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Integrating geothermal into coal-fired power plant with carbon capture: A comparative study with solar energy

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ABSTRACT

A new system integrating geothermal energy into post-combustion carbon capture is proposed in this paper. Geothermal energy at medium temperatures is used to provide the required thermal heat for solvent regeneration. The performance of this system is compared with solar assisted carbon capture plant via technical and economic evaluation. A 300 MWe coal-fired power plant is selected as the reference case, and two different locations based on the local climatic conditions and geothermal resources are chosen for the comparison. The results show that the geothermal assisted post-combustion carbon capture plant has better performances than the solar assisted one in term of the net power output and annual electricity generation. The net plant average efficiency based on lower heating value can be increased by 2.75% with a thermal load fraction of about 41%. Results of economic assessment show that the proposed geothermal assisted post-combustion carbon capture system has lower levelized costs of electricity and cost of carbon dioxide avoidance compared to the solar assisted post-combustion carbon capture plant. In order to achieve comparative advantages over the reference post-combustion carbon capture plant in both locations, the price of solar collector has to be lower than 70 USD/m^2, and the drilling depth of the geothermal well shall be less than 2.1 km.

1. Introduction

The rising trend in global greenhouse gas (GHG) stimulates the concerns on climate change. According to the data reported by PBL Netherlands Environmental Assessment Agency in 2015 [1], CO_2 is the main sources of GHG. The emissions of CO_2 from fossil-fuel combustion and industrial processes in 2014 totaled 35.7 billion tonnes, which is still increasing compared to 2013. Facing with this serious situation, worldwide efforts have been made to search for effective approaches, including technologies, policies and regulations, to cut the CO_2 emissions below an acceptable level. The 2015 COP21, also known as the 2015 Paris Climate Conference, was aimed to achieve a legally binding and universal agreement on climate, with the aim of keeping global warming below 2 °C [2].

Carbon capture and storage (CCS) has been identified as a feasible solution for CO_2 reduction [3]. As reported by the IEA Technology Roadmap 2013, CCS will account for 14% of the total GHG mitigation potential [4]. Among three main technologies, namely the post-combustion, pre-combustion and the oxy-combustion technologies, the post-combustion CO_2 capture technology, which is based on chemical absorption processes, has already been proven and commercially available in the oil and gas industry, and on a moderate scale for the flue gases [5]. However, high energy penalty is the main barrier for its application. A power plant equipped with CCS technologies leads to high energy penalty. This result in significant losses in power plant output ranging from 19.5% to 40% of the original output of conventional power plants, of which most is for capture and compression [6].

To reduce the energy consumption from power plants due to CO_2 capture, integrating solar energy into CCS is a novel option [7]. Solar energy is the most abundant resource and can in principle cover a multiple of the global energy needs [8]. Meanwhile, solar thermal energy at low-to-medium temperatures is easy to be collected by most of the solar collectors, such as the evacuated tubes, parabolic trough and linearly Fresnel reflectors [9]. Since Wibberley first proposed the description of solar energy assisted chemical absorption in 2006 [10], this system has received much attention recently. Most of the previous studies are focused on the technical and economic feasibility assessment [11]. For example, to efficiently utilize solar energy, Plaza et al. [12] developed a three-stage flash configuration as an alternative stripper in the

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Nomenclature

A_n	annual costs
C_c	CO_2 emissions of the CO_2 reduction systems
C_r	CO_2 emissions of the reference system
E_n	amount of electricity produced
I	capital costs
n	plant lifetime
r	interest rate
MD	well depth

Acronyms

CaL	calcium looping
CCS	carbon capture and storage
COA	cost of CO_2 avoidance
CSP	concentrating solar power
DNI	direct normal irradiation
EGS	enhanced geothermal system
FLH	full load hour
GGR	geopressured geothermal reservoirs
GHG	greenhouse gas
GPCC	geothermal assisted post-combustion CO_2 capture
HDR	hot dry rocks
HTF	heat transfer fluid
IEA	international energy agency
LCOE	levelized costs of electricity
LHV	lower heating value
MEA	monoethanolamine
NGCC	natural gas combined cycle
NREL	national renewable energy laboratory
ORC	organic Rankine cycle
PCC	post-combustion CO_2 capture
PTC	parabolic trough collector
SAM	system advisor model
SPCC	solar assisted post-combustion CO_2 capture
TES	thermal energy storage
TLF	thermal load fraction

