STUDY OF PROCESS INTENSIFICATION OF CO_2 CAPTURE THROUGH MODELLING AND SIMULATION

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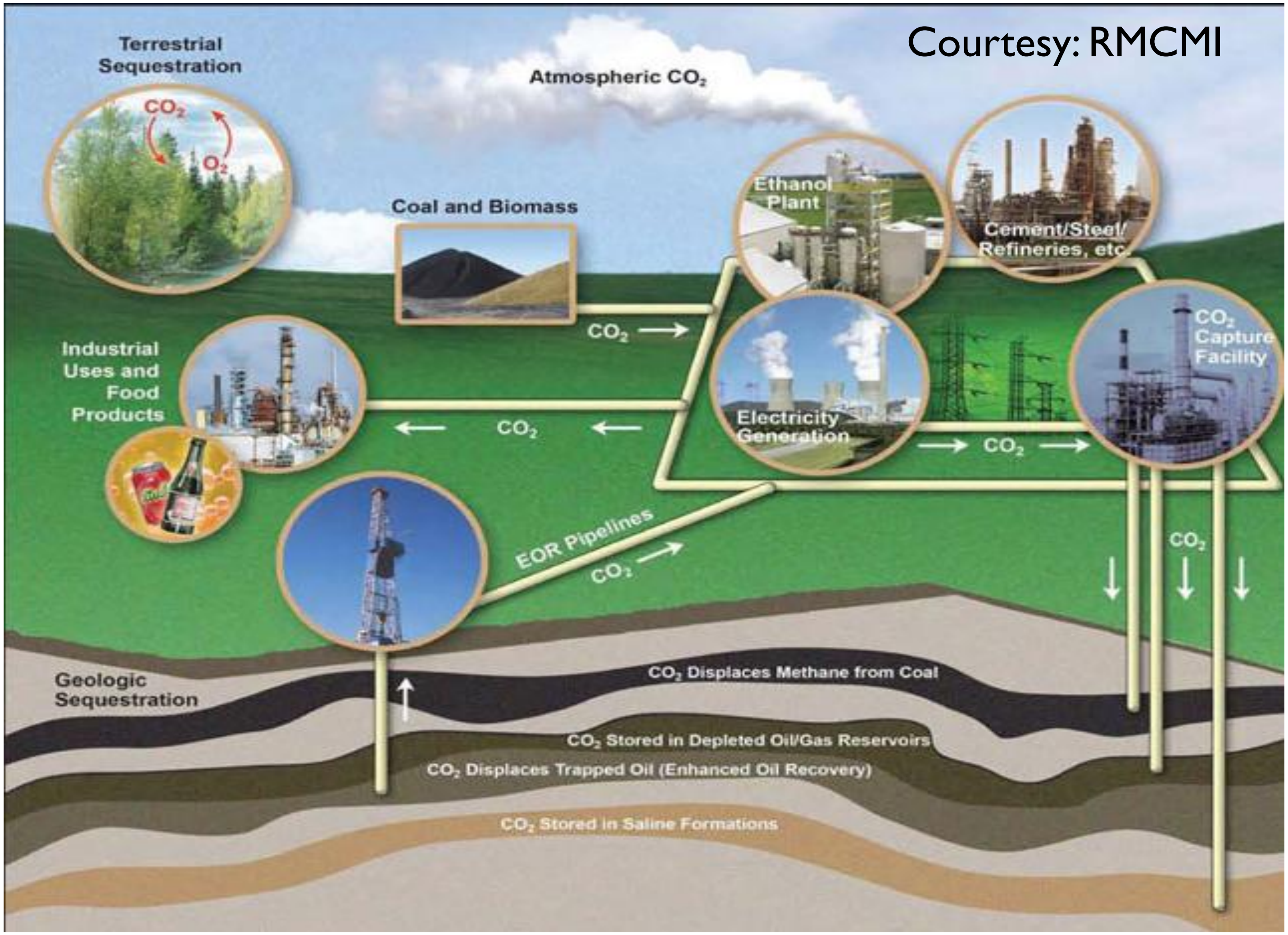
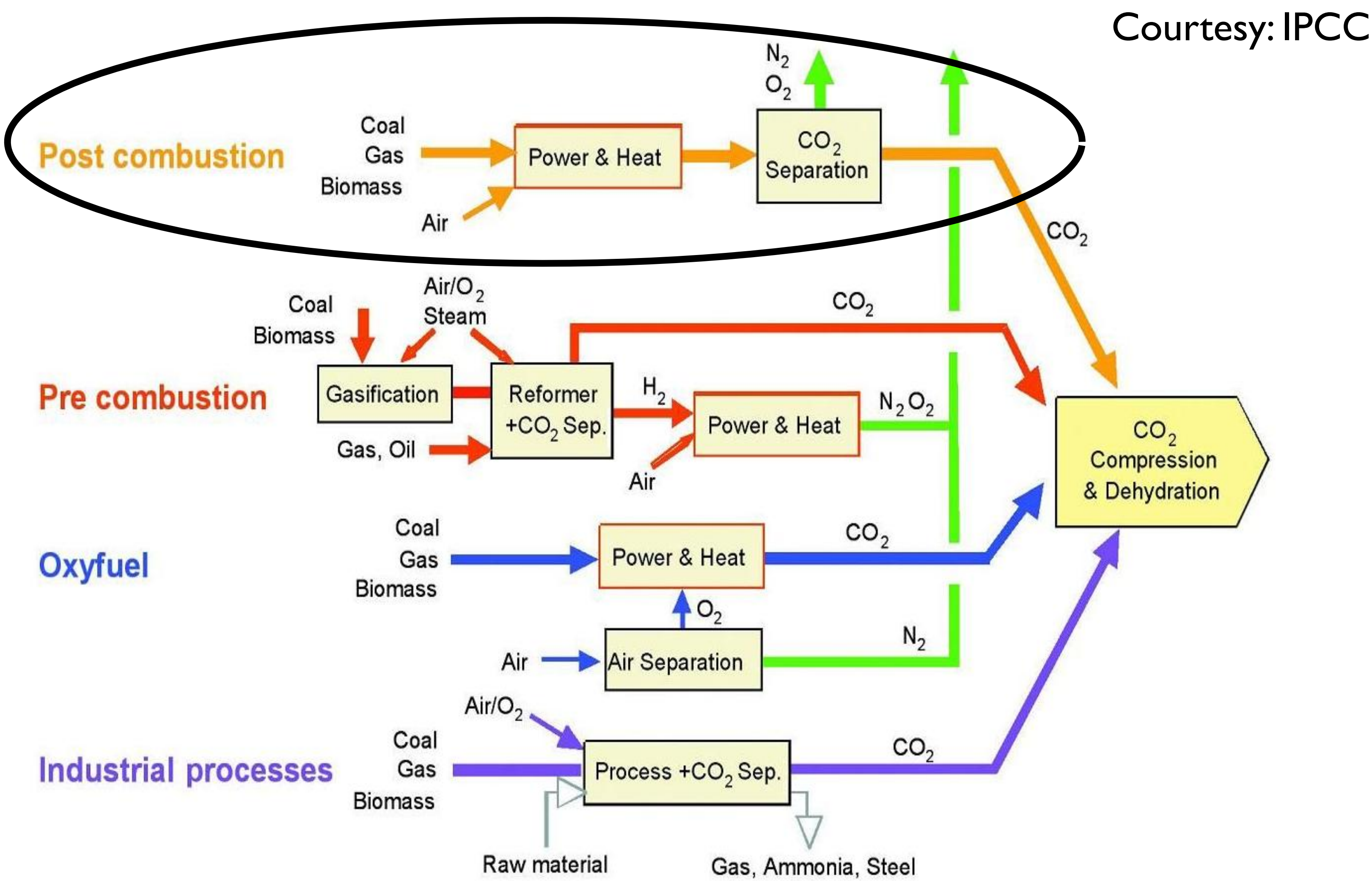
Outline

