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Integration of Organic Rankine Cycle with Lignite Flue Gas Pre-Drying for Waste Heat and Water Recovery from Dryer Exhaust Gas: Thermodynamic and Economic Analysis

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Abstract

The flue gas pre-drying of lignite produces a moisture rich dryer exhaust gas which can be further cooled to recover the waste heat and water vapor. An environmental friendly power system is investigated in the present work, which integrates the lignite flue gas pre-drying system with an organic Rankine cycle (ORC) to utilize the waste heat to generate power and capture the condensed water. Simulation models of the integrated system are developed, incorporating thermodynamic and economic evaluation indicators. The optimal energy and exergy efficiencies of the ORC system are calculated to be 3.10 % and 24.57 %, respectively, for an evaporation temperature of 51 °C when R245fa is used as the working fluid. Accordingly, the ORC power output is 3.61 MW and the absolute plant efficiency improvement is 0.27 % points. Moreover, 55.17 % of the water vapor can be recovered. The economic performance significantly relies on the specific investment cost of ORC and the electricity selling price. Typically, the break-even points of the specific investment cost are 2300 €/kW and 3700 €/kW when electricity selling prices are 0.05 €/kWh and 0.08 €/kWh, respectively.

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Keywords: Lignite; Flue gas pre-drying; Waste heat recovery; Organic Rankine cycle

1. Introduction

Lignite, with competitive low price, will obtain an increasing share in the fuel market for power

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generation. However, the high moisture content and low heating value features are unfavourable factors in its utilization, because of high investment cost, low energy efficiency, and high CO_2 emissions. Lignite pre-drying concept means the removal of the moisture in the dryer before combustion process. Kakaras et al. [1] found that the integration of pre-drying into lignite-fired power plants resulted in remarkable efficiency improvements. From that milestone, different state-of-the-art designs of pre-drying systems were proposed, using flue gas dryer [2], steam dryer [3], air fluidized bed dryer [4], and combined-type fluid-bed dryer [5], etc. They have shown energy-saving potentials to different extents according to the pre-drying degree, unit capacity, and operating parameters. In general, pre-drying has been recognized as a sensible choice for highly efficient utilization of lignite in power generation.

Moreover, pre-drying is an energy-intensive process, in which most of the heat provided by the drying agent is consumed for moisture evaporation. The dryer exhaust gas carries away waste heat, along with evaporated vapor, which if recovered, would contribute to the overall plant efficiency improvement [6]. The organic Rankine cycle (ORC) is a promising technology to convert low-grade waste heat to electricity. It applies the principle of steam Rankine cycle, but uses organic synthetic or natural substances with low boiling points to recover heat from low temperature sources. A brief overview of ORC architectures can be found in the review article of Lecompte et al. [7] Currently, the ORC has been widely used in solar-aided, biomass-fired, and geothermal power plants, internal combustion engines, and industrial waste heat recovery scenarios. However, the integration of ORC with lignite flue gas pre-drying for waste heat and water recovery from the dryer exhaust gas has not been investigated.

Therefore, the scope of the present work is to study the feasibility of this integration. Thermodynamic and economic analyses models were developed to determine the optimal operation parameters for the ORC system to be integrated with lignite pre-drying system as well as to assess the technical and market feasibility of the concept.

2. System Description

The flue gas pre-dried lignite-fired power system (FPLPS) integrates the boiler-steam cycle with hot flue gas drying (Fig. 1). Through pre-drying, the humidity of lignite decreases and the heating value increases, so that the boiler efficiency can be evidently improved. The dryer exhaust gas has a high concentration of evaporated vapor. To recover the waste heat, especially latent heat from the gas, a standard ORC circuit is integrated, which is composed of an evaporator, an expander, a generator, a condenser and a pump.

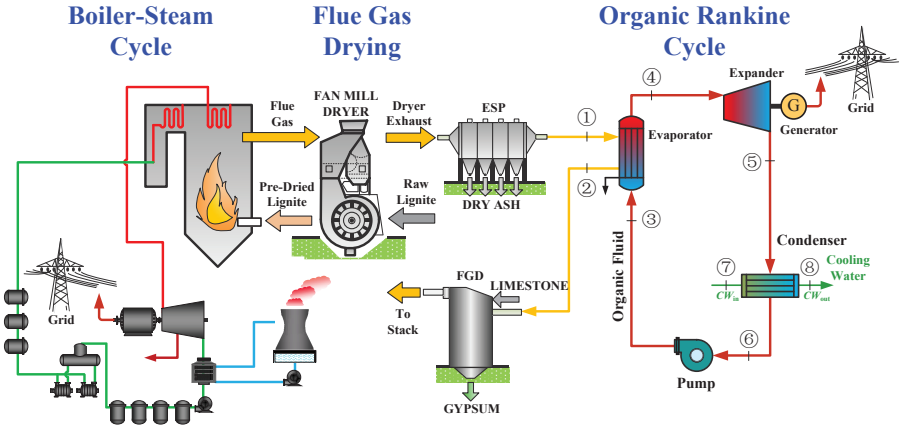

Fig. 1. Flow chart of the FPLPS integrated with organic Rankine cycle.