Exergy evaluation of a supercritical coal-fired power plant considering pollution emissions

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Abstract

To study the mutual relationship of the conventional power plant and the pollutant emission requirement, a thermodynamic system model of traditional 600MW coal-fired units coupled with environment protect equipment is established. The equipment of the system is classified according to its function and the environment protection component is treated as dissipative device in the model. The operating boundary is summarized as: load rate, ambient state, fuel composition and pollutant emission restrict which treated as a special power unit running boundary condition. Simulation using different boundary value based on reference model is developed, the corresponding total system performance and characteristic pollutant emission in flue gas is derived. The result show that the exergy destruction of boiler subsystem is about half of the total system fuel in reference model, in addition, the net exergy efficiency of plant is 41% in this condition, the cost of energy and resources consumption for remove the pollutant only account for a little part in the thermodynamic viewpoint. The performance of system and environment protect equipment will be influenced as boundary conditions changed. Emission controlling equipment influences each other while single boundary condition varies, and the desulfurization subsystem in the terminal of flue gas process is affected notable.

Keywords:

Coal-fired power plants; exergy evaluation; emission concentration

1. Introduction

The thermal power generation in China keeps the dominant position in power supplication for decades with the installed capacity and electricity generating capacity scoring 69.34% and 78.36% by the end of 2013[1]. It calls for even stricter criteria for the pollutant emission reduction from thermal power units, such as flue gas dust, SO_2 and NO_X, etc.[2]. For this, the installations for dust removal (de-duster), flue gas desulphurization (FGD) and NOx removal (de-NOx) have been widely equipped in China's coal-fired power plants[3]. These components conversely results in more complication and uncertainty in the safe and economic operation of thermal power units. First, these components enlarge the whole structure of power units and the varying operation boundaries and the coupling effect between components will be of more uncertainties; second, the normal operation of such components arises more electricity consumption. It becomes more substantial to evaluate the complex coal-fired power generation process taking the pollutant emission and environment into account.

Traditional energy analysis practices are mainly based on the first law and the second law of thermodynamics [4, 5], 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, typically as the exergy analysis, concentrates on the irreversibility of processes within system and characterizes the work potential of a system. In the light of this, exergy-based analytics have been introduced to evaluate the economic performance of different power generation systems to get the exergy losses and exergy efficiency of thermal power units[6-9]. These researches, however, are available to obtain a rough distribution of exergy destruction and exergy losses of certain energy systems instead of the causes and features of such losses, let alone considering the pollutant emission and environment factors.

Translating to the effect of environment factor on coal-fired power generation; the exergy environment method was used incorporate with life cycle assessment method to evaluate the components of the whole power generation system, in which the environment factors were distributed in each stream of exergy flow[10,11]; Kopac discussed the effects of ambient temperature on the exergy destructive, especially the ratios of the irreversibility rates to the fuel exergy rate[12]. Most of these researches are based on rough and conceptual model, ignoring the coupling effect and interaction between power generation unit and pollutant removing systems, the varying operation boundaries of coal-fired power units such as load, coal composition and ambient temperature etc[13,14].

This paper focuses on the evaluation of energy-consumption behavior for large coal-fired power units considering pollutant emission under varying operation conditions and boundaries. For this purpose, the main parts of this paper include:

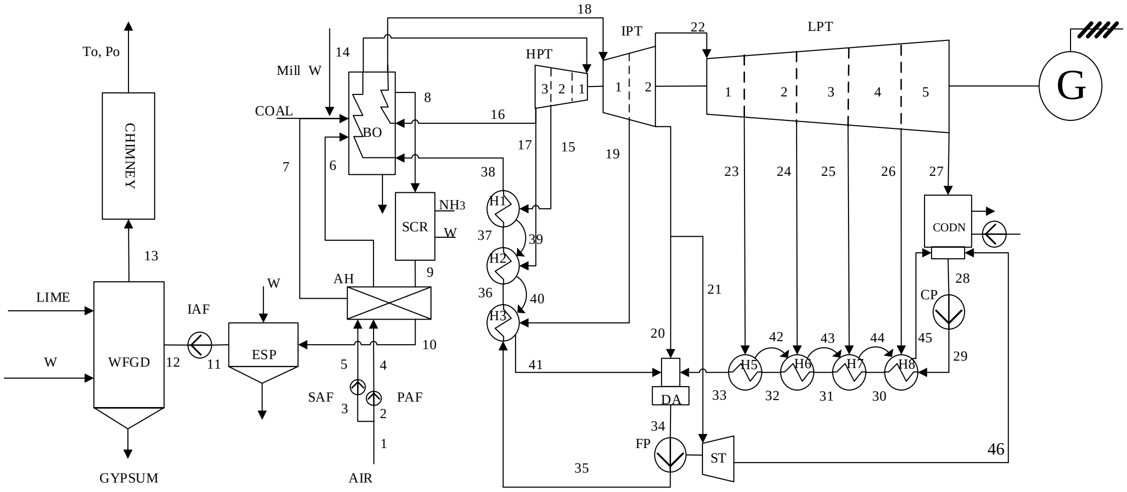
- to classify the components and operation boundaries depending on the individual function and influence;
- to build the exergy-based analytic and evaluation model with the constraints of multi boundary including emission criteria for SO_2, NOx and dust;
- to determine the key parameters and interaction of the system and pollutant emission under specific working conditions and boundaries in the exergy method.

2. System description

2.1 Schematic process description

The thermodynamic system is shown in Fig.1, which is a single-reheat supercritical coal-fired conventional water cooling plant with a capacity of 600 MW in Tianjin city of China, it consists of the main energy converting components, auxiliary devices and the environment protect installations.

The coal combustion process and the heat transfer between flue gas and working fluid occur in the boiler (BO). The main steam is expanded in the high-pressure turbine (HPT) and then the steam is reheated and expanded through the stages of intermediate-pressure (IPT) and low-pressure turbines (LPT). The generator (GEN) is driven by the steam turbine to product electricity for the system. A surface condenser (COND) is used to remove heat to the environment from exhausted steam. a feedwater regenerative system with three high-pressure heaters (H1-H3), a deaerator (DA) and four low-pressure heaters (H5-H8) is configured for efficiency. The flue gas is exhausted from the gas discharge with a high temperature and a large amount of composition harm for the environment (such as nitrogen oxides, sulphides, soot, and greenhouse gases). The flue gas has its most NOx removed via a selective catalytic reduction (SCR) device with a corresponding consumption of reactant ammonia, most dust of the gas is removed by an electrostatic precipitator (ESP) and the gas pressure is enhanced by induced air fan (IAF). Then the gas enters the wet desulphurization system (WFGD) and then exhausted to the environment through the chimney.



AH: air preheater
SAF: second air fan
PAF: primary air fan
H: feedwater heater
HPT: high pressure turbine

IPT: intermediate pressure turbine
LPT: low pressure turbine
DA: deaerator
FP: feedwater pump
ST: steam turbine

WFGD: wet flue-gas desulfurization
IAF: induced air fan
ESP: electrostatic precipitator
BO: boiler
SCR: Selective Catalytic Reduction;

GEN: generator
CON: condenser
CCP: circulating cooling-water pump
CP: condensate pump;

Fig. 1. Schematic diagram of the reference supercritical power plant

2.2 Functional equipment classification

As seen in Fig.1, the thermal system in a power plant consists of variety types of components and many pipes which connect components together, the component can be divided into following types: productive component, which fulfil a productive purpose, and dissipative components such as condenser, and environment protection devices, whose contribution can only be detected when considering the efficiency of the overall system, environment protection devices (SCR, ESP and WFGD) consumes electricity and the materials (such as ammonia and lime stone, etc.) to purification gas and minimize the damage for the environment. The greenhouse gas (such as CO_2) emission devices, which are a type of dissipative components different from other ones, are not considered in this paper.

