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SCIENTIFIC PAPER

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MODELING OF MIXING FOR STIRRED BIOREACTORS

3. Mixing time for aerated simulated broths

This paper presents the experiments on mixing efficiency for aerated media for a laboratory stirred bioreactor with a double turbine impeller. The effects of stirrer rotation speed, air volumetric flow rate and stirrer position on the shaft on mixing time for aerated water and simulated broths (CMCNa solutions) were analyzed. Compared to non-aerated broths, the results indicated that the variation of mixing time with the considered parameters is very different, due to the complex flow mechanism of the gas-liquid dispersion, a mechanism which is changed by changing the broth properties or fermentation conditions. Using the Statistics Toolbox of MATLAB some correlations between the mixing time and rotation speed, air volumetric flow rate and stirrer position on the shaft were established. The proposed equations agree well with the experiments, the average deviation being $\pm 9.02\%$.

The accumulation of biomass or biosynthesized product (extracellular polysaccharides, protein molecules) leads to the continuous modification of the medium rheological properties, producing the appearance of heterogeneous regions in the bioreactor. Under these conditions, one of the most important problems which must be solved is the establishment of the optimum hydrodynamic regime for the bioreactor.

The mixing time represents one of the most useful criteria for the characterization of the mixing intensity and for the scale-up of biosynthesis processes. The mixing time, t_m , is defined as the time needed to reach a given mixing intensity at a given scale, when starting from a completely segregated situation [1]. This parameter depends on a multitude of geometrical (dimensions of the mixing system, dimensions of the bioreactor) and technological factors (fermentation conditions, physical characteristics of the medium, power consumption, dissipated energy), the general correlation that describes the mixing time being of the following type [2]:

$$t_m = f(d/D, N, \eta, \rho, V_a/V, P/P_a, \varepsilon_T) \quad (1)$$

The experimental measurement of mixing time involves the use of tracers (acidic, alkaline or salt solutions, heated solutions, colored solutions) which are added to previously homogenized broths. The mixing time is the time needed for the considered parameter M (pH-value, temperature, absorption) not to exceed the considered range $M \infty \pm 0.5 \times \Delta M$ [1–3]. For example, an alkaline pulse is added to the liquid, this method being used in the paper experiments in this study. The system can be regarded as completely segregated at $t=0$. After a certain time, which is the mixing time, the pH remains in the considered range of deviation from the ideally

mixed state. In this way, the mixing time can be related to the mixing intensity.

Numerous equations have been proposed in the literature for the calculation of the mixing time. These equations take into account the type of fermentation (aerobe or non-aerobe), the rheological characteristics of the broths and the fermentation conditions [1–16]. Because of the complexity of the rheological behavior of the broths, of the flow phenomena and of the particularities of fermentation systems, the accuracy of the proposed models is very limited, especially for aerated broths. Furthermore, most of these models can predict the mixing time values for $Re > 10,000$, this flow regime being rarely reached in large-scale bioreactors due to microorganism sensitivity to shear stress. For $Re < 10,000$, these models need some corrections [1].

For these reasons, the aim of our experiments was to analyze the dependence between the mixing time, the rheological characteristics of the broths, the fermentation conditions and the biomass concentration, for a stirred bioreactor. For emphasizing and quantifying the effects of the biomass presence in the medium, the studies were carried out with simulated and real broths.

Previous results obtained for simulated broths indicated that, for water or liquids with low viscosity, the distance between the stirrers assembled on the shaft had to take into account the interference of the stirrer flow lines and, for viscous liquids, the position of the stagnant region in the bioreactor [3,16,17]. The presence of biomass in fermentation broths considerably reduces the mixing efficiency, even at low viscosity of the suspensions. The magnitude of this effect depends on the nature, concentration and morphology of the biomass. Experimental studies concerning the mixing of bacteria (*Propionibacterium shermanii*), yeasts (*Saccharomyces cerevisiae*) and fungus (*Penicillium chrysogenum*, free mycelia and mycelial aggregates or pellets) non-aerated suspensions in a stirred bioreactor provided with a double impeller have emphasized that the value of the mixing time increased as follows [17]:

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bacteria < yeasts << fungus pellets <
< fungus free mycelia.

Due to their higher viscosity and pronounced non-Newtonian behavior, the mixing time for fungus suspensions was significantly higher than for bacteria and yeast suspensions, at the same biomass concentration and operational conditions. Furthermore, the mixing time for free mycelia suspensions was about 2–3 times greater than for mycelial aggregates, owing to the higher viscosity. But, the mycelial aggregates exhibit an accentuated tendency of solid–liquid separation, the influence of the distance between the stirrers being more important in this case. Generally, as opposed to the mixing of simulated broths without biomass, for increasing the mixing efficiency of biomass suspensions, the stirrers had to be placed near the bottom of the vessel to avoid solid phase deposition [3, 17].

