PMW Technology

This project is part-funded by

European Union
European Regional Development Fund

University of Chester

Experimental exploration of carbon capture by frosting on a moving bed

David Cann[1], Paul M. Willson[2], Carolina Font-Palma[1]

[1]Department of Chemical Engineering, Faculty of Science and Engineering, Thornton Science Park University of Chester, Chester, CH2 4NU, UK

[2]PMW Technology Limited, High Growth Centre, Thornton Science Park, Chester, CH2 4NU, UK

1. Introduction

- Cryogenic carbon capture is typically a post-combustion process that captures carbon dioxide by cooling flue gases below the sublimation temperature of carbon dioxide to form a frost.
- Cryogenic carbon capture has advantages over chemical absorption due being able to operate at near atmospheric pressure and being effective at separation of gas streams with relatively low CO_2 concentrations.
- Literature review states that freezing of carbon dioxide in a packed bed is feasible. A frost front is created that advances along the bed over time.
- Current methods of cryogenic capture lead to an accumulation of frost in the heat exchanger, the process loses efficiency as it continues to run.
- This method of carbon capture can be used effectively in scenarios where chemical absorption cannot be effectively scaled down.

2. Background

- This proposed method of carbon capture is a post combustion process that utilizes a moving bed of particles .
- Moving the bed in a counter-flow will result in the frost front remaining stationary, avoiding the scenario of the capture column being saturated with frost.
- The cold beads are fed into the capture column to allow carbon dioxide to form frost on the bed. Frosted bed leaving the column is warmed to separate the carbon dioxide, re-cooled and recirculated into the capture column.
- Recirculating the bed material instead of freeze-thaw cycling the heat exchangers results in more efficient heat transfer and less thermal related stresses on the equipment.
- Lack of supporting research means that the implementation of a moving bed into carbon capture requires preliminary experiments.

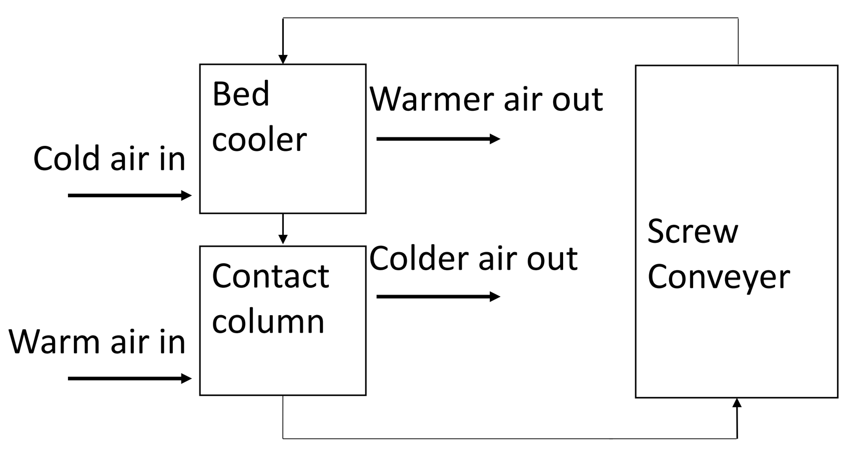
3. Aims and Objectives

- Demonstrate the working principle of heat exchange in a moving bed with a purpose build rig.
- Develop a rig that will desublimate a gas stream containing water vapour to investigate the effect of desublimation on the rig.
- Design and characterise a pilot scale cryogenic rig that will capture CO_2 from a binary gas stream of CO_2 and nitrogen for evaluation of the process.

