ХОЛОДИЛЬНА ТЕХНІКА ТА ЕНЕРГОТЕХНОЛОГІЇ

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Development of energy-saving technologies and cooling systems for grain storage of small seed cultures

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In the modern world, refrigeration equipment systems, in particular, continuous refrigeration chain systems, without which food safety cannot be fully ensured, are becoming more and more popular. Special interest in artificial cooling systems in the grain economy of Ukraine, which is one of the country's budget-generating industries. Grain is one of the most important basic human food products, for the cultivation and collection of which large resources are involved. Post-harvest processing and storage is a key link in grain production. According to the Food and Agricultural Organization of the United Nations (FAO), about 20% of harvested grains in the world spoil annually. Reduction of grain losses at all stages of harvesting, transportation, storage and processing and ensuring its preservation is determined by the technology after harvest processing. In the conditions of ever-increasing volumes of grain and high rates of harvesting, the problem of preserving the harvest, more than half of which is harvested in a wet state, is becoming increasingly acute. Freshly harvested wet seed grain is unstable in storage and requires immediate processing. Low-temperature conservation in the places of preparations allows to solve the problem of long-term and high-quality storage of grain products. Small grain varieties due to their small inherent linear size, are most prone to damage during heat drying. Combined compression-absorption water-ammonia refrigerator the machine allows you to abandon the use of mains electrical sources for 7 months of the year. Such a refrigerating machine can be made in a transport autonomous version and solve the task of air conditioning in field conditions. To adapt to field conditions, the absorber is made with two-phase thermosiphons and with air heat removal to the environment.

Keywords: *Primary processing; Low-temperature storage; Small-seeded grain; Compression refrigerators; Absorption refrigerators; Alternative energy sources; Energy.*

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1. Introduction

The solution to the country's food security problems within the parameters set by the Law of Ukraine "On Food Security of Ukraine" and the stabilization of food prices are connected, first of all, with the development of its own high-tech and competitive agro-industrial production.

In the conditions of ever-increasing volumes of grain and high rates of harvesting, the problem of preserving the harvest, more than half of which is harvested in a wet state, is becoming increasingly acute. Freshly harvested wet seed grain is unstable in storage and requires immediate processing.

Conservation of wet grain is possible with the help of organic acids, by storing grain without access to oxygen (hermetic and in an environment of inert gases), as well as by cooling.

In the modern world, refrigeration equipment systems, in particular, continuous refrigeration chain systems, without which food safety cannot be fully ensured, are becoming more and more popular.

Special interest in artificial cooling systems in the grain economy of Ukraine.

It should be noted that among all types of grain products, the greatest effect of primary low-temperature processing can be achieved for small grain varieties (rapeseed, flax). They, due to their small inherent linear size, are most prone to damage during heat drying.

Due to the fact that rapeseed can be effectively used for the production of biofuel, at the beginning of the XXI century. in Ukraine, this culture began to conquer new areas. It is a well-known fact that German biofuel producers intended to lease 50,000 hectares of agricultural land in Ukraine in 2008 in order to provide themselves with raw materials for a long time.

2. Literature analysis

2.1. Technical aspects of cold storage of grain products

Grain masses are stored in bulk or in containers. The main and most common is the first method.

In typical granaries, grain is placed in bins or in bulk in piles.

Such warehouses are mechanized and non-mechanized. In warehouses with horizontal floors, several different batches of grain are stored. For this, the warehouse is divided into compartments with the help of collapsible shields.

Grain silos and ground granaries are being built on farms. The first are convenient for separate storage of small batches of seed and variety, and the second - for large batches of commercial grain.

Combined granaries are also being built. The grain is also stored in a container, the length of the stack depends on the size of the storage and the batch of seeds, the width and length of three to five bags, the height – the number of bags stacked up (depending on the crop and the season). Each batch of grain is placed separately in a stack on a wooden floor, which is located at a distance from the floor of at least 10 cm. The distance between the stacks and the storage walls is at least 0,75, and between individual stacks – 1 m.

According to the degree of mechanization, granaries are mechanized (with stationary means for mechanizing the loading and unloading of grain), partially mechanized (with stationary means for performing one operation, more often - for loading, which makes it possible to ensure the quick acceptance of grain and seeds and store them in an embankment of the maximum permissible height , and unloading is carried out by means of mobile mechanization) and non-mechanized (to facilitate the work, only mobile means of mechanization are used).

