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Paddy Drying in Mixed-flow Tower-type Dryer

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Abstract: The purpose of this paper is to present the relevant data for paddy drying in mixed-flow dryer, obtained with conducted research on high-capacity dryer. An examination was carried out to reach the correct drying condition in industrial rough rice dryer. The attention was concentrated on main dryer element, the horizontal drying module. One drying module is composed of one or two drying rooms and one tempering section. By field tests, the heat flow amount and continuity were observed and evaluated in multi-thermal zoned drying process. The dryer is composed of five modules with double drying room and one tempering section, one module of three drying rooms without tempering section and four drying rooms in package as cooling section. Two thermal-zones drying system was exploited, with inlet air temperatures up to 44 ^{o}C, and with inlet air temperatures up to 40 ^{o}C. In the cooling section the air temperature was dictated by the grain outlet temperature up to 36 ^{o}C. Intermittent paddy tempering of up to two hours was accepted.

Keywords: Mixed-flow dryer, Intermittent process, Paddy.

1. Introduction

Rice is one of the most important food for humans and animals. World production in 2021 was more than 787.000.000 tonnes [1].

The rice varieties in North Macedonia are mostly from Italian origin. In 2023, rice was cultivated at 3.000 ha and production of about 18.000 tonnes was realized [2]. In the past times, maximum reached values were, area of 10.000 ha and 50.000 tonnes paddy crop. Rice is important component of national food reserves.

About 50 % of world paddy production is parboiled. Parboiled rice is more nutritious than white rice. Paddy parboiling is done in three steps: soaking, steaming and drying [3]. During the steaming, nutrients contained in the bran, diffuse in the mass of white rice. Parboiled rice is also dried in mixed-flow tower-type dryers.

Rice quality depends on rice variety, environmental conditions during the growing period, time and system of harvesting, postharvest treatment, storage practices and transport procedures [4].

The harvested rice kernel, known as paddy or rough rice, is enclosed by the hull. Paddy has the roughest hull surface of all cereals. About one-fifth of paddy weigh is hull. The losses for dehulling are up to 30 %. Paddy hull removed in the milling process is then stored in silos for the drying period, when it is used as a fuel.

Rice is harvested at moisture contents that are too high for safe storage. Therefore, paddy is exposed to drying process, ideally within 24 hours. To avoid the uneven drying, harvested paddy ought to be cleaned.

The final moisture content of dried paddy depends of intended use: for sale, for one year storage or for many years storage. Some paddy producers, waiting for better price on the market, store the grain up to 5 years, and only than dehull it and sell it as white rice. Visually, the staleness of white rice kernel cannot be discovered, but the quality is different.

The change of moisture content during the drying process is most often elaborated graphically, in the form of drying curves [5].

In mixed-flow tower-type dryer, paddy is introduced at the top of the dryer, then passes into the drying modules and finally into the cooling section. Grain is moving down by gravitation. Its falling is disturbed by the elements of internal module construction and by the air flow. Air is moving by ventilator effect. Its direction is formed by deflectors and regulation valves. At the bottom of the dryer horizontal unloading auger is located. Its duties are the regulation of the grain movement and the bringing out of the dried product. The dryer used in the research was designed as universal, for all cereals drying. Some corrections in the dryer construction were made in order to obtain specific dryer for rice, to involve multi-thermal zoned drying, to enable the intended procedure for measurement and regulation.

Drying process is crucial for rice quality. Rice quality is estimated according to grain size, shape uniformity, translucency, milling yield, cooking characteristics, cleanliness and soundness.

In the actual mixed-flow dryer, the dried product, paddy, and the drying medium, atmosphere air, are in mutual movement which is combination of cocurrent-flow, cross-flow and countercurrent-flow. Such an action of the flow, provides very small variation in the rice moisture content.

The drying process is interrupted by inserting tempering section. A tempering section offers enough time for harmonization of dried product state. During the tempering period the grain is not exposed to hot air flow and thus the temperature and moisture gradients within the individual kernels are diminished before drying is resumed. Drying rice slowly, with intermittent tempering is a suitable drying method, because rice is highly sensitive to the amount and the intensity of received heat. That favors the application of mixed-flow dryer whit discontinuous heat supply.

Paddy drying is thermal process of simultaneous heat and mass transfer. The process consists of two phases: 1. water pass in gas state and 2. water vapor is taken away from the dried product. The intensity of transport phenomena is under the influence of the characteristics of dried product, drying medium and dryer.

