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TECHNICAL AND ECONOMIC EFFICIENCY ASSESSMENT OF HEAT PUMP ELECTRIC REGULATOR APPLICATION ON AGRICULTURAL OBJECT

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ABSTRACT

The energy costs of existing equipment operation for maintaining the microclimate of agriculture products during active ventilation are sufficiently high, which requires the finding of new solutions for energy-saving tasks. So, in this paper, we evaluated the technical and economic efficiency of an upgraded electric regulator application for a heat pump in the developed systems to maintain the microclimate of products storages. Heat pump assisted drying provides a controllable drying environment (temperature and humidity) for better products quality at low energy consumption.

1. INTRODUCTION

In order to regulate and maintain temperature and humidity regimes in storage areas, it is necessary to create ventilation, artificial cooling, humidification, and technological heating systems [1]. The energy costs of existing equipment operation for maintaining the microclimate of potato storage during active ventilation (especially during the treatment period, as well as during the storage in winter and warm season, before product sending to a consumer) are sufficiently high, which requires the finding of new solutions for energy-saving tasks [2,3]. Therefore, the measures to maintain the microclimate in potato storage room require the installation of modern energy-saving equipment, which must be operated

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during a long storage period [4].

One of the ways to solve energy saving problems is to use a renewable low-potential energy source using heat pumps, in which the regulation of energy flow (heater or coolant) plays an important role [5]. As compared to electric heaters, heat pumps that have a high conversion rate - the ratio of heat output to power consumption. These pumps are several times more efficient since they allow to get 3-7 kW of heat energy per 1 kW of consumed electrical energy [6].

The aim of the work is to evaluate the technical and economic efficiency of a heat pump modernized electric regulator use to maintain the microclimate of a potato storage facility.

2. METHOD

The technical re-equipment of production, based on the introduction of highly economical equipment and the improvement of technological processes, as well as the reduction of losses and the encouraging of energy resource rational use provide a significant increase of energy efficiency. The conduct of a strict regime of energy resource saving in all sectors of the economy, at each workplace necessitates the implementation of a wide range of effective measures to save and rationalize energy use. The main directions of energy saving are an active implementation of highly economical equipment and the reduction of direct losses on fuel and energy. The efficiency of potato storage consists of two main components - the loss of potatoes and energy costs. The first depends on the initial quality of tubers, the compliance with temperature and humidity storage parameters and storage microclimate. The second one depends on the type of fans and drives engine power, as well as on the energy consumption class used for storing potatoes [7].

This study considers the methodology for a heat pump (with electric regulator) effectiveness determination to store potatoes. When they solve complex tasks of scientific and technological progress acceleration, it is very important to assess the technical and economic level comprehensively and determine the prospects and main trends for this level increase using the system of corresponding indicators [8].

Let's consider the method of the integral indicator determination concerning the technical-economic level of work and the system of indicators, the generalization, namely:

- the technical level of work organization;
- economic level of work;
- labor organization level;
- social level.

The economic level of $У_э$ work is characterized by the value of the annual operating work costs and is calculated by the following formula [9],

$$У_э = \frac{1}{к_э}, \quad (1),$$

$$к_э = \frac{U}{Э} \cdot 100\ \%, \quad (2).$$

Where $к_э$ – the share of labor costs in the total cost of production,
U – the annual operating work costs, rub.,
$Э$ – general production costs, rub.

Annual operating costs for the work consist of the following expenditure items:

- wages of employees with accrual;
- social insurance contributions;
- the payment of energy costs necessary for equipment operation;
- the deductions on equipment depreciation and maintenance;
- the additional costs associated with the loss of potatoes and other causes.

3. RESULTS AND DISCUSSION

The calculation of an electric regulator cost with a solid filler and electric heater is presented below. The appearance of the electric regulator is presented in Figure 1.

Figure 1: Electric regulator with solid filler and EH.

3.1 BOOK VALUE OF STRUCTURE

3.1.1 COST OF CONSTRUCTION AND PURCHASED ITEM

Electric regulator with solid filler and electric heater, details are given about the cost of construction (Table 1), purchased item cost (Table 2).

Table 1: The cost of materials.

Detail	Dimensions	Total, *rub.*
Cast iron housing	Dimensions 100×100×2 мм	400
The rod with brass valves	Rod d 20 mm Valve d 120 mm	180
Microprocessor control unit	Dimensions 150×110 mm	490
Automation elements		310
Electric heater body made of insulating plastic material	Dimensions 100×80 mm	150
Electric heater cover	Dimensions 100×80 mm	100
Guiding bush	Dimensions 50×50 mm	130
Total		**1760**

Table 2: Purchased item cost.