Dry grain is placed in elevator-type silos up to 30 meters high.

One of the most important ways to reduce losses and improve the quality of products is the obvious provision of each farm with its own modern granary. Thus, in agriculturally developed countries, up to 80% of the harvest is kept by its producer.

In the USA and Canada, and recently in Europe, tower storages equipped with active ventilation and a grain temperature control system are becoming more and more common, with the help of which information is output to a computer laboratory.

2.2. Technological aspects of refrigeration processing of grain products

Grain is a living biological system, it has a complex chemical composition, is in a state of constant changes, in it there is a continuous biological exchange of substances both within the grain itself and with the environment.

The main task of grain storage is:

- save grain without mass loss or with minimal loss;
- save grain without quality deterioration;
- to reduce the cost of labor and money per unit mass of grain while preserving its quantity and quality in the best possible way.

As long-term experience in the technology of primary processing of freshly harvested grain has shown, one of the urgent tasks is its cooling to temperatures that ensure safe storage. Numerous physiological, biochemical and technological studies have established that lowering the temperature of grain below 8-10 °C sharply reduces the intensity of physiological and biochemical processes, helps preserve the original quality of grain and increases its storage time, both during long-term storage of grain and during its temporary storage to possible additional processing in the dryer.

Thus, according to the data of the company "GRANIFRIGOR" (Table 1), the duration of storage of grain (even wet) increases significantly.

***Table 1** – Grain storage terms depending on temperature and humidity*

Initial moisture,%	Seed grain		Food grain		Forage grain	
	Storage temperature, °C	Duration of storage	Storage temperature, °C	Duration of storage	Storage temperature, °C	Duration of storage
12…15	9…12	unlimited	10…12	unlimited	10…12	unlimited
15…16,5	8…10	1…1,5 years	9…10	unlimited	9…10	unlimited
16,5…18	5…7	4…6 months	8…10	5…10 months	8…10	6…13 months
18…20	5	2…3 months	8…10	2…7 months	9…10	3…9 months
20…22	5	3…4 weeks	6…8	4…16 weeks	6…8	5…20 weeks

The combination of high temperature and humidity of the grain mound determines the intensive vital activity of seeds and microorganisms and rapid self-heating.

An increase in grain temperature can be observed in the hopper of the combine and in the body of motor vehicles. Pre-cleaning somewhat slows down the process of self-heating, but to completely prevent it requires more radical measures to ensure grain preservation.

A freshly harvested seed is a biologically living object that requires moisture, heat, and oxygen to maintain its vitality. The intensity of the physiological activity of seeds depends on the level of influence of these factors. By managing them, you can direct the life process in the necessary direction.

Along with humidity, the temperature of the grain mass has a decisive influence on the development of respiration. At 0 °C, grain respiration is practically zero, in the range of 0…10 °C it increases slightly, and at a temperature above 10 °C, it sharply intensifies. A decrease in the temperature of the grain mass to 8…10 ° C, as L. A. Trisvyatskyi points out, has a noticeable inhibitory effect on the entire microflora of the grain, and although it does not lead to its death, it greatly inhibits its development.

Artificial cooling contributes, without the risk of reduction, to a better preservation of the initial quality of the grain, prevents its self-heating, reduces the intensity of its respiration and thus reduces the heat release of the grain.

Reduces the loss of dry matter, inhibits and stops the development of microflora, mold, fungi and their mycotoxins; protects grain stocks from being eaten by insect pests, and grain losses from their activity are reduced.

Costs for grain fumigation are reduced, there is no need to process grain expensively and in such a way that harms the environment of chemical processing and prevents possible contamination of grain.

Cooling of grain will eliminate the main causes of biological loss of grain such as respiration, germination, development of microorganisms and mites, self-heating and, therefore, will eliminate mass loss and deterioration of grain quality.

2.3 Types of refrigerating machines used for refrigerating processing and low-temperature storage of small-seeded grains.

Various types of refrigerating machines are usually used as a source of cold necessary for the processes of air cooling and drying. Refrigerators of various types, differing in device and principle of operation, have their own characteristic features, thanks to which they can satisfy one or another requirements of consumers of artificial cold.

