SELECTIVE OXIDIZATION OF 2- AND 3-AMINOTOLUENE BY OZONE IN THE GLACIAL ACETIC ACID TO THE CORRESPONDING AMINOBENZOIC ACIDS

Проведені дослідження кінетичних закономір-ностей і механізму реакцій окиснення 2- і 3-аміно-толуену та їх ацильованих похідних у крижаній оцтовій кислоті. Вивчено процес каталітичного рідкофазного окиснення 2- і 3-ацетамідотолуену озоном у присутності солей перехідних металів та їх сумішей з калій бромідом до відповідних аце-тамідобензойних кислот

Ключові слова: 2-амінотолуен, 3-амінотолуен, 2-ацетамідотолуен, 3-ацетамідотолуен, озон, окиснення, 2-ацетамідобензойна кислота, 3-аце-тамідобензойна кислота

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Проведены исследования кинетических зако-номерностей и механизма реакций окисления 2- и 3-аминотолуола и их ацилированных произ-водных в ледяной уксусной кислоте. Изучен про-цесс каталитического жидкофазного окисления 2- и 3-ацетамидотолуола озоном в присутствии солей переходных металлов и их смесей с броми-дом калия до соответствующих ацетамидобен-зойных кислот

Ключевые слова: 2-аминотолуол, 3-аминото-луол, 2-ацетамидотолуол, 3-ацетамидотолуол, озон, окисление, 2-ацетамидобензойная кислота, 3-ацетамидобензойная кислота

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1. Introduction

In the acetic acid the toluene react with ozone mostly for double bonds of the aromatic ring to form ozonides. The output of the oxidation products of the methyl group in these conditions does not exceed 16 % [1]. Investigation of the influence of electron donor and acceptor substituents on the oxidation of the methylbenzenes and their derivatives by ozone in acetic acid were carried out in [2, 3]. It is shown that in the presence of electron donor (-CH$_3$, -OH) substituents direction of attack by ozone of the methyl group is virtually absent, but the presence of electron acceptor (-NO$_2$) substituents increases selectivity of the methyl group to 36 % [3]. The data of the oxidation of animotoluenes by ozone in the acetic acid in the literature are mostly absent. Therefore, the study of the reaction of ozone with 2- and 3-aminotoluene in acetic acid to further clarify the nature of the substituent influence on the selectivity and composition of the oxidation products of methylbenzenes are actual.

2. Analysis of literature data

Isomeric aminobenzoic acid is an important chemical product of organic synthesis used in the production of synthetic dyes, medicinal and aromatic substances, wines, pesticides, etc [4, 5]. In chemical industry, 2-aminobenzoic acid (2-ABA) is produced from phthalimide [6], 3-aminobenzoic acid (3-ABA) is produced by reconstitution from 3-nitrobenzoic acid [7], which in its turn is the product of oxidation of 3-nitrotoluene by mineral-oxidants and molecular oxygen. Oxidation by mineral oxidants is unpromising from the point in view of the environmental problems that thereby occur. In contrast, oxidation by molecular oxygen eliminates environmental issues, but this process is conducted in harsh conditions and requires sophisticated equipment. Thus, the purpose of this work was to investigation the reaction of the oxidization of 2- and 3-aminotoluenes by gases containing ozone in the liquid phase with the purpose of reception of the corresponding 2- and 3-aminobenzoic acid under mild conditions and in high yield.

3. The methodology of the experiment

Ice acetic acid of the qualification "chemically pure" was used for the experiments and before usage it had been purified by distillation under vacuum in the presence of potassium permanganate; 2-, 3-aminotoluene (3-AT) of the qualification "chemically pure", 2-, 3-acetamidotoluene (3-AAT) (white crystalline powder, the melting point is 147 ºC) after repeated recrystallization from water. The acetate of cobalt (II) tetrahydrate of the qualification "pure" and bromide of potassium qualification of the "pharmaceutical grade" were used.

