The Optimization Of Boiler Operation Based On Intelligent Algorithm

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Abstract: Boiler efficiency is influenced by many factors. In order to find and realize optimum efficiency of boiler , the concept of controllable operating parameter is introduce to select the parameters and optimize them. Finally, 3 parameters are determined to participate in optimization, namely, excess air coefficient α ,exhaust gas temperature ϑ_{py} and main steam flow D . Then this paper conclude the relationship between these parameters and boiler efficiency respectively. By using the function optimization algorithm based on genetic algorithm and nonlinear programming, the optimum scheme of boilers and calculate optimal solution of η_{glzy} is achieved, that is η_{glzy} =93.110%.

Introduction

Boiler is one of the key equipments in thermal power plant, it's efficiency effect the economy of power plants directly. In modern power station, the main performance index reflecting boiler operation conditions is boiler efficiency. The efficiency of power plant boiler are calculated by using a counter balance, namely：

$$\eta_{gl} = q_1 = \frac{Q_1}{Q_r} \times 100 = 100 - （q_2 + q_3 + q_4 + q_5 + q_6） \text{ ,\%} \quad （1）$$

Where: q_1: the effective utilization of heat $\quad$ q_2 :heat loss due to exhaust gas

q_3 : heat losing of chemistry $\quad$ q_4 : mechanical incomplete combustion heat loss

q_5 : heat losing of dispelling heat of boiler $\quad$ q_6 : the physical heat loss of ash and slag

There are some researches indicate the relationship between q_2, q_3, q_4 and α [1], finding optimum excess air coefficient α to make minimum heat loss, so boiler optimum efficiency problem is solved by optimum excess air coefficient model. They get the relationship between excess air coefficient α and q_2, q_3, q_4 :

$$q_2 + q_3 + q_4 = 4.283\alpha + \frac{53.19}{\alpha + 1.009} + \frac{0.0002106}{\alpha + 0.14} - \frac{53.19}{\alpha - 3.775} - 41.16 \quad (2)$$

Then they get the conclusion that when the optimum excess air coefficient $\alpha_p = 1.152596$,the boiler efficiency is the best. However, this paper aim to find the best boiler efficiency and optimize it in other aspects, not only q_2, q_3, q_4 ,but also q_5, q_6 ,exhaust gas temperature ϑ_{py} ,and main steam flow D , etc.

Determination of optimal parameters一controllable operating parameters[2]

Parameters which influence economic operation of boilers are composed of controllable operating parameters and uncontrollable operating parameters. Nowdays, the power plants usually adopt checking method of small operating indices, namely to check carbon content in fly ash, exhaust gas temperature, boiler efficiency,power consumption of the auxiliary equipment and so on. Although all these parameters determine the economic operation of equipments, they are not the most immediate

parameters.So we introduce concept of controllable operating parameters, which effect the economy significantly and operating personnel can adjust them directly.

Uncontrollable operating parameters usually include: ambient temperature, load of boiler, boiler load, kind of coal and coal fineness, etc. Controllable operating parameters can be controlled and adjusted at any time. It is of great pertinence and practical significance to adopt these parameters to operate optimally. We make comprehensive consideration of the parameters and finally 3 parameters are determined to participate in optimization, namely, air coefficient α 、 Exhaust Gas Temperature ϑ_{py} 、 main steam flow D .

Optimum excess air coefficient

In foundation of heat balance principle[3],boiler efficiency can be achieved by calculating each heat loss . So we conduct further discussion on q_5 and q_6, finding the relationship between α and q_5, q_6 and then get the relationship of α and η_{gl} .

● calculation of heat loss q_5

When a boiler is running, furnace wall,pipeline and some other parts are always higher than the ambient air temperature, the percentage of heat losing of dispelling heat of boiler accounts for heat input is q_5 ,which is calculated by the following formula:

$$q_5 = 5.82(D)^{-0.38} \quad (3)$$

Where D denotes main steam flow, the empirical data of D is 1074t/h.By running the program,we get $q_5 = 0.4102$.

