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A Research of Simplified Method in Boiler Efficiency Test

Tai Lv[a], Linghao Yu[a] ,Jinmin Song[b]

[a] *Northeast Dianli University ,Jilin 132012, China*

[b] *Shenyang Equipment Inspection and Research Institute ,Shenyang 110035, China*

Abstract

It is needed to make ultimate analysis of coal when testing boiler efficiency by traditional method. However, it is so costly and so long that it is impossible to test boiler efficiency frequently. However, it is much easier to make proximate analysis of coal, and most enterprise may operate. In this paper, a mathematics model has been established based on proximate analysis so as to replace ultimate analysis of coal in boiler efficiency testing. Theoretical air requirement, heat loss due to exhaust gas, and heat loss due to unburned gases were compared by this new model. Errors are no more than 5%, and it shows that the method is feasible and valid.

Keywords:boiler efficiency; ultimate analysis; proximate analysis; mathematics model

1.Introduction

To achieve low carbon economy by saving energy is the trend of today's society. Boiler is a kind of common equipments with high energy consumption. At present, boiler efficiency is not high and a great deal of energy has been wasted seriously in China. The test of boiler efficiency is an effective way to identify boiler problems and improve its efficiency. Until 2008, the total number of using industrial boilers has been amounted to 578200 units. The traditional method to test boiler efficiency is time consuming and expensive, and the test of boiler efficiency needs ultimate analysis of fuel. However, the test of the ultimate analysis of fuel is in need of long time, and its related equipment is also more expensive. In this paper, taking coal-fired boiler for example, through the regression analysis, a new calculated model is proposed. Ultimate analysis is replaced by proximate analysis of coal in boiler efficiency testing. This method can simplify the experimental procedure greatly. Save time and cost in the experiment.

2.The Simplified Calculation of Heat Loss Due to Exhaust Gas

In the process of calculation of anti-balance thermal efficiency testing for boiler, heat loss due to unburned carbon in refuse q_4, heat loss due to radiation q_5 as well as the heat loss due to sensible heat in

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slag q_6 is simple. On the contrary, calculate the heat loss due to exhaust gas q_2 and heat loss due to unburned gases q_3 is complicated. Both of them need the data of proximate analysis and ultimate analysis of fuel [1-2].This paper is mainly to simplify q_2 and q_3 .

Theoretical computational method of heat loss due to exhaust gas is as follow:

$$q_2 = \frac{K_{q4}}{Q_{\mathrm{net,\ v,\ ar}}}(H_{\mathrm{py}} - H_{lk}) \times 100 \ . \quad (1)$$

Where H_{py}, H_{lk} is exhaust gas enthalpy and enthalpy of cold air into the furnace, $Q_{\mathrm{net,v,ar}}$ is as-received basis net calorific value of coal which assume that the heat input is equal to it.

Exhaust gas enthalpy can be calculated as:

$$H_{\mathrm{py}} = V_{\mathrm{gy}} C_{\mathrm{gy}} t_{\mathrm{py}} + V_{\mathrm{H_2O}} C_{\mathrm{H_2O}} t_{\mathrm{py}} \ . \quad (2)$$

According to the main component of dry gas, it can be simplified to

$$\begin{aligned} H_{\mathrm{py}} &= V_{\mathrm{RO_2}} C_{\mathrm{RO_2}} t_{\mathrm{py}} + V^0{}_{\mathrm{N_2}} C_{\mathrm{N_2}} t_{\mathrm{py}} + \\ &V^0{}_{\mathrm{H_2O}} C_{\mathrm{H_2O}} t_{\mathrm{py}} + (a_{\mathrm{py}} - 1) V^0 C_{\mathrm{k}} t_{\mathrm{py}} + \\ &0.0161 (a_{\mathrm{py}} - 1) V^0 C_{\mathrm{H_2O}} t_{\mathrm{py}} . \end{aligned} \quad (3)$$

Where $V_{\mathrm{RO_2}}$, $V^0{}_{\mathrm{N_2}}$, $V^0{}_{\mathrm{H_2O}}$, V^0 is three atomic gas volume, theoretical volume of nitrogen, theoretical volume of water vapor and theoretical air volume, and C is the specific heat of the gas.

