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Research of Technical and Economic Properties of Material of Porous Fuel Briquettes from the Solid Combustible Waste Impregnated with Liquid Combustible Waste

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Keywords: porous solid materials, fuel briquettes, combustible solid waste, combustible liquid waste, environment protection technologies, economic effect.

Abstract. The study evaluates the impact of the enterprise for production of industrial electronics on the components of the environment, in particular the lithosphere of Kharkiv by solid and liquid combustible waste. The environmental protection technology by the method of waste disposal of solid and liquid combustible substances by improving the technology of production and storage of fuel briquettes with improved ingredient composition, utilization of thermal energy from their combustion in a solid fuel boiler and purification of its exhaust gases been developed. A new ingredient composition of the fuel briquettes has been developed and the technology of their storage has been improved, and a feasibility study has been provided. Rational values of mass-size, technical and economic properties of the fuel briquettes taking into account properties of materials of their solid and liquid components has been defined.

Introduction

The issue of ensuring compliance with the normatively established indicators of the level of ecological safety (ES) of production activities of any industrial enterprise, in particular the manufacturer of industrial electronics, is urgent and acute in an urban ecosystem. Pollution by materials of such a component of the environment as the lithosphere in the form of solid and liquid combustible waste is special given the limited area of organized landfills for their disposal and storage. On the other hand, issues of rational energy management, in particular ensuring the energy autonomy of the enterprise, are closely related to air pollution by thermal energy and consumption of non-renewable fossil fuels.

Problem Formulation

On the basis of results of analysis of scientific, technical, reference, patent and regulatory literature it need to find the comprehensive solution of waste disposal problems and ensuring energy autonomy of the enterprise for the production of industrial electronics. At the same time at first it is rational to perform the development of environmental protection technology (EPT) for the disposal of solid and liquid combustible waste for the enterprise. Then it is necessary to implement the determination of properties of solid and liquid combustible waste of the enterprise as components of fuel briquettes of new ingredient composition. Finally, it should be done the determination of mass-size and technical, economic properties of components of fuel briquettes of new ingredient composition as well, as development of a rational way of storing fuel briquettes of new ingredient composition.

Analysis of Publications

ES of production and economic activity of an enterprise for the production of industrial electronics should be based on the material basis of the relevant EPT [1–7]. Such EPT is a set of executive bodies that work according to various principles and physical phenomena and need design and optimization calculation research to continuously improve the efficiency of their work [8–12]. Such studies are knowledge-intensive and require mathematical and physical modeling, experimental studies for all areas where oxidation processes occur – in the operation of power plants with reciprocating internal combustion engines (RICE) [1, 13–17], in the disposal of solid waste [18], in the prevention, localization of fire and elimination of fire consequences [19–22]. Appropriate methods [23–25] and regulatory framework [26–28] are used to assess the impact of technogenic objects on the components of environment. It is important to take into account the features of the production process of a particular enterprise, climatic features and the current ecological situation in the region of its location [29–31]. Research of optimal modes of preparation of wood waste generated at industrial enterprises for their combustion (ratio of binder component and wood waste, method of binder component supply, granulation methods), which determines its relevance and importance for ES of Ukraine [32, 33]. On the other hand, industrial enterprises usually also generate a significant amount of waste technical combustible liquids (TCL), which, like wood waste, is a valuable energy resource and a dangerous pollutant [34–38]. Simultaneous utilization of these two types of waste is a very important scientific and technical task, which has signs of scientific novelty, and the results of its solution, obviously, have significant prospects for practical implementation.

Aim of Paper

The aim of the study is determination of mass-size, technical and economic indicators of the material of porous fuel briquettes of new ingredient composition from solid combustible waste of industrial enterprise impregnated with liquid combustible waste as a by-product of EPT.

Object of the study is mass-size, technical and economic indicators of fuel briquettes material of new ingredient composition. Subject of the study is dependences of values of object of the study on properties of materials of their solid and liquid components.

