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INVESTIGATION OF THE EQUIPMENT FOR FOOD PRODUCTION WASTE INCINERATION

The paper presents classification of thermal means for food production waste utilization (incineration, pyrolysis, gasification) as well of the equipment for their realization. A scheme of a special highly efficient waste incineration furnace is proposed. Dependencies for determination of air flow parameters in working zones of the furnace are presented.

Key words: *food production waste utilization, incineration furnace.*

Introduction

Currently, one of the vital problems in Ukraine is environment pollution with industrial waste, including waste of the food industries (alcohol bard, bear pellet, beet waste, coffee and barley sludge, etc.). In most cases such waste is poured into specialized grounds, which results in deterioration of ecological situation in the corresponding region. Therefore, the task of finding waste utilization methods, which would be safer for the environment, is still quite relevant. From the point of view of the author it is rational to divide waste into solid and liquid phase and then the first could be used as an additive to agricultural feed or as a fuel, while the liquid phase (water) is returned to the production process [1]. This work considers possible methods of incineration, pyrolysis and gasification of the solid phase of food production waste after their separation. Implementation of such methods will enable partial or complete solution of the problem of domestic food industry provision with heat and steam for production needs, which is especially important in the conditions of growing costs for natural gas and other energy carriers. So, the paper also proposes special highly efficient waste incineration equipment.

Different sources [2 – 4] give analysis of the methods and equipment for industrial waste utilization. From the author’s point of view, however, in each case this analysis is not sufficiently complete and does not take fully into account specificity of the waste considered. As to the proposed equipment, it is mostly universal, and, therefore, not sufficiently efficient for food production waste utilization. In [2, 3], for example, there is a detailed analysis of incineration methods and pyrolysis of industrial waste, but practically nothing is said about their use for food production waste utilization as well as about special features of the equipment, required for this. Work [4] considers mainly thermal methods of decontamination and conditioning of sewage sludge for further drying. Besides, the notion of pyrolysis and gasification methods is given, but again without reference to the waste of food production.

Accordingly, the aim of this paper is development of classification of the thermal methods for food production waste utilization and of the equipment for their realization, discussing advantages and disadvantages of each method as well as designing the scheme of a special highly-efficient furnace for waste incineration after its final vibration-impact dehydration [1], taking into account moisture content (20 – 25%) and other physical-mechanical properties of the waste.

Main part

Fig. 1 presents classification of the known methods and equipment for realization of the thermal methods for food production waste utilization. These methods could be divided into three groups: incineration in furnaces and burners, pyrolysis, gasification.

