Research on modelling and stability of seamless dust removal system based on generalized system

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ABSTRACT – REZUMAT

Research on modelling and stability of seamless dust removal system based on generalized system

The dedusting system is the parameter selection and the degree of cooperation between several dust collector components. The stability of the system plays a decisive role in the dust removal efficiency of the whole system. The existing dust removal system model is a mechanism model, and the bag size, filter bag distribution and other parameters are optimized by simulation results. It cannot provide a model reference for the use of a new filter bag. In this research, the generalized model of the dust removal system is established by MATLAB. The factors affecting the service life of filter bag and dust removal efficiency of dust removal system are analysed. A differential equation is used to describe the influence of these factors. The dynamic model of the dust removal system is established. When considering the problem of flue gas emission, the algebraic equation with dust is constructed. The model of the bag-type dust removal system is described by a generalized system. Finally, the model's stability is analysed using the method of generalized system analysis, and the necessary and sufficient conditions for the stability of the model are obtained. Given the advantages of a seamless filter bag in filtration efficiency and mechanical properties, the stability of the system is studied. The results show that the system stability increases by 55.4% and 41.9% respectively. The performance of the filter bag is introduced into the modelling of the dust removal system, which plays a key role in the overall evaluation of the filter bag.

Keywords: *seamless filter bag, generalized system, dust removal system, system stability*

Cercetări privind modelarea și stabilitatea sistemului de îndepărtare a prafului pentru sacul filtrant fără cusătură pe baza unui sistem generalizat

Sistemul de desprăfuire reprezintă selecția parametrilor și gradul de conlucrare dintre mai multe componente ale colectorului de praf. Stabilitatea sistemului joacă un rol decisiv în eficiența de îndepărtare a prafului întregului sistem. Modelul existent de sistem de îndepărtare a prafului este un model de mecanism, iar dimensiunea sacului, distribuția sacului filtrant și alți parametri sunt optimizați prin rezultatele simulării. Nu se poate furniza model de referință pentru utilizarea noului sac filtrant. În această cercetare, modelul generalizat al sistemului de îndepărtare a prafului este stabilit utilizând MATLAB. Sunt analizați factorii care afectează durata de viață a sacului filtrant și eficiența de reținere a prafului de către sistemul de îndepărtare a prafului. Ecuația diferențială este utilizată pentru a descrie influența acestor factori. Se stabilește modelul dinamic al sistemului de îndepărtare a prafului. Apoi, luând în considerare problema emisiei de gaze arse, se construiește ecuația algebrică pentru praf. Modelul de sistem de îndepărtare a prafului tip sac este descris de sistemul generalizat. În sfârșit, se analizează stabilitatea modelului prin utilizarea metodei analizei generalizate a sistemului și se obțin condițiile necesare şi suficiente pentru stabilitatea modelului. Având în vedere avantajele sacului filtrant fără cusătură în ceea ce privește eficiența filtrării și proprietățile mecanice, se studiază stabilitatea sistemului. Rezultatele arată că stabilitatea sistemului crește cu 55,4% și, respectiv, 41,9%. Performanța sacului filtrant este introdusă în modelarea sistemului de îndepărtare a prafului, care joacă un rol cheie în evaluarea generală a sacului filtrant.

Cuvinte-cheie: *sac filtrant fără cusătură, sistem generalizat, sistem de îndepărtare a prafului, stabilitatea sistemului*

INTRODUCTION

The dedusting system was the parameter selection and the degree of cooperation between several components of the dust collector, which included several parts, a filter bag, bag type, ash hopper, air inlet and outlet, etc. [1–3]. Dust removal stability determined the stability of each component during operation. It played a decisive role in the dust removal efficiency of the whole system [4–7]. The performance of the filter bag was the key factor affecting the efficiency and stability of the dust removal system. Therefore, the performance of the filter bag was introduced into the modelling of the dust removal system, which played a key role in the overall evaluation of the filter bag [8–10].

Many factors need to be considered to model the entire dust removal system. The uncertainty of these factors was greater. Therefore, there were few researched on it. Chang analysed the operation stability of the bag-type dust removal system in a garbage incineration plant and established the qualitative relationship between the factors affecting the operation stability of the dust removal system. Then through the quantitative treatment of each influence factor, using the primary and secondary factor analysis method and fuzzy mathematical evaluation matrix mathematical modelling, the study of the smooth operation of the dust removal system seamless dust removal system research qualitative generalized system and the quantitative relationship between the influence factors was obtained. The model was optimized to improve the stability of the new dedusting process [11]. Liu quantified the factors that may affect the dust removal efficiency of bag-type dust removal system by establishing a mechanism model. Its influence on dust removal efficiency with time was analysed. The stability of the bag-type dust removal system was studied and evaluated by the coefficient of variation of dust removal efficiency under normal working conditions in the same year. Finally, the influence of the new process on the stability of the dust removal system was studied in the waste incineration plant. The model was employed to predict the maximum expansion scale of the enterprise and provide relevant suggestions for the detection of environmental protection departments [12]. Combined with the calculation model of the dust removal system, the further development of the simulation model of the EAF comprehensive process was proposed by Merier [13]. Further chemical composition and gas radiation were added to improve gas phase calculations. The results obtained from the EAF process model were used for subsequent calculations of the dust removal system model, such as predicting waste heat recovery potential, cooling system load, or analysing the post-combustion process. The deterministic implementation of these two models allowed for quick and easy adaptation of various EAF and detailed study of energy distribution and mass transfer within EAF. The model could be used in the design and control strategy of electric furnace. The existing dust removal system model was a mechanism model, and the bag size, filter bag distribution, ash bucket size, inlet and outlet location and other parameters were optimized through the simulation results, and the change of process parameters did not include the filter bag property. It had no reference value for the use of a filter bag and could not provide a model reference for the use of a new filter bag.

