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РОЗЧИННІСТЬ ЕТИЛОВОГО ЕСТЕРУ 2-ЦІАНО-3-[5-(4-МЕТИЛФЕНІЛ)-2-ФУРАНАКРИЛОВІ КИСЛОТИ В ОРГАНІЧНИХ РОЗЧИННИКАХ

Визначено розчинність етилового естеру 2-ціано-3-[5-(4-метилфеніл)-2-фуран] акрилової кислоти в ацетонітрилі, бензолі, пропанолі-2 та етилацетаті в інтервалі температур 299,0-333,0 К. За температурною залежністю розчинності етилового естеру 2-ціано-3-[5-(4-метилфеніл)-2-фуран] акрилової кислоти розраховано ентальпію та ентропію розчинення в досліджених розчинниках. За даними диференційно-термічного аналізу визначено ентальпію і ентропію плавлення етилового естеру 2-ціано-3-[5-(4-метилфеніл)-2-фуран] акрилової кислоти та перераховано їх на 298К. Встановлено вплив полярності розчинників на розчинність та величини ентальпії і ентропії змішування при 298 К.

Ключові слова: ентальпія розчинення, ентропія розчинення, ентальпія змішування, ентропія плавлення; диференційний термічний аналіз, етиловий естер 2-ціано-3-[5-4-метилфеніл)-2-фуран] акрилової кислоти.

SOLUBILITY OF ETHYL ESTER OF 2-CYANO-3-[5-(4-METHYLPHENYL)-2-FURAN] ACRYLIC ACID IN ORGANIC SOLVENTS

The solubility of ethyl ester of 2-cyano-3-[5-(4-methylphenyl)-2-furan] acrylic acid in acetonitrile, benzene, 2-propanol and ethyl acetate at temperatures 299.0-333.0 C was determined. From the temperature dependence of the solubility of ethyl ester of 2-cyano-3-[5-(4-methylphenyl)-2-furan] acrylic acid enthalpy and entropy of dissolution in investigated solvents were calculated. According to differential thermal analysis the enthalpy and entropy of melting of ethyl ester of 2-cyano-3-[5-(4-methylphenyl)-2-furan] acrylic acid were identified and adjusted to 298K. The influence of solvents polarity on the solubility and magnitude of enthalpy and entropy of mixing at 298K was established.

Key words: enthalpy of dissolution, entropy of dissolution, enthalpy mixing, entropy melting, differential thermal analysis, ethyl ester of 2-cyano-3-[5-4-methylphenyl)-2-furan] acrylic acid.

Problem statement and publications analysis. Ethyl ester of 2-cyano-3-[5-(4-methylphenyl)-2-furan] acrylic acid (ECMF) is a yellow crystalline substance, with molecular formula $C_{17}H_{15}O_3N$, molecular mass – 281,311 g/mol. The chemical structure of a substance is shown on Fig. 1. ECMF is heterocyclic furan derivative which like other furan derivatives exhibits biological activity [1]. Such substances are used as starting materials in the synthesis of biologically active compounds or as components of drugs. Most reactions used in chemical and pharmaceutical industries take place in

solutions, so these temperature dependences of the solubility of the investigated substance in organic solvents are needed to optimize the synthesis, purification and processing of the substance.

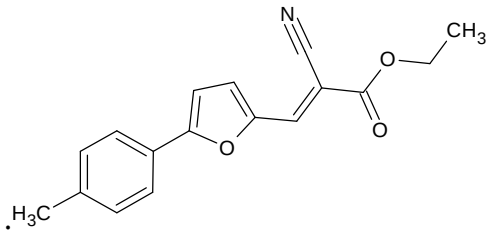

Fig. 1. Structural formula of ethyl ester of 2-cyano-3 [5-(4-methylphenyl)]- furan-2] acrylic acid

The purpose of the work. To determine the thermodynamic parameters of solubility and melting of ethyl ester of 2-cyano3-[5-(4-methylphenyl)-2-furan] acrylic acid in organic solvents.

