) gas composition.

Previously we have worked with simulation of blast furnace gases in the ULCOS project:

- Tobiesen, F.A., Svendsen, H.F. and Mejdell, T, "Modeling of Blast Furnace CO2 Capture Using Amine Absorbents", *Ind. Eng. Chem. Res., 2007*, 46, 7811-7819.
- Mejdell, T., Tobiesen. A, Svendsen, H., CO_2 Capture with Chemical Absorption, ULCOS report nr 515960: 2006.
- Mejdell and Tobiesen, CO_2 Scrubbing with Amines, UCLOS: SP6 2006, Trollfjord, Norway

Objective: Establish energy requirements and equipment sizing for a **solvent based CO2 capture process**

1. Working on various flue gases present in an integrated steel plant
2. OBF flue gases

Input:

- Various flue gas streams present in a conventional steel plant, provided by Swerea Mefos

Investigation

- Establish energy requirements and equipment sizing
- Evaluate the concept of single absorbers for the *Steam generation, Hot stove + Coke , Lime Production* flue gases combined with solvent transport to common desorber site (second pass)
  - Evaluate CO2 recovery of 85, 90 and 95% from the different streams to remove 75% CO2 total
- Simulate oxygen blast furnace flue gas separation

Flue gas qualities

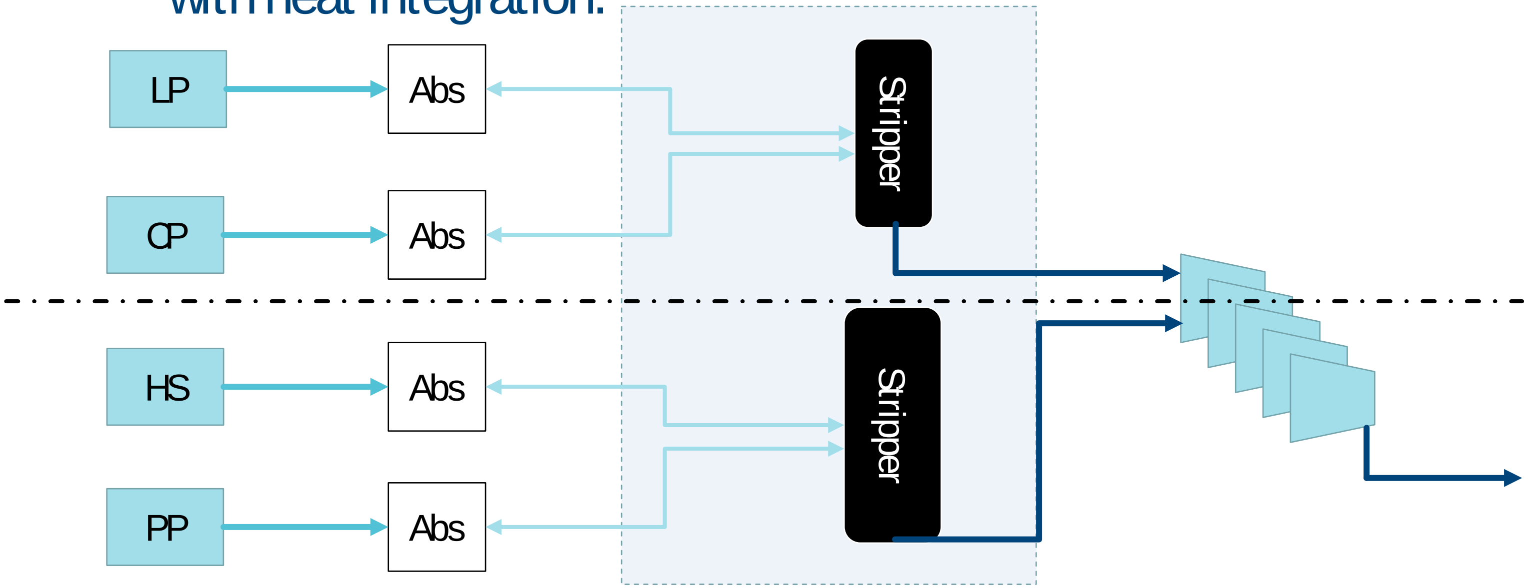
Flue gas:		Lime Production	Coke Production	Sinter Plant	Hot Stoves	Reheating furnace	Steam Gen.
Case abbrev.		LP	CP	SP	HS	RF	PP
CO2	%	19.8	14.7	4.9	27.3	5.0	27.4
N2	%	60.0	69.5	72.0	65.6	71.3	66.1
O2	%	7.6	5.0	14.8	0.8	5.9	0.7
H2O	%	12.7	10.8	7.5	6.3	17.8	5.8
Temp	oC	120	250	120	270	500	120
Pressure	bar abs	1.08	1.08	1.08	1.08	1.08	1.08
NOX	ppmv	15.0	150.0	100.0	37.0	247.0	50.0
SOX	ppmv	3.6	21.3	106.0	18.0	5.0	14.0
CO2-flow	t/yr	298,341	771,130	1,075,557	1,660,318	230,783	3,871,852
Sum CO2 all streams	**t/yr**	**7,907,980**					

