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Optimization and Scheduling of Byproduct Gas System in Steel Plant

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Abstract: A mathematical model was proposed to optimize byproduct gas system and reduce the total cost. The scope and boundaries of the system were also discussed at the same time. Boilers and gasholders were buffer users to solve the fluctuation of byproduct gases. The priority of gasholders should be ranked the last. The allocation of surplus gases among gasholders and boilers was also discussed to make full use of gases and realize zero emission targets. Case study shows that the proposed model made good use of byproduct gases and at least 7.8% operation cost was reduced, compared with real data in iron and steel industry.

Key words: iron and steel industry; byproduct gas; energy saving; optimization; scheduling

Symbol List

b——The number of boilers ($b=1, 2, \cdots, B$);

k——The number of gas holders ($k=1, 2, \cdots, K$);

m——The number of mixed gas users ($m=1, 2, \cdots, U_m$);

s——The number of single gas users ($s=1, 2, \cdots, U_s$);

t——Period ($t=1, 2, \cdots, P$);

H_G——Heat value of gas G, kJ/m^3;

H_i^{min}——Minimum heat value demand of user i, kJ/m^3;

H_i^{max}——Maximum heat value demand of user i, kJ/m^3;

Q_i^{min}——Minimum heat demand of user i, kJ;

Q_i^{max}——Maximum heat demand of user i, kJ;

V_H^G——Upper bound of byproduct gas G in gasholder, m^3;

V_L^G——Lower bound of byproduct gas G in gasholder, m^3;

V_{HH}^G——Maximum amount of byproduct gas G in gasholder, m^3;

V_{LL}^G——Minimum amount of byproduct gas G in gasholder, m^3;

V_{max}^G——Maximum volume of gasholder, m^3;

$V_{s,t}^{G,min}$——Minimum flow rate of byproduct gas G supplied to single gas user at time t, m^3;

$V_{s,t}^{G,max}$——Maximum flow rate of byproduct gas G supplied to single gas user at time t, m^3;

$\Delta V_{s,t}^{G,max}$——Maximum difference between real and normal amount of gas G supplied to user s, m^3;

$\Delta V_{i,t}^{G,max}$——Maximum difference between real and normal amount of gas G supplied to user i, m^3;

$V_{gen,t}^G$——Amount of byproduct gas G generated at time t, m^3;

$V_{b,t}^{G,e}$——Normal amount of byproduct gas G supplied to boiler b at time t, m^3;

$V_s^{G,e}$——Normal amount of byproduct gas G needed by user s at time t, m^3;

$V_m^{G,e}$——Normal amount of byproduct gas G needed by user m at time t, m^3;

$V_i^{G,e}$——Normal amount of byproduct gas G needed by user i at time t, m^3;

ΔW_s^G——Penalty for gas G deviation from normal amount in user s, RMB/m^3;

ΔW_m^G——Penalty for gas G deviation from normal amount in user m, RMB/m^3;

W_b^G——Penalty for gas G deviation from normal amount in user b, RMB/m^3;

W_E^G——Penalty for byproduct gas G emission, RMB/m^3;

W_H^G——Penalty for gasholder working at high level, RMB/m^3;

W_L^G——Penalty for gasholder working at low level, RMB/m^3;

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$v_{b,t}^{G}$ —— Amount of byproduct gas G supplied to boiler b at time t, m^3;

$v_{h,t}^{G}$ —— Amount of byproduct gas stored in G gasholder at time t, m^3;

$v_{s,t}^{G}$ —— Amount of gas G used in single gas user s at time t, m^3;

$v_{m,t}^{G}$ —— Amount of byproduct gas G consumed in user m at time t, m^3;

$v_{i,t}^{G}$ —— Amount of byproduct gas G consumed in user i at time t, m^3;

$\Delta v_{E,t}^{G}$ —— Amount of byproduct gas G emitted at time t, m^3;

