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THERMOELECTRIC DEVICE FOR COLLECTING EXHALED AIR CONDENSATE

The article presents the results of the design development and a description of the manufactured experimental sample of a new highly efficient thermoelectric condenser of pulmonary air for the diagnosis of coronavirus and other diseases with an extended range of condensation temperatures below – 20 °C and close to – 70 °C. The method of using the developed device in medical diagnostics and the results of its experimental studies are described. Bibl. 5, Figs. 5.
Key words: diagnostics, coronavirus, condensate, exhaled air, thermoelectric cooling.

Introduction

Exhaled air condensate is a promising source of lung disease biomarkers. It can be considered either as a body fluid or as a condensate of exhaled gas. There are three main contributions to exhaled air condensate. First, these are particles or droplets of various sizes that are aerosolized from the liquid lining the respiratory tract – such particles probably reflect the liquid itself. Secondly, it is distilled water that condenses from the gas phase with almost water-saturated exhalation, significantly diluting the aerosolized liquid of the respiratory tract. Thirdly, these are water-soluble volatile substances that are exhaled and absorbed into the condensing breath. Of interest are both non-volatile components, mainly derived from particles of liquid lining the respiratory tract, and water-soluble volatile components, which are present in much higher concentrations and, therefore, easier to analyze than non-volatile compounds.

Diagnostic testing plays a crucial role in overcoming the pandemic of the coronavirus disease COVID-19, caused by the severe acute respiratory syndrome coronavirus SARS-CoV-2. Given that COVID-19 is transmitted through aerosols and droplets exhaled by humans, the detection of SARS-CoV-2 in lung condensate may serve as a promising non-invasive diagnostic method. This method is proposed in the works of scientists from Japan, the USA, Ireland and other countries as a more sensitive and reliable method of detecting COVID-19 [1 – 3]. Usually, special devices are used to collect condensate - condensers, in which vapors from the air exhaled by a person condense at a temperature from 0 to – 70 °C and are collected in a container for further research by the RT-PCR method [4]. Lowering the condensation temperature makes it possible to speed up obtaining the amount of biological material required for research. At the same time, the operating temperatures of condensers that use ice at 0 °C or compressor cooling down to – 20 °C are insufficiently efficient and do not provide a high condensation rate. In addition, compressor condensers are complex, expensive, with insufficient regulation and maintenance of operating temperature, as well as the presence of dangerous refrigerants. The temperature of – 70 °C, which is achieved using dry ice (solid $CO2$), is excessive and extremely inconvenient for operation, which radically reduces the possibilities of using this method. The paper [5] gives the results of the computer design of a thermoelectric device for collecting exhaled air condensate with precisely regulated condensation temperatures lower than – 20 °C and close to – 70 °C without the use of dry ice.

The purpose of this work is to develop the design of the thermoelectric condenser of pulmonary air, its manufacture and experimental studies.

1. Description of the design of a thermoelectric condenser of pulmonary air

The general design of the developed device for collecting exhaled human condensate from the air is shown in Fig. 1. The device consists of two units – a cooling unit, in which a test tube for collecting condensate is placed, and a control unit for the device.