The structure of rice body is capillary-porous. The movement of evaporated water inside the grain is influenced by capillary forces, but at the kernel surface, the partial vapor pressure difference, between the water-vapor in the kernel and the surrounding air, is the driving force. The moisture movement in capillary-porous body is also influenced by diffusion and Earth gravitation. The problem of simultaneous heat and mass transfer from indeterminate and changeable space and mass, under the influence of outside state, capillary forces, diffusion, gravitation and location in the dryer is complicated.

The existing theory for simultaneous heat and mass transfer in capillary-porous body cannot offer solution for drying rate calculation under different drying conditions. It remains to search for the results with the use of field and laboratory tests.

Field tests can show the real situation, but their application is expensive because the mixed-flow tower-type dryer uses large quantities of dried product. In the case of incorrect drying, that mass of grain is lost. Therefore, theory of similarity can be used to carry out the research in laboratory conditions.

2. Equipment - Mixed-flow Tower-type Dryer

Before the realization of planned tests, the construction of the dryer was modified in order to enable zoned air flow, to uniform the air velocities at the drying module entrance, to make simultaneously stop of grain movement and hot air supply and to have access at all measuring points.

The hot air duct was divided in two hot air ducts. Deflectors were placed in the air ducts. The function of the centrifugal ventilators and the unloading auger was coordinated. Measuring platforms and sampling tubes were installed.

Mixed-flow tower-type dryers are high-capacity dryers. Exploited dryer is composed of filling module, 13 drying rooms, 5 tempering sections, 4 cooling modules, unloading auger, three centrifugal ventilators and two heat exchangers.

The dimensions of one drying room are: 3 m x 3 m x 1 m, Figure 1. The inner construction of the drying room provides mixed-flow. The tempering section is 0,5 m high. It is built as vertical duct without direct drying air supply. This is the first pause in grain heating. Its duration depends of drier construction. The second pause in grain heating is planned by the intermitting regime, and is controlled by unloading auger and heating supply.

The heat exchanger, composed of several heating coil sections assembled into a bank, uses hot water as heating medium. The heat demand for heat exchangers is provided by applying paddy hulls as fuel.

In total, the dryer reaches 26 m height.

On the one side, the dryer is connected with hot air duct and cold air duct, while at the opposite side the modules are equipped by regulatory valves. The hot air flow is divided in two hot air ducts. During the pass in the upper side of the dryer, since paddy is still cool and has relatively high moisture content, hot air temperature can be higher.

Dried material state, drying medium state and dryer function were continuously controlled by visual evaluation, measurements and test judging. The measurement program included: 1. grain moisture content and temperature, 2. air temperature, relative humidity and velocity, and 3. dryer zonal drying time and energy consumption. Measuring points were selected for initial, zonal and final state.

For paddy state control, the method of sampling in time and space was used. Measuring platforms and sampling instrument were added. Sampling tube, constructed as tube-in-tube device, enabled to take specimen from every module. The movement of the sampling probe is not easy, because it is obstructed by the paddy hull roughness. Grain specimens were examined in the laboratory, to verify the expected rice quality. Direct measurement, moisture content determination method, with device based on infra-red radiation was applied.

For drying medium state control, fixed and portable digital psychrometers and anemometers were used.

For dryer function control, the basic regime parameters were continuously checked and operation problems were immediately resolved. The air flow rate from centrifugal fans was controlled by measurement, conducted before the start of the drying process.

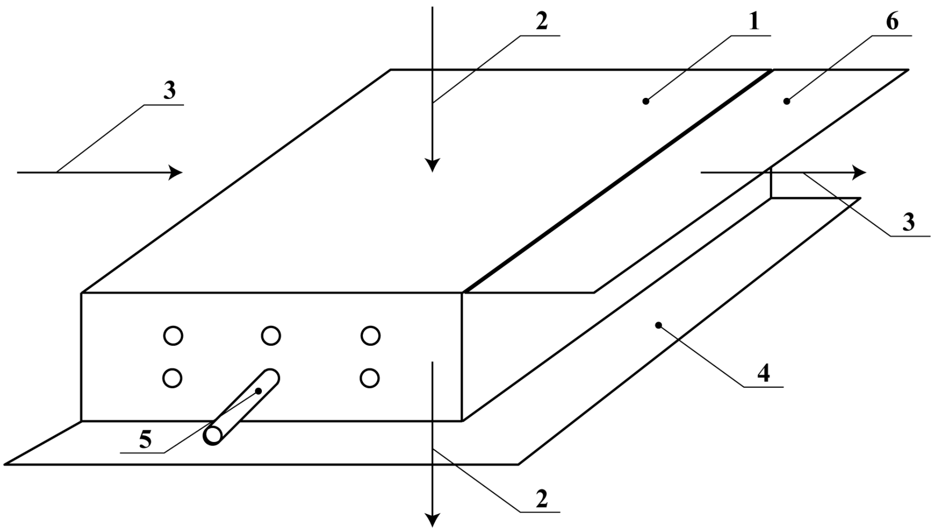

Figure 1. Drying room of mixed-flow tower-type dryer; 1-Module, 2-Paddy (in/out), 3-Air (in/out), 4-Platform, 5-Sampling tube, 6-Valve

3. Results and Comments

Reconstructed dryer showed good effects in practice. The installed five tempering sections were enough for satisfying the tempering process. With two hot air ducts, equipped by deflectors, the distribution of hot air at the entrance of the drying rooms was favorable. Added measuring platforms were functional.

