Experience of technical development of obtaining cold as a component of national food security

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Abstract. A priori, the fact remains that the current situation of the development of the agricultural sector in Russia is certainly connected with ensuring food security. This article reveals the historical and technical experience of solving the issues of providing cold and operational manufacturability of modern storage facilities, including a buried type, taking into account the dynamics of development and improvement of the qualities of cryogenic equipment. The article assesses the possibility of optimizing the temperature regime of storage facilities on the basis of expanding the functional potential of existing devices and introducing new production systems integrated on the basis of an alternative gravitational-type drive, the operation of which is carried out due to the cyclical formation of volumetric masses of liquid in storage tanks before it is supplied to the consumer, as well as air flow formation systems in natural cold conditions.

1 Introduction

Statistics on the development of the agro-industrial complex, indicates morally and physically outdated equipment in storage facilities. The old automation used and the virtually missing tightness of the walls do not provide a mode of long-term storage with minimal losses. Vegetable storage facilities are not equipped with sufficiently efficient humidification systems and refrigeration equipment. Russian farmers are trying, with minimal investment, to reconstruct storage facilities or compensate for the maximum profit by building new capacities for storing the resulting products. Special attention is paid to projects that are costly, but significant for small agricultural enterprises and agricultural enterprises. Agricultural producers face the fact that the harvest is doomed without high-tech complexes for long-term storage during the period from harvest to harvest [1].

Today, only 15-20% of the capacities available in our country for storing vegetables correspond to a high-tech level. Violations of the technology and rules when storing products make the launch of additional storage with modern climate control systems ineffective and lead to significant losses, despite the latest equipment. According to leading experts, storage facilities equipped with a microclimate system with control of the storage chamber parameters by temperature, product humidity, CO_2 concentration level, and having several degrees of protection against damage to vegetables by cold air are not enough in the

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agricultural complex. Already built or currently under construction using Dutch vegetable storage technology, in Russian conditions may not be functional due to the peculiarities of the climate. The marginal values of seasonal temperature intervals do not allow ventilation systems to maintain the optimal mode for extending the shelf life of products. According to experts, during the current period there is a problem with the storage of at least 40-50% of vegetable products grown in Russia, since most of the operating vegetable storages were built back in Soviet times, which was reflected in their physical condition [1,2].

Nevertheless, the fact of today is a gradual but tangible improvement in the situation in technologies for storing and prolonging the terms of a high-quality state of biological products. First of all, this concerns the modernization of old vegetable storage facilities and increasing the pace during the construction of new ones. According to statistics, storage facilities with a total capacity of about 200 thousand tons are built annually in Russia [1,2]. However, the presence of modern storage does not at all indicate a high quality level of products sold. The use of expensive technologies in terms of construction and operation requires the elimination of errors that lead to serious losses and do not allow justifying costs [3].

In the design of refrigeration equipment, cooling as a phenomenon is considered in terms of the continuity of the physical process of heat exchange between bodies. At the same time, the low temperature source must operate constantly, which is possible with a sufficiently large supply of coolant or its cyclic restoration to the initial state. This method is widely used in refrigeration technology using various refrigeration machines [4].

The type and structure of refrigeration systems depends on the size of the vegetable storage, its design features and the type of stored products, the content of which is planned to be provided during the required period. The difficulty is that each type of product needs to create an individual temperature and humidity storage mode, which allows you to most efficiently save the harvested crop and get the maximum profit from its implementation [5].

In our country and abroad, air cooling system with compressor refrigeration units is most often used in vegetable storage-refrigerators. Heat is redistributed between products and air flow, due to which cooling occurs. This direct cooling system is economical and simple. Compressor, condenser, evaporator and control valve in it are integrated into centralized closed cycle implemented by means of pipelines, using refrigerant (ammonia or freon - 22), changing liquid state to gaseous state and vice versa, making it possible to easily control temperature in chambers by changing its quantity. In this case, the requirements for the tightness of pipelines supplying refrigerant increase, which is necessary to prevent it from entering the storage chamber and adversely affecting the quality of products [6].

