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Mobile device for drying paddy and justification of its parameters

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ABSTRACT

The article presents the results of scientific research on the development of a mobile device for drying paddy. A description of the patented design of a mobile device for drying paddy, developed on the basis of an analysis of the advantages and disadvantages of some existing devices for drying grain products, is given. The movement of the paddy in a drying drum is investigated and its geometric dimensions are substantiated. The results of experimental studies to determine the optimal parameters of the device for drying paddy and its technical characteristics are presented.

Key words : rice, grain products, screw conveyor, coupling.

1. INTRODUCTION

In the world, it is important to increase the rate of growth of production of processing grown grain products based on the creation of effective technologies and equipment. According to world statistics “sown fields in 2017 were 166.08 million hectares, in 2018 - 167.13 million hectares” [1] and “rice consumption in 2019 amounted to 486.622 million tons, in 2020 - 493.126 million tons "[2]. In this direction, in connection with the gradual increase in the cultivation and consumption of rice, special attention is paid to the introduction of modernized energy and resource-saving technical means and technologies that contribute to the high-quality drying of the paddy harvest.

In world practice, a number of devices and equipment have been developed to ensure high-quality drying of the paddy. Some of them are recommended as designs for new machines. However, in these studies, the issues of the influence of drying parameters on quality for certain types of grain, in particular, paddy, have not been sufficiently studied.

The aim of the study is to develop a new design of a drum drying device that provides the quality of drying paddy with minimal energy consumption and substantiation of its parameters.

Research objectives:

review of existing paddy drying plants;

development of a technological scheme and design;

study of the movement of the pa ddy in the drying drum, taking into account its parameters;

substantiation of the optimal parameters of the drying device for the paddy;

evaluation of the economic efficiency of the device for drying paddy.

2. MATERIALS AND RESEARCH METHODS

The analysis of patent information materials, carried out research works on the development of technologies and techniques that reduce energy consumption for drying paddy and other types of grain.

In research by H.S.Md. Sazzat, N.I. Mohd, A.A. Norashikin and S.P. Mohd [3] provides an energy analysis of a device for drying a paddy used in industry, the drying capacity of which is 22 t/h. The drying performance is high, but only 31.18-37.01% of the energy is used to dry the paddy.

S.Firouzi, M.Rez.Alizadeh and D.Haghtalab [4] have developed a horizontal drum dryer for drying a paddy. The research was carried out at a drying agent temperature of 38-40 ºC, a speed of 0.171 m/s, and the energy consumption and the quality of the dried paddy were studied. According to the data obtained, the specific energy consumption is 5500-17410 kJ/kg and the quality of the dried paddy is high relative to the dried paddy in other devices. However, according to the research results, it was observed that the specific power consumption in the device is relatively high.

Studies by T. Dissanayakea, D. Bandaraa, H. Rathnayakea, B. Thilakarathnea and D. Wijerathneb [5] provide information on a mobile device for drying paddy, which provides drying of a 1 ton paddy with a moisture content of 18-24% at a drying agent speed temperature 60°C. According to the results of the experiments, it is shown that the efficiency of the device is 0,18, the heat utilization coefficient is 0,82, and the heat output is 46.83%. According to the research results, it has been observed that the efficiency of the device is relatively low.

From the side of M.S.H. Sarker, M. Nordin Ibrahim, N. Ab. Aziz wa P. Mohd. Salleh [6] developed an industrial device for drying the paddy. The device provides drying of the paddy of 15 tons, the research was carried out at a moisture removal of 10.5% and on the quality and quantity of rice obtained from the processing of the dried paddy. At 39°C high quality rice was obtained with a large quantity relative to the drying temperature of the paddy 41 - 42°C.

