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PORTABLE DEVICE FOR WATER PURIFICATION IN EMERGENCIES

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RESUME

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In the conditions of war and extreme life situations, the main task is to provide people with basic life products and drinking water, the shortage of which occurs as a result of the numerous destruction of infrastructure facilities. In the conditions of war in the front and near-front zones and in the newly de-occupied territories, the restoration of critical water infrastructure is impossible due to constant shelling and repeateable destruction.

To solve this problem there are mobile complex systems for treatment of surface or underground water, with the help of which the main pollutants are removed from the source water, namely, mechanical, organic and microbiological. Usually, the technology of water treatment with such systems includes disinfection of water with chlorine and dechlorination on carbon filters. However, for the effective operation of such equipment, it is necessary to ensure an uninterrupted power supply, a stable water source and specialized maintenance, which is not always possible in wartime conditions.

Therefore, the creation of a portable device with a filter element of the "carbon block" type is a very urgent task today. The use of such a device can allow the implementation of water purification from any source to the level of the requirements of drinking water quality standards and provide basic needs for safe drinking water in extreme conditions.

A carbon filter with a fixed structure of the "carbon block" type was developed, in which polyethylene was used as a binding material, and a device was created for the purification of water from natural sources in emergency situations with its use.

Recommendations for the use of the developed device for obtaining safe water in the field are formulated.

GRATITUDE

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AUTOBIOGRAPHY

I, Anastasia Kozak, was born on April 15, 2007 in Kyiv. From 2013 to 2017, studied at Olesya Honchara Specialized School 76. Since 2017, I have been studying at Lyceum 142 in Kyiv. Mother - Kozak Alla, born in 1982, Ukrainian, has a higher pedagogical (philological) education. Father - Volodymyr Kozak, born in 1977, Ukrainian, educated as an electrician. My hobbies are painting and creative writing. Have repeatedly taken places at All-Ukrainian level competitions and subject Olympiads at the city level. Took 3rd place at the 2nd stage of the 3rd All-Ukrainian national selection of the IJSO International Youth Science Olympiad, 3rd place at the final of the All-Ukrainian competition "Eco-Techno Ukraine 2022". In 2021, won 2nd and 3rd place at the II stage of the All-Ukrainian competition for the defense of scientific and research works of students-members of Junior Academy of Science of Ukraine, and in 2022 - took two 2nd and 3rd places. I live at the address: Kyiv, str. Verhovynna 18, ap. 87, contact phone number: +380 (67) 7361088, email: anasta.koz10@gmail.com

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CONTENT

page

INTRODUCTION

In the conditions of war and extreme life situations, the main task is to provide people with basic life products and drinking water, the shortage of which occurs as a result of the numerous destruction of infrastructure facilities. In the conditions of war in the front and near-front zones and in the newly de-occupied territories, the restoration of critical water infrastructure is impossible due to constant shelling and repeated destruction. The problem is large-scale, and it is almost impossible to meet all military and civilian drinking water needs with a centralized water supply. In most cases, in these situations, drinking water is delivered by transport, but during the period of mass shelling, there are interruptions in supplies and, accordingly, a shortage of drinking water.

To solve this problem, there are mobile complex systems for cleaning surface or underground water, with the help of which the main pollutants are removed from the source water, namely, mechanical, organic and microbiological. Usually, the technology of cleaning with such systems includes disinfection of water with chlorine and dechlorination on carbon filters. However, for the effective operation of such equipment, it is necessary to ensure an uninterrupted power supply, a stable water source and specialized maintenance, which is not always possible in wartime conditions. Therefore, the creation of a portable device with a filter element of the "carbon block" type is a very urgent task today. The use of such a device can allow the implementation of water purification from any source to the level of the requirements of drinking water quality standards and provide basic needs for safe drinking water in extreme conditions.

The aim of the study – development of a portable device based on a filter of the "carbon block" type to ensure a person's daily need for safe drinking water in extreme situations.