2 Research methodology

The simplest and most economical method for obtaining cold is based on the method of reducing the pressure of equilibrium steam above the surface of the liquid, that is, vacuumizing the vapor space. The disadvantage of this method is the loss of a significant supply of working substance in the form of steam. This can be prevented by making the system closed, i.e. condensing the steam and returning it back to the evaporator. However, coolant losses still cannot be avoided, since the removal of thermal energy from the air in the refrigerator chamber, which provides cooling of the chamber walls and products lying on the shelves, occurs due to an actively evaporating coolant (liquid) at low temperature in the container (evaporator). The boiling point of the refrigerant depends on the pressure in the vessel, which can be changed using a compressor and a valve, and heat removal from the heat-insulated chamber creates cold in it with the required temperature (T_0) [7, 8, 9].

Technically, in order to carry out the process of obtaining low temperatures, it is necessary to have a working medium - a coolant, the entropy of which depends on temperature and pressure. These parameters should be controlled to implement the cooling process with a decrease in entropy and simultaneous consumption of thermal energy equivalent to external work [9].

Earlier studies have shown that the continuous operation of the refrigeration machine provides a cyclic thermodynamic process of changing the state of the working medium, called the reverse or refrigeration cycle. At the same time, the energy balance of this cycle ($Q_1 + E_{\mathrm{BH}} = Q_2$) is actually a combination of the amount of heat removed from the working medium during cooling (Q_1), which is the cooling capacity of the machine, and the external energy spent on completing the cycle (E_{BH}). If we take into account the equivalence of this set to the amount of heat transferred to the environment, then the thermodynamic efficiency of the refrigeration cycle can be reliably estimated by the refrigeration coefficient ($\varepsilon = \frac{Q_1}{E_{\mathrm{BH}}}$) [10].

In this regard, and taking into account historical experience, the development of the theory of design of refrigeration systems, characterized by highly efficient parameters of cold production, continues. However, design interest does not focus only on the forced supply of cold facilities for storing consumer products. Thus, despite the low cold performance, the machine implementing the steam-water ejector principle received a theoretical justification for its use in cooling technologies.

