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A Method to Assess the CO_2 Capture Potential from a Biomass-fired CHP

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ABSTRACT

The bioenergy with CO_2 capture and storage (BECCS) is an important solution to reduce CO_2 emissions. This paper proposed a new method that can accurately access CO_2 capture potential from a biomass-fired combined heat and power (BCHP). Chemical absorption is used as CO_2 capture technology. By carefully considering the temperatures of the heat required by district heating and CO_2 capture, the allocation of the available heat from flue gas condensation and extracted steam condensation for different purposes has been optimized. By using a real BCHP with a thermal capacity of 200MW as a case study, results show that the captured CO_2 was 23.42t/day without any change in heat and power supply, which was 1.77% of the total released CO_2.

Keywords: bioenergy with CO_2 capture and storage, biomass-fired combined heat and power plant, flue gas condensation, amine-based CO_2 capture, process optimization

NONMENCLATURE

Abbreviations	
BCHP	Biomass-fired combined heat and power
BECCS	Bioenergy with CO_2 capture and storage
DH	District heating
FGC	Flue gas condenser
ESC	Extracted steam condensation
BSC	Bypass steam condensation

1. INTRODUCTION

Bioenergy with CO_2 capture and storage (BECCS) is a carbon-negative technology that captures CO_2 from the bioenergy conversion [1]. According to the OECD Environmental Outlook to 2050 released at the 2011 UN Climate Change Conference, meeting lower CO_2 concentrations "depends significantly on the use of BECCS" [2].

When chemical absorption based CO_2 capture is integrated into a combined heat and power (CHP) plant, the heat required by the CO_2 desorption can compete with the heat needed by district heating (DH). There have been studies investigating the CO_2 capture potential of CHP [3] plant and the operation optimization of integrated units [4]. However, previous works were mainly conducted based on energy balance, and didn't consider the influence of temperature. Some heat can be used for DH, but not for chemical absorption CO_2 capture, which has a specific temperature requirement. In addition, the chemical absorption usually needs a temperature higher than DH, which implies that the extraction of steam needs to be retrofitted. Consequently, it will further influence the downstream power generation. In order to accurately estimate the amount of CO_2 that can be captured, a new method is needed to take into account the temperature of the heat demand. Based on chemical absorption using MEA, this work aims to develop such a method that can optimize the allocation of the available heat from both flue gas condensation (FGC) and extracted steam condensation

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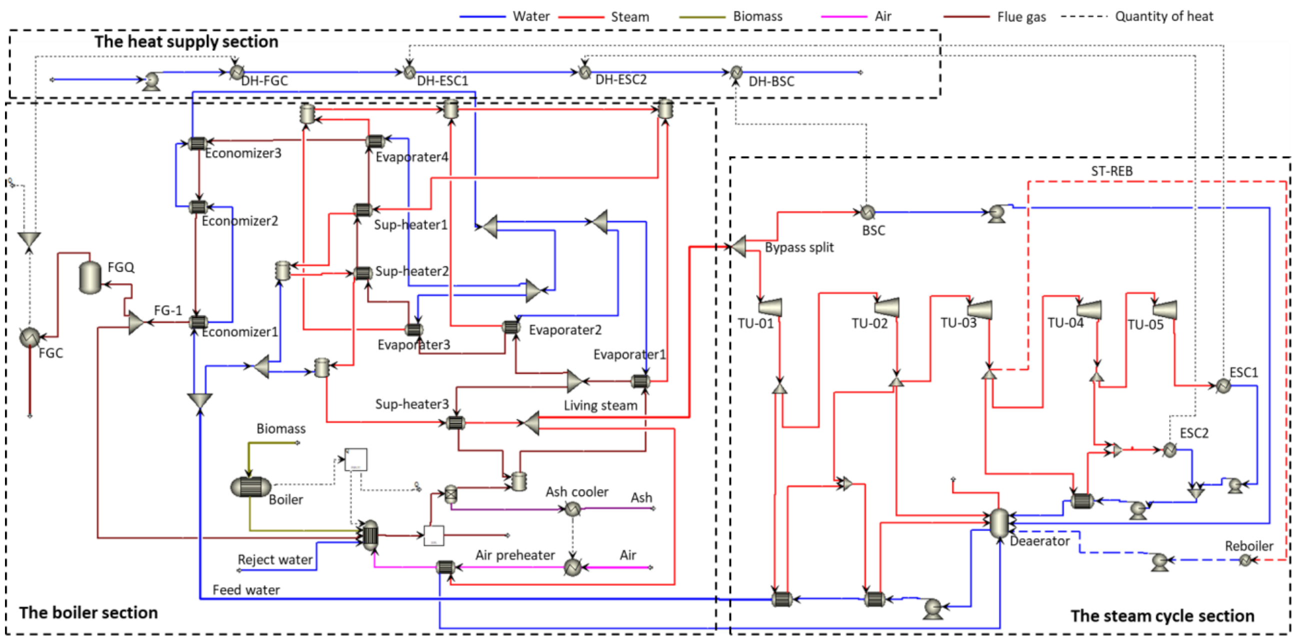