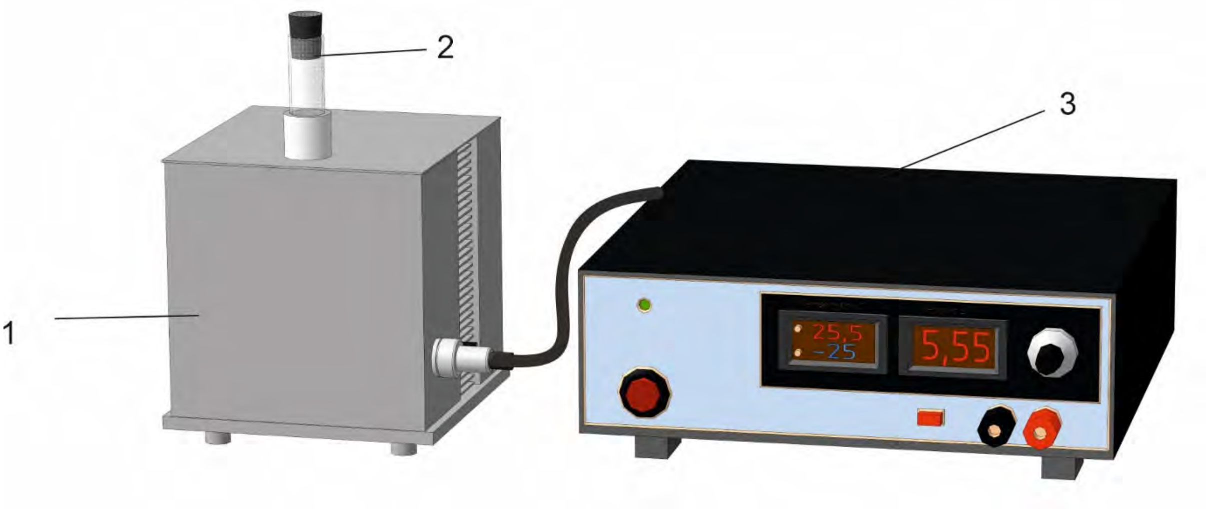

Fig. 1. General view of the design of a thermoelectric device for collecting condensate from the air exhaled by a person: 1 – cooling unit; 2 – tube for collecting condensate; 3 – device control unit.

Fig. 2 shows the expanded design of the cooling unit of the thermoelectric condenser of pulmonary air.

The cooling unit consists of a housing 1, a working cooling chamber 2, a thermoelectric module 3 of the Altec-2 type, and a system for removing heat from the thermoelectric module into the environment, containing an air heat exchanger 4 and a fan 5.

The device for collecting exhaled air condensate works as follows: when the control unit supplies electric current to the thermoelectric module, the latter ensures the set temperature in the working cooling chamber, where the tube for collecting condensate is placed. The air exhaled by the patient enters the test tube, where it cools. At the same time, exhaled air vapours are condensed and collected in a test tube for further research by the RT-PCR method or others.

The cooler control unit is designed to provide electrical power to the elements of the heat exchange unit and measure the temperature of the refrigerating chamber.