The investigations were carried out in the temperature-controlled glass column (V=0,02 l) with a porous barrier for dispersing gas in the kinetic regime of oxidation. The column was loaded with 0.01 liter of glacial acetic acid, 0.4 mol/L of 3-acetamidotoluene (3-AAT), cobalt(II) acetate tetrahydrate, then the gas was fed (air, oxygen or an ozone-air mixture) at the rate of 30 l/h, the concentration of ozone in the gas phase was $(1,5 \div 6,0) \cdot 10^{-4}$ mol/l. If the

catalyst is to be introduced into the system in the oxidized form, a preliminary solution of acetous acetate cobalt (II) had to be prepared, it was ozonized by passing through an ozone-air mixture until exhaustive oxidation of Co (II) to Co (III). After the cobalt oxidation, the gas flow was stopped and the column was loaded with the calculated amount of 3-AAT and renewed supplying the ozone-containing gas. At the end of the oxidation, the reaction mixture was poured into the glass beaker, two-thirds filled with finely divided ice, and then diluted with cold water so that the total volume was 50 ml. After its precipitation, 3-acetamidobenzoic acid (3-AABA) was filtered and washed with cold water. Then, 10 ml of concentrated HCl, 20 ml of water, and 4 ml of alcohol were added, and the mixture heated for one hour in a flask with a reverse refrigeration with stirring. The reaction mass was then cooled, and the precipitated 3-ABA was filtered and dried.

4. The methods of analysis

The ozone concentration in the gas phase at the inlet and outlet of the reactor was determined by spectrophotometry. 2- and 3-AAT, the corresponding alcohol and aldehyde were analyzed by gas-liquid chromatograph with a flame ionization detector on the column of 3 m long, 4 mm in diameter, filled with a carrier "inerton AW-DMCS", coated with a stationary phase "SE-30" in amount of 5 % by weight of the carrier under the following conditions: the temperature of the evaporator 250 °C, thermostat temperature 190 °C, the rate of carrier gas (nitrogen) is 1.8 l/h, hydrogen – 1.8 l/h, and air – 18 l/h. As the internal standard, 4-nitrochlorobenzene was used. The current concentration of 2- and 3-AABA was determined by titration with alkali; for this purpose 0.5 ml from the reaction mixture was sampled from which the solvent was then removed, its dry residue was then dissolved in 30 mL of a 50 % solution of ethyl alcohol, neutralized to phenolphthalein, and the obtained solution was titrated with 0.05 N of sodium hydroxide solution.

The effective reaction rate constant of ozone with 2- and 3-AAT and the quantity of ozone absorbed in the course of the reaction was determined by the procedures described in [8]. The reaction rate constants for Co (III) with 2- and 3-AAT was calculated graphically for the case of one-sided second-order reactions.

The structure of peroxide compounds formed during ozonation, was determined by IR spectroscopy, and their concentration by iodometric titration.

5. Research results oxidation of aminotoluenes by ozone and discussion of this data

The previous studies [9] have found out that ozone in the solution of glacial acetic acid reacts with 2- and 3-AT rapidly. The effective reaction rate constant equals to $2,46 \cdot 10^3$ l·mol^{-1}·sec^{-1} for 2-AT and $2,15 \cdot 10^3$ l·mol^{-1}·sec^{-1} for 3-AT respectively. Ozone attacks mainly the lone pair of electrons of the nitrogen atom with formation, mainly, of polymers of azo compounds, and trace amounts of nitrotoluene, toluhinone and nitroso compound. The products oxidation on methyl group are not formed in these conditions. Practically, the resulting composition of the products does not differ from that described in the literature

and corresponds to the scheme of the transformations that P. S. Bailey suggested for the reaction of ozone with aromatic amines. His scheme presumes a fast attack by ozone of the free pair of electrons of nitrogen atom with the further development of the reaction in two directions: a) the formation of aromatic nitro products and b) the formation of ion-radical pair, which, depending on the structure of the amine, can transform into a variety of products, most of which are polymeric azo compounds.

