POWER INPUT OF AERATED AGITATOR SYSTEM OF HIGH-SPEED FERMENTER

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A correlation complying a simple model idea about function of an agitator in aerated high hold-up system has been found on basis of power input measurement of four fermenter agitators.

Fermentation processes, especially those producting animal feed proteins, require intensive oxygen transport from air to microbial phase. The limited factor of the whole process is oxygen transfer over gas–liquid interfacial area which is usually formed by a rotating agitator under which air is supplied, by pneumatic mixing or systems where energy of circulating pumps is utilized or by various combinations of systems.

The first question of industrial size fermenter design is the question of power consumption of such a mixing unit. Power input of an agitator in aerated system may be, in agreement with number of papers[1–12] estimated. In literature[5,6,13–15] it is also possible to find whether agitator operates above flooding conditions or if recirculation of disperse gas bubbles occurs[10,13,16]. Calculation of power input of a stirrer in aerated liquid leads often, according to different authors, to completely different results, especially in case of large units. Most of the published relations were obtained on a small device and their utilization for design of an industrial size apparatus is hazardous if the agitator drive design was solved without taking into account the agitator power input in unaerated liquid. Such an overdesign would not be profitable for animal feed production since the installed input is not effectively utilized for the fermentation process.

Problem Formulation

The dependence of agitator power input in aerated liquid on system parameters is mostly expressed as a ratio of input P_G in aerated medium to input P in liquid only:

$$Y = P_G/P\,, \qquad (1)$$

Y being calculated *e.g.* according to refs[2–5,8,9,12,13,17]

$$Y = f(\mathrm{Kp_G}, \mathrm{Fr}, \text{geometry of system})\,. \tag{2}$$

Another possibility how to express the influence of aeration upon agitator power input can be found in papers[1,7,16]. Van't Riet and co-workers[16] have called attention to the fact that the bubble recirculation in aerated liquid can be responsible for limited validity of various power input correlations during scale-up process.

Looking for suitable power input dependence of agitator system (shown in Fig. 1) in aerated fermentation broth several assumptions have been done:

1. Relative air hold-up Φ_G in a fermentation broth is high (minimum 25%), while

$$\Phi_G = (V - V_0)/V\,. \tag{3}$$

2. Presence of a large quantity of air in mixed medium influences distinctively density and viscosity of fermentation broth.

3. Three flows are mixed in rotor of radial agitator

A – air flow from distributor: $\dot{V}_G$

B – recirculating air flow through radial agitator: $(\Phi_G \dot{V}_L)$

C – recirculating liquid flow through radial agitator: $(1 - \Phi_G)\,\dot{V}_L$.

4. Hold-up distribution is homogenous in the whole volume of fermentation broth.

5. Axial agitator operates in a liquid of mean gas hold-up Φ_G.

6. Power input of tangential foam breaker (Fig. 2) may be neglected in comparison to power input of radial and axial agitators.

7. Change of agitator power input in aerated liquid depends on density of medium in area of agitator rotor mainly.

8. Agitators are not flooded.

Relative hold-up of air in radial agitator area can be written as (see Fig. 1):

$$\Phi_{G,R} = (\dot{V}_G + \Phi_G \,.\, \dot{V}_L)/(\dot{V}_G + \dot{V}_L)\,. \tag{4}$$

Substitution of dimensionless groups yields

$$\Phi_{G,R} = (\mathrm{Kp_G} + \Phi_G\,\mathrm{Kp_L})/(\mathrm{Kp_G} + \mathrm{Kp_L})\,. \tag{5}$$

Relation between hold-up $\Phi_{G,R}$ and Φ_G may be expressed as

$$1 - \Phi_G = (1 - \Phi_{G,R})(\mathrm{Kp_G}/\mathrm{Kp_L} + 1)\,. \tag{6}$$

Including densities in agitator area: $\varrho_L(1 - \Phi_G)$ for axial and $\varrho_L(1 - \Phi_{G,R})$ for radial, the power input of the agitator system is expressed by the following formula

$$P_G = [\xi_R(1 - \Phi_{G,R}) + \xi_A(1 - \Phi_G)]\, \varrho_L \,.\, n^3 d_R^5 \tag{7}$$

or

$$P_G = \mathrm{Eu}_G \,.\, \varrho_L n^3 d_R^5 \,, \tag{8}$$

where Eu_G – the power number – can be found experimentally. Comparison of Eqs (7) and (8) shows that

$$1 - \Phi_{G,R} = \frac{\mathrm{Eu}_G}{\xi_R} - \frac{\xi_A}{\xi_R}(1 - \Phi_G)\,. \tag{9}$$

