Optimisation of post combustion carbon dioxide capture by use of a facilitated carrier membrane

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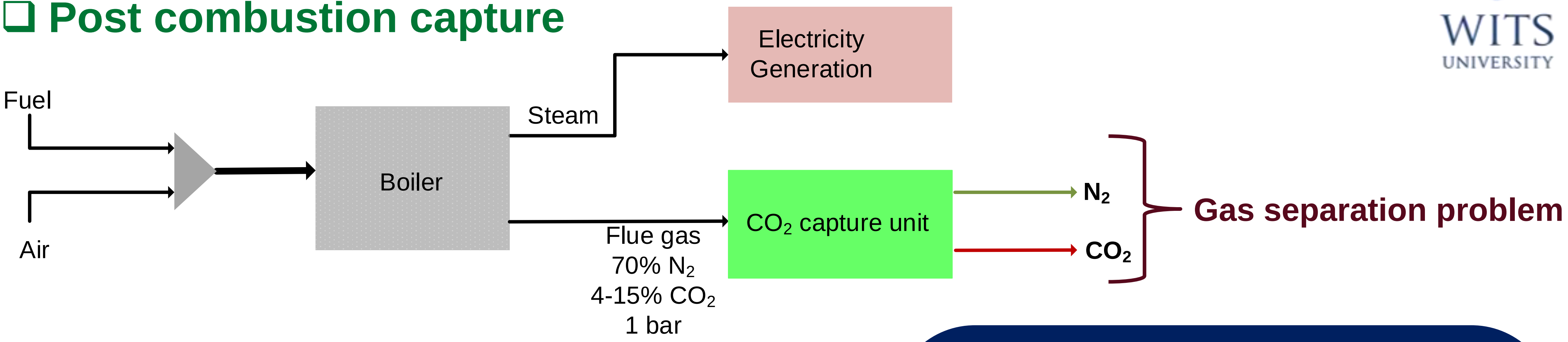
Outline

- Background and Motivation
- Problem Statement
- Model Development
- Case Study
- Conclusion

Background and Motivation

❑ Post combustion capture



Fuel

Air

Boiler

Steam

Electricity Generation

Flue gas
70% N_2
4-15% CO_2
1 bar

CO_2 capture unit

N_2

CO_2

Gas separation problem

- ❖ **Draw backs of chemical absorption by amines**
  - ➢ Huge energy demand during regeneration of amine
  - ➢ Corrosive to equipment
  - ➢ The solvent degrades in the presence of common flue gas
- ❖ **Other technologies**
  - ➢ Adsorbents
  - ➢ **Membranes**

Membranes: Advantages

- ❖ Less energy intensive
- ❖ No moving parts hence low maintenance
- ❖ Relatively more environmentally friendly

Membranes: Challenges

- ➢ Driving force

Low CO_2 concentration in flue gas, low feed pressure

- ➢ Need for membranes with high CO2 permeance
- ➢ And selectivity

Background and Motivation

❑Fixed site carrier facilitated membrane

- Transport of CO_2 across the membrane is due to diffusion and the reversible reaction of CO_2 and NH_2 groups in the presence of H_2O.
- FSC membranes enhanced permeance and increased CO_2 selectivity
- Therefore results in lower cost of CO_2 capture

❑FSC membrane application considerations

- Permeance highly dependent on relative humidity
- Water vapour as sweep is suitable
- Water highly permeable

Background and Motivation

	Hussain & Hagg 2010	**He & Hagg (2014)**	**He et al., (2015)**	**Current Study**
Process flow	Predetermined	Predetermined	Predetermined	Superstructure based model
Membrane stages	2	2	2	Multi
Components	4	4	2	4
Pressure ratio	fixed	fixed	fixed	Variable
Relative humidity	-	fixed	-	variable
Recycle stream	-	-	-	✓
Permeate pressure generation	Vacuum & sweep	vacuum	vacuum	Vacuum & sweep gas
CO_2/H_2O selectivity	4.4e8	1	-	1

Aim & Objectives

❑ Aim

- ❖ To develop a mathematical model for the optimal design of FSC process flow system minimising the total annualized cost in order to further reduce the cost of CO_2 capture by FSC membrane.

