Gas-liquid flow characteristics study on the amino acid fermentation tank

Zhixi Liang, Jianpeng Wang and Xiangsong Qi

College of Mechanical and Electronic Engineering, Shandong University of Science and Technology, Qingdao, China

Abstract

Amino acid fermentation is the use of the growth of microbial metabolic activity, with sugar, inorganic salt and the oxygen in the air as raw material, through the biological synthesis of various amino acids. In the process of fermentation, oxygen deficiency can lead to low output, resulting in waste of resources. The Euler - Euler two fluid model and population balance model and MRF(multiple reference frame) method are used to analysis the flow field which the six curved blade disc turbine agitator and axial flow down four levels of blender mixing four pages produce together in fermentation tank. The information of the oxygen content is obtained from the distribution of the local gas holdup and the particle size of bubble size. The axial flow is produced on the three superior level blender and the radial flow is produced on the lowest level in the tank. The circulating flow field is caused between them and the flow field on the inner wall of the tank. The axial flow that the axial flow stirring four pages produce and the radial flow that the six curved leaf disc turbine stirrer produce interact with each other, which improves the gas holdup in the fermentation tank amino acid. The beginning, the gas holdup in the fermentation tank is increased with the extension of mixing time. After a period of time, the gas holdup unchanged essentially, oxygen content has been stable.

Keywords

Amino acid fermentation; Euler model; MRF; Gas holdup; PBM.

1. Introduction

Universal fermentor is the most commonly used type. Ventilated fermentor is mainly divided into two categories: one is mechanical stirring fermentor, the other is airlift fermentor. The model used in this simulation is the first type of fermentor. The fermentor used in the analysis has not only ventilation tube, but also four-layer agitator, the top three-layer agitator is axial flow pattern, and the bottom agitator is radial flow pattern. The smaller the bubble is, the larger the relative surface area of the bubble is, and the faster the dissolution rate of oxygen in the liquid is. This has a positive effect on accelerating the medium reaction in the tank. In the whole fermentation process, the content and uniformity of dissolved oxygen in fermentation broth is an important index related to whether microorganisms have high activity and normal acid production. Air consumption, fermentation and dissolved oxygen will even affect the quality of fermentation indicators . Controlling aerobic dissolved oxygen, finding out the aerobic condition of bacteria in fermentation process, increasing or decreasing dissolved oxygen properly will greatly increase the fermentation yield . Therefore, it is important to study the influence of gas-liquid two-phase flow field and bubble size and distribution on the flow field in fermentor for the performance evaluation and analysis of fermentor.

In this paper, the gas-liquid two-phase flow in a general fermentation tank was analyzed by numerical simulation method. The bubble size distribution, the total gas holdup and the local gas holdup distribution in the fermentation broth were obtained, and the performance of the fermentation tank was analyzed.

2. Theoretical model of gas-liquid two-phase flow

This paper mainly studies the fluid characteristics in the gas-liquid two-phase fermentation tank, simulates the local and overall gas holdup, bubble size and bubble size distribution, and analyzes the flow field. The interaction (coalescence and breakup) between bubbles is modeled by Luo et al. . The theoretical part mainly involves continuity equation, momentum equation, Euler-Euler two-phase flow model, population equilibrium model and Realizable k-e model.

2.1 Basic equations of gas-liquid two-phase flow

In the multiphase flow model, the Euler method is used to describe and process the continuous media in all phases. The basic equations of gas-liquid two-phase flow include continuity equation and momentum equation.

Continuity equation: equation of continuity for phase Q see formula (1)

$$\frac{\partial}{\partial t}(\alpha_q \rho_q) + \nabla \cdot \left(\partial_q \rho_q \overrightarrow{v_q}\right) = \sum_{p=1}^{n}\left(\dot{m}_{pq} - \dot{m}_{qp}\right) + S_q \tag{1}$$

Among them, q is the speed of phase Q; MPQ is mass transfer from phase Q to phase p; mqp is mass transfer from phase p to phase Q. Sq is a source item, its default value is zero, or it can be specified as a constant or user defined quality source item.