chemical absorption process. Results show the three-stage flash can reduce energy consumption by 6% compared to a simple stripper. However, their study only focused on the design of equipment, but did not give any results on the overall power generation system. Mokhtar et al. [13] evaluated the revenue of the solar assisted post-combustion CO_2 capture (SPCC) with the influences of the electricity prices, Solar load-Fraction (SF) and the carbon tax. Li et al. [14] investigated this integration with a focus on the cost of solar thermal collectors, CO_2 removal ratio and thermal energy storage (TES). They both concluded that SPCC was very location and climatic sensitive and factors like electricity price and location would considerably influence its viability. Meanwhile, concentrated high temperature solar collector is also used to assist CO_2 capture. Tregambi et al. [15] studied the post-combustion CO_2 capture by integrating a Calcium Looping (CaL) cycle with a Concentrated Solar Power (CSP) system, so that the thermal energy required in the calciner can be supplied by CSP. Lambert et al. [16] investigated the effect of solar thermal energy on the energy penalty for natural gas combined cycle (NGCC) power plants with CO_2 capture. The solar thermal technology used in their studies is a solar tower system with the maximum of 1000 °C, and is used to provide heat to the first of the two combustion chambers in the gas turbine.

However, a critical drawback of solar energy is its intermittence which has a flexible impact on SPCC systems [17]. To maintain its operation, thermal energy storage (TES) is usually used, but this increases the investment of SPCC tremendously. Mokhtar et al. [13] argued that all the regeneration thermal energy provided by solar collectors would be prohibitively expensive to be as a very large solar field and TES would be required for night operation. Meanwhile, the energy management systems (EMS) are the vital supervisory control tools used to optimally operate and schedule thermal energy when the economic index is considered [18]. Qadir et al. [17] conducted the flexible dynamic operation of SPCC under the influence of weather conditions to obtain the maximum revenue. In summary, for SPCC systems, the use of auxiliary power sources such natural gas and steam extraction needs to be added to compensate the insufficient solar thermal energy, and further flexible operation strategies are a necessity to determine optimal daily operation.

Compared with solar energy, geothermal energy has the capacity to provide stable thermal energy due to its non-intermittent nature, and has drawn much attention over the decades [19]. Currently, geothermal reservoirs are mostly utilized to generate electricity directly. However, investigations have highlighted that this technology suffers high investment and low thermodynamic efficiencies. For most low-enthalpy geothermal water with temperatures lower than 150 °C, the thermal efficiencies of geothermal organic Rankine cycle (ORC) systems continue to be lower than 12% [20]. Therefore, integrating geothermal energy into conventional power plant to save the investment in a power block has been proposed and studied recently [21]. Meanwhile, geothermal can also be used to replace the steam extraction of CO_2 capture process due to their ubiquitous availability and coincidences well with CO_2 capture process based on chemical solvents [22]. Previous studies of geothermal hybrid conventional power plant and CO_2 capture show better performance than the standalone geothermal systems.

However, the distribution of geothermal resources varies significantly with location as well as solar energy. The endowment of energy is a common factor limiting its application. A comprehensive resource exploration and evaluation is the basis for the implementation of these technologies. Though the economic feasibility of utilizing solar energy for solvent regeneration has been largely addressed in literature [6], few work involves the analysis of integrating geothermal energy into CO_2 capture, especially the comparison of solar energy with geothermal energy in terms of assisting CO_2 capture. Hence, the present study proposed a new integration system termed geothermal assisted post-combustion carbon capture (GPCC), using medium temperature geothermal energy to partly replace the regeneration energy. The solar assisted post-combustion carbon capture system is also analyzed and compared to investigate the advantages and disadvantages of these integrations. Technical and economic analyses are performed based on the actual locations with different distributions of solar and geothermal resources. The objective of the study involves providing suggestions on the efficient and economic use of geothermal energy, and identifying the areas in which geothermal and solar energy can be economically adopted to assist CO_2 capture.