- Combination of the PP+HS and CP+LP streams into common desorbers because the streams have a similar CO_2 level.
- Power Plant/ Hot Stoves and Coke and Lime Production flue streams have high CO2 content (slightly higher than conventional coal derived flue gas)
- Very low O2 level of the PPHS case, CPLP similar to conventional coal case

- SOx and NOx for solvent degradation
  - Both NO2 and SO2 seem ok and manageable (similar to coal flue gas)

Second pass

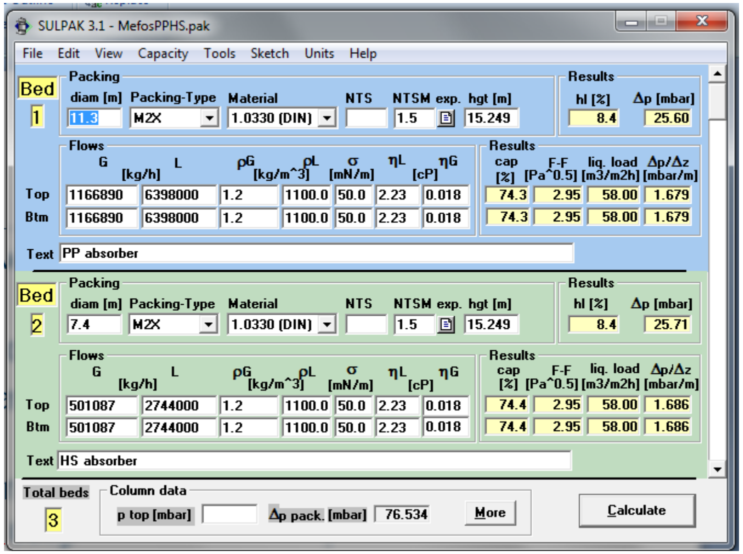
- Focus primarily on the four main process streams
  - Because of distance between process streams and cost of ducting etc, we chose an option to have single absorbers for each gas at the process area and pump the solvent to a common solvent regeneration unit (desorber) next to the steam boiler, first with standard MEA
  - Test advanced energy saving solvents including process configurations with heat integration.



