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(RECOMMENDED CITATION)

Dedicated to Professor Liviu Literat
On the occasion of his 85th birthday

SETTLING OF COAGULATED DILLUTED YEAST SUSPENSIONS

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ABSTRACT. Specific settling tests have been made using diluted yeast suspensions coagulated/flocculated in the presence of $FeCl_3$ at constant pH of 4.0 in order to determine the flocs/aggregates size and gel solid concentration, parameters which are necessary in numerical simulation and characterization of sedimentation processes. The sizes of the incipient aggregates and the gel point show to be dependent on coagulant concentration. The size of aggregates and the gel point has increased with the increase of coagulant concentration.

Keywords: *settling tests, yeast coagulated suspensions, aggregate sizes, gel solid point.*

INTRODUCTION

Numerical simulation of sedimentation processes and design of specific apparatus are based on equations which contain characteristic parameters as settling rates (w), floc/aggregate sizes (d_A) and gel solid concentration (C_{Vg}) [1].

In the case of stable suspended solids as yeast suspension contains, the presence of coagulants/flocculants makes possible the change of solids structure with the formation of a connected aggregate or floc, which fall more quickly than the individual particles because of their larger mass to surface ratios.

The influence of $FeCl_3$ concentration used as coagulant on the settling rates, primary size of aggregates and on the suspension gel solid fraction is analyzed in this study.

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a. Settling rates and floc/aggregate sizes

In order to determine the floc/aggregate size, the group settling rate and the settling rate of an individual uniform and spherical particle can be connected by Richardson & Zaki equation [2]:

$$\mathbf{w} = \mathbf{w}_{\mathbf{St}}\boldsymbol{\varepsilon}^{4.65} = \mathbf{w}_{\mathbf{St}}(1-\mathbf{C}_{\mathbf{V}})^{4.65} \tag{1}$$

where: C_V is the particle volume fraction and w_{St} the Stokes' settling rate for the single uniform spherical particle, as equation (2) shows:

$$\mathbf{w}_{\mathbf{St}} = \frac{1}{18}\cdot\frac{(\rho_{\mathbf{A}}-\rho)\cdot\mathbf{d}_{\mathbf{A}}^2}{\eta}\cdot\mathbf{g} \tag{2}$$

In equation (2), - ρ_A and ρ are the aggregate and the medium density, d_A is the average, (equivalent), aggregate/particle diameter, η is the medium viscosity, and g is the gravitational acceleration.

According to literature references, the aggregate diameter, d_A, can be considered independent of solid concentration over the "dilute" range, and so it does not change once the settling begun [3, 4].

From the material balance, the initial settling rate of aggregate can be considered as equation (3) shows [3]:

$$\mathbf{w}_0 = \frac{1}{18}\cdot\frac{(\rho_{\mathbf{Y}}-\rho)\cdot\mathbf{d}_{\mathbf{A}}^2}{\eta\mathbf{C}_{\mathbf{AY}}}\cdot\mathbf{g}\cdot(1-\mathbf{C}_{\mathbf{AY}}\mathbf{C}_{\mathbf{VY}})^{4.65} \tag{3}$$

where: ρ_Y is the yeast density and C_{AY} is the ratio:

$$\mathbf{C}_{\mathbf{AY}} = \frac{\mathbf{C}_{\mathbf{VA}}}{\mathbf{C}_{\mathbf{VY}}} = \frac{\textbf{volume of aggregate}}{\textbf{volume of yeast in aggregate}}\ .$$

Writing the equation (3) in the form:

$$\mathbf{w}_0^{\,1/4.65} = \left(\frac{1}{18}\cdot\frac{(\rho_{\mathbf{Y}}-\rho_{\mathbf{w}})\mathbf{d}_{\mathbf{A}}^2}{\eta_{\mathbf{w}}\mathbf{C}_{\mathbf{AY}}}\cdot\mathbf{g}\right)^{1/4.65}(1-\mathbf{C}_{\mathbf{AY}}\mathbf{C}_{\mathbf{VY}}) \tag{4}$$

and plotting $w_0^{1/4.65}$ against the corresponding value of yeast volume fraction C_{VY} results a straight line, which gives us the possibility to estimate the aggregate size from the slope and intercept.

b. Gel point

The behavior of sedimentation process and the efficiency of solid-liquid separation in a sedimentation column depend on initial solid volume fraction, (C_{V0}) and volume solid fraction at gel point, (C_{Vg}). The critical volume fraction, C_{Vg}, called gel point is defined as the lowest concentration at which flocs are able to form a self-supporting network [5].