M. Beigi, M. Torki-Harchegani and M. Tohidir [7] in their studies studied the process of drying the paddy by the convective method in an experimental device with different modes of parameters. Increasing the temperature and speed of the drying agent shortened the drying time; higher values of the initial moisture content of the paddy led to an increase in the drying time. According to the experimental data obtained, it was determined that at a high temperature value and at a lower value of the speed of the drying agent, the initial moisture content of the paddy, the energy performance of the device was improved. Increasing the temperature increases the drying performance, however, it will cause the rice to crack in the paddy.Thus, the device has not fully solved the problem of high-quality drying of the paddy.

In a study by D.T.M.R. Dissanayake. D.M.S.P. Bandara. H.M.A.P. Ratnayake. B.M.K.S. Tilakaratna. D.B.T. Wijerathne [8] a mobile dryer one ton capacity was developed and its performance was evaluated in terms of overall thermal efficiency, heat utilization factor and rice yield .

In a study by K.Soontarapa, J.Arnusan [9] a chitosan membrane drier was used and the direction of the air flow was substantiated on the basis of the performed mathematical analysis.

P. Udomkin, S. Romuli, S. Shock, B. Mahayoti, M. Sartas, T. Vossen, E. Nyukme, B. Vanlaum, J. Müller [10] investigated the types of solar dryers used in Africa and Asia, and emphasized that a noticeable effect of their use on product quality.

Y. Mohara, R. Mohanapria, T. Anukitutica, K.S. Yoha, J. Moses, K. Anandharamakrishnan [11] explored the possibility of using solar energy to replace energy-intensive food processing operations.

D.Yu.Danilov [12], in his research, developed an energy-saving cassette device for drying wheat on farms. In the study, it was achieved that with a specific energy consumption of 8 ± 2.5 W h/kg, a drying agent temperature of 60 ± 2.5°C, a moisture removal of 5% in one pass is provided in the device.

In the study of A.Zh.Sagindikov [13] a device for drying wheat has been developed, the drying performance has been increased by improving the design and technological parameters. It has been achieved that the drying capacity is 40 kg / h with a specific energy consumption of 3.2 - 3.6 mJ/kg.

In the device for drying grain developed by V. I. Kurdyumov and A. A. Pavlushin [14], the drying quality is improved and the metal consumption is reduced. However, the device has a complex design.

In the device developed by the research of M.M. Abdyushev [15], drying performance is increased and fire safety is ensured.

N.V. Tsuglenok, S.K. Manasyan and N.V. Demskiy [16] conducted studies to improve the quality of grain drying and reduce material costs. However, the devices presented in [15] and [16] are stationary and have large overall dimensions.

The drum device presented in the study by A. Khramov [17] is designed for drying bulk materials. The study achieved an increase in drying performance and a decrease in specific energy consumption. However, the device is stationary and the drum is long.

In the study of A.P. Parpiev, R.D.Artikov, I.T.Tursunov, M.Akhmatov and I.D. Madumarov [18], a drum device for convective drying was developed. It is equipped with V-shaped blades and is designed for drying raw cotton.

In the research of O. Rakhmatov [19], an energy-saving device for drying was developed. It is intended for drying grapes.

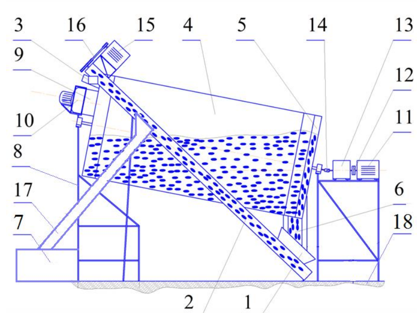
In the study of B.P. Shaimardanov [20], the main parameters of the device based on the convective drying method were developed and substantiated. Research has been done for melon drying.

In [21], a stationary drum device for drying bulk materials is presented. In this device, the movement of the drum is provided on tires and support rollers using gears. In industry specimens, its length is 4-16 meters, diameter is 1-2.8 meters. The main disadvantages of this device are: non-uniformity of drying as a result of uneven displacement, large dimensions and the use of fuel oil and diesel fuels for drying.

