MACROMOLECULAR COMPOUNDS AND POLYMERIC MATERIALS

Relationship between Energy Characteristics of Surface of Polymeric Membranes and Their Transport Properties

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Abstract—Molecular theory of wetting was used to calculate the specific free surface energy of membranes based on amorphous polymers of varied chemical structure from experimental wetting angles obtained for test fluids. A relationship was found between the dispersion component of the surface energy of a membrane, its gas permeability, and free volume of the polymer. This makes it possible to employ the wetting method to prognosticate the transport properties of polymeric membranes. In wetting of membranes with aqueous solutions of alcohols, the concentration of an alcohol corresponding to the onset of its sorption into the membrane was determined. The correlation of the value obtained with the alcohol concentration that corresponds to the onset of sorption and is determined independently by the gravimetric method enables use of wetting angles for optimizing the conditions of experiments on nanofiltration and pervaporation.

Keywords: wetting, wetting angle, surface energy, membranes, free volume, gas permeability, nanofiltration

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The possibility of using polymeric materials to solve some specific applied problems largely depends on the energy-related characteristics of their surfaces. These characteristics determine, for example, the adhesion and adsorption properties of polymers and the mechanical stability of polymeric materials in various media.

The surfaces of most polymers are commonly regarded as low-energy. The surfaces are characterized by a specific free surface energy at the interface with air $\gamma_{SV} \le$ 60 mJ m–2 [1, 2]. There exist a number of methods and approaches to calculating the surface energy of polymers. Some of these use the physicochemical characteristics of the polymeric phase (refractive index, compressibility, cohesion energy, parachor [3, 4]), others (atomic-force microscopy, wetting method) employ experimental data characterizing only the surface of a polymer [2–7].

The wetting method is a rapid-test technique for determining the energy characteristics of polymer– air interfaces (specific free surface energy γ_{SV}) and polymer–liquid interfaces (interface energy γ_{SL}) [1, 2]. The equilibrium wetting angle θ of a fluid drop on a solid surface is determined by the Young equation

$$\gamma_{\rm LV}\cos\theta = \gamma_{\rm SV} - \gamma_{\rm SL},\tag{1}$$

where γ_{LV} is the surface tension of a liquid [1, 6].

It is rather simple to determine experimentally the values of γ_{LV} and θ , whereas the number of methods for determining γ_{SV} and γ_{SL} of polymeric objects is limited [1, 2].

The development of the theoretical aspects of the phenomena related to the formation of wetting angles resulted in that various methods and approaches to determination of γ_{SV} and γ_{SL} have been developed [1, 2, 6, 8]. The values of γ_{SV} , calculated from the data furnished by the wetting method, are in good agreement with the results of other techniques 3]. Therefore, being rather simple and fast, the wetting method is in wide demand for determining the surface energy of polymers of various classes.

The value of γ_{SL} can be used to assess the prospects for application of polymers in development of biomedical materials, adhesives, or finishing agents [5, 6]. The wetting method is the only way to determine this value. An approach to determining γ_{SL} has been developed [5].



Fig. 1. Dependence of the surface energy of polymers and the surface tension of low-molecular liquids $(20-25^{\circ}C)$ on the cohesion energy and heat of evaporation, respectively.

This approach takes into account the lability of polymer chains in the surface layer of a film brought in contact with a fluid [5].

At present, solid membranes based on amorphous glassy compounds are widely used to separate gases and fluids [9–12]. The specific feature of these membranes consists in the inhomogeneous packing density of polymer chains and in the large fraction of the nonequilibrium (unrelaxed) free volume (FFV) [13]. Knowing the values of FFV, determined both experimentally [14] and with the use of calculation methods [11], we can assess the transport properties of polymeric membranes [9, 10, 12]. However, experimental methods for determining the free volume (extended hydrostatic weighing technique, annihilation of positrons) and the mass transfer across the membrane (gravi- and volumometry) are rather laborconsuming, with the task additionally complicated by the nonequilibrium state of membranes based on amorphous glassy polymers. Thus, it is necessary to develop rather simple and fast methods for assessing the transport properties of polymeric membranes.

A theoretical approach employing a set of additive prognostication methods has been developed for these purposes, and a permanently renewed database of transport parameters has been created [15, 16].