The establishment of the dust removal system model was to further explain the advantages of weft-knitted biaxial seamless air filter material in the improvement of mechanical properties and filtration efficiency in practical application. A generalized system was employed to model the dust removal system. Matlab was employed to simulate the stability of the dust removal system, which could better analyse the stability of the dust removal system. The dedusting efficiency and stability of the system were studied by changing the life of the filter bag and the initial dedusting efficiency. It was proved that the use of a seamless filter bag played a positive role in improving the efficiency and stability of the whole dust removal system. It provided a theoretical reference for the application of a seamless filter bag.

MODELLING ASSUMPTION

Aiming at the stability of the dust removal system, the stability of the dust removal system studied in this research was comprehensively measured by the service life of the filter bag, the dust removal efficiency and the total amount of flue gas emissions. In the process of dust removal, all factors were changing. To facilitate this research, the system stability was defined when the above three factors kept a certain value unchanged during the system operation. The shorter the time for the system to reach stability, the higher the corresponding system stability was.

Firstly, the factors affecting the service life of the filter bag and the dust removal efficiency of the dust removal system were analysed. The differential equation was applied to describe the influence of these factors on the service life of the filter bag and the dust removal efficiency of the dust removal system. The dynamic model of the dust removal system was established. Secondly, considering the problem of flue gas emission, the algebraic equation with dust was constructed. The model of the bag-type dust removal system is described by a generalized system. Finally, the stability of the model was analysed by using the method of generalized system analysis. The necessary and sufficient conditions for the stability of the model were obtained. The following assumptions were made for the successful establishment of the model and the smooth operation.

Assumption 1: The failure of the ash transport system during the operation of the dust removal system was not considered.

Assumption 2: The influence of the control system on the dust collector was not considered.

Assumption 3: The proportion of waste incineration to flue gas remained unchanged.

Assumption 4: The pressure difference in the furnace did not change during the operation of the system.

Assumption 5: The scale of an incinerator was multiplied by the efficiency of dust removal.

INFLUENCING FACTORS OF MODEL

To make a better explanation of the solution of the equation, the Hurwitz theorem was introduced here. Its content was below. The necessary and sufficient condition for the stability of the system was that all eigenvalues of the coefficient matrix A of the system had non-positive real parts. In addition, its eigenvalues with zero real part were simple roots of its minimal polynomial. The asymptotic stability of the system was required if all eigenvalues of the system coefficient matrix A had negative real parts.

The influence factors of the dust removal system were mainly divided into two parts. The first part was the factors affecting the service life of filter bag. The second part was the factors affecting the dust removal efficiency of the system.

The factors affecting the service life of the filter bag

Uneven distribution of flue gas

The local filter wind speed in the air chamber was too high. This caused the dust to increase the impact and wear of the filter bag. The degree of uneven distribution of flue gas is expressed by $d_1, d_1 \in [0,1]$. When the value was 1, it indicated that the flue gas was not evenly distributed. However, when the value was 0, it indicated that the flue gas was evenly distributed and hardly wear the filter bag.

Pressure difference in the furnace

A larger differential pressure means that the filter bag was subjected to greater resistance during operation. This was one of the reasons why the damage of the filter bag is aggravated. The pressure difference in the furnace was set as p_1. The larger its value was, the more the service life of the filter bag was reduced.

Distance between filter bags

The distance between the filter bags was too small. This could cause wear and tear between filter bags or flexion of cage bones. The gap between the cage bone and the bottom of the filter bag was too small. This could cause impact wear between the filter bag and the cage bone. Therefore, the influence of the direct distance of the filter bag on the service life of the filter bag was considered. In addition, the distance between the filter bags was set as d_2.

Cleaning times of the filter bag

Cleaning the filter bag too often would accelerate the wear of the filter bag. It would also affect the service life of the filter bag. The filter bag cleaning times were set as n.

Temperature of the flue gas

It was easy to damage the filter bag when the flue gas temperature exceeded 220 °C. This could greatly reduce the life of the filter bag. Therefore, the influence of flue gas temperature on the service life of the filter bag was also considered. It was set as γ_3 and meets the following conditions.

$$\text{if } T_2 \leq 220, \text{ then } \gamma_3 = 0$$

The factors affecting system dust removal efficiency

Temperature of the flue gas

The temperature of incoming flue gas was strictly controlled between 130 °C and 220 °C. Flue gas condensation was easy to occur when the temperature was lower than 130 °C. Dust adsorption on the filter bag was not easy to fall off. e of the flue gas was set as γ_3 and meets the following conditions.

$$\text{if } T_2 \geq 130, \text{ then } \gamma_3 = 0$$

Air leakage

Air leakage leads to fly ash plate and agglomerate, blocking the filter bag and affecting the filtering effect. Caking in the chamber and tube wall affected the conveying effect of fly ash. The influence factor is set as a_1, $a_1 \in [0,1]$. If the value was set to 1, the filtering effect was greatly affected. If the value was set to 0, the filtering effect was almost unaffected.

Leakage in flue and body

Leakage of the flue and body leads to condensation of flue gas. The condensation precipitated acidic liquid, leading to serious corrosion of the dust collector structure. Inhaling rainwater on rainy days further aggravated the damaging effects of caking, acid, etc. This impact factor was as a_2, $a_2 \in [0,1]$. When the value was 1, it had a great influence on the life of the filter bag. When the value was 0, it basically had no influence.

