Applied Thermal Engineering 110 (2017) 442–456

Contents lists available at ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Research Paper

Water extraction from high moisture lignite by means of efficient integration of waste heat and water recovery technologies with flue gas pre-drying system

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HIGHLIGHTS

- Energy-saving potential of FPLPS in different cold-ends and lignite types is evaluated.
- Water-saving of FPLPS is realized through recovery of water extracted from lignite.
- Integrations of low pressure economizer and spray tower with FPLPS are proposed.
- Thermodynamic and economic performances of different schemes are investigated.

ARTICLE INFO

Article history:
Received 7 March 2016
Revised 21 August 2016
Accepted 27 August 2016
Available online 28 August 2016

Keywords:
Lignite
Flue gas pre-drying
Waste heat utilization
Water recovery
Economic analysis

ABSTRACT

The flue gas pre-dried lignite-fired power system (FPLPS) integrates the fan mill flue gas dryer with an open pulverizing system and yields an increase of the boiler efficiency. Particularly, the dryer exhaust gas contains a large amount of vapor removed from high moisture lignite, which exhibits great potential for waste heat and water recovery. Two available options are considered to realize the extraction of water from lignite: the low pressure economizer (LPE) for water-cooled units and the spray tower (SPT) integrated with heat pump for air-cooled units. This paper aims at evaluating the energy saving and water recovery potentials of the FPLPS integrated with both schemes. Results showed that the plant efficiency improvement of the FPLPS at base case varied from 1.14% to 1.47% depending on the moisture content of raw lignite. The water recovery ratio and plant efficiency improvement in the optimal LPE scheme were 39.4% and 0.20%, respectively. In contrast, 83.3% of water recover ratio and 110.6 MW_{th} heat supply were achieved in the SPT system. Both schemes were economically feasible with discounted payback periods of around 3 years. Moreover, parametric analysis was conducted to examine the economic viability of both schemes with different lignite types and market factors.

1. Introduction

Lignite is extensively used today in power generation for its large deposits, stable supply and competitive price. However, lignite-fired power plants are particularly plagued by low boiler thermal efficiencies attributed to the high moisture content and low calorific value of the raw lignite. Through pre-drying, a portion of the moisture is removed prior to the fuel combustion in the furnace, thus the boiler efficiency can be improved remarkably. Nikoloupolos et al. [1] defined the lignite pre-drying concept as "a step toward optimal lignite utilization and upgrade", and reviewed the currently existing drying technologies. Moreover, many researchers focused their attention on the design and optimization of the integration of lignite pre-drying with power systems. The proposed flue gas pre-dried lignite-fired power system (FPLPS) [2–6], steam pre-dried lignite-fired power system [7–10], and air fluidized bed drying power system [11,12] have shown attractive energy saving potentials. Some novel power systems, integrated with combined-type fluid-bed dryers [13] and vacuum dryers [14], also exhibit strong competitiveness. Obviously, pre-drying is becoming a sensible choice for efficient utilization of high moisture lignite.

Meanwhile, it is convenient to recover water from the high moisture lignite through pre-drying since the moisture removed

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http://dx.doi.org/10.1016/j.applthermaleng.2016.08.178
1359-4311/

Nomenclature

Abbreviation

ACF	annual cash flow
BYH	Baiyinhua lignite
COP	coefficient of performance
DPP	discounted payback period
FPLPS	flue gas pre-dried lignite-fired power system
LPE	low pressure economizer
NPV	net present value
NPVR	net present value ratio
SPT	spray tower
TIC	total investment cost
WFGD	wet flue gas desulfurization
WHWR	waste heat and water recovery
WJF	Wujianfang lignite
YM	Yimin lignite
ZLNE	Zhalainuoer lignite