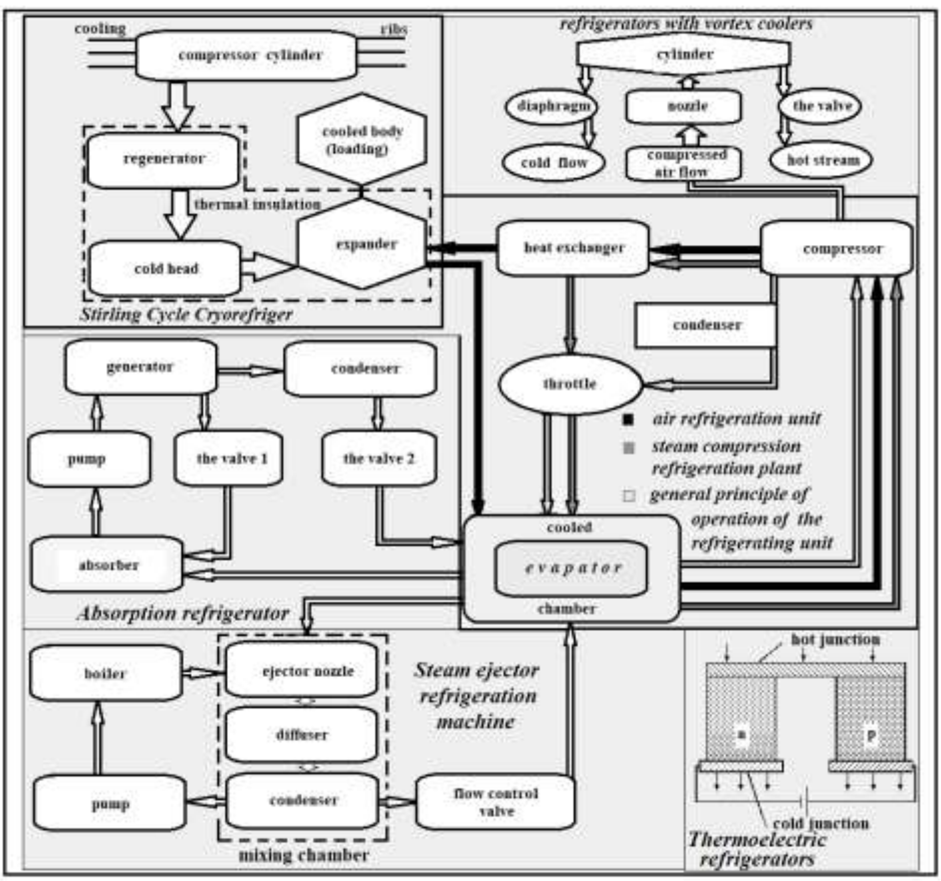

Fig. 1. Functional block diagram of refrigeration units.

Based on the developed method, it was possible to implement the technical supply of hot steam from the steam boiler (Fig. 1) under high pressure to the narrow nozzle of the ejector and immediately exit it at a great speed into a special chamber. After that, vapors from the evaporator connected to it immediately rush into the chamber with the resulting vacuum, where a deep vacuum is also created, and boiling water at a low temperature (up to + 5 °) takes heat from the cooled object. But since it is not yet possible to solve the issue of organizing the passive steam flow in the suction zone, this type of machine does not have a wide practical demand [7, 8, 9].

The cooling effect of boiling liquid also underlies the functionality of absorption refrigerators (Fig. 1). Here, the ammonia vaporizer is located in the cooled chamber or in the brine cooling tank. Ammonia boils and, taking heat from the air in the chamber, cools it. An attractive feature of the absorption method is that vapors from the evaporator remove and lower the pressure in it, not a compressor, but a vessel with water - an absorber. In this regard, this type of machine operates on the cheap energy of the exhaust steam or exhaust gases of the internal combustion engines. It is noteworthy that in such technological schemes there is no compressor that creates noise during operation and requires technical maintenance, and this is a significant advantage of absorption refrigerators [9, 11, 12].

In recent years, in turn, new generation absorption machines have been used, in which the refrigerating agent is not water, but the absorbing substance - lithium bromide [11, 12].

Currently, research is ongoing on the process of obtaining low temperatures as a result of boiling a refrigerant, which is one of the main processes in steam compression refrigerators. Any liquid can be made to boil at a very low temperature. To do this, it is enough to create a low pressure in the evaporator, for example, using a compressor, which is used in a refrigeration machine called compression and which is the most common for obtaining low temperatures (up to -120 ° C). Machines of this type are very economical, and the energy consumption required to transfer heat between bodies is insignificant [13].

The methodological aspect of the formation of any technical direction is always based on historical experience, which has its origin and its reflection in the modern era. It is well known that if the pressurized gas vessel by means of a valve begins to discharge this gas into the space, the temperature in the vessel will decrease according to the adiabate equation. In this regard, the history of the development of cryogenic technology has an interesting fact when, by chance, engineer Gorry (1845) discovered the phenomenon of gas cooling by exhaustion from a constant volume. The use of this phenomenon in cryogenic technology as a method for liquefying helium and other gases began much later, but in the historical experience of technical development it still occupies a worthy place.

Today, the industry has the ability to cool gases and liquids based on the principle of throttling. Actually, the process of expanding the flow without energy exchange with the environment and without increasing the speed of the flow was discovered and studied in 1852 by English physicists D. Joule and W. Thomson (Kelvin). The hypothesis put forward that with adiabatic expansion and the performance of work, the gas is cooled, since the work in this case is carried out due to a change in its internal energy, formed the basis of a whole series of experimental methods and the creation of technological equipment for their implementation. In fairness, it should be noted that in December 1877. S. Kayete, conducting experiments on the liquefaction of acetylene, developed an experimental installation in which the return of compressed gas to its original state was carried out by releasing from the system a part of the liquid used to perform compression. Thus, a very effective cooling method was discovered, which is the expansion of gas during its outflow from a vessel of constant volume [13, 14, 15, 16].