- Background
- Motivations
- Process Intensification
- Rotating Packed Bed
- Methodology
- Model Validation
- Process analysis
- Conclusions

BACKGROUND


Courtesy: RMCMI
Terrestrial Sequestration
CO_2
O_2
Atmospheric CO_2
Coal and Biomass
Ethanol Plant
Cement/Steel/ Refineries, etc.
CO_2
Industrial Uses and Food Products
CO_2
Electricity Generation
CO_2
CO_2 Capture Facility
EOR Pipelines
CO_2
CO_2
Geologic Sequestration
CO_2 Displaces Methane from Coal
CO_2 Stored in Depleted Oil/Gas Reservoirs
CO_2 Displaces Trapped Oil (Enhanced Oil Recovery)
CO_2 Stored in Saline Formations

BACKGROUND



Courtesy: IPCC
Post combustion
Coal
Gas
Biomass
Air
Power & Heat
CO2 Separation
N2
O2
CO2
Pre combustion
Coal
Biomass
Air/O2
Steam
Gasification
Reformer +CO2 Sep.
Gas, Oil
H2
Power & Heat
Air
N2 O2
CO2
Oxyfuel
Coal
Gas
Biomass
Power & Heat
O2
Air
Air Separation
N2
CO2
CO2 Compression & Dehydration
Industrial processes
Air/O2
Coal
Gas
Biomass
Process +CO2 Sep.
CO2
Raw material
Gas, Ammonia, Steel

MOTIVATIONS

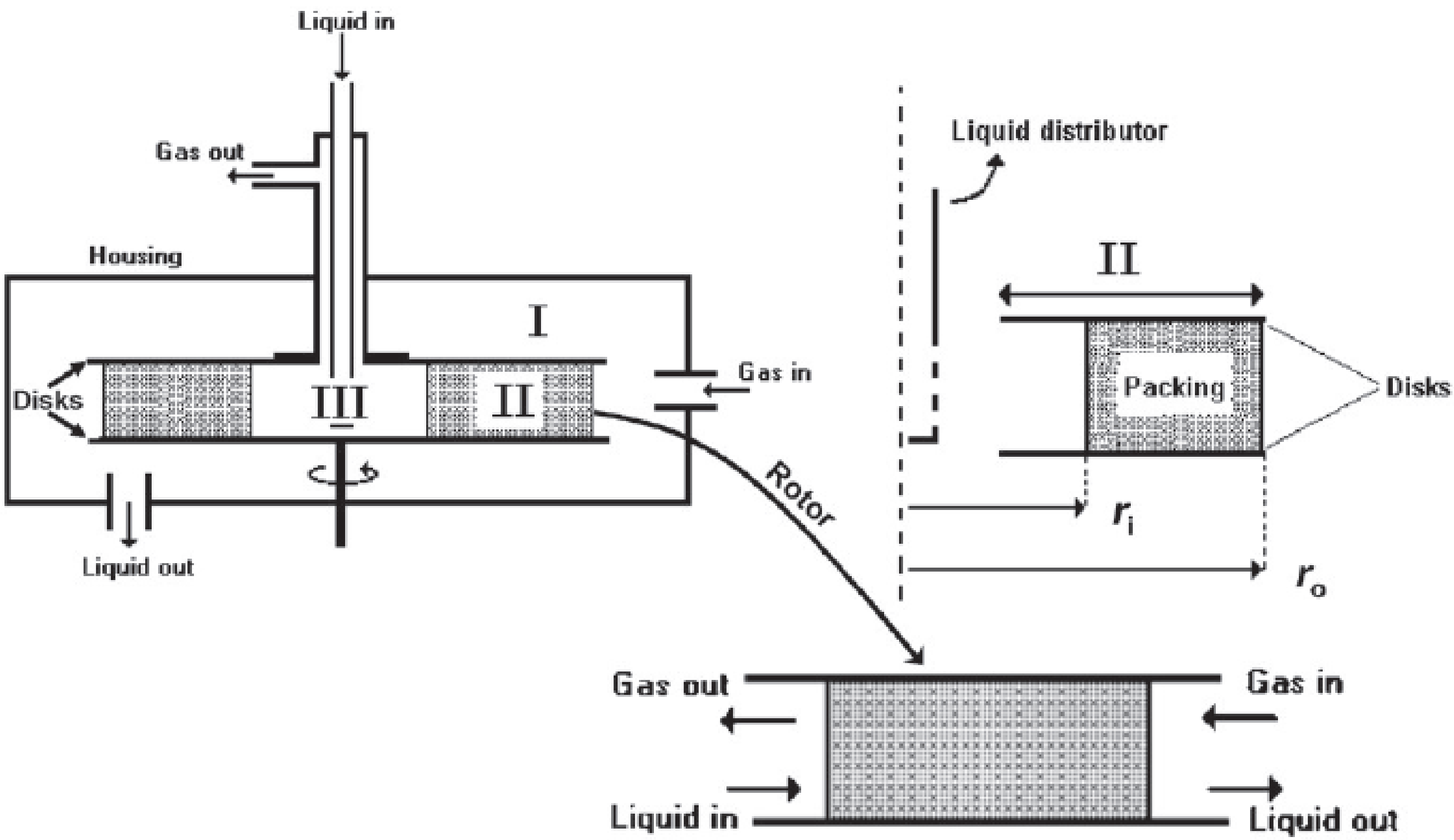
- BERR (2006) reported that a 500 MWe supercritical coal fired power plant operating at 46% efficiency (LHV basis) would release over 8,000 tonnes of CO_2 per day.
- Raynal and Royon-Lebeaud (2007) reported that for 400 MWe coal-fired power plant it produces approximately 1.1 x 10^6 Nm^3/hr of flue gas.
- Lawal *et al.* (2012) reported two absorbers will be required of 17m in packing height and 9m in diameter to separate CO_2 from flue gas of 500MWe subcritical coal fired power plant.