Momentum equation: the momentum equation of phase q is shown in formula (2).

$$\begin{aligned}\frac{\partial}{\partial t}\left(\alpha_q \rho_q \overrightarrow{v_q}\right) + \nabla \cdot \left(\alpha_q \rho_q \vec{v}_q \vec{v}_q\right) &= -\alpha_q \nabla_p + \nabla \cdot \overline{\overline{\tau}}_q + \alpha_q \rho_q \vec{g} \\ &+ \sum_{p=1}^{n}\left(\vec{R}_{pq} + \vec{m}_{pq}\vec{v}_{pq} - \vec{m}_{qp}\vec{v}_{qp}\right) \\ &+ \left(\vec{F}_q + \vec{F}_{lift,q} + \vec{F}_{vm,q}\right)\end{aligned} \tag{2}$$

Among them, G is the acceleration of gravity, and the stress strain tensor of phase q is shown in Formula 3.

$$\overline{\overline{\tau}}_q = \alpha_q \mu_q \left(\nabla \vec{v}_q + \nabla \vec{v}_q^{\,T}\right) + \alpha_q\left(\lambda_q - \frac{2}{3}\mu_q\right)\nabla \cdot \vec{v}_q \overline{\overline{I}} \tag{3}$$

Among them, Mu Q and lambda Q are the shear viscosity coefficient and volume viscosity coefficient of the QTH phase, Fq is the external volume force, Flift, q is the lift, Fvm, q is the virtual mass, RPq is the interphase interaction force, P is the same pressure shared by each phase, vpq is the phase velocity.

The interphase interaction must be used; the proper expression of RPq closes the formula (2). The interphase force is related to friction, pressure and adhesion and satisfies the conditions of Rpq=-Rqp and Rqq=0. FLUENT takes a simple form:

$$\sum_{p=1}^{n}\vec{R}_{pq} = \sum_{p=1}^{n} K_{pq}\left(\vec{v}_p - \vec{v}_q\right) \tag{4}$$

2.2 Turbulence model Realizable k- e model

Liquid as the basic phase of this paper, due to the existence of stirrer, baffle and other structures, stirred reactor fluid exists strong streamline bending, whirlpool and rotation of the working conditions. In this paper, turbulence model with swirl correction of the Realizable k-e model, about K and e equation see (5) (6).

$$\frac{\partial}{\partial t}(\rho k)+\frac{\partial}{\partial x_i}(\rho k\mu_j)=\frac{\partial}{\partial x_i}\left[\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right] +G_k+G_b-\rho\varepsilon-Y_M+S_k \tag{5}$$

$$\frac{\partial}{\partial t}(\rho\varepsilon)+\frac{\partial}{\partial x_j}(\rho\varepsilon\mu_j)=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial\varepsilon}{\partial x_j}\right] +\rho C_1 S\varepsilon-\rho C_2\frac{\varepsilon^2}{k+\sqrt{\nu\varepsilon}}+C_{1\varepsilon}\frac{\varepsilon}{k}C_{3\varepsilon}G_b+S_\varepsilon \tag{6}$$

$$C1=\max\left[0.43,\frac{\eta}{\eta+5}\right] \qquad \eta=S\frac{k}{\varepsilon} \tag{7}$$

2.3 Population balance equation

Population Equilibrium Model (PBM) can be used to study the effect of bubble coagulation and breakage on bubble size in detail and vividly, and to have a deeper understanding of bubble variation and its influence in gas-liquid two-phase system.

Researchers at home and abroad have measured the size distribution of bubbles in air floatation [5-7]. The size of bubbles is the key problem affecting the calculation results. Population Balance Model (PBM) is more in line with the real physical process, and can get more accurate results [8]. When the PBM model is applied to the gas-liquid two-phase model, only the coalescence and fragmentation of bubbles are considered, the expression is as follows:

$$\frac{\partial}{\partial t}n(\nu,t)+\frac{\partial}{\partial t}\left(u_{gt}(\nu,t)n(\nu,t)\right)=B_B-D_B+B_C-D_C \tag{8}$$

$$B_B=\int_\nu^\infty g(\varepsilon;\nu)n(\varepsilon,t)d\varepsilon \tag{9}$$

$$D_B=n(\nu,t)\int_0^\nu g(\nu,\varepsilon)d\varepsilon \tag{10}$$

$$B_C=\frac{1}{2}\int_0^\nu Q(\nu-\varepsilon;\varepsilon)n(\nu-\varepsilon,t)n(\nu,t)d\varepsilon \tag{11}$$

$$DC=n(\nu,t)\int_0^\infty Q(\nu;\varepsilon)n(\varepsilon,t)d\varepsilon \tag{12}$$

