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Micromixing simulation of novel large-double-blade impeller

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ABSTRACT

The novel large-double-blade impeller spans a wide range of industrial application areas owing to its obvious advantages in the rapid reactions. So it is indeed necessary to have a profound understanding of micromixing characteristics about the novel large-double-blade impeller. This paper establishes a model to analyze the three main factors' effect on the segregation index through the numerical simulation which is used to research the performance of novel large-double-blade impeller. The three main factors are separately feed discretization number, feeding location and agitation speed. Through the analysis above, the turbulent energy dissipation rate and concentration distribution of H^+, $I_3{}^-$ would be deduced. Meanwhile, it compared with the Fullzone (FZ) impeller and double ribbon (DHR) impeller. The results show that (1) when the feed discretization number is over 35, the segregation index would tend to be the fixed specific value. And only in that situation, the effect of macro mixture could be ignored. (2) The optimized feeding location is in the blade area with a vast, turbulent energy dissipation rate to achieve a better micromixing performance, which is demonstrate by the consumption curve of H^+ and the generation contour of I^{3-}. (3) The main spot of the consumption of H^+ and the generation of I^{3-} is on the one side of the feeding location. Besides, compared with FZ impeller and DHR impeller in the same scale and operating condition, novel large-double-blade impeller has a better micromixing performance.

1. Introduction

Stirring device has been widely applied in the process industry, such as chemical industry, pharmaceuticals industry, food industry, metallurgy, papermaking, sewage treatment and so on. The comprehensive performance of the stirring device largely depends on the most indispensable part—the impeller. Thus, it is of significance to design and select an efficient impeller [1]. In most simple processes, traditional small-blade impeller with single function would be applied because of its simple structure, convenient operation and completed design method. When it comes to the reaction system under the changing viscosity, the impellers only fitted with low or high viscosity system can't meet the requirements of the various parts of a chemical process. Thus, wide-adapted double-shaft agitator and large-single-blade impeller were designed to fit the requirements of various system [2]. Through the comparison between two of these impellers, the novel large-double-blade impeller is more favorable for its simple structure, unsophisticated dynamic seal and the lower expense of operation and maintenance.

Among the researches involving the large-blade impellers, the main factor that had been considered is the macromixing characteristics [3–6]. In industrial production, the large-blade impeller spans a range of application in rapid reactions of process industry. It showed that the quality of the final product in rapid reaction largely depended on the micromixing characteristics [7,8]. When the intrinsic reaction rate is larger than or close to the mixing rate, reactions are almost or even already completed before reactants are homogenized in the molecular scale. Thus, rapid reactions actually occur at the local inhomogeneous state which will influence the distribution and quality of the product and the stability of the system. That's why the micromixing could affect the process in rapid reaction. Considering the application and research conditions of large-blade impeller in rapid reactions and the effect of micromixing exerted on the products of rapid reaction, it's really necessary to study the micromixing characteristics of the large-blade impeller.

Generally, micromixing characteristics of the impellers were measured through the experiment by analyzing the conversion rate of reactant. The experimental method is much more expensive and time-consuming by which it could only obtain the general micromixing characteristics and could not obtain the local information in details and the current changing process. Therefore, the micromixing of the impellers was simulated numerically through computational fluid dynamics (CFD) method to obtain the local information in details besides the general micro-mixing characteristics. But micromixing numerical simulation including the reaction