Detail	Dimensions	Price per 1 piece, *rub.*	Total, *rub.*
Temperature Sensor TCM-50M	1 pc.	500	500
Thermal force sensor with solid filler	Sensor d - 40 mm Solid filler mass – 2.5 g	450	450
Electric heater (posistor), 60 W	1 pc.	400	400
Sealing gasket	1 pc.	50	50
Mounting screws M8×40	8 pc.	10	80
Rubber bushing	1 pc.	95	95
Compression spring	1 pc.	110	110
Sealing ring	1 pc.	10	10
Load sensor	1 pc.	400	400
Total	–	–	**2095**

3.1.2 THE COST OF ORIGINAL PART MANUFACTURING

3.1.2.1 WORKER LABOR COSTS

Taking into account the labor intensity of manufacturing, a worker grade rate makes 50.26 rubles/hour.

- additional payment 50.26 · 0.3 = 15.08 rubles;
- Surcharge for service length (50.26 + 15.08) · 0.11 = 7.19 rubles;
- vacation payment (50.26 + 15.08 + 7.19) · 0.0834 = 6.02 rubles;

labor remuneration 50.26 + 15.08 + 7.19 + 6.02 = 78.55 rubles.

Insurance contributions to extra-budgetary funds (30.2%):

78.55 * 30.2 / 100 = 16.18 rubles.

The remuneration with the deductions for social benefits per man-hour.

$З_{от}$ = 78.55 + 16.18 = 94.73 *rub./h.*

3.1.2.2 THE COST OF LABOR FOR THE MANUFACTURE OF ORIGINAL PARTS

The amount of labor costs for the manufacture of original parts makes 4878.6 rubs, with the following detail.

1) Cast iron body 21 man- h. * 94.73 = 1989.33 *rub.*;
2) The rod with brass valves, 4 man-hours * 94.73 = 378.92 rubles;
3) Microprocessor control unit - 6 man-hours * 94.73 = 568.38 rubles;
4) The electric heater cover - 2.5 man-hours * 94.73 = 236.83 rubles;
5) Automation elements - 16 man-hours * 94.73 = 1515.68 rubles;
6) The electric heater body of insulating plastic material - 2 man-hours * 94.73 = 189.46 *rub*.

3.1.3 THE COST OF ELECTRICITY DURING THE MANUFACTURE OF PARTS

$З_{эн} = T_{ем} * C_{кВт/ч}$

$З_{эн}$= 58.5 * 2.20=128.7 rub.

where $T_{ем}$ – the complexity of original part manufacture, man-hours;

$C_{кВт/ч}$ – the cost of 1 kW/h of electricity, rub.

3.1.4 EXPENDITURES FOR CONSUMABLES

– cutting wheel 1 pc. · 30 rub. = 30 rubles;

– drills –30 rub.;

The sum of expenses for consumables makes (30 + 30) = 60 rubles.

The sum of the cost for original part production is equal to (4878.6 + 128.7 + 60) = 5067.3 rubles.

3.1.5 THE COST OF STRUCTURE ASSEMBLING

The cost of assembly labor:

– the assembly of an electric regulator housing with a stem and valves:

94.73 rub./h. · 2 h = 189.46 rub.;

– the assembly of the machine with an electric heater, the temperature sensor, and solid filler 94.73 rub./h. · 3 h. = 284.19 rubles;

– the assembly of temperature and load sensors and control unit

94.73 rub./h. · 2 h = 189.46 rub.

The sum of structure assembly cost is equal to 189.46 + 284.19 + 189.46 = 663.11 rubles.

3.1.6 PRODUCTION WORKSHOP EXPENSES

General production workshop expenses make 175%:

The labor costs for the manufacture of original parts and structure assembly cost:

5067.3 + 663.11 = 5730.41 *rub*.;

5730.41 ·1.75 = 10028.22 *rub*.

Book value (total construction cost):

2095+1760 + 5067.3 + 663.11 + 10028.22 = **19613.63 *rub.***

3.2 TESTING OPERATING COSTS FOR POTATO STORAGE

during 10 months (using an electric regulator with solid filler and an electric heater)

The duration of the electric regulator operation for 10 months - 950 h.

3.2.1 LABOR PAYMENT COSTS

The annual payroll fund for the operator serving the device

$З_{ОТ\ оп.}$ = 4661 · 1.866 · 1.5 · 10 = 130461.39 *rub*..

where 1.866 – the tariff rate of the 9th category employee;

1.5 – surcharge rate to the tariff rate;

10 – the number of regulator operation months per year.

3.2.2 THE COST OF ELECTRICITY

Electricity costs. taking into account the operating time of the regulator with solid filler and an electric heater during potato storage for 10 months.

$З_{эн\ рег} = З_{эн} * \tau = 2.20 * 950 = 2090$ rub.

where τ – the duration of the regulator operation. hours.

The annual amount of the electric controller depreciation with solid filler and electric heater with the depreciation rate of 10% (GOST RF 28923-91):

A = 19613.63 · 10 / 100 = 1961.36 *rub*..

where *A* – the structure balance cost. rub.