● Calculation of the physical heat loss of ash and slag q_6

Generally speaking,we only take q_6 into consideration under the following condition[4]:
(1)Slag tap boiler with large amount of ash and high temperature
(2)Stoker furnace with large amount of ash
(3)Solid state slag-tap coal dust boilers which burn high ash coal

The computational formula of Q_6 is:

$$Q_6 = \frac{A^y}{100}[\frac{a_{fh}(\vartheta_{py} - t_0)c_{fh}}{100 - C_{fh}} + \frac{a_{lz}(t_{lz} - t_0)c_{lz}}{100 - C_{lz}} + \frac{a_{cjh}(t_{cjh} - t_0)c_{cjh}}{100 - C_{cjh}}], kJ / kg \quad (4)$$

Where c_{fh}、 c_{lz}、 c_{cjh} represent thespecific heat of fly ash, slag and fallout.We can get their specific values by looking up <specific heat capacity scale of solid fuel ash >, a_{cjh} is so small that we neglect it. Then we get:

$$Q_6 = \frac{A^y}{100}[\frac{a_{fh}(\vartheta_{py} - t_0)c_{fh}}{100 - C_{fh}} + \frac{a_{lz}(t_{lz} - t_0)c_{lz}}{100 - C_{lz}}](5)$$

Because $q_6 = \dfrac{Q_6}{Q_r}$ and C_{fh} is the function of α ,we get the following figure:
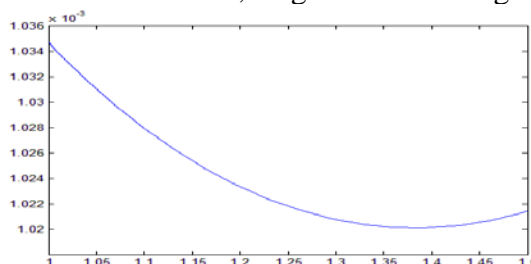

Fig. 1 The relationship between physical heat loss of ash and slag and excess air coefficient

According to the above figure we can see that q_6 decrease first and then increase with the increase of α and the magnitude of q_6 is 10^{-3} ,which is relatively small. We introduce ash converted

by coal-fired A_{zs} as the constraint. When $A_{zs}<10\%$ ($A_{zs}=\dfrac{4187A_y}{Q_{ar,net}}$) , we will neglect the heat losing of dry-bottom boiler fired pulverized coal . We calculate that $A_{zs}=2.56\%$ $<<10\%$, so we neglect it.

- The relationship of boiler efficiency and excess air coefficient

According to the formula(2),(3), we get the formula of boiler efficiency dependence of excess air coefficient by using back balance method.

$$\eta_{gl}=1-(q2+q3+q4+q5+q6)$$
$$=-\frac{45.99(15.46\alpha^2-42.76\alpha+33.6)}{-16.71\alpha^2+46.23\alpha+63.68}+\left(\frac{0.002916}{\alpha+0.14}-1.368\right)0.4866(6.321\alpha+0.7388)-0.07486\alpha+98.69 \quad (6)$$

Simplifying the above formula by MATLAB :

$$\eta_{gl}=140.7-\frac{53.19}{\alpha-3.775}-\frac{53.19}{\alpha+1.009}-\frac{0.0002106}{\alpha+0.14}-4.283\alpha \quad (7)$$

Then we get the figure below:

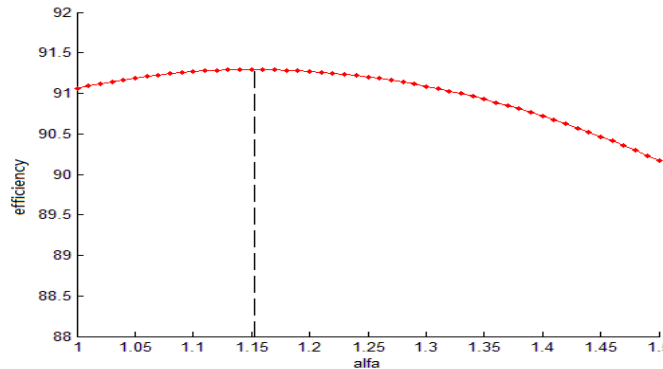Fig 2. The relationship of boiler efficiency and excess air coefficient

- **The influence on the boiler efficiency from exhaust gas temperature θ_{py}**

As the main heal losses，heat loss due to exhaust gas decide the improvement of boiler efficiency directly. Heat loss due to exhaust gas mainly depends on exhaust gas temperature and exhaust gas volume.When the fuel and air supply conditions are stable, changes of exhaust gas volume can be neglect and so it is important to find the influence trend of exhaust gas temperature θ_{py} on boiler efficiency.

