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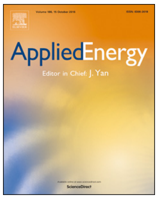

Integration of heat recovery unit in coal fired power plants to reduce energy cost of carbon dioxide capture

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HIGHLIGHTS

- Direct flue gas heat recovery scheme to reduce solvent regeneration is presented.
- Silicone oil identified as non-aqueous heat transfer fluid through TGA.
- No reactions between flue gas/HTF and CO_2 rich-amine solvent/HTF observed.
- 31.2% reduction in reboiler heat duty providing additional 7 MW_e from the LP turbine.

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ABSTRACT

This work presents the feasibility of utilizing a novel heat recovery unit (HRU) technology, to directly recover thermal energy contained in flue gas utilizing an inert non-aqueous heat transfer fluid (HTF), which can then be utilized to lower CO_2 capture costs and increase overall power plant efficiency. Silicone oil was identified as the HTF for use in this direct heat recovery process, as the fluid is thermally stable and resistant to oxidation. Interactions between the HTF and flue gas were investigated with the HTF found to be chemically resistant to SO_2 and CO_2. The viability of using an HTF as an energy vector between flue gas and CO_2 rich-amine solvent was studied via bench-scale experimentation showing distinct phase separation devoid of reactions between the HTF and CO_2 rich-amine solvent. Energy savings in reboiler heat duty with HRU integration were estimated using Aspen Plus simulations. Simulation results suggest HRU integration schemes could lower reboiler heat duty between 15.1% and 31.2%.

1. Introduction

Anthropogenic CO_2 emissions are considered to be a key contributor to global warming [1]. The primary source of CO_2 emissions is the combustion of fossil fuels, such as coal and natural gas, which are dominant in the current electrical power sector [2]. Carbon capture and sequestration (CCS) is one of the best options to decrease CO_2 emissions and allow for sustainable utilization of fossil fuels [3]. Three categories of CO_2 capture technologies are being developed to reduce emissions from coal-based power generation including pre-combustion, post-combustion and oxy-fuel combustion [4,5].

Post-combustion CO_2 capture techniques include absorption by chemical solvents such as monoethanolamine (MEA) [6], chilled ammonia [7,8], and 2-amino-2-methyl-1-propanol (AMP) [9], solid adsorption [10], calcium looping [11], and membrane techniques [12,13]. Implementing CO_2 capture through post-combustion processes appears to be the most promising, as it enables retrofitting of existing power plants. Aqueous amine solvents are regarded as the best option for large-scale CO_2 capture from a coal-fired power plant due to the technology's maturity, cost effectiveness and capability to handle large volume flue gas streams. MEA has been widely recognized as a vital solvent for CO_2 capture, due to its fast reaction rate and high CO_2 selectivity. Further, MEA-based solvents have been proven at commercial scale, and are usually considered as a baseline for comparison with alternative carbon capture technologies [14,15].

However, MEA's regeneration requirements significantly reduce power plant efficiency [16,17]. MEA's heat of regeneration for a 90% CO_2 capture process from a conventional coal-fired power plant is approximately 3.6–4.0 MJ kg^{-1} CO_2, lowering coal-fired power plant efficiency by 20–40% [16,18,19]. To reduce amine solvent regeneration

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Nomenclature

HRU	heat recovery unit
CO_2	carbon dioxide
CCS	carbon capture and sequestration
COE	cost of electricity
SO_2	sulfur dioxide
HTF	heat transfer fluid
LP	low-pressure
MEA	monoethanolamine
MDEA	methyldiethanolamine
AMP	2-amino-2-methyl-1-propanol
PZ	piperazine
PC	pulverized coal
TGA	thermogravimetric analysis
FTIR	Fourier infrared spectroscopy
DSC	differential scanning calorimetry
BPR	back pressure regulator
Nu	Nusselt number
Pr	Prandtl number
Re_D	Reynolds number
NTU	number of transfer units
ε	effectiveness
h_D	convective heat transfer coefficient, W/(m^2 K)
C_p	specific heat capacity, kJ/(kg K)
D	diameter of ropes, m
k	thermal conductivity, W/(m K)
A	total surface area, m^2
C_{min}/C_{max}	capacity rates of fluids

energy, significant efforts have been devoted to developing new amine solvent formulations [20] and blends [21], which have the potential to improve energy efficiency and reduce overall carbon capture costs. Sakwattanapong et al. [22] experimentally studied the stripper heat duty requirement for MEA, diethanolamine (DEA), methyldiethanolamine (MDEA), AMP and blended amine solvents in a bench-scale setup and found that DEA and MDEA require less reboiler heat duty than MEA. Commercial adoption relies heavily upon technical and economic feasibility at a large scale which is dependent upon many properties including CO_2 solubility, energy consumption for regeneration, chemical reaction kinetics, mass transfer characteristics, and solvent stability [23].