MODEL ESTABLISHMENT OF DUST REMOVAL SYSTEM

According to the analysis of the influencing factors of the system in the preparation part of the above model, the differential equation of the service life of the filter bag can be obtained as shown in equation 1. In the equation, α_1 is the influence factors of mechanical properties of filter bags on service life, d_1 – the degree of irregularity in the distribution of flue gas, d_2 – the interaction factor between two filter bags, n – the influence of filter bag cleaning times on filter bag life.

$$T'(t) = \alpha_1 \rho(t) T(t) - (1 - d_1) T(t) - d_2 T^2(t) - nT(t) \quad (1)$$

Based on the above analysis of the influencing factors of the system dust removal efficiency, the differential equation of the system dust removal efficiency can be obtained as shown in equation 2. In this formula, n is the influence of cleaning times on dust removal efficiency, a_1 and a_2 – the influence factors of air leakage and water leakage on dust removal efficiency respectively, α_2 – the influence of the service life of filter bag on dust removal efficiency.

$$\rho'(t) = n\rho(t) - a_1 \rho(t) - a_2 \rho(t) - \alpha_2 \rho(t) T(t) \quad (2)$$

The ceiling of total emissions per unit area around incineration plants shall be set. The total amount of flue gas discharged was equal to the flue gas produced by garbage incineration minus the flue gas discharged by the dust removal system. The algebraic equation about the total amount of flue gas discharged was given below, as shown in equation 3. In this formula, β is the conversion rate of garbage to flue gas, S – the conversion rate of garbage to flue gas, M – the amount of garbage treated per unit area of the standard incinerator, m – the amount of filter bags, $\rho(t)$ – the filtration efficiency.

$$N(t) = (\beta - m\rho(t)) SM \quad (3)$$

According to equations 1, 2 and 3, the model of the dust removal system was shown in equation 4.

$$\begin{cases} T'(t) = \alpha_1 \rho(t) T(t) - (1 - d_1) T(t) - d_2 T^2(t) - nT(t) \\ \rho'(t) = n\rho(t) - a_1 \rho(t) - a_2 \rho(t) - \alpha_2 \rho(t) T(t) \\ 0 = (\beta - m\rho(t)) SM - N(t) \end{cases} \quad (4)$$

STABILITY ANALYSIS OF DUST REMOVAL SYSTEM

Equation 4 could be expressed as follows:

$$A(t) X'(t) = \big(T(t), \rho(t), N(t)\big)$$

In this formula,

$$X(t) = G\big(T(t), \rho(t), N(t)\big)$$

$$A(t) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{bmatrix}$$

$$G\big(T(t), \rho(t), N(t)\big) =$$

$$= \begin{bmatrix} \alpha_1\rho(t)T(t) - (1-d_1)T(t) - d_2T^2(t) - nT(t) \\ n\rho(t) - a_1\rho(t) - a_2\rho(t) - \alpha_2\rho(t)T(t) \\ (\beta - m\rho(t))SM - N(t) \end{bmatrix}$$

$$\begin{cases} \alpha_1\rho(t)T(t) - (1-d_1)T(t) - d_2T^2(t) - nT(t) = 0 \\ n\rho(t) - a_1\rho(t) - a_2\rho(t) - \alpha_2\rho(t)T(t) = 0 \\ \big(\beta - m\rho(t)\big)SM - N(t) = 0 \end{cases}$$

Three equilibrium points are solved according to the system formula.

$$P_1 = (0, 0, MS),\ \ P_2 = \Big(\frac{d_1 - n - 1}{d_2}, 0, \beta MS\Big)$$

$$P_3 = \Bigg(\frac{n - a_1 - a_2}{\alpha_2}, \frac{\alpha_2 - a_1d_2 - a_2d_2 - \alpha_2d_1 + \alpha_2n + nd_2}{\alpha_1 + \alpha_2}, \frac{MS(a_1d_2m - \alpha_2m + a_2d_2m + \alpha_2d_1m - \alpha_2nm - d_2nm + \beta\alpha_1\alpha_2)}{\alpha_1 + \alpha_2}\Bigg) \quad (5)$$

Subsequently, the stability of model 4 at the above three equilibrium points was researched. The Jacobian determinant of the system was shown in formula 6.

$$J_p = \begin{vmatrix} \alpha_1\tilde{\rho} - (1-d_1) - 2d_2\tilde{T} - n & \alpha_1\tilde{T} & 0 \\ -\alpha_2\tilde{\rho} & n - a_1 - a_2 - \alpha_2\tilde{T} & 0 \\ 0 & -mSM & -1 \end{vmatrix} \quad (6)$$

Firstly, the stability at the point P_1 was considered. The Jacobian determinant of the characteristic equation of the dust removal system 5-4 at the point P_1 was as follows.

$$\det\left|\lambda - J_p\right|_{p_1} =$$

$$= \begin{vmatrix} \lambda - [\alpha_1\tilde{\rho} - (1-d_1) - 2d_2\tilde{T} - n] & -\alpha_1\tilde{T} & 0 \\ \alpha_2\tilde{\rho} & \lambda - (n - a_1 - a_2 - \alpha_2\tilde{T}) & 0 \\ 0 & SM & \lambda + 1 \end{vmatrix}_{p_1}$$

$$= (\lambda + 1 - d_1 + n)(\lambda - n + a_1 + a_2)(\lambda + 1)$$

The above system has three characteristic roots as follows.

$$\lambda_1 = d_1 - 1 - n$$

$$\lambda_2 = n - a_1 - a_2$$

$$\lambda_3 = -1$$

According to the Hurwitz theorem, when the dust removal system meets $\lambda_1 < 0, \lambda_2 < 0, \lambda_3 < 0$, the dust removal system is asymptotically stable at the point P_1 as shown in equation 7. It could be concluded that when the coefficient of the dust removal system meet condition 7, the dust removal system 4 was asymptotically stable at the point P_1.

$$\begin{cases} d_1 - 1 - n < 0 \\ n - a_1 - a_2 < 0 \end{cases} \quad (7)$$

Secondly, the stability at the point P_2 was considered. The Jacobian determinant of the characteristic equation of the dust removal system 4 at a point P_2 was as follows.