The direction of the ozone's attack can be altered and directed on the methyl group, as well as by an aromatic ring, by acylation of the amino group. In this case, the amino group is largely deactivated by the conjugation of the undivided pair of nitrogen's electrons to the carbonyl group of the acetyl. After the acylation of 2- and 3-AT, the effective reaction rate constant k_{ef} is reduced by three orders of magnitude (Table 1) and is close to the value of the k_{ef} of methylbenzenes (Fig. 1).

At the atmospheric pressure and the temperature of 293 K, the oxidation of 2-AAT or 3-AAT by ozone in the glacial acetic acid proceeds without an induction period and mainly on the aromatic ring.
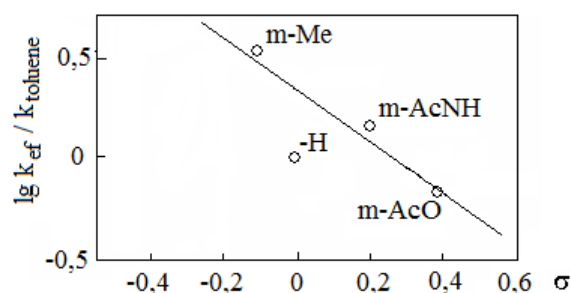

Fig. 1. Relative reaction rate constants of liquid-phase reactions of ozone with the derivatives of toluene at 288 K, on the value of σ — Hammett sigma constant

The total yield of the products of oxidation of the methyl group of 2- and 3-AAT is 5,1 and 12,4 % respectively, the yield of the products from ozonolysis on the aromatic ring (aliphatic peroxidic compounds) is 92,9 and 84,7 %, the yield of the unidentified products is 2,0 , 2,9 % (Table 2).

Table 1

Rate constants of ozone the reaction with toluene derivatives in the solution of glacial acetic acid at 293 K

Substance	$[O_3]_0 \cdot 10^4$, mol·l^{-1}	$[ArCH_3]_0 \cdot 10^2$, mol·l^{-1}	k, l·mol^{-1}·sec^{-1}
Toluene	0,28÷0,57	7,7÷28,3	0,82±0,08
2-AT	0,45÷0,80	2,7÷18,3	$(2,46±0,20) \cdot 10^3$
3-AT	0,45÷0,80	2,7÷18,3	$(2,15±0,20) \cdot 10^3$
2-AAT	0,28÷0,57	10,1÷27,9	2,17±0,20
3-AAT	0,28÷0,57	10,1÷27,9	1,26±0,15

Among the products of oxidation of the methyl group identified at the early stages are 3-acetaminobenzaldehyde (13.1 %) and 3-acetaminobenzyl alcohol ($\approx 10^{-4}$ mol·L^{-1}). At the later stages of oxidation, the main product with the aromatic structure kept is 3-AABA (14. 2 %) (Fig. 2).

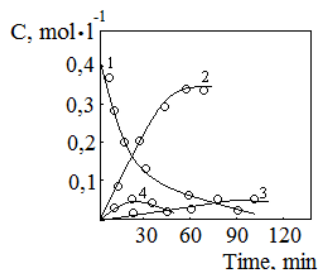Fig. 2. Kinetics of oxidation of 3-AAT by ozone in acetic acid; T=293 K; $[O_3]_o$=4,7·10^{-4}; $[AcNHArCH_3]_o$=0,4mol·L^{-1}; V_r=0,01 l; gas flow speed - 5,6·10^{-4} L·s^{-1}. Change of concentration of 3-AAT (1), peroxides (2); 3-AABA (3); 3-acetaminobenzaldehyde (4)

