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USE OF ADSORPTION OXYGEN CONCENTRATOR IN MEDICAL PRACTICE

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The article deals with the use of pure oxygen in medicine. In a comparative vein, the main ways of providing medical and prophylactic institutions with oxygen are considered, information on the requirements for modern equipment of specialized medical facilities and departments is provided. Those problematic aspects of a fatigue, which are regularly encountered by the heads of medical institutions, are highlighted, taking into account many factors that were not taken into account when the well-established work of the centralized supply of medical oxygen (climate, the transport component, the economic issue, the situation with competent technical personnel, document flow work in supervising institutions, etc.). The regulatory frameworks on the arrangement of various oxygen supply systems are presented. Information on safety requirements when working with liquid and gaseous oxygen in vessels under pressure is provided. With reference to the regulatory documentation, the point of view is stated that, taking into account modern economic and economic aspects, in a number of medical institutions, in addition to the traditional-cryogenic method of obtaining medical oxygen, a short-cycle adsorption without heat is very often an expedient method of obtaining oxygen. This adsorption allows to produce pure gas with relatively low pressure and ambient temperature directly at the place of the gas consumption. The method of non-heating adsorption is described, and information on design of the installation for the production of oxygen is given in detail. The technical characteristics of various types of oxygen concentrators of various production capacities are given.
Key words: marine medicine, oxygen, air, oxygen supply, medical institutions, diseases, adsorption, short-cycle adsorption, oxygen concentrator, safety, molecular sieve.

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History of oxygen use in clinical practice. Oxygen is unique at its contribution to both the human race and the biological envelope. Its extremely strictly regulated content in the atmospheric air (20.95% by volume, or 23.15% by weight) provides all living organisms with biological activities precisely in the life forms created during the evolutionary process. Even insignificant changes in the oxygen content can lead to serious consequences. That is why studying the role of oxygen in biology, chemistry, medical sciences, as well as in other natural sciences is very important. In this article, it is impossible to even briefly describe at least some of the areas of oxygen use, therefore, given the magazine's target audience, the authors decided to focus on specific clinical aspects of its use.

Oxygen as a chemical element takes part in various biochemical processes of intracellular metabolism, due to which the cells of the human body function. Oxygen as a separate substance became known only in the second half of the XVIII century, when Joseph Priestley managed to isolate it. Its importance for human life was investigated a little later, for the first time oxygen was used in medicine in 1810, but from that moment its effect on the human body became so widely used in various types of medical care that it is impossible to do without it now. The effect of oxygen on biological processes in the body continues to open up to medical specialists more and more new directions for its use, they have learned to use it correctly and rationally and thus save the lives of patients. Today, oxygen is used in almost all areas of medicine. It takes its place in the treatment of both acute and chronic diseases and disease states. Oxygen is the cornerstone of therapeutic interventions in the intensive care. It is especially important when carrying out cardiopulmonary resuscitation, artificial ventilation of the lungs and in heavy patients for the intensification of metabolic processes in the body. Oxygen is also used in medicine for cardiac and pulmonary pathology, when its entry into the body or delivery to tissues is impaired. Doctors refer to the lack of oxygen in the blood as hypoxemia. One of the readily available parameters for its evaluation is the indicator of blood saturation – the amount of oxygen saturation of hemoglobin, red blood cell protein, which is responsible for the transport of oxygen from the lungs to the tissues. In all conditions when the saturation of the blood falls, the appointment of oxygen inhalation is mandatory. Then the inhalation of oxygen, or rather the air mixture with a high oxygen content, can significantly alleviate the patient's condition, and in a number of areas of medical care – to prevent death. Inhalation of pure oxygen leads to an increase in its content in the respiratory tract, which increases the concentration of oxygen in the blood. All these processes improve the delivery of oxygen to the tissues, and, accordingly, improve metabolism.

However, oxygen application in medicine is not limited by its use in a hospital ward, pressure chamber, etc. In a number of indications, in certain diseases oxygen inhalation is useful for a longer time than the period of inpatient or outpatient treatment.