Experimental results and discussion. ECMF was synthesized by a known method [2]. The substances obtained after the 3,4 multiplicities of recrystallization from a mixture of ethanol-dimethylformamide solvents were used for the research. The structure of the substance was confirmed by the results of NMR spectroscopy. ^{1}H NMR spectra were recorded on a Varian 600 instrument (600 MHz) solvent DMSO – d6. Chemical shifts (δ ppm) are relative signals DMSO (2,5 ppm): ^{1}H NMR (600 MHz, DMSO) δ 1.30 (t, *J* = 7.1 Hz, 3H, $\underline{CH_3}CH_2$), 2.35 (s, 3H, CH_3), 4.29 (q, *J* = 7.1 Hz, 2H, $CH_3\underline{CH_2}$), 7.34 (m, 3H), 7.59 (d, *J* = 3.7 Hz, 1H, fur), 7.82 (d, *J* = 8.0 Hz, 2H, C_6H_4), 8.10 (d, *J* = 9.0 Hz, 1H, CH).

Purity of the substance was indirectly confirmed by the permanence of the melting temperature and melting enthalpy value of the samples taken after different degrees of recrystallization.

For solubility research of ECMF commonly used organic solvents with boiling point near 358 K, high volatility and with different polarities were selected. Solvents used in the research were purified by fractional distillation (acetonitrile, 2-propanol, ethylacetate); and recrystallization benzene).

Purity of the solvents was identified by the index of refraction (n_D^{20}) and boiling point (T_{boil}). By the method of gas-liquid chromatography established that the content of the main component is at least 99.8 % by weight. Table 1 shows published data of physicochemical properties of the selected solvents and values that we received.

Table 1

Physicochemical properties of the used solvents

Solvents	*M* g/mol	ε	μ, D	n_D^{20}		T_{boil}, K		Main com. cont.,%mass
				lit.	exp.	lit.	exp.	
Acetonitrile	41.053	38.8 [3]	3.92 [3]	1.3442 [3]	1.3440	81.6 [3]	81.4	99.9
Benzol	78.110	2.3 [3]	0 [3]	1.5011 [3]	1.5012	80.1 [3]	79.9	99.8
Propanol-2	60.096	19.9 [3]	1.66 [3]	1.3776 [3]	1.3773	82.4 [3]	81.9	99.8
Ethylacetate	88.106	6.1 [3]	1.78 [3]	1.3723 [3]	1.3722	77.1 [3]	76.8	99.9

ε – permittivity; μ – dipole moment.

Enthalpy ($\Delta_{sol}H$) and entropy ($\Delta_{sol}S$) of dissolution were determined by the temperature dependence of the solubility ECMF in investigated solvents.

Dissolution of the substance was carried out in a sealed vessel equipped with a thermometer, stirrer and an opening for sampling. Containers which carried the dissolution were immersed in thermostat, temperature control accuracy ±0,1 K. Speed of stirring was 30 rev/min; dissolution time was 90 minutes with constant stirring.Due to the fact that in the process of dissolution ECMF formed suspension sampling performed after complete her deposition. To confirm the balance experiments were conducted in both modes of temperature rise and decrease; no hysteresis loop for the temperature dependence of the solubility curves (Fig. 2) confirms achievement of a state close to equilibrium. Samples of solutions weighing

0.5–0.7 g which were selected and placed in pre-prepared and weighed cups, after which they were quickly closed and weighed, were used to determine the mass of saturated solution. Then, the cups were opened and placed in the dryer, where the solvent was evaporated at 323–333 K until the mass of the cup reemained constant. The mass was determined by weighing the dry residue sample bottle with the matter after drying. Weighing at all stages was carried out on scales VLR-200 with an accuracy of ± 0,0002 g.

