Study on the Efficiency Characteristic Model of Desulfurization System Based on LSSVM

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Abstract

In this paper, the main factors affecting the desulfurization efficiency of the wet flue gas desulfurization system were studied. The least squares-support vector machine(LSSVM) was used to establish efficiency characteristic model, which takes following parameters as the input variables,such as the unit load, flue gas volume, inlet flue gas SO2 concentration, inlet flue gas temperature, flue gas oxygen content, dust concentration, the slurry pH value, the liquid-gas ratio, the slurry density respectively, and the desulfurization efficiency as the output variable. The characteristic model has been applied for efficiency prediction in a 600 MW unit. The results of model analysis show that the LSSVM efficiency model is proved to be applicable, which is completely within the permitted range of engineering application and it can be used for further optimization operation.

Keywords

WFGD, desulfurization efficiency, characteristic model, LSSVM.

1. Introduction

The limestone/gypsum wet flue gas desulfurization system(WFGD), bringing tremendous environmental protection effects, has been widely used to reduce SO_2 emission in fossil power plants[1]. However, WFGD systems significantly increase the energy consumption and the operation costs of power plants. It has important theoretical and practical significance for reducing the energy cost of power plants. Therefore, it is meaningful to study the operating characteristics of WFGD systems and develop new energy conservation optimization methods for power plants. A accurate efficiency characteristic model related with operation modes of desulfurization system and the flue gas parameters is a prerequisite for operation optimization. Eden[2] and Ruhland[3] proposed a mathematical model for wet desulfurization based on the absorption, oxidation, limestone dissolution, and gypsum crystallization of the desulfurization tower. Lin et al. [4] and Zhong et al. [5] established a mathematical model using non-steady-state mass transfer permeation theory under different conditions. Although these theoretical models can be applied for the efficiency prediction, numerically calculated, the mathematical equations used in the theoretical model are complex and the solution are difficult. They can only be used for characteristic analysis and difficult to used for on-line operation guidance. With the increasingly application of Distribute Control System(DCS) and Supervisor Information Systme(SIS) for power units, more and more power plants have established plant-wide real-time historical data centers with unprecedented data. The hybrid intelligent models can be well established based on these massive data. Hu et al. [6] conducted a regression analysis of wet desulfurization system using operation data. By analyzing various factors affecting desulfurization efficiency, a multiple regression equation for desulfurization efficiency was obtained. Hong et al. [7]

used least squares support vector regression (LSSVM) algorithm to predict desulfurization efficiency and analyzed the prediction results. In this paper, the desulfurization efficiency characteristic model of limestone/gypsum WFGD system for a 600MW power plant is established using LSSVM algorithm, and the characteristics of the established model are analyzed.

2. LSSVM Desulfurization Efficiency Characteristic Model

2.1 LSSVM Model

LSSVM is a modification of the standard SVM developed to overcome these shortcomings, which results in a set of linear equations instead of a quadratic programming problem[8,9].

In a given training data set $\{(\mathbf{x_i},\mathbf{y_i})\}_{i=1}^{n}$ with $x_i \in \mathbf{R^n}$ as input vectors and $y_i \in R$ as output vectors, LSSVM model is expressed as follows:

$$\min_{w,b,\xi} J(\mathbf{w},\xi) = \frac{1}{2}\mathbf{w^T w} + \frac{C}{2}\sum_{i=1}^{n}\xi_i^2 \tag{1}$$

The constraint condition of equation (2):

$$\mathbf{y_i} = \mathbf{w}^T \varphi(\mathbf{x_i}) + b + \xi_\mathbf{i} \qquad i = 1, 2, \cdots, n \tag{2}$$

Where w is the weight vector, $C \in R^+$ is penalty parameter, $\xi_\mathbf{i}$ is the approximation error, $\varphi(\cdot)$ is the nonlinear mapping function and b is the bias term. Constrained optimization of equation (3) can be translated to unconstrained optimization by constructing Lagrange function. Using the Karush–Kuhn–Tucker (KKT) conditions, the solutions can be obtained by partially differentiating with respect to w, b, $\xi_\mathbf{i}$ and $\varphi(\cdot)$:

$$\begin{bmatrix} 0 & \mathbf{I_v^T} \\ \mathbf{I_v} & \mathbf{\Omega} + c^{-1}\mathbf{I} \end{bmatrix} \begin{bmatrix} b \\ \mathbf{a} \end{bmatrix} = \begin{bmatrix} 0 \\ \mathbf{y} \end{bmatrix} \tag{3}$$