Currently, the problem of individual use of medical oxygen is solved by the production of portable cylinders, which can be used at the workplace, at home, as well as in the field conditions. In addition, the size and weight of the container allows you to carry it with you in your carry-on baggage. Such a solution is useful both for patients who are prescribed oxygen therapy after discharge from an inpatient hospital, and for prophylactic use by a certain contingent of people for medical and professional reasons. Inhalation of pure oxygen causes constriction of cerebral vessels, which is important in treatment of so-called cluster headaches, migraines, and operational use of medical oxygen prevents the development of a number of occupational diseases. When complying with safety requirements for transportation and operation, the use of portable oxygen cylinders is absolutely safe. In addition to portable oxygen cylinders, which have certain disadvantages, individual (bedside) adsorption oxygen concentrators are successfully used in modern practice.

Physical and chemical properties of oxygen and the main safety issues when handling it. Oxygen is an odorless and colorless gas, it is not fire and explosion hazardous, it is not flammable, but it is a strong oxidizing agent, and it intensively supports combustion. It can cause ignition of flammable materials (wood, paper, oil, etc.) and explode when mixed with fumes. The permissible volume fraction of oxygen in the ambient air, which does not contribute to the ignition of clothing and equipment, is not more than 23%. Gaseous oxygen is undangerous to living organisms.

Liquid oxygen is a blue liquid; it has moderately cryogenic properties with a freezing point of –222.65°C and a boiling point of –182.96°C; odorless; not fire-explosive; not flammable, but is a strong oxidizing agent. Combustible porous materials impregnated with liquid oxygen (asphalt, polystyrene foam, polyurethane foam, wood, clothing, etc.) form fire hazardous substances – oxylquites. Liquid oxygen is a danger to living organisms. Contact with liquid oxygen in open areas of the body causes frostbite, as well as damage to the mucous membrane of the eyes.

By themselves, air with an increased volume of oxygen (more than 23%) and pure oxygen are not toxic and cannot burn or explode. Yet since oxygen is an active oxidizing agent, most of the substances and materials in an oxygen environment or in an environment with a high oxygen content form physicochemical systems with increased explosion and fire hazards. The energy required to ignite materials in an oxygen environment is many times less than the energy required to ignite air in the environment under the same conditions. And so the initiators of the ignition of many materials in an oxygen environment can be safe in other conditions causes: smoking, discharge of electricity, discharge of static electricity, heating of mechanical particles during friction, etc. Many materials, which don't burn in the air, such as sheet steel, steel pipes, and the like, do it in oxygen. The ability of materials to fire increases with increasing pressure and temperature of oxygen.

Working with oxygen involves the following hazards:

- ignition of equipment, pipelines and fittings working with oxygen or air with a high oxygen content;
- ignition of clothes and hairs of the attendants who are in the environment of gaseous oxygen or air with the increased content of oxygen;
- explosion of hydrocarbons and other explosive impurities when their content in liquid oxygen is exceeded;
- an explosion during the impregnation of porous organic materials with liquid oxygen (asphalt, foam plastic, wood, etc.);
- structural and sealing non-metallic materials (fiber, nylon, polycarbonate, rubber based on natural rubbers, etc.) can easily ignite in high-pressure oxygen when an ignition source is detected.

When clothing is ignited, one should immediately plunge into a bath with water or have an emergency shower. In the absence of water, clothing should be dropped immediately or torn from the victim. Oxygen-soaked clothing may burn for a while without oxygen, therefore it is not advisable to shoot down a flame or wrap the victim in a felted shirt.

Oxygen use in medical and prophylactic institutions.

It is difficult to imagine a modern hospital or another medical institution for medical care in hospital environment without a single oxygen supply system.

Oxygen supply is provided at the following specialized facilities:

- operating theaters;
- anesthetic;
- resuscitation halls;
- pressure rooms;
- prenatal, patrimonial, and postpartum wards;
- postoperative wards;
- intensive care wards (including for children and for newborns);
- dressings;
- procedural offices;

- blood collection premises;
- procedural endoscopy and angiography;
- wards for 1 and 2 beds of all departments, except psychiatric;
- wards for newborns;
- and wards for premature babies.