In the formula, n (v, t) is the probability function of the number density of the bubble size; BB, DB, BC and DC represent the bubble formation and extinction rates after fragmentation and coalescence; g (e; v) is the bubble breakage rate function; Q (v; e) is the bubble coalescence rate function.

The movement of bubbles in liquid is a complex and unstable process. Under the action of gravity, buoyancy and liquid surface tension, significant deformation will occur, such as rupture, fusion and other phenomena will also lead to the surrounding liquid jet, turbulence and other hydraulic phenomena [9].

3. Constructing fermentor model and dividing grid

The fluid flow in fermentor is a highly unsteady three-dimensional process. The two-dimensional axisymmetric model is an approximation of the three-dimensional flow process. It is difficult to simulate the real flow state of the fluid in stirred tank. The three-dimensional numerical model must be used to capture the details of the flow field. This fermentor has four stirrers, the lowest is a six-curved blade disc turbine stirrer, the top three are axial downpressure stirring four pages, the top three stirrer diameter is 900mm, the bottom stirrer diameter is 1000mm. There is a defoaming device above the agitator, which is used to destroy the generated bubbles, control the increase of foam and eliminate a large number of bubbles. Fermentation tank has four hollow baffles uniformly distributed, the tank has two inner and outer coil, 48 outer coil, 62 inner coil, upper and lower heads are elliptical head, short radius of 990 mm, tank diameter of 3800 mm. There is an air outlet at the upper head with an aperture of 150 mm. A gas distributor is located at the bottom of the tank. There are eight small holes on the distributor with an aperture of 150 mm.