The transport properties are also correlated with other physicochemical parameters of membranes. For example, it has been shown [17] that a change in the transport properties of membranes based on substituted polyacetylenes affects their electrical conductivity, which is due to the sensitivity of both quantities to the degree of sorption swelling of a polymer. The process in which a substance penetrates across the membrane begins from its sorption in the surface layer. Therefore, the energy characteristics of the surfaces of polymeric films can be used as parameters characterizing their permeability. Consequently, the wetting method can be used to assess the transport properties.

A relationship between the macroscopic surface characteristics (γ_{LV}) and intermolecular interaction in the bulk of the phase, characterized by the evaporation energy Eevap, is well known for condensed phases of lowmolecular substances [18]. The intermolecular interaction energy depends on the distance between particles in the phase and becomes lower with decreasing density of the substance. Analysis of reference data [3, 19, 20] demonstrates similar runs of the dependences γ_{LV} = $t(E_{evap})$ and $\gamma_{SV} = f(E_{coh})$, where E_{coh} is the cohesion energy of the polymer (Fig. 1). This enables a comparison of γ_{SV} , which reflects the packing density of functional groups in the surface layer [8], and FFV, the quantity associated with the density of the polymer [21]. This concept underlies our systematic studies of the wetting of polymeric membranes. These studies were aimed to find the possibility of using the energy characteristics of their surfaces as parameters for prognostication of the transport properties of membranes toward fluids and gases [22, 23]. In the present communication, we summarize the results of these studies.

EXPERIMENTAL

As objects of study served films of amorphous structures with varied chemical structure of the monomer unit (Table 1). The film thickness was 30–50 µm. The physicochemical characteristics of commercial statistic copolymers of tetrafluoroethylene with 2,2,4-trifluoro-5trifluoromethoxy-1,3-dioxolane, Hyflons®ADX (Solvay-Solexis) AD 60 and AD 80, and 2,2-bis(trifluoromethyl)-4,5-difluoro-1,3-dioxolane, Teflons®AF (Du Pont) AF 1600 and AF 2400, have been determined previously [24].

Polynorbornenes [28, 33], poly(4-methyl-2-pentine) (PMP) [34], and poly[1-(trimethylsilyl)-1-propyne (PTMSP) [10] were synthesized and characterized at the Institute of Petrochemical Synthesis, Russian Academy of Sciences. Polynorbornenes were synthesized by both metathesis (MPNB) [33] and additive (APNB) [29] polymerization of the corresponding monomers.

	-	-			
Structural formula of monomer unit	Polymer	Glass transition temperature, °C	Gas permeability <i>P</i> , bar	Free volume FFV	Reference
	MPNB	37 in Ar	3	0.16	[22, 25]
	Me ₃ Si–MPNB	102 in Ar	21	0.20	[22, 26]
SiMe ₃	(Me ₃ Si) ₂ –MPNB	167 in Ar	95	0.22	[22, 27]
Me ₃ Si SiMe ₃					
$\int \int f_n$	APNB 2,3	> 350	6.9	0.125	[28]
Ĭ,	Me ₃ Si–APNB 2,3	> 350	780	0.275	[28]
<u> </u>					
SiMe ₃					
- <u>c</u> = <u>c</u> -	PTMSP	> 300	9700	0.33	[10, 29, 30]
CH_{3} Si(CH ₃) ₃					
CH ₃	PMP	> 250	2700	0.28	[31]
$CH(CH_3)_2$		250	1140	0.015	F11 003
	AF 2400:	250	1140	0.315	[11, 32]
$+C-C$ $+CF_2-CF_2$ $+I$	n = 0.8 /	156	170	0.253	
0,0	n = 0.65	150	170	0.235	
CF ₂ CF ₂	<i>n</i> 0.05				
F OCF ₃	AD 80:	135	194	0.095	24
	n = 0.85				
$\begin{bmatrix} 0 & -0 \\ 1 & 0 \end{bmatrix} = \begin{bmatrix} 0 & 0 \\ 1 & 0 \end{bmatrix}$	AD 60:	110	5	0.094	
	n = 0.6				
F					
				1	1

 Table 1. Structural formulas of monomer units and physicochemical characteristics of polymers

Polymer films were prepared by casting of solutions onto a solid support ($10 \times 15 \times 1$ mm Al plate), followed by drying at 20°C for 48 h. We used solutions of metathesis polynorbornenes in toluenes, additive polynorbornenes in cyclohexane, Ad and AF in octafluorotoluene (polymer concentrations in solutions 1 wt %), with all solutions being of chemically pure grade from Sigma-Aldrich. The procedures for preparing PTMSP and PMP films were described in [10].