Simulation approach

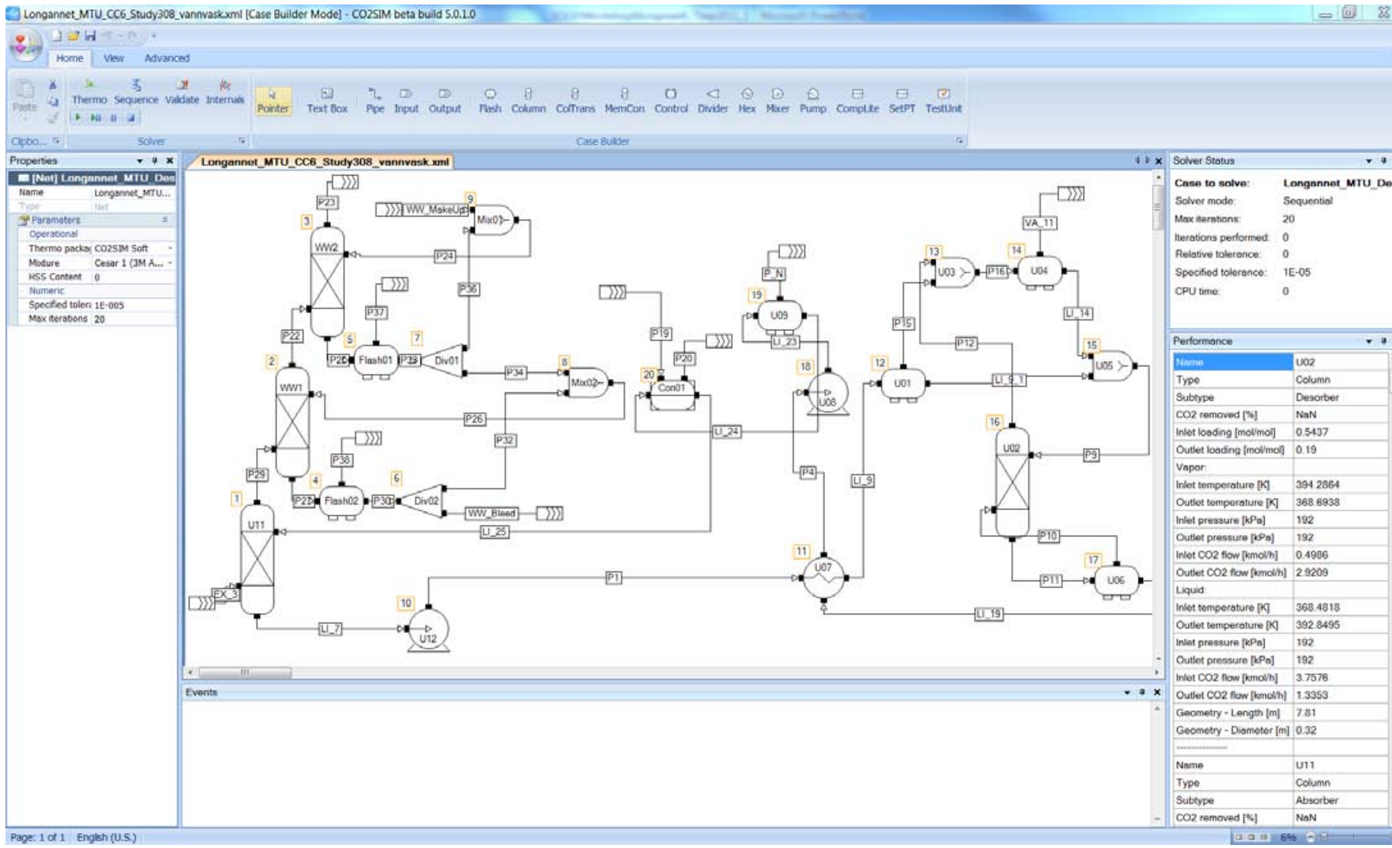
- Set-up of simulation case in CO2SIM
- Definition of a near optimal case, based on the CO2 input level, characterized with a given lean loading, liquid circulation rate and reboiler duty
- Absorber and desorber dimensioning based upon the Sulpak software from the packing vendor Sulzer, using gas and liquid properties from CO2SIM as input.
- Optimization study using routines built in CO2SIM
  - Varying lean loading and observe the impact on reboiler duty and process utilities (cooling water and electricity for pumps and blower).

Sulpak Tower dimensioning (diameter):