From Eqs (6) and (9)

$$f_1(\mathrm{Kp}_G) = \mathrm{Kp}_G/\mathrm{Kp}_L + 1\,, \tag{10}$$

the final relation was derived

$$\frac{1 - \Phi_G}{\mathrm{Eu}_G} = \frac{(1/\xi_R)\, f_1(\mathrm{Kp}_G)}{1 + (\xi_A/\xi_R)\, f_1(\mathrm{Kp}_G)}\,. \tag{11}$$

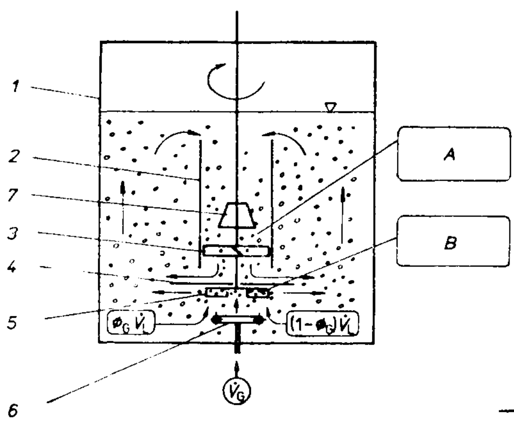

FIG. 1

Model idea scheme of operation of aerated agitator: *1* vessel, *2* circulation cylinder, *3* axial agitator, *4* separating annulus, *5* radial agitator, *6* air distributor, *7* tangential agitator. *A* gas hold-up Φ_G, *B* gas hold-up $\Phi_{G,R}$

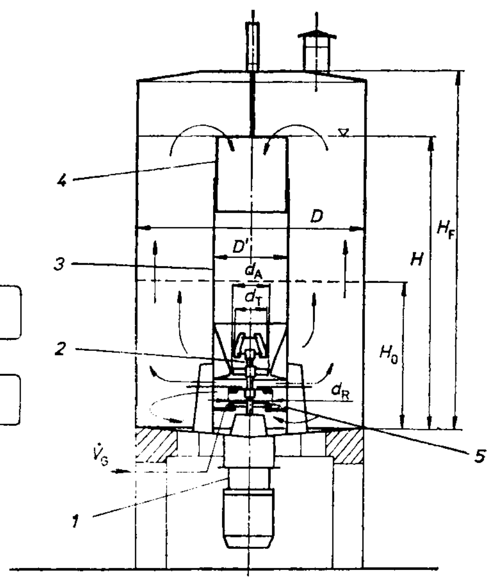

FIG. 2

Scheme of fermenter Chepos: *1* engine, *2* shaft with stirrers, *3* circulation cylinder, *4* mobile adapter, *5* air distributor

Relation (*11*) expresses the dependence among experimentally found quantities Eu_G, Φ_G, and Kp_G. The other parameters of Eqs (*10*) and (*11*): ξ_A, ξ_R, and Kp_L are supposed to show a relative small change depending on flow number Kp_G. For experimental data processing the following final relation can be recomended:

$$\frac{1 - \Phi_G}{Eu_G} = f_2(Kp_G)\,. \tag{12}$$

EXPERIMENTAL

Power input of agitator during aeration was measured in four sizes of vessels: 0·05, 1, 10, and 200 m^3 at *Torulopsis* feed yeast cultivation on ethanol substrate only. All four sizes of fermenters were equipped by a direct bottom drives. Set-up scheme is shown in Fig. 2. Geometric ratios of fermenters are shown in Table I.

The employed system of agitators and baffles[18] consisted of a bottom radial agitator for air dispersion, placed above air distributor and under static separating annulus. Above this flat plate an axial inclined blade agitator was placed which pumped the fermentation broth from circulation cylinder to the wall of the vessel and to the intercylinder area. A tangential agitator for mechanical defoaming was placed above the axial agitator. All agitators were sited on the same central, bottom entry shaft. Revolutions of agitator shaft were $n = 1\,000\ min^{-1}$ for all vessel sizes. (The fermenters 0·05 and 1 m^3 enabled to change revolutions smoothly but only experiments at $n = 1\,000 \pm 50\ min^{-1}$ were included to results.)

Power input of agitator system was measured by tensometers and torsional moment sensors at fermenters 0·05 and 1 m^3 and by wattmeters at fermenters 10 and 200 m^3 (passive loss of drive system was not included).

