Using the organic Rankine cycle for heat supply of greenhouses at agricultural enterprises

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Abstract. The greenhouses are used at agricultural enterprises producing crop products. It is proposed to utilize the heat of the ground in order to increase the high-quality energy supply of these facilities. Organic Rankine cycle is needed to get heat in the form of hot water, as well as electricity. Hot water can heat air in heaters and maintain the required air temperature in the greenhouses themselves. Electricity production is possible due to its generation by a micro-turbine or an expander. The most promising area is the conversion of the kinetic energy of freon into mechanical work in Tesla's radial turbines. The article proposes a variant of the heat supply scheme of the greenhouse. The most effective technological solutions of putting into practice the organic Rankine cycle are shown.

1. Introduction
Cultivated constructions of sheltered soil are production facilities that are protected from the external environment by a translucent roof and walls. They are intended for growing vegetables and flowers. The main elements of such structures are the soil, where plants are grown, and engineering networks for heating the room. Small-sized constructions are simple constructions designed for growing early vegetables. They consist of a transparent polymer film, frame. Large-sized structures are, in fact, greenhouses, which will be discussed in the article. In the production of products in sheltered ground, the main expenditure of energy resources is accounted for by irradiation of plants and heating of the greenhouse in the winter.

There are several types of heating greenhouses. The first of these is electric heating. In agriculture, electrical energy is used to heat various objects. Electric heating plants, widely used in agriculture, include electric water heaters and steam generators, electric heaters and plants for heating the soil in greenhouses, greenhouses and floors in livestock buildings. Water heating is carried out using elemental and electrode water heaters. The working body of elemental water heaters is a tubular electric heater. Electrical heating installations are used for air heating and are used in heating and ventilation systems of livestock and poultry farms, greenhouses, domestic and industrial premises, at grain cleaning drying centers. Their advantage is that heating and ventilation functions are combined in one unit. They have simple flow control and the amount of air supplied. The heating elements are divided into independently adjustable sections. For agriculture, electric air heaters with centrifugal fans and axial fans are produced. To heat the soil in greenhouses, a wire is used that is designed for a voltage of 220 V or 380 V. It is laid on the bottom of the pit in two sections and covered with a cement screed, as well as a metal mesh. Sometimes the heating wire is laid in a monolithic asphalt concrete block, laid under the soil layer. The
second type of heating is the construction of its own boiler room. The boiler room can be hot water or steam. Steam boilers are often used. In this case, it is necessary to additionally construct a condensate drainage system back to the boiler room. During the construction of a boiler house, it is necessary to build heating networks. The main element of engineering networks is a heater. Air is heated with hot water in this heat exchanger. Air can be additionally forced by a fan.

2. The principle of operation of the technological scheme and scientific novelty

The optimal composition is understood as the selection of thermal units of this type and quantitative ratio, which make it possible to obtain products in agriculture at the lowest cost of labor and funds per unit of output. The selection and justification of the optimal composition of thermal units and utilities is a very responsible task [1]. Its complexity is because agricultural enterprises are diversified farms cultivating various crops, and the conditions for making production decisions are diverse. Almost every type of thermal aggregates and devices in their technical capabilities can be most effectively used only in a certain range of natural-production conditions for which it is designed. Therefore, from the wide variety of units, only the minimum necessary number is selected, which will ensure that all work is performed with the greatest economic effect. It is advisable to start the choice with energy resources, which account for the largest share of cost and operating costs. These options include the use of the organic Rankine cycle. In this case, fuel costs are sharply reduced. Fuel is the main type of cost in any industrial enterprise [2, 3]. The principle of operation of the proposed technological complex is as follows. The scheme was developed taking into account the latest research by the authors [4, 5].

As the evaporator, soil heat exchange tubes 7 are used, in which freon boils. These pipes are in the soil 8. Freon steam is compressed by the compressor 9. The compressed steam is sent to the condenser 3. In the condenser, the freon steam gives its heat to water, which is pumped by a circulation pump 4. A radial micro turbine 5 is used as an expander, which transfers mechanical work to the electric generator 6. An important factor in heat transfer in a greenhouse is air exchange. Cold air 10 is pumped by the fan 11. Next, the air is sent to the air heater (it is not shown in the figure). Air circulates in the air supply system 12. Heat exchangers 2, ventilation 12 and air conditioning systems are widely used in industry [6, 7].