$\Delta v_{H,t}^{G}$ —— Deviation amount of byproduct gas above upper bound of G gasholder, m^3;

$\Delta v_{L,t}^{G}$ —— Deviation amount of byproduct gas below lower bound of G gasholder, m^3;

$\Delta v_{s,t}^{G,+}$ —— Deviation above normal amount of gas G supplied to user s, m^3;

$\Delta v_{s,t}^{G,-}$ —— Deviation below normal amount of gas G supplied to user s, m^3;

$\Delta v_{i,t}^{G,e+}$ —— Deviation above normal amount of gas G supplied to user i, m^3;

$\Delta v_{i,t}^{G,e-}$ —— Deviation below normal amount of gas G supplied to user i, m^3.

Iron and steel industry is one of the most energy-intensive industries. Many research efforts have been made in production and energy planning in steel plants[1-4]. However, few researches focused on byproduct gases whose energy cost constitutes about 30% of the total energy-consuming cost[5]. Mixed integer linear programming (MILP) models were proposed to solve the optimization of byproduct gas system and cost reduction[5,6]. Yi and Han[7] applied simultaneous compensation with gross error candidates to the flow networks of byproduct gases. Zhang et al.[8] established models to predict and adjust the byproduct gas holder level. An improved echo state network was introduced to predict blast furnace gas (BFG) generation, consumption and gasholder level[9]. Other models have been made to seek the minimum cost or find a way to optimize the gas distribution in steel plant[10-13]. In most previous work, parts of the systems were analyzed. Although some of the equipments or processes were energy-efficient, the whole system maybe ran in poor condition[14].

In a systematic view, a mathematical model was proposed in this study to make the byproduct gas system work under energy-saving condition. The boundary of the system was also defined. Boilers were used to solve large amount of surplus byproduct gases; gasholders can be used as buffer users and its priority ranked the last. It was known that different gases with different parameters mixed with each other could lower gas quality and waste energy. Thus, the use of mixed gases in the system was minimized.

1 Problem Analysis

Byproduct gases are important driving force for the operation process of material flow in a steel plant. Fig. 1 shows the byproduct gas system in iron and steel industry.

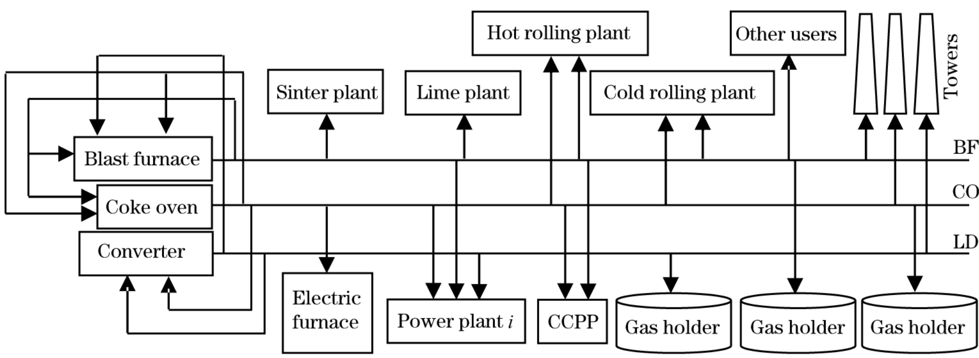

Fig. 1 Schematic diagram of byproduct gas system

BFG comes from blast furnaces (BFs), coke oven gas (COG) is produced in coke ovens (COs), and Linze-Donawitz gas (LDG) results from the steelmaking process in basic oxygen furnace (BOF). Users of byproduct gases are associated with each other. Some definitions of byproduct gas system are not accurate. Their boundaries of the system are too complicate and will influence model accuracy and impact operation speed. The stable operation of gasholder should not be regarded as the only objective in the system. In order to eliminate fluctuations in the system and keep steady pressure in gas network, timely adjustment of gasholder levels is required.

Due to imprecise operation and equipment defects,