3.2.3 CURRENT REPAIR

(the norm makes 24% per year):$Т_р$ = 19613.63 · 0.24 = 4707.27 rub.

3.2.4 OTHER EXPENSES

$П_р$ = (130461.39 + 2090+ 1961. 36 + 4707.27)·0.05 = 6856.50 *rub./month.*

General production and maintenance costs:

P_{ox} = 130461.39 ·0.15 = 19569.23 *rub.*

Total operating costs:

130461.39 + 2090+ 1961.36 + 4707.27+6856.50 + 19569.23 = ***165675.75 rub.***

3.2.5 THE COST OF POTATOES

The cost of potatoes according to the project version is 37500 Rub per ton.

3.3 OPERATING COSTS FOR POTATO STORAGE USING RTP-M SOLID FILLER REGULATOR. ACCORDING TO THE BASE CASE

The basic variant is the RTP-65-75-1M regulator with a bronze casing TU 25-02.092101-78 (Figure 2). with a fixed setting value of 75 °C. the temperature sensors with a solid filler of TDM type are the temperature-sensitive element. The book value of the thermal regulator makes 29736 rubles.

Figure 2: The thermal regulator RTP -65-75-1M.

3.4 LABOR PAYMENT COSTS:

Annual payroll fund for the operator serving the device

З $_{\text{ОТ оп.}}$ = 4661 · 1.866 · 1.5 · 10 = 130461.39 *rub.*.

where 1.866 – the tariff rate of the 9th category employee;

1.5 – the coefficient of surcharge to the tariff rate;

10 – the number of regulator operation months per year.

3.5 THE COST OF ELECTRICITY WHEN THE ELECTRIC REGULATOR IS USED WITH A SOLID FILLER (BASIC VERSION)

The power consumption makes 30 kW/h.

The duration of the basic version operation - 6000 hours per year.

Then the annual energy consumption makes 30 · 6000 = 180.000 kW.

The cost of electricity makes 180.000 · 2.20 = 396000 rubles.

The annual depreciation of the electric regulator with a solid filler and the depreciation rate of 10%

A =29736 · 0.10 = *2973.6 rub.*.

where $A = 29736$ *rub.* – the book value of the regulator RTP-65-75-1M. rub.

The deductions for maintenance:

$A = 29736 \cdot 0.24 = 7136.64$ *rub.*

Other expenses:

Π_p = (130461.39 + 396000 + 2973.6 + 7136.64)·0.05 = 26828.58 rub.

General production and maintenance expenses:

P_{ox} = 130461.39 ·0.15 = ***19569.21 rub.***

The total amount of operating costs according to the basic variant:

130461.39 +396000 + 2973.6 + 7136.64+ 26828.58 + 19569.21 = 582969.41 rub.

- The cost of potatoes according to the basic version 41500 rubles/ton. The cost is reduced by the proposed heating method.

In this paper. the definition of the annual economic effect is based on the comparison of the reduced costs by basic and new equipment.

The technical and economic indicators of an electric regulator introduction with a solid filler and an electric heater are presented in Table 3.

Table 3: Technical and economic indicators of the electric regulator implementation with solid filler and electric heater

Indicators	Basic	Project
Book value. rub.	29736	19613.63
Electricity consumption. kWh	30	95
Number of regulator operation hours per year (for 10 months)	6000	950
Annual electricity consumption. kW	180000	90250
Operating expenses. rub / year	582969.41	165645.75
Potato losses during year storage (10 months). %	18	13.5
Potato cost. rub / ton	41500	39180
Potato selling price. rub/t	55000	55000
Profit. rub.	13500	15820
The volume of sold products. t	410	433
Capital costs. rub./t (book value / sales volume)	72.5	45.3
The economic effect. rub. (the difference between reduced costs)	[(41500+0.20·72.50) - (39180+0.2·45.30)]·433 = 102811.52 rub./year	
Profitability (%) [profit/production cost · 100]	32.5	40.4
Payback period. year (book value/economic effect)	-	0.19

When calculate the economic efficiency, it is necessary to consider four possible trends.

1. The production and the use of new labor tools [10].

2. The use of new technological processes of agricultural product processing [11] and heat treatment [14. 15].

3. The use of new or improved work items [12. 13].

4. The production of high-quality products and the means for their processing [16. 17].

4. CONCLUSION

The use of modernized electric regulators in a heat pump will allow you to maintain the potato storage microclimate. At the same time. in order to obtain 1 kW hour of heat energy, you will need to spend 0.2-0.3 kW/hour.

The result of a modernized electric regulator (with a heat pump electric heater) production tests showed that the economic effect of its use makes 102.81 thousand rubles/year.

5. DATA AVAILABILITY STATEMENT

The used or generated data and the result of this study are already included in this article.

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