DOI: 10.31388/2220-8674-2022-2-9

UDC 66.047.75

L. Yu. Bondarenko, PhD ORCID: 0000-0001-5858-7375
Dmytro Motornyi Tavria State Agrotechnological University
e-mail: larysa.bondarenko@tsatu.edu.ua, тел.: (098)8460056

PREPARATION OF SAWDUST AND CHIPS OF CUT BRANCHES OF FRUIT TREES FOR PELLETIZING

Summary. The paper considers the preparation of sawdust and chips of cut branches of fruit trees for pelletizing by drying, with the further use of pellets as fuel for solid fuel boilers. A calculation method and a paradigm for determining the drying parameters are proposed; a scheme for preparing sawdust and chips for pelletizing by drying is proposed. Sawdust and chips of cut branches of fruit trees are prepared for drying, they are transferred to a drying drum, where they are dried to the required moisture content. Therefore, it is important to correctly calculate the amount of water removed during the drying process. The proposed method for calculating the drying process and the scheme for preparing sawdust and chips of cut branches of fruit trees for pelletizing by drying can be used in the design and selection of equipment.

Key words: preparation, sawdust, wood chips, cut branches of fruit trees, drying, drying drum, hopper, furnace, auger, raw material moisture content, pelletizing.

Formulation of the problem. At present, the issue of saving energy resources is very relevant. Cut branches of fruit trees are a byproduct of horticulture, but most often they are thrown away. Although according to DSTU ISO 13600-2001, cut branches are a renewable resource that can be used as an energy product for heating [1]. One of the most rational ways to use fruit tree branches is to burn them in crushed wood chips or sawdust. The heat of combustion $Q^{р}_{н}$ of sawdust and chips of cut branches of fruit trees ranges from 10 MJ/kg to 16 MJ/kg [2]. However, pellets from cut branches of fruit trees are much more convenient for transportation, storage and burning. The industry began to produce various press granulators and press briquettes for pressing dry plant waste [3]. The experience of real work of briquetting presses showed that when chips or sawdust from cut branches of fruit trees of high humidity are fed into the pressing chamber, where it is compressed and simultaneously heated to a temperature of 280-310 ° C, the water in them boils, forming high pressure steam that "shoots" the briquette or pellet with great force, destroying it and presenting a danger to workers.

Therefore, one of the main preliminary operations before pelletizing chips or sawdust from cut branches of fruit trees is their drying.

Analysis of recent achievements. The work is devoted to the issue of preparing chips or sawdust from cut branches of fruit trees for pelletizing by drying. Since the dryer performs a technological technique that affects subsequent operations and their results, the role of the dryer is associated with the main technological process for the manufacture of fuel pellets from cut branches of fruit trees. There are various designs of dryers for vegetable raw materials produced by the world mechanical engineering [3-5], but they do not cover the entire range of plant performance. Conventionally, dryers can be divided into three sizes: for industrial production, for small-scale production and for subsidiary farming [6,7]. To date, the 1st and 2nd types are quite fully covered, as for the subsidiary plots, the dryers are represented insignificantly.

Formulation of the objectives of the article. The main purpose of the article is to show the sequence of calculation of the drying process for the preparation of chips or sawdust from cut branches of fruit trees for the pelletizing process.

The task of the work is to propose a method for determining the amount of water that must be removed from wood chips or sawdust from cut branches of fruit trees and calculating the amount of fuel required to remove it by drying in a dryer. Give the main design parameters of the dryer, allowing you to perform the drying process.

The main part. Plant waste pelletizing plant allows, to obtain high-quality fuel pellets from a wide variety of plant waste, including wood chips or sawdust from cut branches of fruit trees such as cherry, apricot, apple, pear, plum, and vine branches with the subsequent use of the obtained pellets in the form of fuel for boilers of various modifications. Pellets are produced without chemical binders under high pressure. The pellet press consists of a receiving hopper, a dosing screw, a pressing screw, a divider, an exhaust hood. Pre-dried to the required moisture content (6...8%), plant waste enters the receiving hopper and then evenly, by a dosing screw, is fed into the pressing chamber, where compression and simultaneous heating of the crushed mass to a temperature of 280-310°C. Under the influence of temperature, the surface of the pellets melts, which contributes to a very long storage and convenient transportation of products. As a result of heat treatment, a natural binder is released: lignin, and with a strong degree of compression, raw material is pelletized to a specified density of 950 ... 1200 kg/m^3. After pressing, the pellets come out of the press and are divided by a divider into pellets of a certain length. The resulting pellets are sent for cooling and storage. At the same time, such a pellet does not ignite in air, since it does not contain hidden, self-igniting pores.