Primary data of ECMF temperature dependence of the solubility in organic solvents, expressed in mole fractions (x_2) is shown in Table 2. The same table shows the weight of the solvent (m_1) and solute (m_2) and the equation $\ln x_2 = \Delta_{sol}S/R - \Delta_{sol}H/(R \cdot T)$ is the temperature dependence of solubility. Hereinafter all error values are given using Student's criterion of the significance level of 0.95.

Table 2

The temperature dependence of the solubility of ethyl ester of 2-cyano-3-[5-(4-methylphenyl)]-furan-2] acrylic acid in organic solvents

T, K	m_1, g	m_2, g	$x_2 \cdot 10^2$	T, K	m_1, g	m_2, g	$x_2 \cdot 10^2$	T, K	m_1, g	m_2, g	$x_2 \cdot 10^2$
1	2	3	4	5	6	7	8	9	0	11	12
Acetonitrile											
299.0	0.4589	0.0232	0.73	308.5	0.4816	0.0342	1.03	316.7	0.4451	0.0468	1.51
299.0	0.4381	0.0223	0.74	308.5	0.5448	0.0387	1.03	316.7	0.5409	0.0568	1.51
299.0	0.5618	0.0280	0.72	311.0	0.4477	0.0353	1.14	316.7	0.4471	0.0465	1.50
301.3	0.4247	0.0233	0.80	311.0	0.4618	0.0361	1.13	317.7	0.3521	0.0393	1.60
301.3	0.4594	0.0253	0.80	311.0	0.5410	0.0426	1.14	317.7	0.4120	0.046	1.60
301.3	0.5686	0.0315	0.80	313.5	0.4470	0.0400	1.29	317.7	0.4651	0.0521	1.61
303.6	0.5238	0.0306	0.85	313.5	0.4578	0.0410	1.29	318.4	0.3158	0.0368	1.67
303.6	0.5394	0.0313	0.84	314.5	0.4272	0.0426	1.43	318.4	0.4192	0.0485	1.66
303.6	0.7822	0.0482	0.89	314.5	0.4350	0.0425	1.41	318.4	0.4199	0.0486	1.66
306.0	0.4252	0.0271	0.92	314.5	0.5217	0.0511	1.41	321.0	0.4112	0.0559	1.95
306.0	0.4380	0.028	0.92	315.4	0.3907	0.0392	1.44	321.0	0.4278	0.0579	1.94
306.0	0.5143	0.0326	0.93	315.4	0.5676	0.0561	1.42	321.0	0.4569	0.0620	1.94
308.5	0.4500	0.0318	1.02	315.4	0.5887	0.0586	1.43				
$\ln x_2=(9.14\pm0.55)-(4220\pm170)\cdot 1/T$											
Benzol											
304.2	0.5035	0.0467	2.51	311.0	0.5142	0.0793	4.11	317.4	0.5372	0.1248	6.06
304.2	0.5378	0.0500	2.52	311.0	0.5278	0.0819	4.13	319.7	0.3233	0.0930	7.40
304.2	0.5835	0.0539	2.50	312.9	0.4546	0.0781	4.56	319.7	0.5346	0.1490	7.18
306.0	0.5020	0.0518	2.79	312.9	0.4551	0.0835	4.85	319.7	0.5600	0.1572	7.23
306.0	0.5104	0.0523	2.77	312.9	0.5787	0.1004	4.60	321.6	0.4341	0.1264	7.48
306.0	0.5926	0.0610	2.78	315.2	0.4549	0.0878	5.09	321.6	0.4510	0.1311	7.49
308.1	0.4486	0.0529	3.17	315.2	0.4869	0.0940	5.09	321.6	0.4871	0.1416	7.47
308.1	0.4754	0.0547	3.10	315.2	0.5603	0.1092	5.13	323.7	0.3786	0.1240	8.34
308.1	0.5092	0.0587	3.10	315.5	0.3901	0.0781	5.27	323.7	0.4330	0.1423	8.36
309.0	0.4809	0.0666	3.71	315.5	0.4494	0.0870	5.10	323.7	0.5105	0.1687	8.41
309.0	0.4856	0.0670	3.69	315.5	0.5514	0.1094	5.22	326.0	0.3881	0.1413	9.18
309.0	0.5789	0.0803	3.71	317.4	0.4104	0.0927	5.90	326.0	0.4482	0.1621	9.13
311.0	0.4913	0.0758	4.11	317.4	0.4262	0.0991	6.06	326.0	0.4784	0.1757	9.26
$\ln x_2=(16.24\pm0.64)-(6054\pm201)\cdot 1/T$											
Propanol-2											
316.0	0.4719	0.0071	0.32	319.5	0.4401	0.0084	0.41	324.5	0.4361	0.0105	0.51
316.0	0.4782	0.0078	0.35	319.5	0.4452	0.0085	0.41	324.5	0.4672	0.0114	0.20
316.0	0.5383	0.0083	0.33	319.5	0.5400	0.0107	0.42	328.1	0.5344	0.0104	0.56
316.4	0.4125	0.0067	0.35	320.4	0.4229	0.0080	0.40	328.1	0.5386	0.0144	0.57
316.4	0.4956	0.0082	0.35	320.4	0.5015	0.0095	0.40	328.1	0.6023	0.0159	0.56
316.4	0.5095	0.0085	0.36	320.4	0.5770	0.0110	0.41	330.0	0.4318	0.0128	0.63
317.5	0.4639	0.0077	0.36	321.5	0.4381	0.0087	0.42	330.0	0.5326	0.0159	0.63
317.5	0.4621	0.0077	0.35	321.5	0.4439	0.0090	0.43	330.0	0.5502	0.0162	0.63
317.5	0.5608	0.0093	0.35	321.5	0.5598	0.0113	0.43	333.0	0.4355	0.0156	0.76
318.5	0.4712	0.0083	0.37	322.5	0.4437	0.0094	0.45	333.0	0.4651	0.0164	0.75
318.5	0.5581	0.0093	0.35	322.5	0.5627	0.0117	0.44	333.0	0.5515	0.0212	0.82
$\ln x_2=(9.85\pm0.77)-(4914\pm248)\cdot 1/T$											