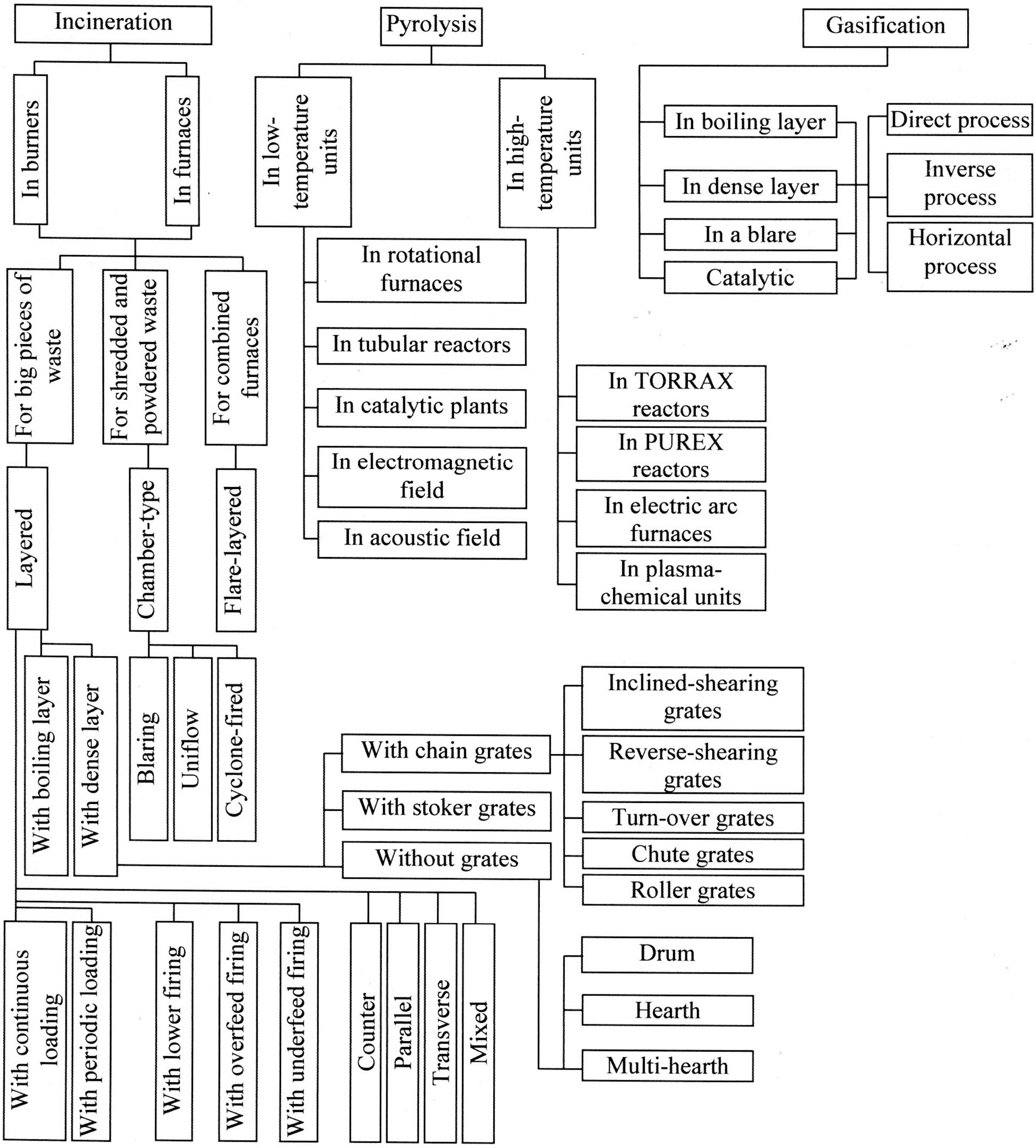

Fig. 1. Classification of the thermal methods for food production waste utilization and of the equipment for their implementation

Incineration is the most common method of thermal utilization of industrial waste [3], including the waste of food production. It is realized in furnaces and burners of various designs. Burners could be components of furnaces or steam boilers. Depending on the type of waste, there are spherical (for burning big pieces of waste) and chamber-type (for burning shredded and dust waste) furnaces and burners. Combined furnaces and burners allow burning waste containing both big fragments and particles in the form of powder. Taking into account relationships between the directions of gas-air and fuel-sludge flows, spherical furnaces and burners are classified as counter, parallel, transverse and those of mixed type. One of the disadvantages of spherical furnaces and burners is the necessity to equip them with chain grates of various types with mechanical or hydraulic drive for stoking and shifting the waste [3]. Multiple hearth furnaces are distinguished by high material consumption and cost. They require application of a drive for providing continuous rotation of the massive shaft with blades for mixing waste as well as the system for cooling the shaft and the blades. Besides, among the disadvantages of such equipment the impossibility to create considerable specific thermal loads inside the furnace as well as to locate rotation elements in its high-temperature zone should be noted [2]. Drum furnace is the most common industrial waste incineration equipment [3], but in view of the food production waste condition after dehydration (compressed wet mass), they will not provide the required efficiency of combustion. In addition, it has low degree of working volume loading and requires high capital and operating expenses [2]. According to [2], furnaces and burners with boiling layer and those of cyclone type are the most productive, mainly, because waste particles are burned in a suspended state during intensive heat exchange with the gas (heat transfer in a boiling layer is four times more intensive than in a stationary layer [3]). But this equipment also has certain drawbacks: the necessity to create optimal combustion mode, taking into account the type and properties of the waste, as well as the need for powerful dust collecting devices [2, 3].