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Nomenclature

Latin letter

B	blade width, mm
$c_{j,r}$	molality of reactant/product j in reaction r, mol/L
C	distance of lower blade to the vessel bottom, mm
C	concentration of reactant, mol/L
C_i	molar concentration of species i, kmol/m^3
$\langle C_i \rangle$	bulk molar concentration of species i, kmol/m^3
C_ξ	volume ratio constant
C_τ	time scale constant
D	impeller diameter, mm
E	engulfment parameter, L/s
h_1	height of upper blade, mm
h_2	height of lower blade, mm
h_3	height of extension plate of upper blade, mm
H	axial distance between the upper and lower blade, mm
K	kinetic energy, J/kg
$k_{b,r}$	reverse rate constant in reaction r
$k_{f,r}$	positive rate constant in reaction r
$M_{w,i}$	molecular weight of species i
N	component number in stirring vessel
N	agitation speed, rpm
N_r	number of chemicals in reaction r
P	fluid pressure, Pa
P_v	power consumption per unit volume, W/m^3
R_i	production rate of species i per unit volume, kg/(s·m^3)
$R_{i,r}$	net production rate of species i in reaction r, kg/(s·m^3)
T	time, s
t_{m}	characteristic time, s
U	velocity vector of fluid, m/s
u_i	fluid velocity on the i direction, m/s
$v'_{i,r}$	stoichiometric coefficient for reactant i in reaction r
$v''_{i,r}$	stoichiometric coefficient for product i in reactant r
x_i	length dimension of the i direction, m
X_S	segregation index
Y	ratio of acid mole number consumed by reaction (2) divided by the total acid mole number injected
Y_i	mass percentage of species i
Y_{ST}	value of Y in total segregation case when micromixing process is infinitely slow
Z	number of grids

Greek letter

A	radial angle between the upper and lower blade, °
B	radial angle between the flanged plate and lower blade, °
Γ	generalized diffusion coefficient
Γ_i	diffusion coefficient of species i
E	energy dissipation rate, m^2/s^3
$\eta'_{j,r}$	rate exponent for reactant species j in reaction r
$\eta''_{j,r}$	rate exponent for product species j in reaction r
λ_k	finest scale
M	dynamic viscosity, Pa s
P	density, kg/m^3
Σ	feed discretization number
σ_r	rth feeding portion
Φ	universal variable
Ω	generalized source term
Ω_i	source term on the i direction

Abbreviation

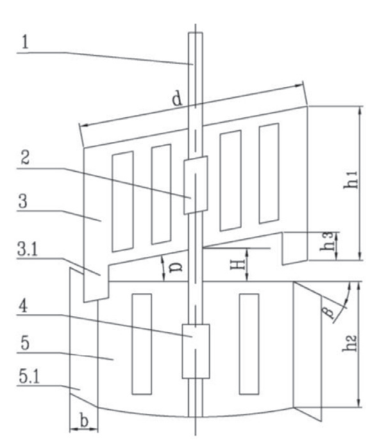
CFD	computational fluid dynamics
DHR	double-helical-ribbon
EDC	eddy-dissipation-concept
FZ	Fullzone
MB	Maxblade
SM	Sanmeler

which is based on molecular probe method is more complicated, meanwhile it lacks relevant data to validate models. So the reports about this theme have been rarely seen by now, except that Han et al. [9] numerically analyzed the micromixing performance of Rushton turbine in viscous system. They analyzed the influence of operating parameters on its micromixing performance and obtained the FR/ED model parameter experimentally which is helpful for reactor design, scale-up and optimization. Thus, the micromixing characteristics of novel large-double-blade impeller in viscous systems was numerically simulated in this paper to provide guidance for optimizing its operation in rapid reaction.

2. Structure of novel large-double-blade impeller

Novel large-double-blade impeller is a wide-adapted impeller which is evolved from FZ impeller and MB impeller. As shown in Fig. 1, it is mainly composed of upper blade and lower blade which are fixed on the shaft through the upper and lower shaft sleeves [10]. There are extension plates installed at down the edges of the upper blade and flanged plates installed on the left and right edges of lower blade. Meanwhile the bottom profile of the lower blade matches with the profile of the lower vessel's head. Both upper blade and lower blade have grids symmetrically, which are arrayed in a specific axial distance and radial angle.

The unique structure contributes to the advantages of novel large-double-blade impeller. Specifically, (1) Due to the diameter ratio exceeding 0.7, that is the area of impeller divided by the area of longitudinal profile of stirring vessel, it clarifies to be larger-blade impeller, and also enjoys the advantages of both MB impeller and FZ impeller, which is adaptable in a variety of systems, flow patterns and conditions. But the large power consumption of this kind of impellers can't be avoided despite its wonderful mixing performance. (2) The extension plates of upper blade will cultivate the fluid flowing between upper blade and low blade. (3) The flange plates of lower blade can promote the discharge of radial



5- shaft 2-upper shaft sleeve 3-upper blade 3.1-extension plate 4-lower shaft sleeve 5-lower blade 5.1-flanged plate

Fig. 1. Structure of novel large-double-blade impeller.

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