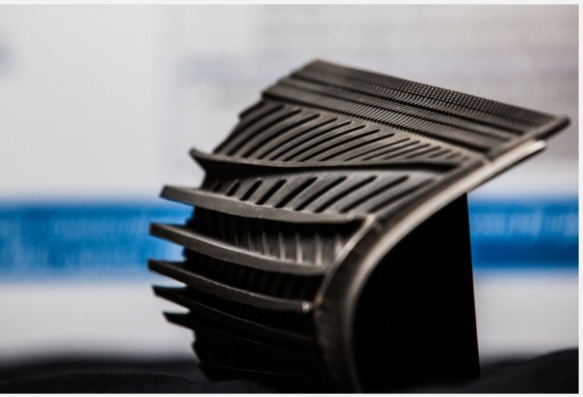
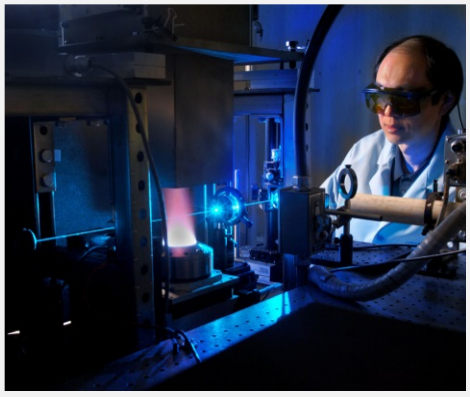
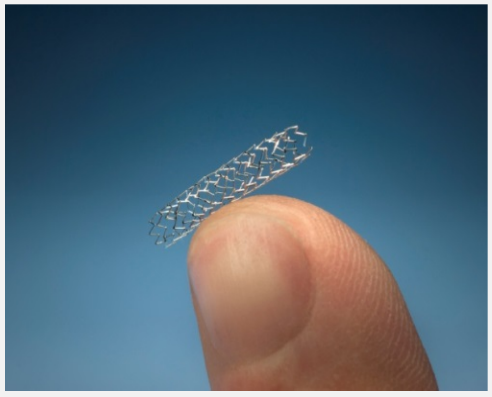
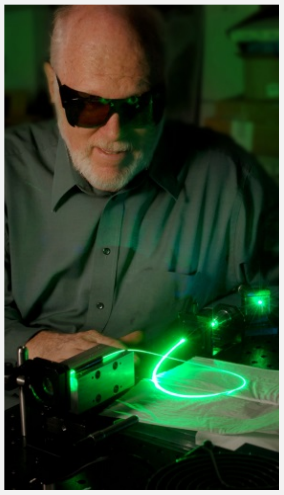
Driving Innovation ♦ Delivering Results


Simulation and Evaluation of Heat Recovery Exchangers for Solid Sorbent Carbon Capture Systems

