ISSN 2004-2965 Energy Proceedings, Vol. 23, 2021

International Conference on Applied Energy 2021
Nov. 29 - Dec. 5, 2021, Thailand/Virtual
Paper ID: 895

Capturing CO_2 from Wood Fast Pyrolysis

Yingying Sun[1], Beibei Dong[1,2], Liang Wang[3], Eva Thorin[2], Hailong Li[2*]
[1]Tianjin University of Commerce, China
[2] School of Business, Society and Technology, Mälardalen University, Sweden
[3] SINTEF Energy Research, P.O. Box 4761, Sluppen, 7465 Trondheim, Norway

ABSTRACT

To achieve the climate goal set by the Paris Agreement, negative emission technologies (NETs) will play an important role. Bioenergy with carbon capture and storage (BECCS) is one of the most promising of NETs. This work aims to find a suitable technology for capturing CO_2 from fast pyrolysis, which include Monoethanolamine based chemical absorption (MEA-CC), temperature swing absorption (TSA) and calcium looping (CCL) are considered. By using validated models, the CO_2 capture rate, CO_2 purity and energy penalty are employed as key performance indicators to compare the performance of those technologies. It has been found that CCL has the highest CO_2 purity, MEA-CC, TSA and CCL have similar CO_2 capture rates and TSA has the lowest energy penalty. Results provide insights and suggestions about the selection of CO_2 capture technology for pyrolysis.

Keywords: BECCS, Negative emission technologies, Fast pyrolysis, Capture rate, Energy penalty

NONMENCLATURE

ΔH	Chemical reaction heat
BECCS	Bioenergy with carbon capture and storage
CC	chemical absorption
CCL	Calcium looping
CO_2	Carbon dioxide
$E_{x,loss}$	Exergy loss
MEA	Monoethanolamine
N_2	Nitrogen
NASA	National Aeronautics and Space Administration
NETs	Negative emission technologies
P_H	High pressure
P_L	Low pressure
$Q_{reboiler}$	Reboiler load
Q_{carb}	Carbonator load
T_{cal}	Temperature of calciner
T_{carb}	Temperature of carbonator
T_H	High temperature
T_L	Low temperature
$T_{reboiler}$	Reboiler temperature
TSA	Temperature swing absorption

1. INTRODUCTION

According to the Paris Agreement, the contracting countries need to take effective measures to reduce greenhouse gas emissions, and control the global temperature rise within 2°C and, for a better case, not to exceed 1.5°C. In order to reach the target, the United Nations Environment Programme reported that the annual CO_2 emissions need to be 15 billion tons lower than the current level in 2030 [1]. To achieve such a goal, negative emission technologies (NETs) can have a big contribution. Bioenergy with carbon capture and storage (BECCS) is among the most promising of NETs [2], which mainly consists of biomass conversion, CO_2 capture and CO_2 storage.

Fast pyrolysis is a technology that decomposes biomass into biooil, syngas and biochar under isolating air and high temperature conditions. Due to its ability to produce liquid oil, it has attracted huge attention for the decarbonization of the transport sector. Therefore, integrating CO_2 capture with pyrolysis is a promising option of BECCS. However, different CO_2 capture technologies are available and there has not been a guideline regarding how to select the capture technology for pyrolysis.

The objective of this article is to evaluate the technical performance of some mature CO_2 capture technologies, including MEA based chemical absorption (MEA-CC), temperature swing absorption (TSA) and calcium looping (CCL), in order to provide insights and

Selection and peer-review under responsibility of the scientific committee of the 13th Int. Conf. on Applied Energy (ICAE2021).

suggestions about the selection of CO_2 capture technology.

2. METHODOLOGY

Models for pyrolysis, MEA-CC, and CCL are developed in Aspen Plus; while the TSA model is developed in MATLAB. After model validation, the performance of capture technologies is compared based on simulations.

2.1 Model descriptions

2.1.1 Pyrolysis

Wood fast pyrolysis in nitrogen is considered in this work. Wood is used as the raw material for pyrolysis, which properties are shown in Table 1.