Materials and Methods

Materials studied in this article is solid and liquid combustible waste of enterprise as manufacturer of industrial electronics – wood sawdust and sawdust of other solid combustible waste and also mixture of diesel fuel, gasoline, motor oil and ethyl alcohol.

Methods of the study is following: analysis of scientific, technical, reference, patent and regulatory literature, the main provisions of the disciplines «Environmental Protection Technologies», «Design and development of environmental safety systems», «Technical mechanics of liquid and gas», «Theory of heat transfer processes», «Theory of oxidation reductive reactions», «Theory of machining by cutting», «Theory of machining by pressure».

Main Part

Development of environmental protection technology for an enterprise for the production of industrial electronics technology for solid and liquid combustible waste disposal

According to the results of the analysis of the features of production activity of LLC RPA «Vertical» (Kharkiv) it is established that at present there are two urgent tasks: 1) ensuring energy autonomy of the enterprise in terms of heat carrier for heating industrial and domestic premises and hot water for utilities; 2) utilization of solid and liquid combustible wastes of production activity.

To solve both problems at once, the EPT is developed, the scheme of which is illustrated in Fig. 1. In Fig. 1 the following symbols are used: Objects: A – storage of pallets; B – sorting section; C – tank; D – crusher; E – mixer; F – briquetting press; G – solid fuel boiler; H – atmosphere;

I – consumer of thermal energy; J – cyclone book; K – ash storage; L – own construction; M – CO and C_nH_m oxidizer; N – NO_x absorber; O – gas cylinder; Substances: 1 – pallets; 2 – combustible solid production waste and household waste; 3 – combustible liquid production waste; 4 – wood sawdust; 5 –impregnated sawdust; 6 – fuel briquettes; 7 – air; 8 – thermal energy; 9 – exhaust gases (EG); 10 – loose ash; 11 – compacted ash; 12 – EG, cleaned of PM; 13 – EG, purified from CO and C_nH_m; 14 – EG purified from NO_x; 15 – natural gas CH_4.

The proposed scheme provides for the manufacture of fuel briquettes from a crushed mixture of wood sawdust and sawdust of other solid combustible waste by pressing and impregnating the pores of the briquettes with combustible liquid waste. The obtained briquettes are burned in a solid fuel boiler, where natural gas is also supplied, the obtained thermal energy is utilized for the enterprise's own needs. The EG obtained in the boiler are emitted into the atmosphere, having been pre-cleaned of PM in a conical cyclone, the products of incomplete combustion of fuel – in the oxidizer, and nitrogen oxides – in the absorber. The ash formed in the boiler after periodic extraction, grinding and mixing is used in conducting its own construction work at the enterprise as a component of construction mixtures.

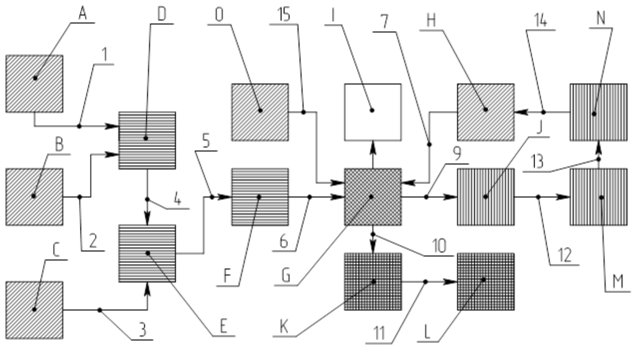


Fig. 1. Scheme of developed EPT

Development of a new ingredient composition of fuel briquettes and improvement of their storage technology

It is a known fact that the moisture content of wood waste from which sawdust is produced, which is mixed with crushed other solid combustible industrial waste, and then pressed into fuel briquettes of various shapes and compositions, may or may not undergo a drying operation, and therefore its humidity may fluctuate within $\varphi_w = 5\ldots 50$ %. After the pressing operation in presses or extruders of various designs, the porosity of fuel briquettes ψ_{fb} is from 5 to 50 %.