Based on the analyzes carried out, it was determined that individual devices have a relatively low efficiency, complex design, stationarity and do not provide uniformity of drying due to the lack of uniform mixing during grain drying.

3. RESEARCH RESULTS

Based on the analysis of the previous work performed and the result of the research carried out, a technological diagram of a device for drying a paddy [22], based on a convective method, has been developed (see Fig. 1).

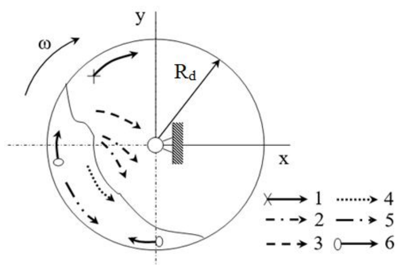


1 - bunker; 2 - screw conveyor; 3, 6 and 17 - gutters; 4 - drying drum; 5 - adjustable slot; 7 - finished product vessel; 8 - fixed section; 9 - heater; 10 - fan; 11, 15 - electric motors; 12, 14 - couplings; 13– reducer;16 - belt drive; 18 – base

Figure 1: Technological diagram of the drying device paddy

The principle of operation of the device is as follows: the dried paddy passes through the bunker 1 to the screw conveyor 2. The paddy up with the help of the screw conveyor and after loading a certain amount through the chute 3 into the drying drum 4 the feeding of the paddyfrom the hopper 1 stops. At this moment, the heated air in the stationary section 8, created in the heater 9 by the fan 10 is fed into the drying drum. The adjustable slot 5 opens in the drying drum 4 and the paddy is lowered into the screw conveyor 2 with the help of the chute 6 for subsequent drying. The drying cycle continues, the finished product, i.e. the dried paddy is delivered through the chute 17 to the finished product vessel 7 and packed in bags.

The movement of the cross-section of the embankment of the paddy consists of the joint movement of parts such as centrifugal, cataract, cascading, rolling and sliding (see Fig. 2).



1 - centrifugal; 2 - cataract; 3 - cascade; 4 - rolling;
5 - sliding; 6 - general circulation direction

Figure 2: Schematic representation of the movements of parts of the paddy embankment in a drying drum

Investigated according to the scheme shown in Fig. 3.the trajectory located on the 1-quadrant of the part of the embankment of the paddy*M* in sliding having a mass m_a, in the form of a circle of a drying drum rotating with a constant angular velocity ω, having an angle of slope α with a horizontal plane and lifting upward by an angle β [23].

The following forces act on part of the paddy hill:$G_a=m_a g$ - gravity; $F_{in}=m_a\,\omega 2R_d$ – centrifugal force; F_N is the reaction force on the inner surface, its component on the Z axis is the F_{NZ} force, and the component of the friction force F_{fr} on the Z axis is the force F_{frZ}.

In fig. 3. shows a diagram of the forces acting in the *YZ* plane on a part of the paddy embankment.

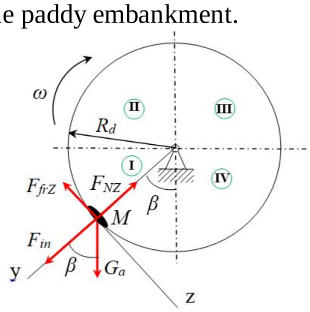


Figure 3: Diagram of the acting forces along the *YZ* plane on a part of the paddy embankment

Unlike traditional schemes, on the *YZ* plane the centrifugal force F_{in} helps to move, that is, to move a part of the paddy embankment inside the drum. According to Fig. 3, on the *YZ* plane, the force of gravity G_a and centrifugal force F_{in} make a part of the paddy embankment slide down. This process is impeded by the friction force F_{fr}. The friction force component F_{fr} on the *YZ* plane is determined by the following formula

$$F_{frZ} = fF_{NZ} = f\,(m_a\omega^2 R_d + m_a g\cos\beta), \quad (1)$$

where f - coefficient of friction; m_a - mass of paddy embankment, *kg*; ω - angular speed of the drying drum, s^{-1}; R_d - radius of the drying drum, *m*; g – free fall acceleration, m/s^2; β - the angle of ascent of a part of the embankment between the direction of gravity and the *Y*-axis, degrees.