The objectivity of historical experience lies in the comparative assessment of various ways and methods of investigating processes that have adequate target settings. Therefore, it is possible to additionally note the thermoelectric cooling method developed by the French physicist J. Peltier in 1834. He gave a theoretical justification for the phenomenon with the effect of inverse thermoelectric, discovered by the German physicist T. Seebeck in 1821.

Called the Peltier effect (heat transformer), it is based on the fact that when two DC semiconductors pass through the junction at the point of their contact, depending on the direction of the current, a certain amount of heat is released or absorbed. The advantages of thermoelectric cooling - the quiet operation, the direct transition of electric energy to thermal energy, the compactness of the installation - determine the prospects for its development, but on the other hand, the thermoelectric cooling method has a low efficiency and the inability to achieve a significant temperature difference [8, 9, 13, 17].

The historical experience of creating and studying cooling methods is certainly not limited to household or production consumption structure. Laboratory bases are taken into account, where special experiments are carried out at temperatures close to absolute zero. The developed electrocaloric and magnetocaloric methods are based on the phenomenon of polarization of dielectrics in the electric field, as a result of which they are heated, and when the electric field is removed, the dielectric is cooled. Thus, using magnetoelectric and electrocaloric heat transformers of a similar nature, the engineers created a technology based on the depolarization of solid working bodies. This process takes place due to the internal energy of the working medium, as a result of which it is cooled. If, after polarization, the heat generated is taken from the working medium, then during depolarization, the cooled working medium is able to remove heat from the cooled object. However, the production of cold by electrocaloric or magnetocaloric means is periodic. [7, 9, 11, 13].

The methods developed in modern conditions by engineers are aimed at continuing the creation of technical projects taking into account the physics of the process of pushing gas through a porous partition from an area with high pressure (P_1) to an area with low pressure (P_2) (often $P_1 >> P_2$). Typically, the volume of the second portion (V_2) in the high pressure region beyond the porous partition is significantly larger than the first (V_1). The temperature of the order ($T_к \sim 300$ K) for all gases except hydrogen H_2 and helium He contributes to the cooling of the gas when passing through the porous partition ($T_1 > T_2$) [9, 10, 13, 17, 18].

Referring to cooling methods applied to cryogenic and low-power refrigeration plants, throttling should be indicated as one of the main processes in steam compression refrigeration machines, which consists in a pressure drop and a decrease in the temperature of the refrigerant when it flows through a narrowed section under the influence of a pressure difference without performing external work and heat exchange with the environment. This phenomenon is called the throttling effect, and the method is based on the process of compression of air to a pressure of dozens of megapascals, followed by cooling in the refrigerator.

The technology involves further movement of air through the inner tube of the heat exchanger, after which it is passed through the throttle, greatly expanding and cooling. The expanded air is sucked again through the external tube of the heat exchanger and returned to the compressor [9, 11, 13].

In cryoengineering, the throttling effect got its technical continuation when the process was carried out with external useful work, when a special expander device was installed on the path of the gas flow moving under the influence of a pressure difference, where the gas flow rotated the wheel (or pushed the piston). In this case, after the expander, the temperature of the coolant will decrease simultaneously with the pressure decrease. By this method, during expansion, the gas is cooled much more strongly than when throttling with the same pressure difference, which allows air and gas refrigeration machines to obtain temperatures from -50^0 to -100^0 C [11].

The method of obtaining ultra-low temperatures up to -261^0 C and below is successfully practiced through mechanical cryorefriters, modern advanced models of which are designed based on the implementation of the Sterling cycle and the use of the Vuillemier cycle.

Studies have shown that if the cylinder of the compressor connected to the expander through the regenerator and cold head without intermediate valves (Fig. 1) provide cooling fins for heat exchange with the environment, and introduce the piston expander into direct heat exchange with the cooled body (load), and at the same time the system will be in thermal insulation, then a functional cascade of devices of this type allows you to achieve even lower temperatures with high efficiency [9, 11, 13, 18, 19].

However, there are many drawbacks in operating expander devices. Here is the complexity of the design, the high cost, and the small technical resource. In addition, the expander requires a mandatory load (generator, compressor), as well as special rooms with foundations, etc. In order to eliminate the described drawbacks, the designers proposed to replace the expander with an improved vortex pipe (Fig. 1).