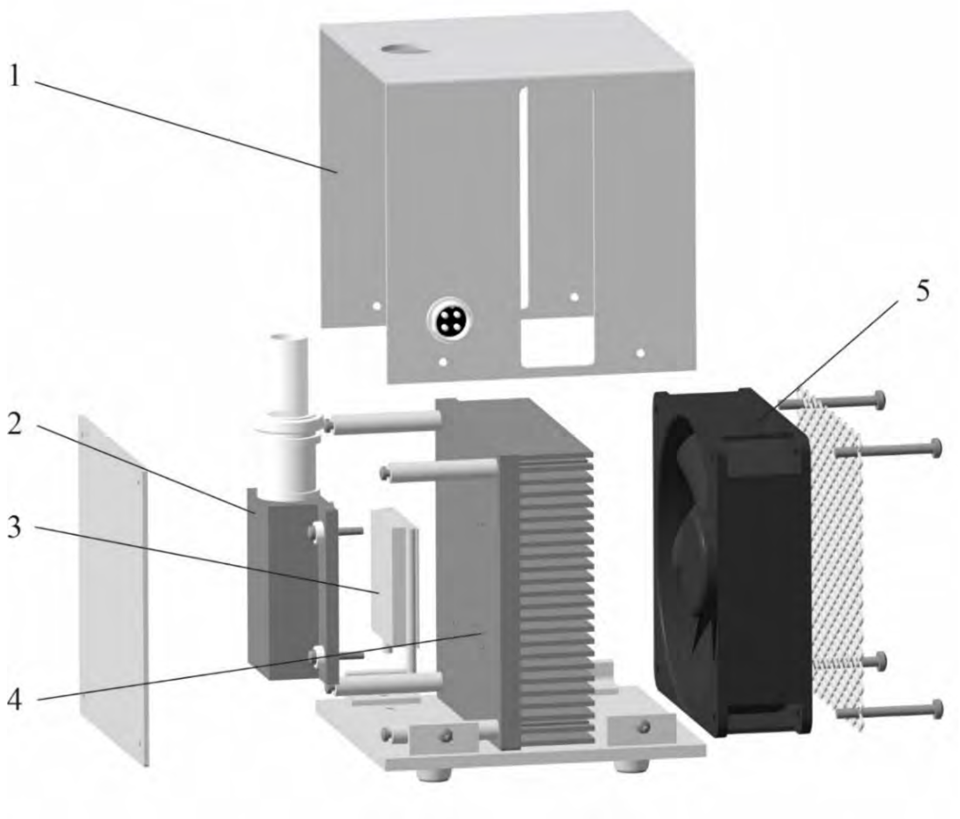

Fig. 2. Cooling unit of thermoelectric condenser of pulmonary air: 1 – housing; 2 – working cooling chamber; 3 – thermoelectric module of the type Altec-2; 4 – air heat exchanger; 5 – fan.

The control unit diagram is shown in Fig. 3. The unit consists of a standard pulse power supply unit – A1, with an output voltage of 12V DC, up to 20 A. Such power is due to the use of a high-power thermoelectric module in the cooling unit.

To fine-tune the speed of cooling by the thermoelectric module of the working chamber, it is necessary to select the voltage (current) of its power supply. For this purpose, the output voltage of the pulsed power supply unit is supplied through the step-down DC/DC voltage converter A3 with the possibility of its adjustment within wide limits. The control unit uses a panel DC voltmeter A2 to control the supply voltage of the module. The output voltage from the pulse power supply is also supplied to the cooling fan, in the circuit of which the rheostat R3 is connected - to regulate the rotation speed within small limits. The supply voltage for the thermoelectric module and the fan is supplied to the cooling unit via the power cable through the connector X2.

To limit the maximum cooling of the working chamber, the digital thermostat A4 is used in the control unit. To turn off the current through the thermoelectric module when setting the operating mode of the thermostat, an additional switch SW2 is used in the control unit circuit. The power key on the field-effect transistor Q1, connected to the output of the thermostat, switches the current through the thermoelectric module and also serves to increase the reliability of the control unit. Temperature control in the working chamber is carried out by the NTC sensor, which is located in the housing of the working chamber and is connected to the control unit by a separate cable X3.