$$\det\left|\lambda - J_p\right|_{p_2} =$$

$$= \begin{vmatrix} \lambda - [\alpha_1\tilde{\rho} - (1-d_1) - 2d_2\tilde{T} - n] & -\alpha_1\tilde{T} & 0 \\ \alpha_2\tilde{\rho} & \lambda - (n - a_1 - a_2 - \alpha_2\tilde{T}) & 0 \\ 0 & SM & \lambda + 1 \end{vmatrix}_{p_2}$$

$$= (\lambda + d_1 - n - 1)\Big(\lambda - n + a_1 + a_2 + \alpha_2\frac{d_1 - n - 1}{d_2}\Big)(\lambda + 1)$$

The above system has three characteristic roots as follows.

$$\lambda_1 = -d_1 + 1 + n$$

$$\lambda_2 = n - a_1 - a_2 - \alpha_2\frac{d_1 - n - 1}{d_2}$$

$$\lambda_3 = -1$$

According to the Hurwitz theorem, when the dust removal system meets $\lambda_1 < 0, \lambda_2 < 0, \lambda_3 < 0$, the dust removal system is asymptotically stable at the point P_2 as shown in equation 8. It could be concluded that when the coefficient of the dust removal system meet condition 8, the dust removal system 4 was asymptotically stable at the point P_2.

$$\begin{cases} -d_1 + 1 + n < 0 \\ n - a_1 - a_2 - \alpha_2\dfrac{d_1 - n - 1}{d_2} < 0 \end{cases} \quad (8)$$

Secondly, the stability at the point P_3 was considered. The Jacobian determinant of the characteristic equation of the dust removal system 4 at the point P_3 was as follows.

$$\det\left|\lambda - J_p\right|_{p_3} =$$

$$= \begin{vmatrix} \lambda - [\alpha_1\tilde{\rho} - (1-d_1) - 2d_2\tilde{T} - n] & -\alpha_1\tilde{T} & 0 \\ \alpha_2\tilde{\rho} & \lambda - (n - a_1 - a_2 - \alpha_2\tilde{T}) & 0 \\ 0 & mSM & \lambda + 1 \end{vmatrix}_{p_3}$$

$$= \big\{\big[\lambda - \big(\alpha_1\rho - (1 - d_1) - 2d_2T - n\big)\big] \cdot$$

$$\cdot \big[\lambda - (n - a_1 - a_2 - \alpha_2T)\big] + \alpha_1\alpha_2T\rho\big\}(\lambda + 1) =$$

$$= \left(\begin{matrix} \lambda^2 + (a_1 + a_2 - d_1 + A_1 + A_2 + A_3 + 1)\lambda + \\ (a_1 + a_2 - n + A_3)(n - d_1 + A_1 + A_2 + 1) - \dfrac{\alpha_1(a_1 + a_2 - n)A_4}{\alpha_1 + \alpha_2} \end{matrix}\right)(\lambda + 1)$$

$$A_1 = \frac{\alpha_1(a_1 + a_2 - n)}{\alpha_2},\ \ A_2 = \frac{2d_2A_4}{\alpha_1 + \alpha_2},\ \ A_3 = \frac{\alpha_2A_4}{\alpha_1 + \alpha_2}$$

$$A_4 = \alpha_2 - a_1d_2 - a_2d_2 - \alpha_2d_1 - \alpha_2n - d_2n$$

The system had three characteristic roots, among which $\lambda_1 = -1 < 0$. The other two roots were determined by equation 9.

$$\left(\begin{array}{l} \lambda^2 + (a_1+a_2-d_1+A_1+A_2+A_3+1)\lambda + \\ (a_1+a_2-n+A_3)(n-d_1+A_1+A_2+1) - \dfrac{\alpha_1(a_1+a_2-n)A_4}{\alpha_1+\alpha_2} \end{array} \right) = 0 \qquad (9)$$

It was known that both roots of the equation had negative real parts when the coefficients satisfied the following conditions through Weida's theorem.

$$\begin{cases} a_1+a_2-d_1+A_1+A_2+A_3+1 > 0 \\ (a_1+a_2-n+A_3)(n-d_1+A_1+A_2+1) - \dfrac{\alpha_1(a_1+a_2-n)A_4}{\alpha_1+\alpha_2} > 0 \end{cases}$$

According to the Hurwitz theorem, when the dust removal system meets $\lambda_1 < 0$, $\lambda_2 < 0$, $\lambda_3 < 0$, the dust removal system is asymptotically stable at the point P_3 as shown in equation 10. It could be concluded that when the coefficient of the dust removal system meet condition 10, the dust removal system 4 was asymptotically stable at the point P_3.

$$\begin{cases} a_1+a_2-d_1+A_1+A_2+A_3+1 > 0 \\ (a_1+a_2-n+A_3)(n-d_1+A_1+A_2+1) - \dfrac{\alpha_1(a_1+a_2-n)A_4}{\alpha_1+\alpha_2} > 0 \end{cases} \qquad (10)$$

Since the service life of the filter bag and the dust removal efficiency of the system were both positive numbers, the stability of the system only considered the stability of the system at the positive equilibrium point. That was, the following stability premise was the stability at the positive equilibrium point. Therefore, the premise of stability was to meet the conditions of the point P_3.

To verify that the theorem conditions could ensure the stability of the dust removal system, the relevant parameters set was shown in table 1. The number of filter bags represented the relative number (unit: 10,000).

The system status response was shown in the following two figures. Figure 1 shows the service life diagram of the filter bag. Figure 2 shows the smoke emission chart. The values in the figure represent relative sizes, not specific values. It could be seen from the figures that the system could finally reach a stable state within a certain period. Therefore, the solution of the equilibrium point P_3 was reasonable and reliable.

RESULTS AND DISCUSSION

Influence of mechanical properties on filter bag life

In this model, α_1 was not the specific mechanical property value, which represented the influence factors of mechanical properties of filter bag on service life. The parameter was set to four different values, 1, 2, 3, and 4. The increase in this value represented the improvement of the mechanical properties of the filter bag itself. The influence of the parameter α_1 on the life of the filter bag was shown in figure 3. It was obvious in this figure that the overall performance of the system would eventually be stable when the system changes the influence factor of the mechanical properties of the filter bag on the service life. The greater the influence factor of the mechanical properties of the filter bag on the service life, the longer the service life of the filter bag system was. The life of the filter bag at different values was shown in table 2.

