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MODELS OF COALESSENCE AND FRAGMENTATION OF DROPS AND BUBBLES IN ISOTROPIC TURBULENT FLOW

Abstract

Coalescence and fragmentation of drops in a turbulent flow are the basis of many chemical, oil refining processes, food and pharmaceutical technologies, and are mainly associated with changes in the number of spectra and particles in a single volume that determine the size of the mass and heat transfer phase. Coalescence due to collision and subsequent enlargement of drops is widely used in emulsions, suspensions and other multi-phase media in the processes of phase separation and stratification (sedimentation, surface emergence). Fragmentation of drops required for the growth of the interfacial surface in gas-liquid reactors, liquid extraction, absorption in mass transfer processes, dusting, combustion, etc. is used quite widely in processes.

Keywords: *isotropic turbulent flow, fragmentation drops and bubbles, coalescence drops and bubbles, size of drops, frequency of fragmentation*

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İzotrop turbulent axında damlaların və qabarcıqların koalessensiya və parçalanma modelləri

Xülasə

Turbulent axında damlaların koalessensiyası və parçalanması fiziki hadisələri bir çox kimyəvi, neft emal edən proseslərin, qida və əczaçılıq texnologiyasının əsasını təşkil edir, əsasən, kütlə və istilik ötürmənin fazalararası səthinin ölçüsünü müəyyən edən vahid həcmdə spektrin və hissəciklərin sayının dəyişməsi ilə əlaqədardır. Damlaların toqquşması və növbəti iriləşməsi ilə bağlı koalessensiya emulsiyalarda, suspenziyalarda və digər çoxfazalı mühitlərdə fazaların ayrılması və təbəqələşməsi (çökmə, suyun üzünə çıxma) proseslərində geniş istifadə olunur. Fazalararası səthin böyüməsi üçün lazım olan damlaların parçalanması qaz-maye reaktorlarda maye ekstraksiya, absorbsiya kütlədəyişmə proseslərində, toz halına salma, yanma və s. proseslərdə kifayət qədər geniş istifadə olunur.

Açar sözlər: *izotrop turbulent axın, damla və qabarcıqların parçalanması, damla və qabarcıqların koalessensiyası, damlaların ölçüsü, parçalanma tezliyi*

Introduction

The essence of the processes of coalescence and disintegration of drops and bubbles is the loss of aggregative and, in some cases, sedimentation stability of the entire dispersed system under the influence of internal forces or spontaneously.

The main features of these processes are the frequency of coalescence (collision) and fragmentation, and in this isotropic turbulent flow is determined by the dissipation energy and turbulence scale, as well as the size and characteristics of the particles themselves and the environment (density, viscosity, surface tension) and is determined by the minimum and maximum dimensions of the bubbles. The minimum particle size characterizes the tendency of the dispersed system to coalescence of drops and bubbles, while the maximum size tends to deform and disintegrate. Another feature of the dispersed system in which coalescence and fragmentation processes take place is the rate of change of particle size and number, in other words, the movement of the separation function by size and time, and their theoretical and experimental studies are given in (Aksjanova, 1994:194; Blanchette, Bigioni, 2009: 333-350).

Fragmentation frequency of drops and bubbles

The fragmentation of drops and bubbles in an isotropic turbulent flow is an important factor in increasing the interfacial surface area and mass transfer rates in disperse systems. The mechanism of fragmentation of deformed particles is determined by a number of factors, including the following:

a) Turbulent pulsations that change the structure of drops and bubbles by affecting their surface. From (Davydova, Teplyakov, 2010:175; Narsimhan, 2004:197-218; Gudrat, Taghiyev, Manafov, 2021:201-236) the frequency of change in the structure of the drop surface is determined by the expression Relay.

$$\omega(k) =[(\frac{2\sigma}{\pi^2\rho_m\, a^3})(\frac{(k+1)(k+2)k(k-1)}{(k+1)^{\rho_d}/\rho_m})]^{1/2} \quad (1)$$

when k = 2 drops and bubbles from this expression ($\rho_d << \rho_m$): $\omega(a) = \frac{2\sqrt{6}}{\pi}\ (\frac{\sigma}{\rho_m a^3})^{1/2}$, drops and bubbles ($\rho_d \gg \rho_m$) : $\omega(a) = \frac{4}{\pi}\left(\frac{\sigma}{\rho_d\, a^3}\right)^{1/2}$ equations can be obtained to determine the frequencies corresponding to the fragmentation. As a result, minor deformations that do not take into account the structure of the drop are determined by the superposition of linear harmony.

