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INVESTIGATION OF OZONE SOLUBILITY IN WATER IN HEIGHT OF THE LIQUID

The paper presents the dissolution patterns of ozone in the water column height from processing parameters. These studies are necessary to develop new technologies of disinfection of water wells and water supply using ozone. Generally known data of the solubility of ozone in water does not allow to use them for this purpose.

The investigations have been carried out on two experimental apparatuses. The following parameters as time processing, flow of the gas mixture, the concentration of ozone in the gas mixture, the height of the liquid layer have been studied.

Research results for each apparatus are presented in the graphical form of dependences of the concentrations of residual ozone in water from the selected processing parameters. The influence of each variable parameter on residual ozone concentration in the water has been described, and the factors that affect the increase of the concentration of ozone dissolved in water at the height of the first 3 m have also been shown.

Such mathematical models describing the dependence of the concentration of ozone in the water from the set parameters as the height of the insertion point of the gas mixture, the concentration of ozone in the gas mixture, processing time, flow of the gas mixture are presented. The significance of the regression equations has been checked out.

Key words: disinfection, water supply, facility, ozone solubility.

Introduction. Over the last years ozone has been frequently used in water treatment [1–3]. First of all it is connected with considerable improvement of ozone generators.

According to a number of regulatory documents [4–6] disinfection of potable water is acceptable by ozone alongside with chlorine treatment, UV-radiation and other methods approved by Chief public health official of the Republic of Belarus or his deputies.

Using ozone in water treatment is one of the upcoming trend, for example, in drinking water supply systems for disinfection of water and pipelines [7]; ozone is also recommended to use for disinfection of water supply wells and potable water systems [8].

As it was mentioned earlier [8] for development of these technologies it is necessary to solve a number of problems such as evaluation of steel corrosion resistance (material for well casing, pipelines and isolating device) [9], evaluation of effectiveness of microorganisms destroying, evaluation of life cycle alongside with analysis of life cycle cost and as a result – technical and economic assessment of usage of recommended technology in comparison with chlorine substances that are currently used.

Ozone dissolution in water is the main process in technology of ozone usage in water treatment.

Dissolution of ozone in water is described by Henry's law [10]. However, in references there is no any data on ozone dissolution from top to bottom of water column as the main stage in analyzing process.

In references there are some data on ozone dissolution in water depending on temperature according to Khorvats [11] and solvability reference book by V. B. Kogan [12] where Buzen coefficient is used.

Due to the above mention sources it is possible to predict theoretical steady-state concentration of ozone at different depth. These common factors provide straight line that at certain height will be crossed at the point with zero concentration. However, many factors such as oxidants, ozone concentration in gas mixture, pressure, size of gas bubbles forming by aerator and others influence ozone dissolution in natural water.

Aim of this paper – establishment of rules of ozone solvability in water from top to bottom of liquid depending on processing parameters.

Main part. For establishment of ozone solvability in water from top to bottom of liquid two experimental units were erected, Fig. 1 provides the scheme of the units.

The unit is made as a plastic pipe: the 1st unit has a diameter of 0.1 m and height of 2 m, the 2nd unit – diameter of 0.3 m and height of 5 m. There are some sampling access holes spaced at intervals of 0.5 m.

During the tests experimental ozonator made by OSC “RovalantSpetsService” was used in the first unit for ozone generation [13], and in the second unit – ozonator by Finnegan-Reztek (USA). For establishment of weight content of ozone in the gas phase ozone analyzer BMT 961 by Ozone Systems & Technology International (USA) was used. Establishment of ozone concentration in tap water

has been carried out according to NSS 18301–72 “Potable water. Methods of establishments of residual ozone content” [14]. Sensitivity of the method – 0.05 mg O₃/l.

During the trial the following parameter of water treatment was used:

– for the first unit ozone concentration in gas mixture – 2.7 g/m³; processing time – 1; 10; 30; 60 min; gas mixture consumption – 3.3; 6.6; 13.2 l/h;

– for the second unit ozone concentration in gas mixture – 35; 45; 55 g/m³; processing time – 15; 30; 45; 60 min; gas mixture consumption – 700 l/h.