For refrigerating processing and low-temperature storage of small-seeded grains, the following types of use of refrigerating machines can be distinguished:

1. On the basis of vapor compression refrigerating machines, which have become widespread in installations used to process their air flow. It is they who make up the largest (one might say the majority) part of the fleet of all installations operating in the world.

In comparison with machines of other types, they have a higher (other things being equal) cooling coefficient and low energy consumption during operation. Compressors of various types are used in their composition.

Piston compressors have a high compression ratio, but they are characterized by greater vibration than other types of compressors. Pistons are very good in machines with low and medium cooling capacity and are too bulky, heavy and less energy efficient in machines with high cooling capacity.

So, for example, FrigorTec GmbH has been producing GRANIFRIGOR ™ grain cooling units (Fig. 1) in series for many years.

Recently, screw compressors have been widely used. Screw compressors have a higher cooling capacity than reciprocating compressors with similar dimensions. In addition, their electricity consumption is much lower. Screw compressors that have a large capacity have the most pronounced difference in efficiency (higher).

Figure 1 – *Unit for grain cooling GRANIFRIGOR ™*

However, in the area of low refrigerating capacity, they still cannot compete with reciprocating units in terms of energy efficiency, but they are almost comparable to them in terms of this indicator in the area of medium refrigerating capacity. The main advantage of screw compressors is high reliability, they are not afraid of water hammer and low vibration. Disadvantages include the increased noise level and the bulkiness of the oil system.

2. Absorption refrigerating machines (ARM). In contrast to compression refrigerating machines, in ARM the circular process is carried out by a working mixture of substances, consisting most often of two components. These substances have significantly different boiling points at the same pressure. One component is a refrigerant, the other acts as an absorbent. The compression of refrigerant vapors from the suction pressure to the high condensation pressure is performed by a thermochemical compressor, which represents a set of devices in which heat and mass exchange is carried out.

There are intermittent and continuous ARM. In industry, only continuous-acting AHMs have been used, and in the future only this type of refrigerating machines will be considered. Solid and liquid substances are used as absorbents.

According to the type of refrigerant, the solutions used in ARM can be divided into the following groups: water, ammonia, alcohol, freon, hydrocarbon. The group of solutions in which water is used as a cooling agent includes: H_2O-LiBr, H_2O-LiCl, H_2O-LiJ, H_2O-NaOH, H_2O-$CaCl_2$, H_2O-LiCl-LiBr. Of all the listed solutions, the working mixture H_2O-LiBr has become the most widespread, and to obtain cold water in air conditioning systems on an industrial scale, bromistolithium refrigerating machines are mainly used, which allow the use or disposal of heat of low temperature potential.

The advantages of absorption refrigerating machines include:

- a small number of moving parts;
- the ability of machines to work on a cheap heat source (exhausted steam, gases, hot water, etc.);
- a slight change in cooling capacity with a decrease in temperature boiling.

The disadvantage of absorption machines is the increase in their mass as a result of replacing the compressor with thermal devices.

Also, absorption refrigerators have a number of indisputable advantages compared to compression ones, their number primarily includes:

- absence of moving parts and, therefore, higher reliability and durability;
- absence of heterogeneous and expensive materials in the refrigerating apparatus, and, therefore, higher manufacturability and lower cost;
- silent operation and the possibility of using cheap sources of thermal energy instead of electric energy;
- high performance in conditions of increased outdoor air temperature (in areas with a tropical climate), etc.

The listed advantages and increased energy performance of absorption refrigerators indicate that they can compete with compression refrigerators.

3. Research

The purpose of the research is to develop cooling systems for the primary low-temperature processing and storage of grain of small-seeded crops. To achieve the goal, the following main tasks must be solved:

1) conduct an analysis of the current technical and technological state of development and research of cooling systems for primary low-temperature processing and storage of grain of small-seeded crops and determine the most promising ones;

2) to develop promising energy-saving systems of primary low-temperature processing and storage of grain, including with the help of alternative renewable energy sources.

The systems of primary low-temperature processing and storage of grain of small-seeded crops include enclosures with air supply and exhaust air ducts and refrigerating machines that ensure cooling of the air flow to the required temperature.

Let's consider promising schemes and designs of systems for primary low-temperature processing and storage of grain of small-seeded crops.

Let's start with artificial cooling systems.