Because the previous results are adequate only for non-aerated broths, these studies have been developed for aerated simulated and real broths, under similar experimental conditions. The experimental results for simulated broths consisting of carboxymethylcellulose sodium salts of different viscosities are presented in this paper. By means of the obtained data and using the *nlinfit* function from the Statistics Toolbox of MATLAB, some correlations between the mixing time and rotation speed, air volumetric flow and distance between the stirrers on the shaft were obtained for the considered systems.

MATERIALS AND METHODS

The experiments were carried out in a 5 dm³ (4 dm³ working volume, ellipsoidal bottom) laboratory bioreactor (Biostat A, B, Braun Biotech International), with computer-controlled and recorded parameters. The bioreactor mixing system consisted of two turbine stirrers and three baffles. The bioreactor and impeller characteristics are given in Table 1.

The upper stirrer was placed on the shaft at a distance varying between 32 and 128 mm (0.5d and 2d) from the lower one. The rotation speed was maintained between 200 and 600 rpm. The experiments were carried out for Reynolds number intervals below 6,000, which correspond to laminar and transitory flow, and avoid "cave" formation at the broth surface (for rotation speeds greater than 800 rpm and L = 2d).

The sparging system consisted of a single ring sparger with 64 mm diameter, placed at 15 mm from the vessel bottom, having 14 holes of 1 mm diameter. The air volumetric flow rate was varied from 75 to 450 l.h⁻¹.

Table 1. Characteristics of the bioreactor and impeller

d, mm	d/D	H/D	w/d	l/d	h/d	No. blades	No. baffles	s/d	d'/d	l'/d
64	0.36	1.15	0.12	0.28	1	6	3	0.20	0.21	2.81

Water and simulated fermentation broths were used in the experiments. The simulated broths consisted of carboxymethylcellulose sodium salt (CMCNa) having an apparent viscosity in the range of 0.01–2.69 g/cm·s.

Owing to the difficulty of *in-situ* measurement of the viscosity during the experiments, the viscosity was measured before and after each experiment using an Ostwald viscometer. Both the experiments and viscosity measurements were carried out at 21°C.

The following homogeneity criteria for mixing were considered for determining the mixing time values [1, 2]:

$$I = \frac{pH_{\infty} - 0.5\Delta pH}{pH_{\infty}} \times 100 = 99\% \quad (2)$$

where $\Delta pH = 0.02$.

The values of the mixing time were determined by means of a solution of 2N KOH as tracer, by recording the time needed for the medium pH-value to reach the value corresponding to the considered mixing intensity. The tracer volume was of 0.5 ml, the tracer being injected opposite to the pH electrode, at 10 mm from the liquid surface. The pH electrode was placed at 20 mm from the vessel bottom. Because the tracer solution density is similar to the liquid phase density, the tracer solution flow follows the liquid flow streams and there are no errors due to tracer buoyancy. The pH variations were recorded by a bioreactor computer–recorded system. Each experiment was carried out three or four times, for identical conditions, using the average value of the mixing time. The maximum experimental error was $\pm 3.2\%$.

RESULTS AND DISCUSSION

For an aerobic bioreactor provided with one or more stirrers, the flow mechanism is complicated due to the combined action of mechanical and pneumatic mixing. Compared to non-aerated systems, different flow patterns can exist when gas is sparged into the broth.

Generally, analysis of the mixing efficiency for aerated mechanically stirred systems is derived from that of non-aerated systems, due to the less complicated flow phenomena for the latter. In this case, it was assumed that the gas phase did not influence the flow of the liquid phase in stirred vessels [1]. But, the values of the mixing time for aerated broths calculated by means of the equations established for non-aerated systems are lower than the experimental ones about 1.2–2 times [18].

The influence of aeration on the mixing efficiency is much more complex and must be distinctly analyzed.

For numerous fermentations, owing to the decrease in the pumping capacity of the stirrer, due to cavity formation, and compartmentalization in regions around each of the stirrers, aeration increases the mixing time compared to non-aerated systems. However, as confirmed in the literature, deviations from the values obtained for non-aerated broths depend on the constructive and functional characteristics of the bioreactor. Thus, the influence of the number and position of the stirrers on the shaft is unknown and the influence of the gas flow rate is different for different rotation speed or Reynolds number values [1].

In this context, the aim of this paper was to study the effects of stirrer rotation speed, air flow rate and stirrer position on the shaft on the mixing time for aerated water and simulated broths having different viscosities.

Influence of stirrer rotation speed

As opposed to non-aerated media, for which the mixing time is reduced by increasing the rotation speed value, for aerated broths the influence of this parameter is different and must be related to the apparent viscosity, air flow rate and distance between the stirrers placed on the shaft.

For water, the mixing time initially decreases with the rotation speed, reaches a minimum value for 100 rpm and then increases for all the considered air flow rates or distances between the stirrers (Figure 1.a).

