International Conference on Applied Energy 2020
Dec. 1 - Dec. 10, 2020, Bangkok / Virtual
Paper ID: 706

Dynamic simulation of CO_2 capture from biomass power plant by MEA

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ABSTRACT

The bioenergy with CO_2 capture and storage (BECCS) is a promising solution to cut CO_2 emissions and will play an important role in achieving the climate goal of 1.5°C. As the properties of biomass varies significantly, it is of importance to understand the dynamic performance when capturing CO_2 from biomass fired power plants. This work is to reveal the dynamic performance of chemical absorption. The aqueous solution of monoethanolamine (MEA) was selected as the solution. By using the real flue gas (FG) data , the influence of FG flow rate on CO_2 capture were studied by doing dynamic simulations. It has been found that as the FG flow rate decreases, the CO_2 capture rate first rose before going down; and the reboiler duty decreased while the energy consumption of CO_2 capture increased.

Keywords: BECCS, Monoethanolamine (MEA), Energy consumption, Dynamic, Carbon dioxide capture

NONMENCLATURE

Abbreviations	
BECCS	Bioenergy with CO_2 capture and storage
CHP	Combined heat and power
CO_2	Carbon dioxide
FG	Flue gas
H_2O	Water
MEA	Monoethanolamine
N_2	Nitrogen
O_2	Oxygen

1. INTRODUCTION

The COP21 set a global target to keep global temperature rise below 1.5°C above pre-industrial levels [1]. According to United Nations Environment Programme, in order to achieve this goal, CO_2 emissions must be reduced by 7.6% each year [2] between 2020 and 2030.

Bioenergy with CO_2 capture and storage (BECCS) is a carbon-negative technology that is to capture CO_2 from the bioenergy conversion. It will play an important role in achieving the climate goal with a contribution of CO_2 removal up to 16 $GtCO_2$ per year by the mid of this century [3].

Among different capture technologies, post-combustion capture is considered the most suitable option for retrofitting the existing plants [4], and chemical absorption is the only commercialized one, which has the advantages of being able to capture CO_2 at low concentrations, high capture rate and high CO_2 purity [5].

Intensive research has been carried out to advance MEA-based chemical absorption. However, most of studies are based on steady-state simulations. For the actual power plant, FG dynamically changes depending on the operating states, therefore it is important to understand the dynamic characters, which are important for the development of control and the improvement of system performance. The object of this work is to explore the dynamic effect of the FG change on the performance of chemical absorption CO_2 capture, which includes the energy consumption and CO_2 capture rate.

2. MODEL DESCRIPTION AND VALIDATION

2.1 Model description

Selection and peer-review under responsibility of the scientific committee of the 12th Int. Conf. on Applied Energy (ICAE2020).