In Fig. 2 presents a diagram of grain cooling using a vapor-compression ammonia refrigerating machine (VCARM).

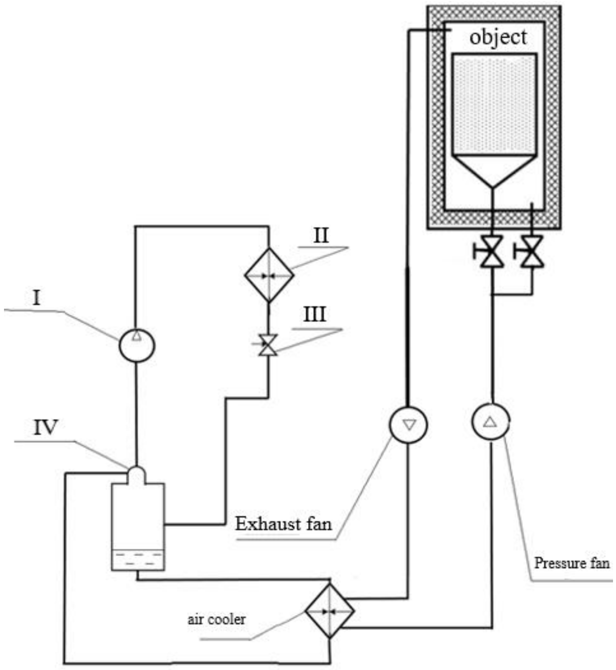

Figure 2 *– Scheme of grain cooling using a vapor compression refrigerating machine: I – compressor; II – condenser; III – regulating valve; IV – liquid separator*

The mobile refrigerating machine is connected with the help of flexible hoses to the object of cooling - grain of small-seeded crops. The circuit of the system is closed and the air, after passing through the grain mass, is supplied to the evaporator, where it is cooled, and moisture falls on the heat exchange surface of the air cooler. Next, the heat-treated air enters again to cool the small-seeded grain.

In Fig. 3 presents a diagram of grain cooling using an absorption water-ammonia refrigerating machine (AWARM).

AWARM can be used as stationary refrigerating units for heat treatment of small-seeded grain crops. Air cooling is also carried out in a closed cycle – this allows us to save energy costs during heat treatment of air.

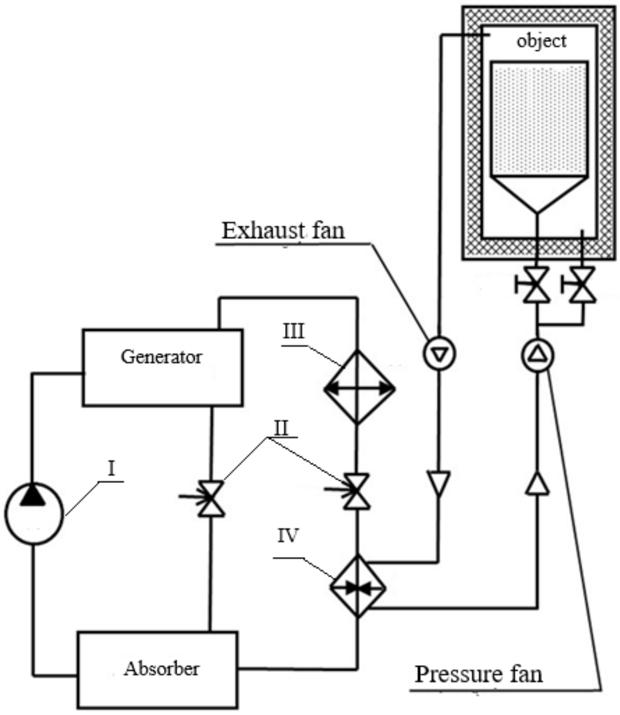

Figure 3 *– Scheme of grain cooling using an absorption refrigerating machine: I – pump; II – regulating valves; III – condenser; IV – evaporator*

Prospective scheme of a combined refrigerating machine for primary low-temperature processing and storage of small-seeded grain

When developing the scheme, the requirements of environmental safety and minimization of energy costs were taken into account.

It is possible to use alternative renewable sources - biogas and solar thermal radiation.

The schematic diagram of a refrigerating machine for primary low-temperature processing and storage of small-seeded grain is shown in Fig. 4.