This evolution could be the result of the modification of the mixing mechanism with the increasing rotation speed in the presence of bubbles. Thus, at low rotation speed, the contribution of pneumatic mixing is considerable, the increase of rotation speed additionally intensifying the broth circulation in the bioreactor. At higher rotation speed, the bubble retention time increases, the gas-liquid dispersion flow becomes complex and the circulation velocity is lower than that of the flow streams created by mechanical mixing in non-aerated media. The value of the rotation speed which corresponds to the minimum of the mixing time is called the *critical rotation speed* [2].

The increase of the liquid phase apparent viscosity or the modification of fermentation conditions can lead to a change of the variation of mixing efficiency with rotation speed. As may be observed from Figures 1.b-f, regardless of the broth apparent viscosity, by increasing the stirrer rotation speed, the mixing time reaches a minimum value for most of the studied systems. However, the value of the critical rotation speed depends on the apparent viscosity and air flow rate. Therefore, with increasing apparent viscosity from 0.082 to 2.69 g/cm-s, the value of the critical rotation speed increases from 300 to 500 rpm, for air flow rates between 80 and 400 dm³/h, or between 200 and 600 rpm, for air flow rates greater than 400 dm³/h. As mentioned earlier, this variation is a result of the change

in broth circulation in the bioreactor, as a consequence of the increase in gas hold-up, and less intensive mixing. Thus, for an apparent viscosity of 98.5 g/cm-s and 300 rpm, the gas volumetric ratio was 2.6-3%, becoming 11-12% for 700 rpm.

Although this variation of mixing time is characteristic for most of the considered systems, it can be modified as a function of the stirrer position on the shaft and the aeration rate.

Influence of air volumetric flow rate

The aeration influence on mixing intensity strongly depends on the apparent viscosity of the liquid phase. For water and liquids with similar viscosity, the mixing time continuously decreases with air flow rate, the magnitude of this effect being a function of the rotation speed (Figure 2.a).

This variation of the mixing efficiency with aeration rate considerably changes for viscous media. Up to about 0.1 g/cm-s the coalescence characteristics of the liquid phase are modified, this determining the change in bubble circulation velocity, bubble dispersion and hold-up compared to non-aerated media [19]. Thus, at lower aeration rates, with increasing viscosity, bubble coalescence increases and very large bubbles are formed, which can reach 80 mm diameter for a distance of 0.5d between the stirrers. Under these circumstances, the heterogeneous distribution of air in the liquid phase, the reduction of air hold-up and the rise of bubbles through preferential central routes were observed resulting in higher values of the mixing time. An increase of the air flow rate leads to the intensification of gas-liquid dispersion circulation, therefore to a decrease of the mixing time which reaches a minimum value (Figures 2.b-f). The value of the air volumetric flow that corresponds to the minimum mixing time, called the *critical flow rate*, depends on the liquid apparent viscosity, rotation speed and stirrer position on the shaft. Thus, for most of the studied systems, the mixing time minimum was reached critical flow rates of 150-200 dm³/h. But, for apparent viscosities lower than 1 g/cm-s, the increase of rotation speed can lead to the modification of the critical flow rate to higher values (250-300 dm³/h for rotation speed values greater than 300 rpm).

For constant rotation speed values, the additional increase of the aeration rate induces an increase of the mixing time. This variation is the result of the formation of smaller bubbles having a lower rise velocity, thus leading to an increase in the gas hold-up value and to a decrease of the dispersion circulation velocity. The phenomenon was more evidently observed for the experimental conditions at which mechanical agitation exhibits a significant role in the dispersion and retention of bubbles in the media.

At higher air flow rate values, the mixing time reaches a maximum and then decreases. The maximum