Continuation of table 2

1	2	3	4	5	6	7	8	9	10	11	12
T. K	m_1. g	m_2. g	$x_2 \cdot 10^2$	T. K	m_1. g	m_2. g	$x_2 \cdot 10^2$	T. K	m_1. g	m_2. g	$x_2 \cdot 10^2$
Ethylacetate											
303.5	0.5227	0.0341	2.00	310.5	0.6222	0.0519	2.55	314.4	0.5207	0.0507	2.96
303.5	0.5311	0.0347	2.01	311.3	0.5002	0.0437	2.66	314.4	0.6009	0.0594	3.00
306.5	0.2385	0.017	2.18	311.3	0.5133	0.0448	2.66	316.4	0.4622	0.0500	3.28
306.5	0.5515	0.0389	2.16	311.3	0.6221	0.0543	2.66	316.4	0.5090	0.0540	3.22
306.5	0.5553	0.0398	2.19	312.5	0.4977	0.0445	2.73	316.4	0.6073	0.0648	3.24
308.5	0.3653	0.0282	2.36	312.5	0.4995	0.0452	2.76	317.5	0.5023	0.0561	3.38
308.5	0.4907	0.0387	2.41	312.5	0.6298	0.0566	2.74	317.5	0.5077	0.0569	3.39
308.5	0.5689	0.0442	2.37	314.4	0.4764	0.0469	2.99	317.5	0.5857	0.0653	3.38
310.5	0.5040	0.0427	2.59	314.4	0.4870	0.0477	2.98	320.0	0.4741	0.0592	3.77
310.5	0.5116	0.0423	2.53	314.4	0.4987	0.0485	2.96	320.0	0.6098	0.0761	3.76
$\ln x_2 = (8.48 \pm 0.35) - (3768 \pm 109) \cdot 1/T$											