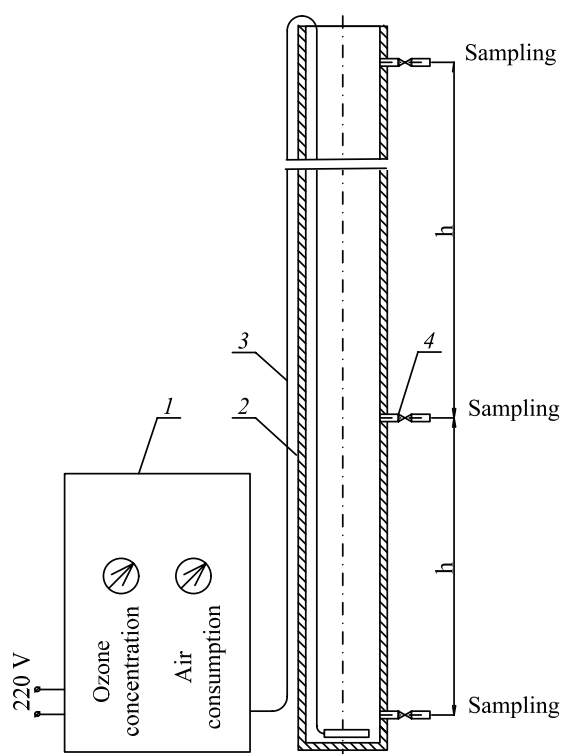


Fig. 1. Unit scheme

for establishment of ozone solvability from top to bottom of liquid column:

1 – ozonator; 2 – pipe; 3 – gas flue; 4 – sampling fitting

During the trials at test stand on the first variant the results provided by Aig. 1 and 3 were obtained.

According to the data provided by Aig. 2 during 10 min water treatment increase of consumption of delivering gas mixture of more than 6.6 l/min does not result to considerable increase of concentration of dissolved ozone in water, however, during the processing time of 60 min increase of consumption of more than 6.6 l/min results to increase of residual ozone concentration in water. Ozone half-life period that depends on a number of parameters [15, 16] and makes 10–20 min should also be considered.

Fig. 3 provides concentration of dissolved ozone in water from top to bottom of liquid column depending on time of processing.

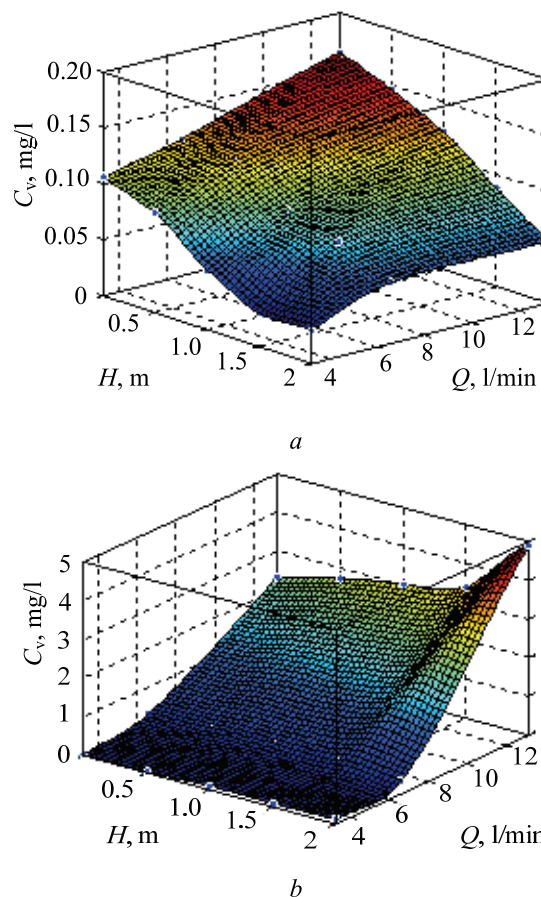


Fig. 2. Concentration of dissolved ozone in water from top to bottom of liquid column depending on gas mixture consumption:
a – processing time of 10 min;
b – processing time of 60 min

According to the above mentioned regularities increase of gas consumption results to increase of ozone consumption due to considerable increase of surface mass exchange.