Table 1

PARAMETER SETTINGS

Parameter	α_1	α_2	a_1	a_2	β	m	S	M
Number	1	0.5	0.5	0.5	0.8	0.01056	10	1

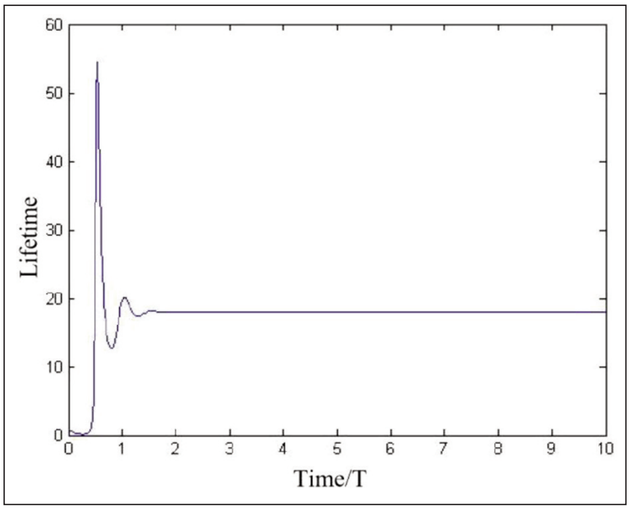

Fig. 1. The service life diagram of the filter bag

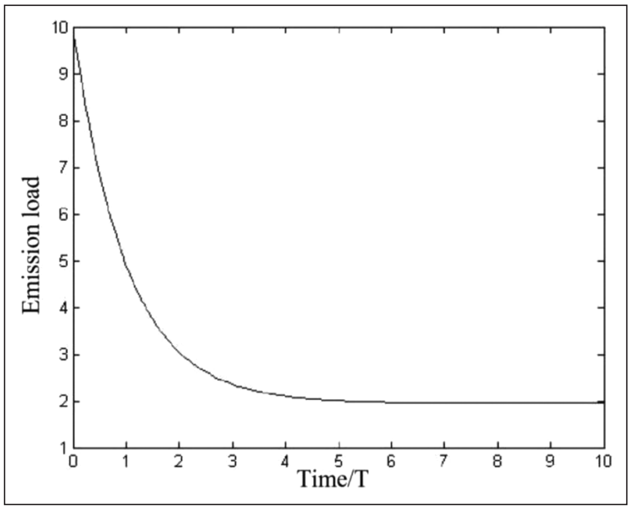

Fig. 2. The smoke emission chart

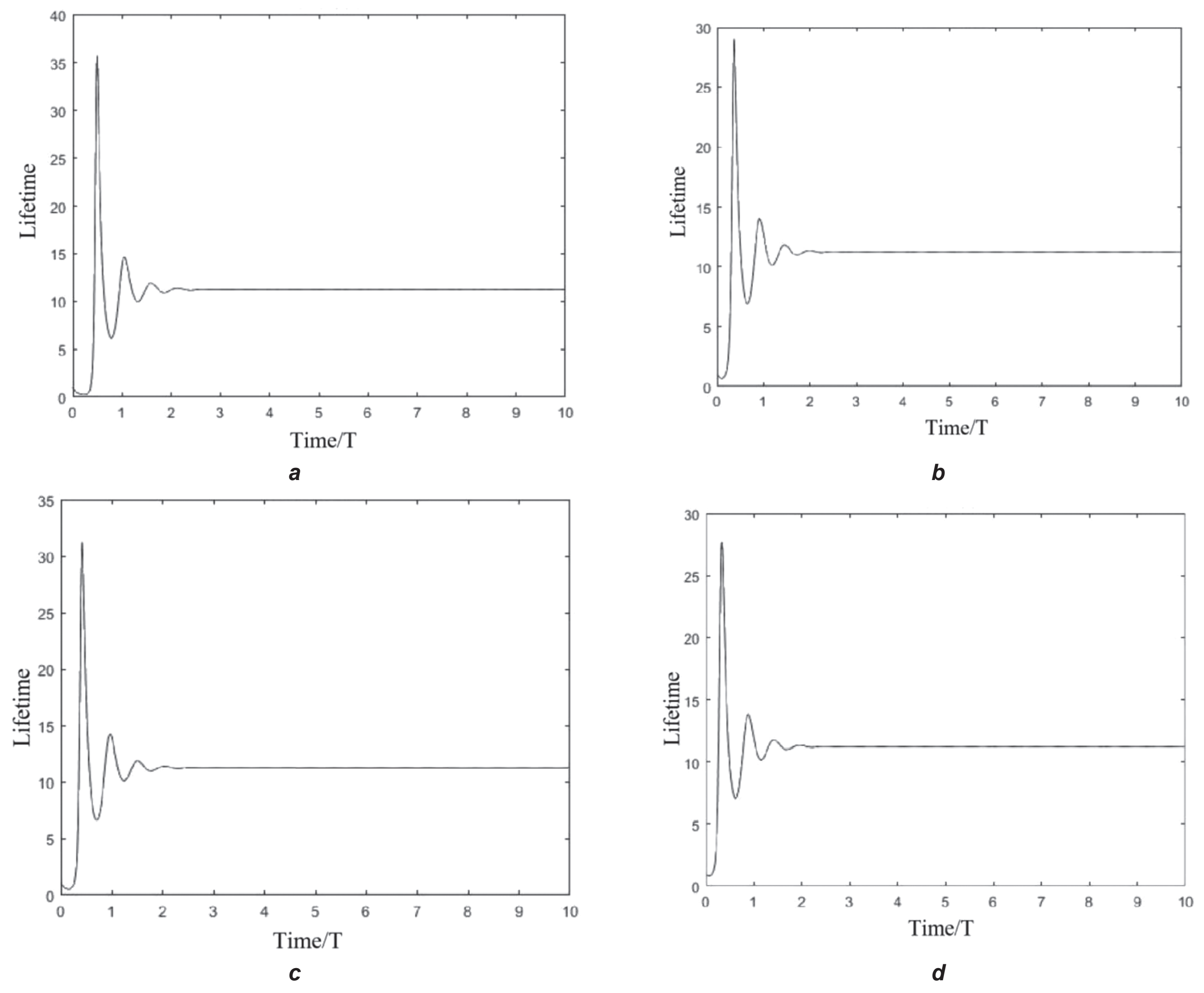

Fig. 3. Influence of different mechanical properties on filter bag life and system stability: *a* – $\alpha_1 = 1$; *b* – $\alpha_1 = 2$; *c* – $\alpha_1 = 3$; *d* – $\alpha_1 = 4$

Table 2

THE LIFE OF THE FILTER BAG AT DIFFERENT VALUES

α_1	**The life of the filter bag**
1	11.2
2	12.8
3	15.0
4	17.9

Table 3

THE INFLUENCE OF THE PARAMETER α_2 ON THE DEDUSTING EFFICIENCY OF THE SYSTEM AND THE STABILIZATION TIME OF THE SYSTEM

α_2	**The stabilization time**	**The dedusting efficiency**
0.5	2.35	16.15
1	2.72	14.99
1.5	4.01	13.51
2	5.28	12.75

Influence of service life on dust removal efficiency of filter bag

In this model, α_2 represented the influence factor of the service life of filter bag on dust removal efficiency. The parameter was set to four different values, 0.8, 1, 1.5 and 2. The increase of this value represented the greater impact of the service life