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Optimization of pre-combustion capture for thermal power plants using Pinch Analysis

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ABSTRACT

Carbon dioxide emissions from the chimneys of thermal power plants create major environmental risks. Therefore, an important step toward reducing the emissions in these power plants can be the carbon dioxide pre-combustion capture process. In this paper, a 150 MW thermal steam cycle power plant fueled by bagasse was studied. The power plant has an efficiency of 32.74%, and emits 246.52 t/h carbon dioxide. First, the design and simulation of a suggested pre-combustion carbon dioxide capture process was outperformed. In this process, the amount of carbon dioxide separation and capture using mono ethanol amine (MEA) 30 wt% as solvent is 90%. In this condition, the mass flow of bagasse was increased about 60% to keep the plant efficiency constant. At the same time, the energy loss as a result of the addition of the carbon dioxide recovery unit was around 11%. The process was optimized through Pinch Analysis to reduce energy waste and fuel flow. Moreover, it was indicated that power plant efficiency could be increased around 8% by integrating the hot exhaust gases from the gasification unit with power plant boiler using a heat recovery steam generation (HRSG) unit. With this modification, bagasse consumption was decreased by 23%.

1. Introduction

One of the most important issues facing researchers today, leading to significant global climate change is greenhouse gas emission to the atmosphere. Carbon dioxide (CO_2) is the most significant anthropogenic greenhouse gas, arising mainly out of power generation. Carbon dioxide capture and storage (CCS) is one of the measures required for the reduction of CO_2 emission. CO_2 capture processes can be divided into three general categories: (1) Post combustion capture, (2) oxy-fuel combustion, and (3) pre-combustion capture [1]. Many processes are available for separating carbon dioxide from gas mixtures based on physical absorption, chemical absorption, adsorption, membrane processes, etc. In the standard absorption process, flue gas in the absorber contacts with the lean solvent. The CO_2 is absorbed by the solvent, which is sent to the stripper and heated there to release the CO_2. Finally, the regenerated solvent is re-cycled to the absorber [2].

Several studies have indicated that high selectivity can be reached with absorption processes using chemical solvents, with the result being the increased production of pure CO_2 [3]. Davidson [4] and Kothandaraman et al. [5] reported that recovery of carbon dioxide using chemical solvents was more practical. Comparing different solvents, they found that Mono Ethanol Amin is the best for carbon dioxide separation in terms of energy consumption and Techno-Economics. Addition of CCS processes to power plants increases the energy loss, reducing the produced net power by 10–15% [6]. In 2011, Kunze et al. [7] conducted a study using exergy analysis on an integrated gasification combined cycle (IGCC) power plant with a CCS unit, and found that much of the energy was wasted in the gasification unit. The energy loss caused by the addition of a CCS unit could be reduced by the employment of various methods. In the processes where solvents were used to absorb gas, the energy required for solvent recovery could be reduced by changing the type of solvent [8].

It is worth saying the total energy requirement in the reboiler can be reduced by improving the design of the solvent recovery unit. Besides, the use of the heat generated by CCS process in the steam cycle can contribute to the decreased energy loss resulting from CCS unit [9]. Romeo et al. [10] suggested that the optimal method is to extract saturated steam midway through the low-pressure section of the turbine. In this method, the lowest quality

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steam is used to meet the reboiler requirements. Additionally, Mimora et al. [11] used 14% of the heat generated in the condenser of the stripper to heat the inlet water of boiler feed water.

Pfaff et al. [12] studied the usage of heat lost from the desorber overhead condenser and from the CO_2 compressor into the boiler feed water. They also studied the number of coolers required among CO_2 compressors for optimization and use of the heat losses of these coolers in the steam cycle. Duan et al. [13] suggested the use of the heat of outlet gases from the regeneration process, and the heat recovered from a carbon dioxide compressing unit. Pinch Analysis is a practical method in optimizing CCS process. This method determines the minimum energy required by a process through maximizing the heat recovery of the process [14]. Besides, solvent regeneration needs a considerable amount of heat, provided by extracting steam from low-pressure turbines and exhaust steam [15]. Harkin et al. [14,16] used Pinch Analysis and heat integration combined with linear programming to reduce energy losses in a base power plant with pre- and post-combustion capture. Bernier et al. [17] used multi-objective optimization to optimize natural gas combined cycle (NGCC) with post combustion capture. Khalilpour et al. [18] investigated Pinch Analysis to reduce the energy penalty from 19% to 15.4% of solvent-based post-combustion carbon capture processes. In similar studies, Leng et al. [19] used Pinch Analysis to reduce the waste energy from 17.6% to 12.3%.

This study is aimed at designing pre-combustion capture unit for a 150MWe power plant fueled by biomass. This process is also, optimized using Pinch Analysis and heat exchanger network (HEN) optimization to reduce not only carbon dioxide emission but also heat waste caused by adding CCS to power plant. To achieve the goal, three kinds of studies were conducted; first is base case steam cycle power plant without CO_2 capturing, second is integration of base case power plant with pre-combustion capture unit, and third is optimization of heat exchanger network.