Fig 1 Aspen Plus flowsheet of the BCHP.

between DH and CO_2 capture to maximize the emission reduction.

2. METHOD DESCRIPTION

For a BCHP, there are mainly three heat sources: extracted steam condensation (ESC), bypass steam condensation (BSC) and FGC. For DH, the needed heat is primarily provided by ESC. When the heat of ESC is not enough, heat recovered from FGC is used. If the heat demand further increases, steam bypasses the steam turbine and condenses to provide more heat. When MEA based on chemical absorption CO_2 capture is integrated, heat at temperature between 110-120°C is needed for solvent regeneration. Such a temperature is normally higher than that needed by DH. In order to meet such a requirement, ESC is still the major option and the pressure of steam extraction needs to be lifted compared to that used for DH only. As the core business of CHP is to supply heat for DH, this work is conducted based on the assumption that the heat demand is always satisfied. Meanwhile, in order to not reduce the profit from selling electricity, it is also assumed the electricity production is not changed. According to the temperature requirements from CO_2 capture and DH, the steam extraction and the operation strategy are retrofitted.

2.1 CHP model

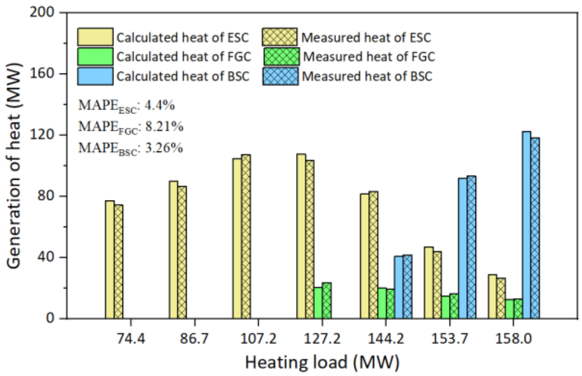
A model of a BCHP plant, as shown in Fig 1, is first developed in Aspen Plus, which consists of three blocks: the boiler block, including the combustion of biomass, steam generation and FGC, the steam cycle block and the district heating block. The main input parameters of the BCHP are listed in Table 1 [5].

To validate the BCHP model, the simulated power and heat generation under different heat loads are compared with the measured results in Fig 2. The biggest mean absolute percentage error (MAPE) appears in the heat recovery of the FGC, which is 8.21%, and the MAPEs of generation of the electricity, heat of the ESC and heat of the BSC are 4.56%, 4.40% and 2.36% respectively.