Exhaust gas is bound to consume part of the fuel when it change from cold air into the exhaust, thus forming heat loss due to exhaust gas[5]. It is obviously that heat loss due to exhaust gas increase with the increase of exhaust gas temperature θ_{py} ,so we find the relationship between θ_{py} and heat loss due to exhaust gas and then find the influence on the boiler efficiency from θ_{py} .

The relationship between exhaust gas temperature ϑ_{py} and heat loss due to exhaust gas q_2 is calculated as the following formulas:

$$q_2=\frac{Q_2}{Q_r}\times100\% \quad (8)$$

Where： $$Q_2=Q_2^{gy}+Q_2^{H_2o}, \quad kJ/kg \quad (9)$$

$$Q_2^{gy} = V_{gy} c_{p,\ gy}(\vartheta_{py} - t_0)\ ,\quad \text{kJ/kg (10)}$$

$$Q_2^{H_2o} = V_{H_2o} c_{p,H_2o}(\vartheta_{py} - t_0)\ ,\quad \text{kJ/kg (11)}$$

Q_2^{gy} : heat carried off by dry flue gas $Q_2^{H_2o}$: sensible heat of steam contained by flue gas

V_{gy} : volume of dry flue gas $c_{p,\ gy}$: average specific heat capacity at constant pressure of dry

flue gas from t_0 to ϑ_{py} c_{p,H_2o} : average specific heat capacity at constant pressure of steam

from t_0 to ϑ_{py}

Then we get the relationship of q_2 and ϑ_{py} (here we take $\alpha = \alpha_p = 1.1143$)

$$q_2 = \frac{\left[0.1238(\vartheta_{py} - 100)/100 + 11.0153\right](\vartheta_{py} - 20)}{24042} = (\vartheta_{py} - 20)(0.51 \times 10^{-7}\vartheta_{py} + 0.00045) \quad (12)$$

According to the above formula, we can see that itsfigure is a parabola.We select 110-150 degree centigrade as the reference range of exhaust gas temperature and within the scope of this it approximate to a straight line:

$$K = (452 + 0.1\vartheta_{py})10^{-6} \quad (13)$$
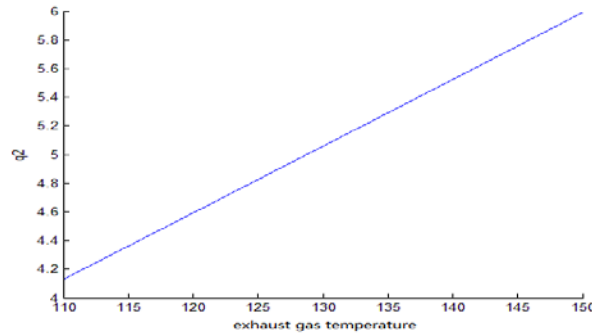
The function image is shown below:

Fig. 3.The relationship of exhaust gas temperature and heat loss due to exhaust gas q_2

As indicated in the above figure, heat loss due to exhaust gas linearly increases with the increase

of exhaust gas temperature. According to the counter balance theory，the increase of q_2 will lead to

the decrease of η_{gl} and boiler efficiency will linearly decreases with the increase of exhaust gas temperature.

Generally speaking,if exhaust gas temperature increase by 10-15℃, the boiler will decrease 1%[6],which confirms the results of our model。However, if we reduce exhaust gas temperature excessively,sulfuric acid in the flue gas will condense so that the plants expend additional costs.So in condition of economics，we should choose the exhaust gas temperature reasonably in practice.