The principle of operation of the vortex pipe is based on the method of separating hot and cold air in a swirled flow inside a cylindrical chamber. Device provides for control of cold gas temperature and cold capacity, which is performed by conical throttle at hot end of vortex pipe.

Although vortex tubes have been known since 1931, they have not been widely used as refrigerators due to their low efficiency. Currently, engineers are developing new types of vortex pipes with increased efficiency [9, 10, 13].

3 Study results

Comparative studies in the practice of cooling vegetable storages showed the competitive use of original brine systems using an intermediate coolant - an aqueous solution (brine) of calcium chloride, table salt or ethylene glycol. But brine cooling turned out to be more expensive than direct cooling, since its device is more complicated, and brine preparation is laborious. Moreover, the premises for the maintenance of products must be reliably insulated, as well as have a high level of tightness and good ventilation of the chambers. It should be noted that all this is due to the method of supplying brine to the batteries of all chambers, and its equal temperature level, therefore, air temperature control in each specific chamber was provided by means of temperature sensors that control the valves at the inlet of brine to the cooling batteries [6, 20, 21].

To implement the cooling process, the capacity of refrigeration plants for vegetable storages should be in the range from 42 thousand to 2 million 500 thousand kJ/h and aspect analysis of the functional shortcomings of the operated systems is necessary taking into account the storage of various types of products. As a result, on the basis of large storage facilities with high-capacity ammonia refrigeration plants, temperature control is difficult directly for each of them, and since the condenser is cooled by water, cooling towers have to be additionally built for its use [22].

Evaluation of freon plants immediately shows their lower performance, but cooling of the condenser in them is carried out by air, so they are easier and more economical to operate. In the food and processing industry, decentralized cooling systems are introduced with freon installations of the KhMF-16 and KhMF-32 types that are individual for each chamber. This makes it easier to create an optimal temperature regime for each product type in the chambers [17, 22].

At the same time, it is not possible to increase the cold performance by switching to battery equipment without disrupting the cooling process, which is expressed in the unevenness of the temperature regime for the stored mass of the product with its hypothermia or even freezing. In this regard, it is advisable to block the evaporator of the refrigerating unit, the fan, and in some cases, the humidifier into a single function. Such a functional model does not allow product freezing.

It should be noted that to limit the entry of external heat inputs into the chambers, the upgraded refrigerators are equipped with a mixed cooling system, which includes air coolers and wall batteries, which operate simultaneously during the cooling period of the product [20].

Studies show that the annual increase in the cost of electricity, which increases the cost of servicing refrigeration plants, which consume almost 75-80% of its total volume, significantly affects the cost of final products. Experience in the operation and construction of refrigeration warehouses indicates the possibility of implementing energy saving by supplementing the main facilities with recovery systems that provide a partial return of energy for its reuse. Economic calculations confirm that, despite the use of more expensive equipment, additional costs will be justified. The total savings from the implementation of such technical solutions reach 50% of electricity [7]. Therefore, the development of cold supply systems, especially systems for warehouse complexes, requires mandatory interpenetration with energy saving issues, which underlie the scientific and technical approach to reducing the cost of operating warehouses and storage facilities.

It is rational and practical to talk about such methods of saving electricity as reducing the power of refrigeration units due to the introduction of evaporative air cooling condensers irrigated with water, special drop collectors, minigradirene [8].

It is possible to use friculation systems that reduce the energy consumption of warehouses located in the cold and temperate climate zone by up to 80%. In this method, in winter, single-circuit systems are cooled by direct supply of cold outside air, and cooling of double-circuit systems is carried out by indirect cooling in a dry cooler (drycooler) of an intermediate coolant. As a result, the technology allows you to transfer the process from compressor equipment to circulation pumps and fans that consume less electricity, further extending the service life of compressors.

In the economic aspect of consideration of thermal stabilization of vegetable storages during the cold period, air solar collectors acting as an independent or additional heat supply system should not be overlooked. Thus, by ensuring optimal storage conditions for products, it is possible to significantly reduce economic costs due to the prompt installation of equipment and its further autonomous operation.