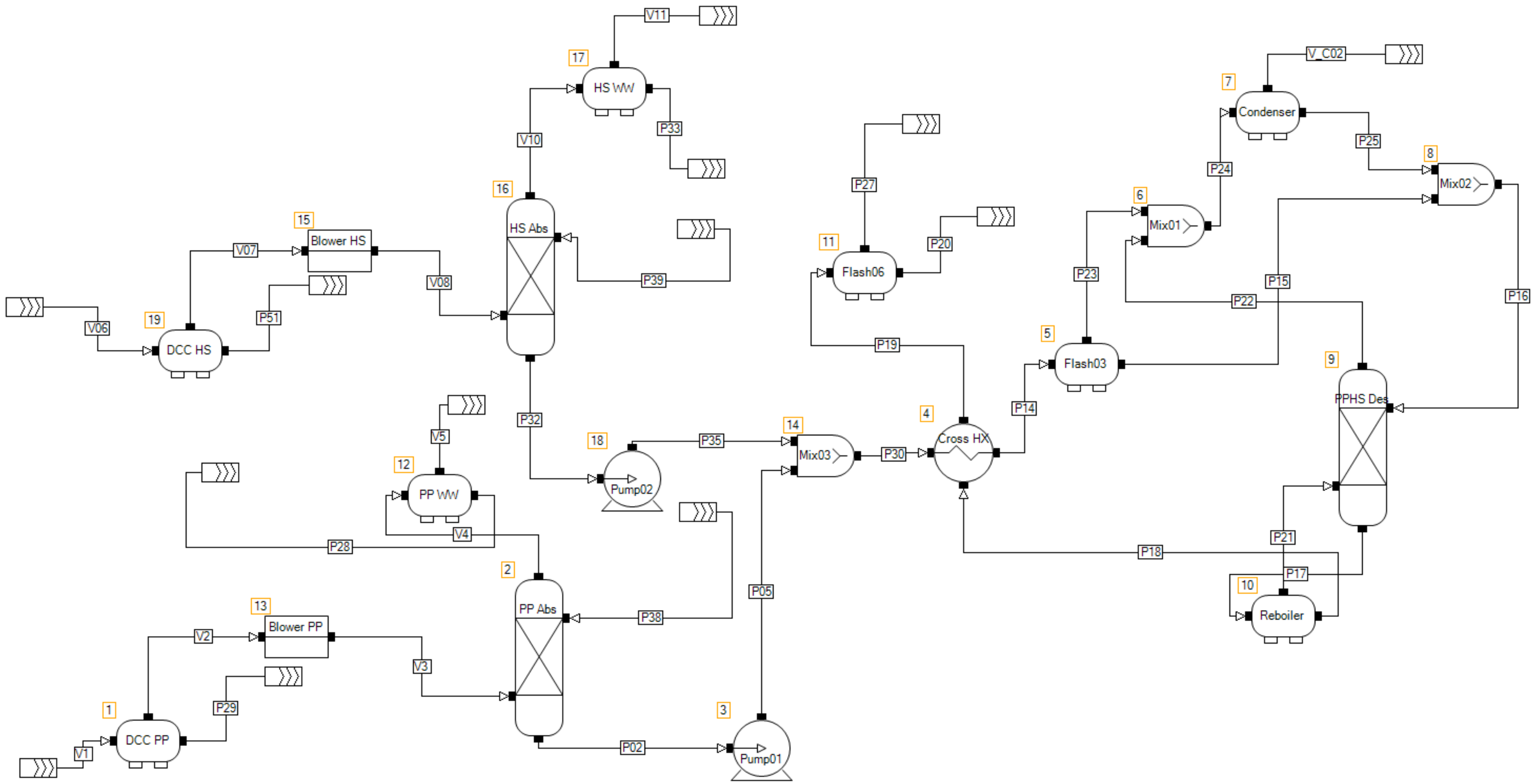


CO2SIM – simulation tool for post combustion capture

- Developed at SINTEF/NTNU
- CO2SIM gives specific methodology related to process optimization and handling of information flow
- Rigorous modeling approach
- Rate based mass and heat transfer models
- e-NRTL thermodynamics for CO2-amine systems
- Tool for process optimization and design