Taking into account the features of the modes of low-temperature processing and storage of small-seeded grain and ecological and energy requirements, it is proposed to make the refrigerating machine in a combined form, which consists of a vapor-compression VCARM block and a block of an absorption water-ammonia refrigerating machine (AWARM).

Consider the operation of such a compressor-absorption type machine in the modes of low-temperature processing and storage of small-seeded grain. Ammonia is the working fluid in the VCARM cycle, and water-ammonia solution (WAS) in the AWARM cycle. In all cases, the working body is a natural component that does not harm the ecology of the planet.

WAS is fed into the ammonia vapor generator 1. The amount and composition of WAS is selected on the basis that part of the ammonia in the liquid phase will constantly be in the liquid separator 18.

To move ammonia to the liquid separator 17, the AWARM is started by supplying heat to the generator 1 from a waste or alternative energy source, 11 and 12, respectively. When the AWARM is started, the valves 14, 16 on the emission sources are open, and 13, 15, 17 are closed.

On the solar heat source, valves 13 and 16 are open, and 14, 15 and 17 are closed.

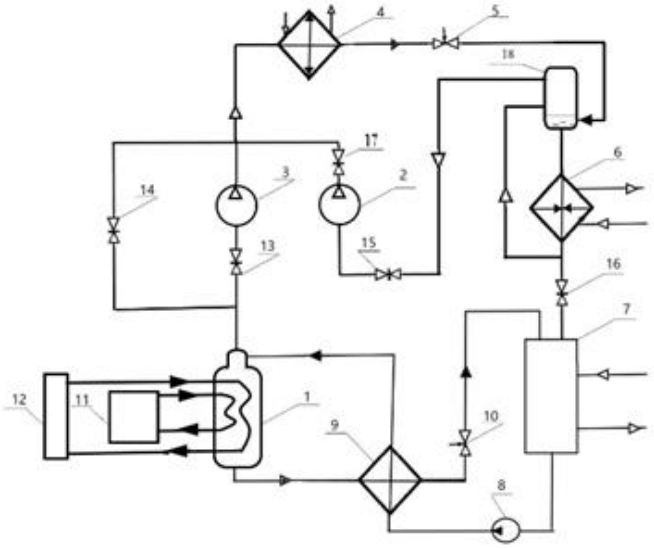

Figure 4 *– Refrigerating machine with electric, waste and solar energy sources: 1 – ammonia steam generator; 2 – main compressor; 3 – booster-compressor; 4 – air condenser; 5 – throttle of liquid ammonia; 6 – evaporator-air cooler; 7 – air absorber; 8 – circulation pump of solid solution; 9 – heat exchanger of strong and weak solution; 10 – weak solution throttle; 11, 12 – sources of heat energy, respectively, waste and sun; 13-17 – latches; 18 – liquid separator*

In both cases, the work of generator 1 AWARM will take place until the liquid compartment 18 is filled with liquid ammonia. Mode I – grain loading at ambient temperature.

In this case, the maximum cooling capacity of the cooling system is required, and for this, the VCARM unit is connected.

When electric energy is supplied to the main compressor 2, the pumping of ammonia vapors from the evaporator 6 and its injection into the air condenser 4 begins. In the condenser 4, the ammonia vapors are liquefied and through the throttle 5 are sent to the lower part of the liquid separator 18 (below the level of liquid ammonia). From the liquid compartment 18, ammonia enters the evaporator 6, where it boils at low pressure and temperature, ensuring the production of artificial cold. The pressure in the evaporator 6 is selected taking into account the maintenance of the required temperature of the cooling object – small-seeded grains.

Evaporator 6 is made in the form of an air cooler. The air fan is selected based on the calculation of the supply of the required amount of cooled air and pressure to overcome the local resistances of the pipeline fittings and the layer of processed grain.

When the required grain temperature is reached, the main compressor 2 is turned off and the refrigerating machine is switched to mode II – grain storage.

In the storage mode, the main compressor 2 is cut off from the system with the help of latches 15 and 17, and with the help of latch 16, the absorber 7 AWARM is connected.

A heat load is supplied to the generator 1 of the AWARM from a waste 11 or solar 12 heat source.

In the first case, latch 14 is open, and 13 is closed.