The dryer is designed for continuous drying of vegetable raw materials: chips or sawdust from cut branches of fruit trees before pelletizing. The dryer is operated indoors with the installation of ventilation smoke exhaust equipment. The dryer is a drum, which is adjoined by a loading hopper and a firebox (heat generator). The main part of the dryer is an inclined cylindrical drum. A rotating auger with special blades is installed inside the drum, ensuring uniform distribution and good mixing of the material.

The drying agent is hot air. The drying agent is heated in a furnace (heat generator). Inside the drum, along its entire length, there is a screw with blades, which, when rotated, contribute to pouring the dried product, mixing it with simultaneous gradual movement to the discharge opening. When the auger rotates, the blades grab and lift the material, and then it, falling down, is washed by hot air. Continuously mixing, the dried material moves to the unloading device. The dried material is automatically removed through the discharge opening.

We have developed a method for determining the amount of water that must be removed from chips or sawdust from cut branches of fruit trees and calculating the amount of fuel required to remove it by drying in a dryer. To do this, it is necessary to set the following conditions: for drying, we use atmospheric air at an initial temperature t_1 = 20^{0}C and humidity φ = 60%. In the heater, the drying agent (air) is heated to t_2 = 95^{0}C and sent to the dryer, from where it exits at t_3 = 35°C.

To perform calculations, it is necessary to determine the final relative humidity of the air, φ_2 % (to prevent moisture condensation, it must be less than 95%); air consumption per 1 kg of evaporated moisture, V, m^3/kg (knowing the air consumption, you can accurately select the fan number); heat consumption per 1 kg of evaporated moisture, q, kJ/kg (knowing the heat consumption, it is possible to determine the fuel consumption in the furnace necessary for high-quality drying).

According to the $H – d$ - diagram, we find point at the intersection of the lines t_1=20 °C and φ_1=60% and for it we determine the water content in a cubic meter of air (moisture content) equal to d_1 = 8.9 grams per kg and enthalpy H_1 = 42,7 kJ/kg.

We draw the line d = const from this point to the intersection with the isotherm t_2 = 95 °C. The point of intersection characterizes the state of the air at the outlet of the furnace.

From this point we draw the line H = const until it intersects with the isotherm t_3 = 35°C. The intersection point characterizes the state of the air leaving the dryer. The moisture content of the drying agent (air) at the outlet of the dryer will be: d_3 = 33 grams/kg; enthalpy at the exit from the dryer will be: H_3 = 120 kJ/kg.

We determine the change in the moisture content of moist air, relative to 1 kg of dry air:

$$\Delta d = d_3 - d_1, \quad (1)$$

$$\Delta d = 33 - 8{,}9 = 24{,}1 \text{ grams/kg}$$

That is, 1 kilogram of air can take 24.1 grams of water from chips or sawdust from cut branches of fruit trees and remove it in the form of water vapor (it is very important that the steam does not condense in the dryer or at its outlet).