❑ Objectives

- ❖ To develop a comprehensive FSC superstructure
- ❖ To determine the effect of varying pressure ratio on the total cost of CO_2 capture
- ❖ To investigate the effect of permeate pressure generation by vacuum and, or sweep gas
- ❖ The feasibility of this proposed system is evaluated by optimizing the process based on the minimum total annualised cost of capturing CO_2.

Problem Statement

- **Given:**
  - Flue gas of known flowrate, components, temperature and pressure
  - Desired permeate purity and desired capture ratio
  - Permeance and selectivity of the membrane
- **Determine:**
  - The membrane process system that minimises the total annualised costs for the carbon capture for target separation factor.
  - The optimum operating and design conditions of the membrane units:
    - flowrate of streams,
    - area of the membrane,
    - permeate and retentate pressure,
    - Relative humidity
    - sweep gas flow rate and
    - compressor and vacuum pumps power consumption.

Model Development

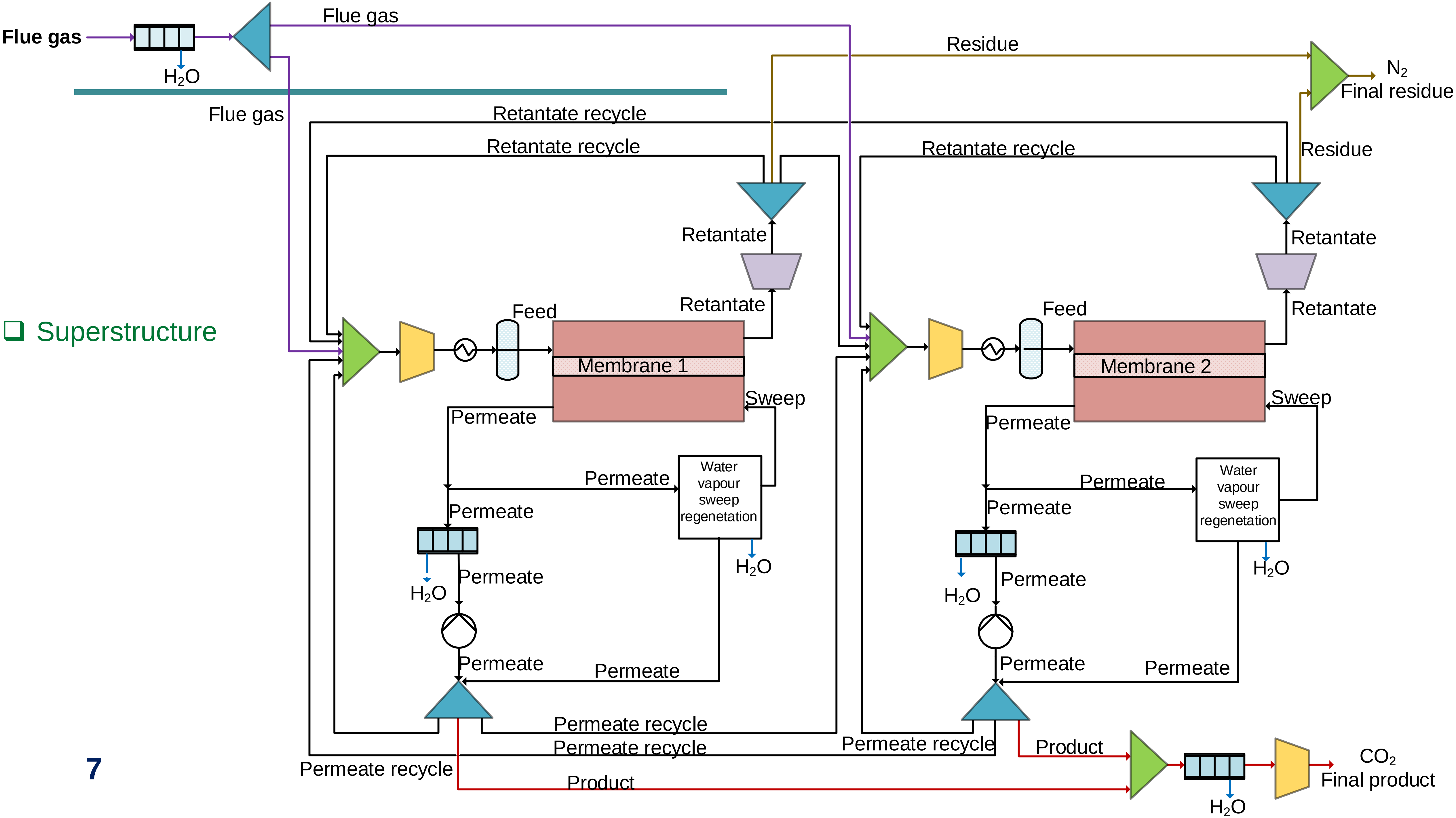
❑ Major assumptions

- ❖ Concentration polarisation on the membrane is negligible
- ❖ The pressure drop along the membrane is negligible.
- ❖ The overall permeance of component is not affected by pressure nor by concentration variation
- ❖ Counter-current flow is considered.

❑ Constraints

- ❖ Gas permeation
- ❖ Mass balances
- ❖ Energy consumption of compressors, vacuum pumps and energy recovered by expanders
- ❖ Heat transfer area
- ❖ Separation targets- capture ratio and product purity
- ❖ Objective function

❑ Superstructure



Model Development

❑ Major mass balance constraints

- ❖ Feed mixer

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- ❖ Bubble column

[illegible]

- ❖ Balance on permeate condenser / sweep gas recovery

[illegible]

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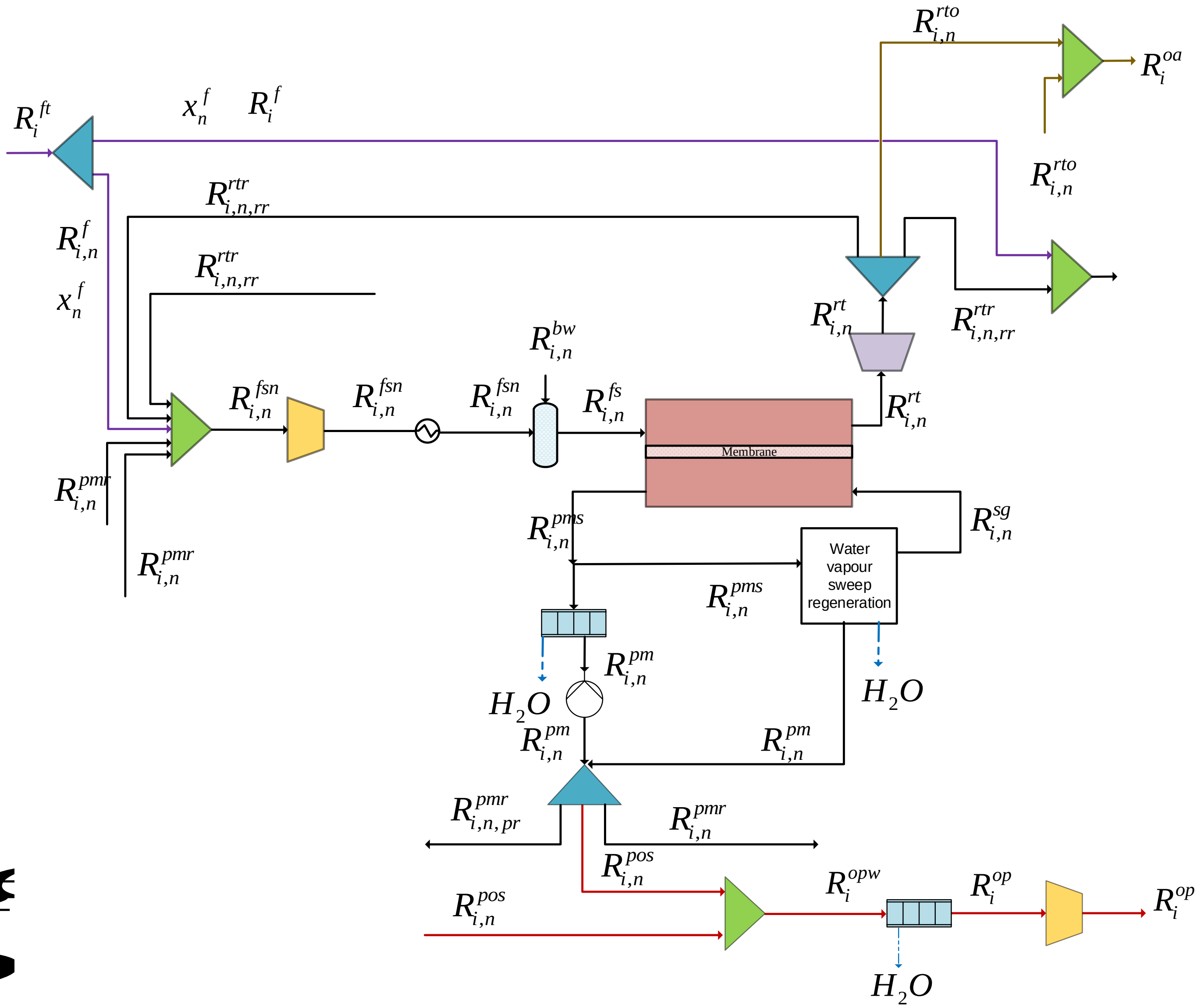