The introduction of thermal stabilizing systems and systems producing cold in storage complexes always requires increased attention to refrigeration equipment and its performance, the degree of its reliability, as well as the duration of its technical life, continuity of operation, the possibility of using cheap refrigerants (products of its own technologies), the use of secondary energy resources, with mandatory maximum automation of technological processes.

To date, serious science-intensive methods for studying temperature regimes and methods of cold supply of storage facilities based on them have been developed (Fig. 2).

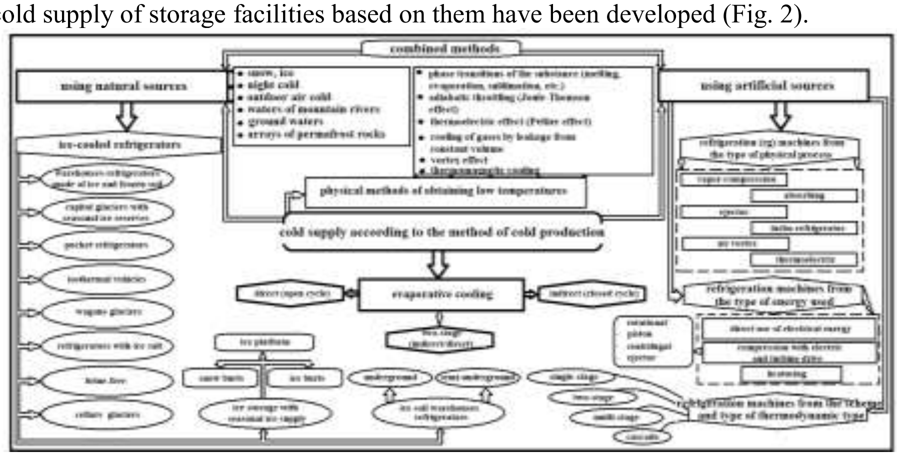

Fig. 2. Cold supply methods.

The depth of research is determined by the nature of the phenomenon under study or the physics of the process, and the prerequisite for the technical or technological development of cooling methods is the actual process of obtaining cold.

Figure 3 shows the process flow diagram implementing the cold supply of the buried vegetable storage, based on an alternative gravity drive.

