MODELLING AND SIMULATION OF INTENSIFIED REGENERATOR FOR POST-COMBUSTION CO₂ CAPTURE

By

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OUTLINE

- Background
- What is process intensification
- Motivations
- Aim and Objectives
- Rotating Packed Bed Stripper
- Methodology
- Model Validation
- Process analysis
- Conclusion and future work
Micromixing controlled processes

Nanoparticles Syntheses

Polymerization

Fast reaction

Mass transfer limited processes

CO₂

H₂S/CO₂

SO₂

Micromixing and mass transfer controlled process

A desulfurization site (Qian et al., 2012)
**MOTIVATION**

**BERR (2006)**
500 MWe supercritical coal fired power plant
46% efficiency  8,000 tonnes of CO$_2$ per day.

**Lawal et al. (2012)**
Size of regenerator required will be 17m in packing height and 9m in diameter

**Kothandaraman et al. (2009)**
Majority (approximately 62%) of the energy that was consumed during the CO$_2$ capture process was required for the regeneration of absorbent
AIM AND OBJECTIVES

To develop a model of intensified post-combustion carbon capture (PCC) process for capture of $\text{CO}_2$ from a fossil fuel-fired power plant

- Modelling and simulation of intensified absorber
- Modelling and simulation of intensified regenerator
- Modelling and simulation of intensified heat exchanger
- Modelling and simulation of intensified PCC process
Schematic diagram of a rotating packed bed regenerator
METHODOLOGY

Aspen Plus® Rate Based Model

Writing the user defined correlations in Visual FORTRAN Compiler

Linking Visual FORTRAN compiler with Aspen Plus model

Running the simulation

Model Validation

Process Analysis
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquid phase mass transfer coefficient</td>
<td>Chen <em>et al.</em> (2006)</td>
</tr>
<tr>
<td>Gas phase mass transfer coefficient</td>
<td>Chen, (2011)</td>
</tr>
<tr>
<td>Effective interfacial area</td>
<td>Luo <em>et al.</em> (2012)</td>
</tr>
<tr>
<td>Liquid hold-up</td>
<td>Burns <em>et al.</em> (2000)</td>
</tr>
<tr>
<td>Pressure drop</td>
<td>Llerena-Chavez and Larachi (2009)</td>
</tr>
<tr>
<td>Heat transfer coefficient</td>
<td>Chilton and Colburn analogy</td>
</tr>
<tr>
<td>Parameters for equilibrium constant</td>
<td>Austgen <em>et al.</em> 1989</td>
</tr>
<tr>
<td>Kinetic parameters</td>
<td>Aspen, 2008</td>
</tr>
</tbody>
</table>
Model validation
## MODEL VALIDATION

### Input process conditions (Jassim et al., 2007)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Run 1</th>
<th>Run 2</th>
<th>Run 3</th>
<th>Run 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotor speed (RPM)</td>
<td>800</td>
<td>800</td>
<td>800</td>
<td>800</td>
</tr>
<tr>
<td>Rich-MEA temperature (°C)</td>
<td>67.1</td>
<td>68</td>
<td>69</td>
<td>70</td>
</tr>
<tr>
<td>Rich-MEA pressure (atm)</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Boil-up ratio</td>
<td>0.9</td>
<td>0.2</td>
<td>1.0</td>
<td>0.5</td>
</tr>
<tr>
<td>Rich-MEA flow rate (kg/s)</td>
<td>0.2</td>
<td>0.5</td>
<td>0.2</td>
<td>0.4</td>
</tr>
<tr>
<td>Rich-MEA composition (wt %)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H₂O</td>
<td>58.116</td>
<td>54.117</td>
<td>54.013</td>
<td>61.536</td>
</tr>
<tr>
<td>CO₂</td>
<td>8.984</td>
<td>10.383</td>
<td>10.287</td>
<td>7.664</td>
</tr>
<tr>
<td>MEA</td>
<td>32.9</td>
<td>35.5</td>
<td>35.7</td>
<td>30.8</td>
</tr>
</tbody>
</table>
MODEL VALIDATION

The agreement of simulation and experimental $K_{Ga}$

The agreement of simulation and experimental lean–MEA loading
From the graph the error prediction of the model for $K_{Ga}$ is less than 30% and for lean-MEA loading is less than 11%.

The 30% error of the model might be from error in measuring the amount of desorbed CO$_2$ from the experimental study.

Error due to contamination of sample content by atmospheric air and that was unavoidable because it happened very fast (Jassim et al., 2007).

The model has predicted the experimental data reasonably, then the authors decides to carry out process analysis.
Process analysis
It should be noted that the experimental study by Jassim et al. (2007) was done using steam as the stripping agent.