From the point of view of sanitation, pyrolysis processes differ favorably from combustion due to reduced amount of waste gases, which should be cleaned, and of solid residue. The latter, in most cases, is soot or charcoal that could be used in industry. Thus, some pyrolysis techniques are related to waste-free technologies [3]. In order to maintain PUREX pyrolysis processes, even additional fuel is not required. Advantages of pyrolysis installations include provision of a continuous working process and absence of movable elements in them. Powerful industrial installations for implementation of this utilization technique are rather universal but, at the same time, quite expensive. E. g., the cost of pyrolysis installation with the power of 310 000 t of waste per year with equipment use factor 0, 85 is about 16 mln. USD in prices of 1990 [3]. Realization of some pyrolysis technologies requires temperatures up to 1650 ºC [3], which imposes limitations on the choice of materials for manufacturing some installation components. In addition, equipment safety level is reduced. There is also a rather complicated problem of accumulation and storage of combustible gas that is formed during pyrolysis processes, and so some manufacturers of pyrolysis plants demand that gas consumer should be at the distance not exceeding 1 – 3 km [3].

As to the gasification methods, they are mainly more complicated and less efficient than pyrolysis processes as they require gasification agents (air, oxygen, carbon dioxide, water) to be supplied to the working zone of the plants. Besides, gasification processes have almost all above-mantioned disadvantages of pyrolysis technologies. Therefore, gasification is not so common for waste utilization than pyrolysis or incineration [2, 3].

In the process of choosing the most rational method for food production waste utilization and designing the scheme of equipment for its implementation the following requirements and parameters were taken into account:

- initial characteristics of the waste to be utilized;
- provision of the pre-determined productivity and continuity of the utilization process;
- minimization of the drawbacks of the known utilization methods, particularly, provision of maximally efficient use of energy carriers, creation of high specific temperature loadings in the working zone of the plant to be developed as well as considerable loading degree of the available equipment volume, optimal and not very high temperatures in the working zone, reduction of the negative factors for people and the environment, reduction of the amount of secondary products (solid and gaseous residues), provision for working process realization in a fully automatic mode at minimal time and costs for equipment operation and maintenance, reduction of the size, material consumption and cost of the plant to be designed, simplification of its design and improvement of reliability;
- using all the experience of creation and operation of various equipment for thermal utilization

of industrial waste.