In addition to solvent choice, process configurations play an important role in stripper reboiler heat duty [24,25]. Process modification schemes such as rich-solvent splitting [26], overhead condenser bypass [27], or altering the stripping pressure via a multi-pressure stripper [20] have been reported to achieve an energy reduction of 8–20%, compared to a conventional MEA-based capture process. Ahn et al. [26] showed the combination of absorber intercooling, condensate evaporation and lean amine flash modifications results in 37% reduction in terms of low-pressure (LP) steam required. Jung et al. [28] suggested an alternative stripper configuration by combining rich vapor compression and cold solvent split can reduce the solvent regeneration energy requirement to 2.75 MJ kg^{-1} CO_2, 15% lower than the conventional

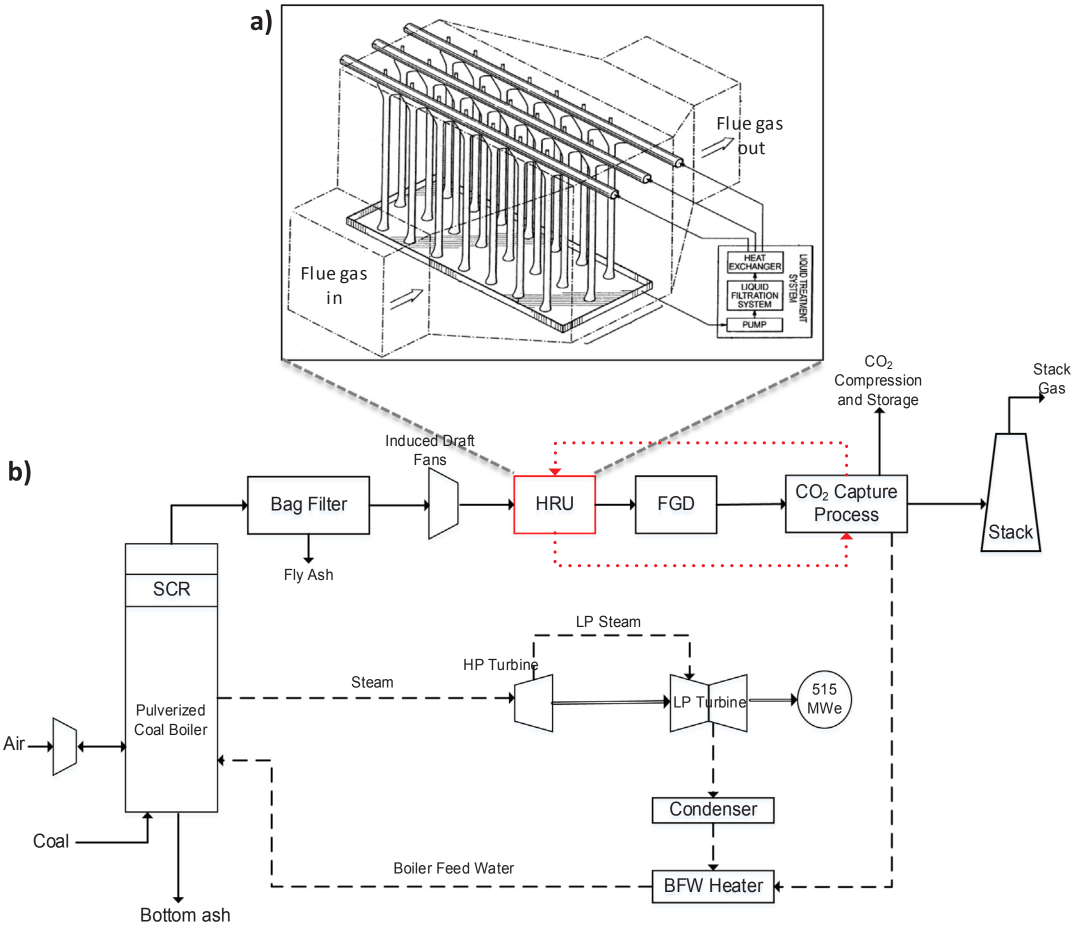

Fig. 1. (a) Schematic of cross-flow HRU, (b) block flow diagram of a coal-fired PC power plant showing location of HRU to reduce CO_2 capture costs.