PROCESS INTENSIFICATION (PI)

- PI is a strategy for making major reductions in the volume of processing plant without compromising its production rate.
- Rotating packed bed (RPB) is one of PI equipments proposed originally by Dr. C. Ramshaw 1979.
- RPB takes advantage of centrifugal force to generate high gravity and consequently boost the mass transfer performance.

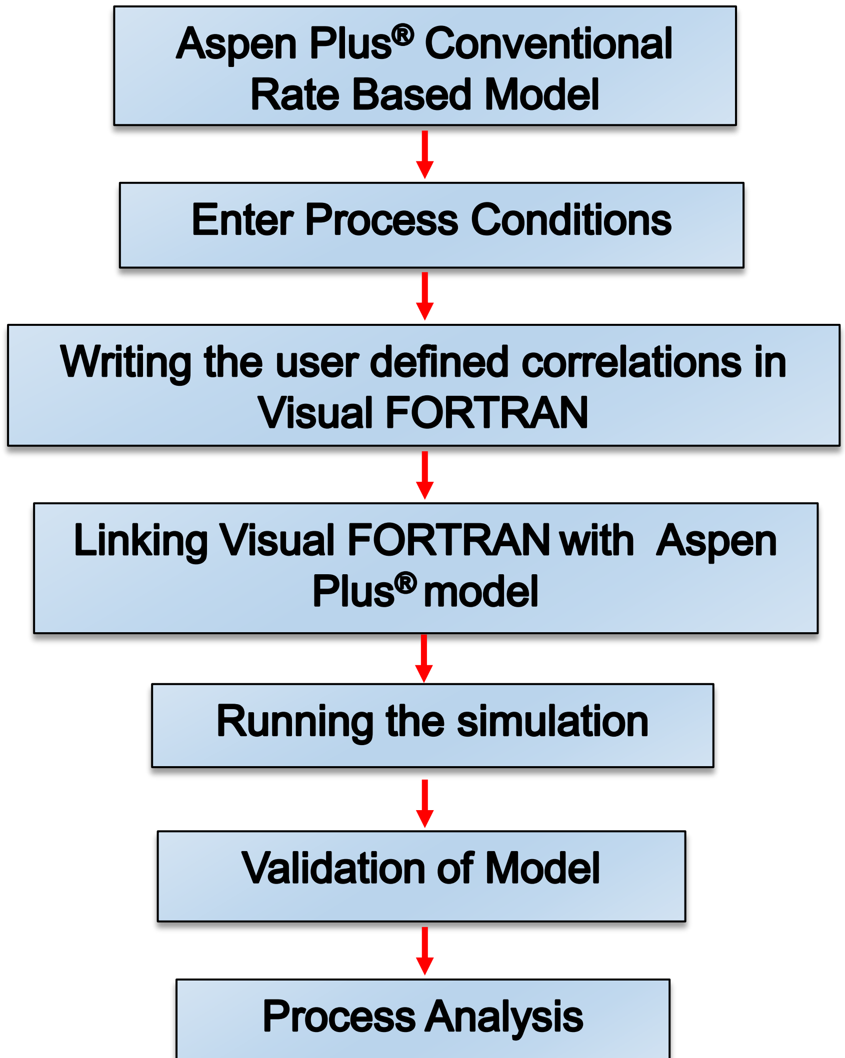
Rotating Packed Bed used for REACTIVE STRIPPING –40 times smaller plant (Dow Chemical, HOCl process)