As the boiler exhaust gas temperature is generally within 500 ℃, the average specific heat can be calculated according to empirical formula:

$$C_{\mathrm{R_2O}} = 1.1572 \cdot t_{\mathrm{py}}{}^{0.0827} . \quad (4)$$

$$C_{\mathrm{N_2}} = 0.8445 \cdot t_{\mathrm{py}}{}^{0.0827} . \quad (5)$$

$$C_{\mathrm{H_2O}} = 0.9889 \cdot t_{\mathrm{py}}{}^{0.0827} . \quad (6)$$

$$C_{\mathrm{k}} = 0.8805 \cdot t_{\mathrm{py}}{}^{0.0827} . \quad (7)$$

According to (3), (4), (5), (6), and (7), we can obtains the formulas as:

$$\begin{aligned} H_{\mathrm{py}} - H_{\mathrm{lk}} &= (1.1572 \cdot V_{\mathrm{R0_2}} + 0.8445 \cdot V^0{}_{\mathrm{N_2}} + \\ &0.9889 \cdot V^0{}_{\mathrm{H_2O}} - 0.8964 \cdot V^0) t_{\mathrm{py}}{}^{1.0827} + \\ &0.8805 \cdot a_{\mathrm{py}} \cdot V^0 \cdot (t_{\mathrm{py}}{}^{1.0827} - t_{\mathrm{lk}}{}^{1.0827}) + \\ &0.0159 \cdot V^0 \cdot a_{\mathrm{py}} \cdot t_{\mathrm{py}}{}^{1.0827} . \end{aligned} \quad (8)$$

Assume

$$\begin{aligned} X &= 1.1572 \cdot V_{RO_2} + 0.8445 \cdot V^0{}_{N_2} + \\ &0.9889 \cdot V^0{}_{H_2O} - 0.8964 \cdot V^0 . \end{aligned} \quad (9)$$

$$Y = 0.8805 \cdot V^0 . \quad (10)$$

$$Z = 0.0159 \cdot V^0 . \quad (11)$$

Then, (8) can be:

$$\begin{aligned} H_{\mathrm{py}} - H_{\mathrm{lk}} &= X \cdot t_{\mathrm{py}}{}^{1.0827} + Y \cdot a_{\mathrm{py}} \cdot (t_{\mathrm{py}}{}^{1.0827} - t_{\mathrm{lk}}{}^{1.0827}) + \\ &Z \cdot a_{\mathrm{py}} \cdot t_{\mathrm{py}}{}^{1.0827} . \end{aligned} \quad (12)$$

Therefore

$$q_2 = \frac{K_{q_4}}{Q_{net,v,ar}}(X \cdot t_{py}^{1.0827} + Y \cdot a_{py} \cdot (t_{py}^{1.0827} - t_{lk}^{1.0827}) + Z \cdot a_{py} \cdot t_{py}^{1.0827}) \times 100. \quad (13)$$

X is related to the ultimate analysis of coal, and (9) will be processed as:

$$X = 0.0029 C_{ar} + 0.001 S_{ar} + 0.0067 N_{ar} + 0.0532 H_{ar} + 0.0071 O_{ar} + 0.0123 M_{ar}. \quad (14)$$

According to the 《Coal Quality Analysis》[3]and mass of data which is from some scholars who used artificial neural network to process the data of coal property, the values of ultimate analysis and proximate analysis of coal show multiple linear prominently[4-6]. Based on the ultimate analysis of coal, we can obtain X, and use the proximate analysis to regress [7]:

$$X = 1.57 \times 10^{-3} \cdot FC_{ar} - 6.69 \times 10^{-3} \cdot A_{ar} + 5.3 \times 10^{-3} \cdot M_{ar} - 7.18 \times 10^{-6} \cdot Q_{net,v,ar} + 7.06 \times 10^{-1}. \quad (15)$$

The regression analysis results of X is showed in TABLE Ⅰ. It can clearly be seen that it works well.

$$V^0 = 0.0889 (C_{ar} + 0.375 S_{ar}) + 0.265 H_{ar} - 0.0333 O_{ar}. \quad (16)$$

Process V^0 by regression analysis in the same way:

$$V^0 = 2.23 \times 10^{-2} \cdot FC_{ar} - 6.12 \times 10^{-2} \cdot A_{ar} - 9.83 \times 10^{-2} \cdot M_{ar} + 9.55 \times 10^{-6} \cdot Q_{net,v,ar} + 6.81. \quad (17)$$

The regression analysis results of V^0 is showed in TABLE Ⅱ, and it works well.