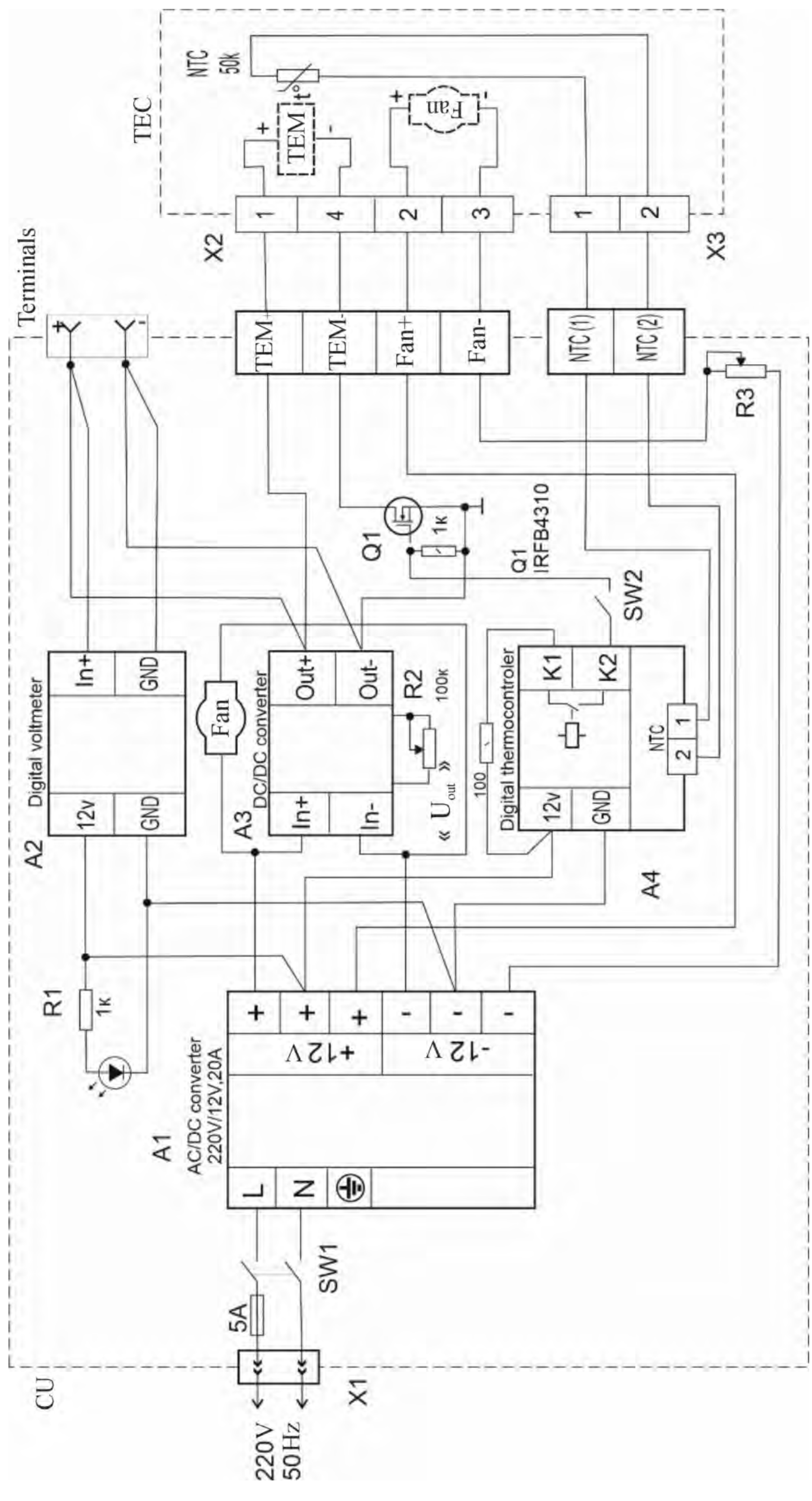

Fig. 3. Schematic diagram of the control unit of the thermoelectric condenser of pulmonary air.

The displays of the voltmeter A2 and the thermoregulator A4, the switches SW1 and SW2, the handle of the supply voltage regulator R2 and the control terminals are located on the front panel of the control unit housing. The handle of the fan regulator R3 and the power cables with connectors X1, X2, X3 and the fuse are on the rear panel of the control unit housing.

The appearance of the developed and manufactured pulmonary air condenser for the diagnosis of coronavirus and other diseases "ІТЕ-ДПЛ " is shown in Fig. 4.