At the oxidation of 2-AAT yield of reaction products from methyl group is reduced by almost 3 times. Hence, the previous acylation of amino group protects it from the effects of ozone and provides small amounts of oxidation products for the methyl group. Reduced output of products of oxidation by methyl group at the ozonation of 2-AAT to 5, 1 %, probably due to steric complications caused by the presence acetamino group in ortho-position relative to the methyl, leading to a decrease in the stability of the aromatic ring (Fig. 3).
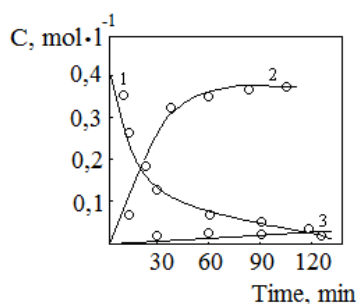

Fig. 3. Kinetics of oxidation of 2-AAT by ozone in acetic acid; T=293 K; $[O_3]_o$=4,7·10^{-4}; $[AcNHArCH_3]_o$=0,4mol·L^{-1}; V_r=0,01 l; gas flow speed − 5,6·10^{-4} L·s^{-1}. Change of concentration of 2-AAT (1), peroxides (2); 2-AABA (3)

Table 2

Oxidation of 2- and 3-AAT by ozone in glacial acetic acid at 293 K. $[O_3]_o$=4,7·10^{-4}; $[AcNHArCH_3]_o$=0,4mol·L^{-1}; V_r=0,01 l

	Selectivity, %		
Substance	On the methyl group	On the aromatic ring	Unidentified products
2-AAT	5,1	92,9	2,0
3-AAT	12,4	84,7	2,9

Peroxide compounds formed in the process of ozonation are quite stable at 293 K and inert to the further action of ozone. To identify their chemical nature, the solvent was distilled under vacuum of 5 mm Hg. The peroxides were isolated as an oily viscous liquid of light-yellow color. The liquid is difficult to dissolve in acetic acid, it reacts with alkali and potassium iodide, the reaction ends in about 1 hour, when molecular iodide is released in a quantity equivalent to one peroxide group. These findings do not contradict the

literature, according to which, the hydroperoxide groups easily react with potassium iodide (the recovery of dialkyl-peroxide groups ends in ≈20-24 hours). IR spectrum analysis showed the absence of aromatic structures in the peroxides produced. The absorption bands of IR spectra in the area of 760, 1050 and 1300 cm^{-1} are related to the oscillation of hydroperoxide groups, while the band in the area of 1620 cm^{-1} to that of carbonyl groups, and the bands in the area 3200 cm^{-1} to that of -CONH groups.

These facts, as well as the found stoichiometric coefficients of the reaction with ozone at 288 K (n≈1), presume that the oxidation of the aromatic ring produces aliphatic compounds, which are formed by the scheme of Krihe [10].

Thus, ozone reacts with 2- and 3-AAT in two directions: on the methyl group and the aromatic ring. Oxidation proceeds as follows:

$$AcHNArCH_3 + O_3 \rightarrow AcHNArCH_2^{\bullet} + OH^{\bullet} + O_2, \quad (1)$$

$$AcHNArCH_3 + O_3 \rightarrow AcHNArCH_2OH + O_2, \quad (2)$$

$$AcHNArCH_3 + O_3 \rightarrow aliphatic\ peroxides\ (ozonolysis). \quad (3)$$

Thus, the dominant reaction is the ozonolysis of aromatic ring (3). In order to obtain the necessary information for producing selective syntheses of aminobenzoic acids, we further studied kinetic characteristics and mechanism of reaction of ozone with acetaminotoluenes in the presence of salts of transition metals (STM) that were found to be electron donors during ozonation [11].

We studied the acetates of Co (II), Mn (II), Cr (III) and Ni (II) as the potential catalysts for selective oxidation of 2- and 3-AAT by ozone in the presence of glacial acetic acid. It was found that the selectivity for the oxidation of methyl group depends on the magnitude of oxidation-reduction potential of the couples M/M^+ of the studied catalysts. The selectivity also depends on the velocity of interaction between renewable forms of metal and ozone, as well as on oxidized forms of metal in the original substrate. In this study, kinetically, acetate Co (II) was found to be the most effective catalyst, but the output of 2- and 3-AABA in given conditions is quite low – for 2-AABA it reaches only 25,0 and for 3-AABA 31,2 %, because the predominant the direction of reaction remains the ozonolysis of aromatic ring.

