The Application of Particle Swarm Algorithm in MBR Simulation System

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Abstract: This paper researches three main factors that influence membrane fouling: Mixed Liquor Suspended Solid (MLSS), pressure and temperature, and establishes a conjunctive mathematic model based on the separate analysis of the impact on membrane flux caused by these three factors. And by analyzing the experimental data obtained by treating industrial wastewater, we establish the mathematical model of membrane flux combined with the three factors, and optimize the parameters of the mathematical model using Particle swarm algorithm. The experimental data obtained by the mathematical model fits the actual data well, and this model has a more accurate simulation and prediction on the process of the treatment on MBR.

Keywords: MBR; Flux; MLSS; Mathematic Model

1. Introduction

Presently, researches on how to apply Membrane bioreactor (MBR) to wastewater treatment is developing quickly both at home and abroad. MBR maintains a high growth both in the field of application and the expansion in scale because of its efficient retention which improves the processing efficiency of the system. However, the high energy consumption and processing cost caused by membrane fouling become a bottleneck of membrane bioreactor technology. Therefore, using a mathematical model to describe membrane fouling becomes one of the main problems which need to be settled when studying the membrane bioreactor process. And the project draws the attention of many scholars both at home and abroad.

In this paper, Firstly, we studied the three factors which affect the membrane flux, they are: MLSS, pressure and regulation of temperature variation, and then we establish the joint of Flux and the three factors. Thirdly, using Particle swarm algorithm to optimize the important parameters which may cause MBR fouling, and then simulating the process of treating MBR fouling of industrial wastewater. Finally forming a new emulated analyzing technology in range of MBR has important meaning both on theory and practice.

2. MBR's Single-Factor Model

2.1. Mathematical Model of Flux with Operating Pressure

Membrane module's operating pressure is a significant parameter for running a MBR Most bachelors focus on how working pressure influence membrane flux in the aspect of qualitative analysis, that is, the higher the operating pressure the more membrane flux you will gain. To filter the model according to the authoritative theory of Darcy [1], the rate of membrane's solvent penetrating can be showed as following:

$$J = \frac{\Delta P}{m(R_w + R_g + R_c)} = \frac{\Delta P}{mR} \quad (1)$$

In the equation: J - membrane flux (m3/ m2· s); ΔP - the pressure in opposite sides of membrane, m - filtrate's viscosity; R - resistance (L/m) .

2.2. Mathematical Model of Flux with Temperature

Temperature affects viscosity of the MLSS. Thus it influences the quantity of the water that get through membrane. Characteristic of MLSS decides how temperature affect membrane flux, when MLSS is 18000 mg/L, temperature is from 33 to 36℃, whenever temperature get 1℃ higher than before, membrane flux increase 1 L/(m2• h) [2]. On the same conditions of Wastewater and MLSS, the amount of permeable relationship with the temperature can be expressed as follows：

$$Q_{vT} = Q_{v25} \times (1.0215)^{(T-25)} \qquad (2)$$

in the equation : Q_{vT} - membrane flux when T℃ (m3/d); Q_{v25} - membrane flux when 25℃(m3/d) ; T - the temperature of the water (℃).

2.3. Mathematical Model of Flux with MLSS

The source of Membrane fouling in MBR is MLSS. In terms of the formation mechanism of cake layer on the surface of membrane, as the concentration of suspended sludge in reactor increases, membrane fouling rate will also increase. As the formation of cake layer are directly related to sludge concentration, so MLSS have a direct impact on the amount of membrane permeable and the filter resistance. As MLSS increases, filtration resistance increases and permeability declines. When MLSS is in the range of 10000 ~ 12000mg/L,10% changes of SS concentration will cause 5% change in volume caused by flooding [3], the amount of permeable relationship with the MLSS can be described with the following equation:

$$J = -1.57\log(MLSS) + 7.84 \quad (3)$$

3. MBR's Multi-Factor Model

3.1. Experimental Data Analysis

Collect related data of the actual operation is the foundation of building mathematical models. We systematically observe and analysis the problem, summarize the objectives of decision and all aspects limits in decision-making, collect information on parameters and data, then clear the quantitative relationship between the various elements and the variable range. The paper obtained experimental data by the treatment of highly concentrated refractory organic wastewater in the laboratory, and manually adjust the experiment data obtained by these three parameters: temperature, pressure and MLSS.