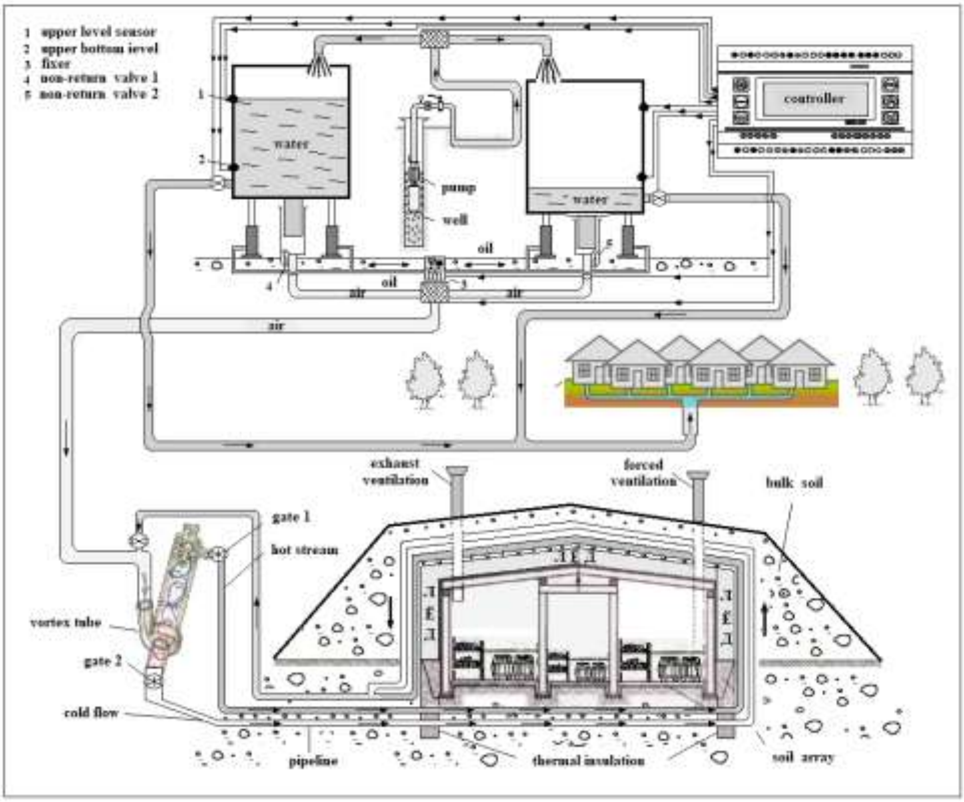

Fig. 3. Process diagram of energy-saving vegetable storage.

This development relates to the field of cold supply of buried storage structures, the task of which is to stabilize the cold supply process regardless of the time of year, as well as to increase the technological parameters of the device for accumulation, preparation and transportation of compressed air. The set temperature conditions of storage facilities that ensure the duration and quality of stored products are possible due to the supply of compressed air to the cascade of vortex pipes, and then the distribution pipeline passing through the frozen soil mass, compensating for the need for cold air flow intensity. This technical solution is possible if we use an energy-saving power plant as a compressor, using a gravity drive, operating in a cyclic change of filling the tanks with water from the well to a specified level, in order to create and supply compressed air of the required pressure (0,6-0,7 MPa) to the vortex tube cascade. Separated flows of cold and hot air through the pipeline go to the process facility, and the frequency of turning on the vortex pipes in winter and summer ensures the maintenance of the optimal temperature in the storage chambers. The space surrounding the structure is frozen with ice to provide low-potential heat to the walls of the operated storage. The mass of heat-insulated soil located in the lower part of the storage is provided by cold charging to a freezing depth of up to 80-90 cm.

4 Discussion of results

The specific cooling capacity of the vortex pipe is 3 times lower, for example, than that of the turbo expander with constant operation. However, if both hot and cold air are needed for a short period of time during the year, the vortex pipe is more economical than the turbo expander due to the low cost, the absence of rotating parts, as well as minimal maintenance. It remains a fact that if compressed air is a gift for the air conditioning system, then the use of vortex pipes will be most rational for private operating conditions. Therefore, it is particularly advantageous to use them when the cost of producing air supplied to the vortex tubes and used thereafter for cooling is practically not taken into account. For example, when air is taken from an existing compressed air network in which the flow rate is incommensurably greater than required for vortex tube operation.

Thus, for optimal use of the vortex tube, it is necessary to have a large amount of compressed air and ensure moderate performance for it, and in case of neob¬khodimosti high performance, the vortex tubes must be assembled into blocks, which is assumed by this installation.

The proposed development can be used in various regions, regardless of climatic conditions and is recommended for peasant farms and private entrepreneurs as a storage facility with a capacity of up to 1000 tons of products.

5 Conclusions

Thus, the simplest devices are available and installations operating on ready-made cold carriers: water or dry ice, ice salt mixtures, liquid gases, etc. The main drawback is a complete dependence on the capabilities and conditions for obtaining coolants, a large amount of work related to charging the cooling system. This drawback is not machine thermal control, which consumes only energy or air from the outside, which makes it the most common and operationally convenient cooling method, which occupies about 90% of the socio-technological sphere of human activity. But with all this, do not forget about significant electricity consumption, service costs, etc.

In this regard, technical solutions and physical models based on alternative energy with possible synthesis into technological systems that make it possible to radically solve the issue of resource and energy saving can be considered as the most promising. For example, the use of cryotransportation systems consisting of multi-chamber vortex tubes for supplying a working medium (air) to cold supply devices of buried vegetable storages and creating an optimal temperature regime that increases the quality of stored products. But this issue is complex, since such systems are not energy-generating, therefore, the movement of the working medium in regulatory temperature proportions must be provided by power plants. This aspect will be advisable if the energy of the coolant transportation process is designed on the basis of an alternative gravitational drive, the operation of which is carried out due to the cyclic formation of volumetric masses of liquid in storage tanks before supplying it to process facilities. In fact, we are talking about the creation of a mathematical model of the technological system, which allows for the applied optimization of the structural, mode and technological parameters of the elements of the functional and economic complex in a specific area. This will make it possible to provide peasant farms with specialized equipment for storage facilities and rural premises adequately to their budget level.