According to the results of completed trials regression equation has been made. Under the test conditions the model is:

$$C_v = -1.26425 + 0.07103 \cdot C_g - 0.29158 \cdot H - 0.01035 \cdot T + 0.00745 \times C_g \cdot H + 0.00059 \cdot C_g \cdot T + 0.00107 \times H \cdot T - 0.00084 \cdot C_g^2 + 0.00033 \cdot H^2, \quad (1)$$

where C_v – concentration of residual ozone in water, mg/l; C_g – concentration of ozone in gas mixture, g/m³; H – height, m; T – time, min.

The square root of RMS error is 0.2753 and value of updated R -square is 0.7418. These criteria prove proper similarity of initial data to parametric model. Model correlation coefficient is high and makes 0.8.

RSME values closer to zero mean proper similarity of initial data to parametric model.

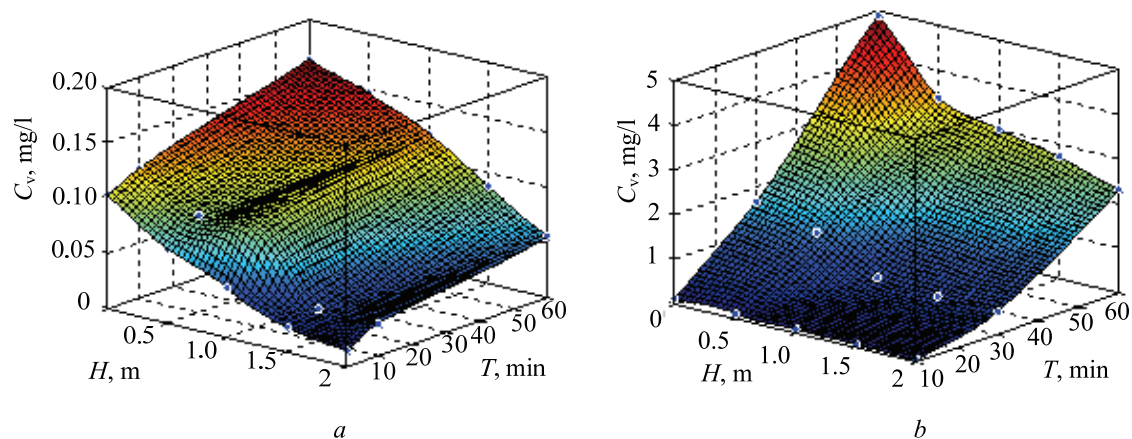


Fig. 3. Concentration of dissolved ozone in water from top to bottom of liquid column depending on processing time:
a – gas mixture consumption of 3.3 l/min; *b* – gas mixture consumption of 13.2 l/min