Model Development

- ❑ Permeate pressure range for vacuum
- ❑ Allowable membrane area
- ❑ Sweep gas flow rate

- ❑ Permeate pressure range for sweep
- ❑ Relative humidity
- ❑ Separation targets- capture ratio and product purity
  - ❖ Target capture ratio
  - ❖ Desired purity

Model Development

- ❑ Objective function
  - ❖ Cost of electricity
  - ❖ Cost of labour

    } OPEX

  - ❖ Purchase and installation cost of operational units } CAPEX

[illegible]

Case Study

- ❑ Case study (He & Hägg, (2014))
- ❖ Techno economic feasibility study of CC by FSC membrane
- ❖ Predetermined two membrane stage process flow
- ❖ Cascading process flow, no recycle streams

Parameter	Value
CO_2/N_2 selectivity	135
CO_2/H_2O selectivity	1
CO_2/O_2 selectivity	30

Parameter		Value
Flue gas flow rate (kmol/s)		26.6111
Flue gas temperature (°C)		50
Mole fractions of components	CO_2	0.137
	N_2	0.7289
	H_2O,	0.0365
	O_2	0.0973
Membrane Temperature (°C)		35
Membrane permeance of CO_2 (kmol/m^2bar.s)		2.48E-05
Permeate pressure (bar)		0.25
Retentate pressure (bar)		2

Results and Discussions

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Process flow	Predetermined	Model determined	Model determined	Model determined
Membrane stages	2	3	3	3
Pressure ratio	Parameter	Variable	Variable	Variable
Relative humidity	Parameter	variable	Variable	variable
Permeate pressure	Vacuum	Vacuum	Combination	Sweep gas
Recycle streams	-	✓	✓	✓

Results & Discussion

Scenario	1	2	3	4
Number of mem stages	2	3	3	3
Capture ratio (%)	90	90	90	90
CO_2 product purity (%)	95	95	95	95
TAC (M $)	174,7	144.1	141.8	144.4
Operating costs, (M $)	46.5	44.8	50.3	52.6
Capital costs (M $)	128,2	99.6	91.5	91.7
Total membrane (Mm^2)	4.05	1.75	1.83	2.04
Total net power (MW)	154,6	149.0	167.2	176.1
Total power (MW)	208	224	217.5	223.7
Power recovered by expander (MW)	53.4	75.1	76.9	47.6

Scenario	1	2	3	4
Specific membrane area ($m^2/tCO_2.h$)	7708.1	3348.2	3526.8	3911.0
Heat transfer area (m^2)	78605.9	112319.2	67405.9	34932.7
CO_2 capture rate (ton/h)	521	521	521.3	521.3
Specific power consumption (kWh /ton)	296	286	321	292
Specific energy (GJ/tCO_2)	1.065	1.03	1.15	1.22
TLC ($\$/tCO_2$)	44.7	36.8	36.3	36.9
% saving on TLC	**-**	**17.6**	**18.7**	**17.4**

Results & Discussion

❑ Conclusion

- ❖ Integration and optimisation will help in making the CCS by FSC membranes more economical
- ❖ Combination of sweep and vacuum give optimum flow
- ❖ Membrane area decrease by 56.7%
- ❖ Cost of capture is reduced by 17%.

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Thank you

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