ROTATING PACKED BED



Schematic diagram of a rotating packed bed setup and corresponding segmentation (Llerena-Chavez and Larachi, 2009)

METHODOLOGY



MODEL VALIDATION

Table 1 process condition, at 600 RPM and 75 wt% MEA

variable	
Rotor speed (RPM)	600
Lean temperature (°C)	41
Lean pressure (atm.)	1
LEAN-MEA flow rate (kg/s)	0.66
LEAN-MEA composition (wt %) H_2O = CO_2 = MEA =	 22.32 2.68 75.00
Flue gas flow rate (kmol/hr)	2.87
CO_2 composition in flue gas (vol %)	4.4

Table 2 process condition, at 1000 RPM and 55 wt% MEA

variable	
Rotor speed (RPM)	1000
Lean temperature (°C)	39.6
Lean pressure (atm.)	1
LEAN-MEA flow rate (kg/s)	0.35
LEAN-MEA composition (wt %) H_2O = CO_2 = MEA =	 41.03 3.97 55.00
Flue gas flow rate (kmol/hr)	2.87
CO_2 composition in flue gas (vol %)	4.35

Table 3 Model result compared to expt. Data at 75wt% MEA and 600RPM

variable	Model	Expt.	Relative error (%)
CO_2 loading of LEAN–MEA, (mol CO_2/mol MEA)	0.0496	0.0496	
CO_2 loading of RICH-MEA, (mol CO_2/mol MEA)	0.0528	0.0531	0.5682
Average LEAN-MEA/RICH-MEA, (mol CO_2/mol MEA)	0.0512	0.0514	0.3906
CO_2 capture level, %	98.21	98.20	0.0102
CO_2 penetration, %	1.79	1.80	0.5556

Table 4 Model result compared to expt. Data at 55wt% MEA and 1000RPM

variable	Model	Expt.	Relative error (%)
CO_2 loading of LEAN–MEA, (mol CO_2/mol MEA)	0.0997	0.0997	
CO_2 loading of RICH-MEA, (mol CO_2/mol MEA)	0.1064	0.1073	0.8459
Average LEAN-MEA/RICH-MEA, (mol CO_2/mol MEA)	0.1031	0.1035	0.3880
CO_2 capture level, %	89.92	89.90	0.0222
CO_2 penetration, %	10.08	10.10	0.1980

Conclusion from validations

Table 3 and 4, the model predictions are compared to experimental data at the input conditions shown in **Table 1 and 2**. In all the runs considered, relatively error of prediction for the various variables accessed is less than 1% which is acceptable.

Based on this, the model can be used to analyse typical RPB behaviour at different input conditions.

PROCESS ANALYSIS

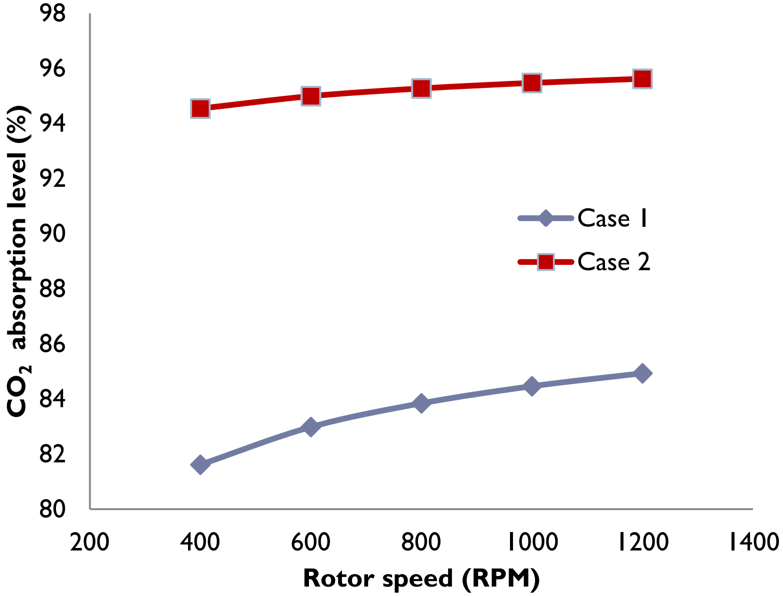
The model developed and validated is used to analyse the process characteristics of the RPB absorber.

