A CRITERION OF THE QUALITY OF MULTIPHASE DISPERSE SYSTEMS SEPARATION AND ITS APPLICATION TO THE PROCESSES OF SLAUGHTER ANIMALS' BLOOD SEPARATION

Plate separators are used in the meat industry for separating and purifying fat systems, meat broths, gelatine and glue, for separating blood into formed elements and plasma.

Increasing requirements to the quality of multiphase systems purification and separation makes a comprehensive substantiation of quality criterion of the above two processes an urgent task.

At present the most reliable criterion of separation quality is the limit diameter of the particles, precipitated in the interplate space, provided that the total curve of size distribution of the suspended particles of the initial product and of the clarified fraction is known. As may be seen from experiments, the dispersed composition does not change considerably prior to and after clarification. It is connected with the fact that small particles in the clarified fraction are partially coagulated (due to the Brownian movement, the presence of electrostatic charges, etc.). So, to assess the quality of separation, it is enough to know the limit diameter of the particles isolated and the total curve of size distribution of the particles in the initial product.

Formulae, suggested for the determination of the limit diameter of particles, are derived on the basis of a simplified diagram of suspended particles movement in the interplate space. Our task was to strictly study the suspended particle movement in the interplate space of a separator and, on this basis, to calculate the minimum radius of a particle, precipitated in the interplate space.

The solution of this problem is based on the analysis of differential equations for the relative movement of a spheric suspended particle, which are written down in a special system of coordinates: (r, φ, z), shown in Fig. 1. These equations are as follows:

$$m\frac{dV_r}{dt} = -6\pi\mu a\left(V_r - \frac{f_1}{r\,\mathrm{Sin}\gamma}\right) + A\omega^2 r\,\mathrm{Sin}^2\gamma + 2A\omega V_\varphi \mathrm{Sin}\gamma$$

$$m\frac{dV_\varphi}{dt}=-6\pi\mu a\left(V_\varphi-\frac{f_2}{r\sin\gamma}\right)-2A\omega V_r\sin\gamma-2A\omega V_z\cos\gamma$$

(1)

$$m\frac{dV_z}{dt}=-6\pi\mu a(V_z-U_z)+A\omega^2 r\sin\gamma\cos\gamma+2A\omega V_\varphi\cos\gamma,$$

where m - mass of a particle;
a - particle radius;
μ - dynamic coefficient of liquid viscosity;
ω - angular speed of plate rotation;
V_r, V_φ, V_z - projections of relative velocity vector of a particle on r, φ, z axis (respectively);
$\frac{f_1}{r\sin\gamma}, \frac{f_2}{r\sin\gamma}, U_z$ - projections of relative velocity vector of a liquid on r, φ, z axis (respectively) with f_1 and f_2 being the functions of the coordinate z only /1, 2/, and $U_z \equiv 0$.

The average meanings of the functions f_1 and f_2 for clearance thickness between the plates are

$$f_1^{av}=-\frac{Q}{2\pi h}; \quad f_2^{av}=\frac{Q(\lambda-1)}{2\pi h}. \qquad (2)$$

where Q - liquid flow-rate in each interplate space;
h - distance between the plates;
λ - dimensionless parameter $(\lambda=h\sqrt{\frac{\omega\sin\gamma}{\nu}}$.

with ν as the kinematic coefficient of liquid viscosity

The minus in the first formula (2) shows that the mean radial speed of liquid flow is directed towards the top of the conic plate; the second formula (2) is applicable to the parameter $\lambda>3$ this taking place in real separators for slaughter animal blood.

The constant A is

$$A = \frac{4}{3}\pi a^3 (\rho_p - \rho_e) \tag{3}$$

where ρ_p - density of a particle;
ρ_l - density of a liquid.

The analysis of equations (1) shows that one can, to a high accuracy, neglect the terms in the left members for particles having the size of ($a \sim 10\,cm$). Solving the derived system of equations relative to particle velocities V_r , V_φ and V_z and neglecting the summands of a much higher order of smallness in the derived formulae we shall have:

$$V_r = \frac{6\pi\mu a f_1 + 2A\omega f_2 \sin\gamma + A\omega^2 r^2 \sin^3\gamma}{6\pi\mu a r \sin\gamma} \tag{4}$$

$$V_\varphi = \frac{3\pi\mu a f_2 - A\omega f_1 \sin\gamma}{3\pi\mu a r \sin\gamma} \tag{5}$$

$$V_z = A\omega \frac{6\pi\mu a f_2 - 2A\omega f_1 \sin\gamma + 3\pi\mu a \omega r^2 \sin^2\gamma}{18\pi^2\mu^2 a^2 r \sin\gamma} \cos\gamma \tag{6}$$

The radial relative speed V_r of a particle may be called the speed of particles throw-away from the interplate space, while the speed V_z , that is perpendicular to the top plate, may be called the speed of precipitation.