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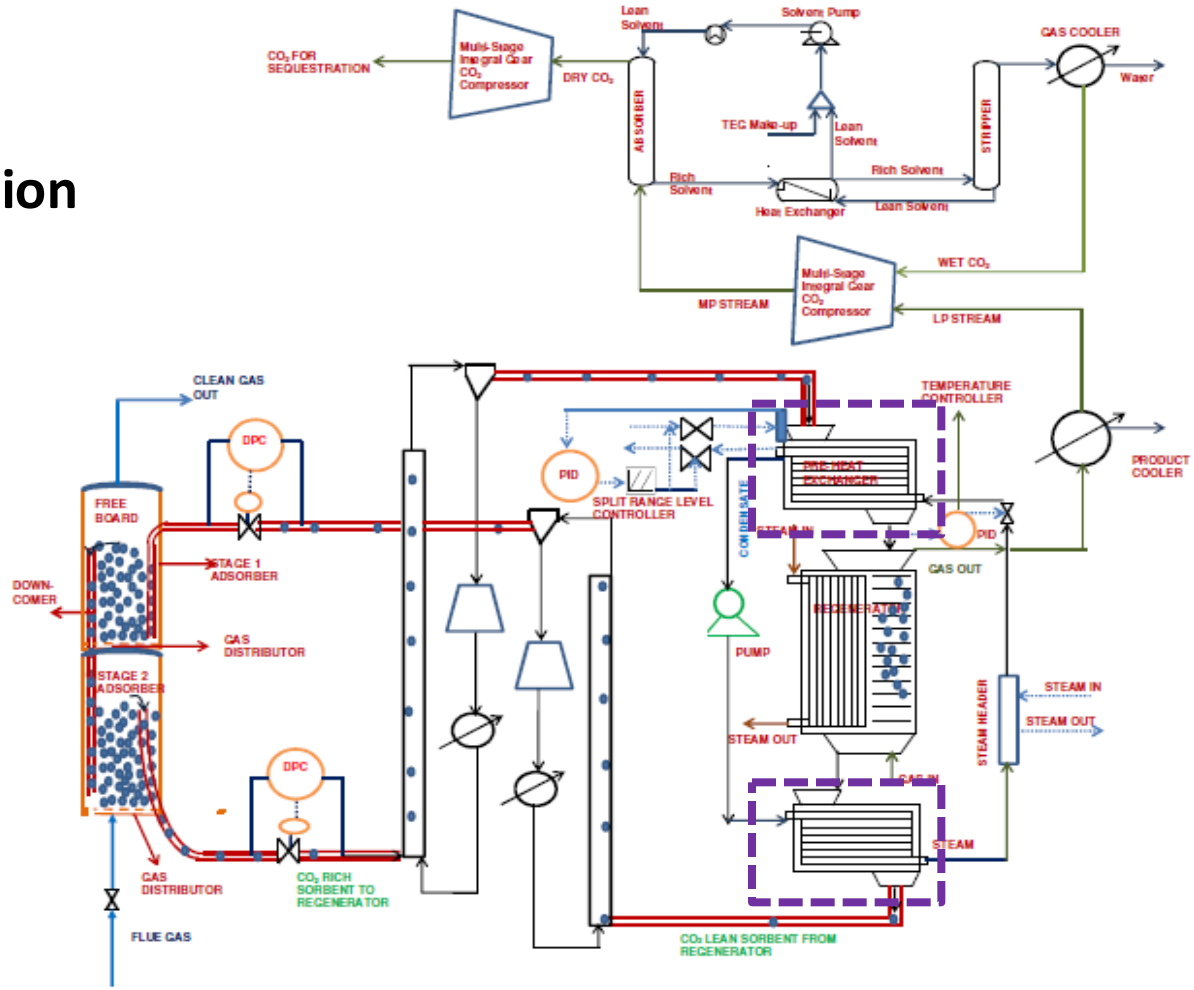
  - Solid Sorbent CO2 capture process
- **Motivation**
- **Heat recovery system**
- **Model development**
- **Design specification**
- **Area requirement**
- **Cost implication**
- **Conclusion**

Solid Sorbent CO_2 Capture Processes

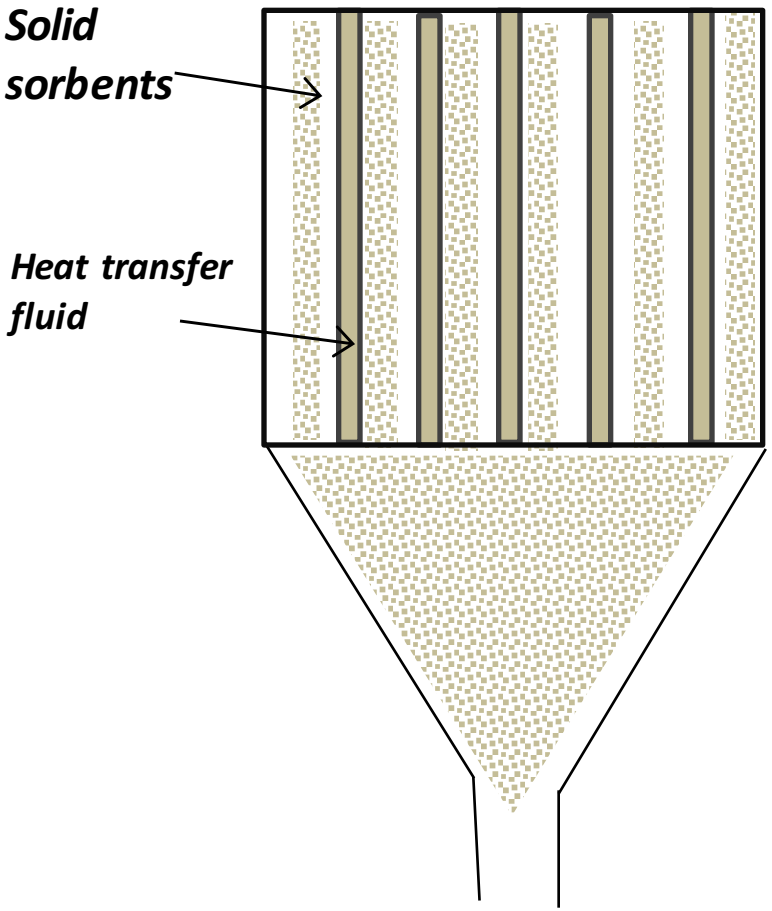
- Alternative to solvent systems
- Significant energy for regeneration
- Heat integration important to minimize operating cost