Oxygen supply can also be provided in other premises in accordance with the process specification, in which case it indicates the oxygen consumption for these spaces. Oxygen consumption is determined in accordance with the approved calculation method and cannot be less than the specified parameters. In this article, in order to avoid any information glut, the calculations are omitted. A definite exception to the general scheme is the calculation of the consumption of medical oxygen in field hospitals, where the number of beds in wards may increase depending on the current medical situation. However, this aspect is also taken into account when planning the equipping of a field hospital with medical property by taking for the calculated value of the serviced fund the maximum possible number of profiled beds to be deployed.

Ways to address the issue of medical oxygen supply to the end point of consumption. As a source of oxygen supply, the central oxygen point, the oxygen-gasification station (OCS) or the medical adsorption oxygen concentrator (hereinafter referred to as the oxygen concentrator) can be used. In addition to these sources of oxygen supply, an oxygen ramp is also usable, which is used in medical organizations as:

- the main source with a small organization’s need for oxygen (in this case, the total capacity of the cylinders must provide oxygen for the organization to work for at least 3 days);
- reserve (emergency) source in addition to the main source of oxygen (OCS or central oxygen point), if there is an operating or resuscitation unit in the organization.

Below are the main requirements for the placement and equipment, as well as the real production problems in the operation of all of these main sources of oxygen supply.

Central Oxygen Point. The central oxygen point can be placed at wall-mounted fireproof closets, one-story annex buildings, or separate buildings (Fig.1)

Fig. 1. Central oxygen point

In a wall-mounted fireproof cabinet or a single-storey extension no more than 10 cylinders of hydraulic capacity of 40 liters with a gas pressure of 150 atm are located. Wall cabinets are placed on platforms with a mark of 1.2 m from ground level. The floor of a single-floor annex is located on the same level.

When the number of the cylinders or the recipients with a hydraulic capacity of 200 and 400 liters with a gas pressure of 150 atmospheres is more than 10, they are placed in a separate building with heating (with a temperature not lower than + 5 C) with reinforced concrete or brick walls without window openings that have direct access to the outside. In the design and construction of the oxygen point, building materials should be used with parameters not less than those specified below: thickness of a reinforced concrete wall is 100 mm (type 150 concrete with reinforcement 0.1%); brick wall thickness is 380 mm (type 75 brick and type 25 mortar).

The reception area and the floor of the building are located at around 1.2 m from the ground level. The cylinders are placed in containers, 8 pieces in each one, or in cages for storage, 20 pieces in each one. Location in the building of recipients and cylinders at the same time is possible. Oxygen is supplied to the external network from the ramps for oxygen cylinders or the control unit when recipients are installed. Two groups of ramps with oxygen cylinders or recipients are installed – one working, the other reserve. The central oxygen point is supplied with the help of mechanization for unloading and placing the cylinders. Storage of empty and filled cylinders must be provided separately. Cylinders must be installed in a vertical position and secured with devices that prevent them from falling.
The central oxygen points should be located at a distance of at least 12 m from buildings and structures. The floor of the oxygen room should have a concrete coating.
When organizing and operating a central oxygen facility in a medical institution, the following factors of production and financial risks should be taken into account:

- high fire hazard of the object;
- permanent dependence of the medical institution on the organization engaged in filling cylinders with oxygen; the ever-increasing cost of oxygen; in regions with a monopolized market of medical gases, the price of oxygen supplied may exceed average market values by 400–500%;
- constant replacement, delivery and unloading/ loading of cylinders weighing 70 kg with the help of allocated staff of the medical institution who have undergone special training and having the admission to work;
- significant costs for the purchase and delivery of cylinders to the hospital by special transport (front exhaust emissions, etc.);
- maintenance of cylinders is carried out only by certified personnel of the medical institution;
- when increasing the number of beds and expanding the list of medical services, an increase in the number of the cylinders required for supplying a hospital with oxygen often creates production problems with their placement in accordance with the requirements of existing rules and regulations;
- and over time, there is a need to re-examine or purchase new gas cylinders.