The film samples were certified by wetting angles of water, measured under inflowing conditions (θ_a) on depositing a drop onto the sample surface and outflowing conditions (θ_r) on bringing an air bubble to the surface of a sample submerged in water [35]. Samples were selected

Polymer	θ_a (of test liquids), deg		θ_r (of	$\Delta \theta = \theta_a - \theta_a$	Surface energy and its components, mJ m ⁻²		
	H ₂ O	ethylene glycol	water), deg	$\theta_{\rm r}$, deg	$\gamma^d_{\rm SV}$	$\gamma^p_{\rm SV}$	$\gamma_{\rm SV}$
MPNB	92	68	77	15	20	4	24
Me ₃ Si–MPNB	95	74	83	12	15	4	19
(Me ₃ Si) ₂ -MPNB	100	88	93	7	12	5	17
APNB 2,3	91	62	50	41	28	2	27
Me ₃ Si–APNB 2,3	97	73	58	39	12	5	17
AF 2400	114	98	112	2	9	1	10
AF 1600	111	93	108	3	11	1	12
AD 80	112	89	112	0	14	1	15
AD 60	115	93	114	1	16	~ 0	16
PTMSP	85	74	72	13	7	15	22
PMP	77	62	75	3	11	17	28

Table 2. Surface characteristics of polymeric films

for which the deviation from the corresponding average values in Table 2 of did not exceed $\pm 1^{\circ}$. The averaging was performed over the results of angle measurements for 5–6 drops or bubbles on the surface of a single sample. The wetting angles were determined by the sitting-drop method on an MG-1 horizontal microscope with a goniometric attachment (25× magnification) with accuracy of 1°.

The surface energy of polymeric groups, γ_{SV} , and its dispersion (γ^{d}_{SV}) and polar (γ^{p}_{SV}) components were found by using the molecular theory of wetting (Owens– Wendt–Kaelble approximation) [1, 2] via solution of the system of equations

$$(1 + \cos \theta_{L1})\gamma_{L1} = 2(\gamma_{L1}^{d}\gamma_{SV}^{d})^{1/2} + 2(\gamma_{L1}^{p}\gamma_{SV}^{p})^{1/2}, \qquad (2)$$

$$(1 + \cos \theta_{L2})\gamma_{L2} = 2(\gamma_{L2}^{d}\gamma_{SV}^{d})^{1/2} + 2(\gamma_{L2}^{p}\gamma_{SV}^{p})^{1/2}, \qquad (3)$$

where, θ_{L1} and θ_{L2} are the experimental wetting angles for the inflow of test liquids (θ_a) on the polymer surface; γ_L^d and γ_L^p , dispersion and polar components of the surface tension of test liquids (distilled water with refractive index $n_D^{20} = 1.333$ and ethylene glycol (chemically pure, Sigma-Aldrich) with $n_D^{20} = 1.432$ [35].

Films based on highly permeable polymers PMP and PTMSP are promising membrane materials for nanofiltration separation of fluids. The separating properties of membranes under model conditions are commonly studied with aqueous solutions of various alcohols. We examined the transport properties of membranes in the present study with solutions of ethanol and butanol-1. Ethanol was chosen due to its wide use as the object of study in direct nanofiltration experiments. The use of butanol-1 made it possible to find how the length of the hydrocarbon radical of the molecule affects the state of the membrane–solution interface.

Solutions of the alcohols (Sigma-Aldrich, chemically pure, >99.8%) were produced by successive dilution of the starting solutions prepared by dissolution of a weighed portion of a substance in an aliquot of water. The polymer–solution interface energies (γ_{SL}) were calculated by the Young equation (1) from the experimental values of the outflow wetting angles (θ_r) in the solution–polymer system and from the surface tension of alcohol solutions (γ_{LV}), determined by the Wilhelmy method (equilibration of a platinum plate) [7, 18]; $\Delta \gamma_{LV} = \pm 0.5$ mJ m⁻².

It is known that the surface properties of polymeric films may change when the films are brought in contact with liquid media of varied polarity [5, 36]. Therefore, the films were kept in water or solutions for 30 min, dried to constant mass, and then the inflow wetting angles were determined for the test liquids and values of γ_{SV} were calculated by Eqs. (2) and (3).



Fig. 2. Relationship between the dispersion component of the surface energy of membranes and the free volume of amorphous polymers.

The error in determining the surface and interfacial energies of polymeric films $\Delta \gamma = \pm 1$ mJ m⁻². All the measurements were made at 20°C.