Table 1. Experimental Data

J / ΔP / T / MLSS	10℃			20℃			30℃		
	10kPa	20kPa	30kPa	10kPa	20kPa	30kPa	10kPa	20kPa	30kPa
1600	29.45	68.82	118.4	38.8	97.24	154.1	48.84	102.3	166.2
2400	26.86	63.21	110.2	34.96	89.13	143.2	44.19	93.83	152.3
3200	24.72	58.9	104.2	31.5	83.24	135.2	40.5	86.84	142.2
4000	22.35	55.7	99.88	28.99	78.5	128.9	37.86	81.69	135
4800	21.51	52.96	96.1	27.14	74.46	124.6	36.7	78.32	127.9
5600	20.8	51.13	93	25.3	71.8	120.8	34.15	73.88	122.5
6400	19.14	48.89	90.14	24.16	68.75	116.3	32.52	71.26	118.7
7200	18.6	47.35	88.45	22.84	66.49	113.4	31.65	69.56	115.3

We can see from the table that when temperatures is 10℃ and pressure is10kPa, the membrane flux decreases as MLSS increases, that is, there is negative correlation between MLSS and membrane flux under the certain temperature and pressure condition. When MLSS is 2400 mg /L, pressure is10kPa, temperatures is 10,20,30℃.Flux is respectively 26.86, 34.96, 44.19 ml/min. From the experimental data, It is easy to see that membrane flux is a positive correlation with the temperature and pressure under certain MLSS condition.

3.2. Establish the Multi-Factor Model

In order to simplify our modeling process, we need to analysis several of factors affecting the membrane flux to find the major influencing factors which are MLSS, operating pressure and temperature, and between them we believe that MLSS is the most important factor affecting membrane flux through analysis. Many studies have shown that the membrane flux has a logarithmic relationship with concentration of sludge [4]. In order to obtain equation between flux and MLSS, temperature and operating pressure, consider to simulate the data of experimental with a logarithmic equation[5].

$$J_1 = k_1 \ln(MLSS) + k_2 \quad (4)$$

In the equation: k_1 and k_2 is a function of temperature and operating pressure

Under the experimental conditions, mathematical simulation between membrane flux and MLSS under different temperatures and operating pressures is shown in Figure 3, 4 and 5.

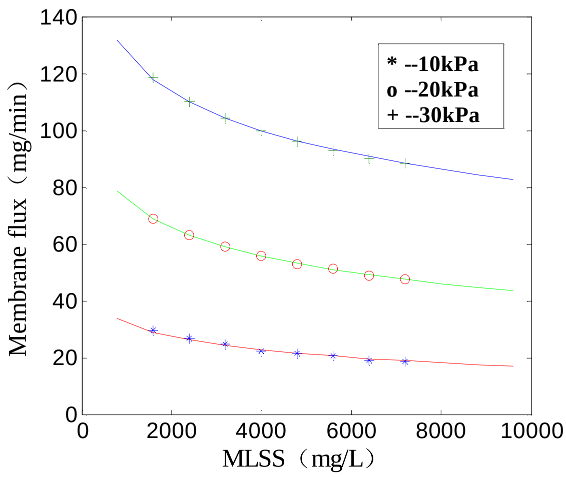

Figure 1. In 10 ℃ the Relation between Flux and MLSS under different Operating Pressures

In 10 ℃ the obtained mathematic relation between flux and MLSS is:

$$\begin{cases} J_{10kPa} = -6.738\ln(MLSS) + 78.627 \\ J_{20kPa} = -14.125\ln(MLSS) + 172.84 \\ J_{30kPa} = -19.635\ln(MLSS) + 262.72 \end{cases} \quad (5)$$

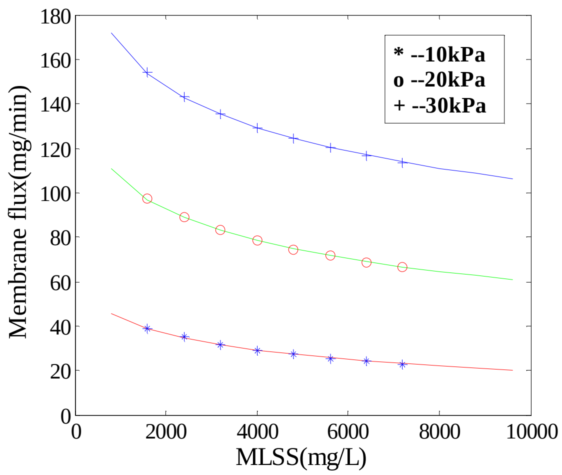

Figure 2. In 20 ℃ the Relation between Flux and MLSS under different Operating Pressures

