JOURNAL OF IRON AND STEEL RESEARCH, INTERNATIONAL. 2015, 22(3): 226-231

Multi-boiler System Optimization in Integrated Steelworks Based on Decomposition and Coordination Method

Guang-yu MA[1,2], Wen-qiang SUN[1], Wei-dong LI[2], Zhu YE[1], Jiu-ju CAI[1]

(1. Institute of Thermal and Environmental Engineering, Northeastern University, Shenyang 110819, Liaoning, China; 2. Ansteel Research Institute of Iron and Steel, Anshan Iron and Steel Group Corporation, Anshan 114009, Liaoning, China)

Abstract: As for the existing problems of boilers in integrated steelworks, the multi-boiler system could be quantitatively optimized with the decomposition and coordination method. Then, case studies were carried out based on the data of an integrated steelworks. Two groups of actual production records were contrastively analyzed, and the calculation results from the optimized program of these two groups indicated that for groups 1 and 2, the costs fall by 5.06% and 3.79% and the fuel consumptions decrease by 2.72% and 1.45%, respectively, compared with the actual data. To analyze the cost and fuel consumption change under the same condition of total load demand, assigned fuel consumption and water temperature, five sets of data were selected for further analysis. It was shown that the total cost and fuel consumption of the optimized program could fall by 3.5% and 1.6% respectively, compared with the actual production records. The optimal allocation significantly contributed to energy conservation and cost reduction. The effects of the system energy conservation cannot be realized by single equipment energy conservation. They were complementary to each other, and should be put on the same stage.

Key words: boiler; self-owned power plant; integrated steelworks; decomposition and coordination method

Most of steam generated in a self-owned power plant was used to generate electricity, and only a few parts are used in other production processes. Blast furnace gas (BFG), coke oven gas (COG), Linz-Doniwitz gas (LDG) and coal can be mixed in a certain proportion to be used in boilers in self-owned power plants[1,2]. The proportion can be changed as the generation or consumption amount of by-product gas changes, namely buffer adjustment. In this sense, a self-owned power plant is not only a power plant to generate electricity, but also an important adjustment part of gas consumption, self-owned power generation and outsourcing electricity, etc.. Thus, the self-owned power plant contributes to energy consumption reduction and improvement of energy efficiency, by avoiding by-product gas dissipation[3,4].

Low-parameter steam, big and frequent load fluctuation, unstable fuel input, and large energy consumption in auxiliary equipment are the general characteristics of self-owned power plants in iron and steel enterprises, resulting in the high cost and coal consumption. To solve these problems, Akimoto et al.[5] reported a mixed integer linear programming (MILP) model with a penalty cost in the objective function when the surplus gas dissipated. Kim et al.[6,7] considered the penalty function for on/off status of burners in boilers to study the fluctuation level of surplus by-product gas. Because of the input and output volatility and considerable boiler stream amount, self-owned power plants in iron and steel enterprise should not only focus on the boiler energy conservation technologies, but also the system energy conservation methods[8-11]. As for the existing problems of boilers in integrated steelworks, the multi-boiler system was quantitatively optimized with the decomposition and coordination method in this study, contributing to the energy conservation of the self-owned power plant.

Foundation Item: Item Sponsored by the Fundamental Research Funds for the Central University of China (N140203002)
Biography: Guang-yu MA, Doctor, Senior Engineer; **E-mail**: maguangyu.ansteel@163.com; **Received Date**: July 16, 2013
Corresponding Author: Wen-qiang SUN, Doctor; **E-mail**: neu20031542@163.com

1 Decomposition and Coordination Method

In general, the solution of nonlinear problem is a very laborious job. Most of the algorithms transform nonlinear programming problems into a series of unconstrained problems or linear programming problems to solve[12]. There are two main types of methods to solve nonlinear programming: penalty function method and feasible direction algorithm. These two methods are very effective, but they will encounter difficulties in the computation or invalid algorithm when the dimensions of the problem increase.

To avoid the difficulties mentioned above and to make full use of information structure in problems are the foundation of decomposition and coordination method[13-16]. The basic idea is to decompose a general issue P into a number of sub-problems P_i, and the goal is transformed from solving extreme value of general issue to the extreme values of sub-problems. Then, the solution of P can be obtained by coordinating the solution of P_i. However, generally, the coordination relationship is impossible to be satisfied because of the conflict among sub-problems. Thus, a vector intervention or coordinate parameter $\boldsymbol{\lambda}$ is needed to be introduced, and then $P_i(\boldsymbol{\lambda})$ is used instead of P_i. The first-order necessary condition of the objective function and constraint function of nonlinear programming problem should satisfy the following theorems.