Motivation

- **Reasons why a model is needed**
  - Lack of accurate models
  - Evaluation of different configurations (co-current, counter-current, etc.)
  - Evaluation of feasibility of overall capture process
  - Needed for accurate estimate of operating and capital cost

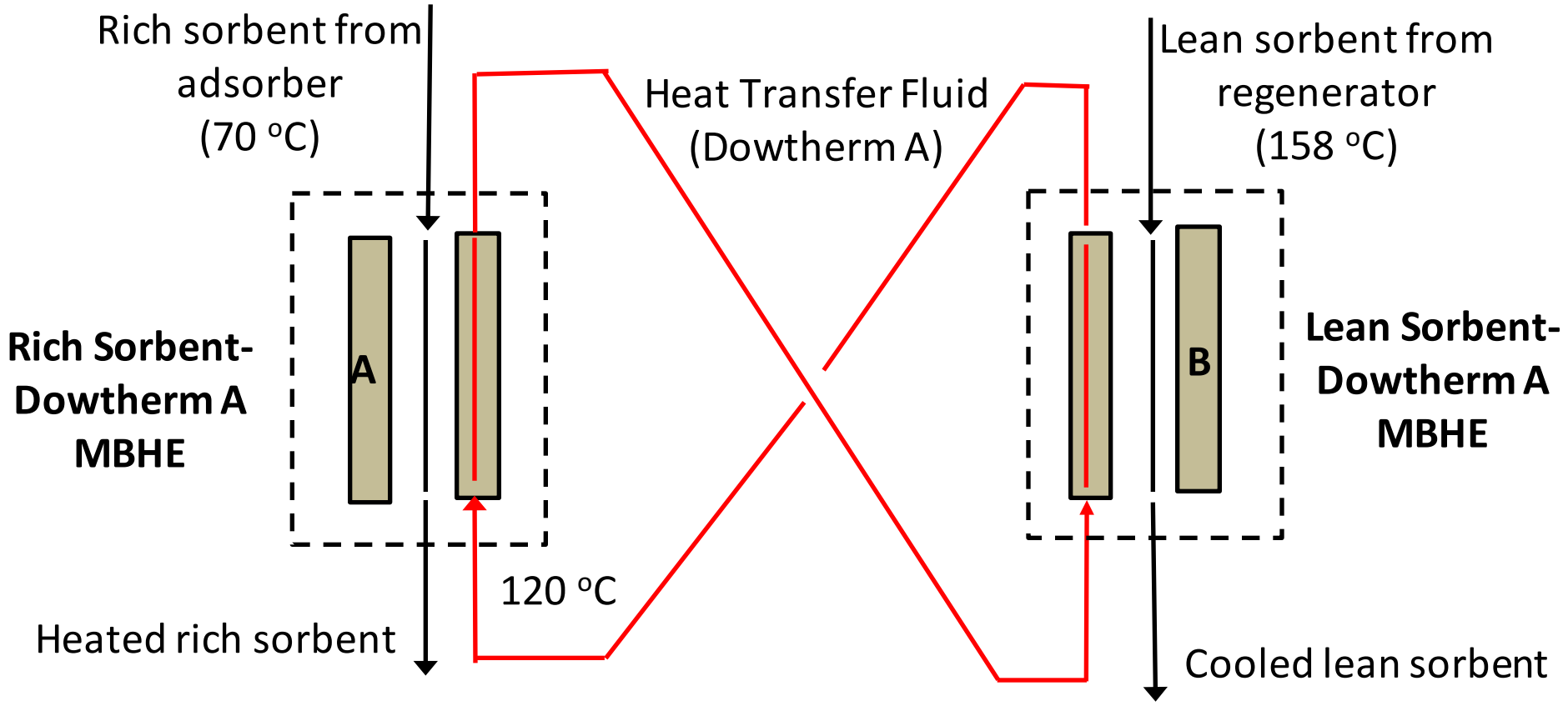
MOVING BED HEAT EXCHANGER



