УДК 54-43:544.723: 546.171.1 doi: 10.33609/2708-129X.88.12.2022.175-188

IMPREGNATED FIBROUS CHEMISORBENTS FOR THE COLORIMETRIC DETECTION OF AMMONIA

T. S. Bienkovska[1,2], R. E. Khoma[1,2*], O. S. Vatral[2], R. M. Dlubovskii[1], S. V. Vodzinskii[1,2], V. V. Menchuk[2]

[1]Physico-Chemical Institute of Environment and Human Protection, 3 Preobrazhenskaya str., 65082 Odessa, Ukraine
[2]Odessa I.I. Mechnikov National University, 2 Dvoryankaya str., 65082 Odessa, Ukraine
[*]e-mail: rek@onu.edu.ua

The paper presents research results on the colorimetric behavior of impregnated fibrous chemisorbents (IFCS) of basic gases with visual identification of the dynamic absorption capacity "response" moment (IFCS-I) during the absorption of ammonia. Chemisorbents were obtained by impregnation of fibrous carriers with polybasic hydroxyl acid aqueous solutions with adding acid-base indicators (Ind). IFCS-I based on oxyethylenediphosphonic (IFCS-OEDPA-I), citric (IFCS-CA-I), and malic (IFCS-MA-I) acids were used. Azolithine (Az), lakmoid (LA), methyl orange (MO), methyl red (MR), Tropeolin OOO (TrOOO), Congo red (CoR), bromocresol green (BCG), broxylenol blue (BXB), bromophenol blue (BPB), bromophenol red (BPR), thymol blue (TB), xylenol orange (XO), and phenol red (PR) were used as acid-base indicators. The specificity of the changes in the colorimetric functions of IFCS-I during the absorption of NH_3 by them was revealed. It was found that the color of the initial IFCS-I samples significantly depended not only on the structure of Ind, but also on the nature of the polybasic hydroxy acid being part of them. The colors of the samples based only on OEDPA (Ind = CoR, BCG, BPB), CA (Ind = CoR, TrOOO, BCG, BPB, BPR, XO) and some MA (TrOOO, BCG) are similar to the colors of aqueous solutions of Brönsted acids. The difference in the colors of the other samples from the colors of strong acid aqueous solutions with the same Ind is apparently due to specific interactions between hydroxy acid anions and neutral dye forms. During "response" to NH_3 only some IFCS-I samples based on OEDPA (Ind: MO, TrOOO, Az and BPR), CA (Ind: CoR, MR, MO, TrOOO, BXB, BPR, TB, PR) and MA (Ind: LA, MR, MO, Az, BXB, XO, TB, PR) are discolored in contrast to the behavior of SO_2 indicator chemisorbents.

Key words: colorimetry, fibrous chemisorbents, ammonia, acid-base indicators.

INTRODUCTION. The service life of any gas filter cartridge (GFC) that cleans polluted air is limited and strongly depends on the operating conditions. Until recently [1], the reaction of the olfactory organ to the appearance of the smell of gas in the space within the mask was widely used for the timely replacement of filters. The above reaction depends on various factors: the composition of the gas mixture, concentration, individual susceptibility of the user, state of health, working conditions, and how quickly the concentration of gases increases, whether the respirator user is familiar with their smell [2, 3]. Different people have a different threshold for perceiving the smell of the same compound. If the gas concentration increases gradually (as the sorbent in the filter is saturated), the sensitivity of the olfactory organ may decrease. Getting used to the smell during long work, colds, concentrating on work – all this makes replacing the filter "by smell" unreliable [4]. In the US, the employer is required to replace the filters on schedule (by calculating [4] or measuring the service life for known working conditions).

A number of authors [1–7] suggest equipping the GFC with an ***End of Service Life Indicator (ESLI***), which would warn the respirator user about the need to replace the GFC; ***ESLIs*** are passive and active.

For the production of GFC, with which light respirators are equipped, the PCIEHP (Odesa) developed impregnated fibrous chemisorbents of basic gases with visual indication of the moment of dynamic absorption capacity "response" (**IFCS-I**) [8, 9], obtained by impregnating fibrous carriers with aqueous solutions of polybasic hydroxy acids, to which acid-base indicators (**Ind**) were added. The dynamic absorption capacity "response" of such chemisorbents during the absorption of the basic gas (ammonia) can be visually determined by the change in the color of the GFC on the side facing the face during the breakthrough of the sorbate.

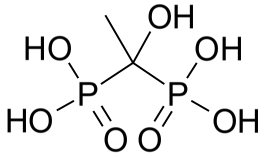
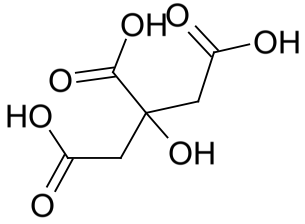
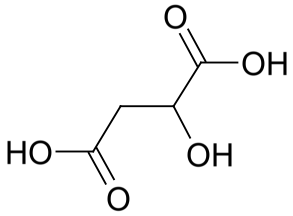
However, the use of the above-mentioned passive ESLIs has a number of disadvantages described in [6]. To date, there is no theoretical basis for the development of indicator chemisorbents for basic gases, in particular ammonia. Previously, we [6, 10, 11] used digital colorimetry in aqueous solutions and on IFCS-I surfaces to quantitatively characterize the behavior of indicator chemisorbents for acid gases. Therefore, the purpose of this work is to establish the features of the colorimetric behavior of IFCS-I during "response" by NH_3, which will become a theoretical basis for the development of active ESLIs. In view of this, the paper presents data on the colorimetric evaluation of IFCS-Is developed by us earlier based on oxyethylenediphosphonic acid (IFCS-OEDPA-I) [8] and citric acid (IFCS-CA-I) [9], as well as of a new IFCS-MA-I based on malic acid (MA).