2.3 System Boundary classification

To ensure the proper function of the above system, which transform fuel energy into electric in a high-efficiency and environmental-friendly way, not only should the various components be allocated properly, but the performance of power plant system should also depend on the system boundary conditions, which means the prerequisites restrict for the proper working of power plant.

(1) Load rate: The output load is usually determined by the grid in normal running, most electricity is provided by coal-fired plants especially in China, and thus the units have the task requirement of peaking loads, in this way, load rate a boundary condition given form outside of the productive thermal system.

(2) Ambient Temperature: Ambient temperature T_0 is concerned with the time of day and seasons. Meanwhile, the changing of ambient temperature will affect heat exchanging effect of cycle cooling system related with condenser, and subsequently impact the total system. In the boiler side, ambient temperature will directly impact on the heat exchanging of air preheater (AH) which infect exhaust flue gas temperature and the flue gas acid dew point.

(3) Coal composition: The fuel composition may distinct with the design value extremely for a fixed structured boiler subsystem. The primary characters of coal are heating value, composition of ash, moisture, sulphur, nitrogen etc. As the lower heating value (LHV) of coal is different, to ensure the output load meet the grid demand, the amount of flow gas and pollutant will be changed either, which will directly impact flue gas cleaning systems and energy consumption of fans. To meet the requirements of the designed situations, however, several different kinds of coal can be blended together based on the previous optimization study.

(4) Pollutant emissions limit: Pollutant emission of power plant is regarded as a special boundary condition here, causing pollutant emission standard is usually implemented by local policy and is forced by laws. In China recently, the pollutant emission concentration of certain specified harmful composition in flue gas meeting the standard value regulated by government rise to the primary precondition for the plant running. This paper only consider the pollutant of NOx, SO_2 and dust in the flue gas.

3. Exergy Analysis

In general exergy can be divided into four parts: physical exergy, chemical exergy, kinetic and potential[5], the latter two parts are negligible as the small change in this study. The physical part, considering as the maximum theoretical useful work, is calculated as a system interacts with an equilibrium state. The chemical exergy is an important part in boiler subsystem processes[15], and is obtained with the departure of the chemical composition of a system from its chemical equilibrium.

Applying the first and the second laws of thermodynamics, the following exergy balance is obtained:

$$\dot{E}_Q + \sum_i \dot{E}_i = \sum_e \dot{E}_e + \dot{E}_W + \dot{E}_D \qquad (1)$$

$$\dot{E}_Q = (1 - \frac{T_0}{T_\mathrm{i}})\dot{Q}_i \qquad (2)$$

$$\dot{E}_w = \dot{W} \qquad (3)$$

$$e = e^{ph} + e^{ch} \qquad (4)$$

It should be noted that the chemical exergy of mixtures such as flue gas is defined as follows [15]:

$$e_{mix}^{ch} = [\sum_{i=1}^{n} X_i e^{ch_i} + RT_0 \sum_{i=1}^{n} X_i ln(X_i)] \qquad (5)$$

where n, X, e^{ch}, R and T_0 represent the composition number of the mixture, the molar fraction of each composition, the specific chemical exergy of each composition, universal gas constant and the reference temperature, respectively. For the inlet fuel specific exergy of the plant system, the value is calculated as:

$$e_f = \xi \cdot LHV \qquad (6)$$

Where, the exergy factor ξ based on LHV can be taken as 1.06 [15]. In an F-P conceptual description, the exergy loss only appears at the level of the overall system [7,15]. Hence, the exergy balance of the k-th component is expressed as:

$$\dot{E}_{F,k} = \dot{E}_{P,k} + \dot{E}_{D,k} \qquad (7)$$

For the overall system, it turn out:

$$\dot{E}_{F,tot} = \dot{E}_{P,tot} + \sum\nolimits_k \dot{E}_{D,k} + \dot{E}_{L,tot} \qquad (8)$$