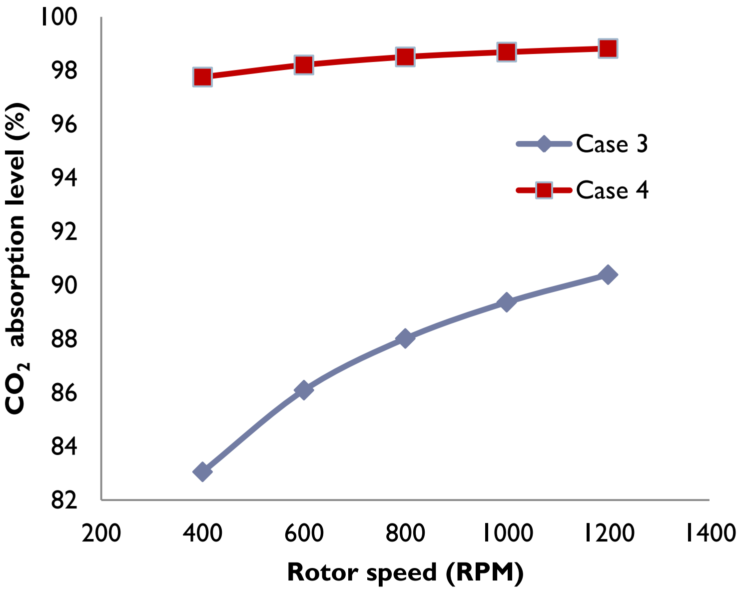
a. *Effect of Rotor Speed on CO_2 Capture Level*

Table 5 Process input conditions

Variable	Case 1	Case 2	Case 3	Case 4
Rotor speed (RPM)	400	400	400	400
Lean temperature (^oC)	20.9	39.5	20.9	39.5
Lean pressure (atm.)	1	1	1	1
Flue gas flow rate (kmol/hr)	2.87	2.87	2.87	2.87
CO_2 composition in flue gas (vol %)	4.35	4.35	4.35	4.35
Lean-MEA flow rate (kg/s)	0.66	0.66	0.66	0.66
Lean-MEA composition (wt %)				
H_2O	41.03	41.03	22.32	22.32
CO_2	3.97	3.97	2.68	2.68
MEA	55.00	55.00	75.00	75.00

- For all cases the input parameters are kept constant with rotor speed varied from 400 rpm to 1200 rpm