2. Base case: biomass power plant

A 150MWe biomass thermal steam cycle power plant with an efficiency of 32.74% is considered as the basis consisting of four parts. Reboiler, as the first part of the unit, is used to convert energy and evaporate water. The temperature and pressure of outlet steam from the reboiler are 540 °C and 126 bar, respectively. The steam quantity is about 525 t/h while the plant is working in high performance. There are 3 co-axial turbines, including a high-pressure turbine with one blend, a medium-pressure turbine with three blends, and a low-pressure turbine with one blend. The outlet steam from the high-pressure turbine becomes warmer in boiler before entering to the medium-pressure turbine. The turbines have a bypass route consisting of high-pressure and low-pressure valves, which can pass the outlet steam to the direct air condenser. In this type of condenser, the outlet steam from low-pressure turbine, which is under vacuum, is entered to the air condenser directly and is cooled down by 30 fans and is ultimately converted to the saturated water. The saturated water is entered to a condensate tank and is pumped to the water steam cycle. The schematic of the process is shown in Fig. 1.

2.1. Biomass analysis

Sugarcane bagasse which is the sugarcane residue after sugar extraction is a resource of papermaking lignocellulosic fibers. This material has been used as fuel in some developing countries. Sugarcane bagasse is produced at an approximate rate of 4.3 Mt/y in Iran [20]. The information of consumed bagasse as fuel for boiler is presented in Table 1.

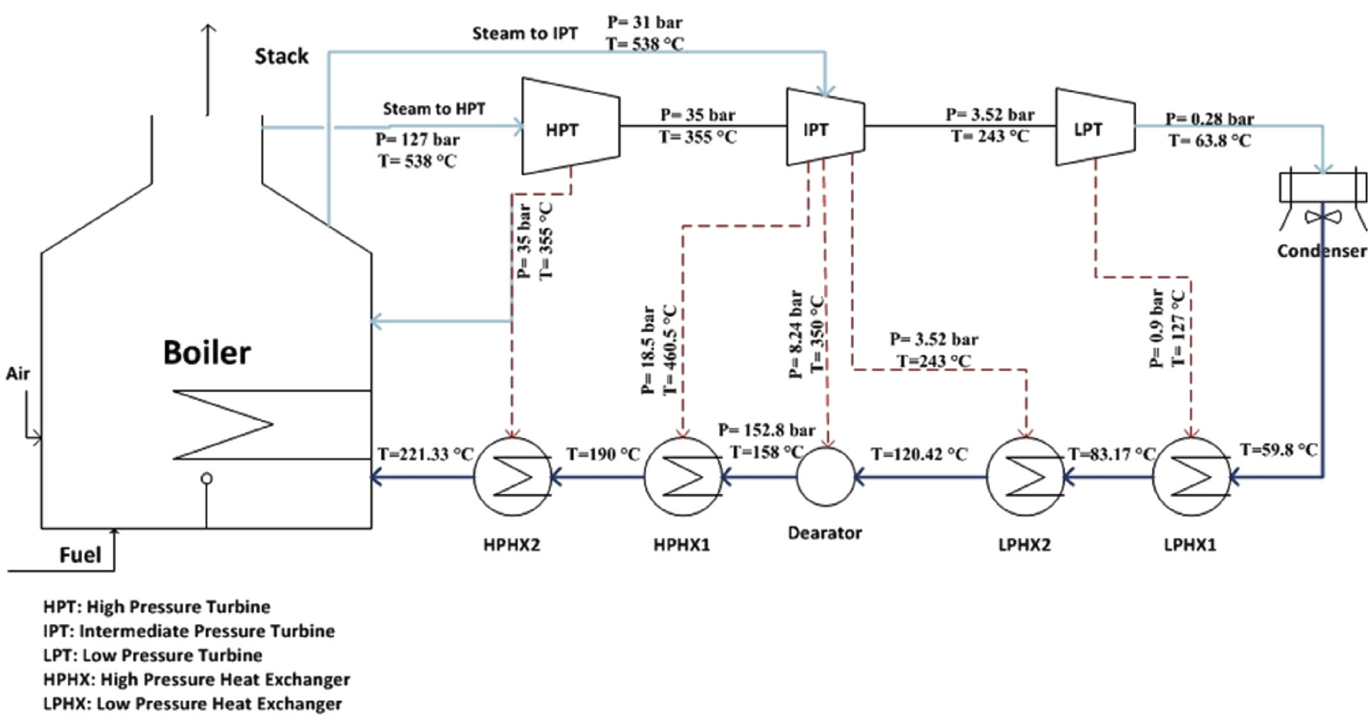

Fig. 1. Base case steam cycle power plant scheme.

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