Schematic diagram of plate heat exchanger

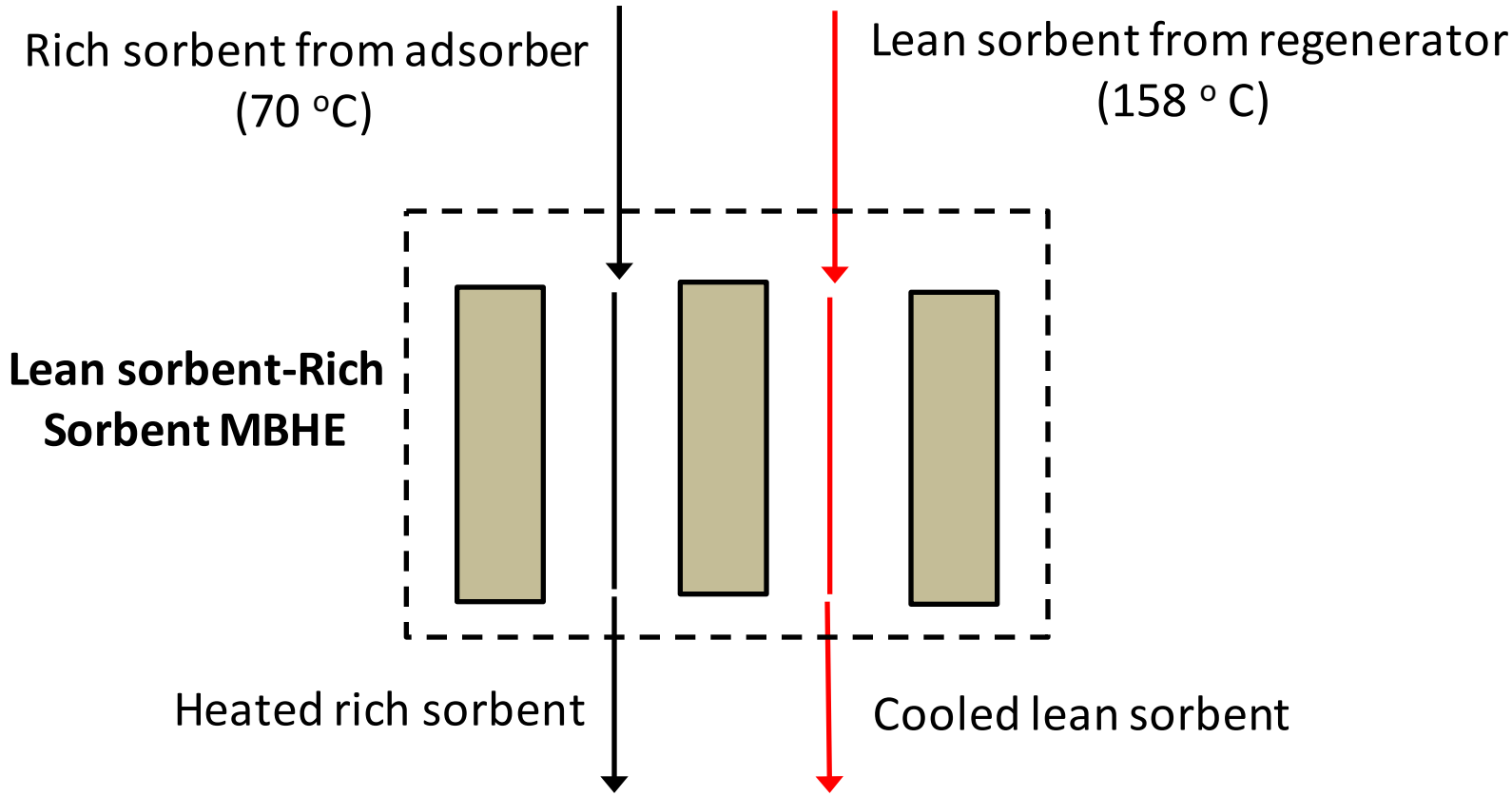
- **Moving bed heat exchangers (MBHE) are widely used to heat or cool solids**
- **Solids move downwards by gravity between the plates.**
- **Mathematical models represent the heat transfer mechanism.**
- **Two types of heat recovery systems considered**