The investigated part of the paddy embankment in the 1-quadrant on the *YZ* plane rises with the wall of the drying drum until the following dynamic equilibrium is violated

$$G_a\sin\beta \geq F_{frZ}. \quad (2)$$

From condition (2) we obtain the following dependence

$$g\sin\beta - f\omega^2 R_d - fg\cos\beta = 0. \quad (3)$$

Considering the dependence of the angular velocity in expression (3) with the number of revolutions of the drying drum, i.e. taking into account the dependence $\omega=(\pi n_d/30)$, one can write [24]

$$n_d = \frac{30}{\pi}\sqrt{\frac{g\sin\beta + fg\cos\beta}{fR_d}}. \quad (4)$$

Calculations were made according to expression (4) with $f=0.3$; $R_d=0{,}22 \ldots 0{,}66$ *m* and $g=9.8\ m/s^2$ to determine the law of variation of the ascent angle β depending on the number of revolutions of the drying drum n_d (see Fig. 4).

From the graphs shown in Fig. 4. it can be seen that at high values of the number of revolutions of the drying drum, the values of centrifugal force and reaction force increase and the latter leads to mechanical damage to a part of the embankment of the paddy. Therefore, in experimental studies of determining the optimal values, the number of revolutions of the drying drum was the goal at low intervals of 16-18 min^{-1}.

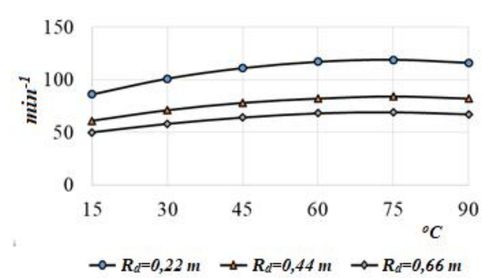


Figure 4: Graphs of the change in the angle of elevation of a part of the paddy embankment, depending on the number of revolutions of the drying drum

The component of the gravity force $m_a\,g\cos\alpha$ along the *Y* axis and the centrifugal force F_{in} impede the movement, and the component of the gravity force $m_a g\sin\alpha$ and the pressure force of the drying agent (air) F_{air} promotes the movement of a part of the embankment of the paddy (See Fig. 5).

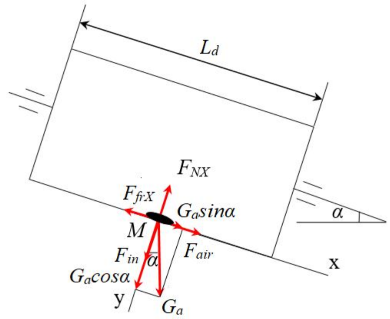


Figure 5: Schemes of forces acting on a part of the embankment along the *XY* plane

The component of the friction force F_{frX} along the X axis is determined as follows

$$F_{frX} = fF_{NX} = f(m_a\omega^2 R_d + m_a g\cos\alpha). \qquad (5)$$

The friction force is

$$F_{fr} = \sqrt{F_{frX}^2 + F_{frZ}^2}. \qquad (6)$$

The differential equation of the investigated part of the section of the embankment of the paddy is expressed in the form

$$m_a\ddot{x} = G_a\sin\alpha + F_{air} - F_{frX}. \qquad (7)$$

The pressure force of the drying agent is determined as follows

$$F_{air} = kV_{air}^2, \qquad (8)$$

where$k$ - coefficient of pressure force of the drying agent, kg/m; V_{air} — speed of the drying agent, m/s.

The coefficient of force of pressure of the drying agent is as follows

$$k = q\rho_x A, \qquad (9)$$

where q - the coefficient of air resistance, $q=0{,}12\text{-}0{,}26$; $\rho_x=1{,}2\ kg/m^3$; A — cross-sectional area of Midelle (projection area of a part of the embankment on the transverse plane), m^2.