In generator 1, when the thermal load is supplied, the WAS boils with the predominant formation of a mixture of ammonia vapor and water. The vapor mixture, passing through a dephlegmator or a rectifier (not shown in Fig. 4.3), is cleaned of water vapor and pure ammonia enters the air condenser 4, where it is compressed with the removal of the heat of vaporization to the environment. Liquid ammonia enters the liquid separator 18 through the throttle 5 and then into the evaporator-air cooler 6.

Ammonia vapor enters the air absorber 7 from the evaporator 6.

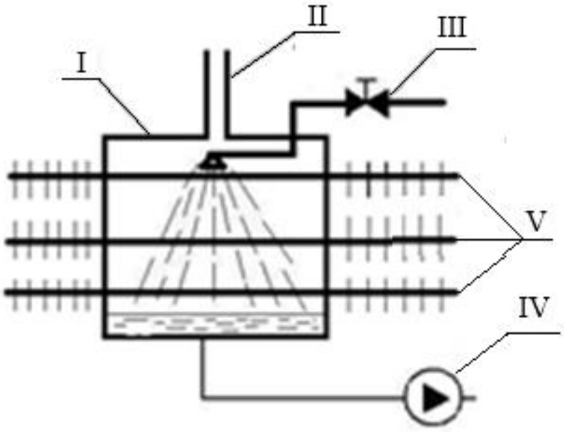

Figure 5 *– Scheme of the air absorber in the combined compressor-absorption water-ammonia refrigerating machine: I – air absorber; II – channel of the evaporator-air cooler; III – throttle of a weak solution; IV – circulation pump of solid solution; V – two-phase thermosyphons with fins in the condensation zone (removal of heat to the environment)*

In the absorber 7 from the generator 1, due to pressure resistance through the regenerative heat exchanger 9 and the throttle 10, the ammonia-depleted weak WAS enters. A weak and partially cooled WAS actively absorbs ammonia vapor from the evaporator, while maintaining a decrease in pressure and temperature. Heat removal of phase transition and absorption is carried out due to air cooling with atmospheric air.

When saturated with ammonia, the "weak" WAS becomes "strong", saturated, and with the help of the circulation pump 8, through the regenerative pump 9, it is fed into the upper part of the generator 1, and the AWARM cycle is repeated.

In the presence of low-potential heat energy sources, for example, solar collectors with a temperature of 70...100 °C, it is necessary to increase the pressure in the air condenser 4.

For this, a special booster-compressor 3 is connected with a valve 13, the main line with a valve 14 is cut off, instead of a waste heat source 11, a solar collector system 12 is connected.

The booster-compressor 3 supplies additionally compressed ammonia vapor to the air condenser 4 and the AWARM cycle is repeated.

An innovative absorber with air cooling is part of the combined development for the operation of AWARM.

Heat removal from the internal volume of absorber 1 is carried out using horizontal two-phase thermosyphons. Each such thermosyphon has one evaporation zone inside the volume and two heat removal (condensation) zones outside the internal volume of the absorber. To intensify the heat exchange in the condensation zones, ribs 5 are installed.

The supply of weak WAS to the absorber is carried out through the throttle 3 in the showering mode through the nozzle.

In the lower part of the absorber, a strong WAS accumulates, which is fed by circulation pump 4 to the regenerative heat exchanger of solutions and then to the AWARM generator.

The location of the evaporation zones in the shower zone allows to maximize absorption heat removal and minimize the weight and size parameters of the structure.

A distinctive characteristic of the combined refrigeration unit is the minimization of the amount of circulating ammonia, and the same amount of ammonia is used during the operation of the compressor part and the absorption part.

Minimizing the amount of ammonia allows you to reduce safety measures for personnel and fire safety measures during operation.

Its operation does not require special water sources to remove heat from heat-loaded elements (condenser, absorber).

Since the condenser and the evaporator-air cooler are common to both the compressor and absorption units, this significantly simplifies the design, reduces the metal consumption and increases the reliability of operation.

At the same time, the proposed scheme of the combined refrigerating machine meets all environmental requirements and in its work, due to waste and alternative energy sources, uses the minimum amount of electrical energy during the climatic calendar year.

4. Conclusions

Combined compression-absorption water-ammonia refrigerator the machine allows you to abandon the use of mains electrical sources for 7 months of the year.

Such a refrigerating machine can be made in a transport autonomous version and solve the task of air conditioning in field conditions.