HEAT RECOVERY SYSTEM: COUNTER-CURRENT



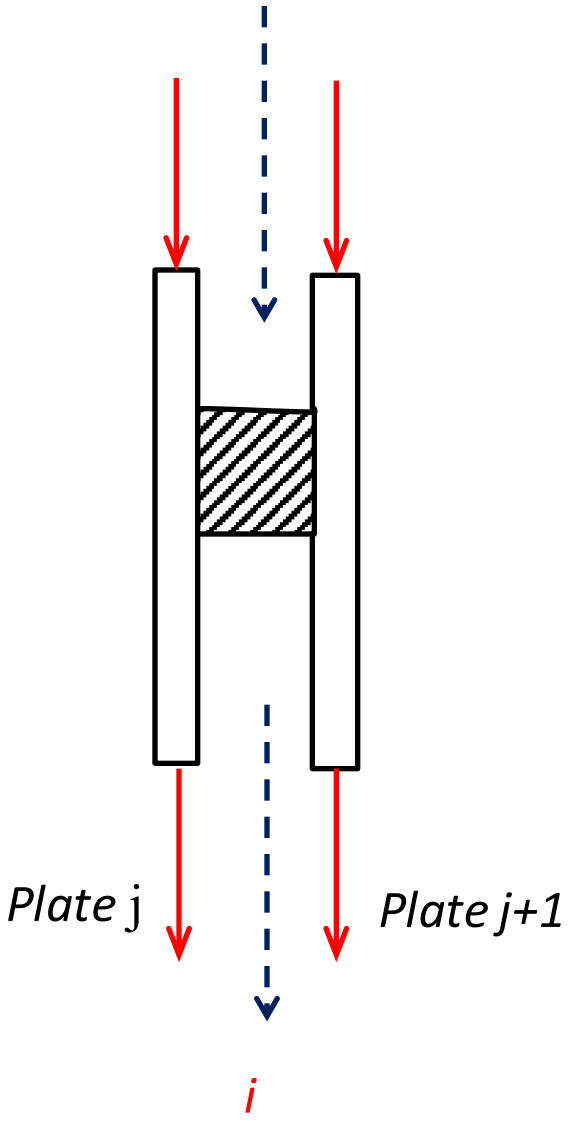
Exchange of heat between rich sorbent and lean sorbent via intermediate heat transfer fluid

HEAT RECOVERY SYSTEM: CO-CURRENT



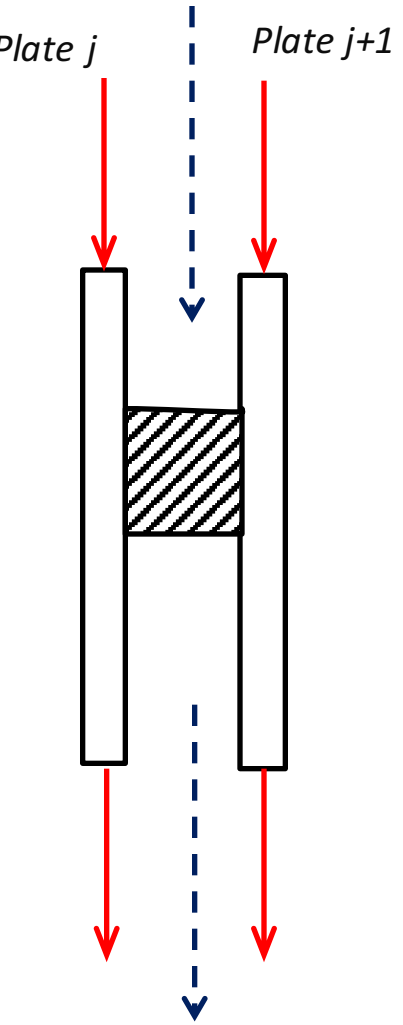
Exchange of heat between rich sorbent and lean sorbent via the plate of moving bed heat exchanger

MODEL DEVELOPMENT: ASSUMPTIONS



- Heat loss to the environment is negligible.
- Flow rate profile is uniform within the channel and plate.
- Overall heat transfer coefficient is calculated using the fluid and plate properties.
- Plug flow is assumed in each channel and hollow plate.
- No axial gas or solid dispersion

MODEL DEVELOPMENT: ENERGY BALANCE



Sorbent stream between plate j and plate j+1:

$$\rho_{s_i} A_i \left(\frac{\partial H_{s_i}}{\partial t}\right) = -F_s \frac{\partial H_{s_i}}{\partial z} + U_i A_i \left(T_{h_i} - T_{s_i}\right) + h_{gs_i} A_i \left(T_{s_i} - T_{g_i}\right) + \sum r_i C_{p_i} \left(T_{g_i} - T_{s_i}\right)$$