Fig. 1 shows the flowsheet model of pyrolysis. Wood is first decomposed into cellulose, hemicellulose, and lignin. RCSTR reactors are used to simulate the pyrolysis based on the kinetic reactions provided by Ranzi et al. [3]. The temperature and pressure of pyrolysis are 500°C and 1 atm respectively. For fast pyrolysis, the residence time is 30s. The produced syngas is combusted to provide the heat needed by pyrolysis and CO_2 is captured after combustion.

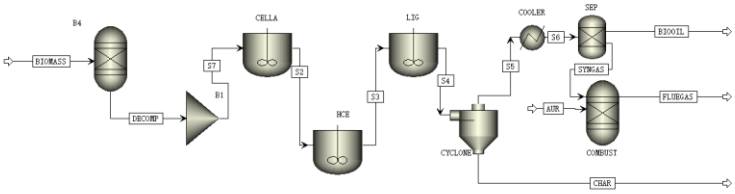

Fig. 1. Aspen Plus flowsheet of pyrolysis

Table 1. Elemental and industrial analysis of biomass and biochar

Nonconventional component	Proximate Analysis (%)				Ultimate Analysis (%)				
	Moisture	Ash	Volatile matter	Fixed carbon	C	H	O	N	S
Wood	25.0	4.5	52.8	17.7	47.3	5.1	40.6	0.8	0.2
Biochar	0	0	49.8	51.2	51.2	2.1	11.5	0.5	0.9

2.1.2 MEA-CC

Fig. 2 shows the rate-based model of chemical absorption using MEA as solvent. The flue gas enters the absorber after gas cleaning, in which CO_2 is removed. The rich solution is sent into the desorber where heat is added to regenerate the solvent and release CO_2. In this work, the inlet temperature of flue gas, the stripping pressure and the reboiler temperature are 31.7°C, 181.9kpa and 117.8°C respectively.

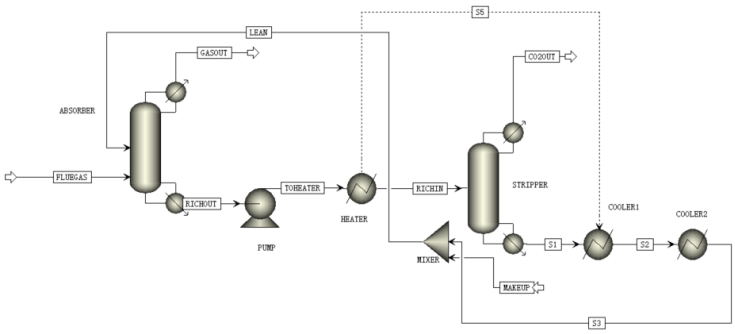

Fig. 2. Aspen Plus flowsheet of MEA

2.1.3 TSA

TSA is based on the principle that the gas quantity adsorbed by adsorbent at low temperature is higher than that at high temperature. Zhao et al. [4] divided TSA into four steps: (i) Vacuuming: the column is vacuumized before the flue gas is fed from the bottom; (ii) Adsorption: CO_2 in the feed gas is selectively adsorbed on the adsorbent, which is Zeolite 13X in this work; (iii) Heating: to release CO_2, the adsorbents are heated to T_H (118°C) using heat transfer fluid; (iv) Cooling: the temperature of the bed is cooled down to T_L=48°C before the next cycle begins.

2.1.4 CCL

The CCL process (Fig. 3) is mainly composed of carbonation and calcination according to the reaction:

$$CaO + CO_2 \Leftrightarrow CaCO_3 \quad \Delta H = \pm 179kJ \cdot mol^{-1} \quad (1)$$

Carbonation is endothermic, in which CaO absorbs CO_2 to form $CaCO_3$ at 650°C. It can reach a CO_2 conversion rate of 90%. Calcination is exothermic and happens at a higher temperature, such as 900°C, to release CO_2 and regenerate CaO, which can be recirculated. The key operating parameters of CCL are shown in Table 2.