Taking the average meanings for the functions f_1 and f_2 from (2), forming a differential equation of particle trajectories in the plane intersecting the generants of the plates and integrating it with respect to coordinate z within the range from 0 to h and with respect to coordinate r within the range from $\frac{R_{max}}{\sin\gamma}$ to $\frac{R_{min}}{\sin\gamma}$, we shall calculate the minimum radius of a particle, that will precipitate onto the top plate surface.

$$a_{min}=1{,}5\sqrt{\frac{Q\mu h}{\omega(R_{max}-R_{min})[\pi h\omega R_{max}R_{min}+Q(\lambda-1)](\rho_p-\rho_e)\,ctg\,\gamma}} \qquad (7)$$

All the particles with the radius more than a_{min} will precipitate in the interplate space or will be thrown away to the slime space of separator drum; the particles with the radius less than a_{min} will be partially carried away together with the flow of the liquid, being refined, and pass to the clarified fraction.

Particle fixation on the top plate surface, when $r=\frac{R_{min}}{\sin\gamma}$ is not obligatory, because for small-sized particles the functions f_1 and f_2 becoming 0 at $z=h$, will be very small (when $z=h-a$). As follows from formula (4), particle dimensions for which $V_z<0$, if $z=h-a$ and $r=\frac{R_{min}}{\sin\gamma}$ will be considerably less than those calculated with the help of formula (7), i.e. these particles will not reach the top plate surface.

Let us discuss the application of the derived formulae. Assume that we know size distribution of particles in the initial product, e.g., the distribution of the formed elements of slaughter animal blood by the maximum size of erythrocites.

Calculating by formula (7) the minimum size of the precipitated particles a_{min} (d_{min}), we can find the percentage of the particles, precipitated in the separator, of the total mass of particles in the initial product. Let it be η%. Assuming all the particles in the liquid as 100%, we shall derive a simple formula to determine the quality of separation of a dispersed system (e.g., blood):

$$\chi=\frac{\eta}{100}=0{,}01\eta \qquad (8)$$

In this formula χ is an abstract quantity which is mostly less than unity because there are particles the limit sizes of which do not allow their separation from a given liquid.

