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Experimental exploration of CO_2 capture using a cryogenic moving packed bed

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Abstract

This study examines a novel cryogenic post-combustion capture process, based on a moving bed of cold beads to freeze $_{CO2}$ out of a flue gas, and this paper presents the first steps in experimental work. The preliminary experiments included the test of fluidization of bed material, if the flow rate of bed material can be kept constant in and out of the column and the estimation of heat transfer coefficient. The obtained results are encouraging for the running of the rig at cryogenic conditions.
Keywords: CO_2 capture; cryogenic; phase change; separation; moving bed

1. Introduction

Anthropogenic CO_2 emissions and increased concerns over global warming are promoting advances on carbon capture and storage (CCS) methods. The most commonly researched and mature technologies are post-combustion carbon capture, due to as their ability to be retrofitted onto existing power plants. The most mature is amine-based absorption, but it has a large footprint on the required space to operate, resulting in large capital costs. Cryogenic carbon capture has emerged to overcome the limitations posed by amine-based absorption by using overall by using less energy. [1]. Cryogenic carbon capture has been investigated by injecting gas mixtures into pre-cooled packed beds to sufficiently cool $_{CO2}$ to desublimate and frost onto the surface. As CO_2 is desublimated onto the packed bed, a frost front advances along the bed over time [2-4]. This CO_2 capture method requires a recovery step, once the CO_2 has frosted over the available surface area the frosted bed temperature is too high for more desublimation to occur. The packed bed is regenerated by reheating the bed and capturing a purified stream of CO_2. The cyclic nature of capture and regeneration steps make the capture of CO_2 using cryogenic packed beds intermittent, requiring multiple packed beds to create a pseudo-continuous process. Therefore, this paper investigates a moving bed to recirculate the bed material back into the column and run cryogenic capture continuously. An experimental rig utilising a moving bed of cold steel beads has been designed and built at the University of Chester, which has been used to experimentally explore CO_2 capture using a cryogenic moving packed bed.

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Nomenclature

CCS	Carbon capture and storage	LPM	Litres per minute
CCCS	Cryogenic carbon capture and storage	OD	External diameter
ID	Internal diameter		

2. Experimental setup and procedure

The main process uses a column of bed material with gas injectors at the bottom to perform heat transfer between gases and the packed bed. The column has a conical outlet with a diameter of 6mm to allow bed material to flow out of the column where it is collected and fed into a screw conveyor that recirculates the bed material back into the column. Before reaching cryogenic conditions the occurrence of fluidization within the packed bed when gas flows are introduced, if the flow rate of bed material in and out of the column can be kept constant and the value of heat transfer coefficient within the rig were investigated.

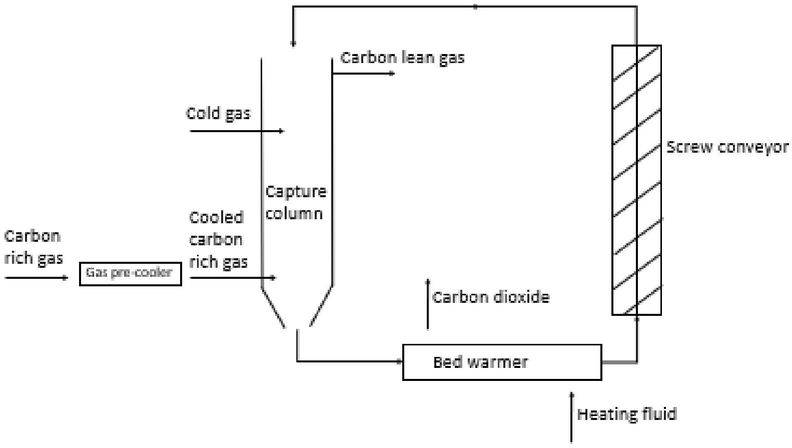

Figure 1. Sketch of proposed design

2.1. Fluidisation rig

The fluidisation rig consisted of a packed bed column constructed out of Perspex (OD=105mm, ID=100mm L=1000mm) with an injector made out of 22mm ID copper pipe with slot openings to deliver compressed air, regulated to 0.3bar, to the packed bed with a pressure gauge attached to the column and in-line flowmeter to measure pressure and flow rate of compressed air into the packed bed. The column is packed with near spherical, stainless steel shot blasting pellets (ρ=7850kg/m^3, d_p=1.4-1.7mm). The experimental procedure was to record the pressure drop that occurred along the stationary packed bed column for varying flow rates of up to 400 LPM and determine if the pressure drop observed matched the theoretical values [5].