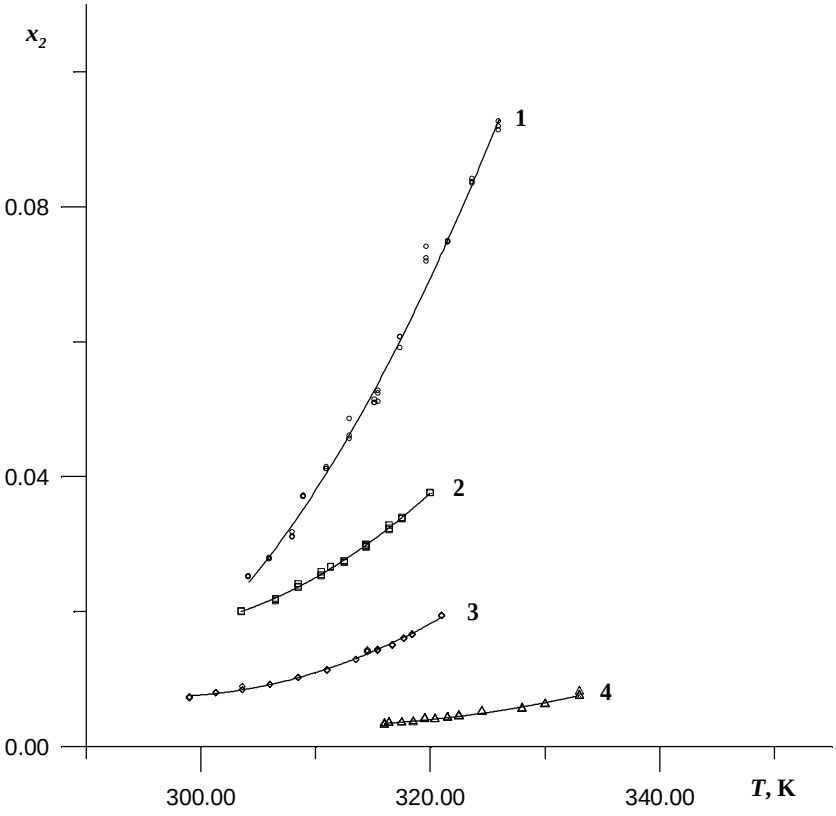

Fig. 2. The temperature dependence of the solubility of ethyl ester of 2-cyano-3-[5-(4-methylphenyl)]-furan-2] acrylic acid in organic solvents: 1 – benzene; 2 – acetonitrile; 3 – ethyl acetate; 4 – propanol-2

According to these values in table 2 and figure 2 for solubility of ECMF, solvents can be placed in the next order benzene> ethylacetate> acetonitrile> 2-propanol. This arrangement solvents is consistent with their polarity, from the least polar benzen to the most polar acetonitrile table 1. Due to the ECMF solubility in propanol-2, which is the smallest, then the substance despite the polar properties similar to table 1 of ethylacetate by hydroxyl group capable of forming hydrogen bonds which are homoconjugate, unlike other solvent selected in the row.

It is known [4] that the values of $\Delta_{sol}H$ and $\Delta_{sol}S$ are including the enthalpy $\Delta_{mix}H^o$ and entropy $\Delta_{mix}S^o$ of mixing of the components and phase transition of the crystalline substance in liquid phase solution. $\Delta_{sol}H^o = \Delta_{mix}H^o + D_{fus}H^o$ и $\Delta_{sol}S^o = \Delta_{mix}S^o + D_{fus}S^o$. Therefore for definition of $\Delta_{mix}H^o$ and $\Delta_{mix}S^o$ there is a need to define enthalpy ($\Delta_{fus}H$) and entropy ($\Delta_{fus}S$) of melting of the substance.

$\Delta_{fus}H$ for ECMF was determined by differential thermal analysis (DTA). Samples were analyzed by Q-1500 D with Paulik – Paulik – Erdey system in dynamic mode at a speed of heating 3 K / min, in the air atmosphere.