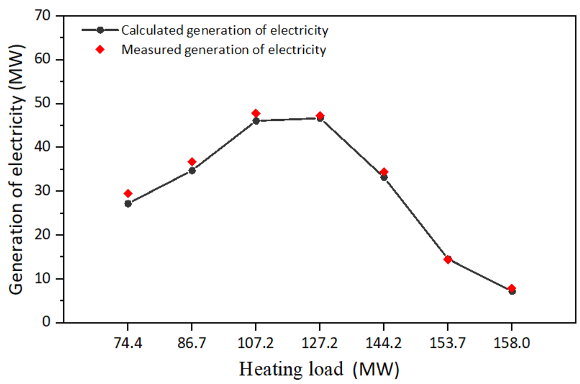
Table 1 Operating parameters of the BCHP.

Parameters	Values
Boiler thermal capacity	200MW
Excess air	5%
Living steam temperature	743K
Living steam pressure	74bar
Feedwater temperature	310K
Turbine isentropic efficiency [a]	$0.83e^{-[\frac{(m-55.32)}{52.89}]^2}+0.07$
Flue gas temperature after FGC	325K
Extraction pressure (for CCS)	2.5bar
Fuel composition (Ultimate analysis % on wet bases)	
Ash	15
Carbon	52.9
Hydrogen	7.3
Nitrogen	1.6
Chlorine	0.5
Sulfur	1.1
Oxygen	21.6
Lower heating value	12MJ/kg

[a] Efficiency is regressed based on real operation data. (where, m is steam mass flow rate)



(a) Comparison on generation of heat



(b) Comparison on generation of electricity

Fig 2 Model validation.

2.2 Allocating heat between DH and CO_2 capture

Since the heat from FGC is the 2nd option for DH in the operation without CO_2 capture, when the heat of FGC is not fully used by DH, it implies that a part of the extracted steam can be used for CO_2 capture, and the reduced heat from ESC needed by DH can be compensated by FGC. In this paper, the pressure of solvent regeneration is 1.6 bar, which corresponds to an operating temperature of 113°C in the reboiler. Considering a temperature difference of 15°C for heat transfer, the needed steam shall have a temperature of 128°C. To satisfy the heat demand of CO_2 capture, the pressure of the steam extracted from the 3rd stage is changed to 2.5 bar.

To maximize the captured CO_2, the allocation heat from different sources should be optimized between DH and CO_2 capture. The objective function is defined by Equation 1:

$$\max Cap_{CO_2} = f\,(Q_{DH}, P_{CHP}) \tag{1}$$

where Q_{DH} and P_{CHP} represent the demand for DH heat and BCHP power generation respectively, which come from the real operating data (MW).

The heat recovered from FGC (Q_{FGC}) is limited by the maximum heat provided by FGC ($Q_{FGC,max}$), which further depends on the operating conditions of CHP:

$$Q_{FGC} \leqslant Q_{FGC,max} \tag{2}$$

The temperatures of heat needed by CO_2 capture and DH shall also meet the requirements. A minimum temperature difference T_{min} (4K) is also introduced for heat transfer:

$$\begin{aligned} T_{FGC,out} &\geq T_{DH\text{-}FGC,in} + T_{min} \\ T_{ESC1} &\geq T_{DH\text{-}ESC1,out} + T_{min} \\ T_{ESC2} &\geq T_{DH\text{-}ESC2,out} + T_{min} \\ T_{BSC} &\geq T_{DH\text{-}BSC,out} + T_{min} \end{aligned} \tag{3}$$

where T is the temperature (K); The subscripts correspond to the heat exchangers in Fig.1, *ESC1 and ESC2* represent 1st ESC and 2st ESC respectively. *DH-FGC*, *DH-ESC* and *DH-BSC* represent the DH water in FGC, ESC and BSC respectively, and the subscripts *in* and *out* represent the inlet and outlet parameters of heat exchangers respectively.

3. RESULT ANALYSIS

To verify the proposed method, simulations were conducted for one day in March, 2019. Real data from the studied CHP were used in simulations, including supply and return water temperature, turbine pressures, living steam temperature and pressure, etc.