According to (10) and (11), Y and Z are related to the V^0.Therefore

$$Y = 1.96 \times 10^{-2} \cdot FC_{ar} - 5.39 \times 10^{-2} \cdot A_{ar} - 8.65 \times 10^{-2} \cdot M_{ar} + 8.41 \times 10^{-6} \cdot Q_{net,v,ar} + 5.99. \quad (18)$$

$$Z = 3.54 \times 10^{-4} \cdot FC_{ar} - 9.73 \times 10^{-4} \cdot A_{ar} - 1.56 \times 10^{-3} \cdot M_{ar} + 1.52 \times 10^{-7} \cdot Q_{net,v,ar} + 1.08 \times 10^{-1}. \quad (19)$$

Then according to (13), (15) (18) and (19), the heat loss due to exhaust gas can be calculated by the data of proximate analysis of coal.

3.The Simplified Calculation of Heat Loss Due to Unburned Gases

Theoretical computational method of heat loss due to unburned gases is as follow:

$$q_3 = \frac{K_{q_4}}{Q_{net,v,ar}} \cdot V_{gy} \cdot (1.2636 CO + 1.0798 H_2 + 3.5818 C_m H_n) \times 100\%. \quad (20)$$

Where V_{gy} is the volume of dry gas, and CO , H_2 , $C_m H_n$ is CO content volume percentage of dry gas, H_2 content volume percentage of dry gas, and $C_m H_n$ content volume percentage of dry gas.

As the content of H_2 and $C_m H_n$ in dry gas is extremely low and in order to calculate easily, Assuming incomplete combustion gas is only CO:

$$q_3 = \frac{K_{q_4}}{Q_{net,v,ar}} \cdot V_{gy} \cdot 1.2636\,CO \times 100\%. \quad (21)$$

V_{gy} can be calculated as follow:

$$V_{gy} = V_{RO_2} + V^0{}_{N_2} + (a_{py} - 1)V^0. \quad (22)$$

The (22) contains excess air factor, the regression can not be handled in the whole. We process it as:

$$V_{gy} - a_{py} \cdot V^0 = V_{RO_2} + V^0{}_{N_2} - V^0. \quad (23)$$

The values of $V_{gy} - a_{py} \cdot V^0$ is related to the ultimate analysis of coal, and (23) will be processed as:

$$V_{gy} - a_{py} \cdot V^0 = 0.008 N_{ar} - 0.0557 H_{ar} + 0.007 O_{ar}. \quad (24)$$

Based on the ultimate analysis of coal, we can obtain $V_{gy} - a_{py} \cdot V^0$, then, use proximate analysis to process it by regression analysis:

$$\begin{aligned} V_{gy} - a_{py} \cdot V^0 = & -5.77\times10^{-4} \cdot FC_{ar} - 5.18\times10^{-4} \cdot A_{ar} + \\ & 6.36\times10^{-4} \cdot M_{ar} - 5.33\times10^{-6} \cdot Q_{net,v,ar} + \\ & 7.78\times10^{-3}. \end{aligned} \quad (25)$$

We can see from table Ⅲ that the results are not as good as the results of table Ⅰ and table Ⅱ. However, the value is small which have little effect on the overall results, and the form of (25) is easy to handle.

According to (17) and (25), V_{gy} can be calculated as:

$$\begin{aligned} V_{gy} = & (2.23\times10^{-2} \cdot a_{py} - 5.77\times10^{-4}) \cdot FC_{ar} - \\ & (6.12\times10^{-2} \cdot a_{py} + 5.18\times10^{-4}) \cdot A_{ar} - \\ & (9.83\times10^{-2} \cdot a_{py} - 6.36\times10^{-4}) \cdot M_{ar} \\ & + (9.55\times10^{-6} \cdot a_{py} - 5.33\times10^{-6}) \cdot Q_{net,v,ar} \\ & + 6.81 \cdot a_{py} + 7.78\times10^{-3}. \end{aligned} \quad (26)$$

Then according to (21) and (26), the heat loss due to unburned gases can be calculated by the data of proximate analysis of coal.