The exergetic efficiency of the k-th component and the overall system are written as Eq. (9) and (10) respectively:

$$\varepsilon_k = \frac{\dot{E}_{P,k}}{\dot{E}_{F,k}} = 1 - \frac{\dot{E}_{D,k}}{\dot{E}_{F,k}} \qquad (9)$$

$$\varepsilon_{tot} = \frac{\dot{E}_{P,tot}}{\dot{E}_{F,tot}} = 1 - \frac{\sum \dot{E}_{D,k} + \dot{E}_{L,tot}}{\dot{E}_{F,tot}} \qquad (10)$$

To identify the part of total fuel exergy input destroyed within the k-th component, the exergy destruction ratio $y_{D,k}$ is defined as:

$$y_{D,k} = \frac{\dot{E}_{D,k}}{\dot{E}_{F,tot}} \qquad (11)$$

It should be emphasized that in the exergy analysis, the dissipative components such as gas cleaning units and throttling valves as well as condensers without any thermodynamic benefits when considered in isolation cannot be assessed by the exergetic efficiency [11].

4. System model and simulation

4.1 Simulation of reference model

4.1.1 Basic information

The software Ebsilon was employed in the calculation process. Some assumptions are also made to perform the model solution. For the steam/water cycle, turbines are segmented to 10 stages by the bleed steam extraction points; for the boiler system, the furnace and heaters including economizer are treated as a whole module, and the flue gas and air were treated as ideal gas, respectively. The pollutant remove installments are treated as dissipative components and their characteristic parameters were set with the policy threshold value in the reference model. For SCR, neglecting the heating from the external heat source to the ammonia liquid. The power consumption caused by the dilution of NH_3 is converted into a constant factor according to the actual operation in the real plant; as for the ESP electrostatic precipitation, the coefficient of the trace leakage of the air is taken into consideration with a value equals to 1% of the imported gas volume. And the standard state of gas is moisture free, 6% O_2 concentration, more details see Table 1.

Table 1. Basic data and key assumption of the model

Item	Description
Main unit parameter	Power: 600 MW; superheat steam: p=242 bar, t=566 ℃; reheat steam: p=36.4 bar, t=566 ℃; exhaust pressure: 0.056 bar;
Turbine cylinders	Efficiency for Turbine 1 to 10 : 0.67, 0.90, 0.90, 0.91, 0.92, 0.91, 0.90, 0.92, 0.92, 0.91; ST: 0.88
Feedwater preheaters	Δt_{pin} : H1, -1.7 K, H2-3, 0K, H 5-8, 2.8K; Extracting pipe ΔP : H1-3, 3%, H4-8, 8%; Feedwater t=275℃
Generator	Efficiency: 98.8 %
Condenser	Δt_{pin} : 5K; include the CP work
Boiler	Air ratio: 1.2; fly ash ratio: 0.9; Portion of unburnt in fly ash: 0.005 ΔP : 0.002 bar
Air preheater	Air leakage ratio: 0.05; primary air ratio: 0.2; Δt_{pin} :60 K
AUX device	Efficiency of fan, pumps and related motor: 0.85; shaft efficiency: 0.998
SCR	NO_X concentration: 100 mg/Nm^3; SCR Work consumption proportional to NH_3 mass flow; t of NH_3: 313K
ESP :	Separation ratio: 0.998; air leakage ratio: 0.015; ΔP : 0.002 bar; dust concentration : 30 mg/Nm^3;
WFGD:	Separation ratio: 0.99; ash removal ratio: 0.5 Ca/S ratio: 1.035; lime stone purity: 0.87; ratio of work consumption to captured SO_2 mass flow:0.38 kWh/kg
Ambient dead	P_0=1.01 bar and T_0=293.15 K.

state

For the WFGD system, neglecting its complex equipment details, only set the separation rate of the SO_2, in the meanwhile, because of its attached removal function with DUST, set its dust separation rate to 0.5. At the same time, the quality of the impurity lime stone that the desulfurization system consumed is proportional to the SO_2 that is separated, the pipeline resistance that the system need to overcome is provided by the induced draft fan. The solve process is depended on the equations of all components which established on the basis of mass, energy and exergy balances principle. The detailed information of the basement model is shown in table1. Part of coal samples' composition information are listed in Table 2.