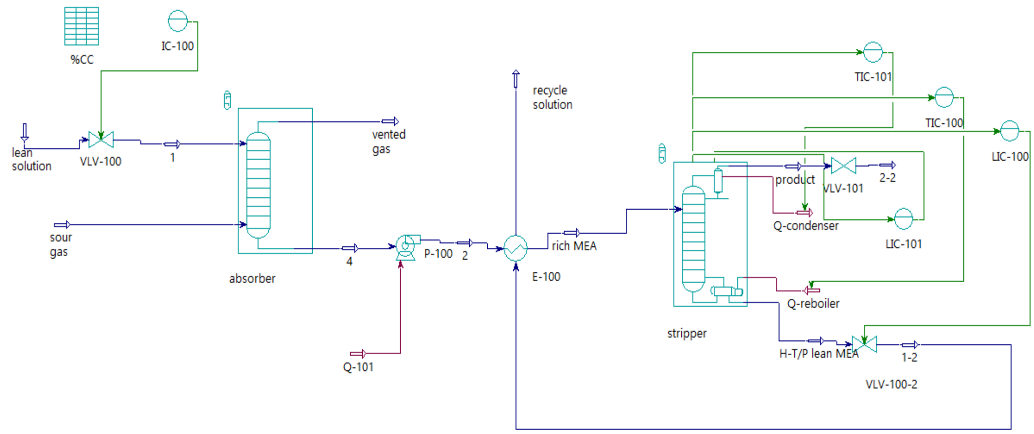

Fig. 1 Chemical absorption CO_2 capture open-loop system

A dynamic model about MEA based chemical adsorption was developed in Aspen HYSYS. An open loop structure, as shown in Fig. 1, was used to simulate such a process. For each time step, the calculated outputs, such as the flow rate and compositions of lean solution, were used as inputs for the next time step. Make-up lean MEA solution was added to control the flow rate of MEA going into the absorber to be constant.

The main inputs are listed in Table 1. In the dynamic simulations, the temperature of the reboiler was maintained as constant, which was achieved by adjusting the reboiler duty. The temperature of the condenser was fixed. The liquid level of the reboiler was used to control the solution flow rate.

2.2 Model validation

To validate the model of the absorber, dynamic simulations were carried out using dynamic flow rate of FG, as shown in Fig. 2, as inputs with other parameters of FG unchanged. The simulated results about the temperature of each stage of the absorber were compared with the results from the ref [8]. In general, good agreements can be seen from Fig. 3. The maximum temperature deviation was 4.34K, which appeared at the bottom of the absorber.

Tab 1: Input values for the dynamic simulations

Parameter	Input data
CO_2 concentration in FG (mol%)	17.5
Solution (30wt% MEA)	
Lean loading	0.3
Solution flow rate (mole/s)	31.4
Lean solution temperature (K)	314
Absorber	
Packing high (m)	6.1
Column diameter (m)	0.43
Packing	IMTP#38MM
Stripper	
Packing high (m)	6.1
Column diameter (m)	0.43
Packing	IMTP#38MM

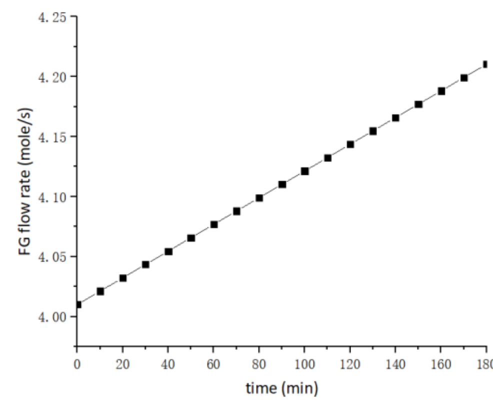

Fig. 2 The input parameters: flue gas flow rate

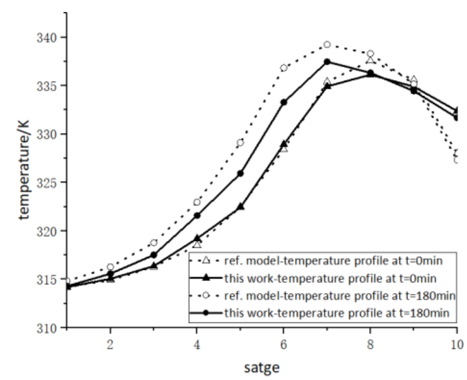

Fig. 3 Validation of the temperature of each stage of the absorber

To validate the model of the stripper, the results about the energy consumption were compared. The operation was simulated for 3 hours. FG started to change at t=0min, before which the operation reached equilibrium state. As plotted in Fig.4, the maximum deviation was 3.42%, which appeared at the beginning of the simulation.