To calculate $\Delta_{fus}H$ the thermochemical equation (1) was used, taking into account an amendment to the loss of mass of the sample in the process of fusion:

$$K \cdot S = q_{fus} + q_{vap} = m_o \cdot \Delta_{fus}H + \Delta m_{vap} \cdot \Delta_{vap}H \quad (1)$$

where: q_{fus} and q_{vap} – amount of heat (J), which is absorbed by the melting and evaporation of the sample, respectively; m_o – weight of sample (g), which corresponds to the melting temperature of the beginning of his T_{fus}; Dm_{vap} – sample mass loss (mass couples, g) for the period taken into account to determine the peak area S (K·s) under the curve DTA; K – heat transfer coefficient (J / K·s) for our installations, defined in [5], $K = 3.668 \cdot 10^{-2} - 1.128 \cdot 10^{-4}T + 2.723 \cdot 10^{-7}T^2$, $S^2 = 5.96 \cdot 10^{-7}$; $D_{fus}H$ and $D_{vap}H$ – specific enthalpy of melting and evaporation of the substance (J/g). Table 3 shows the experimental values of $\Delta_{fus}H$ of ECMF at its melting point T_{fus}= 387.7±1.5 K.

Table 3

Enthalpy of fusion samples of ethyl ester of 2-cyano-3-[5-(4-methylphenyl)]-furan-2] acrylic acid

Sample	m_0, g	Δm_{vap}, g	S, K·c	Q_{vap}, J	$\Delta_{fus}H$, kJ/mol
1	0.2013	0.0002	584.0	0.0645	27.55
2	0.2002	-	549.5	-	26.16
Average: at 26.86 ± 2.1					

$\Delta_{fus}S$ at T_{fus} were calculated by the equation: $\Delta_{fus}S=\Delta_{fus}H / T_{fus.}$

According to the studies. melting enthalpy of ECMF defined melting temperature. enthalpy and entropy and dissolution in temperature ranges close to 298K. Therefore. in order to generalize the results obtained in terms of a need $\Delta_{fus}H$ and $\Delta_{fus}S$ are adjusted from T_{fus} to 298 K. For converting $\Delta_{fus}H$ and $\Delta_{fus}S$ used the modified Kirchhoff equation proposed in [6]. according to which ECMF $D_{fus}H_{298}$ = = 22.3±2.4 кJ/mol a $\Delta_{fus}S_{298}$ = 55.8±3.0 J/mol·K.

Table 4.shows thermodynamic parameters of solubility ECMF in organic solvents at 298 K. The value of Gibbs energy change when mixing components ($\Delta_{mix}G^0$) for the 298 K is expressed by the equation: $\Delta_{mix}G^{0=}\Delta_{mix}H^0$-298·$\Delta_{mix}S^0$

Table 4

Thermodynamic solubility parameters of ethyl ester of2-cyano-3-[5-(4-methylphenyl)] -furan-2] acrylic acidin organic solvents at a temperature of 298 K

Solvent	$x_2 \cdot 10^2$	$\Delta_{sol}H^0$	$\Delta_{mix}H^0$	$\Delta_{sol}S^0$	$\Delta_{mix}S^0$	$\Delta_{mix}G^0$
		кJ/mol		J/mol•K		kJ/mol•K
Acetonitrile	0.67±0.03	35.1±1.4	12.8±3.1	76.0±4.6	20.2±5.4	6.8±3.1
Benzol	1.63±0.04	50.3±1.7	28.0±3.3	135.0±5.3	79.2±6.1	4.4±3.3
Propanol-2	0.13±0.05	40.8±2.1	18.5±3.2	81.9±6.4	26.1±6.8	10.7±3.2
Ethylacetate	1.55±0.02	31.33±0.91	9.0±2.6	70.5±2.9	14.7±4.2	4.6±2.6

Positive value of $\Delta_{mix}H^o$ and $\Delta_{mix}S^o$ for all investigated systems indicate that the destruction of intermolecular bonds in individual substances require more energy than is allocated by the formation of new intermolecular bonds between solvent and solute.