Effect of rotor speed on CO_2 capture level at 55wt% MEA

Effect of rotor speed on CO_2 capture level at 75wt% MEA

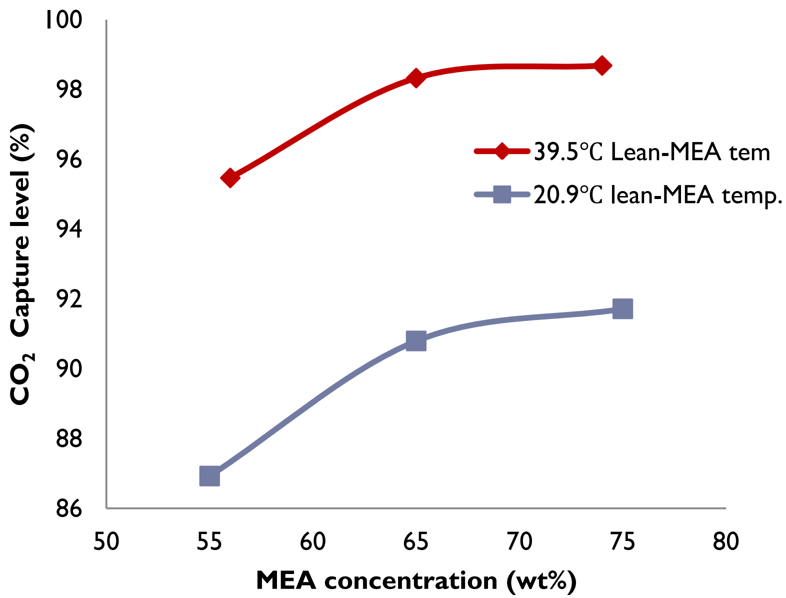
Results & Discussions

- CO_2 capture level increases with increase in rotor speed.
- 75 wt% MEA concentration capture level is higher than at 55 wt% MEA concentration.
- Burns *et al.* (2000) stated that at higher centrifugal acceleration, combined droplet and film flow are prevalent in an RPB absorber leading to enhanced mass transfer flux.
- Higher rotor speed the problem of liquid mal-distribution is overcome leading to higher wetted area which subsequently contributes to improving mass transfer.

Process analysis Cont.

b. Effect of MEA concentration on CO_2 capture level

Process input condition for this case is same as Case 1 and Case 3 above with rotor speed changed and kept constant at 1000 rpm.



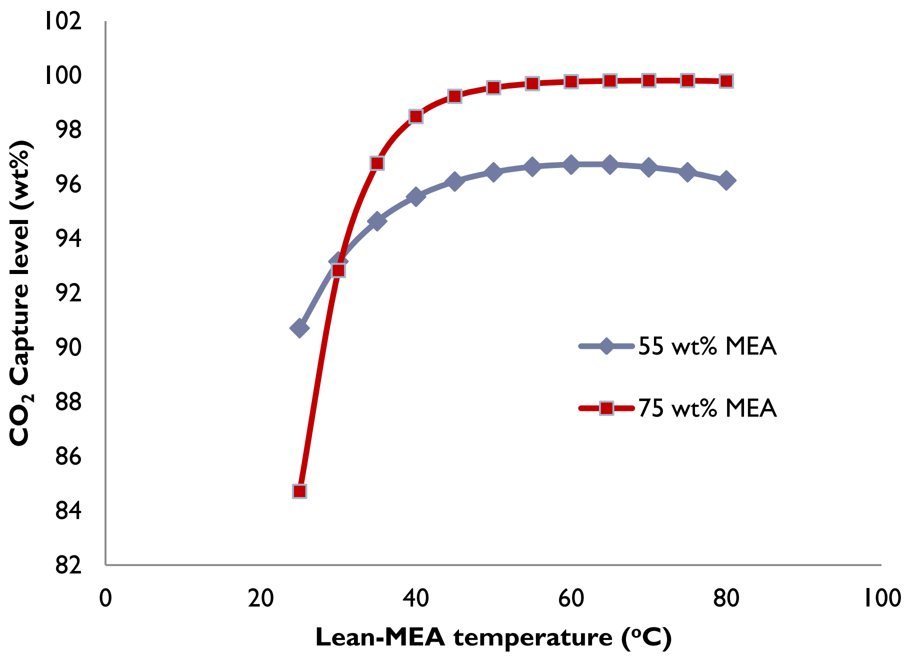
Results & Discussions

- Increasing MEA concentration will means increase in hydroxide ions per unit volume which will results in capture of more CO_2 at constant liquid and gas flow rate.
- Reaction rate will increase with increase in concentration.
- Increase in Lean-MEA temperature results in increase in CO_2 capture level since reaction rate increase with temperature.

Process Analysis Cont.

c. Effect of Lean-MEA Temperature on CO_2 Capture Level

Process conditions same Case 1 and Case 3. The lean MEA temperature is varied from 25 ^oC to 80 ^oC at 55 wt% and 75 wt% lean MEA concentrations.



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Results & Discussions

The improvement of RPB performance as temperature increases can be associated to:

a. Decrease in viscosity of the MEA as temperature increases as stated by Lewis and Whitman (1924) that kinematic viscosity of film fluid is the controlling factor in determining its film thickness.

b. This phenomena leads to improvement in diffusion rate of CO_2 into lean MEA solvent.

c. Increasing lean solvent temperature leads to faster reaction rate.

