drained foams and emulsions, self-organization, interfacial energy

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PROPERTIES OF 2D HIGHLY-ORGANIZED BIDISPERSE CELLULAR FLUIDS

The regular patterns obtained by mixing of two biphasic fluid systems (dispersions of fluids A and B in a liquid C, where A and B are also immiscible), confined between two parallel plates, are studied. Our attention is limited to concentrated and bidisperse systems consisting of equal-size – if of the same composition – cells separated by a thin liquid film. On the basis of the interfacial energy calculations the pseudo-phase diagrams are constructed. The diagrams indicate the conditions under which the three-phase mixtures of cellular fluids are stable. Anisotropy of the resistance and the light transmittance of such well-ordered structures are also demonstrated.

The cellular fluids are the systems consisting of a collection of fluid cells surrounded by a continuous liquid phase tending to minimize its surface. They are represented by the drained foams (*i.e.* foams having a very low liquid fraction) or concentrated emulsions (*i.e.* emulsions having a volume fraction of the dispersed liquid much higher than the critical volume fraction necessary for the close packing of an equivalent suspension of hard spheres). These systems can form - as a result of the interface energy minimization – well ordered structures, which are of potential practical importance in fabrication of structured materials.

Recently, we have shown that under some conditions the mixing of two different monodisperse cellular fluids, confined between two parallel plates, may lead to the spontaneous formation of highly-organized stable structures [1]. In this study we have investigated the properties of these two-dimensional structures, with special attention to the properties relevant to the material science.

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1. MODEL

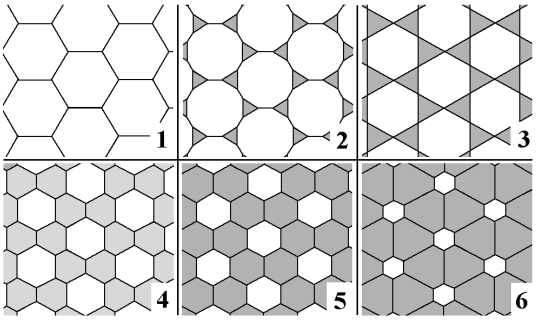

Fig. 1. Structures of ordered mixtures of A (white) and B (gray) cells considered. The structures represent the following tilings: 1) 6_1 (Φ=1), 2) $12_1 3_2$ (3/4<Φ<1), 3) $6_1 3_2$ (Φ=3/4), 4–6) $6_1 6_2$ (0<Φ<4/3)

We consider a three-phase system made of fluids A and B dispersed in a liquid C. In order to force a 2D structure, the system is confined between two parallel plates. The volume of the dispersion medium C is so low that the system can be viewed as a network of polygon cells composed of A and B fluids, separated by thin liquid films made of phase C. The energy of such a system is just the interfacial energy. The network is composed of clusters. Each cluster includes one cell made of fluid A decorated by two cells of fluid B (see Fig. 1).The interfacial tensions acting along A–C and B–C interfaces are different. The system under consideration is assumed to be an unbounded network (or a network large enough to neglect the presence of peripheral clusters).

The interfacial energies of formation of boundary films between cells, E, both for the mixed (E_M) and the separated (E_D) cellular systems, have been calculated from the equation:

$$E = d\sum_i L_i\left(\gamma_X + \gamma_Y\right) \tag{1}$$

where L_i is the length of the i-th film, γ_x and γ_y indicate the interfacial tensions at both sides of the film, d is the distance between plates. The optimization procedure was applied to search for the curvatures of polygon sides that would guarantee the minimum interfacial energy of the patterns studied.

2. RESULTS AND DISCUSSION

The transformation of two biphasic monodisperse systems into the three-phase mixture occurs when E_M/E_D <1. As we have shown in our earlier studies [1], there are values of relative interfacial tension γ_B/γ_A (where indices A and B stand for A-C and B-C interfaces, respectively) and volume fractions of fluid A, Φ, for which this condition is satisfied. In Fig. 2 the plot of γ_B/γ_A versus Φ when E_M/E_D=1is shown. The obtained lines divide the plane into regions corresponding to mixed or separated dispersions. Fig. 2 resembles a phase diagram; it does not describe, however, particular phases in an equilibrium state but only indicates in which regions the three-phase mixture of fluid biphasic monodisperse systems is stable and in which it breaks up into two separate dispersions. As shown in this pseudo-phase diagram there are two regions of the mixture instability: one occurring at small Φ values and another forming “an island” in the middle of the plot and enclosing the curve representing the $6_1 3_2$ tiling.

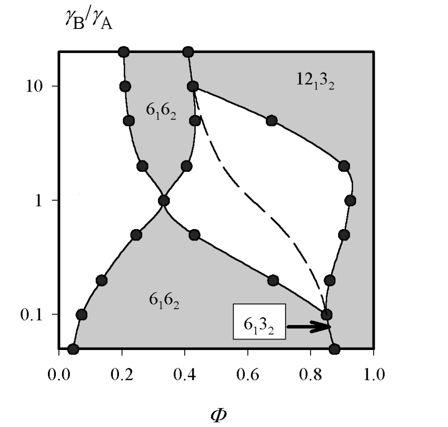

Fig. 2. The γ_B/γ_A-versus-Φ diagram (the gray areas correspond to stable mixtures).