It is worth to pay attention to the straight-line dependence between values of $\Delta_{mix}H^o$ and $\Delta_{mix}S^o$ at 298K for ECMF in benzene. acetonitrile and ethylacetate (Fig. 3).

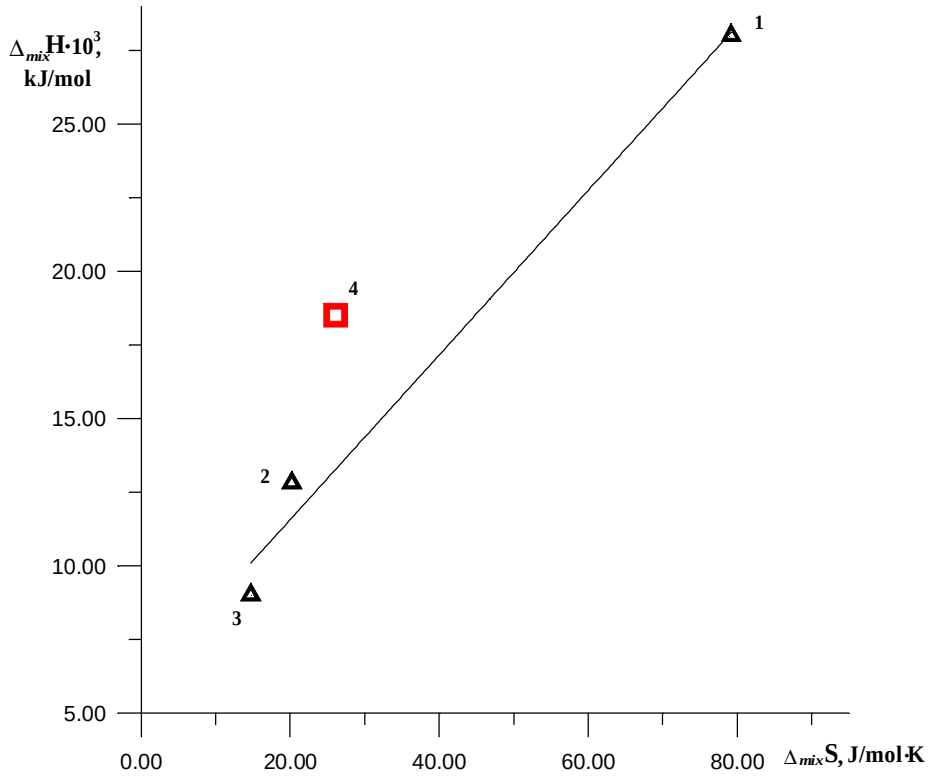

Fig. 3. The dependence between the enthalpy and entropy of dissolution of ethyl ester of 2-cyano-3-[5-(4-methylphenyl)]-furan-2] acrylic acid in organic solvents: 1 – benzene; 2 – acetonitrile; 3 – ethyl acetate; 4 – propanol-2
$\Delta_{mix}H = 0.279 \cdot \Delta_{mix}S + 5.97$; R = 0.987

The point that reflects the dependence of $\Delta_{mix}H^o$ and $\Delta_{mix}S^o$ for propanol-2 is a bit outside from linear dependence. The reason for this deviation can be the strong presence of ~ 20 kJ/mol [4] hydrogen bond formed by the hydroxyl groups in propanol-2. Other solvents used by us do not form a homoconjugate hydrogen bond. or its value is less than 5 kJ/mol (for benzene) [4].

Conclusion: As a result of investigations for ethyl ester of ethyl ester of 2-cyano-3-[5-(4-methylphenyl)]-furan-2] acrylic acid thermodynamic properties of solubility in organic solvents of different polarity were defined and the nature of exposure to the polarity of the investigated solutions was determined.

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