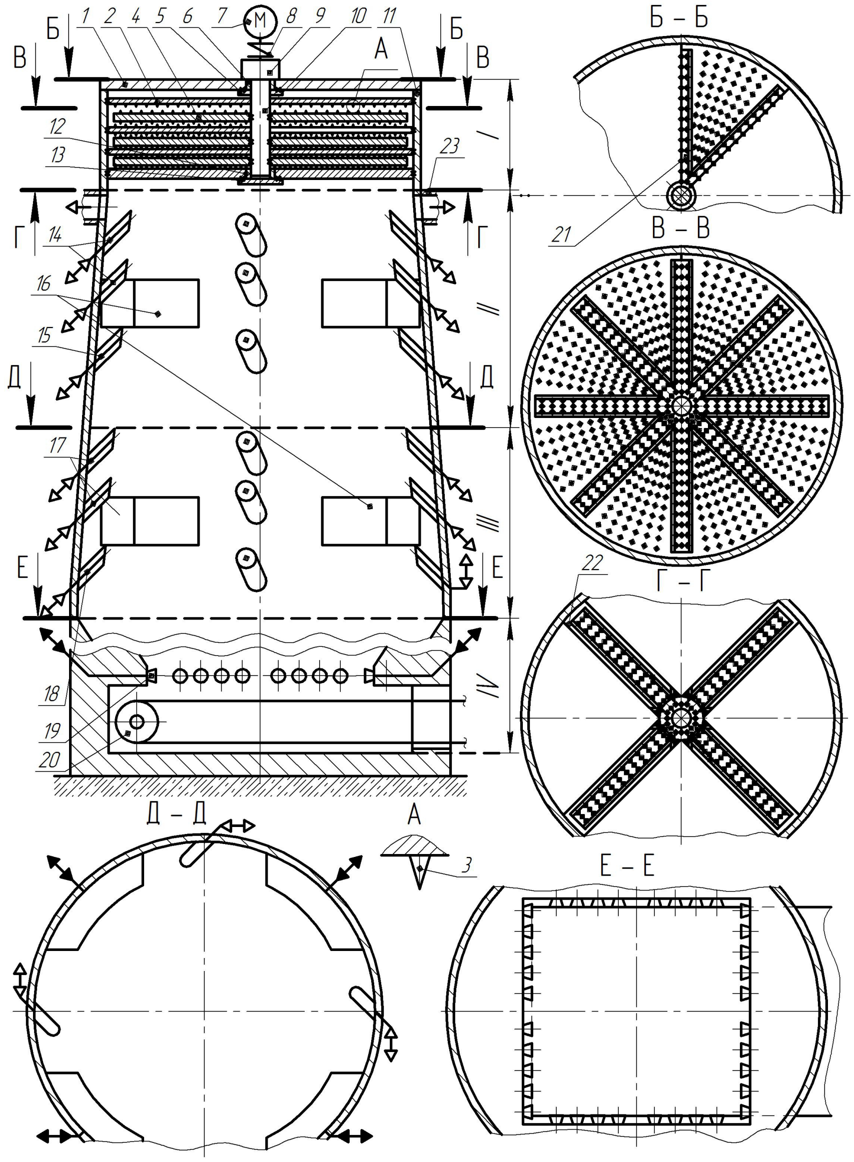

Fig 2. Scheme of a special furnace for food production waste incineration

Fig. 2 shows the scheme of a special furnace for food production waste incineration. It includes body 11 and cover 1. Body 1 is made from firebrick; internal surfaces of the body and the cover are lined with ground sheets of heat-resistant steel for reflecting heat inside. From the outside, body 11 and cover 1 are coated with heat isolation material. Inside the furnace body four working zones can be distinguished: I – for shredding and pre-drying of the waste to be burned; II – final drying and burning; III – final incineration; IV – cooling and discharging the ash. The waste to be burned with initial moisture content U_i = 20 – 25% in the form of big pieces, pressed after dehydration, is loaded through tapered cut 21 in cover 1 (section Б – Б in Fig. 2) and enters the shredder. The latter includes three blade blocks 4 (8 blades in each block, section В – В in Fig. 2) with sharpened edges fixed at shaft 10. Slow uniform rotation of the blades 4 between four stationary partitions 2 is provided by electric engine 7 and planetary reducer 9, which are mounted on cover 1 and connected with each other through coupling 8. Shaft 10 is mounted on slide bearings 6, 12, the edges of which abut the covers 5, 13. On the surfaces of blades 4 and partitions 2 a big number of sharpened pins 3 are fixed (external element A in Fig. 2). Clearances between the blades 4 and partitions 2 are gradually reduced from the upper to the lower level of the shredder. In the second and the third (from the top) partitions 2 tapered cuts are made, similar to those of cut 21, but shifted by the angles of 45º relative to each other. In lower partition 2 four rectangular cuts 22 are made (cross-section Г – Г in Fig. 2). Pieces of the waste, entering the shredder during rotation of blades 4, are cut by their edges at the ends and shredded by pins 3. At each level of shredding the loaded portions of waste are turned by the angle 315º and after that four cuts in partitions 2 move to the lower shredding levels. Four cuts 22, 21 and clearances between blades 4 and partitions pass through hot flows of air from incineration zone II and final incineration zone III, which provides pre-drying of waste in the shredder. Shredded and dried waste is unloaded from the latter though the cuts 22 and enters incineration zone II. There it is caught by hot flows of air, which are supplied through two rows of nozzles 14. The nozzles are installed in such a way that vertical and tangential forces act on the waste particles (cross-section Д – Д in Fig. 2), which causes spinning of the waste about the furnace axis and facilitates its drying. Natural gas or some other type of fuel gas is supplied through nozzles 15. As a result, the temperature of 600 – 800 º is created and waste incineration is realized. The created ash as well waste particles, that are not fully burnt, pass to the final incineration zone III, where two additional rows of nozzles 17 for supplying hot air and nozzles 18 for fuel gas supply are located. Temperature in zone III reaches 900 - 1000º C. Thus, under the influence of heat as well as tangential and vertical forces waste particles are trapped, twisted and burnt. Heat, that is emitted in zones II, III, heats the water circulating in radiators 16, 17 and is used for production needs. Ash of the waste from zone II goes down to zone IV to the belt of conveyor 20 , where it is cooled by the water sprayed from hydrants 19 (cross-section E – E in Fig. 2). The ash is unloaded from the furnace by means of conveyor 20. Part of the waste combustion products from zone II passes through the clearances in the shredder, another part passes through openings 23 into a separate column of a cyclone separator with labyrinth and electromagnetic filters (not shown in the scheme), which is similar to the columns of drum furnace separators. The separator realizes cleaning of the combustion products from mechanical particles. Besides, it incorporates air-passing tubes. Combustion products wash walls of the separator tubes and heat air in them before it is supplied to the furnace, which increases its efficiency. From the separator column combustion products are released into the flue.