Determination of gel point, C_{Vg}, of flocculated suspensions in this study is based on equation (5) [1, 6]:

$$C_{Vg}\left(h_{\infty}\right)=\frac{d\left(C_{V0}h_{0}\right)}{dh_{\infty}} \quad (5)$$

where: C_{V0} and h_0 are the initial volume fraction of solids and initial height of suspension and h_{∞} is the equilibrium height of the sediment bed.

Following the work of Nasser and James, who studied the behavior of kaolin suspensions [1, 4]; synthetic baker's yeast suspensions in distillated water were used in the present work.

RESULTS AND DISCUSSION

a. Settling rates and floc/aggregate sizes

The initial settling rates for yeast suspensions with different concentrations are obtained by batch sedimentation tests, plotting the height of interface between slurry and the supernatant as a function of time. The settling curves obtained for different concentrations of coagulant $FeCl_3$ at pH 4 are shown in Figures 1 (a-d).

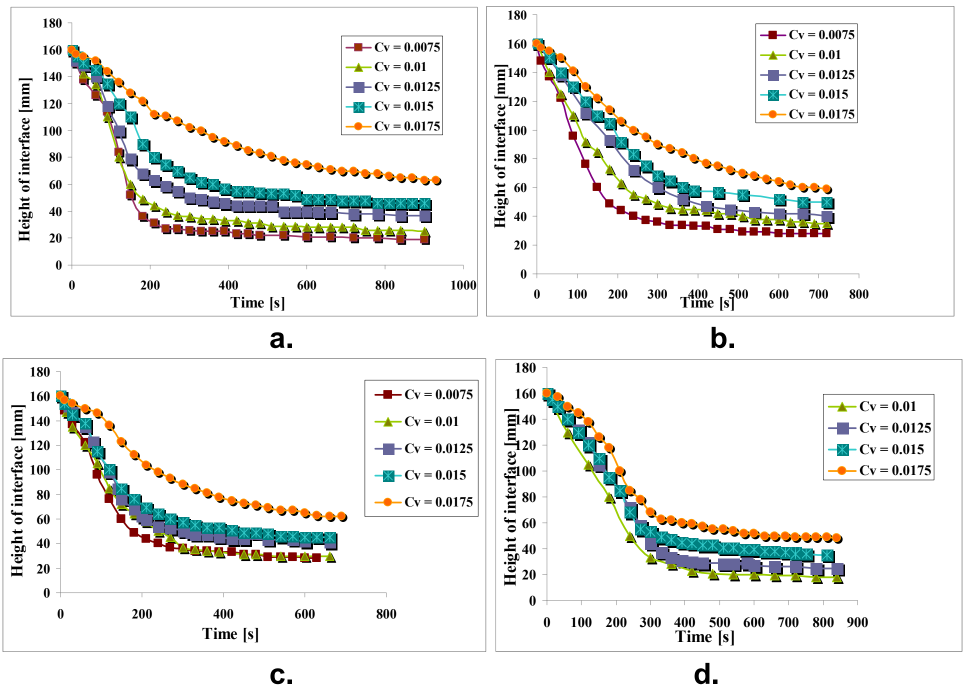

Figure 1. Sedimentation curves of yeast suspensions at the concentration of coagulant $FeCl_3$ of: $4.0\cdot10^{-4}$ M (a), $1.6\cdot10^{-3}$ M (b), $2.4\cdot10^{-3}$ M (c), $4.0\cdot10^{-3}$ M (d).

The yeast volume fraction of between 0.0075 and 0.0175 (m^3/m^3) was selected in order to have only "diluted" and highly flocculated suspensions for all concentration of $FeCl_3$. The decrease in the sediment thickness with time indicates that flocs settle in flocculated form. Early work has shown that the optimal removal of yeast particles from suspension is obtained at pH value between 4 and 4.5 [7].

The initial settling rates can be now determined by tangent method, as the ratio between interface height and the corresponding time period of the linear part of each curve. The obtained values for different concentrations of $FeCl_3$ are shown in Table 1.

Table 1. Results obtained by settling tests

$FeCl_3$ concentration [M]	Volume yeast concentration C_{VY} [m^3/m^3]	Initial experimental settling rate $w_0 \cdot 10^3$ [m/s]	Average aggregate size d_A [μm]
$4.0 \cdot 10^{-4}$	0.0075 0.01 0.0125 0.015 0.0175	0.73 0.600 0.400 0.333 0.166	1000
$1.6 \cdot 10^{-3}$	0.0075 0.01 0.0125 0.015 0.0175	0.667 0.583 0.367 0.222 0.166	1018
$2.4 \cdot 10^{-3}$	0.0075 0.01 0.0125 0.015 0.0175	0.83 0.667 0.416 0.366 0.200	1120
$4.0 \cdot 10^{-3}$	0.01 0.0125 0.015 0.0175	0.500 0.333 0.167 0.133	1140

Typical linear curves result by plotting $w_0^{1/4.65}$ against the corresponding values of yeast concentration C_{VY}, (Figure 2, a-d). From the intercept and the slope of the each line it can be calculated the aggregate size. The average values of aggregates size obtained are shown in Table 1.

