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A Modified Specific Fuel Consumption Analysis for Predicting the Rearrangement of Energy System Structures

Ligang Wang[a,b], Shengwei Huang[a], Lingnan Wu[a], Ningling Wang[a], Changqing Dong[a], Yongping Yang[a,*], George Tsatsaronis[b,†]

[a]*Institution of Advanced Energy Systems, North China Electric Power University, BeinongRd 2, Beijing 102206, China*
b, Institut fuer energietechnik, Technische Universitaet Berlin, Marchstr. 18, Berlin 10587, Germany

Abstract

One variation of exergy analysis, specific fuel consumption (SFC) analysis, was modified according the advanced exergy analysis, where exergy destructions within each component were split into endogenous/exogenous and avoidable/unavoidable parts, and by combining the energy-savings effects of each component. The modified analysis approach can help locate not only the weak points at the component level but also certain bottlenecks from the topology viewpoint, which may indicate adding or deleting some components, or enhancing the thermodynamic interactions between different process or subsystems. The modified approach was then applied to a conventional coal-fired power plant. The detailed spatial distribution of SFC within the current system at different partial-load conditions were deeply discussed at both component and process levels. Further splitting of SFC and the energy-saving effects of each process are also obtained and discussed. The results show that combustion and heat-and-mass transfer processes have the largest SFC. Heat-and-mass transfer process and the vent process have the greatest avoidable SFCs. The closer the component to the final product, the larger its influence on the overall performance, and, thus, a small improvement to these components may lead to a large reduction in the overall fuel consumption. More effective energy-saving measures of coal-fired power plants should focus on the match of heat transfer at intermediate-and-low temperature level and the breakage of the isolation of heat transfer subsystems, especially enhancing the interaction between the air preheating process and feedwater preheating process.

Keywords: *Specific fuel consumption analysis; Advanced exergy analsysis; Energy-savings effects; Topology rearrangement*

* Corresponding author. Tel.:+86 10 617 72011; fax:+86 10 617 72177.
E-mail address: yyp@ncepu.edu.cn
† Corresponding author. Tel.:+49 30 314 24776; fax:+49 30 314 21683.
E-mail address: tsatsaronis@mailbox.tu-berlin.de

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1. Introduction

As exergy analysis is usually conducted according to the energy balances at given conditions, it cannot reveal the thermodynamic interactions among components and the true energy-saving potential of each component, and cannot predict certain topology improvement which may be more effective for reducing the overall fuel consumption. The advanced exergy analysis developed by Tsatsaronis [1,2], which splits the exergy destruction into endogenous/exogenous and avoidable/unavoidable parts, has been widely used to provide additional information on the sources and avoidability of exergy dissipation from a deeper viewpoint. Nevertheless, the energy-saving effects of each component at the system level presenting which component should be improve with a higher priority are not involved in these approaches.

Combining with these new concepts, what can be found by exergy analysis are not only the component bottleneck of the given system but also the topology bottleneck, which may indicate new means by changing the system structure (e.g. adding or deleting certain components, or enhancing the interactions between different relatively-isolated subsystems) to improve the overall performance.

Considering the high acceptance in the industry field, one variation of exergy analysis, the specific fuel consumption analysis [3] which uses specific fuel consumption (SFC, a levelized exergy dissipation based on product quantity), is modified in accordance with the above concepts. The modified approach is then applied to a coal-fired power plant. The detailed distributions of SFC at different partial-load conditions are deeply discussed at the process but not the component level. The interactive influences among different processes, and the energy-saving potentials and effects of each process are discussed. This paper is an attempt to establish a bridge between thermodynamic analysis and topology rearrangement.

Nomenclature

b, b_a	specific fuel consumption of the system, auxiliary SFC due to exergy destruction (D) or loss (L)
b_{min}^{TH}	the minimum theoretical fuel consumption of the system
$\dot{E}_D$, $\dot{E}_L$	exergy destruction, exergy loss
F, e_F	fuel quantity, the specific exergy of the fuel
SFC	specific fuel consumption
P, e_P	product quantity, the specific exergy of the product

2. Methodology: the modified specific fuel consumption analysis

2.1. Conventional specific fuel consumption analysis

The conventional specific fuel consumption analysis of an energy system with a single product can be expressed as Eq. 1, which is a rearrangement of exergy balance equation at the system level.

$$b=\frac{F}{P}=\frac{e_P}{e_F}+\sum_{k=1}^{N_u}\frac{\dot{E}_{D,k}}{P\cdot e_F}+\frac{\dot{E}_{L,tot}}{P\cdot e_F}=b_{min}^{TH}+\sum_{k=1}^{N_u}b_{aD,k}+\sum_{m=1}^{N_L}b_{aL,m} \quad (1)$$

Here, the subscripts D, L and tot are related to exergy destruction, exergy loss and the system. When the system is reversible without any exergy destruction or losses, the total specific fuel consumption is the minimum theoretical specific fuel consumption (b_{min}^{TH}), 123 g standard coal per kWh.