Oxygen Gasification Station. An oxygen-gasification station is located on an open area under a shed with a corresponding fence, which prevents access by unauthorized people.

Fig. 2. Oxygen gasification station

An oxygen gasification station (OGS) is designed to bring in liquid oxygen and comprises cold cryogenic vessels designed for storage and gasification of liquid oxygen (Fig. 2). OGS consists of a reservoir for storing and dispensing the liquid product and evaporators used to gasify liquid oxygen and dispense the gas to a consumer. OGS is designed to bring liquid oxygen in tankers and should be located on an open, illuminated area made of concrete or other inorganic materials (asphalt is prohibited) with an appropriate fencing (at least 1.6 m high) to exclude unauthorized people. For the fencing it is allowed to use a metal grid.
The distance from buildings of medical organizations of at least III degree of fire resistance to OGS tanks (with a total amount of liquid in tanks not more than 16 tons) must be at least 9 m. It is allowed to install tanks with liquid oxygen with a total amount of liquid of not more than 16 tons in the blind sections of the walls of medical organizations, and the distance to windows or openings must be at least 9 m.
The distance from tanks located outside the buildings with liquid oxygen with the amount of liquid of 10 tons or more to the external fire and explosion hazardous installations, as well as to open electrical installations with oil filling must be at least 20 m.
The distance from the boundaries of sites for tanks with liquid oxygen to the drainage drains, pit and basements must be at least 10 m. Storm sewers, pit and cellars located outside the sites with vessels and dischargers at a distance of less than 10 m must have concrete fencing (threshold) not less than 0.2 m high on the side facing the site and stand for

dimensions of the objects to be protected for at least 1 m. The dimensions of the site must stand for the dimensions of the tanks and the detachable connection of the loading / unloading device for at least 2 m. The oxygen reset of the safety devices gasifiers constant pressure is allowed to produce at least 3 meters from ground level.

Oxygen gasification stations must have tanks that provide oxygen for at least 5 days.

When organizing and operating an oxygen gasification station in a medical institution, the following factors of production and financial risks should be taken into account:

1) Extremely high fire and explosion hazard of the object. Upon contact of liquid oxygen with small-pore structures (foam, asphalt), an explosion occurs;

2) Complex regulatory and legal framework for the arrangement and operation of the object. A large amount of document circulation on licensing the station from the Rostekhnadzor, Roszdavnadzor, Gospozhnadzor, and Rospotrebnadzor. Regular financial costs for costly maintenance and verification of the facility (pressure vessel);

3) Oxygen gasification stations need constant refueling, dependence on suppliers of liquid oxygen is maintained, that is, problems similar to those occurring during the operation of the central oxygen station supplied with “balloon-based” oxygen are observed;

4) About 10% of the oxygen drained into the gasifiers during their refueling is lost by evaporation.

Oxygen Concentrator. An oxygen concentrator is a plant that allows oxygen to be released from the surrounding air using an adsorption process. The oxygen concentrator allows obtaining oxygen with a purity of (93 ± 3) % at the outlet and with an outlet pressure of up to 0.8 MPa.

Since September 2013, in accordance with GOST R 10083-2011, air enriched in oxygen to a concentration of at least 90% is allowed for use in medical practice along with medical oxygen.

The oxygen concentrator is mounted either in the premises of the treatment-and-prophylactic institution or in a special block-container.

Oxygen concentrators of low productivity (up to 100 l/ min), used as the main source by an organization with a small need for oxygen, can be placed inside the building (in a separate room with window openings, located at the first and upper floors, taking into account the places of maximum consumption).