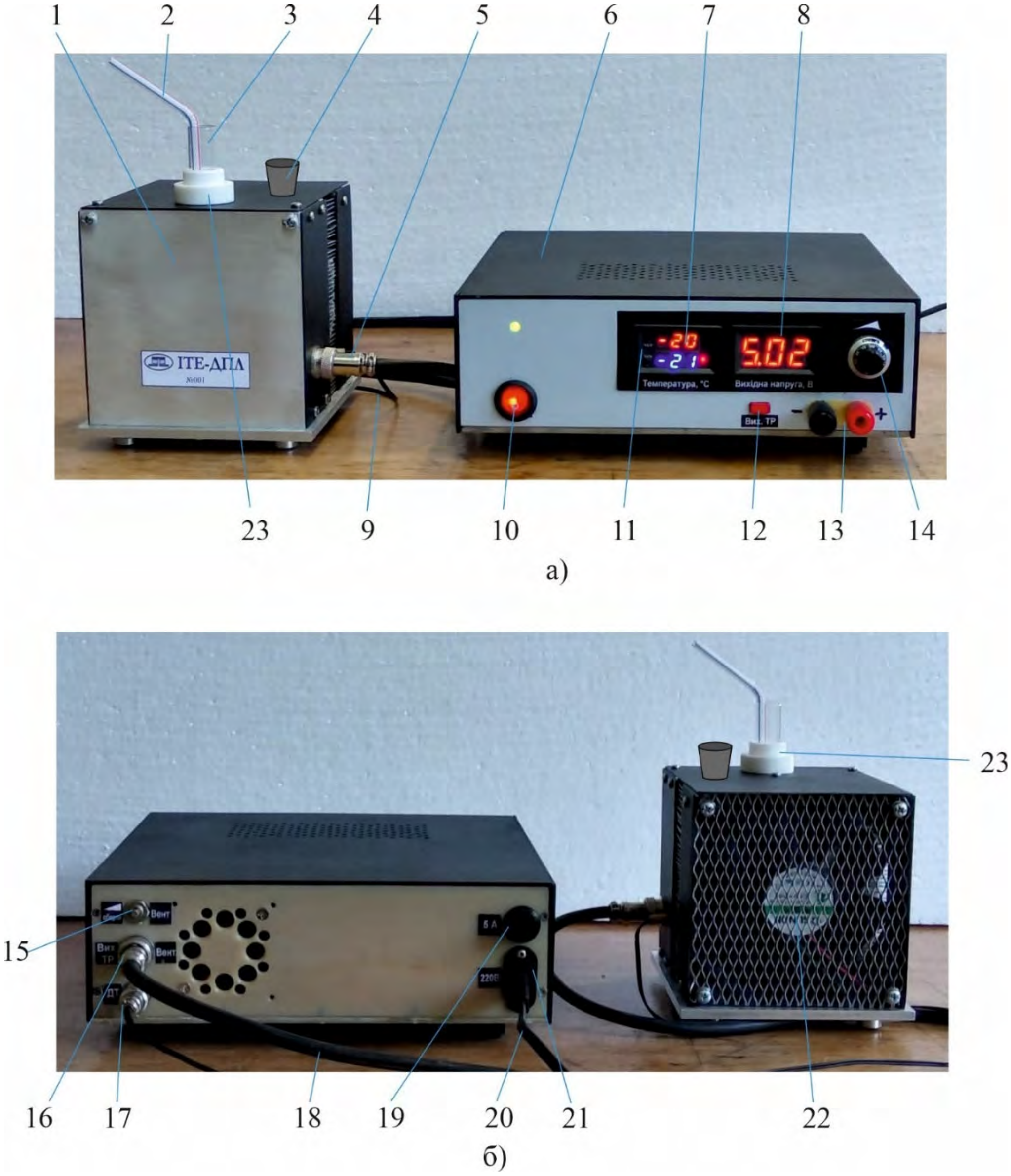

Fig. 4. Pulmonary air condenser for diagnostics of coronavirus and other diseases: a) – front view; b) – back view.