TABLE I. REGRESSION ANALYSIS RESULTS OF X

R	*R-Square*	*Adj. R-Square*	*F Value*	*t -Value*			
0.991	0.982	0.981	F(4,35)=451.7	t_1=2.73	t_2=2.98	t_3=3.88	t_4=2.24

TABLE II. REGRESSION ANALYSIS RESULTS OF V^0

R	*R- Square*	*Adj. R-Square*	*F Value*	*t -Value*			
0.990	0.980	0.980	F(4,35)=430.9	t_1=2.15	t_2=0.99	t_3=0.98	t_4=0.98

TABLE III. REGRESSION ANALYSIS RESULTS OF $V_{gy} - a_{py} \cdot V^0$

R	*R-Square*	*Adj. R-Square*	*F Value*	*t -Value*			
0.96	0.92	0.91	F(4,35)=376.9	t_1=4.06	t_2=0.96	t_3=0.92	t_4=0.91

4.The Errors of This Method Compared With Standard Method

In order to be more representative, an additional six coal samples is selected to compare errors. For simplicity, assume that the necessary data for the calculation of boilers as follows:

a_{py}=1.5, t_{py}=160℃, t_{lk}=15℃, q_4=6%, CO=2000ppm, RO_2=11%, O_2=9%.

TABLE IV. THE COMPARATIVE RESULTS OF COAL SAMPLE 1

Coal data	C_{ar} (%)	H_{ar} (%)	O_{ar} (%)	N_{ar} (%)	S_{ar} (%)	FC_{ar} (%)	A_{ar} (%)	M_{ar} (%)	V_{ar} (%)	$Q_{net,v,ar}$ (kJ / kg)
Value	65.28	3.86	7.65	0.6	0.9	49.64	14.49	7.22	28.65	25080

The error of this method compared with standard method

Comparative item	X (%)	V^0 (%)	$V_{gy}-a_{py}\cdot V^0$ (%)	q_2 (%)	q_3 (%)
Standard method	0.543	6.601	-0.157	7.671	0.923
New method	0.545	6.580	-0.158	7.826	0.917
Absolute errors	0.002	-0.021	-0.001	0.155	-0.006
Relative errors	0.368	-0.318	0.637	2.021	-3.778

TABLE V. THE COMPARATIVE RESULTS OF COAL SAMPLE 2

Coal data	C_{ar} (%)	H_{ar} (%)	O_{ar} (%)	N_{ar} (%)	S_{ar} (%)	FC_{ar} (%)	A_{ar} (%)	M_{ar} (%)	V_{ar} (%)	$Q_{net,v,ar}$ (kJ / kg)
Value	38.6	2.63	9.09	1.04	1.45	29.98	22.59	24.6	22.82	14150

The error of this method compared with standard method

Comparative item	X (%)	V^0 (%)	$V_{gy}-a_{py}\cdot V^0$ (%)	q_2 (%)	q_3 (%)
Standard method	0.627	3.874	-0.075	8.471	0.963
New method	0.631	3.830	-0.078	8.582	0.947
Absolute errors	0.004	-0.044	-0.006	0.111	-0.016
Relative errors	0.638	-1.136	4	1.311	-1.661

TABLE VI. THE COMPARATIVE RESULTS OF COAL SAMPLE 3

Coal data	C_{ar} (%)	H_{ar} (%)	O_{ar} (%)	N_{ar} (%)	S_{ar} (%)	FC_{ar} (%)	A_{ar} (%)	M_{ar} (%)	V_{ar} (%)	$Q_{net,v,ar}$ (kJ / kg)
Value	49.01	3.21	6.26	0.76	1.72	38.60	28.75	10.3	22.35	18910

The error of this method compared with standard method

Comparative item	X (%)	V^0 (%)	$V_{gy}-a_{py}\cdot V^0$ (%)	q_2 (%)	q_3 (%)
Standard method	0.490	5.055	-0.128	7.886	0.936
New method	0.493	5.100	-0.124	8.131	0.942
Absolute errors	0.003	0.045	0.004	0.245	0.006
Relative errors	0.612	0.89	-3.125	3.107	0.641

TABLE VII. THE COMPARATIVE RESULTS OF COAL SAMPLE 4

Coal data	C_{ar} (%)	H_{ar} (%)	O_{ar} (%)	N_{ar} (%)	S_{ar} (%)	FC_{ar} (%)	A_{ar} (%)	M_{ar} (%)	V_{ar} (%)	$Q_{net,v,ar}$ (kJ / kg)
Value	61.85	3.76	7.81	0.83	0.53	49.45	14.31	10.91	25.33	23835