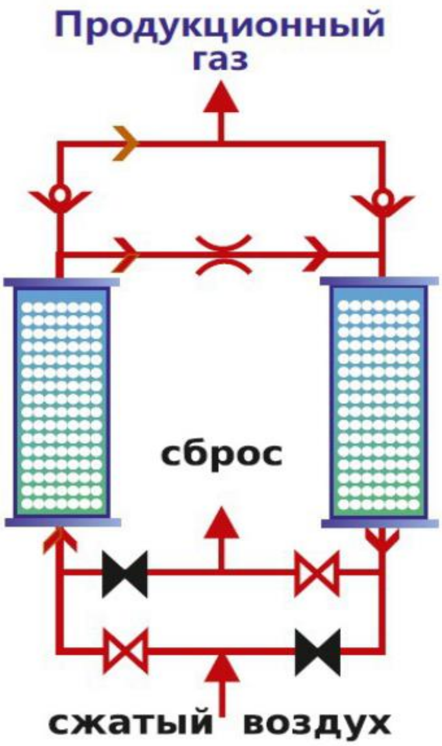
Oxygen concentrators with a capacity of more than 100 l/ min, used when an organization needs a lot of oxygen, should be installed outside the building in special containers (Fig. 3), which must meet the following requirements:

- have a remote control and monitoring system;
- have a forced ventilation system;
- have an air conditioning and heating system (when calculating the work of the equipment installed inside the container in the climatic range from –50 to + 45 C);
- have an automatic fire alarm and extinguishing system;
- have an air compressor heat recovery system;
- have a lighting, heating or air conditioning system.

Fig. 3. Oxygen concentrator (a), container (b)

The distance from a building of medical organizations to a container with installations of oxygen concentrators is not standardized.