We determine the cost of dry air in kg for the evaporation of 1 kg of moisture:

$$l = \frac{1000}{\Delta d}, \quad (2)$$

$$l = \frac{1000}{24.1} = 41.5 kg/kg$$

We determine the consumption of dry air in 1 m^3 for the evaporation of 1 kg of moisture:

$$V = \frac{l}{\rho}, \quad (3)$$

$$V = \frac{41.5}{1.29} = 32.2 m^3/kg$$

Heat consumption in the furnace for heating 1 kg of air:

$$\Delta\text{H} = H_3 - H_1, \quad (4)$$

$$\Delta\text{H} = 120 - 42.7 = 77.8 kg/kg$$

Heat consumption in the furnace for heating 1 m^3 of air:

$$\Delta\text{H}_1 = \frac{\Delta\text{H}}{\rho}, \quad (5)$$

$$\Delta\text{H}_1 = \frac{77.8}{1.29} = 60.3\ kJ/m^3$$

Heat consumption per 1 kg of evaporated moisture (that is, 41.5 kg of dry air):

$$q = l \cdot \Delta\text{H}, \quad (6)$$

$$q = 41.5 \cdot 77.3 = 3208\ kJ/kg$$

The performance of the dryer in terms of the amount of evaporated moisture:

$$W_{c.y.} = G_1 \frac{W_1 - W_3}{100 - W_3}, \quad (7)$$

$$W_{c.y.} = 1000 \frac{50 - 12}{100 - 12} = 431.82\ kg/h$$

At different initial humidity (50...65%), in order to dry chips or sawdust from cut branches of fruit trees to 8...12%, it is necessary to remove from 1000 kg of chips or sawdust from cut branches of fruit trees, from 380 to 570 kg of water.

The performance of the dryer in terms of the amount of dried chips or sawdust from cut branches of fruit trees:

$$G_3 = G_1 - W_{c.y.}, \tag{8}$$

$$G_3 = 1000 - 380 = 620\ kg/h$$

The duration of the drying process of chips or sawdust from cut branches of fruit trees significantly affects the quality of dried chips or sawdust from cut branches of fruit trees and cannot be chosen arbitrarily [7]. In order to ensure the maximum quality of chips or sawdust from cut branches of fruit trees, the drying speed should correspond to the permissible moisture removal - a decrease in moisture per unit time. For chips or sawdust from cut branches of fruit trees, the duration ($\boldsymbol{\tau}$) of the drying process (min) is determined from the ratio:

$$\Delta W = W_1 - W_2 = 0.185\tau + 3 \tag{9}$$

Given that when moving along the drum, chips or sawdust from cut branches of fruit trees are part of the time in a layer with low evaporation, the value of $\boldsymbol{\tau}$ should be taken equal to at least 12 min.

The heat balance of the dryer drum is determined from the heat balance equation for the actual drying process [8]:

$$\begin{aligned}\Delta q &= l \cdot (H_1 - H_0) = l \cdot (H_2 - H_0) = \\ &= q_{fbox} + q_{conv} + q_5 + q_{add} + C_m \cdot t_{chip}\end{aligned} \tag{10}$$

The value of Δq is the amount of heat lost (if $\Delta q < 0$) or added (if $\Delta q > 0$) per 1 kg of evaporated moisture.

Determination of the numerical value of the quantity Δq:

$$\Delta q = q_{add} + C_m \cdot t_{chip} - (q_{fbox} + q_{conv} + q_5) \tag{11}$$

Additional amount of heat introduced into the drying chamber, in this case $q_{add} = 0$; the physical amount of heat of moisture introduced into the material to be dried (chips or sawdust from cut branches of fruit trees): $C_m \cdot t_{chip}$ kJ/kg; $C_m = 4.19$ kJ/kg; the amount of heat spent on heating the material (chips or sawdust from cut branches of fruit trees):

$$q_{fbox} = \frac{G_2 \cdot C_{chip}}{W_1} + (t''_{chip} - t'_{chip}), \tag{12}$$

Where C_{chip} - mass heat capacity of chips or sawdust from cut branches of fruit trees, kJ/(kg·K):

$$C_{chip} = 4.19 \left[\frac{0.37(100 - W_2) + W_2}{100}\right], \tag{13}$$

$q_{conv.}$ - consumption of the amount of heat for heating transport devices, in this case $q_{conv.} = 0$;

q_5 - heat loss to the environment:

$$q_5 = \frac{1}{W_{cb}} \cdot K \cdot F_{c\delta} \cdot \Delta t. \tag{14}$$

$$K = \frac{1}{\frac{1}{a_1} + \frac{\delta}{\lambda} + \frac{1}{a_2}}, \frac{W}{m^2 \cdot K} \quad (15)$$

Where α_1 is the coefficient of heat transfer from flue gases to the inner walls of the drying drum, $\frac{W}{m^2 \cdot K}$.