Process Analysis Cont.

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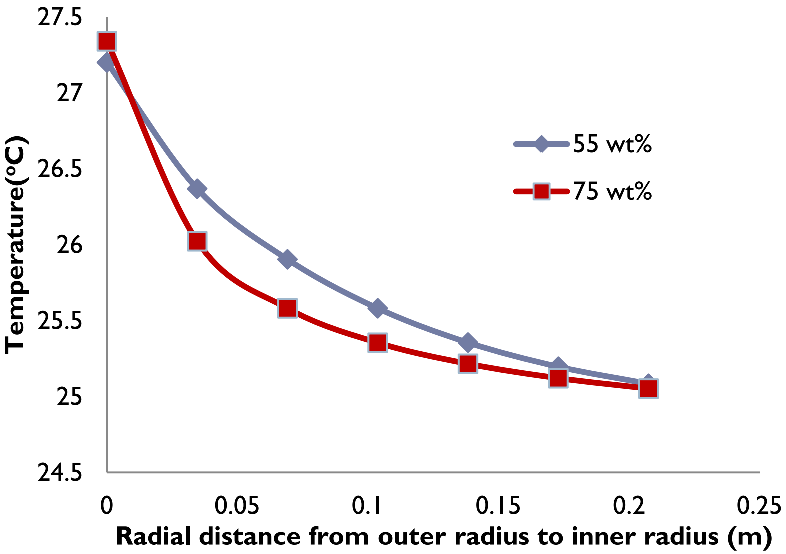
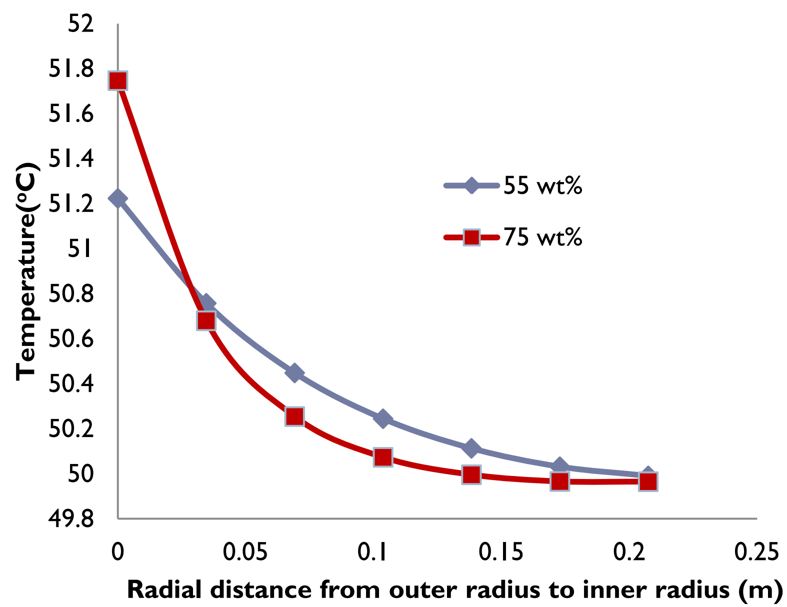
d. Temperature profile in RPB absorber

Process conditions same as Case 1 and Case 3. The flue gas temperature was maintained at 47 °C. The temperature profile is studied at two lean MEA temperatures of 25 °C and 50 °C.



Liquid temperature profile in RPB absorber at 25 °C lean MEA temperature



Liquid temperature profile in RPB absorber 50 °C lean MEA temperature

Results & Discussions

Temperature bulge problem is not pronounced in RPB as can be seen in the figures shown. The reason for this could be

1. Because of the high gravity, most of the flow in RPB is droplet and thin film flow. This makes it difficult for liquid build-up in the packing which may result in energy build-up.
2. High degree of mixing and little residence time of the solvent in column makes it difficult to have energy build-up.

CONCLUSIONS

- New simulation procedure was successfully developed.
- Model validation was performed and the model outputs are in good agreement with experimental results.
- The effect of Lean-MEA temperature, Rotor speed and MEA concentration on CO_2 capture level were studied.
- Temperature profile of the RPB were studied at two lean MEA temperatures.

THANK

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