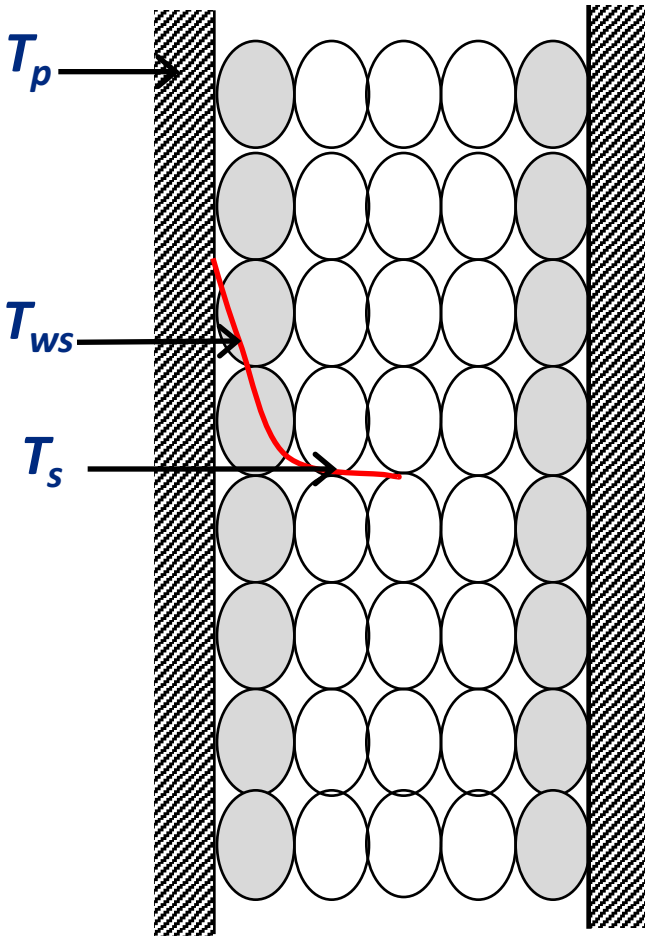
Gas between plate j and plate j+1:

$$\rho_{g_i} A_i \left(\frac{\partial H_{g_i}}{\partial t}\right) = -F_g \frac{\partial H_{s_i}}{\partial z} + h_{gs_i} A_i \left(T_{s_i} - T_{g_i}\right) + \sum r_i C_{p_i} \left(T_{g_i} - T_{s_i}\right)$$

Heating or cooling medium in plate j :

$$\rho_{h_i} A_i \left(\frac{\partial H_{h_i}}{\partial t}\right) = -F_h \frac{\partial H_{h_i}}{\partial z} + U_i A_i \left(T_{s_i} - T_{h_i}\right)$$

MODEL DEVELOPMENT: HEAT TRANSFER



Heat transfer to bulk solid bed

Overall heat coefficient:

$$\frac{1}{U} = \frac{1}{h_h} + \frac{P_t}{k_{p_j}} + \frac{1}{h_{ws}} + \frac{1}{h_b}$$

Heat transfer coefficient between the wall and first sorbent layer (Schlunder, 1984):

$$h_{ws_i} = \tau_w h_{wp} + (1 - \tau_w) \frac{2\,\lambda_G / d_p}{\sqrt{2} + 2\left(l_G + \mu_p\right)/d_p} + h_{WP,rad}$$

Penetration coefficient can be obtained from Fourier's differential equation(Schlunder, 1984)