α_2 is the coefficient of heat exchange between the outer walls of the dryer drum and the outside air, $\frac{W}{m^2 \cdot K}$. We accept:

$$a_1 = a_2 = 1.163(5 + 3.4\upsilon);$$

Where υ – speed of flue gases inside the drying drum approximately. υ = 3 m/s;

δ – drum wall thickness δ = 0.003 m;

λ – coefficient of thermal conductivity of the drum wall. $\lambda = 57 \frac{W}{m \cdot K}$;

Δt - temperature difference:

$$\Delta t = \frac{\Delta t_\delta - \Delta t_m}{2.3lg \frac{\Delta t_\delta}{\Delta t_m}}; \quad (16)$$

F – dryer surface area, m^2:

$$F_{c\delta} = \pi DH + \frac{2\pi D}{2}. \quad (17)$$

Fuel consumption for a real dryer:

$$B = \frac{q_c \cdot W_{c.y.}}{Q_b^{\cdot P} \cdot \eta_m \cdot \eta_{mp}}, \quad (18)$$

$$B = \frac{3.208 \cdot 431.82}{17 \cdot 0.6} = 135.81\ kg/h$$

where η_{mp} – efficiency furnaces taking into account the heat radiation of pipelines. η_{mp}= 0.6.

With different initial humidity, in order to remove from 1000 kg of chips or sawdust from cut branches of fruit trees, from 380 to 570 kilograms of water, it is necessary to burn from 54 to 135.81 kilograms of firewood.

Calculation of the hydraulic resistance of the gas path and fan for the dryer drum.

Resistance of a layer of chips or sawdust from cut branches of fruit trees, mm w.c.:

$$\Delta S_3 = \frac{a \cdot H \cdot \upsilon^2 \cdot p_1 \cdot C_1}{d \cdot 2 \cdot 9.8}, \quad (19)$$

Reynolds number:

$$R_e = \frac{\upsilon \cdot d}{\nu}, \quad (20)$$

at $\upsilon = 3$ m/sec; $d = 0{,}01$ m; $\nu = 20 \cdot 10^{-6}$ m^2/s: $Re = 6 \cdot 10^{-6}$.

$$a = \frac{490}{R_e} + \frac{100}{\sqrt{R_e}} + 5.85, \tag{21}$$

H is the length of the drying drum, $H = 4{,}7$ m;

ρ_1 is flue gas density, $\rho_1 = 1{,}04$ kg/m^3;

$$C_1 = \frac{1+\xi}{\xi}; \quad \xi = \frac{p_k - p_m}{p_k}, \tag{22}$$

where $\rho_к$ – density of chips or sawdust from cut branches of fruit trees, $\rho_к$ =1200 kg/m^3;

p_m – density of chips or sawdust from cut branches of fruit trees in a loose layer, kg/m^3:

$$p_m = \frac{0.25(G_1 - G_2)\eta}{0.75 \cdot 2 \cdot V_\delta};$$

η – drum fill factor, η = 0,33.

V_δ – drum volume, m^3:

$$V_\delta = \frac{\pi D^2}{4} H;$$

d – particle size (chips or sawdust from cut branches of fruit trees), $d = 0{,}008\, m$.

Hydraulic resistance of the cyclone: $\Delta S_c = 30$ mm w.c.

Hydraulic resistance of the firebox: $\Delta S_m = 5$ mm w.c.