The error of this method compared with standard method

Comparative item	X (%)	V^0 (%)	$V_{gy}-a_{py}\cdot V^0$ (%)	q_2 (%)	q_3 (%)
Standard method	0.576	6.252	-0.148	7.704	0.921
New method	0.575	6.210	-0.148	7.831	0.911
Absolute errors	-0.001	-0.042	0	0.127	-0.01
Relative errors	-0.174	-0.672	0	1.649	-1.086

TABLE VIII. THE COMPARATIVE RESULTS OF COAL SAMPLE 5

Coal data	C_{ar} (%)	H_{ar} (%)	O_{ar} (%)	N_{ar} (%)	S_{ar} (%)	FC_{ar} (%)	A_{ar} (%)	M_{ar} (%)	V_{ar} (%)	$Q_{net,v,ar}$ (kJ/kg)
Value	56.54	3.37	6.98	0.62	0.84	44.65	20.53	11.12	23.7	21580
The error of this method compared with standard method										

Comparative item	X (%)	V^0 (%)	$V_{gy}-a_{py}\cdot V^0$ (%)	q_2 (%)	q_3 (%)
Standard method	0.535	5.715	-0.134	7.786	0.929
New method	0.543	5.680	-0.137	7.928	0.920
Absolute errors	0.008	-0.035	-0.003	0.142	-0.009
Relative errors	1.495	-0.612	2.239	1.824	-0.969

TABLE IX. THE COMPARATIVE RESULTS OF COAL SAMPLE 6

Coal data	C_{ar} (%)	H_{ar} (%)	O_{ar} (%)	N_{ar} (%)	S_{ar} (%)	FC_{ar} (%)	A_{ar} (%)	M_{ar} (%)	V_{ar} (%)	$Q_{net,v,ar}$ (kJ/kg)
Value	34.21	2.59	8.69	0.52	0.73	25.02	31.47	21.79	21.72	12300
The error of this method compared with standard method										

Comparative item	X (%)	V^0 (%)	$V_{gy}-a_{py}\cdot V^0$ (%)	q_2 (%)	q_3 (%)
Standard method	0.570	3.462	-0.079	8.784	0.988
New method	0.562	3.430	-0.075	8.836	0.995
Absolute errors	-0.008	-0.032	0.004	0.102	0.007
Relative errors	-1.40	-0.924	-5.063	0.592	0.709

5.Conclusion

The comparison shows that the relative errors are no more than 5%, the difference of results between this method and the national standards is not obvious. Using the proximate analysis of coal to calculate can save mass test time and laboratory instruments cost. In order to adjust the combustion, the conclusion is feasible to calculate the boiler efficiency or to identify problems in boiler operation.

References

[1] G.G.Zhang,Y.Jiang, “Discussion on the influence of boiler heat loss on the boiler thermal balance efficiency,” Coal Quality Technology,vol.4,Jun.2009,pp.46-49.

[2] Q.G.Fan,W.P.Yan, Principles of Boiler,Beijing: China electric power press,2004:658-669.

[3] G.G.Zhang,Y.Jiang, “Discussion on the influence of boiler heat loss on the boiler thermal balance efficiency,” Coal Quality Technology,vol.4,Jun.2009,pp.46-49.

[4] J. R. Bai, Coal Quality Analysis,Beijing:China Coal Industry Publishing House,1990: 658～669.

[5] X. F. Zhao,Z. J. Li,Y. P. Chen, “Establishment and appl ication of the mathematics model on calculation of ultimate analysis of coal,” Coal Quality Technology,vol.1,Jan.2006,pp.16-18.

[6] S.L.Yan,T.X.Li,J.Y.Wang,T.Zhang, “Application of Gradual Regression Analysis in Research of Universal Calculation Model for Analysis of Elements in Coal,” Coal Preparation Technology, vol.3,Jun.2007,pp.17-19.

[7] C.Y.Li,D.B.Liu,F.Li, "Study on Relevant Equations for Two Kinds of Coal Quality Analysis," Coal Geology of China, vol.4,Dec.2004,pp.6-8.

[8] Y.Liu, "Mathematical model of multiple linear regression," Journlal of Shenyang Institute of Engineering, vol.1,Jun.2005,pp.128-129.