The values have shown the increase of the aggregates size from 1000 μm to 1140 μm with the increase of $FeCl_3$ concentration, from $4.0 \cdot 10^{-4}$ to $4.0 \cdot 10^{-3}$ M. The increase of the aggregate size has in the same time a positive effect in acceleration of the settling process.

The Stokes' settling rate for single aggregate is expressed by equation (6), when the yeast density ρ_Y is 1060 kg/m^3, water density ρ is 997 kg/m^3 and water viscosity η is $0.9 \cdot 10^{-3}$ Pas at the work temperature of 25 ^{0}C:

$$w_{St} = 38150 \frac{d_A^2}{C_{AY}} \tag{6}$$

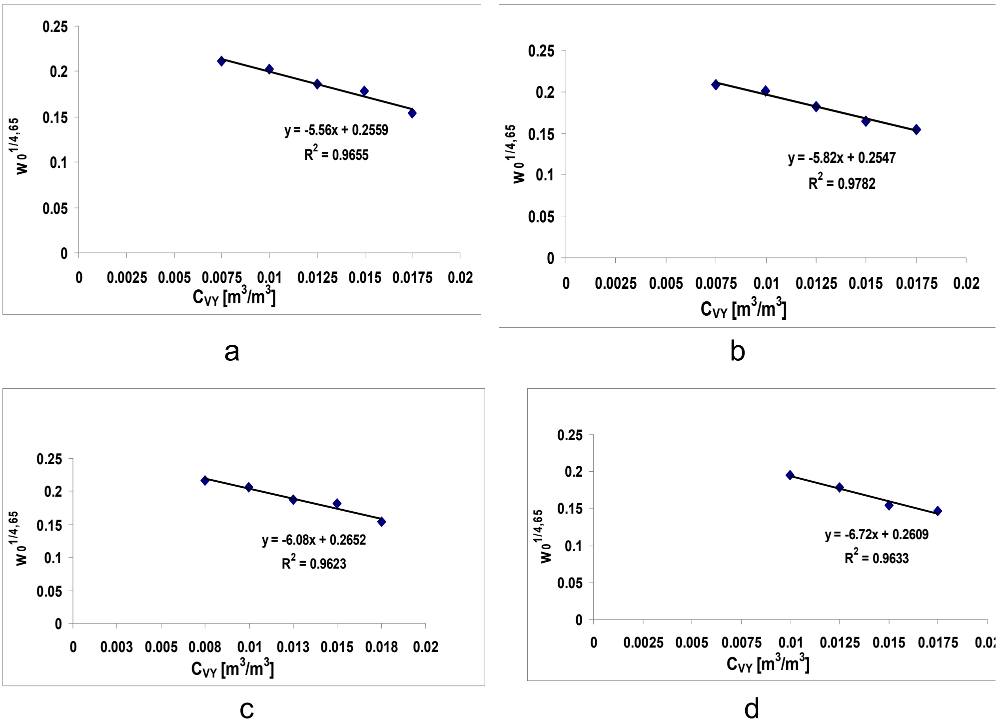

Figure 2. Correlation of settling rate and volume fraction of yeast using the $FeCl_3$ of: $4 \cdot 10^{-4}$ M (a), $1.6 \cdot 10^{-3}$ M (b), $2.4 \cdot 10^{-3}$ M (c) and $4.0 \cdot 10^{-3}$ M (d).

b. Gel point

In order to determine the gel point, the initial yeast volume fraction was chosen between 0.0025 and 0.0175 (m^3/m^3), much lower than the volume fraction at which the gel point is expected to be found [1].

In the present work, the initial height of suspension, h_0, is maintained constant and the initial concentration of yeast, C_{V0}, is varied. The product $C_{V0}h_0$ is plotted as a function of corresponding height equilibrium, h_∞, obtained by settling tests (Figure 3, a-d). The gel point value determined from the slope of each line ($h_\infty \rightarrow 0$) is shown in Table 2.