Main distinguishing feature of the proposed furnace from the known equipment for thermal production waste utilization (Fig. 1) is destruction of big wet pieces of waste to be burnt, their transformation into powered mass, increased surface of their contact with hot gases and intensive drying of particles. Due to the influence of vertical and tangential forces created by air flows in combustion zone II and final combustion zone III, the particles are in a dispersed suspended state, which also facilitates improvement of the proposed equipment efficiency. Drying, combustion, cooling and discharge of the solid and gaseous combustion products is realized in the continuous mode. And, finally, maximally full use of the energy of exhaust gases is provided: for heating waste to be shredded and burnt, for heating water and steam generation for production needs and for pre-heating the air that enters the furnace.

However, for increasing the efficiency of the proposed furnace it is necessary to obtain dependencies in order to determine the required air flow supply through nozzles 14, 17. Application of these dependencies as well as of the heat balance equations for the furnace working zones, presented by the author in another paper, will enable rational use of fuel and air during the processes of drying and burning the waste, taking into account its initial and current physical and mechanical parameters as well as the required productivity of incineration.

Fig. 3 presents a scheme for determining parameters of the air flow in incineration and final incineration zones of the proposed furnace (Fig. 2). Thick arrows show directions of the air flows coming from nozzles 1, 3 and flowing around solid particles 2 to be burnt. It is evident that motion of the waste particles in the furnace is, to a great extent, a stochastic process, which is caused by wide-range variation of the size of particles and distances between them. It is impossible to simulate this process without introduction of assumptions and averaged quantities. Therefore, we assume that particles, after their shredding in zone I of the furnace (Fig. 2), have spherical shape and the same mean diameter d_p. This assumption is rather accurately confirmed by practice for many processes related to food production and waste utilization [5]. Also, taking into account thorough shredding of the waste in zone I and its entering zone II after passing through cuts 22, uniformly located in lower partition 2 of the shredder, we assume that distances between any two neighboring particles in zones II and III are the same in all three planes and equal to l_{ps} (Fig. 3). To determine $l_{ps,}$, we write equation of the motion of the average-size particle with mass m_{pII} in zone II of the furnace relative to vertical axis z

$$m_{pII} a_{pI} = m_{pII} g - P_{vII} = m_{pII} g - p_{vII} \frac{\pi \cdot d_p^2}{4} = m_{pII} g - \rho_a \frac{v_{aII}^2}{2} \frac{\pi \cdot d_p^2}{4}, \qquad (1)$$

where a_{pII} – acceleration of the particle motion in zone II; P_{aII} – force, created by the velocity pressure [6] of the air supplied through nozzles 1 in zone II; v_{aII} – average velocity of the air flow in the upper transverse section of zone II; ρ_a – density of the hot air supplied to zones II, III.

Relationship between speed v_{aII} and total flow rate Q_{aII} of the hot air through nozzles 1 is given by

$$Q_{aII} = v_{aII} \frac{\pi \cdot D_f^2}{4}, \qquad (2)$$

where D_f – initial diameter of the furnace.

Taking into account formulas (1, 2), displacement of the given particle within the time unit could be found as

$$h_{unIn} = \frac{a_{pII} t^2}{2} = \frac{1}{2}\left(g - \rho_a \frac{3}{4} \frac{v_{aII}^2}{d_p \rho_{wII}} \right), \qquad (3)$$

where ρ_{wII} – density of the waste with moisture content U_i.