EXPERIMENT AND DISCUSSION OF THE RESULTS. We used for research chemically pure OEDPA, CA та MA (the characteristics of which are given in table 1) without pre-purification, as well as the following Inds, the characteristics of which are given in table 2. As a fibrous carrier (FC) we used non-woven needle-punched filter cloth based on mylar fiber with a thickness of 4.0 mm and a surface density of 470 g/m^2.

IFCS-I. 30 ml of an aqueous solution containing 0.03 mol/l hydroxy acid was placed in a volumetric flask (100 ml) (OEDPA, CA or MA), 0.04 g of Ind was dissolved according to recommendations [12] and brought to the mark with distilled water. The FC was impregnated with obtained solutions at the rate of 8 ml of solution per FC with a diameter of 58 mm until complete absorption. The samples were dried in air at a temperature of 20–25 ^{0}C.

Table 1.

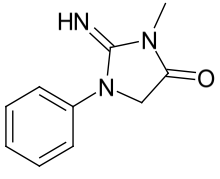
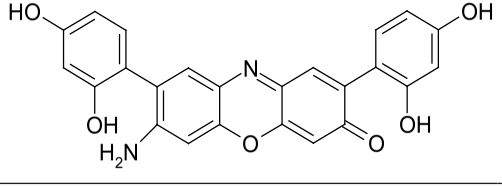
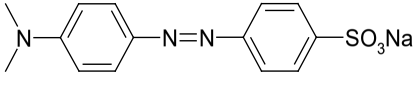
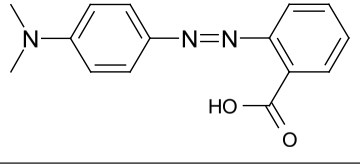
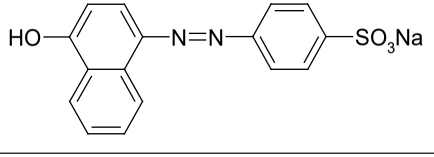
Physicochemical and toxicological characteristics of polybasic acids.

Acid		M, g/mol	pK_a	$T_{melt.}$, °C	T_{boil}, °C	$P_{s.v.}$, Pa (20°C)	lgP_{ow}	LD_{50} *, mmol/kg	LC_{50} **, mmol/ (m^3·h)	References
Oxyethylne-diphsphonic acid (OEDPA)		206.03	1.35 2.87 7.03 11.30	198	579	NA***	-3.80	11.65	NA***	[14-16]
Citric acid (CA)		192.12	3.13 4.76 6.39	156	310	$2.3 \cdot 10^{-6}$	-1.64	15.62	0.94	[14]
Malic acid (MA)		134.09	3.51 5.03	130	>225	$4.4 \cdot 10^{-6}$	-1.26	26.10	2.43	[14]

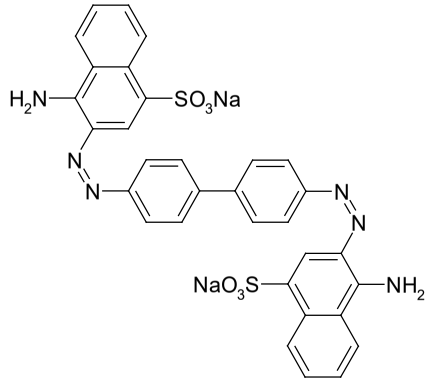
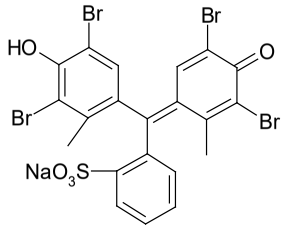
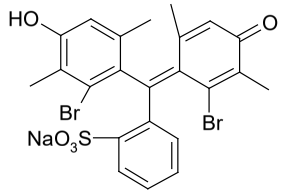
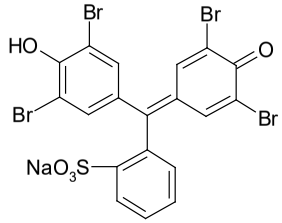
*rats, orally; ** rats, by inhalation; ***NA – not available.

Table 2.