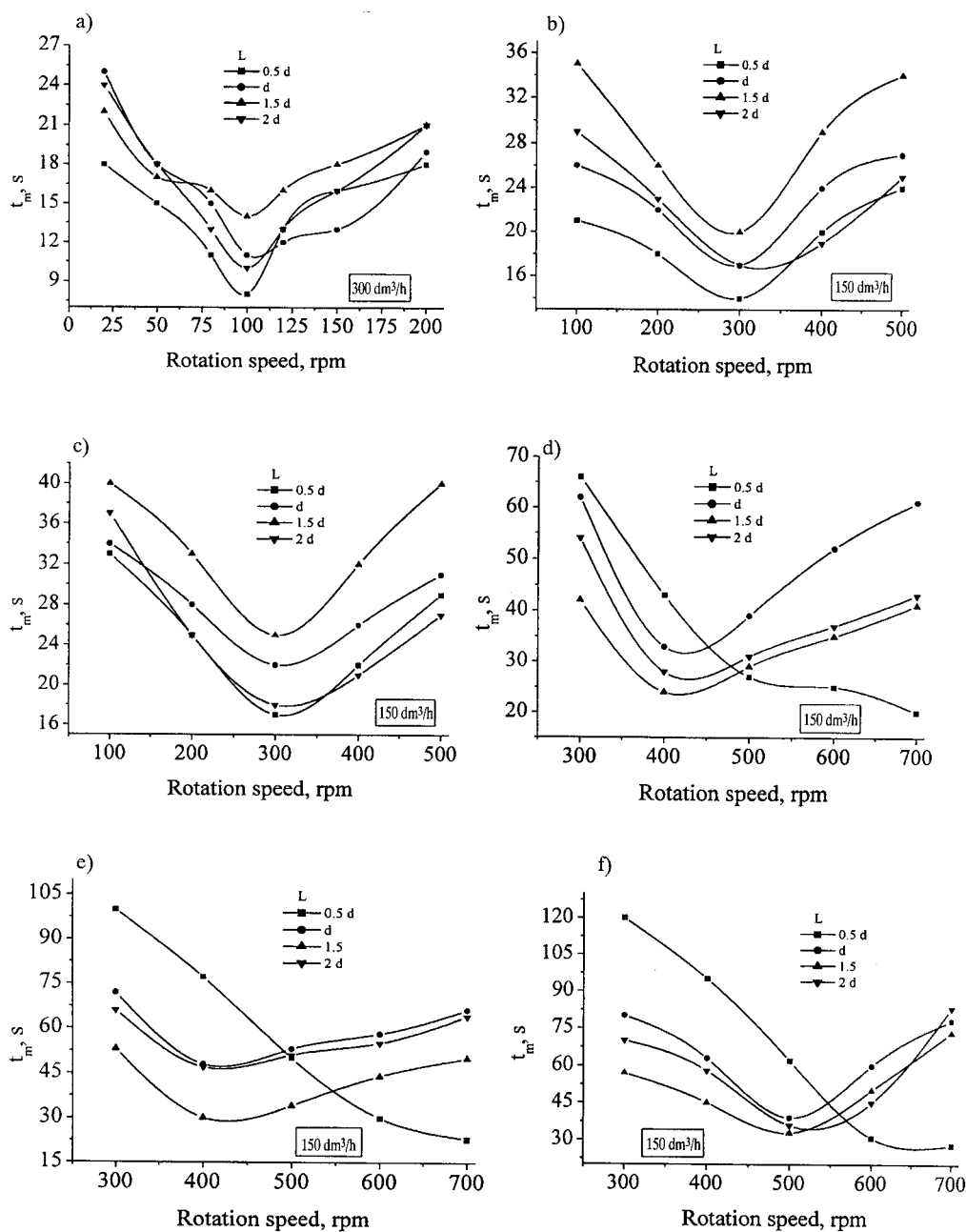


Figure 1. Influence of rotation speed on mixing time (a – water, b – $\eta_a = 0.8$ g/cm-s, c – $\eta_a = 0.32$ g/cm-s, d – $\eta_a = 0.98$ g/cm-s, e – $\eta_a = 1.87$ g/cm-s, f – $\eta_a = 2.69$ g/cm-s).

value corresponds to the flooding point, when the energy dissipated by the air exceeds that of the stirrer. At this moment, the rise velocity of the air increases, determining the simultaneous increase in the intensity of media circulation. The existence of a maximum value of the mixing time and of the flooding phenomena, is specific to some different rotation speed domains controlled by the apparent viscosity. Thus, the maximum was reached at rotation speeds values below 200 rpm for an apparent viscosity lower than 0.32 g/cm-s, at rotation speeds below 400 rpm for apparent viscosities between 0.32 and 0.98 g/cm-s, and at rotation speeds

below 600 rpm for higher apparent viscosities. The flooding aeration rate was 300 dm³/h.

On the other hand, as may be observed in Figure 2, the mixing time either continuously increases with air flow rate after reaching the minimum value, for rotation speeds greater than 200 rpm and apparent viscosities below 0.32 g/cm-s, or decreases for the entire considered aeration domain, for rotation speeds greater than 400 rpm and apparent viscosities between 0.32 and 0.98 g/cm-s. The observed variation of the mixing intensity indicated that in the first case flooding was avoided at