Experimental Stages

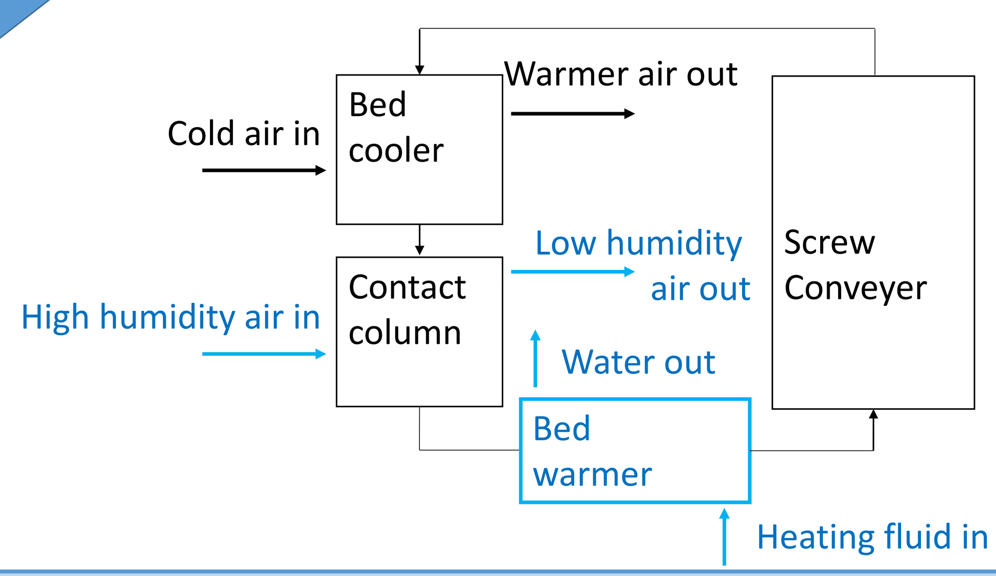
1st generation

- Two conical hoppers in series with a screw conveyor to recirculate.
- Upper hopper has a cold air stream to cool the bed.
- Lower hopper has a warm air stream to warm the bed.
- This design is used to demonstrate that thermal equilibrium is possible.
- No frost is formed in the first generation design.



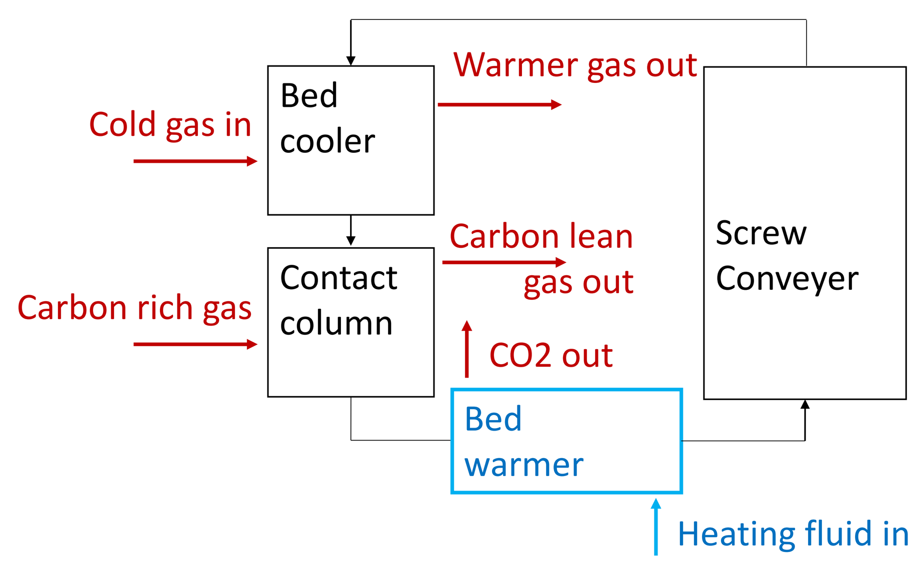
2nd generation

- Warm air is now humid, coming into contact with a cold bed that will dehumidify the air.
- Rig now includes a bed warmer to dry and separate water from the bed. The bed is then recirculated.



3rd generation

- Uses a binary gas or nitrogen and carbon dioxide instead of humid air.
- Operates at near cryogenic conditions.
- This pilot scale design will be integrated into a larger capture scheme including water removal and heat integration at a later stage.