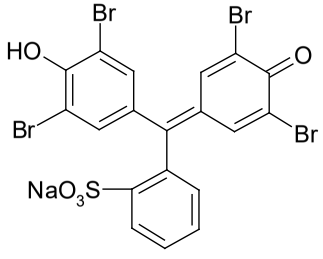
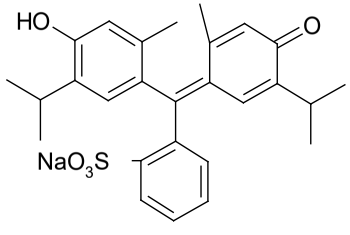
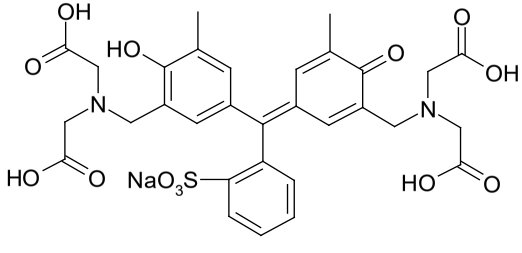
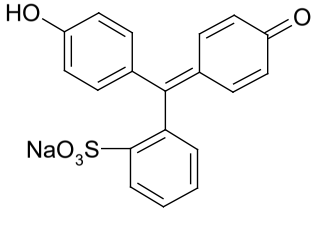
Characteristics of acid-base indicators

Name	Abbreviation	Structural formula	pK_a	Color transition pH range[17]	Color change in aqueous solutions [17]
1	*2*	*3*	*4*	*5*	*6*
Azolitmine	AZ		6.40 [18]	4.5-8.3	
		Azine dye			
Lacmoid	LA		5.31 [17]	4.4-6.4	
		Azo dyes			
Methyl Orange	MO		3.46 3.76 [17]	3.1-4.4	Red-orange-yellow
Methyl Red	MR		2.30 4.95 [17]	4.4-6.2	Red-yellow
Tropaeolin OOO	TrOOO		-0.70 (4'-SO_3H) 2.00 (-N=N-) 8.50 (2-OH) [19]	7.4-8.6 10.2-11.8	amber – orange orange – red

Continuation of table 2.

1	*2*	*3*	*4*	*5*	*6*
Congo Red	CoR		3.00 4.10 [20]	3.0-5.2	blue-red-violet
		Triphenylmethane dyes			
Bromocresol green	BCG		0.3 (=OH^+) 4.6 (4-OH) [21]	3.8-5.4	yellow – blue -green
Bromoxylenol blue	BXB		-1.5 (=OH^+) [19] 6.80 (4-OH) [22]	6.0-7.6	yellow – blue
Bromophenol blue	BPB		0.30 (=OH^+) 4.00 (4-OH) [21]	3.0-4.6	yellow – blue-violet

Continuation of table 2.

1	*2*	*3*	*4*	*5*	*6*
Bromophenol red	BPR		0.50 (=OH⁺) 6.50 (4-OH) [21]	5.2-6.8	yellow – red
Thymol blue	TB		1.65 (=OH⁺) 8.90 (4-OH) [17]	8.0-9.6	yellow – blue
Xylenol orange	XO		-1.10 (=OH⁺) 6.40 (4-OH) [21]	6.4-10.4	yellow – orange-red
Phenol red	PR		1.20 (=OH⁺) 8.40 (4-OH) [21]	6.8-8.4	yellow – red

The research was conducted under dynamic conditions using a special gas-dynamic installation described in [13]. The concentration of NH_3 in the gas-air mixture (GAM) was determined using a Kolion 1B gas analyzer (with calibration for ammonia). The IFCS-I tests were carried out under the conditions of real use of respirators: concentration of NH_3 in the GAM – 300 mg/m^3 (15 MPC); relative humidity of the GAM – 90÷95%; GAM flow rate 2.0 cm/s. The breakthrough corresponded to the moment of appearance of NH_3 in the purified GAM behind the material layer at the level of 1–3 mg/m^3 (MPC = 20 mg/m^3).

The color characteristics of IFCS-I samples (initial samples and those that "response" to NH_3) were evaluated by the method of chemical colorimetry, similarly to [6]. The following colorimetric functions were used: *R, G, B* characteristics; *X, Y, Z* (color coordinates in the system CIEXYZ); *L*, *A*, *B* (color coordinates in the equal-contrast system CIELAB), color saturation (*S*), color tone (*T*), full color difference (ΔE_{76}), yellowness (*G*); the relative whiteness of samples (*W*) and the intensity of the yellow shade (Ky). As analytical signals of the "response" of IFCS-I samples, effective absorption in red (A_R), green (A_G) and blue (A_B) colors, as well as the values of total absorption (A_T), color ratio (C_R) and vector the length in *RGB* color space (A_v), calculated according to [6, 23], were used.

The color and colorimetric *RGB* characteristics for initial IFCS-I samples and those that "responded" to NH_3 are given in tables 3 and 4.