2.2. Heat transfer rig

The heat transfer rig uses the same column replacing the single gas injector with three injectors of the same size at the same level. The bed material enters the top of the column using a screw conveyor to transport bulk material. The cooling column is filled with bed material and heated by the air stream at 333K previously heated using a water bath. Heated air is fed to the moving bed and the temperature of the air and bed material recorded with thermocouples. The aim was to determine the heat transfer coefficient between air and the bed material.

3. Results

The results of the pressure drop experiments did not reveal any signs of fluidization occurring in the rig for the gas flow rates used in the experiments. The pressure drop across the packed bed shows that the experimental data does not change drastically from the estimated pressure drop from equations as shown in Figure 2.

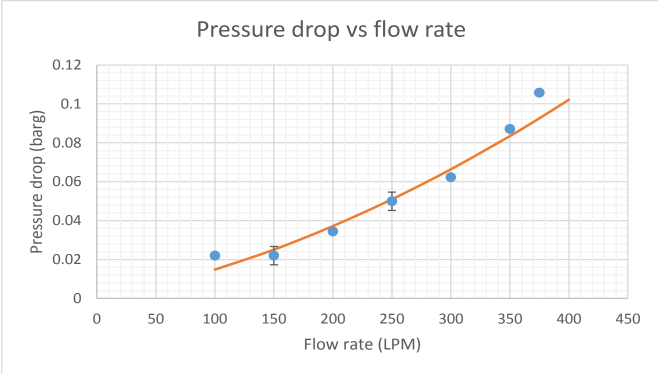

Figure 2. Pressure drop across packed bed column

Temperature measurements from the heat transfer rig were heavily dependent on the height of the bed within the column, the column height would fluctuate slightly over time. Extra pressure drop along the rig caused a drop in gas flow rate. Heat transfer coefficients were calculated from sections of the experiment runs where the temperatures remained stable. The heat transfer coefficient seemed to occur within a few millimeters of the injector, meaning calculations relied on a number of assumptions. This will affect progression of the moving bed to CCCS, as shown in Figure 3.

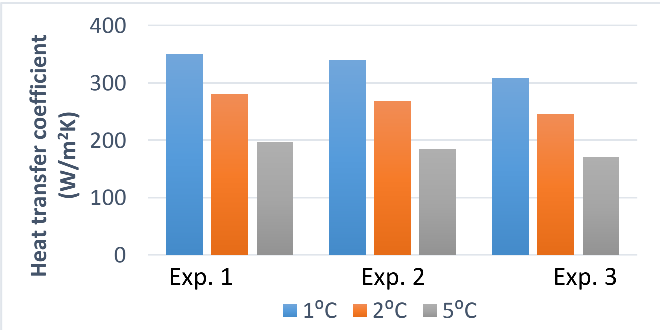

Figure 3. Heat transfer coefficients given different assumed temperature approaches near the top of the column

Conclusions

The heat transfer coefficient calculated has a large amount of uncertainty dependent on the assumptions made, more rigorous testing would be required before a more conclusive value can be determined. The temperature of the bed within the column is heavily dependent on the height of the bed; furthermore, the majority of heat transfer appears to occur near the surface of the injectors. When moving to a cryogenic rig it should be expected that large temperature differences will occur throughout the bed. This will affect the efficiency of a cryogenic rig and modifications to the design must be made to assure the bed temperature can be controlled.

Acknowledgements

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