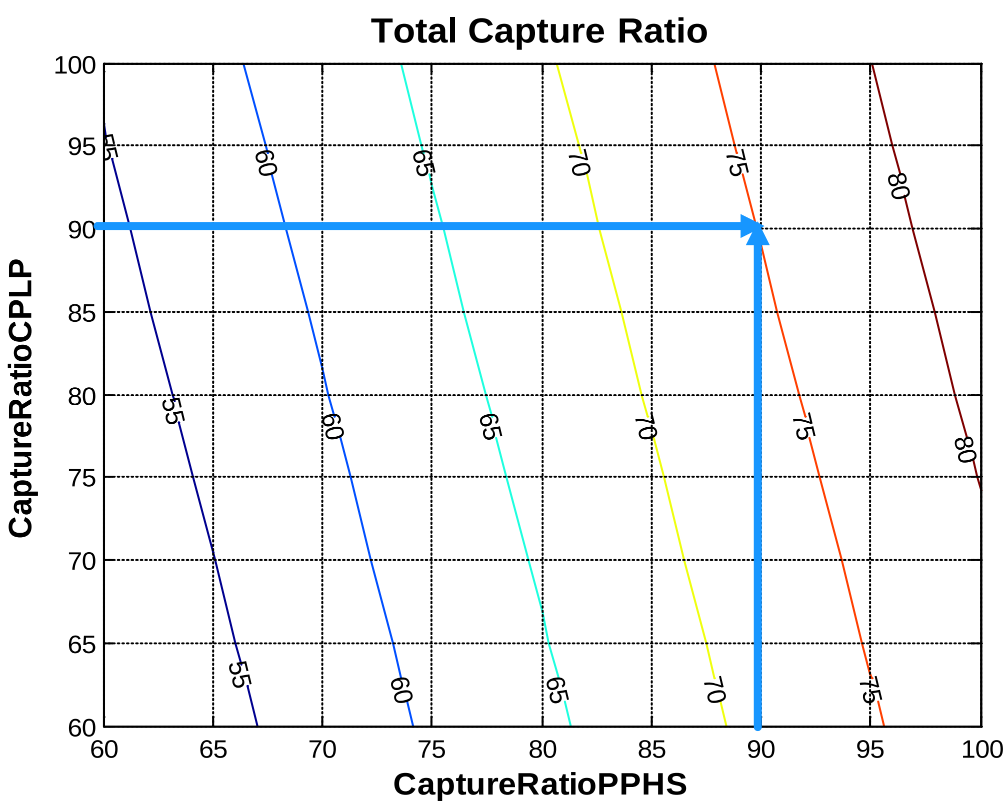


CO2SIM case – Generic absorption process – single absorbers/common desorbers



Steam Generation, Hot stove *+ Coke , Lime Production* flue gases together

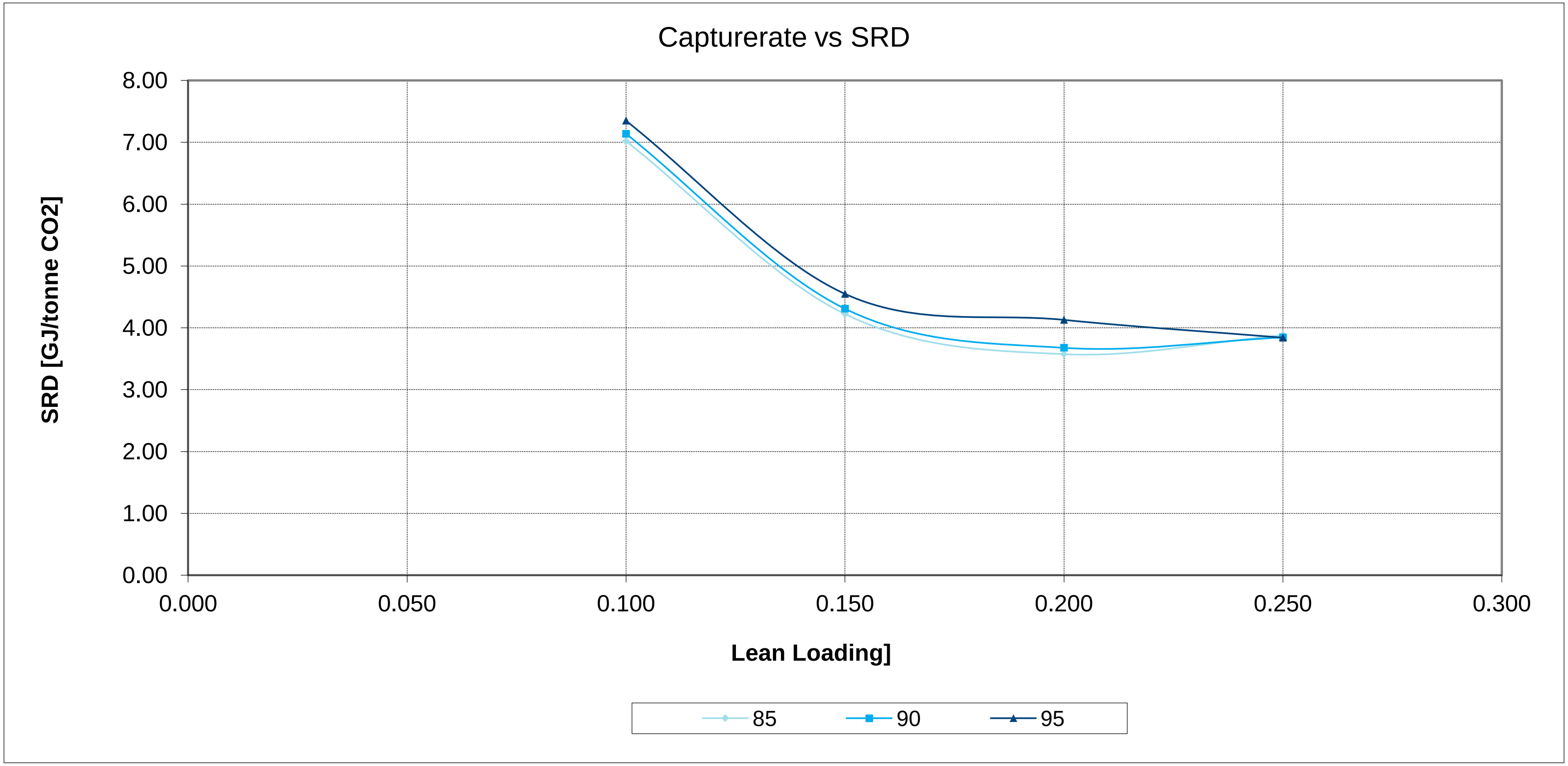
Total CO2 recovery from the steel plant should be 75%