2.2. Endogenous/exogenous and avoidable/unavoidable SFC

For each component or process, the SFC can be split into endogenous and exogenous parts (as Eq. 2), which are caused by the thermodynamic imperfection of the component itself and the remaining components, respectively.

$$b_{aD,k} = b_{aD,k}^{en} + b_{aD,k}^{ex} \quad (2)$$

As for each component (process) there are unreachable (unavoidable) conditions due to either technical or economic reasons, the SFC of the considered component (process) can be further split into avoidable/unavoidable parts as Eq. 3.

$$b_{aD,k} = b_{aD,k}^{av} + b_{aD,k}^{un} \quad (3)$$

2.3. Energy-savings effect of each process

A performance change of a component or process affects the fuel-consumption level of the whole system. The variation amount of SFC of the system does not equal to that of the component or process, where the initial change of the system happens. If we improve a component (process) k to its unavoidable condition, the initial system condition (superscript old) will reach another stable (or equilibrium) condition (superscript new). The SFC difference between these two conditions is considered to be the energy-saving effect of the component on the whole system.

$$b_k^e = b_k^{new} - b^{old} \quad (4)$$

In this way, a four-level fuel-consumption diagnosis at the process level as mentioned above promises to reveal deeper energy-savings bottleneck of energy systems, and, more importantly, to predict certain change or rearrangement of the system topology.

3. Case study, results and discussion

The modified approach was applied to a conventional ultra-supercritical coal-fired power plant [2] with a full load capacity of 660 MW, main and reheat steam conditions of 25.4 MPa/ 571 °C and 4.2 MPa/ 569 °C. The results of the four-level energy-saving diagnosis are presented in Fig. 1 and Table 1.

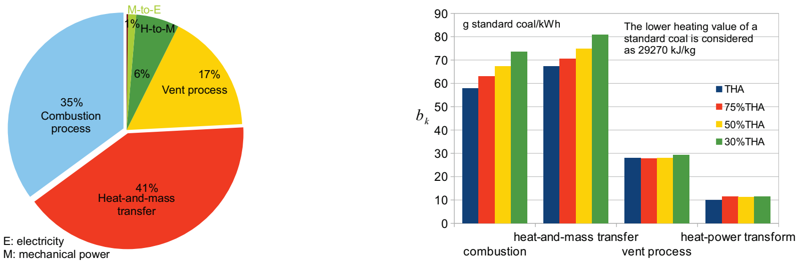

Fig. 1. (a) Spatial distribution of SFC of key processes at full load; (b) The SFC of key processes at different partial-load conditions

Table 1. Results of four-level energy-saving diagnosis (a) key processes; (b) certain sub-processes (unit: g/kWh)

Key processes	b_k	b_k^{ex}	b_k^{av}	b_k^e
Combustion process	58.0	15.5	7.5	3.98
Heat-and-mass transfer	67.5	11.6	29.1	9.42
H-to-M process	10.0	1.5	3.9	9.93
Vent process	28.0	0.0	10.0	-

Key heat transfer process	b_k	b_k^{ex}	b_k^{av}	b_k^e
Boiling and superheating	47.6	7.41	22.7	0.67
Reheating	7.1	1.19	3.3	0.75
Feedwater preheating	2.7	0.90	0.2	1.22
Air-preheating	4.0	0.55	2.9	6.79

Figure 1(a) shows that the heat-and-mass transfer, including boiling-and-superheating, reheating, feedwater-preheating, air-preheating and condensing processes has the largest specific fuel consumption at full load. The share of vent process should not be overlooked, while that of M-to-E and H-to-M are not too much. The increases of specific fuel consumption in partial loads are mainly due to the SFC increase of heat-and-mass transfer and the combustion processes as shown in Fig.1(b). From these aspects, the combustion and heat-and-mass transfer processes are almost equally important for reducing the overall SFC but the remaining process seems not that important.

However, Table 1(a) shows more additional information on how to reduce the fuel consumption of the whole system. The upstream processes, the combustion and heat-and-mass transfer processes, are influenced greatly by the downstream ones, the improvement of which can greatly reduce SFC of the upstream processes. The heat transfer process has the largest avoidable SFC, followed by the vent process. The closer the process to the final product, the larger contribution of its improvement to the overall SFC. That is why the energy-saving effects of H-to-M and heat transfer processes are almost similar. In addition, the effect of the vent process is determined by the means of utilization of low-grade heat.

Table 1(b) shows the boiling-and-superheating process has very large exogenous SFC and its subprocesses are influenced by each other, resulting in a relatively small energy-saving effect. The improvement of feedwater preheating process can directly reduce the steam extraction amount and thus has greater effect. The air-preheating process has a small SFC and is connected with the environment, and its improvement can dramatically reduce the overall SFC. The breakage between the isolated subprocesses, the air-preheating process and feedwater preheating process should be emphasized. The intermediate heat in the air-preheating process should be provided to be efficiently used in the feedwater-preheating process.

4. Conclusions

The specific fuel consumption analysis has been modified with new concepts to reveal the sources and the avoidability of SFC, and the energy-saving effects of each component. The modified approach is proven to be very promising in predicting the improvement of system structure.

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Biography

Ligang Wang is a Ph.D. candidate in both North China Electric Power University and Technische Universiaet Berlin. His research interests focus on the development of thermodynamic approaches for efficient system synthesis, and analysis, optimization and integration of energy systems, especially large-scale coal-fired power plants.