RESULTS AND DISCUSSION

Polymer-air interface. The surfaces of most of the films under study are not wetted by water, with the exception of PTMSP and PMP films characterized by a limited wettability (Table 2). The main contribution to the surface energy of the films of polynorbornenes, Hyflons®ADX and Teflons®AF, is made by the dispersion component (Table 2). The surface energy of metathesis polynorbornenes steadily falls with decreasing γ_{SV}^{d} as the number of trimethylsilyl substituents in the monomer unit becomes larger [12]. The same tendency is observed for additive polynorbornenes. The AD and AF films have small values of γ_{SV} , which are close to the surface energy of polytetrafluoroethylene (16–20 mJ m⁻²). The value of γ_{SV} for AF 1600 is in good agreement with that obtained by calculation in terms of the macroscopic model of the thermodynamic equation of state [37].

PTMSP and PMP are characterized by larger values of γ^{p}_{SV} , compared with the rest of the polymers (Table 2). At the same time, the values of γ^{d}_{SV} for PTMSP and PMP are comparable with γ^{d}_{SV} for Teflons®AF (Table 2). This is presumably due to the steric hindrances in shielding of double bonds in the surface layer of the films: the glass transition points of PTMSP and PMP exceed that for (Me₃Si)₂–MPNB (Table 1).

A correlation is observed for all the polymers under study, except AD, between γ_{SV}^d and FFV (Fig. 2) (For





Fig. 3. Dependence of the gas permeability for oxygen on the dispersion component of the surface energy of films of amorphous polymers.

MPNB, FFV was calculated by the Bondi method with the use of the densities experimentally determined by hydrostatic weighing (isopropanol) [21]. For the rest of the polymers, we used published data on FFV (Table 1). This experimental fact is due to the following. The free volume and the surface energy are affected by the same factor, the packing density of macromolecules, which determines the interaction of unbound units in the bulk of a film and on its surface. The free volume determined by the short-range order is related to the polymer density [21]. The density of a substance is related to its surface energy via the parachor [3, 4, 39, 40]. Thus, despite that the polymer density in the bulk of a film and on its surface may differ [38, 41], there exists a relationship between the value of γ^d_{SV} calculated from experimental data on the state of the surface, and that of FFV.

It is known that the gas permeability *P* is largely determined by the free-volume fraction of the polymer, FFV:

$$P = A \exp(-B/FFV),$$

where *A* and *B* are constants that are individual for each gas [42, 43].

Therefore, the correlation between γ_{SV}^d and published data on the gas permeability of polymeric membranes (Fig. 3) is a direct consequence of the dependence presented in Fig. 2. It is important that gas permeability measurements were made and γ_{SV}^d was determined for the same synthetic polymer samples and films prepared under the conditions identical to those for the electrodes whose gas permeability for oxygen is reported in the literature (Table 1).



Fig. 4. Fraction *x* of regions with lowered packing density of functional groups on the surface of polymeric films, calculated by the Cassie–Buxter equation, and the free volume FFV of polymers.

The data we obtained illustrate the sensitivity of the wetting angles to the packing density of macromolecules in the surface layer of a film, which is related to their packing density in the bulk of the polymer [44].

Taking into account the presence of regions with lowered density on the surface of films, the wetting of films of highly permeable polymers can be interpreted in terms of the model of wetting of heterogeneous surfaces [7, 8]. It is necessary to understand by the heterogeneity in the given case the chemical heterogeneity of the film surface, resulting from the loose packing of macromolecules in the surface layer. The degree of heterogeneity of the film surface can be evaluated by the Cassie–Buxter equation [7, 8]

$$\cos \theta = x \cos \theta_1 + (1 - x) \cos \theta_2, \tag{4}$$

where, x and (1-x) are shares of surface parts characterized by water inflow angles θ_1 and θ_2 , and θ is the experimental wetting angle of water on the surface (Table 2).

When choosing the angles, we assumed that $\theta_1 = 0$ (which corresponds to the homogeneous wetting mode [45]), and θ_2 is the angle corresponding to the state of the surface with densely packed functional groups contained in the monomer units of the polymers under study (Table 3) [8].

An evaluation of the degree of surface heterogeneity by Eq. (4) shows that the fraction of areas corresponding to regions with loose packing of functional groups in the surface layers of the films is comparable for many of the polymers under study (PTMSP, AD 60, AD 80, APNB-2,3, MPNB, Me3Si–MPNB) with their free volume (Fig. 4).