According to the obtained data (Tables 3, 4), the color of the original IFCS-I samples depends significantly not only on the structure of Ind, but also on the nature of the polybasic hydroxy acid being part of them. The presence of hydroxy acids (OEDPA, CA or MA) in the original IFCS-I samples causes an acidic environment on their surface:

$$H_4C_2H_4P_2O_6 + H_2O \rightleftarrows H_3C_2H_4P_2O_6^- + H_3O^+; \quad (1)$$

$$HOC_3H_4(COOH)_3 + H_2O \rightleftarrows HOC_3H_4(COOH)_2COO^- + H_3O^+; \quad (2)$$

$$HOOCCH_2CH(OH)COOH + H_2O \rightleftarrows HOOCCH_2CH(OH)COO^- + H_3O^+, \quad (3)$$

which determines their color. However, the color of the samples based only on OEDPA (Ind = CoR, BCG, BPB), CA (Ind = CoR, TrOOO, BCG, BPB, BPR, XO) and some MAs (TrOOO, BCG) is similar to the color of aqueous solutions of Brønsted acids (tables 3, 4). The difference in the color of the rest of the samples from the color of aqueous solutions of strong acids with the same Ind is obviously caused by specific interactions between hydroxy acid anions and neutral forms of dyes.

IFCS-OEDPA-I. Obviously, the chemisorption of ammonia by IFCS-OEDPA-I samples occurs only in the presence of "free" water, as in [24]. At the same time, as a result of acid-base interaction, mono- and disubstituted ammonium salts of OEDPA are formed:

$$NH_3 + nH_2O \rightleftarrows NH_3\cdot H_2O + (n\text{-}1)H_2O, \quad (4)$$

$$NH_3\cdot H_2O + H_4C_2H_4P_2O_6 \rightarrow (NH_4)H_3C_2H_4P_2O_6 + H_2O, \quad (5)$$

$$NH_3\cdot H_2O + (NH_4)H_3C_2H_4P_2O_6 \rightarrow (NH_4)_2H_2C_2H_4P_2O_6 + H_2O. \quad (6)$$

The color of most of the "responded" IFCS-OEDPA-I samples (Ind = Az, MR, TROOO, BCG, BXB, TB, XO and PR), as i IFCS-CA-I (Ind = Az, MR, BXB, TB, XO and PR), is different from the same properties of aqueous alkali solutions (tables 3, 4).

The change in the color of IFCS-OEDPA-I samples with triphenylmethane dyes during "response" to ammonia is caused by Brønsted interactions of various forms of the above Inds with the anions and ammonium cations formed during this process. This is indicated by correlations between the colorimetric functions Ky_0, Z_r and ΔL ($\Delta L = L_r - L_0$) with acid-base characteristics of Ind:

$$K_{y0} = 171{,}67 - 23{,}378 \cdot pH_1; \quad R^2 = 0{,}9828 \text{ (except BPB and XO)}, \quad (7)$$

$$Z_r = -103{,}89 + 15{,}536 \cdot pH_2; \quad R^2 = 0{,}9360 \text{ (except BKG and XO)}, \quad (8)$$

$$\Delta L = 33{,}839 - 4{,}4516 \cdot pK_a; \quad R^2 = 0{,}9025 \text{ (except BPR and XO)}. \quad (9)$$

For initial IFCS-OEDPA-I samples with azo dyes, the colorimetric characteristics R_0, G_0 and L_0 simbatically change with the pH values of the lower boundary (pH_1) of the Ind color transition:

$$R_0 = 298{,}48 - 20{,}165 \cdot pH_1; \quad R^2 = 0{,}9615 \text{ (except CoR)}, \quad (10)$$

$$G_0 = 157{,}71 - 8{,}252 \cdot pH_1; \quad R^2 = 0{,}8892 \text{ (except CoR)}, \quad (11)$$

$$L_0 = 80{,}259 - 4{,}5119 \cdot pH_1; \quad R^2 = 0{,}9987 \text{ (except CoR)}. \quad (12)$$

Table 3.

Color of IFCS-I samples.

Ind \ Acid	Initial sample			"Responded" sample		
	OEDPA	CA	MA	OEDPA	CA	MA
Az						
LA						
MO						
MR						
TrOOO						
CoR						
BCG						
BXB						
BPB						
BPR						
TB						
XO						
PR						

Table 4.

Colorimetric functions *R*, *G*, *B* of inital IFCS-I samples and those that "responded" to NH_3.

	Initial sample									Sample that "responded" to NH_3								
Am	OEDPA	CA	OEDPA	CA	OEDPA	CA	OEDPA	CA	OEDPA	CA	OEDPA	CA	OEDPA	CA	OEDPA	CA	OEDPA	CA
Ind	R_0			G_0			B_0			R_r			G_r			B_r		
Az	195	213	88	100	130	123	199	155	100	102	124	131	167	-	-	157	-	-
LA	79	105	61	73	79	95	65	78	65	77	82	94	63	-	116	100	-	135
MO	231	152	138	95	147	107	246	210	196	150	138	88	117	228	198	118	183	191
MR	220	178	114	81	99	95	230	203	74	103	61	99	129	-	-	27	-	-
TrOOO	146	202	99	72	106	62	185	207	110	97	96	74	196	-	-	156	-	-
CoR	61	74	91	101	130	128	113	155	63	86	76	104	167	240	212	7	214	179
BCG	252	254	209	180	106	81	238	65	161	150	81	176	88	229	-	7	187	-
BXB	224	253	210	189	182	110	251	252	148	204	48	108	108	232	209	99	191	172
BPB	254	254	159	201	63	107	69	79	113	143	101	184	3	227	199	15	192	167
BPR	245	250	29	90	54	54	251	212	81	113	23	72	152	239	-	183	166	-
TB	202	217	184	149	213	176	217	229	201	215	165	160	113	214	-	117	197	-
XO	254	253	60	145	42	69	252	191	151	119	56	93	161	207	178	106	76	110
PR	244	250	132	108	168	98	249	253	153	166	143	90		214	209	-	195	169

This indicates the Brønsted interaction of OEDPA with the above dyes.