Where $\mathbf{y} = [\mathbf{y_1}, \cdots, \mathbf{y_n}]^T$, $\mathbf{I_v} = [1, \cdots, 1]^T$, $\mathbf{a} = [\mathbf{a_1}, \cdots, \mathbf{a_n}]^T$; $\mathbf{\Omega} = \{\mathbf{\Omega_{ij}} | i, j = 1 \cdots n\}$, $\mathbf{\Omega_{ij}} = \varphi(\mathbf{x_i})^T \varphi(\mathbf{x_j}) = K(\mathbf{x_i}, \mathbf{x_j})$, $K(\cdot)$ is kernel function, Radial Basis Function (RBF) kernel function that obtains a and b by calculating linear operations.

2.2 Model Parameters

The input variables of efficiency characteristic model were mainly based on reaction mechanism of desulfurization system and influencing factors in operation adjustment[10]. In this paper, nine input variables were selected during the modeling process, such as the unit load, flue gas volume, inlet flue gas SO_2 concentration, inlet flue gas temperature, flue gas oxygen content, dust concentration, the slurry pH value, the liquid-gas ratio, the slurry density respectively. The load and flue gas volume represent the flue gas flow rate, slurry pH value, liquid-gas ratio, slurry density for the operation parameters, and other parameters represent flue gas composition.

In order to obtain modeling data, some field tests were conducted. The desulfurization efficiency were changed by adjusting the main operating factors under different inlet SO_2 inlet concentrations. The test adjustments within the scope basically covering the 50% to 100% load section, and a total number of 330 sets of operating data were selected as modeling data.

Through the data correlation analysis of all the samples obtained, the correlation coefficients are shown in Table 1. The analysis shows that five factors have significant influence on the desulfurization efficiency, such as the unit load, flue gas volume, inlet flue gas SO_2 concentration, liquid-gas ratio, slurry pH value of these parameters on the desulfurization efficiency ,which is consistent with the mechanism analysis[11].

Table 1 The correlation between the influence parameters and desulfurization efficiency

Input parameter	Correlation coefficient	Input parameter	Correlation coefficient
Unit load	-0.475	Dust concentration	-0.129
Flue gas volume	-0.466	Slurry pH value	0.618
Inlet flue gas SO2 concentration	-0.704	Liquid-gas ratio	0.548
Inlet flue gas temperature	-0.160	Slurry density	-0.110
Flue gas oxygen content	0.132		

Taking the above nine parameters as input variables of the model, the output is desulfurization efficiency. When the data used to establish model, they need to be standardized, and the value is controlled between 0~1. The model structure is shown in Fig. 1.

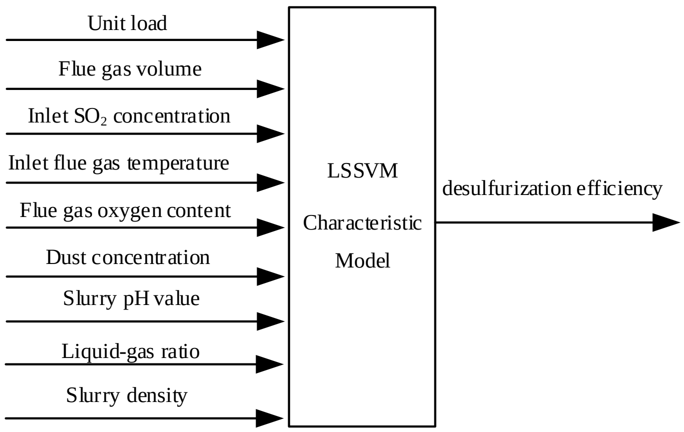
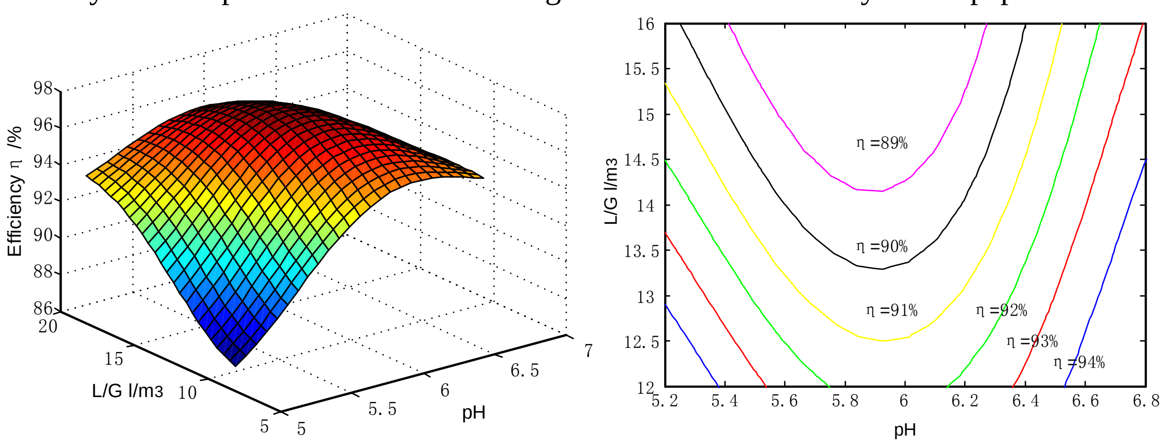


