A Framework of Exergy Efficiency Analysis for Cogeneration Power Plant in Cement Production

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Abstract

As a major energy consumer, cement production industry generates a large amount of waste heat during the clinker production process. There are also lots of dust and sulfur dioxide and nitrogen oxide emission accompanying with the waste heat loss, which are aggravating the eco-environment. It is necessary to develop new energy-saving technologies and push the waste heat utilization in cement industry to improve the utilization rate of waste heat from cement. In this study, an exergy efficiency analysis was conducted for the cogeneration power plant in cement production process. The results showed that cement production system can achieve heat recovery effectively with the cogeneration system.

Keywords: cement production, cogeneration power plant, exergy efficiency

1. Introduction

The cement industry as a major energy consumer has produced large amount of waste heat to the environment during the calcination stage. The previous studies showed that the heat loss from the rotary kilns accounted for 30-40% of the total energy input in cement production [1, 2]. Thus, cogeneration power plant has been widely applied in cement production as it can recycle the waste heat into generate electricity and reduce the electricity cost.

Exergy proposed by Rant in 1956 is expounded from the second law of thermodynamics [3-5]. It can measure the maximum work which is required to its equilibrium state in the irreversible process between the system and the external environment. Thus exergy can be applied to the resources accounting and optimization of system energy consumption and environmental impact assessment. Wang (2009) carried out an exergy analyses for different cogeneration power plants in cement industry, demonstrating that exergy losses in turbine, condenser, and heat recovery vapor generator are relatively large, and reducing the exergy losses of these components could improve the performance of the cogeneration system [6].

In this study, an exergy efficiency analysis was conducted for the cogeneration utilization power plant in cement production process. Sec.2 is the description of methodology. Sec.3 listed the major results and conclusions.

2. Material and methods

2.1 Cogeneration system

The cogeneration system is composed of two waste heat boilers, one of which is the air quenching cooler (AQC) boiler from kiln head, with another is the suspension preheater (SP) boiler from kiln tail, and a set of steam turbines and generator. The system can recycle the heat generated by the furnace and the cooled exhaust gas. Because the waste gas is the media in heat transferring of the kiln cogeneration, the system converts the gas with low exergy into the electricity energy with high exergy through the waste heat precalcining. Water was also consumed during evaporation process, however, the amount of exergy loss during this stage can be negligible compared to exhaust gas and electrical energy. This study accounts for the input exergy of the cogeneration system including the sensible heat exergy provided by the AQC boiler and the SP boiler, the self-use of the power generation system, and the output exergy, i.e., power generation exergy.

2.2 Exergy calculation

The sensible heat exergy input into the SP boiler, $E_{\text{SP,in}}$, can be calculated as:
The sensible heat exergy output of the SP boiler, $E_{SP,\text{out}}$, is given as:

$$E_{SP,\text{out}} = M \times C \times \left[ (T_{SP,\text{in}} - T_0) - T_0 \ln \left( \frac{T_{SP,\text{in}}}{T_0} \right) \right]$$

(1)

The sensible heat exergy input into the AQC boiler, $E_{AQC,\text{in}}$, is presented as:

$$E_{AQC,\text{in}} = M \times C \times \left[ (T_{AQC,\text{in}} - T_0) - T_0 \ln \left( \frac{T_{AQC,\text{in}}}{T_0} \right) \right]$$

(2)

The sensible heat exergy output of the AQC boiler, $E_{AQC,\text{out}}$, is calculated as:

$$E_{AQC,\text{out}} = M \times C \times \left[ (T_{AQC,\text{out}} - T_0) - T_0 \ln \left( \frac{T_{AQC,\text{out}}}{T_0} \right) \right]$$

(3)

The sensible heat exergy output of the SP boiler, $E_{SP,\text{out}}$, is 1.43E+11 kJ, while the sensible heat exergy output, $E_{AQC,\text{out}}$, is 9.02E+9 kJ, and the exergy of electricity used for power generation is 7.13E+10 kJ. The sensible heat exergy input the SP boiler, $E_{SP,\text{in}}$, is 1.36E+11 kJ, while the sensible heat exergy output, $E_{AQC,\text{out}}$, is 9.02E+9 kJ, and the exergy of electricity used for power generation is 1.27E+11 kJ.

According to the power generation system and its self-use rate, the system exergy loss is 8.76E+09 kJ. The water inside the cogeneration system is mainly recycled. The water consumption exergy is 5.42E+08 kJ except the evaporation loss, which is negligible compared to the system exergy loss. In summary, the total cogeneration system has an exergy loss of 47.39% and therefore the system efficiency is 52.61%, which means that cement production system can achieve heat recovery effectively after application of the cogeneration system.

Meanwhile, the power generated from the utilization process has reduced the external power input, thus it can reduce the exergy loss of other stages indirectly. For example, compared to the baseline scenario, the exergy loss coefficient and the exergy loss rate of the calcination process decreased from 50.04% and 30.38% to 44.60% and 28.52%, respectively. In addition, the quality of the exhaust gas is critical to thermal power generation. It can increase the amount of power generation and further reduce the exergy loss when producing main steam with higher heat exhaust gas and producing hot water or low pressure steam with lower temperature exhaust gas.

**Acknowledgement**

This work was supported by the National Natural Science Foundation of China (No. 71704163), and China Postdoctoral Science Foundation (2018M631418).

**Reference**