Table 2. Information of coal composition (as received, sorted by the LHV).

Item	C_{ar}	H_{ar}	O_{ar}	N_{ar}	S_{ar}	A_{ar}	M_{ar}	LHV	[a]S*	[a]ASH*
unit	%	%	%	%	%	%	%	kJ/kg	%	%
1	70.8	4.5	7.1	0.7	2.2	11.7	3	27800	0.33	1.76
[b]2	57.5	3.11	2.78	0.99	2	23.72	9.9	21981	0.38	4.52
…	…	…	…	…	…	…	…	…	…	…
19	48.3	3.3	8.6	0.8	1	23	15	18645	0.22	5.16

[a]: $S^* = S_{ar} \times 4187 / LHV$; $ASH^* = A_{ar} \times 4187 / LHV$

[b]: Sample used in reference model

4.1.2 Exergy results and error analysis

The simulation result of the reference model is given in the Table 3 and Table 4. The detaied distribution of component exergy destruction in Table 3 shows that the system net exergy effiiciency ε_{tot} is 0.41, the rest exergy of fuel is destructed in the process equipment, primary in the BO component, which account for 50.1 percent of the total input exergy of the plant system. The CON and AH component exergy destruction ratio is 2.16 and 1.13 percent, respectively, that is outstanding in the rest equipment. It should be note that the exergy destruction ratio of the three environment protect equipment(ENV), i.e. SCR, ESP and WFGD are 0.004, 0.15 and 0.23 respectively, it is obviously that SO_2 remove system take the biggest part of the destruction of exergy in the ENV. The E_D of all turbine cylinder is bigger than condenser component (CON), the exergy destruction in total feedwater preheaters is smaller than CON, it can be seen E_D in the three ENV is account a little proportion, and which in the other auxiliary equipment (AUX) is bigger than the in the ENV, and in the similar level of GEN.

An error analysis are shown in Table 5, which show that the accuracy meets the need of research well and the assumption used in modeling process are reasonable.

Table 3. Exergetic result of the reference model

Unit	$\dot{E}_{F,k}$, kW	$\dot{E}_{P,k}$, kW	$\dot{E}_{D,k}$, kW	ε_k	$y_{D,k}$,%
BO	1461804.26	729445.69	732358.57	0.50	50.10
HPT1	41302.15	34895.65	6406.51	0.84	0.44

HPT2	134032.39	127427.72	6604.67	0.95	0.45
HPT3	40567.03	38304.25	2262.78	0.94	0.15
IPT1	92908.35	89167.73	3740.61	0.96	0.26
IPT2	74788.61	71759.19	3029.42	0.96	0.21
LPT1	74862.58	70375.67	4486.91	0.94	0.31
LPT2	79006.87	74211.07	4795.80	0.94	0.33
LPT3	37218.47	34677.52	2540.95	0.93	0.17
LPT4	50560.83	46404.93	4155.89	0.92	0.28
LPT5	44175.56	39036.18	5139.38	0.88	0.35
H1	27053.46	26023.30	1030.16	0.96	0.07
H2	40175.76	37789.47	2386.28	0.94	0.16
H3	21475.65	19399.04	2076.60	0.90	0.14
DA	66149.17	62984.32	3164.85	0.95	0.22
H5	17717.47	14831.44	2886.04	0.84	0.20
H6	6496.73	5655.03	841.71	0.87	0.06
H7	7222.61	5676.36	1546.25	0.79	0.11
H8	3255.78	2277.48	978.31	0.70	0.07
FP	19835.26	16006.36	3828.91	0.81	0.26
CON	31502.81	-	31502.81	-	2.16
GEN	626259.91	619997.31	6262.60	0.99	0.43
AH	70556.09	54067.47	16488.62	0.77	1.13
CCP	3105.94	0.00	3105.94	0.00	0.21
CP	876.32	636.33	239.99	0.73	0.02
MILL	1761.70	-	1761.70	-	0.12
PAF	2076.44	1228.41	848.03	0.59	0.06
SAF	1414.98	1011.44	403.54	0.71	0.03
IAF	4339.61	3386.63	952.98	0.78	0.07
SCR	63.25	-	63.25	-	0.004
ESP	2251.62	-	2251.62	-	0.15
WFGD	3416.45	-	3416.45	-	0.23
TOT	1461804.26	600246.10	861558.16	0.41	58.93