3. Theoretical part of using organic Rankine cycle

Cogenerators are easy to transport and install. They allow solving the acute problem of uneven daily electricity consumption, insoluble for large generating plants. Indeed, for a cogenerator, a linear dependence of fuel consumption takes place starting from 15–20% of the rated power. By partitioning the total power operating in parallel, it becomes possible to work from 1.5–4.0% to 100% of the rated load with the estimated specific fuel consumption. Boiler units can be used as a source of thermal energy [8, 9]. Boiler units burn various fuels. At the moment, there are studies regarding water-coal mixtures [10, 11]. Using trigeneration technology allows you to maintain high efficiency year-round. For

![Diagram](image-url)
example, in summer, heating is not required, but it is necessary to air-condition residential premises, offices, hospitals [12]. Cold water and cold are widely used in industry. The disadvantage of cogenerators is only limited power up to 3 MW for one machine. The average industrial consumer has an installed capacity of 1–2 MW. If necessary, several parallel cogenerators can be installed. Technological complexes operating on the principle of the organic Rankine cycle should also be attributed to cogeneration plants. Heat sources for the Rankine organic cycle can be heat from the combustion of natural gas, propane, blast furnace gas, pyrolysis gas, landfill gas, shale gas, associated gas, biomass. In addition, it is possible to use waste heat from geothermal energy, waste hot water of various industries, steam from steam boilers or turbines, heat from the exhaust of gas turbines, waste heat from boiler plants. For effective use in a system based on the organic Rankine cycle, the optimal working environment must satisfy the following requirements. It is necessary that there is a low freezing temperature, and it must be below the lowest temperature of the cycle and below the ambient temperature. High heat of evaporation and density are required for more efficient absorption of energy from a heat source.

4. Practical part. Application
In steam cycles, the pressure to heat ratio of the turbine is very high. As a result, turbines with several expansion stages are typically used. In the organic Rankine cycle, the reduction in heat content is lower and usually one-stage or two-stage turbines are used, which entail a reduction in cost. Additional effects of lower heat reductions in organic fluids include lower rotational speeds. A lower rotation speed allows the direct drive of an electric generator without a reduction mechanism (this is especially beneficial for plants with a low power range); while a low speed reduces the voltage on the turbine blades and simplifies their design. The efficiency of the current high temperature cycle of the organic Rankine cycle does not exceed 24%. A typical steam cycle has a thermal efficiency of more than 30%, but with a more complex design cycle. The Rankine organic cycle is best suited to operate in the low and medium power ranges, as small power plants cannot afford a local operator. The cycle also has a relatively simple structure and does not require components difficult to manufacture. Consequently, it is more adapted to decentralized electricity production. For high power ranges, the steam cycle is more suitable, with the exception of low-temperature heat sources.

5. Conclusion
Thus, the general range of increasing of heat supply efficiency is possible in case energy and technological combination. The main advantages of the Rankine organic cycle are as follows. As noted earlier, organic fluids usually remain superheated at the end of expansion. Thus, there is no need for overheating in the Rankine organic cycle, in contrast to steam cycles. The absence of condensation also reduces the risk of corrosion on the turbine blades, and extends the service life to 30 years, and for steam turbines, the service life is 15-20 years. Another plus is the low heat recovery temperature. Due to the lower precise boiling point and due to properly selected organic working fluids, high temperature can be restored at much lower temperatures. In the organic Rankine cycle, it is possible to use once-through boilers, which avoids steam drums and recycling. This is due to the relatively small difference in density between the vapor and the liquid. In contrast, the low vapor density in steam boilers can produce a completely different heat transfer due to the characteristics of the pressure drop between the liquid and the steam. In order to avoid droplet formation during expansion, in the Rankine steam cycle, due to overheating, temperatures above 450 K are required at the turbine inlet. This leads to higher thermal stresses in the boiler and on the turbine blades, and increases its cost. The pump flow rate is proportional to the volumetric flow rate of the liquid and the pressure drop between the inlet and the outlet. This can be expressed as the ratio of pump operation to turbine operation, which is defined as the pump flow rate related to turbine power. In the Rankine steam cycle, water consumption is relatively low. For a high-temperature organic Rankine cycle using toluene, the ratio is 2-3%. For the low-temperature organic Rankine cycle using tetrafluoroethane (HFC-134a), the values exceed 10%. In the OCR organic Rankine cycle, the pressure does not exceed 30 bar (3000 kPa). In addition, the working fluid does not evaporate
directly, not at the expense of a heat source, but through an intermediate heat exchange circuit. This simplifies heat recovery. To avoid air entering the cycle, it is advisable that the condensation pressure be higher than atmospheric pressure. Low temperature organic liquids such as tetrafluoroethane (HFC-134a), pentane fluoropropane (HFC-245fa) or 2,2-dichloro-1,1,1-trifluoroethane (HCFC-123) meet this requirement. Water is one of the best working fluids. Its main advantages are low cost and high availability, non-toxicity, incombustibility, environmentally friendly (low global warming potential and zero ozone-depleting ability), chemical stability (no deterioration of the working fluid), also low viscosity, leading to lower friction losses, and higher heat transfer coefficient. However, the steam cycles are not very tight: water is lost as a result of leaks, drainage or purging of the boiler. Thus, the water treatment system must be combined with the power plant in order to enrich the cycle with high purity deionized water. A degasser must also be included to avoid corrosion of metal parts due to the presence of oxygen in the cycle.

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