$$h_{b_i} = 2\sqrt{\frac{\rho_s C_{p_s} \lambda_s}{\pi t_c}}$$

DESIGN SPECIFICATIONS

$F_{rich} = 600{,}000$ kg/hr

$T_{rich} = 70$ °C

$w_{Bic} = 0.00135$ mol/kg

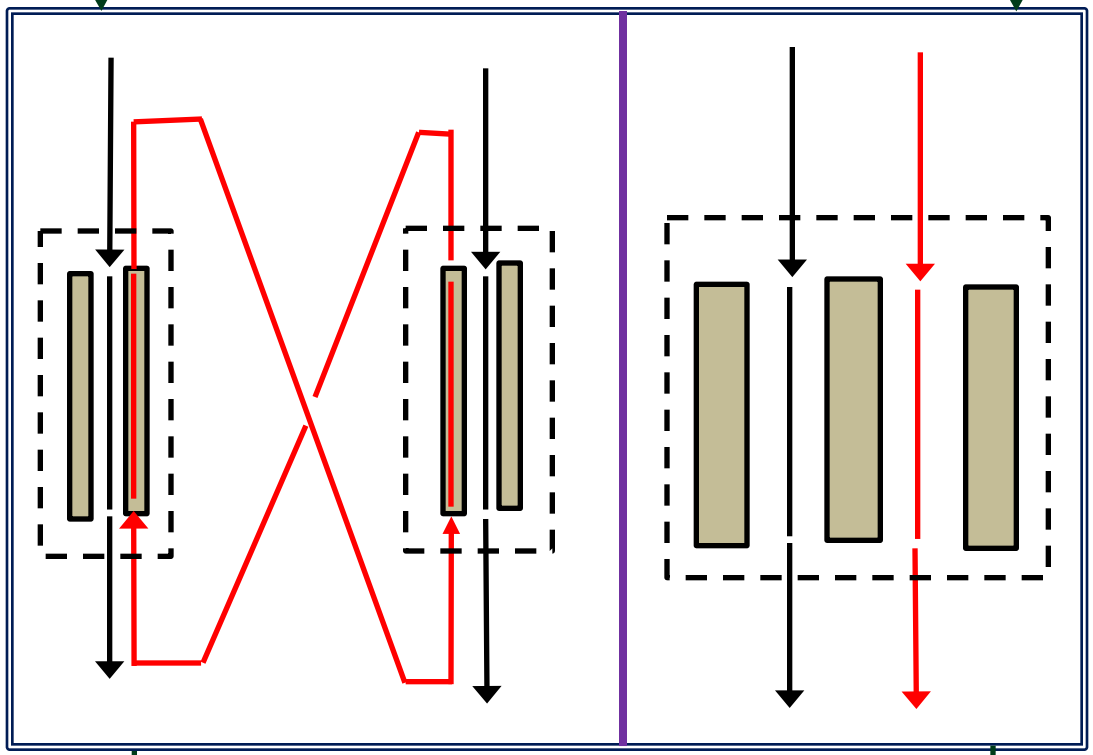
$w_{Car} = 1.995$ mol/kg

$w_{H_2O} = 0.401$mol/kg

$x_{CO_2} = 0.02$ kmol/kmol

$x_{N_2} = 0.78$ kmol/kmol

$x_{H_2O} = 0.2$ kmol/kmol



$F_{lean} = 600{,}000$ kg/hr

$T_{lean} = 158$ °C

$w_{Bic} = 0.00135$ mol/kg

$w_{Car} = 0.557$ mol/kg

$w_{H_2O} = 0.012$ mol/kg

$x_{CO_2} = 0.2$ kmol/kmol

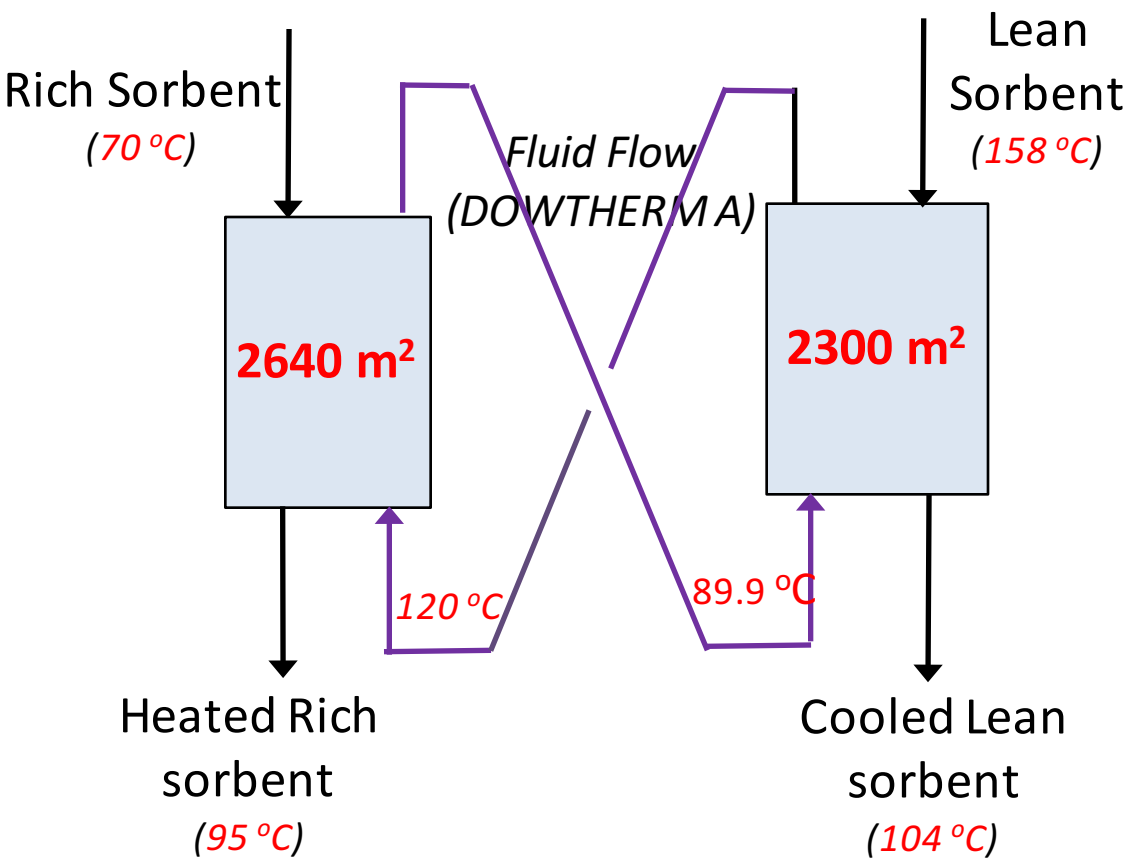
$x_{N_2} = 0.001$ kmol/kmol

$x_{H_2O} = 0.79$ kmol/kmol

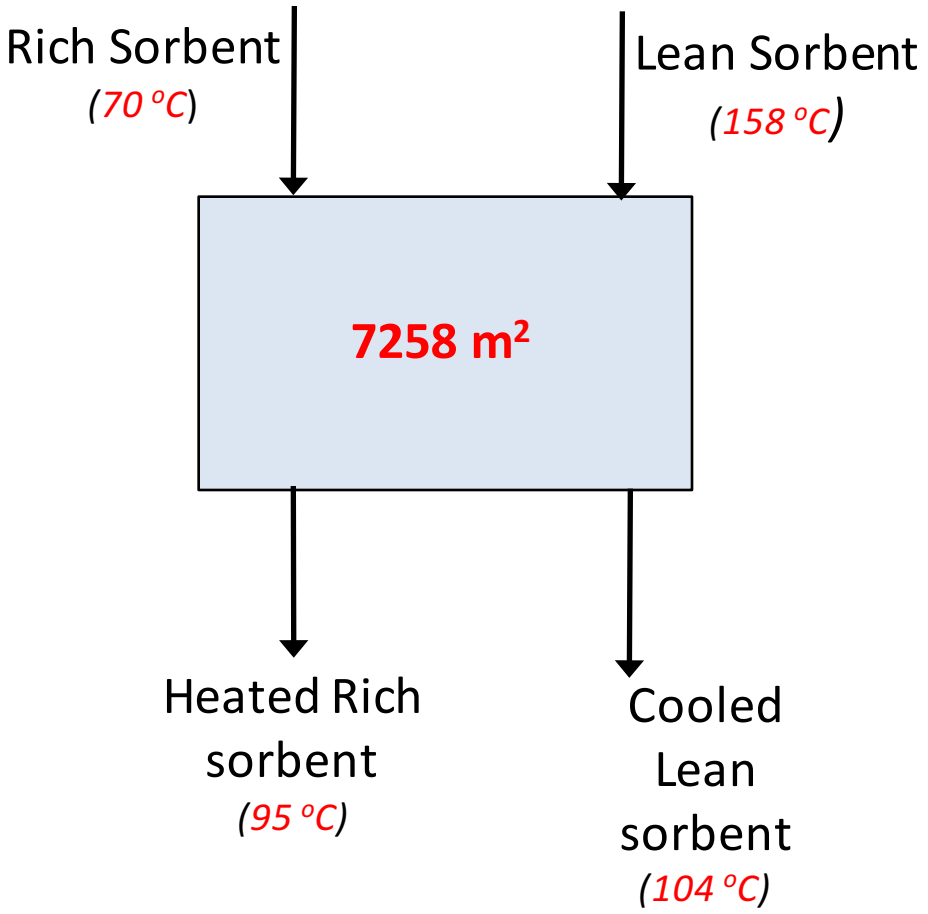
$T_{rich} = 95$ °C

Model development and simulations were undertaken in Aspen Custom Modeler.

AREA REQUIREMENTS FOR DESIGN CASE



Counter-current configuration



Co-current configuration

COST IMPLICATIONS

Key Performance Indicators	Counter-current system *(with intermediate heat transfer fluid)*	Co-current System
Total Area (m^2)	5,000	7,250
Cost of HX		**+35%**
Annual power consumption for pumping heat transfer fluid (MWh/year)	340	0
Annualized cost (includes heat transfer fluid, pump)		**+4%**

CONCLUSIONS

- Mathematical models for moving bed heat exchanger (MBHE) were developed.
- Heat recovery system between adsorber and regenerator is a feasible approach to reduce energy penalty in carbon capture process
- Counter-current heat recovery system with intermediate heat transfer fluid circulating between the MBHEs proves to be best configuration based on the estimated cost.

QUESTIONS?

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