Table 4. Result of environment protect equipment in the reference model (kW)

Item	Unit	Value	Item	Unit	Value
Ammonia consumption	kg/s	0.09	DUST concentration	mg/Nm^3	29.17
Lime stone consumption	kg/s	4.65	WFGD efficiency	%	99.02
SO_2 concentration	mg/Nm^3	98.97	SCR efficiency	%	71.96
NO_X concentration	mg/Nm^3	99.22	ESP efficiency	%	99.78

Table 5. Simulation error analysis

Name	q, kJ/kWh	ε_{tot},%	SO_2, mg/Nm3	NO_X, mg/Nm^3	Dust, mg/Nm^3
Design	7587	41.04	100	100	30
Simulation	7575	41.06	98.97	99.22	29.17
Error (%)	0.16	0.05	1.03	0.78	2.77

4.2 Varying boundaries condition simulation

4.2.1 Varying boundaries assumption

To understanding the characteristic of the calculation has been developed when varying different boundary values separately, some of the assuming and set value should be announced here.

Every operational component and environmental protection equipment can reach the variation range limit in the setting values, and the change of each boundary condition is independently.

Load range: 30-100%, with step of 10%, valve wide open condition and turbine maximum continue rate condition of steam turbine are calculated either.

Temperature range: 5-25℃, with step of 2℃. 18 groups of coal samples have been used. Every coal sample is bituminous coal frequently used in large coal-fired power plant of China and is ranked by LHV, which ranges from 18645 to 27800kJ/kg. To describe the different characters of each coal, the value of converted ash and converted sulphur are shown in the last two column of the Table 2.

Boundary condition of pollutant emission: For SCR and ESP the setting value refers to the chimney inlet (i.e. the outlet of WFGD). NO_X concentration: 30-350mg/Nm^3; dust: 10-190mg/Nm^3.For WFGD the setting value refers to its removal efficiency, which ranges from 91% to 100%.

4.2.2 Varying boundaries simulation results

Comparing the reference model state, the results of the relative variation of exergy destruction of main components vs. load rate show that the tendency of each component is similar, which is decrease when loads rate drops, and the variation of exergy destruction in the feedwater preheaters is more obviously. The ENV equipment has the same character performance, the destruction of which is about 50 percent of the reference condition.The total system net exergy efficiency got the max value in the reference profile, when loads condition offset the design value in the reference model, the efficeieny diminishs, the effiicency decreace to 0.366 from 0.41 as loads drop down to 30 percent of the reference condition, and it deceace to 0.407 as load increase to 115 percent.

The results of the relative variation of exergy destruction of main plant components as the environment temperature changes from 5 to 25 degree Celsius shows that, the E_D of the AUX changes lager comparing with the rest components, which varies not obviously as the temperature changes. The net exergy efficiency of the total system is contrary with the AUX exergy destruction. However, the range of changes of the absolute value is not prominent, which turn out 41.062 to 41.061 percent as the temperaure varies from 5 to 25 degree celsius,obviously it caused by the exergy destruction in the AUX equipments leads the total axiliary equipment energy consumption increase.

The exergy destruction of boiler has a rising trend as the decreasing of LHV in keeping other boundary conditions unchanging, and as a sequence, the exergy efficiency of system diminished, however, the trend is not strictly correlated with LHV. To provide further insights of the influence of varying coal composition, the composition of sulphur and ash are converted to a standard (S^* and ASH^*). In this point, the relevant results shows that when S^* increases from 0.036% to 0.581%, the energy consumption of WFGD grows from 312 kJ/kg to 5265kJ/kg, the consumption of lime stone grows from 0.42 kg/s to 7.16 kg/s, It demonstrates that as the increasing of S^*, the energy cost the system paid is increasing.