To adapt to field conditions, the AWARM absorber is made with two-phase thermosiphons and with air heat removal to the environment.

Minimization of the amount of circulating ammonia and the same amount of ammonia is used during the operation of the compressor part and absorption part.

Особистий внесок авторів CRediT

Болбас Д.Р: перевірка, формальний аналіз, написання – огляд та редагування. **Петушенко С.М:** концептуалізація, методологія, дослідження, написання – оригінальний проект, адміністрування.

References

1. Law "On Food Security of Ukraine" dated on 22.12.2011. Retrived 28 August 2022 from https://www.rada.gov.ua/news/Povidomlennya/.

2. Food and Agriculture Organization of the United Nations (FAO) Retrived 28 August 2022 from http://www.fao.org/home/ru.

3. ZERNO magazine. Retrived 28 August 2022 from https://propozitsiya.com/ua/suchasni-shovishcha-dlya-zerna-abo-yak-zekonomiti-na-elevatornih-zatratah.
4. **Karabynyosh, S., Novytskyi, A.** (2017) Low Temperature Optimum. Retrived 28 August 2022 from https://www.zerno-ua.com/journals/2017/noyabr-2017-god/nizkotemperaturniy-optimum/.
5. **Puzik, L.M., Puzik, V.K.** (2013) Technology of grain storage and processing: teaching. Manual. *Kh.: Khnau, 312.*
6. **Podpryatov, G.I., Rozhko, V.I., Skaletska, L.F.** (2014) Storage technology and processing of plant products: a textbook. *K.: Agrarian education, 393.*
7. **Osokina, N.M., Gaidai, H.S.** (2005) Technology of storage and processing of plant products: a textbook. *Uman, 614.*
8. **Podpryatov, G.I., Skaletska, L.F., Senkov, A.M.** (2004) Technology of storage and processing of plant products. Practicum: Education. manual. *K.: Higher education, 272.*
9. **Novytska, N., Stepanenko, Yu.** (2014) The quality of seeds of field crops depending on the temperature regime of storage. E-conference of the Ternopil State Agricultural Research Station of the National Academy of Sciences of Ukraine. Section 1. Agricultural sciences. Retrived 28 August 2022 from http://econf.at.ua/publ/konferencija_2014_10_16_T7/sekcija_1_silskogospdaski_nauki/jakist_nasinnja_polovikh_kultur_zalezno_vid_temperaturnogo_rezhimu_zberigannja/4-1-0-16.
10. **Velichko, T., Yevdokymova, G., Ovsyannikova, L., Buivol, S.** (2009) Low positive temperatures (5...15 °C) make it possible to significantly extend the duration of storage of flax seeds. *Grain and bread, 1, 40-41.*
11. **Vasylyv, O. B.** (1998) Optimizing the operating modes of devices of various functional uses with absorption-diffusion refrigerating machines: thesis of candidate technical Sciences. *Odessa, 228.*
12. **Vasylyv, O.B., Tytlov, A.S., Kholodkov, A.O.** (2017) Modeling of thermal regimes of the lifting section of the dephlegmator of a household absorption refrigerating unit. *Refrigeration engineering and technology, 54(1), 7-18.*
13. **Ishchenko, I.M., Titlov, O.S.** (2009) Modeling and analysis of cycles of absorption water-ammonia refrigerating machines. *Scientific works of ONAKHT, 36, 2, 263-266.*

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Розробка енергозберігаючих технологій та систем охолодження для зберігання зерна дрібнонасінних культур