To achieve the goal, the following tasks must be completed:

– To conduct an analysis of water from a natural source, the Dnipro River, for the content of the main components;
– To propose a cleaning method that will allow obtaining water of the required quality, which does not harm human health;
– To develop a carbon filter with a fixed structure of the "carbon block" type;
– To develop a portable device based on a “carbon block” type carbon filter for water purification in extreme situations;
– To provide recommendations for using the device in the field.

Object of study – water purification processes from natural sources with increased color and excessive content of active chlorine.

Subject of study – regularities of processes of extraction of suspended and soluble organic substances and excess amount of active chlorine using sorption filter materials.

Research method – search; experimental - titrimetric.

Characteristics of work – applied.

The novelty of the work:

- A carbon filter element with a fixed structure of the "carbon block" type was created to reduce the color and turbidity of water and remove residual active chlorine and a portable device for its use in extreme conditions.
- Recommendations for the use of the developed device for obtaining safe water in the field are formulated.

Practical significance

- Compactness and versatility of use of the device for cleaning water from various sources, which contains soluble and suspended substances, as well as residual active chlorine.
- Ease of manufacture and high efficiency of a “carbon block” type carbon filter for obtaining safe drinking water.
- Sufficient mechanical stability of the developed filter to ensure a person's daily need for safe drinking water without its destruction.

CHAPTER 1
CURRENT STATE OF THE PROBLEM OF SAFE DRINKING WATER CONSUMPTION

Water is considered drinkable if its quality indicators meet the requirements of established standards, which are international or local for each country. In Ukraine, since 2010, the State sanitary norms and rules "Hygienic requirements for drinking water intended for human consumption" have been in force, which regulate the content of 86 substances in water. In the conditions of martial law the other local rulesenters into force, which is characterized by reduced values of requirements for some indicators.

Providing humanity with high-quality drinking water is one of the main problems of today, which require an urgent solution. However, taking into account the length of water networks and their condition, the water that reaches us from the water tap does not always meet the quality requirements. During the centralized preparation of drinking water, special attention is paid to its microbiological stability, therefore, the stage of water disinfection is mandatory before supplying water to the consumer. Most often, the chlorination method is used for this. However, when water is chlorinated in the presence of organic substances, organochlorine toxic compounds are formed, which is very harmful to the human body.

The use of bottled water cannot be a solution to the problem, because plastic bottles, which are used to transport, store and consume water, not only pollute the drinking water itself with toxic components included in their composition, but are also one of the biggest sources of environmental pollution.

However, the problem of access to safe drinking water is especially acute in extreme conditions, when water can only be obtained from natural sources. In this case, it is necessary to ensure water disinfection and removal of residual chlorine, as well as suspended substances, organic impurities and chlorine-derived compounds..

Currently, chlorination is the most common method of water disinfection. In practice, gaseous chlorine, sodium and calcium salts of hypochlorous acid are used – hypochlorites $NaClO$ and $Ca(ClO)_2$, chlorine oxide (IV) ClO_2 [1, 2]. Disinfecting agents in these compounds are chlorine itself, hypochlorous acid and oxygen released during its decomposition. The use of hypochlorites is based on their hydrolysis, resulting in the formation of an unstable acid $HClO$. The bactericidal effect of chlorine-containing reagents is reduced to oxidation and chlorination of the constituent parts of the cytoplasm of bactericidal cells.

The active chlorine of chlorine-containing compounds is determined by the amount of gaseous chlorine equivalent to the amount of oxygen released during the decomposition of these compounds. Chlorine that does not participate in the oxidation of organic and inorganic impurities is called bound.

The amount of chlorine need for the oxidation of organic and inorganic impurities determines the amount of chlorine absorbed by water. The dose of the disinfecting reagent is selected in such a way that after the oxidation of all impurities in the water, some excess amount of chlorine remains - the so-called residual chlorine.