In Fig. 4: 1 – cooling unit; 2 – plastic tube; 3 – test tube; 4 – rubber stopper; 5 – connector for inter-unit cable; 6 – device control unit; 7 – thermal regulator panel; 8 – digital voltmeter of the cooler output supply voltage; 9 – temperature sensor cable 10 – button for turning on the device in the 220 V network; 11 – thermal regulator control buttons; 12 – "Thermal regulator output" button; 13 – additional direct source terminals of the power source; 14 – knob for regulating the output supply voltage of the heat exchanger module; 15 – cooling fan speed controller; 16 – connector for inter-unit cable; 17 – connector for connecting the temperature sensor; 18 – inter-unit cable; 19 – 220 V network fuse; 20 – 220 V network cable; 21 220 V network cable connector; 22 – cooling unit fan; 23 – fluoroplastic cylinder.

The ITE-DPL device kit includes: cooling unit 1 with cable 9; device control unit – 6; inter-unit cable 18; network cable 20; test tube 3 (included – 10 pieces); plastic tube 2 (included – 20 pieces); rubber plug 4 (included – 2 pieces).

The device in the assembled state is shown in Fig. 3.1. The procedure for connecting the parts of the device is as follows:

- cooling unit 1 and device control unit 6 are installed on the work table. The distance between the units is approximately 20 – 40 cm;
- the following are connected to the units: inter-unit cable 18 with one end to connector 5 and the other end to connector 16 and temperature sensor cable 9 to connector 17;
- cable 20 is connected to connector 21, the other end of which is connected to the 220V network;
- 0.2 – 0.5 ml of a 50% x 50% alcohol aqueous solution is introduced into the hole of the fluoroplastic cylinder 23 using a plastic tube 2 to prevent the tube 3 from freezing into the cooling unit 1. After that, the plastic tube is removed outside the unit;
- a test tube 3 is inserted into the hole of the fluoroplastic cylinder 23. In this case, the alcohol solution is displaced by 3 – 10 cm in height into the space between the test tube and the hole to improve cooling of the test tube;
- a plastic tube 2 is inserted into the test tube. After that, the device is ready for work.

2. The method of using a thermoelectric condenser of pulmonary air and its experimental studies

To obtain a liquid condensate of a gas mixture exhaled from the lungs, the following must be done:

- with key 10, the device is connected to the 220V network. As a result, the thermal regulator panel 6 and the operating voltage indication panel start to light up, the fan 22 starts spinning in the control unit;
- regulator 15 regulates the intensity of the fan operation. At an ambient temperature of 20 – 30 °C, the fan operation mode is minimal, which is achieved by turning the regulator to the extreme counterclockwise position. At ambient temperatures above 30 °C, the fan is switched to the intensive operation mode by turning the regulator to the extreme clockwise position;
- the knob 14 regulates the supply voltage of the device cooler. When the knob is set to the extreme counter clockwise position, the voltage is minimal. When the knob is turned to the extreme clockwise position, the supply voltage is maximal. By regulating the voltage, it is possible to supply the cooler depending on the test tube cooling temperature. The voltage value is displayed by indicator 8;
- the required temperature in the test tube is set by buttons 11, which are located on the panel of the thermal regulator 7. At the same time, its indicators provide information about the set temperature – the lower indicator, and the actual temperature – the upper indicator. To set/change the set cooling temperature, briefly (up to 2 s) press the upper button "SET", and when the lower blue indicator of the thermostat panel starts flashing, release the upper button. Then decrease the value of the set temperature with the lower button "°C/F" or increase the value of the set temperature to the desired value with the same upper button "SET". Release the buttons and after a 2-3 second pause, the set value of the set temperature will be fixed;
- press the "Thermal regulator output" button 12 on the front panel of the control unit. The test tube cooling process will begin;
- after setting the required temperatures (approximately 10 – 15 minutes), an air mixture from the

lungs is introduced into the test tube through a plastic tube 2 by exhaling it through the mouth. The condensed liquid collects at the bottom of the test tube in approximately 3 minutes in a volume of about 0.5 ml and increases proportionally with an increase in the exhalation time;

- after receiving the required volume of liquid, the test tube is taken outside the device to conduct the appropriate analysis of the condensate;
- the opening of the fluoroplastic cylinder 23 is closed with a rubber plug 4.