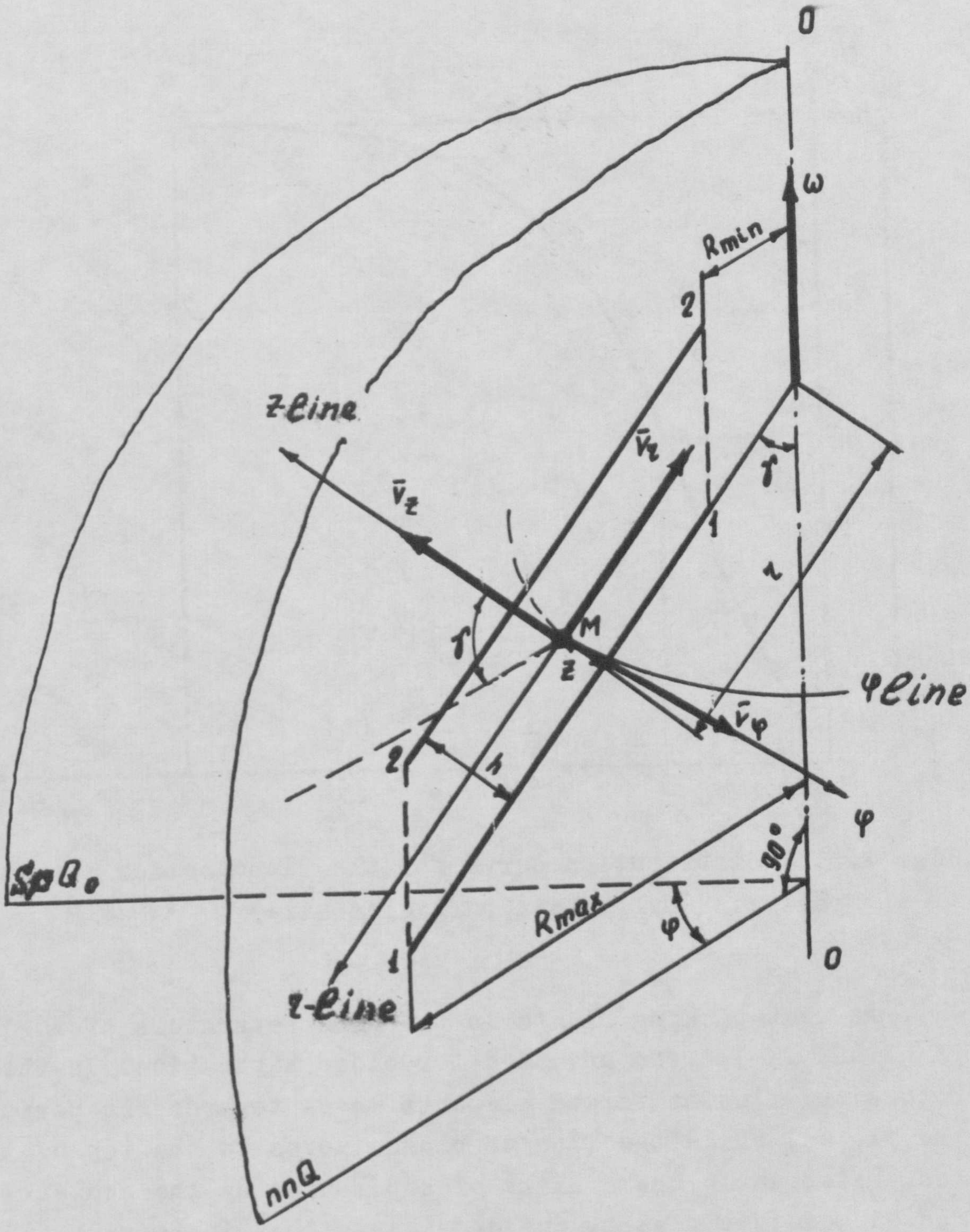

Fig. 1. System of conic coordinates

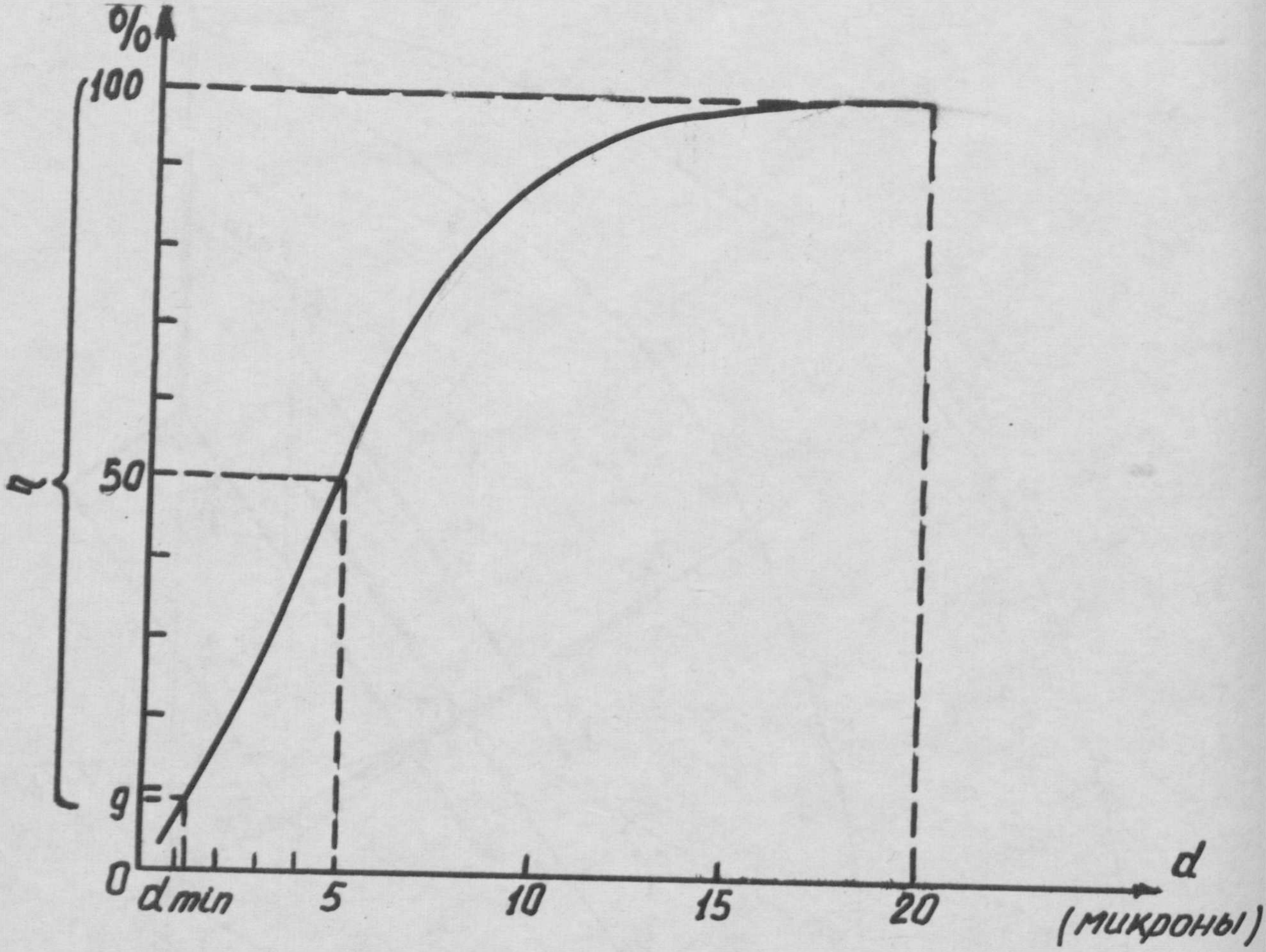

Fig. 2. The distribution curve for the blood solids slaughter animals (by protein particles size)

At meat-packing plants in the USSR separators of AC-I , K/ C and CK-I types are used for blood separation. In these separators the flow of formed elements moves towards the periphery of the plates, while the flow of plasma moves to the top of the plates. Determining the quality of separation by the content of formed elements in plasma, one can assume that in formula (7):

Q is plasma flow-rate in each interplate space;

R_{max} is the distance from the rotation axis to the two phases interface, i.e. from the rotation axis to that of holes in the plates.

Assuming $\mu = 0{,}025 \frac{g}{cm.sec}$, $\rho_p - \rho_e = 0{,}03 \frac{g}{cm^3}$ for blood and using formula (7), with account for the technical characteristics of the above separators, we'shall get the following rated data.

Table

Separator type	d_{min}	$\varkappa$
AC-IЖ	$3\cdot10^{-4}$	0.90
ФК/ЖС	$4\cdot10^{-4}$	0.75
СК-I	$2.4\cdot10^{-4}$	I

Taking into account that the main part of the formed elements is blood erythrocytes, their average equivalent diameter being $d_{eq} \approx 4\cdot10^{-4}$ cm, one can speak about almost complete precipitation of erythrocytes from blood plasma during separation in CK-I separator. When separating blood in AC-I and ФК/ЖС separators, some erythrocytes pass to the plasma, this resulting in its slightly pink colour.

Using the data /3/ about percentage relationship between plasma and formed elements yields, when separating blood in CK-I separators different capacities, one can explain the reason of insignificant colouring of the plasma leaving separators when their capacity exceeds 456 l/hr. Calculations according to formula (7) under these conditions of separation shows that the maximum size of the precipitated particles is not higher than $d_{min} \approx 3.7\cdot10^{-4}$ cm. As calculated, $\chi \approx 0.81$, i.e. blood separation is incomplete.