Fig. 1 LSSVM characteristic model of desulfurization efficiency

3. Results and Discussion

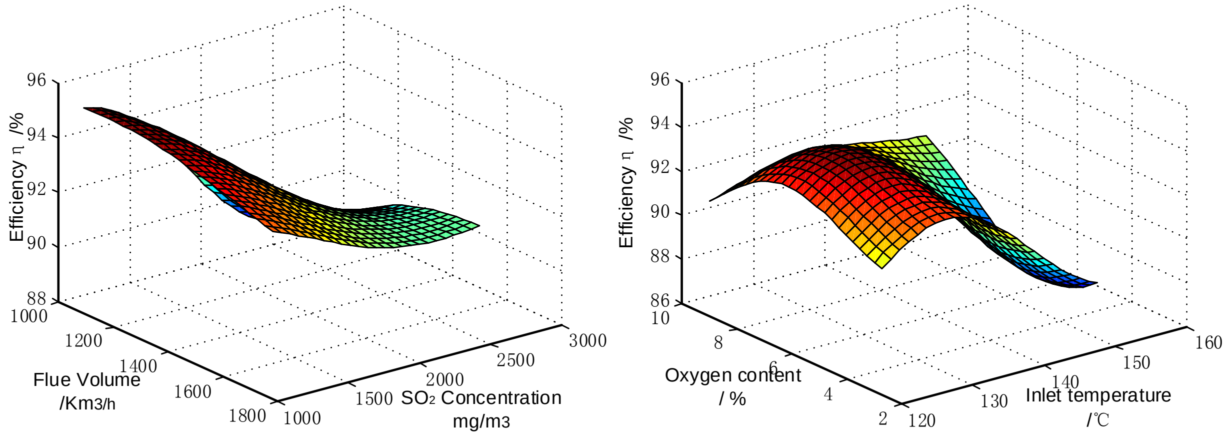
The LSSVM algorithm was used to establish a prediction model of the desulfurization efficiency using the field test data and some supplement operating data under stable conditions. Compared with the single factor analysis in the field tests, the established desulfurization efficiency prediction model can be used to analyze the combined effects of various factors on efficiency. The following model was used to analyze the impact of various influencing factors on the efficiency in this paper.



(a) Effect of pH value and L/G (b) Desulfurization efficiency surface

Fig. 2 Relation between pH, liquid-gas ratio and desulfurization efficiency

The two adjustable parameters of the liquid-gas ratio (L/G) and the pH value have a greater influence on the desulfurization efficiency. It can be seen from Fig. 2(a) that desulfurization efficiency can be significantly performed under the combined effect of pH and L/G adjustment. Higher desulfurization efficiency occurs in the regions with large L/G and high pH. The desulfurization efficiency changes monotonously with L/G. But the efficiency has the highest point with the pH value, indicating the best operating range for the pH value. This is because the SO_2 absorption surface area is determined by the ratio of liquid to air. With the increasing of the L/G, the spray density of the slurry and the contact area between the gas and liquid will be increased, which will accelerate SO_2 absorption. The mass transfer coefficient of SO_2 brings about a significant increase for desulfurization efficiency when the slurry pH increases. However, limestone will be difficult to dissolve in the slurry and $CaSO_3$ oxidation will not proceed easily when the pH is too high, which will result in a decrease of desulfurization efficiency. The prediction model results are consistent with the mechanism analysis. As shown in Fig. 2(b), for a given desulfurization efficiency, L/G should be decreased first and then increased with pH value, and a minimum pH value equal 5.8, which is set as the operation target pH value during operation.