Polymer–liquid interface. The interfacial energy γ_{SL} at the polymer–liquid interface was calculated for films of the highly permeable polymers PMP and PTMSP, which are now actively studied in nanofiltration processes [12]. It is known that the nanofiltration of aqueous solutions of alcohols across PTMSP- and PMP-based membranes is of threshold nature, which is associated with the swelling of a polymer in solution and onset of

Table 3. Wetting angles of water inflow, used in calculationby equation (4)

Polymer	θ_2 , deg	Group
MPNB APNB 2,3	96	-CH ₂ -
Me ₃ Si–MPNB (Me ₃ Si) ₂ –MPNB Me ₃ Si–APNB 2,3 PTMSP PMP	104	CH3
AF 2400 AF 1600 AD 80 AD 60	120	-CF ₃ -CF ₂ CF ₂ -



Fig. 5. Wetting isotherms of PTMSP and PMP by aqueous solutions of (a) ethanol and (b) butanol-1.



Fig. 6. Wetting tension isotherms of PMP and PTMSP membranes by aqueous solutions of (a) ethanol and (b) butanol-1.

the sorption of the alcohol into the membrane after its certain concentration in solution is reached. At alcohol concentrations exceeding the threshold value, the flow of the liquid across the membrane substantially grows [12]. It would be expected that the wetting angles of alcohol solutions on the surface of the membranes are sensitive to the onset of the sorption swelling of the polymer because the packing density of macromolecules in the surface layer of the film will change in this case.

In the wetting of the surfaces of PTMSP and PMP by water, a hysteresis of the wetting angles is observed, $\Delta \theta = (\theta_a - \theta_r)$, with its values being 13 and 5°, respectively. In the wetting of membranes by aqueous solutions of alcohols, $\Delta \theta$ grows with increasing concentration of the alcohol in solution (Fig. 5). For solutions in ethanol, $\theta_r = 0$ at 40 and 50 wt % for PTMSP and PMP, respectively [23].

The increase in $\Delta \theta$ is commonly attributed to the rise in the degree of the energy heterogeneity of the solid surface, associated with the profile nonuniformity and the chemical heterogeneity [7, 45]. We chose for further calculation the values of θ_r because of their being more sensitive to changes in the ethanol concentration in solution, compared with θ_a . In addition, measurements of wetting angles in the outflow conditions more precisely simulate the nanofiltration process [46].

In wetting of low-energy surfaces, γ_{SV} = const when the alcohol concentration c in solution is varied. It is known that γ_{LV} and γ_{SL} decrease with increasing concentration of diphilic substances (alcohols in the given case) and reach a constant value corresponding to the formation of saturated adsorption layers at phase boundaries [47]. In this case, the limiting adsorption of alcohols on various interfaces is reached at close solution concentrations. It follows from the Gibbs and Young equations [7, 18, 37] that the dependences $\gamma_{LV} \cos\theta_r = f(c)$, i.e., the isotherms of wetting tension of polymers by alcohol solutions, must have the form of ascending curves with subsequent leveling-off. However, the isotherms $\gamma_{LV} \cos \theta_r = f(\ln c)$,



Fig. 7. Surface tension isotherms of aqueous solutions of alcohols.

obtained for the polymer–alcohol solution systems under study, are curves with a maximum (Fig. 6).

The concentrations of ethanol at the points of maxima in the $\gamma_{LV} \cos \theta_r = f(\ln c)$ isotherms (30 wt % for PMP and 20 wt % for PTMSP) are in good agreement with the concentrations corresponding to the onset of sorption swelling of polymer PTMSP and PMP films in ethanol solutions [12, 23]. This suggests that a possible reason for the untypical run of the wetting tension isotherms is that the solution contacting with the membrane is locally depleted of the alcohol.

The butanol-1 concentrations corresponding to the maxima of the wetting isotherms are 0.06 and 0.125 M for PMP and PTMSP, respectively. Thus, no one-to-one correlation could be revealed between the length of the hydrocarbon radical of the alcohol, free volume of the polymer, and alcohol solution concentration at which the alcohol starts to be sorbed into the membrane. The reason is that the sorption of alcohols into the membrane can be affected by various factors [12]. On the one hand, the ethanol molecule is smaller than that of butanol-1, which means that the diffusion coefficient of ethanol in the membrane is larger. On the other hand, butanol-1 more effectively reduces the surface tension of the solutions, which favors penetration of the fluid into pores (Fig. 7).