By solving the differential equation (7), taking into account the initial conditions $t_0=0$, $V_0=0.7\ m/s$ and $x_0=0$, we obtain the following dependence

$$x = \frac{(m_a g\sin\alpha + kV_{air}^2 - f(m_a\omega^2 R_d + m_a g\cos\alpha))t^2}{2m_a} + 0{,}7t. \qquad (10)$$

To determine the law of change in the displacement of a part of the embankment along the X axis, depending on the speed of the drying agent, calculations were made according to the formula (10) with values of $m_a=1.0\ kg$;$\omega=2{,}72\ s^{-1}$; $\alpha=20^0$; $f=0{,}3$; $R_d=0{,}44\ m$; $g=9{,}8\ m/s^2$; $k=0{,}0024\ kg/m$ and $t=5\ ...\ 15\ s$ (see Fig. 6).

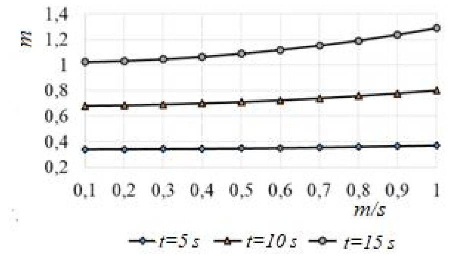


Figure 6: Graphs of displacement of a part of the paddy embankment section along the *X* axis depending on the speed of the drying agent

Analysis of the graphs in Fig. 6. shows that with increasing time, the displacement of a part of the paddy field is accelerated. With the value of the radius of the drying drum $R_d=0{,}44\ m$ and the speed of the drying agent $V_{air}=1.0\ m/s$, it will take 5 seconds to move 1,0 kg of the paddy along the X axis by *0,37 m*, and for *1,8 m 24, 3* seconds. Thus, in a drying drum, *2,47 kg* by *1,8 m* moves per minute, and more than *148 kg* of paddy per hour. On the basis of this, it was found that in the device being manufactured for carrying out experimental research, it is necessary to take the radius of the drying drum $R_d=0{,}44\ m$ and the length $L_d=1{,}8\ m$.

4. DISCUSSION

The mobile device for drying paddy was produced at the Andijan pilot plant and tested at the farms "Teshaboi Ishonchi", "Umida Saida Ishonchi" and "Khamidzhon Ishonchi" in the Izbaskan district of the Andijan region. The appearance of a mobile device for drying a paddy during operation is shown in Figure 7.

a b c

a – loading process for drying paddy; b - paddy drying process; c – the process of removing the dried mass of the paddy.

Figure 7: Mobile device for drying paddy

Experimental studies were carried out in a prototype of a device for drying a paddy to determine the influence of its parameters on drying indicators. Experimental studies have been carried out to determine the influence of the value of the heater power, the speed of the drying agent, the width of the adjustable slot and the number of revolutions of the drying drum on the operating parameters of the device. The results of experimental studies have shown that for high drying performance, the required degree of humidity of the paddy coming out of the drying drum, as well as minimizing the cod of rice, the value of the heater power should be less than *4000 W*, the speed of the drying agent should be less than *0,75 m/s* and the width of the adjustable slot is more than *0,01 m*, the number of revolutions of the drying drum is more than *10 min^{-1}*.

To determine the optimal values of the parameters of the drying device of the paddy, multifactorial experiments were carried out according to the Hartley-4 plan. At the same time, the power of the heater, the speed of the drying agent, the width of the adjustable slot, and the number of revolutions of the drying drum were chosen as the factors influencing the performance of the drying device of the paddy.

As the evaluation criteria, the drying performance, the moisture content of the paddy coming out of the drying drum, and fracturing of rice in the mass of the paddy were taken.