Obviously, during the chemisorption of NH_3 by IFCS-OEDPA-I samples based on azo indicators, specific non-Brønsted (due to the formation of hydrogen bonds) interactions make a significant contribution to the change in the color of their surface. This is indicated by the absence of correlations between the colorimetric functions of the "responded" samples with the acid-base characteristics of the azo indicators.

IFCS-CA-I. The coincidence of the color of the initial IFCS-CA-I samples with triphenylmethane dyes described above is accompanied by the following. The intensity of the yellow shade simbatically change with Ind pK_a:

$$K_{y0} = 4{,}2525 + 11{,}166 \cdot pK_{a(4\text{-}OH)}; \quad R^2 = 0{,}9694 \text{ (except BCG).} \quad (13)$$

Taking into account the data in [25, 26], the chemisorption of ammonia by the specified samples (it also occurs in the presence of "free" water) stops at the stage of formation of ammonium dihydrocitrate:

$$HOC_3H_4(COOH)_3 + NH_3 \cdot H_2O \rightarrow HOC_3H_4(COOH)_2COONH_4 + H_2O. \quad (14)$$

At the same time, both the value of the colorimetric characteristic y_r and relative whiteness (Wr) of the "responded" samples, as well as the absolute change of the colorimetric function A and color tone (T) during the "response" of the specified samples to NH_3 ($\Delta A = A_r - A_0$; $\Delta T = T_r - T_0$) also correlate with Ind pK_a:

$$y_r = 0{,}1507 + 0{,}028 \cdot pK_{a(4\text{-}OH)}; \quad R^2 = 0{,}9848 \text{ (except BPB),} \quad (15)$$

$$W_r = 48{,}544 + 0{,}5453 \cdot pK_{a(4\text{-}OH)}; \quad R^2 = 0{,}9525 \text{ (except BPB),} \quad (16)$$

$$\Delta A = 80{,}452 - 9{,}3847 \cdot pK_{a(4\text{-}OH)}; \quad R^2 = 0{,}9289, \quad (17)$$

$$\Delta T = -3{,}1207 + 0{,}4639 \cdot pK_{a(4\text{-}OH)}; \quad R^2 = 0{,}8958 \text{ (except BCG).} \quad (18)$$

The colorimetric characteristics of initial IFCS-CA-I samples with azo dyes correlate with the pH values of the lower boundary (pH_1) of Ind color transition:

$$G_0 = -15{,}538 + 24{,}477 \cdot pH_1; \quad R^2 = 0{,}9916 \text{ (except CoR),} \quad (19)$$

$$S_0 = -1721{,}6 + 759{,}01 \cdot pH_1; \quad R^2 = 0{,}9922, \quad (20)$$

$$K_{y0} = 15{,}834 - 8{,}8852 \cdot pH_1; \quad R^2 = 0{,}9999 \text{ (except CoR),} \quad (21)$$

$$T_0 = 1{,}8334 - 0{,}1206 \cdot pH_1; \quad R^2 = 0{,}9944 \text{ (except CoR).} \quad (22)$$

After the "responded" of the specified samples to NH_3, their colorimetric characteristics correlate with the pH values of the upper boundary (pH_2) of Ind color transition:

$$G_r = 53{,}408 + 9{,}5405 \cdot pH_2; \quad R^2 = 0{,}9763 \text{ (except CoR),} \quad (23)$$

$$x_r = 0{,}3699 + 0{,}0149 \cdot pH_2; \quad R^2 = 0{,}9812 \text{ (except CoR),} \quad (24)$$

$$Z_r = 21{,}229 - 1{,}3188 \cdot pH_2; \quad R^2 = 0{,}7274, \quad (25)$$

$$\Delta S = 3071{,}2 - 465{,}78 \cdot pH_2; \quad R^2 = 0{,}9113. \quad (26)$$

An interrelation between the values of the colorimetric function Z is also observed for initial and "responded" IFCS-CA-I samples with azo dyes:

$Z_r = 3{,}7427 + 0{,}8592 \cdot Z_o$;

$R^2 = 0{,}9947$ (except BXB та BCG), (27)

This testifies to the significant contribution of Brønsted interactions to the change in the surface color of the samples IFCS-CA-I during the chemisorption of ammonia by them.