Following these results, the further studies of oxidative catalysis of alkylbenzenes were conducted in the presence of alkali metal bromides, which increase selectivity and reaction rate [12]. We found out that the use of our catalytic system (ozone – acetaminotoluene – Co (III) – glacial acetic acid – potassium bromide) significantly increases the reaction rate and the selectivity of substrate oxidation of methyl groups. The main product of oxidation of 2-AAT becomes 2-AABA 55,0 % (Fig. 4).

The main product of oxidation of 3-AAT becomes 3-AABA 71,2 % (Fig. 5), but we also identified small amounts of 3-acetaminobenzylbromide (4.5 %) and traces of 3-acetaminobenzaldehyde.

The maximal selectivity of oxidation of 2- and 3-AAT was achieved at the molar ratio of 1:1 ($[Co(OAc)_2]_0$:$[KBr]_0$). The further increase in the concentration of potassium bromide does not affect the selectivity of oxidation. This is a kinetic evidence of 4-acetaminobenzyl radical formation as a result of inner electron transfer from the π-electron system

of the substrate to the cobalt-bromide radical to form the aromatic cation-radical. The higher rate and selectivity of the oxidation in the presence of potassium bromide (KBr) is tributary to the higher rate of initiation of selective oxidation of the substrate, which is higher by an order of the magnitude for $Co^{2+}Br^{\bullet}$ compared to cobalt acetate.
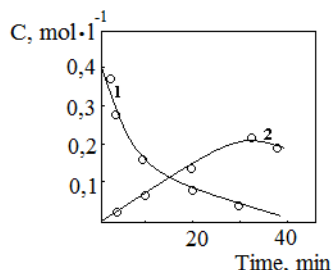

Fig. 4. Changes in the concentration of components of the reaction mixture during the oxidation of 2-AAT by ozone — air mixture in the presence of cobalt bromide catalyst at 368 K; $[AcNHArCH_3]_o=0,4$; $[Co(OAc)_2]_o=0,1$; $[KBr]_o=0,1$; $[O_3]_o=4,5\cdot10^{-4}$ mol·L^{-1}. Change of concentration of 2-AAT (1); 2-AABA (2)
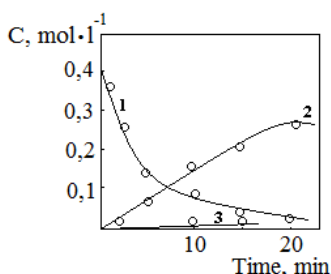

Fig. 5. Changes in the concentration of components of the reaction mixture during the oxidation of 3-AAT by ozone — air mixture in the presence of cobalt bromide catalyst at 368 K; $[AcNHArCH_3]_o=0,4$; $[Co(OAc)_2]_o=0,1$; $[KBr_o=0,1$; $[O_3]_o=4,5\cdot10^{-4}$ mol·L^{-1}. Change of concentration of 3-AAT (1); 3-AABA (2); 3-acetaminobenzyl bromid (3)

Achieving high selectivity of oxidation in the presence of KBr is accompanied by a decrease in the optimal concentration of cobalt by 30 %. The further increase in selectivity for the oxidation on methyl group is achieved by increasing the concentration of molecular oxygen in the gas containing ozone. Replacing ozone-air mixture with the ozone-oxygen mixture leads to higher yield of 2-AABA (70,0 %) and 3-AABA (86,0 %).

5. Conclusion

It has shown that the reaction of ozone with 2- and 3-AT in glacial acetic acid proceeds with high speed and preferably with the free electron pair of heteroatom with the formation of polymeric azo compounds. In these conditions, the products of oxidation on methyl group of substrate are not formed. By the acylation of amino group, the direction of ozone's attack changes and is directed by methyl groups and aromatic ring. Acetaminotoluene are oxidized to form the products of destructive oxidation (ozonolysis) of aromatic ring – aliphatic peroxides (84,7 and 92,9 % respectively for 2- and 3-AAT) as well as the products of oxidation of methyl group – 2- and 3-AABA (5,1 and 12,4 %).