$$r(t,\theta) = R[1 + \sum_k A_k \cos{(\omega_k t)} P_k(cos\theta)] \quad (2)$$

Here $P_k(cos\theta)$ − Legendary function, A_k -$A_k = A_{ko}\exp{(-\beta_k t)}$ the coefficients of the sequence defined as, β_k- the attenuation coefficient is calculated as follows:

$$\beta_k = \frac{(k+1)(k-1)(2k+1)\eta_d + k(k+2)(2k+2)\eta_m}{[\rho_d(k+1)+\rho_m k]R^2} \quad (3)$$

b) General instability as a result of boundary instability on the surface of the drop or the maximum value of the size of the drop $a \geq a_{max}$;

c) Influenced by the external environment; In this case, the fragmentation of the drop is determined by the balance between the external conditions of the continuous phase (dynamic pressure) and the surface tension forces that resist the collapse of the drop (Kelbaliyev, Rasulov, 2020:123-145; Levich, 1969:700; Matveenko, Kirsanov, 2011:243-276). It should be noted that this condition can characterize the deformation of the structures of drops and bubbles;

d) As a result of mutually elastic collisions during intensive mixing of the system. It should be noted that any collision of drops and bubbles does not cause their coalescence and coalescence, and during the elastic collision of the drops can break into smaller pieces, thus changing the distribution spectrum of dimensions. A general overview of the fragmentation of drops and bubbles provides an analysis of the maximum and minimum dimensions and questions related to the nature of the distribution function according to the frequency of fragmentation and particle size studied. Despite the numerous mechanisms of fragmentation of drops and bubbles, the main parameter that characterizes this process is the frequency of fragmentation in turbulent flow, and many studies have been devoted to its determination (Mednikov, 1980:176; Patel, Vashi, 2010:1457-1483; Abiev, Galushko, 2021:369-391). In Study 11, the following expression is proposed for the frequency of fragmentation of drops and bubbles based on the analysis of surface energy and kinetic energy in a turbulent flow:

$$\omega(a) = c_1 a^{-2/3}\varepsilon_R^{1/3} exp\left(-\frac{c_2\sigma}{\rho_m\varepsilon_R^{2/3}a^{5/3}}\right) \quad (4)$$

In we consider the expression of turbulent diffusion by analytical solution of the mass transfer equation (4)

$$\frac{\partial N}{\partial t} = \frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2 D_{tr}\frac{\partial N}{\partial r}\right)$$

$$t = 0, r > R, N = N_0; t > 0, r = R, N = 0; t > 0, r \to \infty, N = N_0$$

$D_T \approx V_\lambda \lambda = \alpha(\varepsilon_R \lambda)^{1/3}\lambda$ - given the expression, we can write this expression as follows

$$\frac{\partial N}{\partial t} = \frac{\alpha}{r^2}\frac{\partial}{\partial r}\left(\mu_R^2 \varepsilon_R^{1/3} r^{10/3}\frac{\partial N}{\partial r}\right) \ (5)$$

the solution to this expression is as follows:

$$N(r,t) = \sum_{n=1}^{\infty} A_n J_2\left[\mu_n ({}^{r}/_{R})^{\frac{1}{3}}\right]\exp(-\mu_n^2 t)$$

Here $A_n = \frac{2}{R^2}\frac{\int_0^{r} N_0 J_2[\mu_n({}^{r}/_{R})^{1/3}]rdr}{\int_1^2(\mu_0)}$, $\mu_n - J_2(q_n) = 0$ expression $\mu_n = q_n(\varepsilon_R^{\frac{1}{3}}\alpha/3R^{2/3})$ special units determined by the solution, $J_1(\mu_n)$ – first and second degree Bessel function. Thus, when the series is assembled quickly, it is sufficient to use the first term and determine the fractionation frequency as follows:

$$\omega(\alpha) = -D_{TP}\frac{\partial N}{\partial r}\mid_{rR} \approx c_1\varphi_0(\frac{\varepsilon_R}{\alpha^2})^{\frac{1}{3}}\exp\left(-c_2\frac{\sigma}{\rho_m \varepsilon_R^{2/3} a^{5/3}}\right) \ (6)$$

Here φ_0 -the volume fraction of particles at first this expression is analogous to (5) $\lambda > \lambda_0$ – is an expression of the fractional frequency. Although the decay time of drops and bubbles is defined in the work (Perrard, Riviere, Mostert, Deike, 2021) as $\tau \sim a^{2/3}\varepsilon_R^{-1/3}$, the expression $\tau \sim \sigma/(\rho_m \varepsilon_R a)$ is accepted. When $\lambda > \lambda_0$ or rather, the decay frequency can be determined as follows by using the second expression (2) for the viscous flow:

$$\omega(a) = C_{01} N_0 a^3 (\frac{\varepsilon_R}{V_m})^{1/2}\exp\left[-C_2\frac{\sigma}{(V_m \varepsilon_R)^{1/2}\, a p_m}\right] \ (7)$$