IFCS-MA-I. Ammonia chemisorption by IFCS-MA-I samples is caused by the formation of ammonium hydromalate:

$$HOOCCH_2CH(OH)COOH + NH_3 \cdot H_2O \rightarrow HOOCCH_2CH(OH)COONH_4 + H_2O. \quad (28)$$

The values of the colorimetric characteristics x_r, y_r and relative whiteness W_r of "responded" samples IFCS-MA-I with triphenylmethane dyes simbatically change with the pH values of the Ind color transition boundaries:

$x_r = -73{,}91 + 13{,}12 \cdot pH_2$;

$R^2 = 0{,}8367$ (except BKG, XO), (29)

$y_r = -62{,}583 + 11{,}306 \cdot pH_2$;

$R^2 = 0{,}8784$ (except BKG, XO), (30)

$W_r = 2{,}9346 + 6{,}6488 \cdot pH_2$;

$R^2 = 0{,}8551$ (except BPR, BXB). (31)

In the case of azo indicators, the following correlations are observed:

$x_0 = 0{,}1274 + 0{,}0642 \cdot pH_1$;

$R^2 = 0{,}9225$ (except MO), (32)

$z_0 = 0{,}6031 - 0{,}0726 \cdot pH_1$;

$R^2 = 0{,}9528$ (except MO), (33)

$b_r = -54{,}407 + 12{,}481 \cdot pH_1$;

$R^2 = 0{,}9212$ (except MO), (34)

$K_{g0} = -70{,}837 + 20{,}174 \cdot pH_1$;

$R^2 = 0{,}9601$ (except MO), (35)

$A_G = -0{,}3895 + 0{,}0534 \cdot pH_1$;

$R^2 = 0{,}942$ (except CR), (36)

$\Delta S = 3065{,}7 - 469{,}92 \cdot pH_2$;

$R^2 = 0{,}9067$, (37)

$\Delta E = 126{,}48 - 18{,}319 \cdot pH_2$;

$R^2 = 0{,}9884$ (except TROOO). (38)

In addition, the following correlations are observed between the colorimetric characteristics of IFCS-OEDPA-I and IFCS-CA-I samples:

$R_{OEDPA} = -26{,}404 + 1{,}0711 \cdot R_{CA}$;

$R^2 = 0{,}9826$, (39)

$X_{OEDPA} = -4{,}3135 + 1{,}051 \cdot X_{CA}$;

$R^2 = 0{,}9047$ (except MP and MO). (40)

On the basis of colorimetric data processing, it was established that during the "response" to ammonia of IFCS-I samples with triphenylmethane dyes based on hydroxycarboxylic acids (CA and MA), effective absorption in red (AR), green (AG) colors and vector length in the RGB (Av) color space are related as follows:

$A_{R(MA)} = -0{,}0265 + 0{,}9738 \cdot A_{R(CA)}$;

$R^2 = 0{,}9846$ (except BPR); (41)

$A_{G(MA)} = -0{,}0098 + 1{,}0975 \cdot A_{G(CA)}$;

$R^2 = 0{,}9667$ (except XO); (42)

$A_{v(MA)} = 2{,}6625 + 0{,}8914 \cdot A_{v(CA)}$;

$R^2 = 0{,}9679$ (except BPR). (43)

For IFCS-OEDPA-I and IFCS-MA-I samples with azo dyes, the following dependencies are observed:

$\Delta E_{76(MA)} = -35{,}819 + 2{,}1256 \cdot \Delta E_{76(OEDPA)}$;

$R^2 = 0{,}9758$; (44)

$A_{v(MA)} = -90{,}85 + 4{,}4172 \cdot A_{v(OEDPA)}$;

$R^2 = 0{,}9650$. (45)

CONCLUSIONS. During "response" to NH_3, only some IFCS-I samples (table 3, 4) based on OEDPA (Ind: MO, TrOOO, Az and BPR), CA (Ind: CoR, MR, MO, TrOOO, BPR, BXB, TB, PR) and MA (Ind: LA, MR, MO, Az, BXB, XO, TB, PR) are decolorized, in contrast to the

behavior of SO_2 indicator chemisorbents [6]. As an analytical signal of the "response" IFCS-I samples to NH_3, we chose the value of total absorption, similarly to [6], the absolute value of which for IFCS -OEDPA-I and IFCS-CA-I decreases in the series of indicators:

XO < MO < TrOOO < BPR < PR< LA < TB < CoR < BCG < MR < BPB< BXB;
MO < TrOOO < MR < CoR < PR < BPR < TB < BXB < XO < Az < LA < BCG < BPB;
PR < LA < TB < TrOOO < BXB < MR < AZ < XO < MO < BPR < BPB < BXG < CoR.

Thus, the specificity of the change in the colorimetric functions of impregnated fibrous indicator chemisorbents during the absorption of NH_3 by them was revealed. The change in the color of IFCS-I samples is caused by both the Brønsted mechanism and specific interactions (due to the formation of hydrogen bonds).

ACKNOWLEDGEMENT. The work was carried out within the framework of the state budget topic "Theoretical principles of the creation of highly effective sorption and filtering materials and respirators based on them", state registration number: 0122U000864.