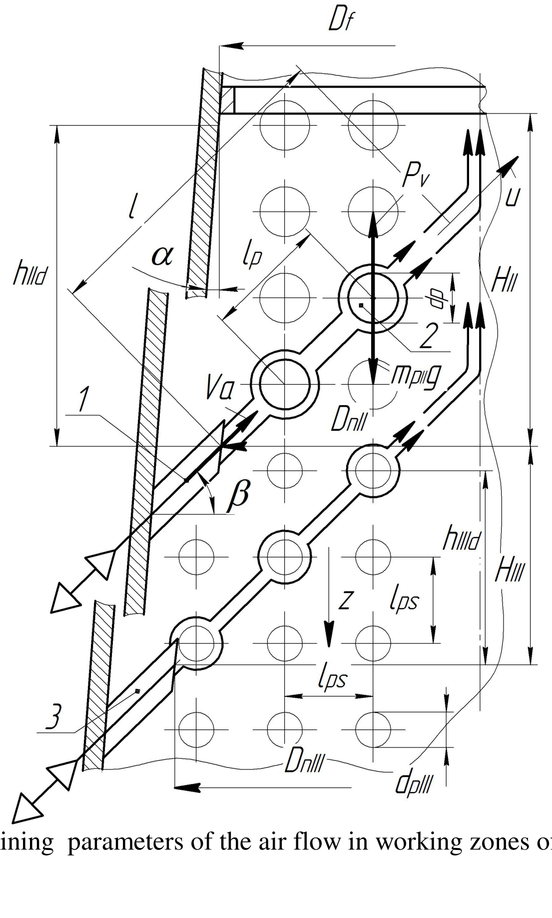

Fig. 3. Scheme for determining parameters of the air flow in working zones of the proposed furnace.

Average number of waste particles with diameter d_p, which enter zone II of the furnace within a time unit is calculated as

$$n_{unII} = \frac{m_{w.un}}{m_{pII}}, \tag{4}$$

where $m_{w.un}$ – mass of the waste entering zone II of the furnace within a time unit.

Taking into account dependence (4), the number of solid particles in a length unit is found as

$$n_{lunII} = \sqrt[3]{n_{unII}} = \sqrt[3]{\frac{m_{w.un.}}{m_{pII}}}. \tag{5}$$

Then the formula for finding l_{ps} will have the following form:

$$l_{ps} = \frac{h_{unIn} - n_{lunII} h_{unII} d_p}{h_{unII}\left(n_{lunII} - 1\right)}. \tag{6}$$

The change of parameters of the air flow, coming from nozzle 1 at a certain distance l from it (l varies within the interval $0 \le l \le D_{nII}/2 \cdot \cos\beta$), relative to axis u (Fig. 3) could be found according to Bernoulli's law [6]

$$\rho_a g \cdot H_{II} + \rho_a \frac{v_{a.nII}^2}{2}\frac{\pi \cdot d_p^2}{4} = \rho_a g\left(H_{II} - l \cdot \sin\beta\right) + \rho_a \frac{v_{a.l.II}^2}{2}\frac{\pi \cdot d_p^2}{4} + \frac{l}{l_p}\zeta_{pII}\rho_a \frac{v_{a.l}^2}{2}, \tag{7}$$

where H_{II} – height of zone II; $v_{a.n.II}$, $v_{a.l.II}$ – velocities of the air flow in sections at the output of nozzle 1 (found taking into account flow area S_n of nozzle 1 and number n_n of the nozzles as $v_{a.nII} = Q_{aII}/n_n S_n$) and at the distance l from it; β – inclination angle of the nozzle 1; l_p – distance between two neighboring particles of the waste along axis u (it could be found as $l_p = l_{ps}/\sin\beta$); ζ_{pII} – local resistance coefficient [6] of a waste particle, when air flows around it in zone II.

Variation of the parameters of air flow outgoing from nozzle 3 relative to axis u for l varying within the interval $0 \le l \le D_{nIII}/2 \cdot \cos\beta$ we find as

$$\rho_a g\left(H_{II} + H_{III}\right) + \rho_a \frac{v_{a.nIII}^2}{2}\frac{\pi \cdot d_{pIII}^2}{4} = \rho_a g\left(H_{II} + H_{III} - l \cdot \sin\beta\right) + \rho_a \frac{v_{a.l.III}^2}{2}\frac{\pi \cdot d_{pIII}^2}{4} + \frac{l}{l_p}\zeta_{pIII}\rho_a \frac{v_{a.l.III}^2}{2}, \tag{8}$$

where H_{III} – height of zone III; $v_{a.nIII}$, $v_{a.l.III}$ – velocity of the air flow in the sections at the output of nozzle 3 ($v_{a.nIII} = Q_{aIII}/n_n S_n$, Q_{aIII} – air flow from nozzle 3 and at the distance l from it; ζ_{pIII} – coefficient of the local resistance of the waste particle, when air flows around it in zone III; d_{pIII} – mean diameter of a solid particle in zone III after its drying and burning in zone II.