A function optimization algorithm based on genetic algorithm and nonlinear programming[7]

● Function optimization algorithm

For the function optimization problems,genetic algorithm has stronger global search ability and weaker local search ability, we can only get the suboptimal solution of the problem normally.However, nonlinear programming has stronger local search ability while its global search ability is weaker.

We combine the two methods, using genetic algorithm to implement global search and nonlinear programming to implement local search and getting the global optimal solution. By testing function we find that the genetic algorithm not only can solve the problem of local optimum solution but also have high searching efficiency after combined with nonlinear programming and we get a

satisfactory result.

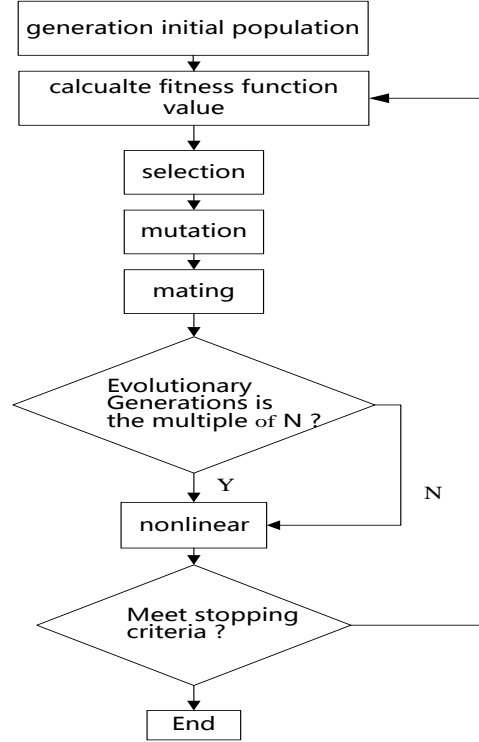Flow chart of genetic algorithm is as follows:

Figure. 4 .flow chart of genetic algorithm

We construct a function optimization algorithm based on genetic algorithm and nonlinear programming to determine optimization scheme and the best boiler efficiency.

We adopt linear programming function ,which is in MATLAB optimization toolbox, to optimize:

$$-\eta = f \min con\left(\alpha, \theta_{py}, D\right) \quad (14)$$

The constraints are: $1.1 \le \alpha \le 1.7 \quad 110 \le \theta_{py} \le 170 \quad 900 \le D \le 1704$

● Optimization scheme

Based on genetic algorithm, we find the optimal solutions by using MATLAB. Parameters of genetic algorithm are: population scale is 300, evolution generations are 2000, crossover probability is 0.6, mutation probability is 0.1.

We get the following optimal solutions:

$$\alpha_{zy} = 1.105; D_{zy} = 1066.329; \vartheta_{zy} = 110.042; \eta_{glzy} = 93.110\%;$$

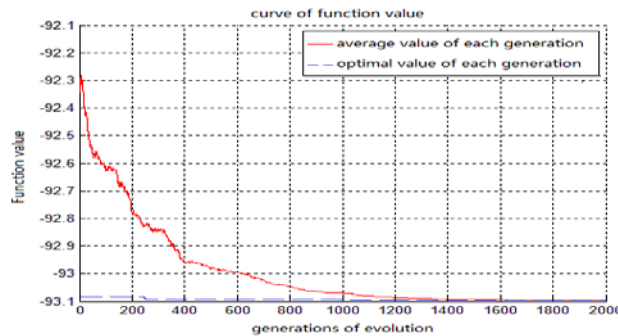The table below is the optimization process:

Figure. 5 .optimization process of nonlinear genetic algorithm

According to the above model,we get the optimum scheme of boilers: When $\alpha_{zy} = 1.105$, $D_{zy} = 1066.329$, $\vartheta_{zy} = 110.042$, Optimal solution of η_{glzy} is : $\eta_{glzy} = 93.110\%$

Summary

    Each parameter is close to the boundary value，which may not be achieved in practice.But we should try to close to the parameters and make the boiler in full-load operation on the premise of ensuring economic and security.

References

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