As can be seen from this expression, the frequency of drops and bubbles in the viscous field or liquid medium is inversely proportional to the viscosity of the medium $\sim V_m^{-1/2}$

$$\omega(a) = c_8 nerfc\ (c_9\frac{\sigma^{3/2}}{n^3 d_t^3 \rho_m^{3/2} a^{3/2}})^{1/3} \qquad (8)$$

The latter expression determines the frequency of disintegration of drops and bubbles in mixing devices and depends on the mixing parameters. In multiphase systems, the frequency of disintegration of drops and bubbles with a volume fraction φ can be determined as follows:

$$\omega(a) = c_{10}\frac{\varepsilon_R^{1/3}}{a^{2/3(1+\varphi)}}\ \exp\left(-c_{11}\frac{(1+\varphi)^2\sigma}{\rho_d a^{5/3}\varepsilon_R^{2/3}}\right) \ (9)$$

The rate of disintegration of drops and bubbles in an isotropic turbulent flow is characterized by a constant rate determined as follows:

$$Re_d < 1 k_R = A_0\frac{\varepsilon_R^{1/3}}{a^{2/3}}\exp\left(-\frac{A_1\sigma}{\rho_m \varepsilon_R^{2/3} a^{5/3}}\right) (10)$$

$$Re_d > 1 k_R = A_0\frac{\rho_m a^{2/3}\varepsilon_R^{1/3}}{\eta_m}\ exp\left(-\frac{A_1\sigma}{\rho_m \varepsilon_R^{2/3} a^{5/3}}\right)$$

The parentheses express the surface energy $(E_\sigma \sim \pi a^2\ \sigma/a \sim \pi a\sigma)$ to the turbulent flow energy $\left(E_T \sim \pi a^2(\Delta P_T, \Delta P_T = c_1\rho_m(\varepsilon_R a)^{2/3}\right)$ indicates the ratio and characterizes the efficiency of the fragmentation process.

$$\frac{E_\sigma}{E_T} \sim \frac{\sigma}{\rho_m \varepsilon_R^{2/3} a^{5/3}}$$

Analysis of the expressions (7) and (10) shows that for the condition $\lambda > \lambda_0$ the decay frequency in the isotropic turbulent flow is mainly turbulence parameters (specific dissipation energy, scale of turbulent pulsations), the density of the medium is the surface tension, and the viscous flow $\lambda < \lambda_0$is determined by its viscosity. It should be noted that the fragmentation of drops and bubbles in an isotropic turbulent flow allows the deformation of their structures, so that the fact that $W_e$can be expressed at fairly small values of high M_o can take the structures.

The coalescence of drops and bubbles plays a key role in the course of various technological processes of chemical technology, first of all, in the reduction of the interfacial surface, in the stratification and separation of particles of different sizes accompanied by subsidence or eruption. The mechanism of coalescence of drops and bubbles is determined by the following stages:

The collision of particles in the flow occurs for various reasons:

a) Due to the convective Brown diffusion of finely dispersed particles, which is characteristic of laminar flow, mainly at small values of the Reynolds number.

b) At the expense of turbulent flow and turbulent diffusion. If the colmogor scale of turbulence is comparable to the size of drops and bubbles in a small or viscous flow area λ_0, the process is accompanied by turbulence, which results in turbulent diffusion, similar to Brownie. However, turbulent diffusion may be characteristic for large particle sizes at large λ distances due to the high intensity of turbulent pulsations and the non-uniformity of the hydrodynamic field.

c) The effect of adhesion resulting from the convective transmission of small particles of a large fragment is the capture of small particles by large particles.

For the coalescence processes of drops and bubbles, the retention coefficient, which determines the difference between the particle retention and the geometric cross section of the rel, plays an important role.

$$\vartheta = \frac{I}{\pi(L+R)^2 N_0 V_\infty} \quad (11)$$

During convective diffusion, the relationship between the Sherwood number and the retention coefficient is as follows:

$$Sh = \frac{1}{2} Pe\vartheta(1+\frac{R}{L})^2 \quad (12)$$

The eclipse coefficient is determined as follows:

$$\vartheta \approx \frac{4}{Pe}\left(1-\frac{N_L}{N_0}\right) b_*(1+b_o Pe), Pe \ll 1 \quad (13)$$

$$\vartheta \approx \left(1-\frac{N_L}{N_0}\right) Pe^{-2/3}\left(1+0{,}738 Pe^{-1/3}\right), Pe \gg 1$$