Theorem 1 is the Kuhn-Tucker theorem. The following assumptions are made in this theorem:

(1) $\boldsymbol{x}^*$ is the local optima of $\min_{\boldsymbol{x}\in D} f(\boldsymbol{x})$, $D=\{\boldsymbol{x}\mid S_i(\boldsymbol{x})\geqslant 0,\ i=1,2,\cdots,m;\ h_j(\boldsymbol{x})=0,\ j=1,2,\cdots,l\}$;

(2) $I=\{i\mid S_i(\boldsymbol{x}^*)=0,\ i=0,1,\cdots,m\}$;

(3) $f(\boldsymbol{x})$, $\boldsymbol{S}(\boldsymbol{x})$ and $\boldsymbol{h}(\boldsymbol{x})$ are differentiable at point $\boldsymbol{x}^*$;

(4) $\nabla S_i(\boldsymbol{x}^*)$ is linearly independent to $\nabla \boldsymbol{h}(\boldsymbol{x}^*)$ for all $i\in I$.

Then, $\mu_1,\cdots,\mu_m$ and $\lambda_1,\cdots,\lambda_l$ exist to satisfy

$$\begin{aligned}&\nabla f(\boldsymbol{x}^*)-\sum_i^m\mu_i S_i(\boldsymbol{x}^*)-\sum_i^l\lambda_i h_i(\boldsymbol{x}^*)=0\\&\mu_i S_i(\boldsymbol{x}^*)=0\\&\mu_i\geqslant 0,\ i=1,\cdots,m\end{aligned}\qquad(1)$$

In Theorem 2, it is supposed that $D=\{x\in R^m\mid g_i(x)=0,\ i=1,\cdots\}$ is composed of convex function $f(x)$, $g_i(x)$, $x\in R^m$, $y\in R^n$, $g_i(x)=0$. Function $\varphi(x,y)$ is the linear combination of $f(x)$ and $g_i(x)$.

$$\varphi(x,y)=f(x)+\sum_i y_i g_i(x)\qquad(2)$$

If (x^*,y^*) is the solution of function $\varphi(x^*,y^*)=\min_{x\in R^m}\max_{y\in R^n}\varphi(x,y)$, i. e., $\varphi(x^*,y)\leqslant\varphi(x^*,y^*)\leqslant\varphi(x,y^*)$, $\forall x\in R^m$, $y\in R^n$, x^* is the solution of the objective function $\min_{x\in D}f(x)$, meaning that $f(x^*)\leqslant f(x)$, $\forall x\in D$.

2 Boiler Optimal Operation Model

The optimal boiler operation in integrated steelworks is a typical decomposition and coordination problem. Each fuel consumed by a boiler is fixed in this study to obtain the extremum of steam generation by coordination. Then, the sub-problem is changed into a series of linear programming problems whose optimum solution can be obtained easily by conventional method.

2.1 Model

The operation cost C_i of boiler i includes two parts: fuel consumption cost and the cost of electricity consumed by auxiliary equipment.

Supposing that m kinds of fuels are used, C_i can be expressed as:

$$C_i=\sum_j^m f_{ij}x_{ij}+C_{P_i}\qquad(3)$$

where, f_{ij} is the price of fuel j consumed in boiler i, RMB/GJ; x_{ij} is the heat input of fuel j of the boiler i, GJ/h; and C_{P_i} is the electricity cost of auxiliary equipment, RMB/h.

For load allocation, C_i was linked with the steam output amount and boiler efficiency. It was supposed that α_{ij} is the percentage of the heat input of fuel j to the whole of boiler i; y_i is the output amount of steam, t/h; F_i is the enthalpy difference of stream and supplied water, GJ/t; and η is the thermal efficiency, %. In the present study, optimal operation objective function of the boiler system is expressed as:

$$\min f=\sum_i^N C_i=\sum_i^N\left[\frac{y_iF_i}{(\sum_j^m x_{ij})^2}\cdot\sum_j^m\frac{x_{ij}}{\eta_{ij}}\cdot\sum_j^m f_{ij}x_{ij}+C_{P_i}\right]\qquad(4)$$

With the constraints of

(1) $y_{i\min}\leqslant y_i\leqslant y_{i\max}$, $x_{ij\min}\leqslant x_{ij}\leqslant x_{ij\max}$,

(2) $\eta_i\sum_j^m x_{ij}=F_iy_i$,

(3) $\sum_i^N y_i=y_o$,

(4) $\sum_i^N x_{ij}=x_{jo}$,

and (5) $\sum_i^N x_{ij}\leqslant x_{jo}$.

2.2 Solution of model

Eq. (4) is a non-convex function, and cannot be