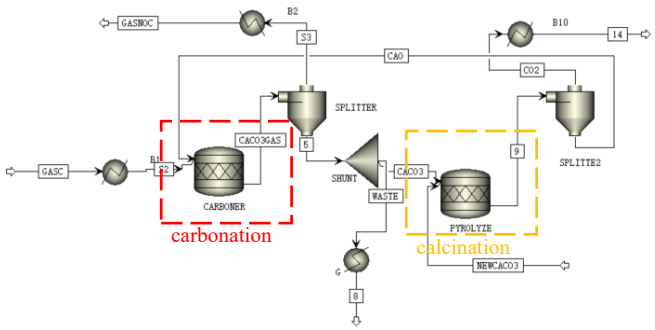

Fig. 3. Aspen Plus flow sheet of CCL

Table 2. Input parameters of CCL

carbonator		calciner	
T_{carb}	650°C	T_{cal}	900°C
CO_2 capture rate	90%		

2.2 Model validation

To validate the developed models, the simulated results are compared with data collected in the literature. The results are shown in Table 3-5. Good agreements can be seen.

Table 3. The comparation of pyrolysis

Parameters/wt-%	Shahbaz et al. [5]	This study	Shahbaz et al. [5]	This study	Visconti et al. [6]	This study
Gas	39	35.96	52	49.6		
Oil	3	4.77	26	24.9		
Char	58	59.28	22	25.5		
H_2					41	42.1
CO					5	4.8
CO_2					26	25.7
CH_4					17	17.9
H_2O					11	9.5

Table 4. The comparation of MEA-CC

Parameter	units	Li et al. [7]	This study	Li et al. [7]	This study	Li et al. [7]	This study
Rich loading	mol/mol	0.512	0.506	0.481	0.511	0.494	0.508
Captured CO_2	kg/h	83.8	84.1	74.2	72.6	96.9	93.9
$T_{reboiler}$	°C	121.1	122.2	117.2	119.3	125.3	126.5
$Q_{reboiler}$	MJ/kgCO_2	4.11	4.19	4.33	4.47	4.01	4.03
Purity of CO_2	vol%	99.1	99.0	97.6	97.4	98.9	98.4

Table 5. The comparation of CCL

Parameter	Rolfe A. et al. [8]	This study	Vorrias I. et al. [9]	This study	Ortiz C. et al. [10]	This study
Captured CO_2/(kg/s)	274.1	269				
Total CO_2 capture rate/%			93.93	97.32	77	77.6
Q_{carb}/ MW	1262	1265.55	303	311.564	711	696.7

3. PERFORMANCE EVALUATIONS AND DISCUSSIONS

3.1 Key performance indicators

In order to compare the performance of different capture technologies, 3 key performance indicators are used in this paper: CO_2 purity, CO_2 capture rate, and energy penalty. CO_2 capture rate, and energy penalty are defined by Eq (1) and (2).

$$CO_2\ capture\ rate = \frac{CO_2\ captured}{CO_2\ emission} \quad (2)$$

$$Energy\ penalty = \frac{E_{x,loss}}{CO_2\ captured} \quad (3)$$

3.2 Technology performance

As shown in Table 6, the highest purity is achieved by CCL and MEA-CC, which is 99.9%. But TSA can only obtain a purity of 90.2% with N_2 as the main impurity.

Table 6.CO_2 purity of MEA, TSA and CCL

Technology	MEA-CC	TSA	CCL
CO_2 purity/%	99.9	90.2	99.9

Table 7 shows the capture rate. All studied technologies can achieve capture rates around 90%.

Table 7. CO_2 capture rate of MEA, TSA and CCL

Technology	MEA-CC	TSA	CCL
CO_2 capture rate /%	90.03	90.00	90.03

The energy penalty shown in Table 8 reveals TSA has the lowest, which is only 2979 kJ/kgCO_2. It is followed by MEA-CC, which is about 3793.7 kJ/kgCO_2. CCL has the highest, 4567.7 kJ/kgCO_2.