It is known that when the dosage of chlorine-containing disinfecting agents is violated in the presence of other pollutants in the water, for example, organic substances, organochlorine compounds, trihalomethanes, can be formed, which are toxic and carcinogenic due to their effect on the human health. To reduce their amount in disinfected water, it is necessary to carry out additional cleaning using sorbtion materials.

CHAPTER 2
EXPERIMENTAL PART

2.1 Determination of indicators of water quality

Determination of indicators of water quality was carried out according to the following methods, which are given in the list of references: dry residue and pH were determined on the instrument Bante 900 (China) [3], total hardness according to the method [4], total iron to [5], manganese to [6], permanganate oxidizability to [7], color to [8], trihalomethanes for [9], total microbial count to [10].

2.2 Methodology for determination of active chlorine in water

According to the State sanitary norms and rules (Standart 2.2.4-171-10), after a 30-minute contact of chlorine with water, the residual chlorine content should be no more than 0.5 mg/L and no less than 0.3 mg/L at the exit from treatment facilities, and no less than 0.1 mg/L in the most remote water intake points. Active chlorine in chlorine-containing compounds, residual chlorine in water and absorption of chlorine by water are determined by the method of iodometry.

Determining the content of active chlorine in water is possible using an express analysis, for which a set of reagents is used:

1. Test tube with reagent crystals «ACT.CHLORINE 1»
2. Dropper 50 mL with reagent «ACT.CHLORINE 2»
3. Dropper 50 mL with reagent «ACT.CHLORINE 3»
4. Dropper 50 mL with reagent «ACT.CHLORINE 4»

The sequence of operations for determining the content of active chlorine by the express method:

1. The analysis should be carried out in a well-lit room.
2. Rinse the measuring tube with the water being analyzed.
3. Pour the water to be analyzed into the measuring tube up to the mark of 10 ml on the lower meniscus.
4. Close the measuring tube with a lid. Further addition of reagents is carried out through the hole in the lid.
5. Add several crystals of the reagent "ACT. CHLORINE 1" and 10 drops of the reagent "ACT. CHLORINE 2". Stir intensively.
6. Add 2-3 drops of the reagent "ACT. CHLORINE 3". In the presence of active chlorine in the water, the color of the solution will turn blue.
7. Next, drop by drop the reagent "ACT. CHLORINE 4", intensively stirring the solution after adding each drop.

8. Addition of the reagent "ACT. CHLORINE 4" is continued until the solution is completely decolorized.

9. The number of drops of the reagent "ACT. CHLORINE 4" is substituted into the formula:

$$\text{ACT. CHLORINE (mg/L)} = \text{the number of drops} \times 0{,}71$$

Additional recommendations: if less than 10 drops of the "ACT. CHLORINE 4", then to increase the accuracy of determining the content of active chlorine, it is recommended to increase the volume of water analyzed to 20 mL or 40 mL. The number of reagents "ACT. CHLORINE 1" and "ACT. CHLORINE 3" must also be increased by 2 or 4 times, respectively. The result of the analysis in this case must be reduced by 2 or 4 times, respectively.

2.3 The method of manufacturing a “carbon block” type carbon filter

1) Preparation of the press form for work. For the convenience of installing the filter material in the device, it is formed in the form of discs - "carbon blocks".

2) Preparation of the mixture for pressing. The pre-prepared mixture weighing 18 g with the content of activated carbon 88% and the mixture of polymer binder 12% is carefully poured into the mold, then compacted in order to achieve an even surface.

3) The press form is connected to the automation cabinet using a special cord. A thermocouple must be connected to the press mold. When the temperature reaches 190 ºC, the power supply stops and the mold works in inertial mode in the range of 185-190 ºC.

5) The mold is heated from 20 ºC to 90 ºC in 30 minutes. 60 minutes are allocated for heating the mixture to 190 ºC, melting the binder and its spreading in the layer of activated carbon.

6) After cooling, the mold is placed on a special push-out cylinder, a load of 2.5 kg is placed on the upper punch. It is necessary to remove the load and the ejector cylinder and leave the "carbon block" for 30 minutes to cool down. Next, carefully release the "carbon block" and leave it in the air for 2 hours for complete solidification.