4. Current challenges in design

Energy considerations

The energy requirement to re-cool a fixed packed bed is given as thus

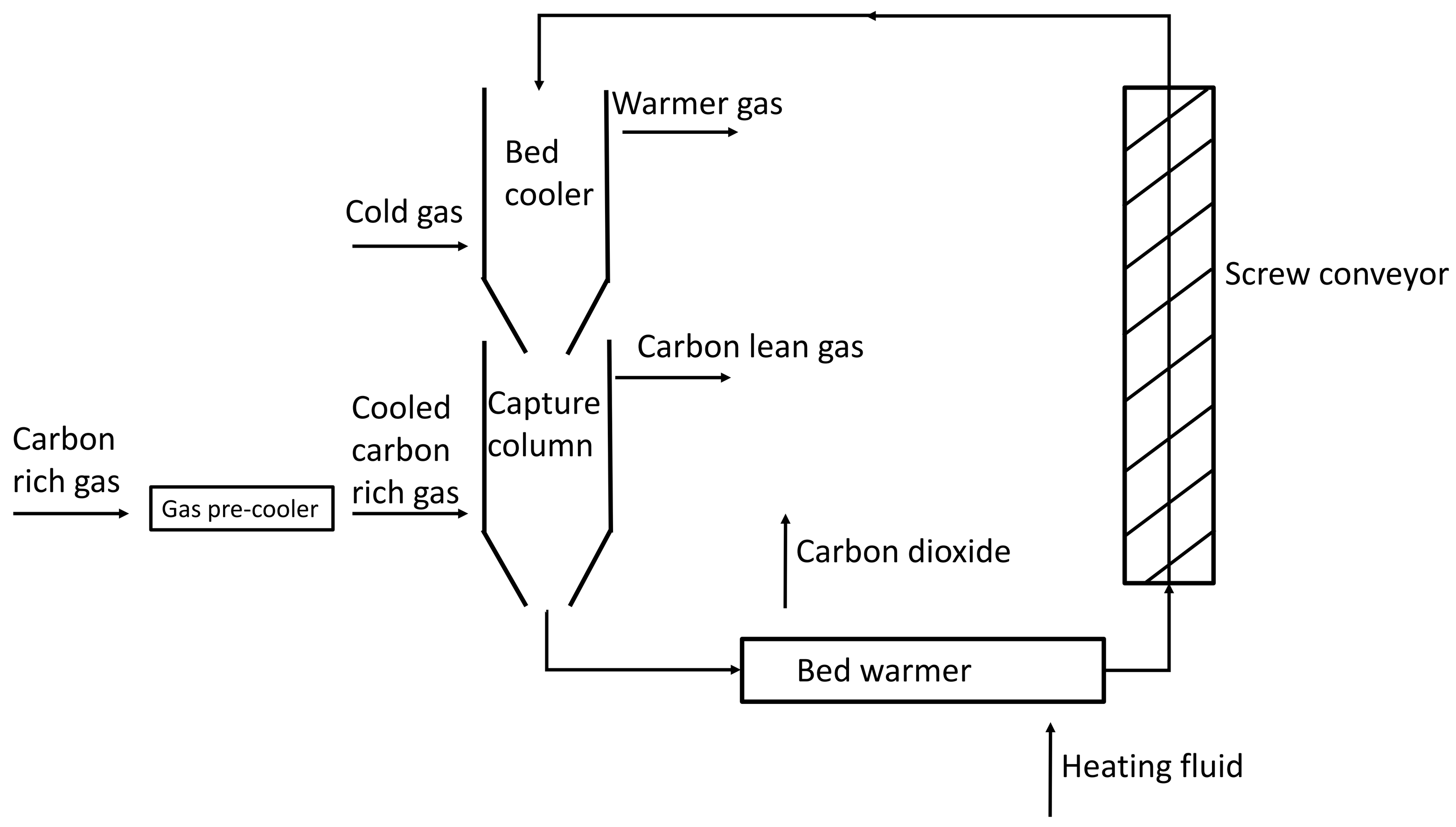
$$Q = \frac{V(1-\varepsilon_g)\rho_s \int_{Ti}^{Tf} C_p dT}{(\Phi_{out} - \Phi_{in})t_{cycle}}$$

(Tuinier, Annaland et al. 2010)

The energy requirement to re-cool a section of moving packed bed is not dependent on time.