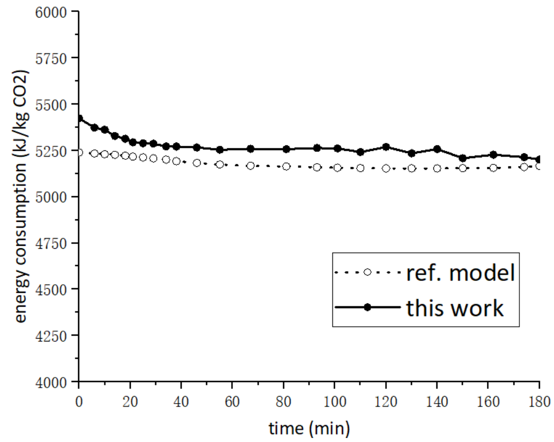

Fig. 4 Validation of stripper: energy consumption

3. INFLUENCE OF FG FLOW RATE

3.1 FG data

The actual operating state of the power plant is not stable. Fig. 5 shows the real FG data for one week. In this work, the impact of FG flow rate changes on the dynamic performance of the system is the main focus.

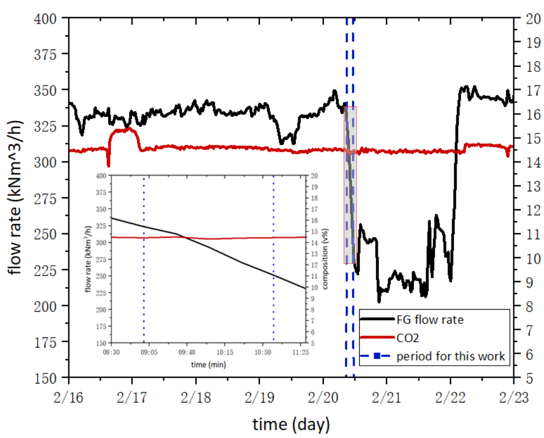

Fig. 5 FG data of one week from a biomass fired CHP plant

2 hours data were selected, as shown in Fig.5 and Table 2. It is clear that during this period the variation of CO_2 concentration was less than 0.2%, which can be assumed to be constant.

Table 2: Biomass fired CHP plant FG flow rate and composition

Time	Flow rate (kNm^3/h)	Composition (v%)			
		CO_2	O_2	H_2O	N_2
2017/02/20 09:00:00	323.64	14.42	5.14	11.44	69.00
2017/02/20 09:30:00	312.88	14.50	5.06	11.30	69.14
2017/02/20 10:00:00	293.08	14.31	5.23	11.33	69.12
2017/02/20 10:30:00	270.45	14.39	5.16	11.33	69.11
2017/02/20 11:00:00	251.22	14.43	5.14	11.34	69.09

3.2 Dynamic influence of FG

To understand the dynamic effect of FG on the performance of chemical absorption, the CO_2 capture rate and energy consumption (kJ/kg CO_2) are used as key performance indicators, which are defined below:

$$CO_2\ capture\ rate = \frac{flow\ rate_{product} * x_{product}^{CO2}}{flow\ rate_{FG} * x_{FG}^{CO2}} * 100\% \quad (1)$$

$$Energy\ consumption = \frac{Q_{reb}}{flow\ rate_{FG} * x_{product}^{CO2}} \quad (2)$$

Using the model presented in Section 2, simulations were done. The results about the CO_2 capture rate are displayed in Fig. 6. The capture rate increases from the initial 95% to 104.3% with the decrease of FG flow rate, within the first 90 mins. During 90-120min, although the FG flow rate is still declining, the capture rate begins to decrease, which drops to 101.28% at the end of the simulation.