Local resistance and friction losses:

$$\sum \Delta S_m = 0.1 \cdot (\Delta S_3 + \Delta S_c + \Delta S_m). \tag{23}$$

Total hydraulic resistance of the tract, mm w.c.:

$$\Delta S = \Delta S_3 + \Delta S_c + \Delta S_m + \sum \Delta S_m. \tag{24}$$

Dynamic head, mm w.c.:

$$H_d = \frac{\upsilon_w \cdot p_1}{2 \cdot 9.81}. \tag{24}$$

υ_w – gas flow velocity in the fan inlet window, $\upsilon_w = 24$ m/s;

Total fan pressure:

$$H_n = H_d + \Delta S. \tag{25}$$

Choice of the drying drum fan according to the speed in the inlet window and fan supply (dry air consumption in m^3 for evaporating 1 kg of moisture):

$$V = \frac{l}{\rho} = \frac{41.5}{1.29} = 32.2 \text{m}^3/\text{kg}.$$

The performance of the dryer in terms of the amount of evaporated moisture:

$$Q_m = V \cdot W_{c.y.}. \tag{26}$$

$$Q_m = 32.2 \cdot 431.82 = 0.54\mathrm{m}^3/s = 13905.7\frac{\mathrm{m}^3}{h}$$

We determine the fan type VR 189-57 number No. 5

Power consumed by the fan:

$$N = 1.15 \cdot \frac{Q_c \cdot H_n}{1.02 \cdot \eta}. \tag{27}$$

where η – efficiency fan is determined by the nomogram, η = 0.44.

$$N = 1.15 \cdot \frac{3.8 \cdot 700}{1.02 \cdot 0.44} = 6.8kW$$

Conclusions. The proposed method can be used for practical application in the calculation of preparatory operations before pelletizing plant waste, such as wood chips or sawdust from cut branches of fruit trees.

With different initial humidity, in order to dry chips or sawdust from cut branches of fruit trees up to 8%, it is necessary to remove from 1000 kg of raw materials from 380 to 570 kilograms of water and it is necessary to burn from 54 to 135.81 kilograms of firewood.

The pipe from the furnace to the dryer drum and the dryer drum itself must be thermally insulated, which will reduce heat losses and prevent water vapor condensation.

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Стаття надійшла до редакції 21.03.2022р.

Л. Ю. Бондаренко
Таврійський державний агротехнологічний університет імені Дмитра Моторного

ПІДГОТОВКА ТИРСИ ТА ТРІСКИ ЗРІЗАНИХ ГІЛОК ПЛОДОВИХ ДЕРЕВ ДО ПЕЛЕТУВАННЯ

Анотація

У роботі розглянуто підготовку тирси та тріски зрізаних гілок плодових дерев до пелетування шляхом сушіння з подальшим використанням пелет як палива для твердопаливних котлів. Запропоновано метод розрахунку та парадигму визначення параметрів сушіння; запропоновано схему підготовки тирси та тріски зрізаних гілок плодових дерев до гранулювання шляхом сушіння. Після аналізу вихідної сировини переходять до початкового етапу, на якому тирсу та стружку зрізаних гілок плодових дерев готують до сушіння, подають у сушильний барабан, де сушать до необхідної вологості 6...8%. Для сушіння використано атмосферне повітря з початковою температурою і вологістю. У нагрівачі (осушувачі) повітря нагрівають до 95^0C і направляють в сушарку.

Визначено зміну вологості повітря в утеплювачі та витрату сухого повітря на випаровування 1 кг вологи. Розраховано витрата тепла в обігрівачі на нагрів повітря. Важливо правильно розрахувати кількість води, що видаляється в процесі сушіння. Встановлено, що при різній початковій вологості, щоб висушити тріску або тирсу зі зрізаних гілок плодових дерев до 8%, необхідно видалити зі 1000 кг сировини від 380 до 570 кілограмів води і спалити від 54 до 135,81 кг дров. З рівняння теплового балансу визначено тепловий баланс барабана сушарки для фактичного процесу сушіння.

Зроблено розрахунок гідравлічного опору газового тракту і вентилятора сушильного барабана, а також опору шару стружки або тирси зі зрізаних гілок плодових дерев. Це дозволило вибрати вентилятор сушильної машини відповідно до швидкості у впускному вікні. Запропонована методика розрахунку процесу сушіння та схема підготовки тирси та тріски зрізаних гілок плодових дерев до гранулювання сушінням можуть бути використані при проектуванні та підборі обладнання.

Ключові слова: підготовка, тирса, тріска, зрізані гілки плодових дерев, сушіння, сушильний барабан, вологість сировини, пелетування.