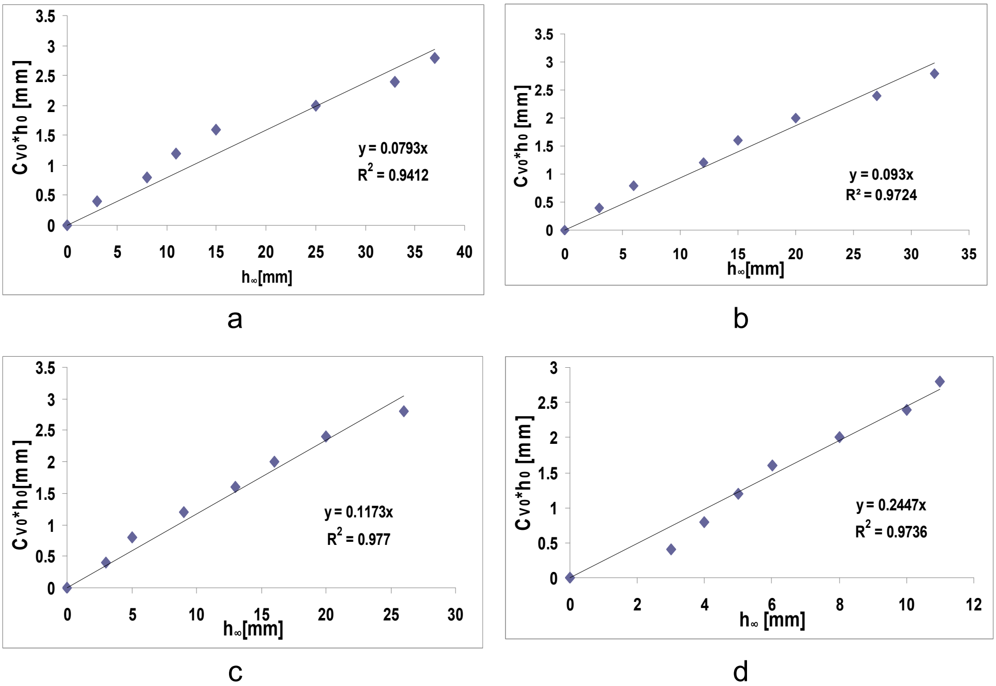

Figure. 3. Gel point determination at different concentrations of $FeCl_3$: $4 \cdot 10^{-4}$ M (a), $1.6 \cdot 10^{-3}$ M (b), $3.0 \cdot 10^{-3}$ M (c), $6.5 \cdot 10^{-3}$ M (d).

As it can be seen, the gel point is sensitive to the coagulant concentration, the gel point concentration increases with the increase of coagulant concentration.

Table 2. Dependence of gel point on coagulant concentration

C_{FeCl_3} [M]	C_{V_g} [m³/m³]
$4.0 \cdot 10^{-4}$	0.079
$1.6 \cdot 10^{-3}$	0.093
$3.0 \cdot 10^{-3}$	0.117
$6.5 \cdot 10^{-3}$	0.245

CONCLUSIONS

The experimental results obtained in this study have shown that the presence of $FeCl_3$ in diluted yeast suspensions made possible the settling tests with the determination of the aggregate sizes and gel point concentration.

The size of the incipient aggregates is found to be influenced by the coagulant concentration, an increase of aggregates size from 1000 μm to 1140 μm with the increase of $FeCl_3$ concentration from $4.0 \cdot 10^{-4}$ to $4.0 \cdot 10^{-3}$ M was obtained.

The gel point was influenced by the coagulant concentration too, the gel point concentration showing an increase of gel point with the increase of coagulant concentration.

The parameters determined in this study can be used with good aggrement in numerical simulation and design of batch apparatus in settling processes.

EXPERIMENTAL SECTION

a. The aggregates/flocs size determination is based on settling tests. Suspensions with different volume fractions between 0.0075 and 0.0175 m^3/m^3 used in the experiments were prepared directly in 100 ml cylinders from dried Pakmaya yeast and distillated water. The pH of solution was maintained at constant value of 4, when the yeast suspensions are highly flocculated for all concentration of $FeCl_3$, by using an appropriate amount of 0.1 HCl. The interface of slurry-supernatant position was recorded with settling time. Three replicate experiments were carried out for each set of experimental conditions.

b. The gel point, which is effectively the solids concentration at the surface of the sediment, was found from the initial slope ($h_\infty \rightarrow 0$) of the product $C_{V0}h_0$ as a function of h_∞ obtained from sequences of settling tests.

A series of 100 ml measuring cylinders were used for the gel point measurements and the initial volume fraction C_{V0} in range of 0.0025 and 0.0175 m^3/m^3 was varied. The $FeCl_3$ concentration was varied from $4 \cdot 10^{-4}$ to $6.5 \cdot 10^{-3}$ M and the pH was maintained at constant value of 4. The suspension was first homogenized and then left to settle. The h_∞ was recorded when it became constant.

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