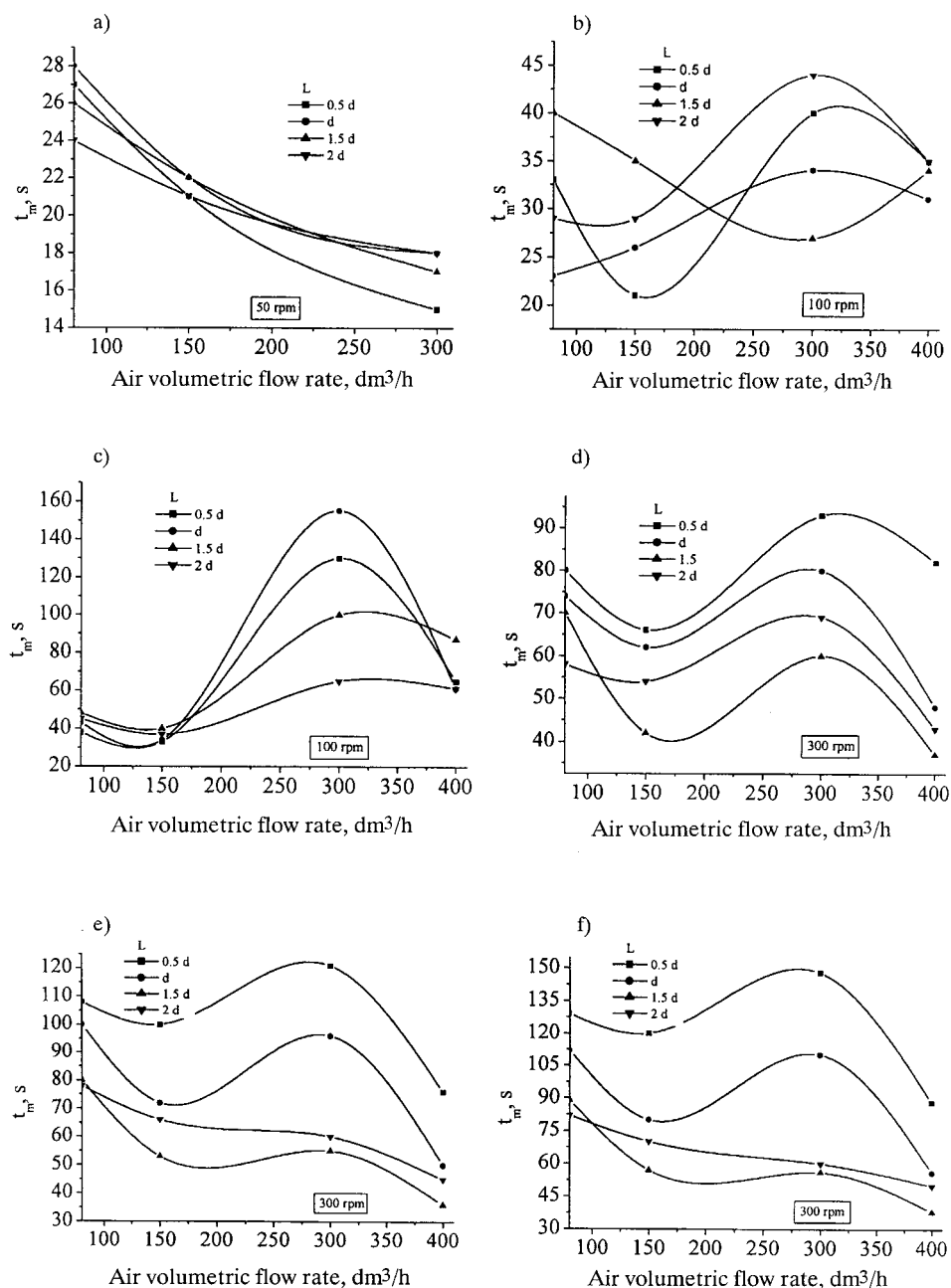


Figure 2. Influence of aeration on mixing time (a – water, b – $\eta_a = 0.082 \text{ g/cm}\cdot\text{s}$, c – $\eta_a = 0.32 \text{ g/cm}\cdot\text{s}$, d – $\eta_a = 0.98 \text{ g/cm}\cdot\text{s}$, e – $\eta_a = 1.87 \text{ g/cm}\cdot\text{s}$, f – $\eta_a = 2.69 \text{ g/cm}\cdot\text{s}$).

higher rotation speeds, and aeration contributed positively to mixing in the second one.

Influence of distance between the stirrers

Except for water, for which the variation of mixing time with rotation speed or aeration rate is similar for all positions of the stirrers on the shaft, the distance between the stirrers may modify the evolution of mixing time with the considered parameters.

It was stated in previous studied that for non-aerated water the minimum values of the mixing time were reached for a distance between the stirrers of

1.5d [3,16]. As may be seen from Figure 2.a, the lowest values of the mixing time for aerated water were obtained for distances of 0.5d–d, as the result of a more homogeneous distribution of bubbles in the liquid phase, especially at higher rotation speeds. As opposed to non-aerated CMCNa solutions, for which a distance of 2d leads to the minimum mixing time, for most of the studied aerated viscous solutions the minimum was also reached for 0.5d. But, from Figures 1.d–f it may be observed that for apparent viscosities greater than 0.32 $\text{g/cm}\cdot\text{s}$, the variation of mixing time with rotation speed for 0.5d completely differs compared to the other

positions of the stirrers on the shaft. Thus, for the entire range of aeration rates and a distance of 0.5d, the mixing efficiency continuously increases with stirrer rotation speed. For viscous liquids this evolution is explained by the tendency of bubble accumulation and coalescence in the region around the stirrer, phenomena that are more pronounced for smaller distances between the stirrers. As mentioned earlier, the accumulation of air around the stirrer reduces the dispersion circulation velocity. By increasing the rotation speed, very large bubbles formed in the stirrer region are dispersed and uniformly distributed in the liquid phase. The rise velocity of the bubbles in the upper compartment of the bioreactor is higher if the stirrers are closely placed on the shaft.