Relative air hold-up Φ_G in fermenter was determined on the basis of height of liquid H_0, and total height of broth (height of "foam" detector reading), H,

$$\Phi_G = (H - H_0)/H\,. \tag{13}$$

Fermentation broth was adjusted on following cultivation parameters: pH = 4·2 ± 0·1, temperature 34 ± 1°C and ethanol concentration 0·1—0·25 $g\,l^{-1}$.

TABLE I

Experimental set-up of fermenters

V m^3	D mm	D' mm	H_0 mm	d_R mm	d_A mm	d_T mm	P_E kW
0·050	387	128	250—350	100	120	80, 100	1·5
1·0	1 100	420	400—600	165	205	176	3
10	2 100	810	1 800—2 300	336	420	350	17
200	5 000	1 440	3 200—5 000	630	650—690	400, 500	200

RESULTS AND DISCUSSION

Correlation *(12)* was evaluated on the basis of experimental data H, H_0, P_G, $\dot{V}_G$ under the constant revolutions $n = 1\,000\ \text{min}^{-1}$, results are displayed in Fig. 3. Decreasing Eu_G with increasing Kp_G at the same relative hold-up Φ_G was observed. Even if relation *(12)* shows certain scattering of results, it expresses quite well influence of fermenter scaling up.

The reasons of scattering of points in Fig. 3 may be partly explained by the discrepancy between assumptions and the real behaviour of the system – hold-up distribution is not quite homogeneous – and partly by unconsistent geometrical similarity of all four used fermenters – as can be seen from Table I. The magnitude of agitator system power input was influenced – to a certain extent – by the height of liquid level in the experimental vessel. The values of Eu_G were greater in case of a deep vortex and smaller if only slight depression of the level inside the cylinder was maintained. Higher load of axial agitator, in case when higher level difference of liquid occurs (between inside and outside parts of the circulation cylinder), may be a good explanation of such deviations.

The values of Eu_G of agitator system changed not only in dependence on air flow and relative hold-up but they depend on fermenter size, too: The smallest $Eu_G = 0.28$ ($200\ m^3$) and the greatest $Eu_G = 2.63$ (50 l) – both in aerated fermentation broth.

Informative measurement of power input of a single agitator operating in fermenter $200\ m^3$ showed the following results:

- radial agitator: 50–85 kW (according to aeration)
- axial agitator: 30–55 kW
- tangential agitator: 10–35 kW.

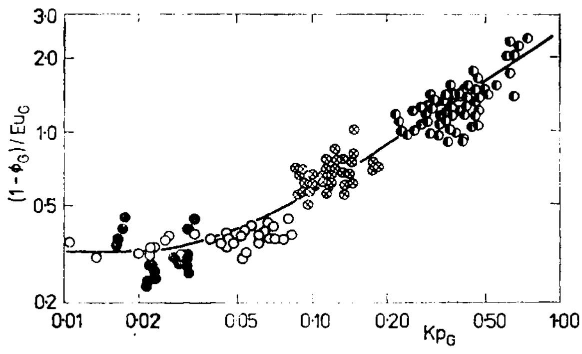

FIG. 3

Power input correlation $(1 - \Phi_G)\,Eu_G = f(Kp_G)$. ● $0.05\ m^3$, ○ $1\ m^3$, ⊗ $10\ m^3$, ◐ $200\ m^3$

CONCLUSIONS

A correlation suitable for power input calculation of an agitator system in aerated fermented mash has been derived on the basis of a simple model idea of agitator function. According to experimental data, the power input under constant revolutions depends on air flow, relative hold-up, and size of apparatus. Power input criterion distinctively decreases with increasing size of apparatus.

LIST OF SYMBOLS

D	fermenter diameter
D'	circulation cylinder diameter
d	agitator diameter
g	gravitational acceleration
H	height of "foamed" fermentation broth
H_0	height of liquid
n	agitator revolutions
P	power input of agitator in liquid
P_E	agitator drive power input
P_G	power input of aerated agitator
$\dot{V}_G$	flow rate of air
$\dot{V}_L$	flow rate of fermentation broth through agitator
V	volume corresponding to the height H
V_0	volume corresponding to the height H_0
Y	relative power input of agitators during aeration
ϱ_L	liquid density
Φ_G	relative air hold-up of fermentation broth
ξ	resistance coefficient
$\mathrm{Eu}_G = P_G \varrho_L^{-1} n^{-3} d_R^{-5}$	power number
$\mathrm{Fr} = d_R n^2 g^{-1}$	Froude number
$\mathrm{Kp}_{G,L} = \dot{V}_{G,L} n^{-1} d_R^{-3}$	flow rate number

Subscripts

A	axial agitator
T	tangential agitator
R	radial agitator

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