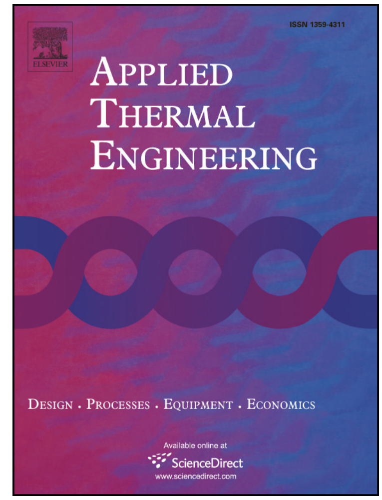

Research Paper

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Energetic and exergetic optimized RANKINE cycle for waste heat recovery in a cement factory

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Abstract

The cement industry is one of the largest industries with regard to energy consumption. In the current study, the waste heat from the chimneys of Sabzevar cement factory was used to generate power with the use of the steam cycle in order to improve the energy efficiency. The results revealed that the increase in the boiler pressure decreased the total amount of the recovered energy due to the increase in the final temperature of the exhaust gases. But, the steam cycle efficiency was increased. Therefore, there would be an optimum pressure for the recovery boiler based on the energy and exergy analyses. Accordingly, the maximum exergy absorption from the waste heat of the chimneys of Sabzevar cement factory occurred at the pressure of 891.8 kPa. Considering the work consumption of air-cooled condenser fans, the maximum net power occurred at the recovery boiler pressure of 1398kPa. The highest overall energy and exergy efficiencies also occurred at this pressure. Moreover, the effects of the important operating parameters, including the maximum cycle temperature, environmental temperature and condenser pressure on the optimum pressure were investigated. Results indicated that the boiler optimum pressure was independent from the operating parameters and remained constant, when these parameters changed.

Keywords: Cement production; steam cycle; waste heat power generation; energy and exergy analyses.

1. Introduction

The global cement production in 2014 reached 4.2 billion tons. With the annual production of 75 million tons, Iran is the fourth largest producer in the world after China, India and the United States. Table 1 shows the annual production of cement for different countries[1]. After the steel industry, the cement is one of the largest industries regarding energy consumption[2]. Energy consumption represents about 40% to 60% of the cost of the cement production[3,4]. The cement industry accounts for about 2% of the energy consumption in the world[5,6]. In Iran, the cement industry accounts for about 3% of the energy consumption[7]. In a cement factory, the heat energy represents about 75% of the total energy consumption and the electrical energy accounts for 25% of the total energy consumption[6]. Cement is manufactured through two processes, which involve a dry process and a wet process. The average energy consumption in a wet process accounts for 5.29Gj, whereas the average energy consumption in a dry process accounts for 3.4GJ [8–10]. Furthermore, about 40% of the energy that enters the kiln system is wasted through three important heat sources, including the exhaust gases of the kiln chimney, hot exhaust air of the clinker cooler, and the losses of the rotary kiln to the surroundings[11]. In recent years, the power generation by waste heat in the cement factories has significantly increased. The heat recovery from the waste heat of the rotary kiln surface has received less attention due to its operational problems. Thermodynamic cycles such as ORC, steam cycle and Kalina cycle can be used to generate power from the waste heat of the chimneys of the cement factory. The main difference between the above-mentioned cycles is their working fluids. The steam cycle is the most common cycle for power generation whose working fluid is water[12]. The main advantage of this cycle is the low initial cost because of the simplicity of its technology[13].

ORC is very similar to the steam cycle except that it uses an organic working fluid. The organic fluid is a fluid whose critical temperature is less than that of the water[14]. This cycle has the highest efficiency for the low temperature thermal sources [15]. There are several heat sources and applications in which the ORC can be used. These heat sources and applications include solar thermal[16], geothermal[17], biomass[18], and waste heat from power plants[19].The main disadvantage of this cycle is the high initial cost of the equipment installation[13].

The working fluid of the Kalina cycle is a combination of water and ammonia[20]. The efficiency of the Kalina cycle is high. One of the reasons of its high efficiency is the thermal matching between the heat source and the