Let us consider the quality of coagulated blood separation in a CK separator. Physical constants of the system being separated are equal to $\mu = 0.01$ g/cm·sec, $\rho_p - \rho_e = 0.05$ g/cm^3. At separator capacity for coagulated blood of 200 l/hr (when deluted with water in the ratio of 1:6, the consumption of the mixture constitutes 1,400 l/hr) the minimum diameter of the precipitated particles by formula /7/ will be $1.2\cdot10^{-4}$ cm. Thus, when processing the given system separator, all the coagulated formed elements must precipitate, i.e. the quality of formed elements separation $\chi = 1$.

Under these conditions, however, some solids pass to the used water. When distributing particles of the solids by size according to Fig. 2, plotted on the basis of the experimental data, we shall have $\chi \approx 0.91$.

So, about 9% of solids must pass to the used water. Proceeding from the results of the tests in a ФСК separator, a dry residue makes up 26.7 kg per the initial II6 kg of coagulated blood having moisture content 77%. In this case about 2.5 kg of a dry residue must pass to the used water. Taking into account the fact that in the experiments the mass of the separated coagulate was equal to 57.6 kg with 58% of moisture, the dry residue in the coagulate constituted about 24.2 kg. So, actually, about 2.5 kg of the dry residue pass to the clarified fraction.

As is seen from the above examples , the results of calculations according to formula (7) are in a good agreement with available experimental data, this proving the validity of the working hypotheses used for deriving formula (7). Formula (7) is recommended as the criterion for the evaluation of the separation of liquid multiphase systems (like blood of slaughter animals) with simultaneous use of the total curves for suspended particles distribution by size, the curves being plotted with account for as complete data as possible on the dispersed composition of the fractions under separation.

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