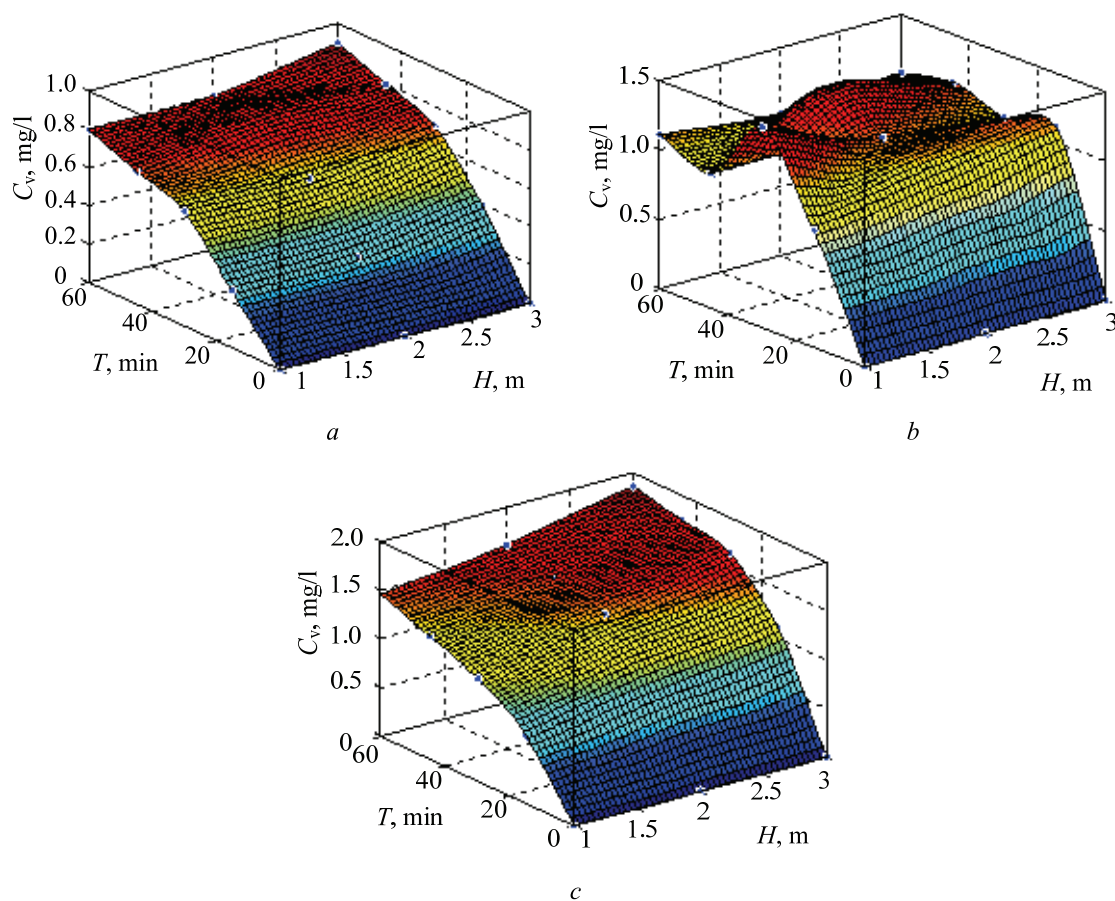


Fig. 4. Concentration of dissolved ozone in water from top to bottom of liquid column depending on its different concentration in gas mixture:

a – concentration of ozone in gas mixture of 35 g/m³; *b* – concentration of ozone in gas mixture of 45 g/m³;
c – concentration of ozone in gas mixture of 55 g/m³

During the trials at test stand on the second variant results provided by Fig. 4 have been obtained.

According to the results of the tests regression equation was made. Under the test conditions the model is:

$$C_v = -0.7823 + 0.1474 \cdot Q + 0.2129 \cdot H + 0.0197 \cdot T - 0.0466 \cdot Q \cdot H - 0.0042 \cdot H \cdot T, \quad (2)$$

where Q – gas mixture consumption, l/min.

This model is the best despite of high value of the square root of RMS error = 0.7972 and low value of updated R -square = 0.4412 that testify about average similarity of initial data to parametric modal. Model correlation coefficient is also average and makes 0.6.

According to the received data at the height of water layer to 3 m increase of concentration of dissolved ozone in water by height is taken place in the majority of cases; it is at variance with theoretical model on solvability. Thus, at the bottom layer ozone concentration in gas bubble is bigger, due to this fact according to Henry's law [10] its massotransfer into water is to be bigger.

When bubbles come up (in connection with its massotransfer into water) decrease of ozone concentration in bubbles should take place, as a result, decrease of its solvability in water should also take place. However, according to the tests

data increase of concentration of dissolved ozone in water is observed in the majority of cases.