Cross-section area of air flows outgoing from nozzles 1, 3 in zones II, III we assume to be equal S_n.

In other volumes of zone II, which are beyond the boundaries of the flows from nozzles 1, the air flow parameters we determine from equation

$$\rho_a g \cdot H_{II} + \rho_a \frac{v_{aII}^2}{2}\frac{\pi \cdot d_p^2}{4} = \rho_a g\left(H_{II} - h_{IId}\right) + \rho_a \frac{v_{aIId}^2}{2}\frac{\pi \cdot d_p^2}{4} + \frac{h_{IId}}{l_{ps}}\zeta_{pII}\rho_a \frac{v_{aII}^2}{2}, \tag{9}$$

where v_{aIIn}, v_{aIId} – velocities of the air flow in the lower section of zone II and in the section at the distance h_{IId} from the lower section, which could be determined by the formulas

$$v_{aIII} = \frac{4\cdot(Q_{aII}+Q_{aIII})}{\pi\cdot(D_a+2\cdot H_{II}tg\alpha)};\ v_{aIII} = \frac{4\cdot(Q_{aII}+Q_{aIII})}{\pi\cdot[D_a+2\cdot(H_{II}-h_{IId})tg\alpha]}, \qquad (10)$$

where α – inclination angle of the furnace walls.

Value of h_{IId} in formula (10) varies in the interval $0 \le h_{IId} \le H_{II}$.

Parameters of the air flows in the volumes of zone III, which go beyond the limits of flows from nozzles 3, we determine from the equation

$$\rho_a g(H_{II}+H_{III})+\rho_a\frac{v_{aIIII}^2}{2}\frac{\pi\cdot d_{pIII}^2}{4}=\rho_a g(H_{II}+H_{III}-h_{Vd})+\rho_a\frac{v_{aIIId}^2}{2}\frac{\pi\cdot d_{pIII}^2}{4}+\frac{h_{Vd}}{l_{ps}}\zeta_{pIII}\rho_a\frac{v_{aIIII}^2}{2}, \qquad (11)$$

where v_{aIIIn}, v_{aIIId} – velocities of the air flow in the lower section of zone III and in the section, which is at the distance h_{Vd} from the lower section. They could be calculated as

$$v_{aIIII} = \frac{4\cdot Q_{aIII}}{\pi\cdot[D_a+2\cdot(H_{II}+H_{III})tg\alpha]};\ v_{aIIII} = \frac{4\cdot Q_{aIII}}{\pi\cdot[D_a+2\cdot(H_{II}+H_{III}-h_{Vp})tg\alpha]}, \qquad (12)$$

where h_{Vd} varies in the interval $0 \le h_{Vd} \le H_{III}$.

At the vertical axis of the furnace air flows from nozzles 1, 3 meet the same flows coming from the opposite nozzles (Fig. 2) and, after interaction with them, change their motion into vertical direction (Fig. 3).

Conclusions

1. Environment pollution, including that with food production waste, is one of the vital problems in Ukraine. Therefore, the task of designing efficient equipment for such waste utilization is rather important.
2. The paper presents classification of the methods and equipment that could be used for thermal utilization of food production waste. Analysis of the said means and equipment has shown that they do not provide efficient solution of the set task since physical and mechanical characteristics of this specific waste are not taken into account at the design stage. As a result, fuel and working volume of the equipment are not used rationally during its operation. Besides, material consumption and cost of the equipment are rather high as well as negative effect on the environment.
3. The author proposes a special furnace for food production waste incineration, which provides pre-shredding of the waste to be burnt for increasing its surface of contact with hot gases and more intensive drying, dispersing and hindering waste particles motion to ensure their full combustion, creation of high specific loads in the furnace at comparatively low temperatures and with moderate energy consumption. Continuous processes of drying, combustion, cooling and ash discharge are also provided in order to increase efficiency and productivity of the developed equipment.
4. Dependencies are presented for determination of air flow parameters in the working zones of the proposed furnace, which could be used in order to elaborate the methods for its design computations and to ensure optimal efficiency indicators.

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