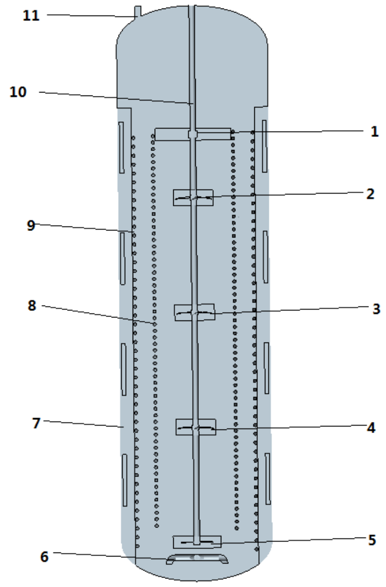


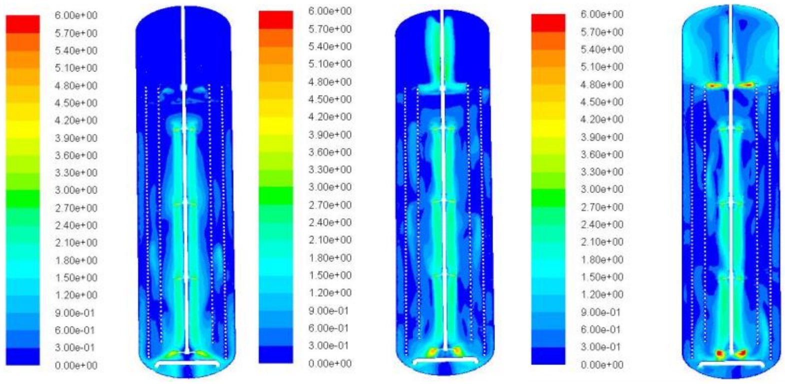
Fig. 1. Calculation model of fermentor

The outlet of tank top is set to Pressure outlet, the cross section of gas distributor inlet is set to Velocity inlet, the stirring shaft and blade are set to Moving wall, and the others are set to Wall. The inlet speed is set to 2.56m/s, the shaft and blade speed is set to 150 rpm, and the pressure outlet pressure is set to 1 atmospheric pressure. The ambient temperature of the tank is 423K and the pressure is 30397.5pa. The semi-implicit pressure-coupled equations are used. The first-order upwind formulas are used for the discrete schemes of turbulent energy, turbulent dissipation rate, pressure, momentum and volume fraction. 12. Euler two-fluid model and realizable k-e turbulence model are used to simulate the two-phase flow. The additional group equilibrium model describes the bubble coalescence behavior as [13]. The gas-liquid two-phase is oxygen and amino acid solution, respectively. The two-phase parameters are as shown in table 1, and the amino acid level is set at 10500mm.

4. Results and discussion

As shown in Fig. (2), the velocity field is not completely stable at 25T. The velocity distribution in the lower impeller region is more uniform than that in the upper three impellers. There are two reasons for this. First, the lower impeller is radial flow pattern and its output is uniform. The generated flow is distributed around, which makes the velocity field distribute more evenly. The upper three impellers are all downpressure axial flow. The fluid flows mainly dSecondly, the existence of inner and outer coils weakens the influence of the emulsion, which affects the oxygen transfer. The existence of the defoaming device can break the bubbles, constantly destroy the generated bubbles, control the increase of the foam, and eliminate a large number of bubbles. It prevents bubbles from blocking the exhaust pipe, which plays an important role in the circulation of oxygen. At 820T, the high-speed zone only concentrates in the narrow area near the agitator, and the velocity field has reached a stable state, which will not change with the increase of rotating time, and there will be a scattered dead zone near the inner and outer coils.

upper three-layer agitator on the radial flow. At 420T, the velocity field is stable, and the velocity field is more uniform than the initial time. The velocity field is blocked by the inner and outer coils. The flow field is not uniform near the inner and outer coils. At this time, the velocity field is more disturbed by the bubbles generated by the gas distributor. With the rising of the liquid level, the bubbles touch the continuous defoaming device, the defoaming device starts to play a role, a large number of bubbles form, and the bacteria and foam form a stabledownward under the action of downpressure, which can not disperse the fluid around. In the radial direction, the high-speed region is mostly near the agitator.



(a), 25Tvelocity field (b), 420Tvelocity field (c), 820Tvelocity field(3)

Fig. 2 Flow field distribution at different time

5. Conclusion

In this paper, the flow field, gas-liquid two-phase and bubble distribution in amino acid fermentor were studied by numerical simulation. The following conclusions were drawn:

(1) The overall gas content of the amino acid fermentor reached 4.44%, and the oxygen content in the fermentor was high, which provided sufficient oxygen for the fermentation of amino acids. However, the local gas holdup is not uniform, especially in the vicinity of the tank wall, the local gas holdup is low, because some bubbles adsorb on the inner and outer coils, resulting in less bubbles passing through the inner and outer coils, and lower bubbles near the tank wall.

(2) There are many dead zones in the flow field and gas-liquid two-phase at stable time, which is related to the larger diameter of the bottom agitator. Although the bottom agitator is a runoff agitator, a small part of the fluid will flow along the axial direction. Because the diameter of the top three agitators is smaller, the shaft thrown from the bottom agitator will be changed. The flow direction of the fluid is difficult to be subjected to the downward pressure of the upper three-layer axial flow stirrer, which results in the weakening of the circulation in the flow field.

(3) From the bubble size distribution and bubble size distribution in the amino acid fermentor, we know that the bubble content in the range of 16 mm to 22 mm is the highest, and they have the greatest influence on the amino acid fermentation.

References

[1] CHADDAN, MALONEMF, DOHERTYMF. Feasible Products for kinetically controlled reactive distillation of ternary mixtures[J].AIChE J 2000,46(5):923-936

[2] De rijk S E, Van der graaf J M, Den blanken J G. Bubble size in flotation thickening[J]. Water Research, 1994, 28(2): 465–473.

[3] Leppinen D M, Dalziel S B. Bubble size distribution in dissolved air flotation tanks[J]. Journal of Water Supply: Research and Technology, 2004, 53(8): 531 –543.