In 20 ℃ the obtained mathematic relation between flux and MLSS is:

$$\begin{cases} J_{10kPa} = -10.315\ln(MLSS) + 114.746 \\ J_{20kPa} = -20.096\ln(MLSS) + 245.169 \\ J_{30kpa} = -26.288\ln(MLSS) + 347.38 \end{cases} \quad (6)$$

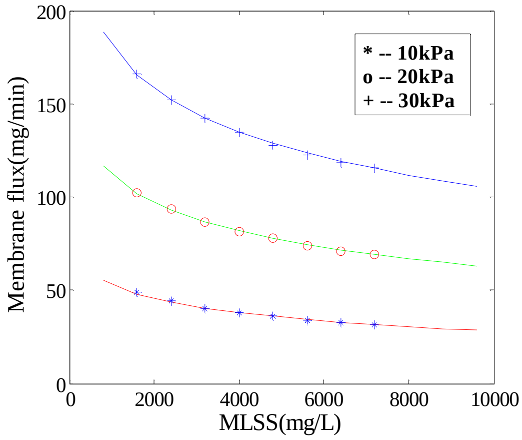

Figure 3. In 30 ℃ the relation between flux and MLSS under different operating pressures

In 30 ℃ the obtained mathematic relation between flux and MLSS is:

$$\begin{cases} J_{10kPa} = -10.891\ln(MLSS) + 128.38 \\ J_{20kPa} = -21.604\ln(MLSS) + 261.18 \\ J_{30kPa} = -33.247\ln(MLSS) + 410.66 \end{cases} \quad (7)$$

The matrix of 9 rows and 2 columns shows the coefficient of the relationship between J and MLSS under different T and △ P (T and △ P represent temperature and operating pressure).

$$\begin{pmatrix} k_1 & k_{10} \\ k_2 & k_{11} \\ k_3 & k_{12} \\ k_4 & k_{13} \\ k_5 & k_{14} \\ k_6 & k_{15} \\ k_7 & k_{16} \\ k_8 & k_{17} \\ k_9 & k_{18} \end{pmatrix} = \begin{pmatrix} -6.738 & 78.627 \\ -14.125 & 172.84 \\ -19.635 & 262.72 \\ -10.315 & 114.746 \\ -20.096 & 245.169 \\ -26.288 & 347.38 \\ -10.891 & 128.38 \\ -21.604 & 261.18 \\ -33.247 & 410.66 \end{pmatrix} \quad (8)$$

On our research, we carry out twice linear regression and polynomial regression. When the temperature is 10, 20 and 30, respectively, it is the first linear regression, getting three equations.

$$\begin{cases} J_{10^\circ C} = (-0.6448\Delta P\text{-}0.6023)\ln(MLSS) + 9.2046\Delta P\text{-}12.6973 \\ J_{20^\circ C} = (-0.7986\Delta P\text{-}2.9267)\ln(MLSS) + 11.6317\Delta P + 3.131 \\ J_{30^\circ C} = (-1.1178\Delta P\text{+}0.442)\ln(MLSS) + 14.114\Delta P - 15.54 \end{cases} \quad (9)$$

Equation (9) is equation of the membrane flux and sludge concentration and operating pressure under different temperature. then we carryout second linear regression and polynomial regression. We can get the mathematical model of the membrane flux with MLSS, temperature and operating pressure.

$$\begin{aligned} J = {} & [(-0.0008T^2 - 0.0094T - 0.6564)\Delta P + 0.0285T^2 \\ & -1.0864T + 7.4152]\ln(MLSS) + \\ & (0.2455T + 6.7407)\Delta P - 0.1725T^2 + 6.7577T - 63.0249 \end{aligned} \quad (10)$$

Equation (10) shows that the membrane flux has negatively correlated with the MLSS either at different temperatures, or in different pressure conditions, MLSS showed the same regularity that the higher MLSS the lower the flux. While equation (10) also proved that the increase in temperature and operating pressure is conducive to an increase in membrane flux.