of the filter bag on dust removal efficiency. Therefore, the service life of the filter bag was lower. The influence of the parameter α_2 on dust removal efficiency was shown in figure 4. It was obvious in this figure that the overall performance of the system tend to be stable when the system changed the influence factor of the service life of the filter bag on the dust removal efficiency. However, when the parameter α_2 was set to different values, the dust removal efficiency of filter bags was different. Table 3 shows the impact of the parameter on the dust removal efficiency and system stabilization time. As the parameter α_2 increased, so did the time to system stability. The efficiency of dusting declined, which indicated the reduction of the service life of the filter bag. The dust removal efficiency

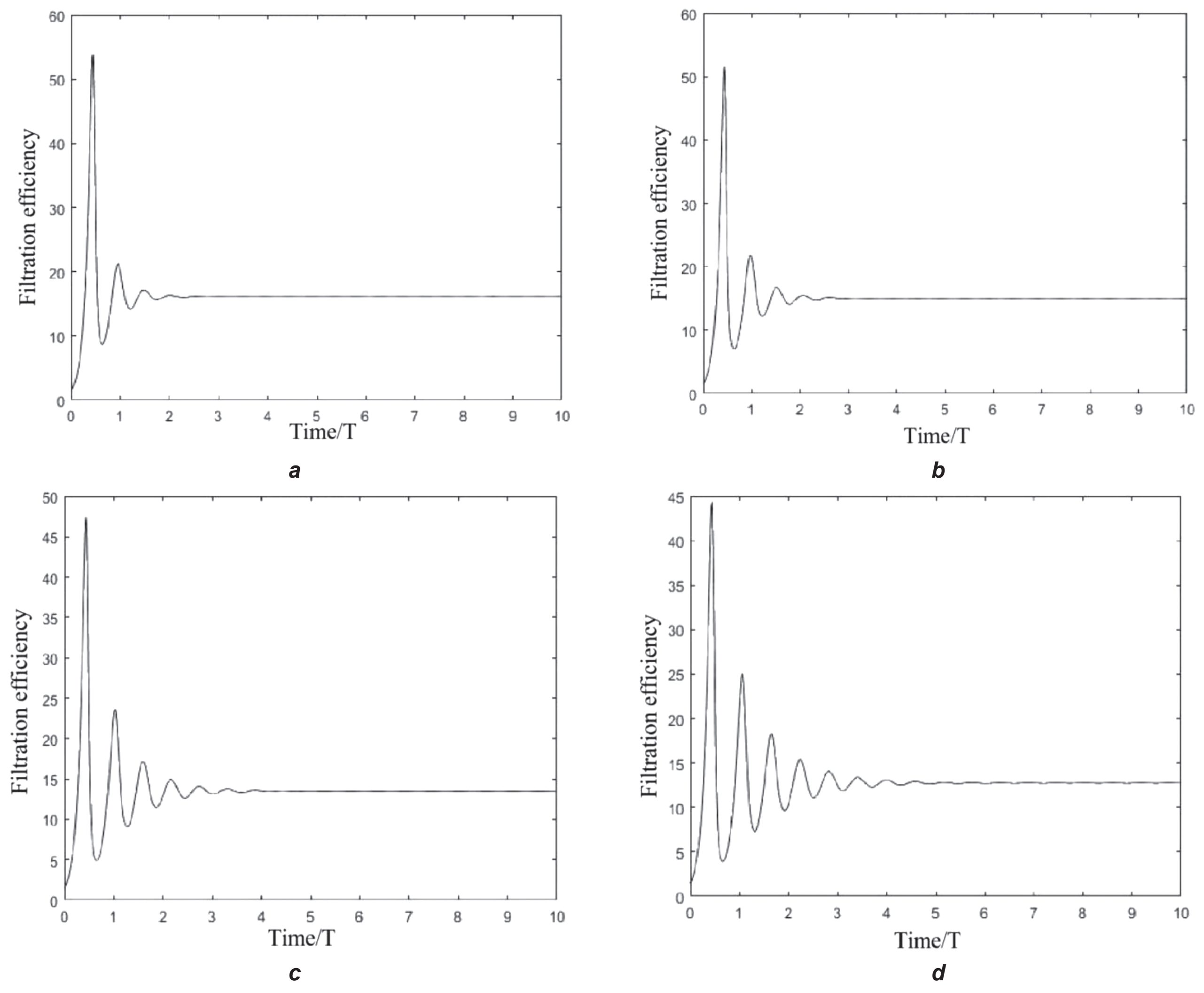

Fig. 4. Influence of different filter bag life on dedusting efficiency and system stability: *a* – $\alpha_2=0.5$; *b* – $\alpha_2=1$; *c* – $\alpha_2=1.5$; *d* – $\alpha_2=2$

of the system decreased. The time to reach stability increased, which was not conducive to the continuous operation of the whole dust removal system.