8) The mold matrix and punches must be thoroughly cleaned after each formation of the "carbon block".

The parameters of the "carbon block" manufacturing process are listed in the table 2.1.

Table 2.1 – Parameters of the “carbon block” carbon filter manufacturing process

The name of the operation	Dimensionality	Value
1	2	3
Weight of the mixture	g	18,4
Weight of intermediate cargo	kg	1
The mass of the main load (0,5 atm)	kg	5

Continuation of Table 2.1

1	2	3
Warming up the mold to 190 ºC	min	30
The duration of the sintering operating mode	min	60
Sintering temperature	ºC	190±5
Expulsion temperature	ºC	125-130
The weight of the carbon filter	g	18,0
Size	mm × mm	55 × 14

According to the described technological regulations, a series of "carbon blocks" (Fig. 2.1) with an activated carbon content of 88% and a polymer binder mixture of 12% (P12) were produced.

The manufactured filter material was then installed in a special nozzle (Fig. 2.2), which was the main element of the device for water purification.

Figure 2.1 – Photo of the "carbon block" P12

Figure 2.2 – The nozzle of the device for water purification

To purify water from impurities, the nozzle is placed in a 5-liter container (Fig. 2.3), in an emergency situation, a 5-liter bottle with water is best suited.

Figure 2.3 – Photo of the water treatment installation

CHAPTER 3
RESULTS OF EXPERIMENTS AND DISCUSSION

3.1 Test results of the obtained carbon filters of the "carbon block" type

The portable device was tested on real water from the Dnipro river. According to the data presented in Table 3.1, the values of water quality indicators from the Dnipro river in terms of color, turbidity and total microbial count do not correspond to regulatory documents that are in effect both in peacetime and in wartime. The values of quality indicators for total iron and permanganate oxidizability correspond to the norms of Standart 683-22, which operates under martial law conditions [11]. All other indicators are within normal limits according to [12].

Stages of water purification during testing include:

1. Determination of chlorine content of water – chlorine content of river water was 3.84 mg Cl_2 per liter.
2. Chlorination of 6 L of water from the Dnipro River to establish a residual chlorine concentration of 1 mg Cl_2 per liter.
3. Water filtration through a “carbon block” element.

Figure 3.1 shows the test of the P12 “carbon block” element on the effectiveness of removing color and residual active chlorine from the water of the Dnipro River.