Fig 3 shows the available heat from FGC and the heat used by DH in the operation without CO_2 capture. It is clear that there exists some heat that is not used. If such heat can be further used for DH, it can free some heat from ESC for CO_2 capture. By using the proposed method, the heat that can be used for DH was identified, which is illustrated by the green area.

3.1 CO_2 capture potential analysis

Correspondingly, the heat from ESC that can be used by CO_2 capture is shown in Fig 4. It shall be noted that the heat taken from FGC for DH cannot replace the same amount of heat from ESC, since some heat from ESC is still needed to guarantee the needed supply water temperature.

According to the steady state simulation of MEA-based CO_2 capture, which shows an energy consumption of CO_2 capture of 4.93MJ/kgCO_2, the amount of captured CO_2 is illustrated in Fig 5. It is clear that capture ratio is rather small, which is less than 5%, and the total capture amount of CO_2 is 23.42t for the studied day. Such results are obtained based on the assumption that there is no change in the generation of heat and electricity.

Therefore, in order to capture more CO_2, it means either the heat or electricity production needs to be sacrificed.

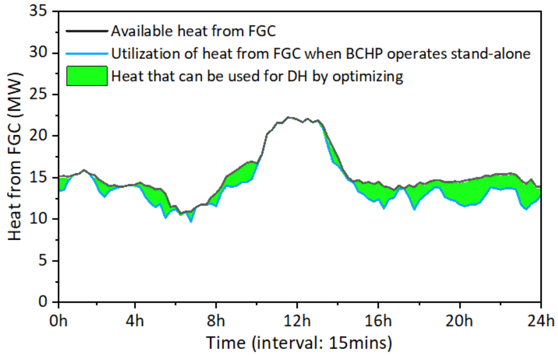


Fig 3 Utilization of the available heat from FGC.

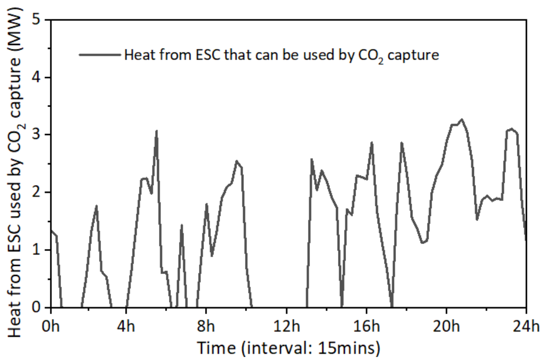


Fig 4 Heat from ESC used by CO_2 capture.

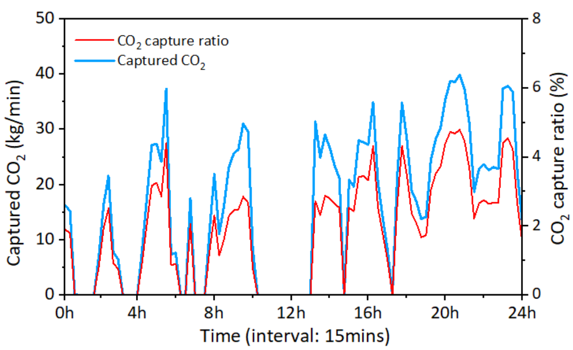


Fig 5 Captured CO_2 and capture ratio.

4. CONCLUSION

In this paper, a new method is proposed to accurately access the capture potential of CO_2 from a BCHP based on chemical absorption CO_2 capture, which takes into account the temperatures of heat required by DH and CO_2 capture. Such a method was verified by doing simulations for one day by using the real operating data from a CHP. Based on the results, it can be concluded that it is possible to capture CO_2 without interfering the heat and electricity production when the heat from FGC is not fully used by DH. However, the amount of captured CO_2 is very limited, and it is dependent on the operating conditions of the CHP.

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