ІМПРЕГНОВАНІ ВОЛОКНИСТІ ХЕМОСОРБЕНТИ ДЛЯ КОЛЬОРОМЕТРИЧНОГО ДЕТЕКТУВАННЯ АМІАКУ

Т. С. Бєньковська[1,2], Р. Є. Хома[1,2], О. С. Ватраль[2], Р. М. Длубовський[1], С. В. Водзінський[1,2], В. В. Менчук[2]

[1]Фізико-хімічний інститут захисту навколишнього середовища і людини МОН України та НАН України,
вул. Преображенська 3, Одеса 65082, Україна;
e-mail: eskvar@ukr.net
[2]Одеський національний університет імені І. І. Мечникова,
вул. Дворянська, 2, Одеса 65082, Україна;
email: rek@onu.edu.ua

У роботі наведено результати досліджень особливостей колориметричної поведінки імпрегнованих волокнистих хемосорбентів (IFCS) основних газів із візуальною ідентифікацією моменту «спрацьовування» динамічної поглинальної ємності (IFCS-I) при поглинанні аміаку. Хемосорбенти одержано шляхом просочування волокнистих носіїв водними розчинами багатоосновних гідроксикислот, до складу яких додавали кислотно-основні індикатори (Ind). Як об'єкти досліджень використовували IFCS-I на основі оксиетилендифосфонової (IFCS-OEDPA-I), лимонної (IFCS-CA-I) та яблучної (IFCS-MA-I) кислот. Як кислотно-основні індикатори було використано наступні: азолітмін (Az), лакмоїд (LA), метиловий оранжевий (MO), метиловий червоний (MR), тропеолін ООО (TrOOO), конго червоний (CoR), бромкрезоловий зелений (BCG), броксиленоловий синій (BXB), бромфеноловий синій (BPB), бромфеноловий червоний (BPR), тимоловий синій (TB), ксиленоловий оранжевий (XO) та феноловий червоний (PR). Виявлено специфіку зміни кольорометричних функцій IFCS-I під час поглинання ними NH_3.

Встановлено що забарвлення вихідних зразків IFCS-I суттєво залежить не лише

від будови Ind, а й від природи багатоосновної гідроксикислоти, що входить до їхнього складу. Забарвлення зразків на основі лише OEDPA (Ind = CoR, BCG, BPB), CA (Ind = CoR, TrOOO, BCG, BPB, BPR, XO) та деяких MA (TrOOO, BCG) подібне до забарвлення водних розчинів бренстедівських кислот. Відмінність забарвлення решти зразків від забарвлення водних розчинів сильних кислот з одними й тими ж Ind, вочевидь, спричинена специфічними взаємодіями між аніонами гідроксикислот і нейтральними формами барвників. Під час «спрацьовування» по NH_3 відбувається знебарвлення лише деяких зразків IFCS-I на основі OEDPA (Ind: MO, TrOOO, Az та BPR), CA (Ind: CoR, MR, MO, TrOOO, BXB, BPR, TB, PR) та MA (Ind: LA, MR, MO, Az, BXB, XO, TB, PR), на відміну від поведінки індикаторних хемосорбентів SO_2.

Ключові слова: кольорометрія, волокнисті хемосорбенти, аміак, кислотно-основні індикатори.

REFERENCES

1. Bollinger N.J. NIOSH Respirator Selection Logic. Cincinnati: OH: DHHS, NIOSH, 2004. 39 p.
2. Favas G. End of Service Life Indicator (ESLI) for Respirator Cartridges. Part I: Literature Review. Fishermans Bend, DSTO, 2005. 45 p.
3. Kaptsov V.A., Chirkin A.V. Proper use of gas masks as prevention of occupational diseases. *Hyg. Sanitation*. 2013. (3): 42–45.
4. Kaptsov V.A., Chirkin A.V. Requirements to respiratory protection for workers (World practices reviewed). *Health Risk Analysis*. 2020. (4): 188–195. doi: 10.21668/health.risk/2020.4.21 (*in Russian*).
5. Checky M., Frankel K., Goddard D., Johnson E., Thomas J.C., Zelinsky M., Javner C. Evaluation of a passive optical based end of service life indicator (ESLI) for organic vapor respirator cartridges. *J. Occup. Environ. Hyg.* 2016. **13**(2): 112–120. doi: 10.1080/15459624.2015.1091956.
6. Khoma R.E., Ennan A.A.-A., Bienkovska T.S., Dlubovskii R.M., Vodzinskii S.V., Mykhailova T.V. The impregnated fibrous chemisorbents for colorimetric detection of the sulfur dioxide. *Ukr. Chem. J.* 2022. **87**(1): 35–48. doi: 10.33609/2708-129X.88.01.2022.35-48.
7. Moon S.M., Lee S., Min H., Park S., Yoon S., Choi J.H., Yoon S.M., Jung B., Im T., Jeong C.-s., Kim B., Lee C.Y. Design and Integration of a Gas Sensor Module that Indicates the End of Service Life of a Gas Mask Canister. *Adv. Mater.* 2022. **7**(3): 202100711. doi: 10.1002/admt.202100711.
8. Ennan A.A.-A., Khoma R.E., Dlubovskii R.M., Abramova N.M. Composition for impregnating filter material. Patent UA 102156, IPC B01D 39/00, no u201413732, 26.12.2014 (*in Ukrainian*).
9. Ennan A.A.-A., Khoma R.E., Zakharenko Yu.S., Abramova N.M. Composition for impregnating filter material. Patent UA 133560, IPC B01D 39/00, no u201811398, 10.04.2019 (*in Ukrainian*).
10. Khoma R.E., Ennan A.A.-A., Bienkovska T.S., Bugova E.Yu., Osadchiy L.T., Menchuk E.M. $HOCH_2CH_2NH_2$ – Tropeolin OOO - H_2O system acid-basic properties in the presence of HCl, $HClO_4$, H_2SO_4 and $SO_2 \cdot H_2O$. *Visn. Odes. nac. univ., Him*. 2021. **26**(4): 26–38. doi: 10.18524/2304-0947.2021.4(80).248292.
11. Khoma R.E., Bienkovska T.S., Bugova E.Yu., Osadchiy L.T., Vodzinskii S.V., Toporov S.V. SO_2 – Am (KOH) – Tropeolin OOO – H_2O (Am – ethanolamines, morpholine) systems acid-base properties *Visn. Odes. nac. univ.,*