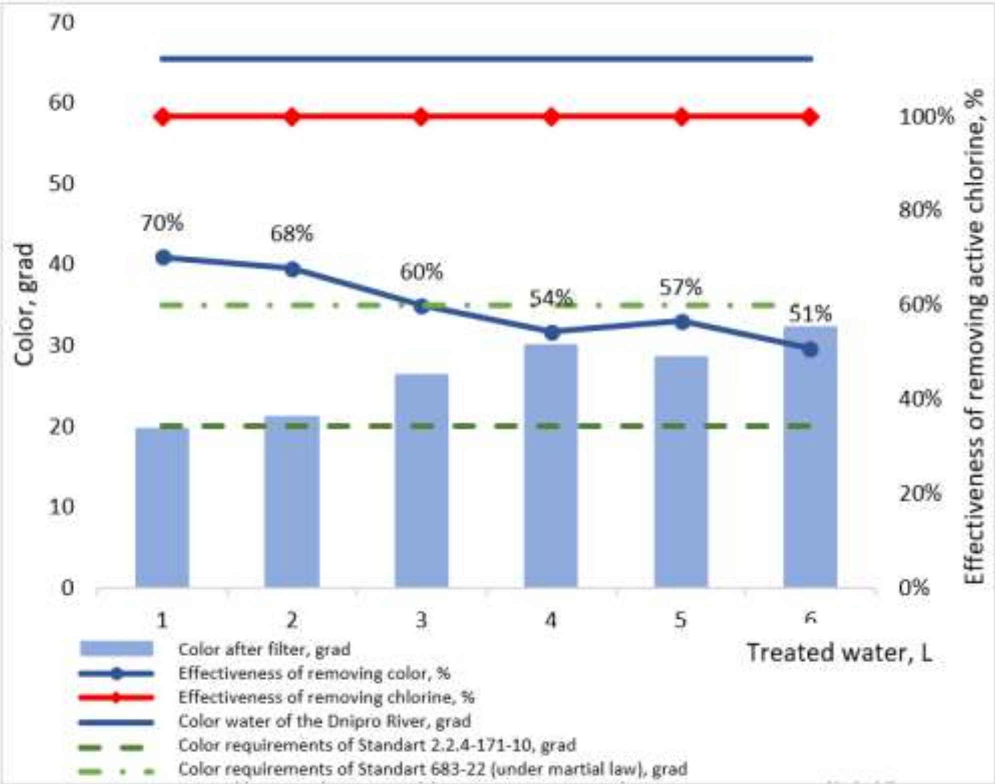

Figure 3.1 – Testing of the P12 “carbon block” element for the effectiveness of removing color and residual active chlorine from the water of the Dnipro river

It can be seen from Figure 3.1 that the efficiency of water color removal in the first liter is 70 %, which corresponds to a color of 19.6 degrees and meets the requirements according to Standart 2.2.4-171-10. From the second to the sixth liters, the color removal efficiency drops from 68 % to 51 %, and the color value increases from 21 to 31.2 degrees, which is acceptable and meets the requirements of Standarts 683-22, which operates under martial law. The degree of removal of active free chlorine in each liter of purified water is 100 %.

Table 3.1 shows data on indicators of the quality of source water from the Dnipro River and that which was chlorinated and then passed through a filter, as well as the requirements of regulatory documents.

Table 3.1 – Indicator indicators of water quality and requirements of regulatory documents

№	Characteristic	Initial river water	Water after chlorination and “carbon block” element	according to Standart 2.2.4-171-10	according to Standart 683-22 under martial law
1	Dry residue, mg/L	310	298	<1000	<1500
2	Turbidity, mg/L	6.8	1.3	<0.58	<2.03
3	pH	7.1	8.0	6.5-8.5	≥ 6.5 and ≤ 9.0
4	Total hardness, mol/L	2	2	<7	<10
5	Total iron, mg/L	0.228	0.037	<0.2	<1
6	Permanganate oxidizability, mg O_2/L	6.20	3.70	<5	without abnormal changes
7	Color, degrees	65.4	25	<20	<35
8	Active chlorine, mg/L	1*	<0.2	<0.5	<0.5
11	Trihalomethanes (sum) μg/L	85*	10	≤100	≤100
12	Total microbial count at 37 °C - 24 h, CFU/mL	613	0	≤50	≤50

* The value of the indicator after chlorination

According to the data presented in Table 3.1, the quality of purified water after the "carbon block" type filter in terms of quality indicators meets the requirements of Standart 2.2.4-171-10, including microbiological ones, except for color and turbidity, according to which there is compliance with Standart 683-22, which operates under martial law.

3.2 Recommendations for the use of a portable device with a "carbon block" carbon filter in the field

The process of water purification in the field includes the following stages:

1) Take water from an available source into a container with a volume of 5 L.
2) Add 45 drops (2.5 mL) of sodium hypochlorite solution with a concentration of 10 g/L to a container with water, close it hermetically and mix thoroughly.
3) Leave the container closed for 30 minutes.
4) Install the device with a "carbon block" filter in a container with a cut bottom.
5) Pour the chlorinated water into the container with the device.
6) Install the faucet for draining the filtered water in a vertical position.
7) Collect purified water in a receiving container.

A photo of field tests of the carbon filter "carbon block" is presented in Annex A.

3.3 Calculation of the cost of a portable carbon filter "carbon block"

Obtaining safe drinking water using the developed portable device based on the carbon filter "carbon block" includes two stages - chlorination of water of unknown quality and filtering of chlorinated water through the manufactured filter.