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У сучасному світі все більшої популярності набувають системи холодильного обладнання, зокрема системи безперервного холодильного ланцюга, без яких неможливо повною мірою забезпечити безпеку харчових продуктів. Особливий інтерес до систем штучного охолодження в зерновому господарстві України, яке є однією з бюджетоутворюючих галузей країни. Зерно є одним із найважливіших основних продуктів харчування людини, для вирощування та збору якого залучаються великі ресурси. Післязбиральна обробка та зберігання є ключовою ланкою виробництва зерна. За даними Продовольчої та сільськогосподарської організації ООН (FAO), близько 20% зібраного зерна у світі щорічно псується. Зменшення втрат зерна на всіх етапах збирання, транспортування, зберігання, переробки та забезпечення його збереження визначається технологією післязбиральної обробки. В умовах постійного збільшення обсягів зерна та високих темпів збирання все гостріше постає проблема збереження врожаю, більше половини якого збирають у вологому стані. Свіжозібране вологе посівне зерно нестійке в зберіганні і вимагає миттєвої обробки. Низькотемпературне консервування в місцях заготовок дозволяє вирішити *проблему тривалого та якісного зберігання зернових продуктів. Слід зазначити, що серед усіх видів зернових продуктів найбільшого ефекту від первинної низькотемпературної обробки можна досягти для дрібнозернових сортів (ріпак, льон, просо, гірчиця). Вони, через свій невеликий властивий лінійний розмір, найбільш схильні до пошкоджень під час теплової сушіння. Комбінована компресорно-абсорбційна водоаміачна холодильна машина дозволяє відмовитися від використання джерел електромережі протягом 7 місяців проятгом року. Така холодильна машина може бути виконана в транспортному автономному варіанті і вирішувати завдання кондиціонування повітря в польових умовах. Для адаптації до польових умов абсорбер виконаний з двофазними термосифонами і з відведенням тепла повітря в навколишнє середовище.*

Ключові слова: *Первинна обробка; Низькотемпературне зберігання; Дрібнонасінне зерно; Компресорні рефрижератори; Абсорбційні рефрижератори; Альтернативні джерела енергії; Енергія.*

Література

1. Закон «Про продовольчу безпеку України» від 22.12.2011. URL: https:// www.rada.gov.ua/news/Povidomlennya/ (дата звернення: 28.08.2022).
2. Продовольча та сільськогосподарська організація Об'єднаних Націй (FAO) URL: http://www.fao.org/home/ru (дата звернення: 28.08.2022).
3. Журнал ЗЕРНО. URL: https://propozitsiya.com/ua/suchasni-shovishcha-dlya-zerna-abo-yak-zekonomiti-na-elevatornih-zatratah (дата звернення: 28.08.2022).
4. **Карабиньош С., Новицький А.** Низькотемпературний оптимум. URL: https://www.zerno-ua.com/journals/2017/noyabr-2017-god/nizkotemperaturniy-optimum/
5. **Пузік Л.М., Пузік В.К.** Технологія в зберігання та переробка зерна: навч. Інструкція. – Х.: Хнау, 2013. – 312 с.
6. **Подпрятов Г.І.** Технологія зберігання та переробки продукції рослинництва: підручник. – К.: Аграрна освіта, 2014. – 393 с.
7. **Осокіна Н.М., Гайдай Г.С.** Технологія зберігання та переробки продукції рослинництва: підручник. – Умань, 2005. – 614 с.
8. **Подпрятов Г.І., Скалецька Л.Ф., Сеньков А.М.** Технологія зберігання та переробки продукції рослинництва. Практикум: Освіта. посібник. – К.: Вища освіта, 2004. – 272 с.
9. **Новицька Н., Степаненко Ю.** Якість насіння польових культур залежно від температурного режиму зберігання // Електронна конференція Тернопільської державної сільськогосподарської дослідної станції НАН України. Секція 1. Аграрні науки. URL:http://econf.at. ua/publ/konferencija_2014_10_16_T7/sekcija_1_silskogospdaski_nauki/jakist_nasinnja_polovikh_kultur_zalezno_vid_temperaturnogo_rezhimu_zberigannja/4-1-0-16.
10. **Величко Т., Євдокимова Г., Овсяннікова Л., Буйвол С.** Низькі позитивні температури (5...15 °С) дають змогу значно подовжити тривалість зберігання. насіння льону // Зерно і хліб. – 2009. – Т. 1. – С. 40-41.
11. **Василів О. Б.** Оптимізація режимів роботи апаратів різного функціонального призначення з абсорбційно-дифузійними холодильними машинами: канд. дис. – Одеса, 1998. – 228 с.
12. **Василів О.Б., Тітлов О.С., Холодков А.О.** Моделювання теплових режимів підйомної секції дефлегматора побутової абсорбційної холодильної установки // Холодильна техніка і технологія. – 2017. – Т. 54(1). – С. 7-18.
13. **Іщенко І.М., Тітлов О.С.** Моделювання та аналіз циклів абсорбційних водоаміачних холодильних машин // Наукові праці ОНАХТ. – 2009. – Т. 36(2). – С. 263-266.

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