- 75% total CO2 capture (of all 6 streams) is given by the red line. This shows that e.g. by capturing 96% in the *Steam Generation, Hot stove* (PPHS) case, 60% capture from the *Coke, Lime Production* (CPLP) case would be sufficient.

A 90% capture degree from both streams seem feasible, and fulfils the 75% target., disregarding the streams from the Sinter Plant and Reheating furnace

CO2SIM optimization of solvent flow for case PP+HS, reference MEA



CO2SIM results, 30wt %MEA reference

	CPLP 90%	PPHS 90%
Absorber A		
Packing height [m]	15	15
Column diameter [m]	6.3	11.3
Solvent Lean flow rate (tonne/h)	1,324	6,485
CO2 at inlet (mol %wet)	14.8 %	27.4 %
H2O at inlet (mol %wet)	10.5 %	5.8 %
CO2 recovery (%)	90.0 %	90.0 %
CO2 Captured (tonne/h)	79	398
Absorber B		
Packing height [m]	15	15
Column diameter [m]	3.5	7.4
Solvent Lean flow rate (tonne/h)	505	2,784
CO2 at inlet (mol %wet)	19.8 %	27.3 %
H2O at inlet (mol %wet)	12.7 %	6.3 %
CO2 recovery (%)	90.0 %	90.0 %
CO2 Captured (tonne/h)	31	171
Stripper		
Packing height [m]	9	9
Column diameter [m]	5.2	11.7
CO2 stripped [kg/hr]	110	568
Reboiler Duty [MW]	114	581
Spesific Reboiler duty [GJ/tonn CO2]	**3.73**	**3.68**

Sizing of absorbers

Absorber column		PP	HS	CP	LP
Packing material		**M2X**	**M2X**	**M2X**	**M2X**
Specific surface	m2/m3	205.00	205.00	205.00	205.00
Diameter	**m**	**11.3**	**7.4**	**3.0**	**2.8**
Packing height	**m**	**15**	**15**	**15**	**15**
Packing surface pr. column	m2	308 384	132 251	22 411	18 324
Number of beds, absorber packing		3	3	3	3
Height pr. bed.	m	5.0	5.0	5.0	5.0
Packing height WW-beds	m	2.0	2.0	2.0	2.0
Number of wash sections	m	2	2	2	2
Height required between secti	m	2.5	2.5	2.5	2.5
Height packed sections	m	29.0	29.0	29.0	29.0
Height mist collector + outlet s	m	2.5	2.5	2.5	2.5
Flue gas duct diameter	m	3.55	2.33	2.16	1.16
Absorber sump	m	3.0	3.0	3.0	3.0
Total absorber height	**m**	**38.0**	**36.8**	**36.7**	**35.7**