The latter is important, since the entry of various foreign particles into the hole for the test tube can lead to jamming of the test tube and its destruction.

If it is necessary to take a number of samples of condensed liquid, the established temperature modes can be used. Thus, one sample for analysis can be taken in 5 – 10 minutes, i.e. approximately 8 – 10 samples can be obtained in one hour.

If necessary, condensate can be obtained in the form of ice. For this purpose, it is recommended to collect samples at maximum supply voltages of unit 1 and lower cooling temperatures (– 20 °C and below). To prevent freezing of plastic tube 2, it should be gradually raised so that its lower end is above the condensed ice. Such control is easily achieved by touching the plastic tube to the formed ice surface.

To turn off the device, press the "Thermal Regulator Output" button 12 on the front panel of the control unit, and then use key 10 to disconnect the device from the 220 V network.

The set values of the supply voltage and the set cooling temperature are saved after the device is switched off and do not need to be re-entered when switched on again, unless there is a need to specifically change the modes to others.

Such a device allows collecting the condensate of air exhaled by the patient with precisely regulated temperatures lower than – 20 °C and close to – 70 °C without the use of dry ice.

Fig. 5. Experimental studies of the developed thermoelectric condenser of pulmonary air.

The developed device can also be used for patients on artificial ventilation of the lungs. For this purpose, the respiratory circuit is connected via a special adapter for the exhalation circuit hoses of the artificial ventilation of the lungs. This allows for diagnostics of patients for whom traditional nasopharyngeal swab sampling is impossible, to study the body's response to a specific type of treatment and, thus, to monitor the effectiveness of therapy. The device is applicable for both adults and children of any age.

Experimental studies of the developed thermoelectric condenser of pulmonary air for the diagnosis of coronavirus and other diseases were conducted at the Center for Infectious Lesions of the Nervous System of the State Institution "L.V. Gromashevsky Institute of Epidemiology and Infectious Diseases of the National Academy of Medical Sciences of Ukraine" (Fig. 5).

Based on the research results, recommendations have been formulated for further improvement of the thermoelectric condenser of pulmonary air, aimed primarily at increasing the convenience of its use. The following studies of its effectiveness are also planned, including for the detection of other respiratory pathogens (viruses, rickettsia, mycoplasma, chlamydia, etc.), including by means of a chain polymerase reaction.

Conclusions

1. The design of a new highly efficient thermoelectric condenser of pulmonary air for the diagnosis of coronaviruses and other diseases with an extended range of condensation temperatures, lower than – 20 °C and close to – 70 °C, without the use of dry ice, has been developed.
2. An experimental sample of a thermoelectric condenser of pulmonary air for the diagnosis of coronavirus and other diseases was manufactured and tested. A method of using a thermoelectric condenser of pulmonary air in medical diagnostics has been developed.
3. The developed device was tested at the State Institution " L.V. Gromashevsky Institute of Epidemiology and Infectious Diseases of the National Academy of Medical Sciences of Ukraine". Based on the research results, recommendations were formed for further improvement of the thermoelectric pulmonary air condenser, aimed primarily at increasing the convenience of its use.

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ТЕРМОЕЛЕКТРИЧНИЙ ПРИЛАД ДЛЯ ЗБИРАННЯ КОНДЕНСАТУ ВИДИХУВАНОГО ПОВІТРЯ

Наведено результати розробки конструкції та опис виготовленого експериментального зразка нового високоефективного термоелектричного конденсатора легеневого повітря для діагностики коронавірусних та інших захворювань з розширеним діапазоном температур конденсації, нижчими від – 20 °C та близькими до – 70 °C. Описано методику використання розробленого приладу у медичній діагностиці та результати його експериментальних досліджень. Бібл. 5, рис. 5.

Ключові слова: діагностика, коронавірус, конденсат, видихуване повітря, термоелектричне охолодження.

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