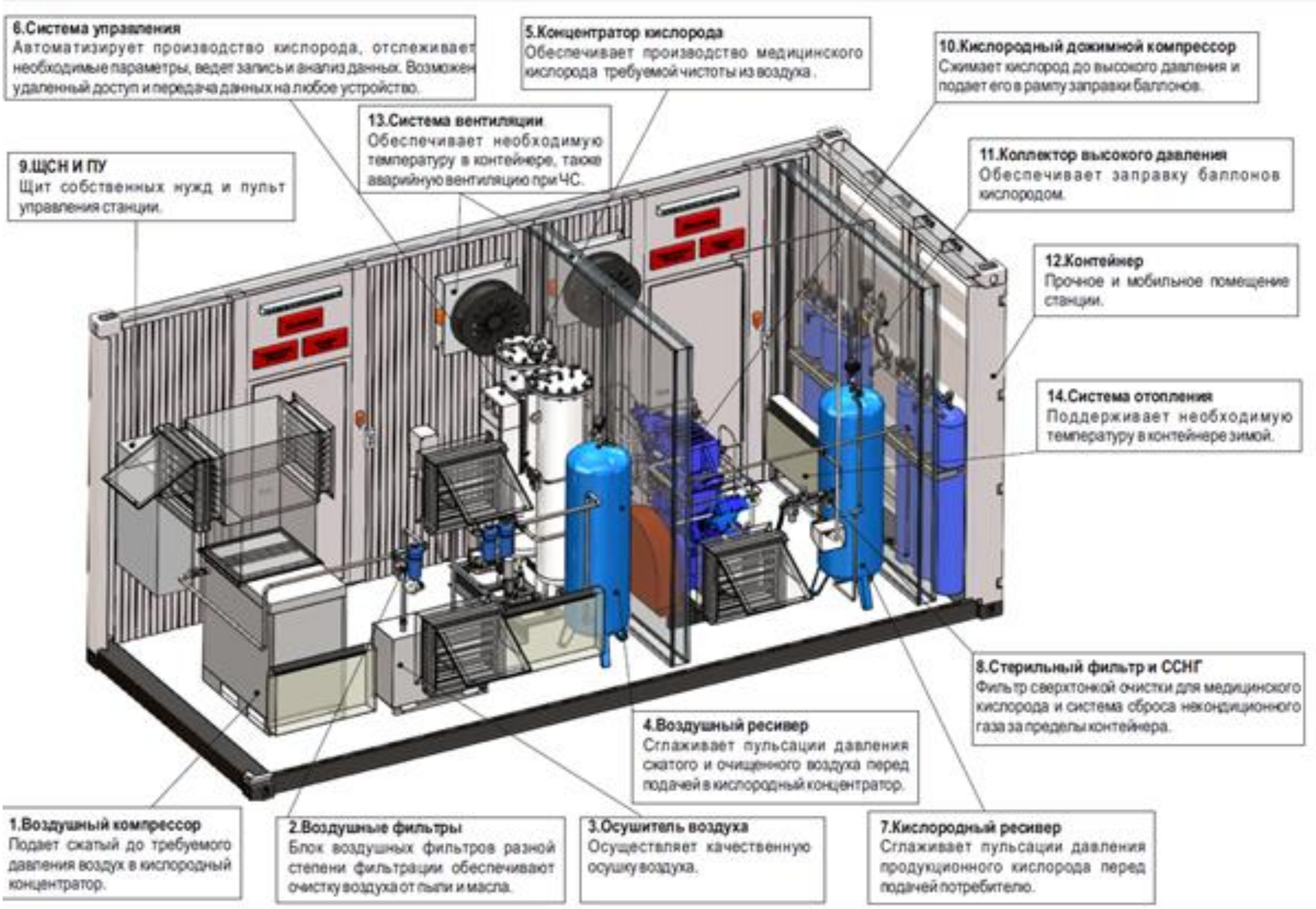
Modern experience shows that it is most expedient to obtain gaseous oxygen directly at the place of its use with the help of compact and economical installations operating on the cycle of the Pressure Swing Adsorption (PSA technology). Distinctive features of the PSA technology are reflected in the words forming its name in Russian (translated into English word by word as "Short-Cycled Heatless Adsorption"). These are, firstly, a short cycle, ranging from a few seconds to two or three minutes. Secondly, the PSA processes are free from artificial heating or cooling of any component of the installation. Therefore, the processes occur at the temperatures close to the ambient ones. The installation of the oxygen concentrator includes: an air compressor, a compressed air preparation unit for an oxygen generator (some filters and a compressed air dryer), an oxygen generator, air and oxygen receivers, and a control unit. The installations in containers can be equipped with filling stations for oxygen being manufactured in the cylinders, which can be used as backup oxygen sources.
An oxygen plant consists of the following components: a screw compressor, a system of filters for cleaning the air from oil, an air dryer, the actual oxygen concentrator, and an oxygen receiver. The plant works like this: the compressor compresses air to a pressure of 6–8 atmospheres. The air, cleared from oil and dried, passes through the air receiver and then goes to the separation in the oxygen concentrator.
The main components of the concentrator are two cylindrical vessels (two adsorbents) filled with molecular sieve (MS). MS has a unique microporous structure and is capable of adsorbing gases, including nitrogen and oxygen. But MS adsorbs nitrogen and oxygen to varying degrees (oxygen is adsorbed less than nitrogen is). The principle of air separation sing the PSA technology is based on this (Fig. 4).
Pure gaseous oxygen extracted from the air accumulates in the receiver, passes a sterilization filter and then is used for direct application.



Produced gas Discharge Compressed air

Fig. 4. The principle of air separation by short-cycle adsorption method

To obtain forcing oxygen (under increased pressure), an oxygen boosting compressor is used, which compresses oxygen to a pressure of 150 bar (15 MPa) and supplies it via a cylinder manifold to the cylinders filled with oxygen. All equipment is mounted either in the medico-prophylactic institution facility or in a special block-container (Fig. 5).