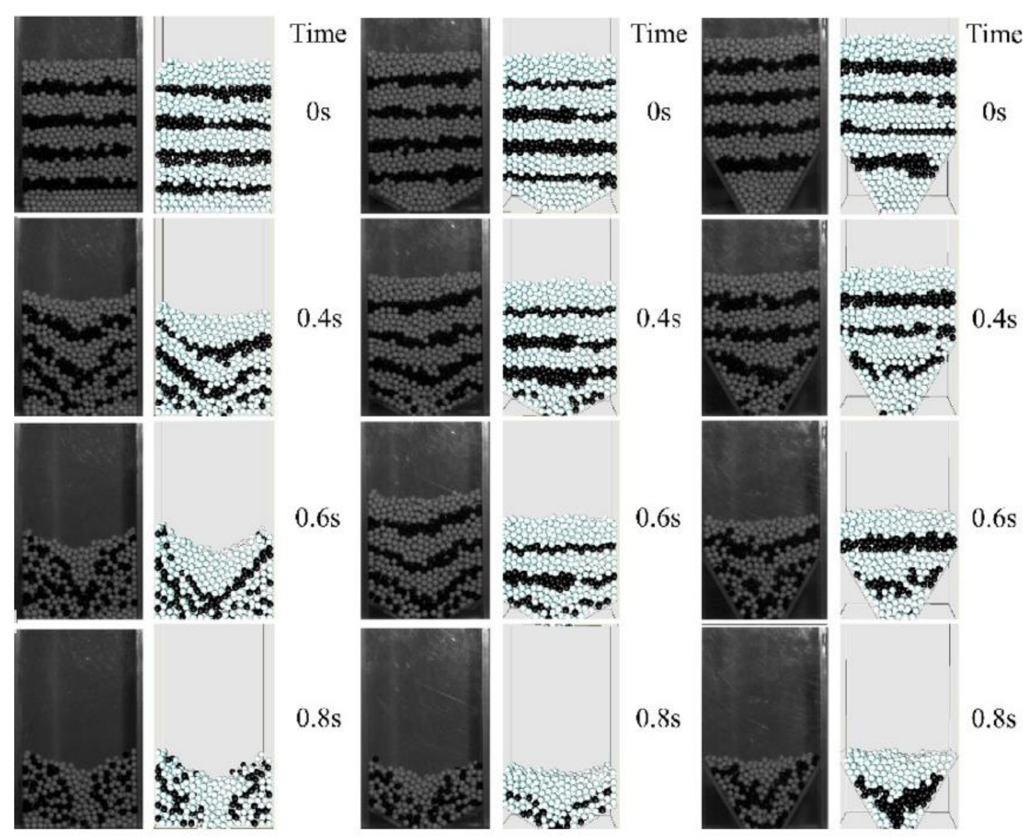
$$Q = \frac{\dot{m} \int_{Ti}^{Tf} C_p dT}{(\Phi_{in} - \Phi_{out})}$$

Diagram of the 3rd generation rig



Understanding solids material flow

The following picture shows the nature of flow in a hopper with angled walls 0˚ 30 ˚ and 60 ˚



(Govender, Wilke et al. 2018)

5. Current work

Research currently indicates that a cryogenic carbon capture process utilizing a moving bed is feasible however there is little supporting research to create a reliable design. Current work includes designing of the 1st generation rig. Sizing the equipment, selecting materials for use and obtaining quotes for specialist equipment.

References

- Abdulmohsin, R. (2013). *Gas dynamics and heat transfer in a packed pebble-bed reactor for the 4th generation nuclear energy.* (doctor of philosophy PhD Thesis), Missouri university of science and technology.
- Tuinier, M. J., Annaland, M. V., Kramer, G. J., & Kuipers, J. A. M. (2010). Cryogenic CO2 capture using dynamically operated packed beds. *Chemical Engineering Science, 65*(1), 114-119. doi:10.1016/j.ces.2009.01.055
- Govender, N., Wilke, D. N., Pizette, P., & Abriak, N. E. (2018). A study of shape non-uniformity and poly-dispersity in hopper discharge of spherical and polyhedral particle systems using the Blaze-DEM GPU code. *Applied Mathematics and Computation, 319*, 318-336. doi:10.1016/j.amc.2017.03.037

Contacts

d.cann@chester.ac.uk , c.fontpalma@chester.ac.uk , Paul@pmwtechnology.co.uk

Acknowledgements

This research is led by PMW Research Limited, in conjunction with the University of Chester. I would like to thank Dr Carolina Font Palma and Paul Willson for their support in this research.

Eco-Innovation Cheshire and Warrington

Project Number: 03R17P01835

This project is led by the University of Chester who have partnered up with Lancaster University to work with local SMEs in the innovation and adoption of Low Carbon Technologies.