Packed column, example (distillation)

Sizing of desorber

Desorber column		PP+HS	CP+LP
Packing height	**m**	**9.00**	**9.00**
Diameter	**m**	**11.7**	**5.2**
Cross section area single. de:	m2	107.5	21.2
Number of beds desorber packing		2	2
Height per bed	m	4.50	4.50
Height water wash section	m	2	2
Number of wash sections		1	1
Height between sections		2.5	2.5
Height packed sections	m	16.0	16.0
Height mist collector + gas ou	m	2.5	2.5
Height required for steam inlet	m	4	2
Desorber sump	m	2	2
Total desorber height	**m**	**24.5**	**22.5**

Packed column, example (distillation)

Summary conventional plant with MEA

- For ***conventional MEA based removal*** of 75% of total produced CO2 from the Steel plant:

CO2 Captured (tonne/h)	31	171
Specific Reboiler duty [GJt/ton CO2]	**3.73**	**3.68**

- Large process units (~8 megatonnes CO2 per year is treated).
- **Necessary to look for ways to improve the capture process->**

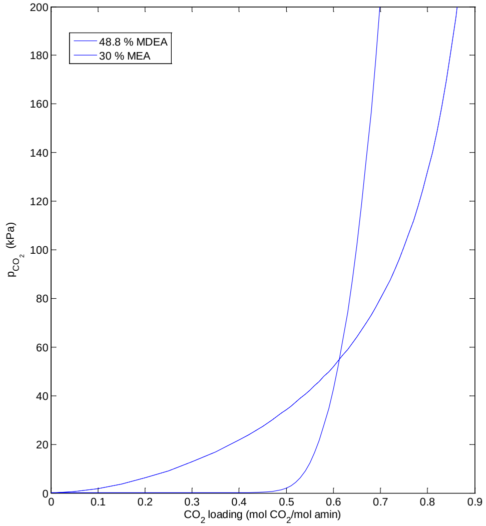
Results new configuration + low energy solvent

- 1. Change to heat integration configuration – from 3.7 to 3.1 GJt/t with MEA (90% removal)
- 2. Heat integration scheme and new solvent – below 2.7 GJt/t

CO2 capture from Oxygen Blast Furnace – OBF case

- OBF gas has a pressure of 4.1 bar and 34% CO2 ,-pCO2= 1.4 bar
  - CO2 partial pressure is 10 times larger than e.g. the Coke Plant flue gas
- This enables a significant reduction of the capture energy requirement
- Thermodynamic potential for energy saving due to less work for the compression of CO2 from the mixture conditions to the pure CO2 product
- Lower volume flow of gas,-reduced size of absorber unit
- Absence of O2 in the gas
  - significantly reduced solvent degradation to be expected

- MDEA or AMP based solvents are able to utilize the pressure benefit and are better suited than MEA for the current case
  - Chosen base case: 40% MDEA with 10% piperazine as activator, process offered commercially by several vendors



Summary and conclusions OBF case

- Simulations showed that the resulting energy requirement was 2.35 GJ/ton CO_2 or 257 MWt in total
  - Using an intercooled absorber with MDEA/Pz solvent.

- Capture of 3.2 Mt CO_2/year from OBF gas/94% CO_2 capture

- Absorber:
  - Diameter: 9m
  - Packing Height 14m
- Desorber:
  - Diameter: 8.52m
  - Packing height: 6m

Summary and conclusions (1)

- *Conventional 'end gases'*
- Utilization of new solvent systems and improved and optimized process configuration will significantly increase the efficiency of the CO_2 capture process.
- Improving the process configuration with MEA shows that the energy requirement can be reduced down to ~3.1 GJ/ton
- In addition changing to a new solvent (activated sterically hindered amine) makes it possible to reduce energy requirement down to 2.7 GJ/ton.

Summary and conclusions (2)

- *OBF gases*
- "Non-Solvent-optimized" example gave SRD of 2.35 GJ/ton
- Chemical absorption is well suited for CO2 removal from OBF top gases.
- Note: Not use of high reacting amines (MEA) but formulated solvents for the particular solvent partial pressure (High CO2 solvent carrier with activator) Could be an amino acid system
  - High CO2 content, large removal rate (94% capture) as well as no oxygen content.