In the varying rang of SO_2 concentration, the system efficiency rise a little, i.e. from 41.06 to 41.08 percent. the lime stone and WFGD energy consumption corresponnding varies from 4.69-4.27 kg/s and 3450-3140 kJ/kg. when outlet dust concentration vary from 9 to 85 mg/Nm^3, the capture ash mass flow rate of the ESP equipment is reduced as the dust concentration boundary increase. The ESP efficiency and plant net exergy efficiency both decrease as when the concentration increase. Due to the WFGD equipment has the ability of separation of part of ash in flue gas, thus the dust boundary considering here is do influence the energy consumption of WFGD system, thus the total auxiliary equipment exergy destruction leads to reduce of the ε_{tot} in a narrow range, which is 41.02 to 41.063 percent. The exergy consumption and the reactant material (ammonia) consumption are diminishing as the NO_X concentration arising. an increase of the outlet NO_X concentration lead to increase of both the SCR equipment efficiency and the system net efficiency, the former due to the ammonia mass flow rate diminishing with the flue gas cleaning burden, the latter, i.e. the system efficiency has similar reason with the ESP subsystem when varying the outlet dust concentration, that means the decrease of the efficiency is due to the WFGD subsystem, the acid composition of the flue gas is increase when the NO_X concentration emission boundary varies. However, the total absolute change rang of the system efficiency is 0.037 percent, which is not notable.

6. Conclusions and discussion

A model of thermodynamic system was established in this study, which combined with contaminants removal equipment and the traditional exergy analysis method was used to evaluate energy consumption of the whole system. Some useful conclusions show in the follow:

In the reference model, when environment protect equipment (ENV) treated as dissipative components, the exergy consumption of boiler system account for about fifty present of the entire system fuel supplication, while the total ENV account for a small proportion, which has the similar level with generator component. The exergy consumption of main components are decreased as load reduced, the net exergy efficiency of system perform the maximum value at reference condition.

Environmental temperature have a significant impact on auxiliary equipment efficiency, and will affect the exergy efficiency of whole system. LVH of different coal samples has a large influence on boiler subsystem. As converted sulphur and converted ash composition increases, exergy and reactant resources consumption raising, It indicates that the energy consumption cost and operational cost are increased to keep the emission boundary.

Considering the pollutant emission restrict as a special boundary condition, the performance of each pollutant removal equipment affects by the other while the boundary value changes, and the WFGD subsystem in influenced by the SCR and ESP equipment notably.

On the perspective of thermodynamics, the cost of energy consumption and operational is bearable when tighten up the pollutant emission boundary, however, the installment economic investment may grow up in a sharp way on this condition. On the other hand, the thermodynamic study of the entire system couple with the environment protect equipment is necessary to provide useful information using in the following operating optimization and diagnosis.

7. Acknowledgements

The author was supported by the Joint Funds of the National Natural Science Foundation of China (U1261210, 51306050), the Fundamental Research Funds for the Central Universities (12QN05，2014XS18, 2014XS19, 2014XS13), the National Science Found for Distinguished Young Scholars of China (51025624), and the National Science and Technology Support Program (2011BAA04B03-2).

Nomenclature

Greek symbols

η	efficiency
ξ	exergy factor
ε	exergetic efficiency
Δ	deferrence

Mathematical symbols

c	concentration of certain composition, mg/Nm^3
$\dot{E}$	exergy destruction, kW
$\dot{Q}$	heat, kW
e	specific exergy, kJ/kg, for gas, kJ/kmol
y	exergy destruction ratio
n	composition number of the mixture
p	Pressure, kPa
R	universal gas constant, kJ/(kmol K)
t	temperature in degree Celsius, ℃
T	absolute temperature, K
X	molar fraction of each composition

Subscripts and superscripts

0	reference environment conditions
D	exergy destruction
e	outlet
f	fuel
F	fuel exergy
i	inlet
k	k-th component
mix	mixtures
P	product exergy
pin	Pinch point
tot	total amount of the overall system

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