The Authors modify the validated model to include a reboiler and then study the following parameters:

- Regeneration efficiency = \( \left( 1 - \frac{\text{Lean CO}_2 \text{ loading}}{\text{Rich CO}_2 \text{ loading}} \right) \times 100 \)

- Regeneration energy = \( \frac{\text{Reboiler duty}}{\text{Mass of CO}_2 \text{ desorbed}} \)
**Effect of Rich-MEA flow-rate on regeneration efficiency**

**Process input condition**

- Rotor speed = 1000 rpm
- Rich-MEA temp = 82 °C
- Rich-MEA pres. = 1 atm
- Rich-MEA comp. (wt. %)
  - H₂O = 58.116
  - CO₂ = 8.984
  - MEA = 32.900
- Reboiler temp. = 105 °C

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![Graph showing the effect of Rich-MEA flow rate on regeneration efficiency](image-url)
The figure shows a decrease in regeneration efficiency as the rich-MEA solvent flow rate increases.

This is so because of decrease in resident time of the solvent in the regenerator.

Which means less CO₂ will be stripped off from the rich-MEA stream.

The regeneration efficiency reduced by 7.6% as the rich-MEA solvent flow rate increase from 0.4 kg/s to 0.9 kg/s.
Effect of Rich-MEA flow-rate on regeneration energy

Process input condition

Rotor speed = 1000 rpm
Rich-MEA temp = 82 °C
Rich-MEA pres. = 1 atm
Rich-MEA comp. (wt. %)
  \( \text{H}_2\text{O} = 58.116 \)
  \( \text{CO}_2 = 8.984 \)
  MEA = 32.900
Reboiler temp. = 105 °C

Effect of Rich-MEA flow rate on regeneration efficiency
Results & Discussion

- It can be observed from the figure above that the regeneration energy increases with increase in rich-MEA flow rate.

- There is 4.7% percentage increase in the regeneration energy as the rich-MEA solvent flow rate increases from 0.4 kg/s to 0.9 kg/s.

- The reason for the increase in regeneration energy is associated to greater quantity of solvent that will be heated.
Effect of Rotor Speed on regeneration efficiency

**Process input condition**

Rich-MEA flow rate = 0.5 kg/s  
Rich-MEA temp = 82 °C  
Rich-MEA pres. = 1 atm  
Rich-MEA comp. (wt. %)  
  \( \text{H}_2\text{O} = 58.116 \)  
  \( \text{CO}_2 = 8.984 \)  
  \( \text{MEA} = 32.900 \)  
Reboiler temp. = 105 °C  
Rotor speed range from 400rpm to 1200rpm

![Graph showing the effect of rotor speed on regeneration efficiency.]
Higher rotational speed creates smaller liquid droplets and thin films in the packing regions of the bed. This leads to greater areas for mass and heat transfer. Higher speed can also produce the opposite effect on mass and heat transfer by decreasing the contact time. From the figure above we can see that the regeneration efficiency increases with an increase in rotational speed. This is so because more CO\(_2\) will be stripped off from the rich MEA stream.
Effect of Rotor Speed on regeneration energy

Process input condition
Rich-MEA flow rate = 0.5 kg/s
Rich-MEA temp = 82 °C
Rich-MEA pres. = 1 atm
Rich-MEA comp. (wt. %)
  $H_2O = 58.116$
  $CO_2 = 8.984$
  MEA = 32.900
Reboiler temp. = 105 °C
Rotor speed range from 400rpm to 1200rpm
The figure shows that as the rotational speed increases the regeneration energy decreases.

This is true because of the increase in mass and heat transfer as the rotors speed increase since we have more droplet and thin films in the bed.

Also at higher rotational speed the problem of liquid mal-distribution is overcome leading to higher wetted area which subsequently contributes to improving mass transfer.
Conclusion and future task
CONCLUSION

- Model validation was performed and the model outputs are in good agreement with experimental results.
- The effect of rich-MEA flow-rate on regeneration efficiency and energy were studied.
- The effect of rotor speed on regeneration efficiency and regeneration energy were studied.
- Finally it can be said that RPB process has great potential application for thermal regeneration.
FUTURE TASK

- Validation of intensified regenerator process which has a reboiler unit.
- Modelling and simulation of intensified heat exchanger for PCC process
- Modelling and simulation of intensified PCC process
- Scale-up of intensified PCC process
ACKNOWLEDGEMENT

The authors would like to acknowledge financial support from EU FP7 (Ref: PIRSES-GA-2013-612230) and UK Research Councils’ Energy Programme (Ref: NE/H013865/2).
REFERENCES

THANK YOU