One more factor affecting the onset of sorption may be the interfacial tension γ_{SL} at the membrane–alcohol solution interface. With equation (1) and the values of γ_{SV} for PMP and PTMSP (Table 2) used for calculating γ_{SL} , a result is obtained that is devoid of physical meaning, specifically $\gamma_{SL} < 0$. Therefore, we performed an experiment aimed to determine the surface energy of polymer films upon their contact with water for 30 min. A calculation demonstrated that $\gamma_{SV} = (\gamma_{SV}^d + \gamma_{SV}^p)$ for membranes that contacted with water is 42 = (6+36) and



Fig. 8. Interfacial tension isotherms at the polymer–alcohol solution interface. (a) Ethanol and (b) butanol-1.

 $60 = (5 + 55) \text{ mJ m}^{-2}$ for PTMSP and PMP, respectively, which indicates that the polar component of the surface energy of the films increases as a result of incorporation of water into their surface layer. Just these values of γ_{SV} were used to calculate the interfacial tension γ_{SL} for the polymer–alcohol solution interface.

The dependences of the polymer–solution interfacial tension on the alcohol concentration, $\gamma_{SL} = f(c)$, show that the values of γ_{SL} that correspond to the onset of the sorption swelling of the polymer are determined by the nature of a polymer and are nearly independent of the length of the hydrocarbon radical in an alcohol: $\gamma_{SL} = 5-6$ mJ m⁻² for PTMSP and $\gamma_{SL} = 24-26$ mJ m⁻² for PMP (Fig. 8). Thus, the onset of the sorption swelling occurs for a polymer with larger FFV at smaller values of γ_{SL} . One more reason why the surface energy γ_{SV} of a film changes may be the adsorption of the alcohol on the surface of a polymer that is in contact with the solution. Keeping PMP and PTMSP films in ethanol solutions for 30 min, with the subsequent drying, leads to deformation



Fig. 9. Dependence of the surface energy of polymeric films modified with solutions of (1) butanol-1 and its (2) polar and (3) dispersion components on the concentration of an alcohol in solution. (a) PMP and (b) PTMSP.

of the films, which gave no way of measuring the wetting angles of liquids on these films. That is why patterns of the adsorption modification of the surface of PMP and PTMSP films were only obtained for butanol-1 solutions (Fig. 9).

In the case of PMP, a slight increase in γ_{SV} of the modified surface at butanol-1 concentrations $c \le 0.125$ M is observed; $\gamma_{SV} = \text{const}$ at 0.125 M $\le c \le 1$ M, with the key contribution coming from the polar component. The dispersion component of the surface energy of the modified PMP surface decreases to $\gamma_{SV}^p = 6$ J m⁻² with increasing butanol-1 concentration in the modifying solution (Fig. 9a).

A more complicated dependence $\gamma SV = f(c)$ is observed for modified PTMSP surfaces (Fig. 9b). At concentrations in the range $c \le 0.125$ M, a slight increase is observed in γ_{SV}^{p} with increasing butanol-1 concentration in solution. At $c \ge 0.125$ M, γ_{SV}^{p} decreases and becomes close to the dispersion component of the surface energy of PTMSP.

The data furnished by the wetting method for PMP and PTMSP are conceptually in agreement with the semiempirical model of transport of solutions or dispersions with a liquid dispersion medium across the membranes with substituted polyacetylenes, suggested in [48]. It follows from this model that the key factor providing a mass transfer of one of the solution or dispersion components across the membranes is its affinity for the polymer forming of the membrane. It is known that the measure of this affinity is the interfacial energy reflecting the extent to which intermolecular forces acting within a phase are uncompensated at the interface. Thus, a study of the energy characteristics of the surface of polymeric membranes brought in contact with substances of varied chemical nature are rather promising for development of scientific principles for prognostication of not only the transport, but also the separating properties of polymeric membranes.

CONCLUSIONS

New opportunities are demonstrated by the wetting method for prognostication and comparison of the transport properties of solid polymeric membranes for fluids and gases. It was shown that the dispersion component of the surface energy of the membranes under study, based on highly permeable glassy polymers, can serve as the parameter making it possible to prognosticate the gas transport across membranes.

It was found that the polymer–liquid interfacial energy is a parameter that determines the onset of the sorption swelling of a polymer in nanofiltration of aqueous solutions of diphilic substances. It was shown that the wetting method can be used to determine the threshold alcohol concentration at which a noticeable flow of the fluid across the membrane is provided, which enables optimization of nanofiltration experiments.

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