(a) Flue volume and inlet SO2 concentration (b) Oxygen content and inlet temperature

Fig. 3 Influence analysis between multi-factor and Desulfurization efficiency

From Fig. 3(a), it can be seen that the desulfurization efficiency will be decreased with the increase of the flue gas flow volume and the inlet SO_2 concentration. The increase of the flow gas volume will cause a decrease of the ratio of liquid to gas, and the flow velocity will increase, resulting in a shorter reaction time in the WFGD system. Under the same conditions, the high SO_2 concentration will result in a low desulfurization efficiency. In addition, from Fig. 3(b), it can be seen that as the temperature of the inlet flue gas increases, the desulfurization efficiency shows a slight increase and then a sharp decrease. The main reason is that the temperature promotes the internal reaction of the slurry, but the higher slurry temperature makes SO_2 difficult to be absorbed, and the effect will be gradually enhanced. The desulfurization efficiency increases with the rise of flue gas oxygen content. The main reason is that the increase of oxygen concentration will cause SO_3^- to SO_4^- ions conversion, and the entire chemical reaction progress is accelerated in the positive direction. However, efficiency falls slightly when the oxygen concentration is above 7%. The main reason is that the increase of oxygen volume will inevitably lead to an increase in the amount of flue gas.

4. Conclusion

In this paper, the actual operating data were used to establish a desulfurization efficiency characteristic model using the LSSVM algorithm, and model characteristic analysis were performed. The results show that the liquid/gas ratio and the pH value have a great influence on the desulfurization efficiency than other adjustment factors. There is an optimal operating range for the pH value. The increase of the flue gas flow volume and inlet SO_2 concentration will lead to a decrease of the desulfurization efficiency. The on-line modeling method proposed in this paper can effectively predict desulfurization efficiency, with well prediction accuracy and generalization ability. It can be used for optimization operation.

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References

[1] Li Qing, Meng Qing-qing, Guo Yue. Desulfurization Transformation Technologies Routes Based on the National Newly Revised Emission Standard of Air Pollutants, North China Electric Power, Vol. 35 (2013) No. 2, p.28-31.

[2] Eden D, Luckas M. A heat and mass transfer model for the simulation of the wet limestone flue gas scrubbing Process. Chemical Engineering Technology, 1998(21):56-60.

[3] Ruhland F, Kind R, Weiss S. The kinetics of the absorption of sulfur dioxide in calcium hydroxide suspension. Chem Eng Sci, 1991, 46(4):934-946.

[4] GUO Rui-tang, GAO Xiang, DING Hong-lei, et al. Study on Flow Field Optimization in Wet Flue Gas Desulfurization Spray Scrubber, Proceedings of the CSEE, Vol. 28 (2008) No. 29, p.70-77.

[5] ZHONG Yi, GAO Xiang, WANG Hui-ting, et al. Performance Optimization of Wet Flue Gas Desulphurization System Based on CFD Technology, Proceedings of the CSEE, Vol. 28 (2008) No. 32, p.18-23.

[6] Hu Man-yin, Liu Song-tao, Liu Bing-wei, et al. Efficiency Prediction for an Ammonia Flue Gas Desulphurization System Based on Least Squares-support Vector Machine, Electric Power, Vol. 37 (2004) No. 7, p. 71-73.

[7] Hong Wen-peng, Liu Guang-lin. Efficiency Prediction for an Ammonia Flue Gas Desulphurization System Based on Least Squares-support Vector Machine, Journal of Chinese Society of Power Engineering, Vol. 31 (2011) No. 11, p. 846-850.

[8] Suykens JAK, Gestel TV, Brabanter JD, et al. Least squares support vector machines. Singapore: World Scientific; 2002.

[9] Suykens JAK, De Brabanter J, Lukas L, Vandewalle J. Weighted least squares support vector machines: robustness and sparse approximation. Neurocomputing. Vol.48 (2002), p. 85-105.

[10] ZHONG Yi, GAO Xiang, LUO Zhong-yang, et al. Factors influencing desulfurization efficiency of wet flue gas desulfurization system, Journal of Zhejiang University(Engineering Science), Vol. 42 (2008) No. 5, p.890-894.

[11] ZHAO Jian-zhi, JING Bao-sheng, ZHONG Zhao-ping, et al. A Study of Experimental and Reaction Models for the Spray Towers of Wet-method Flue-gas Desulfuration, Journal of engineering for thermal energy and power, Vol. 22 (2007) No. 4, p.457-462.