4. Optimize the MBR simulation model parameters with Particle Swarm Algorithm

4.1 The Basic Principle of PSO

PSO simulates the prey behavior of birds [6]. Each solution of optimization problem is regarded as a bird in the search space in PSO, which we call particles. Particle's position stands for the potential solution of optimization problem in the search space, and the speed of particles determines their direction and distance of flight, and all the particles have a adaptive value determined by optimized function. Each particle updates itself by tracking the two "best position". one found by the particle itself (pbest), the other found by all particles of the entire group (gbest), gbest is the best in the pbest value. When executes t+1 time's iterative computation, the particle i updates its speed and position according to the following rules:

$$\begin{cases} v_{ik}(t+1) = wv_{ik}(t) + c_1 rand_1(p_{ik}(t) - x_{ik}(t)) + \\ c_2 rand_2(p_{gk}(t) - x_{ik}(t)) \\ x_{ik}(t+1) = x_{ik}(t) + v_{ik}(t+1) \end{cases} \quad (11)$$

in the equation: w - the inertia weight factor; c_1, c_2 - accelerating factor; k =l,2,...,D; $rand_1$, $rand_2$ - random function changing in [0,1].

4.2. Objective Function and the Range of Parameters

In the optimization and identification of the rate model parameters, the selection of objective function has a direct impact on the results of calculation and speed of optimization. In this paper, the objective function is as follows:

$$F = \left| \frac{J_i' - J_i}{J_i} \right| \quad (12)$$

The range of parameters is as follows:

Table 2. The Range of Parameters

PARAMETERS	ΔP (KPA)	T (℃)	$MLSS$ (MG/L)
MAXIMAL VALUE	**5**	**5**	**800**
MINIMUM VALUE	**35**	**35**	**10000**

4.3. PSO Application Steps in MBR's Multi-Factor Model

Through the analysis of model parameters in MBR simulation, we select three parameters which have greater impact on output, using particle swarm algorithm optimizes parameters in the given range. The steps are as follows：
Step 1: Initialize particles, this calculation will take the population size of 30 particles. on the assumption that the target in a D-dimensional search space, there is a community with m particles. The position of the ith particle is represented as vector X (x1, x2,---, xD), and the flying speed is expressed as V (v1, v2, ---,vD). Giving every particle a initial speed Vi randomly, according to the area of the parameters in table 2, Vmax of each parameter was reached . According to each particle, call MBR simulation models to count the objective function value by equation (12), and use the objective function value of particles as their respective pbest (evaluate of the pbest), and choose one of pbest as gbest (evaluate of the gbest), and set gbest as the best position of current particle. And given the accelerating factor c1 and c2.
Step 2: Setting inertial weight w=1, and calculate the speed of the particle by equation (11), determining if the speed Vi is beyond its range, if out of range, setting it to the boundary value.
Step 3: Calculating the particle's position according to the particle velocity V by equation (11), if any one-dimensional particles is out of range, returning to step 2, recalculating the velocity and position of the particle rely on random numbers, until the particles meet the range requirements ;
Step 4: For each particle, according to its position in the solution space, calling MBR simulation, calculating the objective function value by the equation (12) as its fitness.
Step 5: For each particle, comparing its fitness value and the optimal solution pbest particles have experienced, if the former over the latter, then updated with the current value of the particle memory pbest; Otherwise, keep pbest unchanged;
Step 6: Compare the current optimal solution and the optimal solution found by the particle gest, if the former over the latter, then update gbest; otherwise, keep gbest unchanged;
Step 7: If the end condition (such as the maximum number of iterations) is satisfied, out of the calculation, otherwise return to step 2.

Conclusion

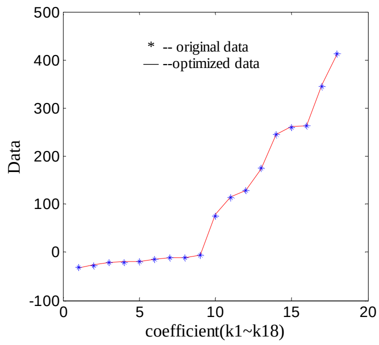

Figure 4. The Comparison between Experimental Data and the Actual Data

From Figure 4 we can see, the values calculated by model and experiment are basically the same, so the model can reflect the relationship between flux and MLSS, temperature and operating pressure correctly.
In this paper, a conjunctive model of these three factors combined with the flux is established through separate analysis of the impact on membrane flux caused by MLSS, temperature and operating pressure, and get a more accurate effect of simulating the membrane fouling through particle swarm algorithm parameters optimized. And we reach a conclusion that with the change of temperature and operating pressure, membrane flux is negatively correlated with the sludge concentration increased, and the flux conditions is positively correlated with temperature and operating pressure in certain MLSS under different operating conditions. Calculation data obtained through the model established agrees with actual data, and our model achieves more accurate simulation and predication of the MBR process .

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