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Research Paper

Advanced exergoenvironmental evaluation for a coal-fired power plant of near-zero air pollutant emission

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HIGHLIGHTS

- Simulation of a supercritical coal-fired power plant (SCPP) is carried out.
- Detailed advanced exergy and exergoenvironmental analyses are provided.
- Improvement potential and component interactions for environmental impacts are revealed.
- The environmental impacts of purification units are investigated.

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ABSTRACT

Advanced exergy and exergoenvironmental analyses based on life cycle assessment (LCA) are conducted to an SCPP with and without dust, SO_2 and NO_X mitigation controls. The analyses show that environmental impacts of components are mainly caused by exergy destruction while combustion chamber (COM) still has great potential to reduce pollutant environmental impact reduced by 99.5% by near-zero air pollutant emission standards. Avoidable environmental impact within each component is endogenous other than most regenerative feedwater heaters. COM has the largest environmental impact of exergy destruction but lower avoidable part compared with superheat transfer (SH) including boiling process. Reheat transfer (RH) shows similar avoidable environmental impact but less exergy destruction in contrast with COM. Turbines play well in exergy efficiency and over 50% of environmental impact within intermediate-pressure turbine (IP) can be avoided. Air preheater (APH) displays a higher avoidable environmental impact than condenser (CND) albeit lower exergy destruction. Pumps and fans have small environmental impacts with over 45% can be avoided. Most environmental impact related to pollutant formation is avoidable and endogenous except for wet flue gas desulfurization (WFGD) which imposes a negative environmental impact on other components. The specific environmental impact of electricity generation is higher than European.

1. Introduction

Since an abundance of coal and its secure supply, global coal demand is expected to increase by 15% by 2040 [1]. Coal-fired power plants play an important role over a long period in electricity supply. High-capacity SCPPs that are of increased efficiency and lower emission prevail the electricity generation in China. Additionally, near-zero air pollutant emission standards rise to confront the increasingly severe environmental situation. Specifically, near-zero air pollutant emission standards mean the concentration of dust, SO_2, and NO_X emissions is less than 10, 35, 50 mg/N m^3 respectively under conditions of reference oxygen content of 6%. Enormous large-scale power plants have been equipped with sophisticated flue gas purification units to meet standard requirements in China. There are hot disputes on whether it is worth spending so much of money and effort to make it. It is of great significance to answer the puzzle from the assessment of environmental impact of the complex power generation system and the influence of flue gas purification system at global and local levels.

Lots of publications [2,3] discussed the technical efficiencies of purification units and pollutant emission rates but studies on the environmental impacts of flue gas purification units on the system are lacking. Meij and Winkel [4] pointed out that a coal-fired power station configured with the electrostatic precipitator (ESP)

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Nomenclature

Symbol

E	exergy rate
m	mass flow rate
e	specific exergy
h	specific enthalpy
s	specific entropy
B	rate of environmental impact
Y	component-related environmental impact
b	specific environmental impact based on exergy
y_D	exergy destruction ratio
f_b	exergoenvironmental factor
r_b	relative environmental impact difference
P	power output
p	pressure
t, T	temperature

Abbreviations

SCPP	supercritical coal-fired power plant
LCA	life cycle assessment
COM	combustion chamber
SH	superheat transfer including boiling process
RH	reheat transfer
LP	low-pressure turbine
WFGD	wet flue gas desulfurization
ESP	electrostatic precipitator
TSP	total suspended particulate
SCR	selective catalytic reduction
BF	boost fan
MGGH	Mitsubishi recirculated nonleak type gas-gas heater
HP	high-pressure turbine
IP	intermediate-pressure turbine
GEN	generator
IDF	induced draft fan
DEA	deaerator
FWP	feedwater pump
CND	condenser
CIRP	circulating pump
CEP	condensate extraction pump
LPH	low-pressure feedwater heater
HPH	high-pressure feedwater heater
BFPT	boiler feedwater pump turbine
APH	air preheater
FDF	forced draft fan
LHV	lower heating value

Greek symbols

α	air–fuel ratio
Δ	difference
ε	exergy efficiency
β	ratio of the chemical exergy to the net calorific value
η_s	isentropic efficiency
η_m	mechanical efficiency

Superscripts/Subscripts

PH	physical
CH	chemical
AV	avoidable
EN	endogenous
EX	exogenous
UN	unavoidable
i/j	stream
0	atmospheric reference state pressure 101.325 kPa and temperature 0 °C
c	coal
lh	latent heat
S	sulfur
f	fraction
C	carbon
H	hydrogen
O	oxygen
N	nitrogen
k	component
D	destruction
F	fuel
L	loss
P	product
dif	dissipative component
CO	construction period
OM	operation and maintenance period
DI	disposal period
PF	pollution formation
in	inlet pollution
out	pollution
ms	main steam
rs	reheated steam
fw	feedwater
fg	flue gas
ex	exhaust
tot	the overall system
pu	purification units
up	higher terminal temperature difference
low	lower terminal temperature difference

and WFGD had negligible contributions to background pollutant concentrations, particularly NO_X and PM10. Benko et al. [5] found that flue gas desulphurization processes had about 80% lower environmental impact than the uncontrolled release of SO_2 into air based on LCA. Singh et al. [6] developed new normalization factors of environmental damage to evaluate an Indian coal-fired power plant with and without CO_2, SO_2 and NO_X mitigation controls. Álvaro Restrepo et al. [7] evaluated a pulverized coal power plant from perspectives of exergy and environmental analyses based on LCA, which have been applied in other energy conversion systems. [8,9] This method concentrates on quantifying environmental impact but lacks the ability of its allocation on components within the system. Meyer et al. [10] proposed a conventional exergoenvironmental analysis to solve this dilemma.

In the conventional exergoenvironmental analysis, the environmental impacts obtained by LCA are apportioned to the exergy streams and it can identify causes of environmental impacts. Investigations through this approach have been conducted to various power plants [11–13]. To avoid the shortages of recognizing improvement potential and component interactions, conventional analyses was replaced by advanced exergy-based analyses [14]. Advanced exergy-based analyses can be extended to advanced exergy analysis and advanced exergoenvironmental analysis. In terms of advanced exergy analysis, it has been applied to SCPP [15], SCPP with CO_2 capture [16], and an existing industrial plant [17]. As for exergoenvironmental analysis, it has been targeted to a simple combined-cycle power plant [18], as well as various renewable or clean power systems [19,20].