We've found that the usage of cobalt-bromide catalyst in oxidation gases containing ozone increases the rate and selectivity of the oxidation of acetaminotoluene to 55,0 % for 2-AAT and output of 3-AABA for the corresponding 3-AAT is 71,2 %. The increase of oxidation rate on methyl group in the presence of catalytic system with supplements of bromides of alkali metals is associated with the formation of highly reactive cobalt-bromide complex, which quickly attracts the substrate in the process of selective oxidation to form corresponding acetaminobenzoic acid.

It has also been found out, that a further increase in selectivity of the oxidation of methyl group to 70,0 and 86,0 % (2- and 3-AABA) and the consumption reduction of ozone by 40 % is achieved in the conditions of oxidation with ozone-oxygen mixture.

References

1. Galstjan, S. G. Osnovi himiï i tehnologiï ridkofaznogo okisnennja toluolu ozonovmisnimi gazami [Text] : avtoref. dis ... kand. tehn. nauk / S. G. Galstjan. – Lugans'k : B.v., 2011. – 20 p.

2. Galstjan, A. G. Kinetika okislennja p-krezolu ozonopovitrjanoju sumishshju u ridinnij fazi [Text] / G. A. Galstjan, G. O. Sedih, G. A. Galstjan // Ukrains-kij himicheskij zhurnal. – 2007. – Vol. 73, № 5. – P. 104–109.

3. Galstjan, G. A. Zhidkofaznoe kataliticheskoe okislenie aromaticheskih soedinenij ozonom [Text] / G. A. Galstjan, N. F. Tjupalo, A. G. Galstjan. – Lugansk: VNU im. V. Dalja, 2009. – 415 p.

4. Belikov, V. G. Farmacevticheskaja himija [Text] / V. G. Belikov. – Moskva. Izd-vo: „med-pres-inform", 2007. – 640 p.

5. Arzamcev, A. P. Farmacevticheskaja himija [Text] / A. P. Arzamcev. – Moskva. Izd-vo: „gektar-media", 2006. – 640 p.

6. Lisicyn, V. N. Himija i tehnologija promezhutochnyh produktov [Text] / V. N. Lisicyn. – Moskva. Izd-vo „Himija", 1987. – 368 p.

7. Vorozhcov, N. N. Osnovy sinteza promezhutochnyh produktov i krasitelej [Text] / N. N. Vorozhcov. – Moskva. Izd-vo „Goshimizdat", 1955. – 839 p.

8. Razumovskij, S. D. Ozon i ego reakcii s organicheskimi soedinenijami [Text] / S. D. Razumovskij, G. E. Zaikov. – Moskva. Izd-vo „Nauka", 1974. – 322 p.

9. Galstjan, A. G. Kinetika okisnennja 4-aminotoluolu ozonom u ridkij fazi [Text] / A. G. Galstjan, A. S. Bushuev, R. M. Solomjannij // Ukr. him. zhurn. – 2008. – Vol. 74, № 7. – P. 57–61.

10. Criegee, R. Ozone [Text] / R. Criegee // Chem. Zeitung. – 1975. – Vol. 99, № 3. – P. 138–141.

11. Galstjan, G. A. Kataliticheskoe okislenie nitrotoluolov ozonom v srede uksusnoj kisloty [Text] / G. A. Galstjan, A. G. Galstjan, P. Ju. Andreev // Vestnik fizioterapii i kul'turologi. – 2005. – Vol. 11, № 5. – P. 157–162.

12. Galstjan, A. G. Kinetika i mehanizm okislenija 4–acetoksitoluola ozonom v rastvore uksusnogo angidrida v prisutstvii marganecbromidnogo katalizatora [Text] / A. G. Galstjan, A. A. Sedyh // Kinetika i kataliz. – 2009. – Vol. 50, № 5. – P. 698–702.