Him. 2022. **27**(3): 43–52.
doi: 10.18524/2304-0947.2022.3(83).268625.

12. Lur'e Ju.Ju. Handbook of Analytical Chemistry. Moscow, Himija, 1989. 448 (*in Russian*).
13. Ennan A.A., Dlubovskiy R.M., Abramova N.N., Khoma R.E. Chemisorption of Sulfur Dioxide by Polyethylenepolyamine Impregnated Fibrous Materials. 2. The Study of Water Vapor Influence on Preadsorbtion SO_2 Chemisorption by Fibrous Materials. *Visn. Odes. nac. univ., Him*. 2014. **19**(3): 20–30.
doi: 10.18524/2304-0947.2014.3(51).40356 (*in Russian*).
14. National Library of Medicine. Available at https://pubchem.ncbi.nlm.nih.gov/
15. Center for Disease Contol and Prevention. Available at https://www.cdc.gov/
16. Purich D. The Inhibitor Index: A Desk Reference on Enzyme Inhibitors, Receptor Antagonists, Drugs, Toxins, Poisons, Biologics, and Therapeutic Leads. 1st Ed. CRC Press, 2017: 1948 p.
17. Sabnis R.W. Handbook of acid-base indicators. Boca Raton: CRC Press, 2008. 416 p.
18. Zevackiy U.E., Samoylov D.V., Ruzanov D.O. Assessment of application field of photoemissive method for determination of pK_a values for organic compounds. *Bull. Saint Petersburg State Inst. Technol*. 2010. (9): 54–59 (*in Russian*).
19. Aragoni M.C., Arca M., Crisponi G., Nurchi V.M., Silvagni R. Characterization of the ionization and spectral properties of sulfonephthalein indicators. Correlation with substituent effects and structural features. Part II. *Talanta*. 1995. **42**(8): 1157–1163.
doi: 10.1016/0039-9140(95)01559-t
20. Naseem K., Farooqi Z.H., Begum R., Irfan A. Removal of congo red dye from aqueous medium by its catalytic reduction using sodium borohydride in the presence of various inorganic nano-catalysts: A review. *J. Clean Prod*. 2018. **187**: 296–307.
doi: 10.1016/j.jclepro.2018.03.209.
21. Snigur D.V. The use of tristimulus colorimetry functions in the study of the acid-base equilibria in solutions of organic compounds. Thesis of Ph.D dissertation, 25.00.02. Uzhgorod, 2017. 140 p. (*in Ukrainian*).
22. Shokrollahi A., Gohari M., Ebrahimi F. Determination of Acidity Constants of p-Rosolic acid and Bromoxylenol Blue by Solution Scanometric Method. *Analyt. Bionalyt. Chem. Res*. 2018. **5**(1): 67–79.
doi: 10.22036/ABCR.2017.89026.1153
23. Schults E.V., Monogarova O.V., Oskolok K.V. Digital colorimetry: analytical possibilities and prospects of use. *Moscow Univ. Chem. Bull*. 2019. **74**(2): 55–62 (*in Russian*).
24. Ennan A.A.-A., Dlubovskii R.M., Khoma R.E. Water role in the gases chemosorporation processes by sorption-active materials. *Visn. Odes. nac. univ., Him*. 2021. **26**(3): 6–28.
doi: 10.18524/2304-0947.2021.3(79).240717 (*in Ukrainian*).
25. Ennan A. A.-A., Khoma R.E., Dlubovskii R.M., Zukharenko Yu.S., Benkovska T.S., Knysh I.M. Mono- and bifunctional impregnated fiber chemosorbents for respiratory purpose. *Visn. Odes. nac. univ., Him*. 2022. **27**(1): 6–36.
doi:10.18524/2304-0947.2021.4(80).248297 (*in Ukrainian*).
26. Khoma R.E., Abramova N.N., Kiro S.A., Knysh I.M. Respiratory organs protection from the ammonia action. *Visn. Odes. nac. univ., Him*. 2022. **27**(2): 93–107.
doi: 10.18524/2304–0947.2022.2(82).264892

Стаття надійшла 11.01.2023.