According to the results of the experiments, regression equations were obtained that adequately describe the evaluation criteria:

by drying performance (*kg/h*)

$$Y_1=147,612+0,847X_1+2,113X_2+1,887X_3+ +4,250X_4–0,604X_1X_3–0,729X_1X_4+0,995X_4–3,538X_2X_3+ +1,795X_3^2+1,662X_4^2 ; \quad (16)$$

by the moisture content of the paddy coming out of the drying drum (*%)*

$$Y_2=13,210–1,003X_1–0,850X_2+0,95X_3+ +0,733X_4+0,728X_1^2–0,071X_1X_2+ +0,087X_1X_3–0,496X_1X_4–0,622X_1^2–0,554\ X_2X4+ +0,578X_3^2+0,504\ X_3\ X_4+0,578X_4^2; \quad (17)$$

by fracturing of rice in the mass of the paddy (*%*)

$$Y_3=1,046+1,528X_1+0,951X_2–1,274X_3–1,004X_4+ +1,743X_1^{\ 2}–0,155X_1X_2+0,154X_1X_3+0,155X_1X_4+ +0,749X_2^{\ 2}+0,352X_2X_3+0,112X_2X_4+ +0,723X_3^{\ 2}–0,152X_3X_4+0,690X_4^{\ 2}. \quad (18)$$

From the obtained regression equations, it can be seen that all factors have a significant impact on the assessment criteria.

The regression equations were solved using the MSExcel and Planex programs under the conditions that criterion Y_1- the drying capacity was more than *150 kg/h*, criterion Y_2- the moisture content of the chalet leaving the drying drum was less than *12%*, criterion Y_3 - the fracturing of rice in the mass of the chal was less *3%.*

Based on the results obtained, it was determined that with a drying capacity of *150 kg/h* and to ensure the required drying quality, the device must have a heater power of *3 kW*, a drying agent speed of *0.7 m/s*, an adjustable slot width of *2.34 sm* and a drying drum speed of *16 , 7 min^{-1}*.

During the tests, the developed device for drying the paddy reliably fulfilled the specified technological process and its performance indicators fully met the requirements.

Its technical characteristics is shown in Table 1.

Table 1: Technical characteristics of the developed mobile device for drying paddy

No.	Indicator name	Measurement unit of indicators	Value of indicators
1.	Drying efficiency (at moisture removal 6%)	kg/h	150
2.	Adjustable slot width of the drying drum	m	0,0234
3.	Mass	kg	450±50
4.	Number of revolutions of the drying drum	min^{-1}	17
5.	Number of revolutions of the shaft of the screw conveyor	min^{-1}	100
6.	Air temperature in the drying drum	degree	up to 308^{o}K
7.	Overal dimensions of the device: -length; -width; -height.	m	 3,5 1,5 2,5

Studies have shown that when using the developed device for drying rice, the drying time is reduced by 3 times, the material costs for drying 1 kg of rice are reduced by 65%. This translates into an annual economic benefit of $ 1207 per year per device.

5. CONCLUSION

Based on the study, the following conclusions are presented:

1. The devices for drying the paddy by the convection method were analyzed and it was found that high-quality drying is not achieved due to the low efficiency of some devices, the complexity of the design, large overall dimensions, and uneven mixing of the mass of the paddy.
2. Based on the analysis, it was decided that the purpose of the study is to develop a new design of a drum dryer that provides high-quality drying of a paddy with low energy consumption, and to justify its parameters.
3. Based on the analysis of scientific data, a technological diagram of a mobile device for drying a paddy was determined and the principle of its operation was determined.
4. An experimental prototype of a mobile device for drying paddy have been developed.
5. The drying capacity of the device is *150 kg/h* and ensuring the quality of drying according to agrotechnical requirements is achieved with a heater power of *3000 W*, a drying agent speed of *0,7 m/s*, an adjustable slot width of a drying drum of *0,0234 m* and the number of revolutions of a drying drum *16,7 min^{-1}*.
6. According to the technical characteristics, the developed mobile device for drying the paddy is recognized as energy- and material-efficient.

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