Influence of initial filtration efficiency on dust removal efficiency

Compared with the traditional filter bag, the seamless filter bag not only improved in mechanical properties but also improved filtration performance to a certain extent. In the model, the employment of a seamless filter bag was shown the improvement of dust removal efficiency ρ_0 in the initial state. Four different initial dust removal efficiency values were adopted in this experiment, which were 0.1, 0.5, 1 and 1.5 respectively. The larger the value was, the greater the initial dust removal efficiency of the filter bag was. The impact of this value on dust removal efficiency and system stability was shown in figure 5.

It was obvious in this figure that the system's overall performance tends to be stable when the system changes the initial value of dust removal efficiency. However, the time reached stability was different. The time when the system reaches stability with different initial dust removal efficiencies was listed in table 4. It was obvious from the table, when the initial value was larger, the time for the system to reach stability was shorter, and the overall operation effect of the system was better.

Table 4

THE TIME FOR DUST REMOVAL EFFICIENCY TO REACH STABILITY AT DIFFERENT INITIAL VALUES

Initial value of dust removal efficiency	The time the system reaches stability
0.1	2.0370
0.5	1.4826
1.0	1.3279
1.5	1.1872

The seamless filter bag researched in this paper could improve the initial value of dust removal. Seamless filter bag played a positive role in improving the stability of the whole filtration system. Therefore, for the model of the air filter bag, the time spent to stabilize the dust removal system was taken as the standard of system stability performance. The calculation formula for system stability was shown in equation 11. The function of the dust removal system

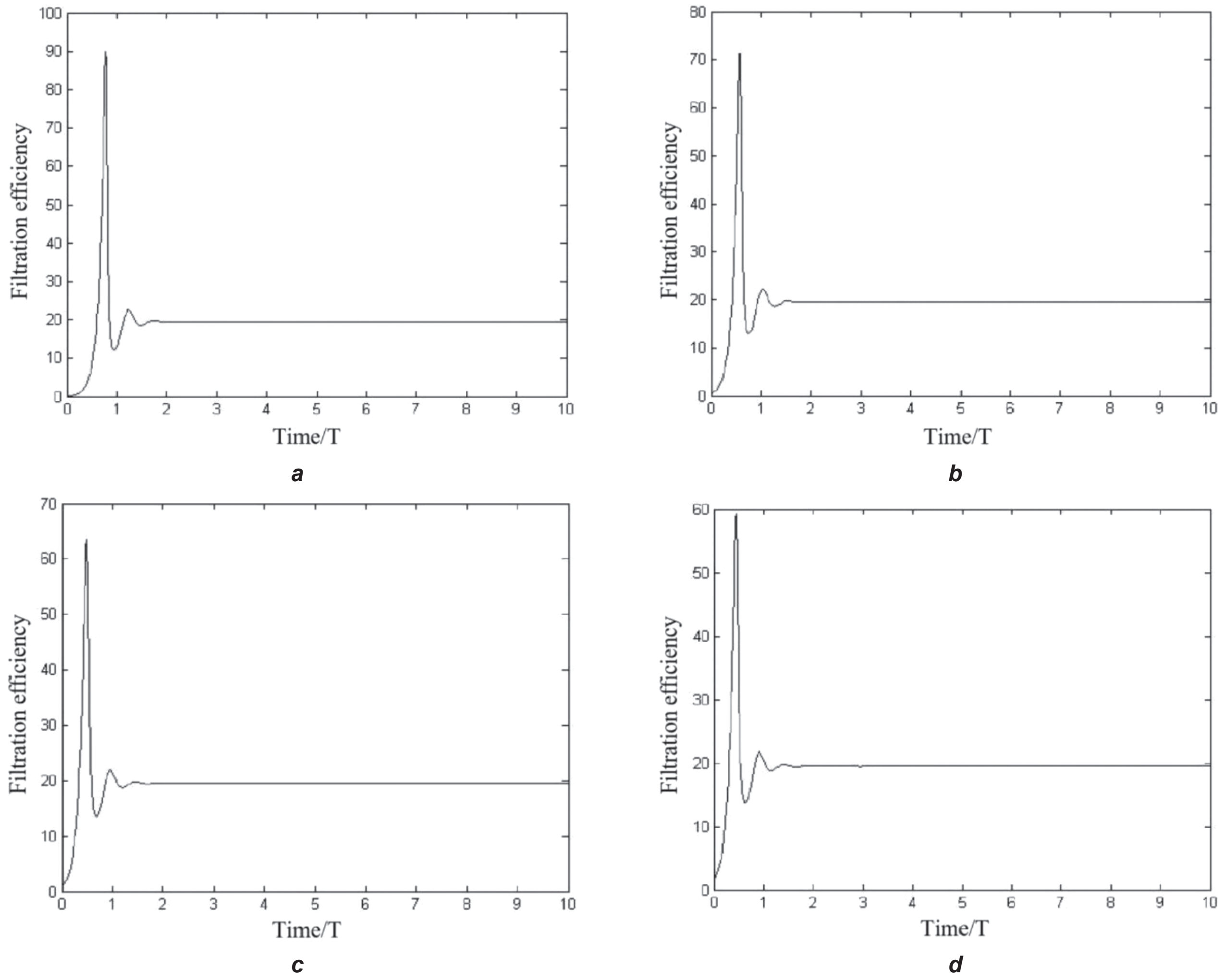

Fig. 5. Influence of different initial filtration efficiency on dust removal efficiency and system stability: *a* – $\rho_0 = 0.1$; *b* – $\rho_0 = 0.5$; *c* – $\rho_0 = 1$; *d* – $\rho_0 = 1.5$

was shown in equation 12. The system stability time was the time that the dust removal system passes when the derivative of the dust removal efficiency function was equal to 0. Equation 13 was obtained after taking the derivative. The time for the system to reach stability was shown in equation 14.