The highest values of the mixing time were obtained for a distance of 1.5d for water, and d for viscous simulated broths, as an effect of compartmentalization of the flow regions and an increase of the retention time of the bubbles in the liquid phase, both reducing the dispersion circulation velocity.

Modeling of mixing for aerated simulated broths

To describe the influence of aeration, rotation speed and distance between the stirrers on the mixing time, some mathematical correlations have been proposed for certain broth viscosity ranges.

The form of the proposed equations depends on the simulated broth viscosity and was established by means of the nlinfit function from the Statistics Toolbox of MATLAB. This function uses non-linear least-squares data fitting by the Gauss-Newton method. Thus, the following correlations for $t_m(s)$ were obtained:

a. water

$$t_m = -6.54 \cdot \lg V_a + 1.17 \cdot 10^{-3} \cdot N^2 + 0.26 \cdot N - 7.32 \cdot 10^2 \cdot L^2 + 1.20 \cdot 10^2 \cdot L - 39.44 \quad (3)$$

b. simulated broths with $\eta_a \leq 0.082 \text{ g/cm}\cdot\text{s}$

$$t_m = -4.15 \cdot 10^{-2} \cdot \lg V_a + \frac{2.77 \cdot 10^{-4} \cdot N^2 - 0.18 \cdot N + 57.77}{38.13 \cdot L^2 - 6.97 \cdot L + 1.63} \quad (4)$$

c. simulated broths with $0.082 \text{ g/cm}\cdot\text{s} < \eta_a \leq 0.98 \text{ g/cm}\cdot\text{s}$ and $V_a = 2.22\text{--}4.16 \cdot 10^{-5} \text{ m}^3 \text{ s}^{-1}$

$$t_m = 2.72 \cdot 10^7 \cdot \eta_a^2 - 17.86 \cdot \lg V_a + \frac{8.47 \cdot 10^{-4} \cdot N^2 - 0.89 \cdot N - 1.28 \cdot 10^3}{-2.07 \cdot 10^2 \cdot L^2 + 34.24 \cdot L + 8.05} \quad (5)$$

$$V_a = 8.33\text{--}11.1 \cdot 10^{-5} \text{ m}^3 \text{ s}^{-1}$$

$$t_m = 2.44 \cdot 10^7 \cdot \eta_a^2 - 31.93 \cdot \lg V_a +$$

$$+ \frac{1.69 \cdot 10^{-3} \cdot N^2 - 2.16 \cdot N - 1.16 \cdot 10^3}{33.57 \cdot L^2 - 6.43 \cdot L + 6.44} \quad (6)$$

d. simulated broths with $0.98 < \eta_a \leq 2.69 \text{ g/cm}\cdot\text{s}$

$$t_m = 3.04 \cdot 10^7 \cdot \eta_a^2 - 1.32 \cdot 10^3 \cdot \eta_a - 19.12 \cdot \lg V_a + \frac{2.77 \cdot 10^{-4} \cdot N^2 - 0.35 \cdot N + 1.08 \cdot 10^2}{1.02 \cdot 10^3 \cdot L^2 - 82.98 \cdot L + 2.032} \quad (7)$$

e. simulated broths with $0.32 \text{ g/cm}\cdot\text{s} \leq \eta_a \leq 2.69 \text{ g/cm}\cdot\text{s}$ and $L = 0.5$

$$t_m = -1.51 \cdot 10^7 \cdot \eta_a^2 + 7.23 \cdot 10^6 \cdot \eta_a - 7.14 \cdot \lg V_a + 1.38 \cdot 10^{-5} \cdot N^2 - 0.17 \cdot N - 9.63 \quad (8)$$

The proposed models agree well with the experimental data, the average deviation being $\pm 7.1\%$ for equation (3), $\pm 10.5\%$ for equation (4), $\pm 9.3\%$ for equation (5), $\pm 10.3\%$ for equation (6), $\pm 8.7\%$ for equation (7) and $\pm 8.2\%$ for equation (8) (Figure 3). By analyzing the corresponding determination coefficients for the proposed equations, it may be concluded that the considered factors influence the mixing time to an extent of 95.9% for equation (3), 88.1% for equation (4), 90.1% for equation (5), 91.1% for equation (6), 92.6.1% for equation (7) and 90.7% for equation (8). The remaindes of 4.1%, 11.9%, 9.9%, 8.9%, 7.4% and 9.3% respectively, may be attributed to the effect of other factors, namely: number and position of the baffles, temperature.