1. Air compressor. Delivers air, compressed to the required pressure, to the oxygen concentrator
2. Air filters. United air filter of varying degrees of filtration cleaning the air from dust and oil
3. Air dryer. Qualitatively dries the air
4. Air receiver. Smoothes pressure pulsations of compressed and purified air before being supplied to the oxygen concentrator
5. Oxygen concentrator. Provides production of medical oxygen of required purity from air
6. Management system. Automates the production of oxygen, monitors the necessary parameters, records and analyzes data. Remote access and data transfer to any distance possible
7. Oxygen receiver. Smoothes ripple of production oxygen pressure before supplying to consumer
8. Sterile filter and OSGDS. Ultrafine filter for medical oxygen and off-spec gas discharge system outside the container
9. ASP and CP. Auxiliary Service Panel and station control panel
10. Oxygen booster compressor. Compresses oxygen to outlet pressure and feeds it to the cylinder filling station
11. High pressure manifold. Provides refilling cylinders with oxygen
12. Container. Robust and mobile station space
13. Ventilation system. Provides the necessary temperature in the container, as well as emergency ventilation during an emergency
14. The heating system. Maintains the necessary temperature in the container in winter

Fig. 5. Model range of oxygen concentrators produced by LLC ProVita (St. Petersburg)

The table below shows the performance of the considered models of the oxygen concentrators, which allows the clients making the choice of the equipment in relation to the real needs of their medical institution.

Table

Equipment performance

Nane	Capacity		Pressure	Oxygen concentration
	l/ min	m^3/ h		
Provita- 30MS	30	1.8	4.5-6 bar	94±1%
Provita- 50MS	50	3	4.5-6 bar	94±1%
Provita-100MS	100	6	4.5-6 bar	94±1%
Provita-140MS	140	8.4	4.5-6 bar	94±1%
Provita-180MS	180	10.8	4.5-6 bar	94±1%
Provita-200MS	200	12	4.5-6 bar	94±1%
Provita-230MS	230	13.8	4.5-6 bar	94±1%
Provita-250MS	250	15	4.5-6 bar	94±1%
Provita-290MS	290	17.4	4.5-6 bar	94±1%
Provita-330MS	330	19.8	4.5-6 bar	94±1%
Provita-400MS	400	24	4.5-6 bar	94±1%
Provita-460MS	460	26.7	4.5-6 bar	94±1%

The main advantages of obtaining oxygen using PSA technology for the needs of treatment-and-prophylactic institutions in comparison with the supply of oxygen from the central oxygen station and the oxygen-gasification station:

1) Full automation of the process of obtaining oxygen. The installation does not require permanent presence of the service personnel, which greatly facilitates personnel work;
2) The equipment is not subject to registration in Rostekhnadzor and other regulatory bodies. The consumer receives certified oxygen according to GOST R ISO 10083-2011, it is allowed to use it in ventilators and pressure chambers;
3) A short time to reach the operating mode of the oxygen concentrator, ranging from 5 to 20 minutes, depending on the concentrator capacity. At any time, the hub can be turned off and on again;
4) Ease of maintenance. Maintenance consists of periodically changing the oil in the compressor and replacing the cartridges in the air purification filters;
5) Saving money due to the low cost of oxygen produced. The main energy costs associated with the compression of air in the compressor and its drying. The cost price of one cubic meter of oxygen currently amounts to no more than 4–6 rubles, energy efficiency is 1.05 kW/ hour per 1 m^3 of gas;
6) Safety. The air pressure in the installation and oxygen does not exceed 8 bar. The equipment works without creating low temperatures, in the absence of liquefied products, and the adsorption process takes place at a low pressure;
7) Ability to connect to the existing internal wiring oxygen supply medical institutions. The possibility of dismantling and transfer to a new installation site;
8) When equipping the complex with an autonomous source of power supply, it is possible to supply oxygen to a medical institution in conditions of remote regions of the Arctic and the Far North. There is a possibility of using this equipment when deploying field hospitals.

Thus, one can see that by now the equipment has been created so that it provides autonomous supply of oxygen to a medical institution, while having such important qualities as ease of operation and maintenance. This technical solution was primarily based on the decisions made by engineers and technicians of medical institutions. We hope that the information presented in the article will interest the heads of medical institutions and specialists in the field of healthcare organization. NEARMEDIC PLUS LLC, as the official representative of the manufacturer of oxygen concentrators ProVita LLC, is ready to supply this equipment to any geographical point of the Russian Federation and guarantee its uninterrupted work.

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