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Heat transfer characteristics and energy-consumption benchmark state with varying operation boundaries for coal-fired power units: An exergy analytics approach

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HIGHLIGHTS

- The idea of 'energy-consumption benchmark state' was proposed.
- The parameters type includes controllable boundaries in operation and maintenance and uncontrollable boundaries.
- Models for benchmark state were built under varying boundaries involving load rate, coal quality and ambient temperature.
- The effect of boundary factors on the heat transfer coefficients of heat and mass transfer process has been illustrated.

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ABSTRACT

The energy-saving analytics of coal-fired power units in China is confronting new challenges especially under varying working conditions and operation boundaries, such as load rate, coal quality and ambient temperature. Compared with traditional optimization of specific operating parameters, the idea of energy-consumption benchmark state was proposed. The exergy analytics was introduced to determine the energy-consumption benchmark state, with the minimum exergy destruction under varying operation boundaries. The heat transfer coefficient and condenser vacuum were calculated by considering the influence of operation boundaries in different coal quality and ambient temperature. The coal rate was figured out for the coal fuel in different composition and calorific values, for the circulating water condition in different temperatures and cooling modes with different load rate. As a case study, the energy consumption model of a 1000 MW ultra supercritical power unit was built on the platform of Ebsilon and tested by practical operation data of power unit. The results show that the heat transfer coefficient and condenser vacuum change greatly with different coal composition and circulating water temperatures under different working conditions. The energy-consumption benchmark state of power unit is also operation condition and boundary-dependant. The coal rate of such benchmark state is considerably less than that of the actual state with the same operation boundaries. This makes great reference for the operation optimization of coal-fired power units.

1. Introduction

Energy conservation in thermal power generation has been increasingly concerned in China for the last decades for several facts. The installed capacity of thermal power units has accounted for 71.5% of the total by the end of 2012 with the coal consumption for power generation shared a steady increase from 47.67% in 2005 to 52.67% in 2011 of the nation-wide coal consumption in overall industries; the coal rate of thermal power generation has reduced dramatically by 59 g/kWh from 385 g/kWh in 2001 to 326 g/kWh in 2012 [1]. It is of great significance for coal-fired power generation to reduce the coal consumption and pollutant emission in considerable extent.

The in-depth energy-saving analytics of coal-fired power units in China is confronting new challenges. Firstly, the coal-fired power units are complex systems with great number of subsystems, equipment and instruments, and there are high-dimension, nonlinear and strong coupling correlation between different

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Nomenclature

Abbreviation

AH	air preheater
AT	spray desuperheater
CAV	cavity
HTC	heat transfer coefficient
CON	condenser
CT	cooling tower
CWP	circulating water pump
CWT	circulating water temperature
DA	decreasing amplitude
DEA	deaerator
ECON	economizer
ES	extraction steam
ESFC	energy specific fuel consumption
FRH	final reheater
FSH	final superheater
FWP	feedwater pump
G	electric generator
GCCR	gross coal consumption rate
HGI	Hardgrove grindability index
Hn	the nth feed-water preheater
HPRH	horizontal primary reheater
HP	high pressure turbine
IP	intermediate pressure turbine
LF	lower part of the furnace
LHV	lower heating value
LP	low pressure turbine
PR	pendant-tube riser
PRH	platen-type reheater
PSH	platen-type superheater
SSH	screen-type superheater
ST	the secondary turbine
UF	upper part of the furnace
VPRH	vertical primary reheater
WW	water wall

Symbols

y	energy-consumption variable of a power unit state
$\vec{x}$	vector of controllable variables of a system
x_a	ath controllable variable
$\vec{x_i}$	ith vector of controllable variable
$\vec{v}$	Vector of noncontrollable variables of a system
v_b	bth controllable variable
$\vec{v_j}$	jth vector of noncontrollable variable
$(\vec{x}, \vec{v})$	power unit state
$(\vec{x}, \vec{v})^b$	energy-consumption benchmark state
$f(.)$	function captures the mapping between $(\vec{x}, \vec{v})$ and y
$\vec{s}$	vector of boundary variables
s_c	cth boundary variable
$\vec{s_i}$	ith vector of boundary variable
$(\vec{x}, \vec{v})^b_{\vec{s_i}}$	energy-consumption benchmark state with boundary $\vec{s_i}$
$(\vec{x_j}, \vec{v_j})_{\vec{s_i}}$	jth power unit state with boundary $\vec{s_i}$
Q	the heat transfer
k	heat transfer coefficient
A	the heat transfer area
Δt	the temperature difference
$y_{\vec{s_i},j}$	energy-consumption variable of jth power unit state with boundary $\vec{s_i}$
Ω	feasible space of boundaries
$Q(\vec{x_j}, \vec{v_j})_{\vec{s_i}}$	the heat between boundary $\vec{s_i}$ and the corresponding power unit state $(\vec{x_j}, \vec{v_j})_{\vec{s_i}}$
$k_{\vec{s_i}}$	heat transfer coefficient with boundary $\vec{s_i}$
$g(.)$	function captures the mapping between boundary $\vec{s_i}$ and $k_{\vec{s_i}}$
$E_{D,k}$	exergy destruction of device k
E_F	exergy of the fuel
E_L	exergy loss
E_P	output exergy
b	energy specific fuel consumption
b_{min}	theoretical minimum energy specific fuel consumption
$b_{D,k}$	energy specific fuel consumption of device k
b_L	energy specific fuel consumption loss
$b_{\vec{s_i},j}$	energy specific fuel consumption of jth power unit state with boundary s_i
P	product

Superscripts

b	benchmark
w	number of controllable variables
m	number of noncontrollable variables
n	number of boundary variables

Subscripts

l	index of variables
i	index of variables
j	index of variables
p	index of variables

sections. It is of more uncertainties, in this mean, to illustrate, evaluate and optimize the economic performance of coal-fired power units [2]; Secondly, the performance of unit proper tends to deteriorate in continuous operation. The heat transfer characteristics, for instance, would become worse by the contamination, ash deposition, erosion and slagging on heat exchanging surfaces [3], in addition to the increasing power consumption of fans and pumps, the decreasing cylinder efficiency resulted from the damaged glands and sealing [4]; Thirdly, the energy-consumption features are dynamically time-dependant especially under the off-designed working conditions and operation boundaries, such as load rate, coal quality and ambient temperature etc [5–7]. The coal-fired power units, even the large-scale power units, have to responsible for the peaking of power grid, partly due to the rapid development of power generation from renewable energy in China [5]; the coal type and coal quality, terribly affected by the demand-and-supply fluctuation of coal market, are quite different and deviated from the designed conditions during the practical operation [6]; in addition, the ambient conditions, such as the ambient temperature and humidity, influences the energy-consumption of coal-fired power units by changing power consumption of pumps and fans and introducing different cooling modes, particularly for the air-cooled coal-fired power units [7].

Traditional energy analysis practices are mainly based on the first law and the second law of thermodynamics [8–10], the former of which focuses on the mass and energy balance, neglecting the properties of the system environment or the degradation of the energy quality through dissipative processes. For the latter,