Table 8. Energy penalty of MEA, TSA and CCL

Technology	MEA-CC	TSA	CCL
energy penalty /(kJ/kgCO_2)	3793.7	2979.5	4567.7

4. CONCLUSIONS

In this work, three CO_2 capture technologies, MEA based chemical absorption (MEA-CC), temperature swing absorption (TSA), calcium looping (CCL), have been compared for capturing CO_2 from wood fast pyrolysis. Based on simulations by using validated models, the main findings of this work can be concluded as follows:

- MEA-CC and CCL can obtain higher purities than TSA, which is only about 90%.
- MEA-CC, TSA and CCL can all obtain a CO_2 capture rate of 90%.
- TSA has the lowest energy penalty, which is 2979.5 kJ/kgCO_2; while CCL has the highest, which is 4567.7 kJ/kgCO_2.

ACKNOWLEDGEMENT

The authors gratefully acknowledge the financial supports from National Natural Science Foundation of China (No. 51776140) and Swedish Energy Agency (Energimyndigheten) for the research project 'AI assisted CO2 capture in biomass CHP plants' (Projektnr: 51592-1).

REFERENCE

[1] United Nations. (2019). Cut Global Emissions by 7.6 Percent Every Year for Next Decade to Meet 1.5°C Paris Target - UN Report. https://unfccc.int/news/cut-global-emissions-by-76-percent-every-year-for-next-decade-to-meet-15degc-paris-target-un-report

[2] Burns W., & Nicholson S.. (2017). Bioenergy and carbon capture with storage (BECCS): the prospects and challenges of an emerging climate policy response. Journal of Environmental Studies & Sciences, 7(4), 1-8.

[3] Ranzi E., Cuoci A., Faravelli T., Frassoldati A., Migliavacca G.,& Pierucci S., et al. (2008). Chemical kinetics of biomass pyrolysis. Energy & Fuels, 22(6), 4292-4300.

[4] Zhao R., Liu L., Zhao L., Deng S., Li S., & Zhang Y.. (2019). A comprehensive performance evaluation of temperature swing adsorption for post-combustion carbon dioxide capture. Renewable & Sustainable Energy Reviews, 114(OCT.), 109285.1-109285.13.

[5] Shahbaz M., Alnouss A., Parthasarathy P., Abdelaal A. H., & Al-Ansari T.. (2020). Investigation of biomass components on the slow pyrolysis products yield using aspen plus for techno-economic analysis. Biomass Conversion and Biorefinery.

[6] Visconti A., Miccio M., & D Juchelková. (2015). An aspen plus tool for simulation of lignocellulosic biomass pyrolysis via equilibrium and ranking of the main process variables. International Journal of Mathematical Models and Methods in Applied Sciences, 9, 71-86.

[7] Li K., Cousins A., Yu H., Feron P., Tade M., & Luo W., et al. (2016). Systematic study of aqueous monoethanolamine-based CO_2 capture process: model development and process improvement. Energy Science & Engineering, 4(1), 23-39.

[8] Rolfe A., Huang Y., Haaf M., Rezvani S., Mcliveen-Wright D., & Hewitt N.J.. (2018). Integration of the calcium carbonate looping process into an existing pulverized coal-fired power plant for CO_2 capture: techno-economic and environmental evaluation. Applied Energy, 222, 169-179.

[9] Vorrias I., Atsonios K., Nikolopoulos A., Nikolopoulos N., Grammelis P., & Kakaras E.. (2013). Calcium looping for CO_2 capture from a lignite fired power plant. Fuel, 113(Nov.), 826-836.

[10] Ortiz C., Chacartegui R., Valverde J.M., & Becerra J. A.. (2016). A new integration model of the calcium looping technology into coal fired power plants for CO_2 capture. Applied Energy, 169(may1), 408-420.