Entered impurities with the paddy mass, weed seeds, soil, twigs and straw provoked same obstruction of needed grain flow. Registered quantity was only 1 % of the dried product mass, but in some modules, the tendency of impurities accumulation was observed and therefore grain cleaner was additionally connected to the filling module. For the drying medium, three zones system was selected as convenient. The temperature at the entrance of the first two modules, was up to 44 ºC, at the entrance of the next eleven heating modules was up to 40 ºC, and at the entrance of the next four cooling modules, was the same as the temperature of the atmosphere air.

The analysis of the drying medium state and estimation of the quantity of atmosphere air, required to remove the moisture from the dried product was based on psychrometry [6]. The maximum ability of moist air to absorb moisture from the dried rice was calculated with the help of the psychrometric chart, as a difference between its saturation moisture at wet-bulb temperature and its moisture content at dew-point.

According to the climatic curves and the psychrometric diagram, the range of atmosphere air temperatures, relative humidities and enthalpies, for the period of rice drying from September until October is: 2 - 30 ºC, 35 - 80 % and 10 - 54 kJ/kg. The calculated amount of heating energy for the two extreme states of atmosphere air (2 ºC, 80 %) and (30 ºC, 35 %) is very different (39 kJ/kg and 11 kJ/kg). These data exactly determine the expected thermal zone in which the drying process will occur.

The process of heat transfer from the hot air to the dried product was interrupted by inserting tempering periods. The pauses of up to two hours, offered conditions for drying process which provided first class dried product.

When the harvest season is wet, the paddy moisture content, wet basis is between 18 % and 30 %, but during the normal, dry harvest season, the paddy moisture content, wet basis is 16 - 28 %. Variations of up to 8 % are registered in the moisture contents, wet basis of mature and least mature kernels.

Three rice varieties were used in the conducted research: Monticelli, Saint Andrew and RS 76. In the rice quality evaluation, the Laboratory for rice and seed quality control in Kočani, was included in the test program.

Paddy was entering in the filling module with moisture contents, wet basis 16 - 28 % and temperatures 12 - 22 ºC. In the first two modules the moisture content, wet basis was 14 - 23 % and the temperature was 15 - 28 ºC. In the third to thirteenth module the moisture content, wet basis was 11 - 15 % and the temperature was 24 - 36 ºC. In the fourteenth to seventeenth module the moisture content, wet basis was 10 % and temperature was 14 ºC. For long term storage, lower exit moisture content is needed. The paddy exit temperature of 35 ºC was not surpassed. During the cooling process some moisture was also removed.

Dried paddy is hygroscopic material, therefore immediately after the exit of the unloading auger it must be stored in a space with controlled atmosphere.

For the control of centrifugal fans capacity, portable flow measuring duct was constructed. Measuring instruments were standard hand-held Pitot-tube in conjunction with a micromanometer and digital anemometer.

By measuring the generated heat, during combustion of paddy hull in calorimeter, heating value of 15 MJ/kg was obtained. This value is 20 % lower of beech wood heating value. The use of paddy hull as fuel has three advantages: 1. secondary product is consumed at the same location where it is produced, 2. the deposition of paddy hulls is solved, because in its composition it has more than 90 % silicon (something lake pebbles at the beach), and it would be very harmful to mix its combustion products with field land, and 3. the burned paddy hull is important component of some cleaning powders.

4. Conclusion

As a result of the carried out research, performed on high-capacity mixed-flow dryer, suitable drying conditions were established in field-test procedure. The universal, for all types of cereals drying construction of the dryer, was modified before the start of the planned research and has shown good effects in practice.

Applied slow drying process, with intermittent heat supply provided quality dried product. The small quantity of broken kernels in the dehulling process was confirmation that they haven't internal stresses acquired in the drying process.

The measurements focused on thermal state of the drying medium and the dried product offered values for minimum and maximum required heat flow in the process.

The search for the results with the use of field and laboratory tests, proved to be an appropriate way in the approach for solving these types of problems in drying.

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