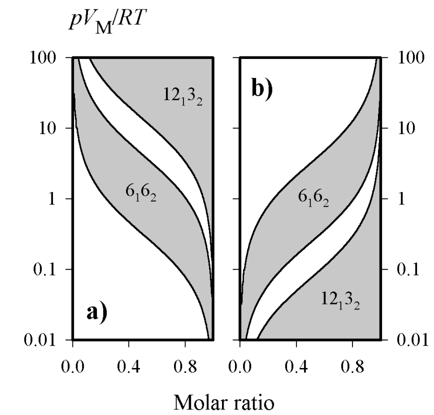

Fig. 3. The pV_M/R_gT–versus–x_A diagram showing the stability/instability regions of foam-emulsion mixtures; a) with A and b) with B phase gaseous).

When one of the dispersed phases is gas, a strong dependence of the system’s behavior on temperature and/or pressure can be observed. Diagrams showing the stability/instability regions of foam-emulsion mixtures for an arbitrarily taken value of γ_B/γ_A=0.20 are presented in Fig. 3 as a function of the molar fraction, x_A, and the dimensionless pV_m/RT ratio (where p is the pressure, V_m – the molar volume, R – the gas constant and T – the temperature). One can find the diagrams obtained for the two systems considered (i. e., with gaseous A or B phase) to be antisymmetrical. As a result, the behavior of the foam-emulsion system, that is the mixing ability and the particular tiling formation, can be controlled by temperature or/and pressure; this might be a useful property for generating complex mesoscopic structures.

For the sake of illustration of anisotropic properties of stable mixtures of cellular fluids under investigation, we have estimated angular dependencies of electric resistance and light transmittance for some exemplary structures. Calculations of the electric resistance were made under assumption that the liquid C (film) was the only conducting phase in the system. In the calculations of the light transmittance it was assumed that the liquid B was the only light absorbing phase and that the thickness of absorbing sample was low (equal to ten cluster lengths). The results are presented in Figs 4 and 5. The angular dependencies are found for both properties examined. The resistances of $12_1 3_2$ and the honeycomb structures are similar both in their values and angular dependencies whereas those for the structure $6_1 6_2$ not only take different values but also the dependence is reversed. The angular dependence of light transmittance can be observed at different volume fractions (as seen in Fig. 5) whereas the honeycombs made of A or B cells only (Φ=0 or 1, respectively) are isotropic.

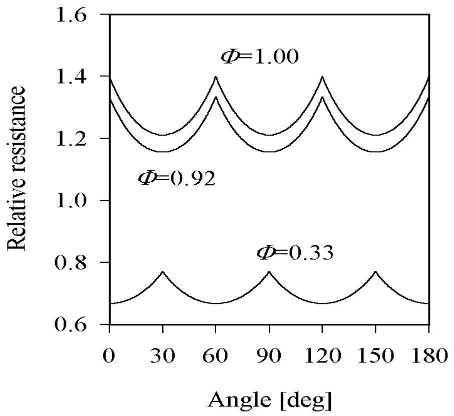

Fig. 4. An angular dependence of the relative electrical resistance for different Φ values

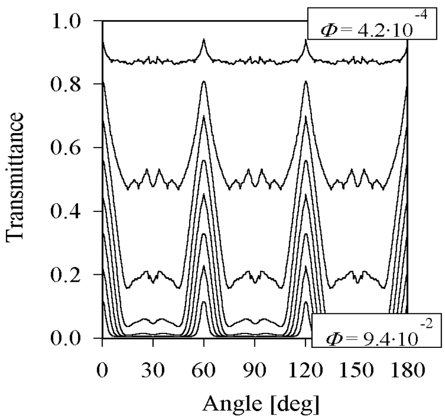

Fig. 5. An angular dependence of the light transmittance (the sample length corresponds to 10 cluster lengths, the extinction coefficients of B cells was equal to 2.3)

The results obtained point to the practical aspects of the studies concerning the cellular fluids, indicating potential applications of such systems, for instance, as interference filters of electromagnetic radiation of the wavelength comparable with the network constant of the cellular system.

REFERENCES

[1] NOWICKI W., NOWICKA G., *Eur. Phys. J. E*, **13**, 409 (2004)

WŁAŚCIWOŚCI DWUWYMIAROWYCH WYSOKO-ZORGANIZOWANYCH BIDYSPERSYJNYCH PŁYNÓW KOMÓRKOWYCH

Stężone piany i emulsje (płyny komórkowe) umieszczone pomiędzy dwiema równoległymi płytami tworzą sieć wypełniających płaszczyznę wieloboków. Topologia takich układów jest określona przez napięcie międzyfazowe, γ, działające na granicy ośrodków komórka – ośrodek dyspersyjny. Opracowano diagram pseudo-fazowy określający strukturę płynu komórkowego jako funkcję ułamka objętościowego, wartości γ dla obu typów komórek, ich składu, ciśnienia i temperatury. Stwierdzono, że materiały o wysokim stopniu mezoskopowego uporządkowania wykazują anizotropię oporu elektrycznego oraz transmitancji światła.