References

1. In Russia, there is nowhere to store up to half of the grown vegetables (Agroinvestor, 2018), https://www.agroinvestor.ru/
2. Features of vegetable storage. How to prevent errors during storage operation. Competence Center for Agricultural Operations of the Stavropol Territory (2018), http://www.stav-ikc.ru/
3. All the secrets and features of modern vegetable storage facilities. Foodbay blog. (Agricultural industry, 2020), https://foodbay.com/
4. *Refrigeration equipment and technology* (INFRA-M, M., 2000)
5. E. V. Malgina, Yu. V. Malgin, V. P. Suedov, *Refrigeration machines and installations* (Food industry, M, 1980)
6. B. S. Babakin, V. A. Vygodin, *Household refrigerators and freezers* (Kolos, M., 1998)
7. S. V. Guzhov, *Methods of determining and methods of confirming the energy-saving effect when transmitting and using electric and thermal energy* (MPEI Publishing House, M., 2015)
8. A. V. Baranenko, V. S. Kalyunov, Yu. D. Rumyantsev, *Workshop on refrigeration plants: a textbook for university students* (Profession, St. Petersburg, 2001)
9. J. Dossat Roy, *Refrigeration Fundamentals* (Light and food industry, M., 1984)
10. V. E. Pigarev, P. E. Arkhipov, *Refrigeration machines and air conditioning units* (Route, M., 2003)
11. *Thermal and structural calculations of refrigeration machines: a textbook for universities specializing in "Refrigeration and compressor machines and installations"* (Mechanical engineering. Leningrad branch, 1987)
12. A. P. Yerkin, A. M. Korenev, V. P. Kharitonov, *Installation and operation of refrigeration units* (Food industry, M., 1980)
13. S. S. Korneev, *Calculation of power systems for compressor equipment: methodological guidelines for practical training* (Samara University, Samara, 2017)
14. A. Ilsters, I. Ziemelis, "Elimination of outside air heat pump evaporators icing", in *Proceedings of the 11th International Scientific Conference "Engineering for Rural Development"* (2012), pp. 122 – 127
15. A. Ilsters, I. Ziemelis, V. Zagorska, "Warming of Piglets Resting Places by Air Heat Pump in Dependence on Outside Air Temperature", in *Proceedings of the 9th International Scientific Conference "Engineering for Rural Development"* (2010), pp. 106 – 111
16. A. Ilsters, I. Ziemelis, H. Putans, "The use of warm outflow ventilation air for increase an open air heat pump efficiency", in *Proceedings of the 9th International Scientific Conference "Engineering for Rural Development"* (2014), pp. 306 – 311
17. K. Harby, D. R. Gebaly, N. S. Koura et al., Renewable and Sustainable Energy Reviews **58**, 347-360 (2016)
18. A. E. Kabeel, Y. A. F. El-Samadony, M. H. Khiera, Applied Thermal Engineering Journal **122**, 204-213 (2017)
19. V. Afonicevs, U. Strauts, N. Bogdanovs, A. Lesinskis, "Riga Technical University, Latvia Evaporative cooling technology efficiency compared to traditional cooling system – case study", in *Proceedings of the 19th International Scientific Conference "Engineering for Rural Development"* (2020), pp. 877 – 883.

20. *Studying the basics of refrigeration equipment* (Podolsk printing house of the Chekhov printing house, M., 1996)
21. A. V. Baranenko, N. N. Bukharin, V. I. Pekarev, I. A. Sakun, L. S. Timofeevsky, *Refrigeration machines: a textbook for students in the specialty "Low Temperature Technology and Physics* (Polytechnic, St. Petersburg, 1997)
22. E. S. Kurylev, V. V. Onosovsky, Yu. D. Rumyantsev, *Refrigeration plants: a textbook for university students specializing in "Low temperature technology and physics," "Refrigeration, cryogenic technology and air conditioning"* (Polytechnic, St. Petersburg, 1999)