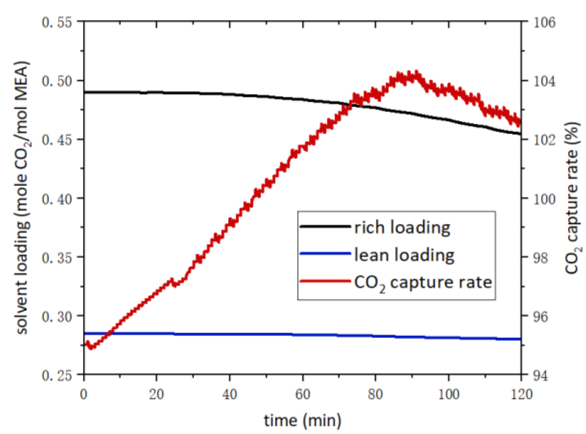

Fig. 6 CO_2 capture rate and solution loading

A capture rate exceeded 100% cannot happen in the steady-state simulation. For dynamic simulations, the change of reboiler is always behind the change of FG. When the FG flow rate started to decrease, less CO_2 is captured. However, the reboiler duty hasn't changed much yet, as a result, the amount of regenerated CO_2 is same, which comes not only from the newly captured CO_2 but also the CO_2 contained in the solution. Therefore the capture rate can rise, even over 100%. In addition, this will lead to an increase of temperature in reboiler and a reduction in CO_2 loading. With the increase of the boiler temperature, the controller will reduce the heat supply to the reboiler, less and less CO_2 will regenerated, resulting in the decline of the capture rate.

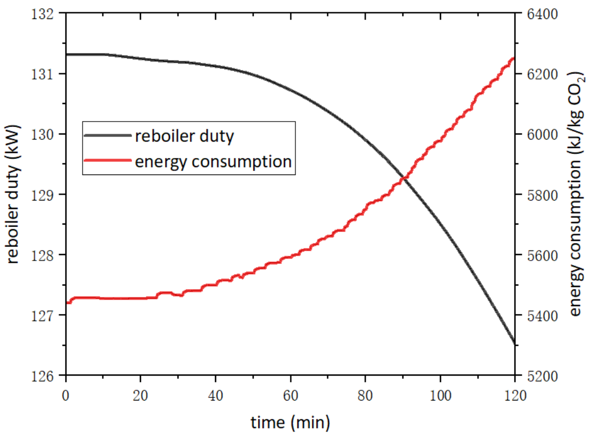

Fig. 7 Energy consumption and reboiler duty

Fig. 7 shows the change of reboiler duty, which decreases with the decrease of the FG flow rate. The reason is mainly due to the rise of reboiler temperature due to less heat is needed since less CO_2 is captured. However, the change of the energy consumption for capturing 1kg CO_2 was opposite, which was also shown in Fig 7. It rose with the decrease of FG flowrate. This is owing to that more water was evaporated when the temperature of the reboiler increased.

3.3 Comparison between steady-state simulation and dynamic simulation

The results of dynamic simulations and steady-state simulations were compared in Table 3. The steady-state simulation was also done in Aspen HYSYS, using the same operating parameters of chemical absorption. But for the FG flow rate, average during the selected two hours was used. The hourly results of the dynamic simulation were aggregated from the minute results. Some clear differences can be observed. Compared to the steady-state simulation, more CO_2 can be captured in the dynamic simulation, which further resulted in a higher CO_2 capture rate. In addition, the dynamic simulation also showed a higher reboiler duty and a less energy consumption of CO_2 capture.

Table 3: The difference between the results of the two simulation methods

Model	CO_2 capture rate	Captured CO_2 (kg/h)	Energy consumption of CO_2 capture (MJ/kg CO_2)	Reboiler duty (MWh)
Dynamic simulation	100.35	82.54	5.67	468
Steady-state simulation	98.52	81.02	5.74	465

4. CONCLUSIONS

Dynamic simulations were conducted for chemical absorption CO_2 capture. Based on the results, the following conclusions were made:

- With the decrease of the FG flow rate, the CO_2 capture rate first rose before going down; and a CO_2 capture rate over 100% can happen.
- With the decrease of the FG flow rate, the reboiler duty decreased while the energy consumption of CO_2 capture increased.
- Clear differences can be observed between the dynamic simulation and steady state simulation.

ACKNOWLEDGEMENT

This work is conducted in the projects: The influence mechanism of impurities on multi-stream heat transfer in the cryogenic purification of CO_2 (No. 51776140) and characterizing major CO_2 streams in BECCS (Projeknr: 49867–1). The financial support from National Natural Science Foundation of China and Swedish Energy Agency (Energimyndigheten) is gratefully acknowledged.

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