Here N_L – radius r = L the concentration of particles on the surface of the sphere;

d) Due to the heterogeneity of the temperature and pressure fields, which lead to the formation of forces proportional to the temperature and pressure gradient and the forces that affect the reduction of these parameters. For the finely dispersed composition of the dispersed flow, their displacement due to thermodiffusion and barodiffusion as a result of the action of these forces is characteristic, which leads to their collision and coalescence;

e) In addition to these events, physical phenomena (evaporation of drops and bubbles, condensation) also cause coalescence and these events are evaporating drops and bubbles (Stefan flow) formation of hydrodynamic thrust (Fassi effect) or is accompanied by the formation of a force acting in the opposite direction during the growth of the drop as a result of condensation.

It is assumed that the dynamic pressure affects a certain part of the surface of the drop and may therefore be related to the coefficient of resistance. From the condition of equality of these forces

$$C_D = (Rc_d)\frac{\rho_c U^2}{2} = \frac{4\sigma}{a_s} \quad (17)$$

If Morton number $M_0 > 10^{-7}$ and $0{,}1 < Re_d < 100$ at that time based on the experimental data and, we obtain $c_D = {}^{16}/_{Re_d}$ and then the maximum size of the drops will be determined in this way.

$$a_{max} \approx 0{,}354\gamma^{-3}\left(\frac{U}{\nu_c}\right)^{3/2}\left(\frac{\sigma}{\rho_m^{1/3}\rho_d^{2/3}}\right)^{3/2} \varepsilon_R^{-1} \quad (18)$$

Result and Discussion. If Morton number $M_0 > 10^{-7}$ and $0{,}1 < Re_d < 100$ at that time expression can be used with a coefficient of 0,192 , if $100 \le Re_d < 400$ at that time a coefficient of 0.068 can be used. Basically for bubbles for $2 < Re_d < 10^3$, it can be assumed that $c_D = {}^{14}/_{Re_d}$ as a result of which the expression (18) takes the following form:

$$a_{max} \approx 0{,}619\gamma^{-12/7}\left[\left(\frac{U}{\nu_c}\right)^{1/2}\left(\frac{\sigma}{\rho_m^{1/3}\rho_d^{2/3}}\right)\right]^{6/7}\varepsilon_R^{-4/7} \quad (19)$$

Expression (19) corresponds to the experimental data.

Table 1.

Comparison of experimental data with calculated values (19)

U, m/c	Re_d	$\varepsilon_R(\frac{W}{kg})$	a_{max}x 10^3m (experimental)	a_{max}x 10^3m (2.1.11)
3,50	1000	6,5	4,3	4,5
3,98	820	13,3	3,1	3,1
4,59	670	32,6	2,2	2,0
6,04	604	69,3	1,5	1,5

The minimum particle size in an isotropic stream characterizes the hydrodynamic resistance of drops and bubbles to disintegration under certain conditions and their tendency to intense collision and coalescence at high particle concentration.

Conclusion

Adjustments made to calculate the minimum and maximum sizes of deformed particles (drops, convex) can be used to solve the problem of separation of coalescence, fragmentation and dispersed systems with a certain accuracy. Numerous theoretical and experimental studies of the state of deformable particles in the turbine flow allow us to propose different formulas for estimating the maximum and minimum sizes of dispersed particles so that as can be seen from the research, these dimensions depend primarily on the specific dissipation energy of the properties of the medium and the particles, the coefficient of resistance of the particles, and in some cases the crisis values of the We number. The use of the coefficient of resistance in the expression of equality allows to expand the area of adequate description of the maximum and minimum particle sizes.

Symbols

K – wave number
I – mass flow to the surface of the separated part
L – characteristic scale of distance
V_∞ – the speed of the environment.
ω – frequency of fragmentation.
R_k – contact surface radius
P_m – maximum value of compression pressure
k_1,k_2 – coefficient of elasticity of drops and bubbles
$a_r = {a_1 a_2}/{(a_1 + a_2)}$ – average size of drops and bubbles
$a_1 a_2$ – diameters of drops and bubbles
b_i – coefficients
D_{TR} – coefficient of turbulent diffusion of particles
D_T – coefficient of turbulent diffusion of liquid
λ_f – the initial length of the turbulence scale
α – coefficient
C_D – resistance coefficient
σ – surface tension coefficient
a_{max} – maximum size of drops
a_{min} – minimum size of drops
ρ_m – the density of the medium
ρ_d – the density of the drop

ε_R – energy dissipation

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