Symbols

A	heat transfer area of the condensing heat exchangers (m^2)
A_{ar}	ash content on as received basis (%)
C_{ar}	carbon content on as received basis (%)
C_{hp}	cost of the hemp pump devices (M$)
C_{SPT}	cost of the spray tower devices (M$)
c_{coal}	price of standard coal per ton ($/t)
c_e	electricity price ($/kW h)
c_h	district heating supply price ($/GJ)
c_w	water price ($/t)
c_{wt}	water treatment cost ($/t)
f_d	domestic factor
H	humidity (g/kg)
H_{ar}	hydrogen content on as received basis (%)
i	interest rate (%)
LHV	low heating value (MJ/kg)
M_{ar}	moisture content on as received basis (%)
N	the operation hours per year
N_{ar}	nitrogen content on as received basis (%)
n	expected life for the equipment
P_e	power generation (MW)
$P_{e,hp}$	power consumption of the heat pump (MW)
O_{ar}	oxygen content on as received basis (%)
Q_{cw}	heat duty of the circulate water in the spray tower (MW)
Q_{fuel}	fuel heat input (MW)
Q_{hs}	district heating supply amount (MW)
S_{ar}	sulfur content on as received basis (%)
t	years
t_{pp}	pinch point temperature approach (K)
W_{da}	water contained in the drying agent (t/h)
W_{de}	water contained in the dryer exhaust gas (t/h)
W_{rec}	water recovered from the dryer exhaust gas (t/h)
W_{rem}	water vapor removed from lignite (t/h)
$\alpha_{O\&M}$	maintenance cost factor
ΔW_{tot}	total water saving amount (t/h)
ΔW_{WFGD}	the reduction in the WFGD water consumption (t/h)
ΔP_e	net work output increment (MW)
$\Delta \eta_{tot}$	plant efficiency improvement (%-points)
Δr	unit water saving rate (t/MW h)
ξ	ratio of the manufacture and installation cost to the material cost
η_b	boiler efficiency (%)
η_{rec}	water recovery ratio (%)
η_{st}	steam turbine cycle efficiency (%)
κ	conversion factor from heat transfer area to facility weight
φ	ratio of material and coal prices
ψ_A	material price ($/t)

from the fuel is concentrated in the dryer exhaust gas. It is estimated that the water contained in the lignite in China (130 billion tons) reaches up to 70 billion tons, which is equivalent to the water storage of two Three Gorges Reservoirs [15]. If it was possible to extract the water in the lignite and utilize it to achieve zero unit makeup water consumption, the development of lignite-fired power plants would not be subject to rivers, reservoirs and urban planning considerations. This will enhance the appeal of firing high moisture lignite, especially for the regions with limited freshwater supply but plentiful lignite resources. Until now, a little research has been devoted to the exploration of the water recovery potential in pre-dried lignite-fired power systems. Liu et al. [16] investigated the water conservation in lignite-fired power plants using steam pre-drying technology. Regarding flue gas pre-drying system [6], the dryer exhaust gas contains a large amount of vapor removed from high moisture lignite, which exhibits great potential for waste heat and water recovery. Energy and water savings could be realized through the integration of an open pulverizing system with waste heat and water recovery technologies.

The waste heat and water recovery from flue gases has garnered increased attention and concern. The energy research center in Lehigh University conducted experimental tests on water recovery from flue gases [17]. Wang et al. [18] developed an advanced waste heat and water recovery technology to extract water vapor and its latent heat from flue gases based on a nanoporous ceramic membrane capillary condensation separation mechanism. Lyu et al. [19] carried out experiments to investigate the feasibility of recycling the evaporated water during lignite flue gas drying process. Water quality analysis showed that the recovered water, after simple treatment, could be used in desulfurization system. Zhu et al. [20] discussed the combination of absorption heat pump and direct-contact heat exchanger for condensing heat recovery from gas boilers. The flue gas could be cooled below 30 °C to improve the total heat capacity by 12% and recover water vapor by nearly 70%. Amón et al. [21] assessed the waste heat and water recovery opportunities in California tomato paste processing. Herraiz et al. [22] proposed a hybrid cooling system consisting of a gas/gas heat exchanger and a direct contact cooler which could reduce the cooling and process water demand of the combined cycle plant by 67% and 35% respectively. Arsenyeva et al. [23] conducted a case study of waste heat recovery from exhaust gas in tobacco drying process using pinch analysis methodology. Li et al. [24] proposed a novel flue gas deep cooling method based on direct contact heat transfer to reduce flue gas temperature below the dew point of vapor and recover the latent heat and water simultaneously. Terhan et al. [25] examined the use of flue gas condenser to recover the latent heat and water from natural gas-fired boiler. The exhaust gas could be decreased to 40 °C using stainless steel horizontal plain tube bundles. Evidently, it is of significance to evaluate the waste heat and water recovery potentials from lignite flue gas pre-drying exhaust gas, to realize the concept of energy- and water- savings in lignite-fired power plants.

One of the most practical techniques to recover heat and water from flue gases in power plants is to install condensing heat exchangers, in which the flue gas temperature drops below the water dew point and the vapor condenses. The heat transfer performance and industrial application benefits of the condensing heat exchangers have lately been the focus of significant research