CONCLUSIONS

The flow mechanisms of aerated and non-aerated broths are very different, this being the result of the different influence of stirrer rotation speed and construction and air volumetric flow rate on the mixing time.

For water and simulated viscous media the increase of rotation speed value leads to the decrease of mixing time, which reaches a minimum value, corresponding to the critical rotation speed, and then increases. The value of the critical rotation speed depends on the aeration rate and varies between 300 and 500 rpm, for air flow rates between 80 and 400 dm^3/h , or between 200 and 600 rpm for air flow rates greater than 400 dm^3/h .

In most of the studied systems, the variation of mixing time with gas flow rate indicates a sinusoidal dependence. Thus, with increasing aeration rate the mixing initially decreases, reaches a minimum value, and increases to a maximum value. For lower rotation speeds or higher apparent viscosity values, the mixing time then decreases by an additional increase of the aeration rate.

The lowest values of the mixing time for aerated water are obtained for a distance of 0.5d-d between the

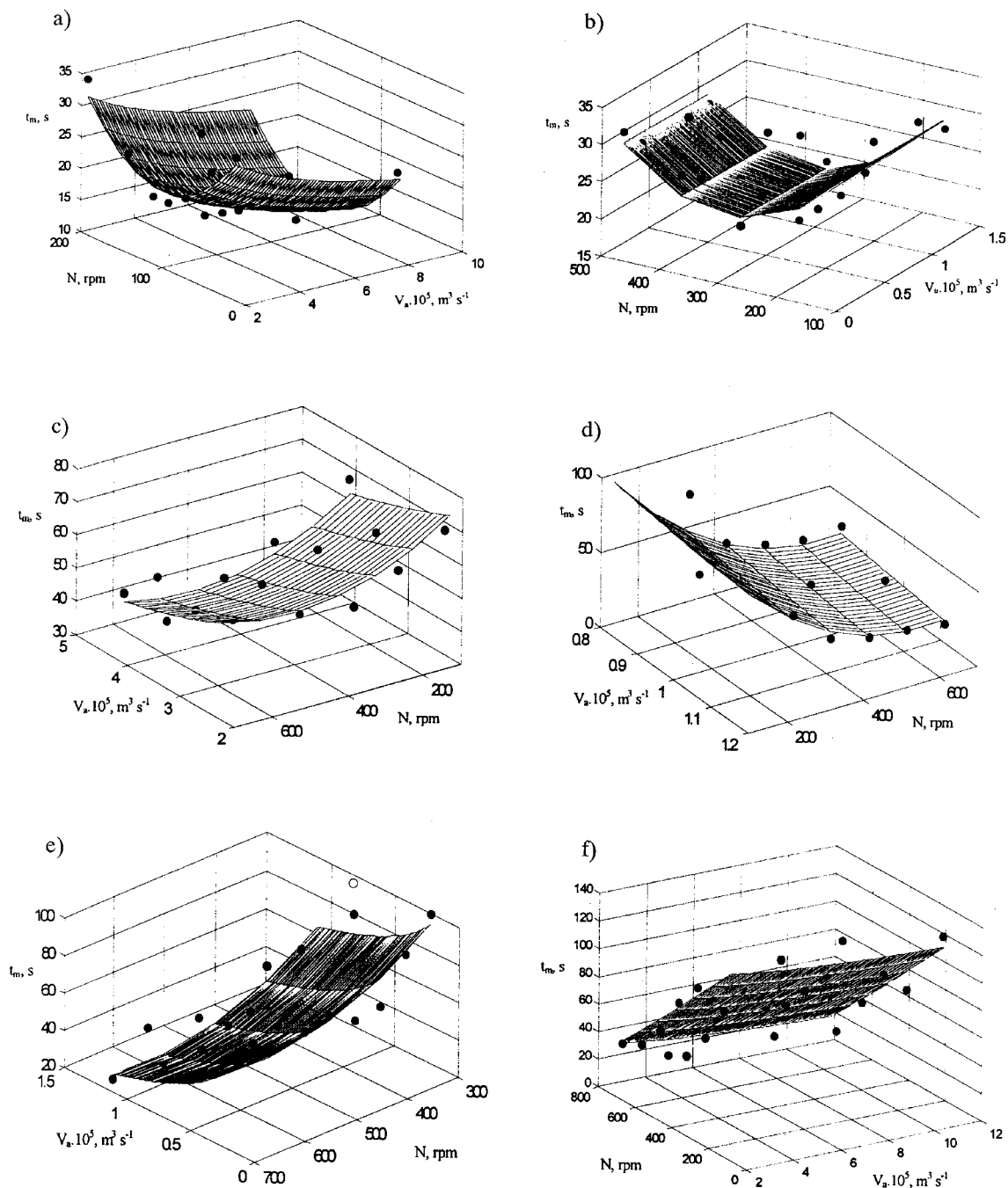


Figure 3. Surface plotted for equations (3) – (8) at $L = d$ (a – eq. (3), b – eq. (4) for $\eta_a = 0.82 \text{ g/cm-s}$, c – eq. (5) for $\eta_a = 0.98 \text{ g/cm-s}$, d – eq. (6) for $\eta_a = 0.98 \text{ g/cm-s}$, e – eq. (7) for $\eta_a = 1.87 \text{ g/cm-s}$) and $L = 0.5d$ (f – eq. (8) for $\eta_a = 1.87 \text{ g/cm-s}$) (* – experimental values).