$$\begin{cases} T'(t) = \alpha_1\rho(t)T(t) - (1 - d_1)T(t) - d_2T^2(t) - nT(t) \\ \rho'(t) = n\rho(t) - a_1\rho(t) - a_2\rho(t) - \alpha_2\rho(t)T(t) \end{cases} \qquad (11)$$

$$\rho(t) = \rho_0 e^{(a_1 + a_2 + \alpha_2 T - n)t} \qquad (12)$$

$$\rho'(t) = (a_1 + a_2 + \alpha_2 T - n)\rho_0 e^{(a_1 + a_2 + \alpha_2 T - n)t} \qquad (13)$$

$$T = \frac{n - a_1 - a_2}{\alpha_2\rho_0} \qquad (14)$$

Therefore, the reduction of time for the system to reach stability was regarded as the standard for improving the stability of the dust removal model. When the initial value was raised, it was calculated according to equation 15. When the seamless filter bag was employed, the stability of the dust removal system model was improved by 20%.

$$\frac{1.4826 - 1.1872}{1.4826} = 20\% \qquad (15)$$

CONCLUSIONS

- In this research, a bag dust removal system model based on a generalized system was obtained by analysing various influencing factors of the bag dust removal system, which was composed of three differential equations, the service life of the filter bag, system dust removal efficiency and total amount of flue gas emission.
- The stability of the dust removal model was analysed by means of the stability analysis of the generalized system. The dedusting model could reach a stable equilibrium point under certain conditions. Finally, the time when the dust removal model reaches stability was employed as the standard to measure the stability performance of the system.
- By increasing the influence factor of the mechanical properties of the filter bag on the service life, the system would be stable. However, with the increase in the service life of the filter bag, the higher the dust removal efficiency of the system was, the shorter the time for the system to reach stability was, and the stability of the system improved by 55.4%. By increasing the initial value of dust removal efficiency, the system's overall performance tends to be stable. But the time to stability was

different. The larger the initial value of dust removal efficiency was, the shorter the time for the system to reach stability was. System stability was improved by 41.9 %. The research showed that the employment of seamless filter bag with high mechanical properties and filtration performance had significantly improved the stability of the dust removal system. It provided a theoretical reference for the application of seamless filtration materials.

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REFERENCES

[1] Hong, S.G., Jung, Y.J., et al., *A study on the optimization design of pulse air jet system to improve bag-filter performance,* In: Journal of the Korea Academia-Industrial cooperation Society, 2012, 13, 8, 3792–3799

[2] Ilić, M., Milutinović, S., et al., *Selection of a dedusting system for the lime stone preparation plant in the deposit "Zagradje-5"*, In: Mining and Metallurgy Engineering Bor, 2020, 3–4, 57–66

[3] Matelli, J.A., *Heat recovery of dedusting systems in electric arc furnaces: concept of a bottoming cogeneration plant and techno-economic analysis*, In: Journal of the Brazilian Society of Mechanical Sciences and Engineering, 2018, 40, 1, 1–14

[4] Omelchenko, E., Trushkova, E., et al., *Study of the Effectiveness of Innovative Air Purification Systems Used in the Design of Road Construction Enterprises*, In: Transportation Research Procedia, 2022, 61, 594–599

[5] Dock, J., Janz, D., et al., *Time-and component-resolved energy system model of an electric steel mill*, In: Cleaner Engineering and Technology, 2021, 4, 100223

[6] Dong, J., Tang, Y., et al., *Environmental consequences of an ultra-low emission retrofit in coal-fired power plants from a life cycle perspective,* In: Waste Disposal & Sustainable Energy, 2021, 3, 4, 309–323

[7] Wu, Q., Gu, M., et al., *Synergistic removal of dust using the wet flue gas desulfurization systems*, In: Royal Society Open Science, 2019, 6, 7, 181696

[8] Guo, L., Nie, W., et al., *The dust diffusion modeling and determination of optimal airflow rate for removing the dust generated during mine tunnelling,* In: Building and Environment, 2020, 178, 106846

[9] Li, Y., Cao, L., et al., *Semi-Interpenetrating Polymer Network Biomimetic Structure Enables Superelastic and Thermostable Nanofibrous Aerogels for Cascade Filtration of PM2.5,* In: Advanced Functional Materials, 2020, 30, 14, 1910426

[10] Liu, Q., Nie, W., et al., *A study on the dust control effect of the dust extraction system in TBM construction tunnels based on CFD computer simulation technology*, In: Advanced Powder Technology, 2019, 30, 10, 2059–2075

[11] Chang, P., Chen, L., et al., *Modeling and optimization of operation stability of bag-type dust removal system*, In: Construction Machinery Technology and Management, 2017, 30, 6, 66–71

[12] Liu, B.D., Jia, P.Y., et al., *Stability model and simulation of bag dust removal system*, In: Mathematical Modeling and its Applications, 2017, 6, 1, 39–52

[13] Meier, T., Kolagar, A.H., et al., *Process modelling and simulation of an EAF and its dedusting system*, In: Chernye Metally, 2018, 2, 18–24

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