Conclusions. The results of the paper allow making a number of conclusions.

It is proved that at the height of up to 3 m from the source of ozone delivery into water increase of its concentration takes place. The following factors influence it:

- speed of massotransfer of ozone from gas phase of the bubble into liquid;
- different distribution of the gas bubbles on size, as a result, their uneven lifting and distribution on height is taken place;
- turbulent mixing of water layer due to a big number of bubbles or their big size.

Received mathematical models permitting to describe dependence of ozone concentration in water on given parameters: height from the point of gas mixture input, ozone concentration in gas mixture, processing time and gas mixture consumption.

References

1. Italian Regulation. ACCORDO tra Ministro della Salute, le Regioni e le Province Autonome di Trento e Bolzano, sugli aspetti igienico sanitari concernenti la costruzione, la manutenzione e la vigilanza delle piscine ad uso natatorio. *Gazzetta Ufficiale della Repubblica Italiana*, del. 3.3.2003, n. 51.
2. Rossi G., Comuzzi C., Barbone F., Goi D. Experimental tests for ozone disinfection treatment in a small backyard swimming-pool. *J. waste water treatment analysis 1:105*, vol. 1, issue 2, p. 126.
3. Tripathi S., Tripathi D. M., Tripathi B. D. removal of organic content and color from secondary treated wastewater in reference with toxic potential of ozone during ozonation. *Hydrol current*, res. 2, p. 111.
4. SanPiN no. 69. Sanitary requirements for centralized drinking water supply. Minsk, Ministry of Health of the Republic of Belarus Publ., 2014. 20 p. (in Russian).
5. SNB 4.01.01-03. Drinking water supply. General provisions and requirements. Minsk, Ministry of Architecture and Construction Publ., 2004. 29 p. (in Russian).
6. TKP 45-4.01-181-2009. Water treatment facilities. Disinfection of water. Design rules. Minsk, Gosstandart Publ., 2010. 32 p. (in Russian).
7. Christopher R. Schulz, Stephen R. Lohman. Method and apparatus for ozone disinfection of water supply pipelines. Patent US, no. 20050249631, 2005.
8. Ramanouski V. I., Hurynovich A. D., Chaika Y. N., Wawzhenyuk P. Ozone disinfection of water intake wells and pipelines of drinking water supply systems. *Proceedings of BSTU. Chemistry and technology of inorganic substances*, 2013, no. 3, pp. 51–56.
9. Ramanouski V. I., Chaika Y. N. Corrosion resistance of carbon steel to disinfectant solutions. *Trudy BGTU* [Proceedings of BSTU], 2014, no. 3, pp. 47–50 (in Russian).
10. Kasatkin A. G. *Osnovnye protsessy i apparaty khimicheskoy tekhnologii* [Basic processes and devices of chemical technology]. Moscow, Chemistry Publ., 1973. 754 p.
11. Punmia B. C., Kr. Jain Arun, Jain Ashok. *Water Supply Engineering*. New Delhi, Laxmi Publication (P) Ltd., 1995. 584 p.
12. Kogan V. B., Fridman V. N., Kofarov V. V. *Spravochnik po rastvorimosti* [Handbook of solubility]. Moscow, Chemistry Publ., 1961. 961 p.
13. Dmitriev C. M., Kondrat'ev M. P. *Generator ozona* [Ozone generator]. Patent BY, no. 2003040115, 2005.
14. GOST 18301–72. Drinking water. Methods of determination of ozone residual content. Moscow, Gosstandart, 1974. 4 p. (in Russian).
15. Lunin V. V., Popovich M. P., Tkachenko S. N. *Fizicheskaya khimiya ozona* [Physical chemistry of ozone]. Moscow, MSU Publ., 1998. 480 p.

16. Draginski V. L., Alekseeva L. P., Samoilovich V. G. *Ozonirovanie v protsessah ochildki vody* [Ozonation in processes of water purification]. Moscow: DeLi print Publ., 2007. 400 p.

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