stirrers placed on the shaft, and $0.5d$ for CMCNa solutions, as the result of a more homogeneous distribution of the bubbles in the liquid phase. Furthermore, the variation of mixing efficiency with aeration rate or rotation speed for a distance of $0.5d$ is completely different to those obtained from the other positions of the stirrers, the mixing efficiency continuously increasing with stirrer rotation speed.

The observed phenomena are the result of changes of the pumping capacity of the stirrer, due to cavity formation, compartmentalization in regions

around each of the stirrers, coalescence and the dispersion of bubbles and flooding. These lead to a very complex flow mechanism of the gas-liquid dispersion, a mechanism which is changed by changing the broth properties or fermentation conditions.

By means of the experimental results and using the nlinfit function from the Statistics Toolbox of MATLAB some correlations were established between the mixing time and rotation speed, air volumetric flow rate and stirrer position on the shaft. The proposed equations agree well with the experiments, the average deviation

being $\pm 9.02\%$ and may be used for scaling-up or for an easy comparison between non-aerated and aerated simulated and real fermentation broths.

NOTATIONS

d	– stirrer diameter, mm
d'	– pH electrode diameter, mm
D	– bioreactor diameter, mm
h	– distance from the inferior stirrer to the bioreactor bottom, mm
H	– bioreactor height, mm
l	– impeller blade length, mm
l'	– pH electrode immersed length, mm
L	– distance between the stirrers, m
N	– impeller rotation speed, rpm
P	– power consumption for the mixing of non-aerated broths, W
P_a	– power consumption for the mixing of aerated broths, W
pH_∞	– value of pH at $t = \infty$
ΔpH	– allowed deviation from the ideally mixed state
s	– baffle width, mm
t_m	– mixing time, s
V_a	– volumetric air flow rate, $m^3 s^{-1}$
V	– volume of the medium, m^3
ϵ_T	– energy dissipated, $W m^{-3}$
η_a	– apparent viscosity, Pa.s
ρ	– density, $kg m^{-3}$

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IZVOD

ISPITIVANJE MEŠANJA U BIOREAKTORIMA SA MEŠANJEM 3. Vreme mešanja aerisanih model fermentacionih medijuma

(Naučni rad)

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Vreme mešanja je značajan parametar kojim se karakteriše intenzitet mešanja fermentacionih medijuma i parametar koji se može iskoristiti kod povećanja razmere biohemijskih procesa. On zavisi u najvećoj meri od reoloških karakteristika fermentacione komine, konstrukcije bioreaktora i uslova pod kojima se izvodi biosinteza.

U radu se prikazuju rezultati ispitivanja efikasnosti mešanja aerisanih medijuma u laboratorijskom reaktoru sa mešanjem sa dve turbinske mešalice postavljene na jednoj osovini. Analiziran je uticaj brzine rotacije, zapreminskog protoka gasa i pozicije mešalice na osovini na vreme mešanja aerisane vode i modela tečnosti koji odgovaraju fermentacionim kominama po svojim reološkim karakteristikama (rastvor karboksimetilceluloze, CMCNa). Rezultati ukazuju da je, u poređenju sa neaerisanim medijumima, promena vremena mešanja sa promenom navedenih radnih uslova veoma različita, pre svega zbog kompleksnog mehanizma promene osobina fermentacionog medijuma ili uslova fermentacije.

Primenom funkcije "Nlinfit" iz programa Statistics Toolbox MATLAB izvedene su korelacije koje povezuju vreme mešanja sa brzinom obrtanja mešalice, zapreminskim protokom gasa (intenzitet aeracije) i pozicijom mešalice na osovini. Predložene korelacione zavisnosti pokazuju dobro slaganje vremena mešanja sa eksperimentalnim podacima ($\pm 9.02\%$).

Key words: Stirred bioreactor • Mixing time • Simulated broths • Aerated broths •

Ključne reči: Bioreaktor sa mešanjem • Vreme mešanja • Simulacione fermentacione komine • Aerisane tečnosti •

300 dm³/h

300 dm³/h

150 dm³/h

150 dm³/h

150 dm³/h

150 dm³/h

150 dm³/h

150 dm³/h

150 dm³/h

150 dm³/h

150 dm³/h

150 dm³/h