The cost of a dropper with a solution of sodium hypochlorite with a nominal volume of 50 mL, designed to disinfect water from a surface source, costs €0.08. The cost of manufacturing a carbon filter of the "carbon block" type consists of the cost of raw materials, production costs and employee wages, and is €0.0745 per piece based on obtaining 5 L of safe water. The cost components for obtaining safe water using the developed portable device with the "carbon block" filter are presented in Table 3.2.

The main purpose of the portable device is to provide people with drinking water in emergency situations such as tourist trips, natural disaster areas and frontline areas. For example, to provide two people with safe drinking water for 5 days (or for 1 person for 10 days), a minimum of 50 L is needed, to obtain which it is enough to have a set that includes a dropper with a solution of sodium hypochlorite for pre-disinfection of water and 10 carbon filters of the type "carbon block". The cost of such a set is €0.745.

For comparison, an alternative solution can be the availability of 50 L of bottled water, the cost of which is €12.5, but transporting such a volume of water is a difficult task in emergency situations. Another alternative solution can be the use of existing portable membrane filters, the cheapest option of which costs €36.5 [13]. However, portable devices based on membranes cannot be used to clean turbid water, because insoluble particles will mechanically destroy the membrane. Another disadvantage of membrane filters is their tendency to biofouling due to the lack of bactericidal action, and the impossibility of preliminary chlorination of contaminated water, because active residual chlorine, which ensures water disinfection, will destroy the membrane fabric, and pathogenic microorganisms and other pollutants can enter the purified water.

Table 3.2 – Components of the cost of obtaining safe water with a portable device

№	Materials	Market value		Filter manufacturing costs	The cost of making a filter		Resource of use for obtaining safe water, L
Preliminary processing							
1	Dropper with sodium hypochlorite solution, 50 mL	0.0809 3.2	€ UAH		0.0809 3.2	€ UAH	50
Filter manufacturing costs							
2	Activated carbon Indocarb WT E501	2.916 115.38	€ UAH	0.0162	0.0472 1.87	€ UAH	5
3	Polymer binder DOWLEX™ 2631UE	2.607 103.18	€ UAH	0.0022	0.0057 0.227	€ UAH	5
4	Production costs, % of the cost price			10%	0.0061 0.242	€ UAH	5
5	Salary expenses, % of the cost price			12%	0.0073 0.290	€ UAH	5
	Σ Costs per 1 use (1 day)				0.0745 2.95	€ UAH	5
	Σ Costs per 10 uses (10 days)				0.745 29.48	€ UAH	50
6	Filter nozzle (multiple use)	1.7 68	€ UAH				

Thus, the developed portable carbon filter of the "carbon block" type is the only reliable and economically feasible way to provide people with safe drinking water in emergency situations. In addition, used filters can be used as briquettes for heating or lighting a fire, as each filter contains 88% activated carbon.

CONCLUSIONS

A carbon filter with a fixed structure of the "carbon block" type, which contains 12% polyethylene as a binding material, was created.

A portable device for water purification in extreme situations using a carbon block filter was created to reduce turbidity and colour of water and remove residual active chlorine.

Recommendations for obtaining safe water in the field conditions using the developed device are formulated.

Pilot tests of the Dnipro River water purification process using a portable device have shown that obtaining water that meets the standards in force in Ukraine during martial law is possible.

The cost of obtaining 5 litres of safe drinking water using pre-chlorination and subsequent filtration through a carbon block filter was calculated and is €0.0745, including the cost of manufacturing the filter.

The cost of a kit to provide two people with safe drinking water of 50 L for 5 days, which includes a dropper with a sodium hypochlorite solution for preliminary water disinfection and 10 carbon filters of the "carbon block" type, was determined. The cost of the kit is €0.745.

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ANNEX A

MANUFACTURING AND FIELD TESTING OF THE "CARBON BLOCK" TYPE FILTER