Humidity of wood $\varphi_w = 20$ %, and fuel briquettes $\varphi_{fb} = 10$ % is accepted as standard. The type of wood, the non-recyclable waste of which is generated at the enterprise in significant quantities, is pine, the calorific value of which at standard humidity Q_{20} is 20 MJ/kg, and the density ρ_{20} = 520 kg/m^3. The density of different types, geometric shapes and methods of formation, and hence porosity, of fuel briquettes $\rho_{fb} = 750 – 1400$ kg/m^3.

The relationship between the magnitudes of the values of density of fuel briquettes ρ_{fb} and their porosity ψ_{fb} and the value of their humidity φ_{fb}, determined in the first approximation, are linear functions, presented in Fig. 2 and are described by formulas (1) and (2) using the least squares method. To obtain an approximate value of the calorific value of wood waste (in particular – pine), from which fuel briquettes should be produced, at different values of its humidity, it can be proposed the following formula (3).

$$\rho_{fb} = -14.444 \cdot \psi_{fb} + 1472.2,\ \text{kg/m}^3; \quad (1)$$
$$\varphi_{fb} = -0.069 \cdot \rho_{fb} + 100.0,\ \%; \quad (2)$$
$$H_u(\varphi_w) = Q_{20} - (\varphi_w - 20) / 100 \cdot Q_{vap}(H_2O) - (\varphi_w - 20) / 100 \cdot Q_{20} \cdot \rho_{H2O}(t_w) / \rho_w,\ \text{MJ/kg}, \quad (3)$$

where Q_{20} = 20 MJ/kg – calorific value at standard humidity $\varphi_w = 20$ %; φ_w – current value of wood moisture, %; $Q_{vap}(H_2O)$ = 2,26 MJ/kg – hidden heat of water vaporization; $\rho_{H2O}(t_w)$ – density of liquid water at temperature t_w, kg/m^3; ρ_w = 520 kg/m^3 – density of wood at standard humidity $\varphi_w = 20$.

The temperature dependence of the value of water density is shown in Fig. 2 and is described by formula (4). Therefore, when 20 °C than ρ_{H2O} = 998,3 kg/m^3. The dependence of the values of calorific value of wood waste $H_u(\varphi_w)$ on the value of its humidity φ_w is also illustrated in Fig. 1.

$$\rho_{H2O}(t_w) = 1.680\cdot10^{-5}\cdot t_w^3 - 6.153\cdot10^{-3}\cdot t_w^2 + 2.955\cdot10^{-2}\cdot t_w + 9.999\cdot10^2,\ \text{kg/m}^3. \quad (4)$$

The essence of the proposed innovations in EPT is that the waste of unprocessed wood and other combustible waste generated at the enterprise, after grinding, mixing and briquetting, in the form of briquettes that retain moisture of the original sawdust φ_w = 20 % and are porous, and the content of pores (which are filled with air) depends on the effort of the pressing press and ranges from ψ_{fb} from 20 to 40 %, it is proposed to impregnate with waste TCL formed at the same enterprise and store them in a sealed tank in a layer of such liquid to prevent of evaporation and leakage of TCL from the pores.

The following types of non-renewable TCL are formed at the enterprise: a) diesel fuel in the amount of G(DF) = 3.0 kg/h, density ρ(DF) = 840 kg/m^3, calorific value H_u = 42.7 MJ/kg, mol mass μ($C_{16}H_{34}$) = 226 mol/kg; b) gasoline in the amount of G(BF) = 1.0 kg/h, density ρ(DF) = 750 kg/m^3, calorific value H_u = 44.0 MJ/kg, molar mass μ(C_8H_{18}) = 114 mol/kg ; c) motor oil in the amount of G(MO) = 4.0 kg/h, density ρ(DF) = 870 kg/m^3, calorific value H_u = 41.0 MJ/kg, molar mass μ($C_{40}H_{82}$) = 562 mol/kg; d) ethyl alcohol in the amount of G(EA) = 2.0 kg/h, density ρ(DF) = 810 kg/m^3, calorific value H_u = 27.0 MJ/kg, molar mass μ(C_2H_5OH) = 46 mol/kg.

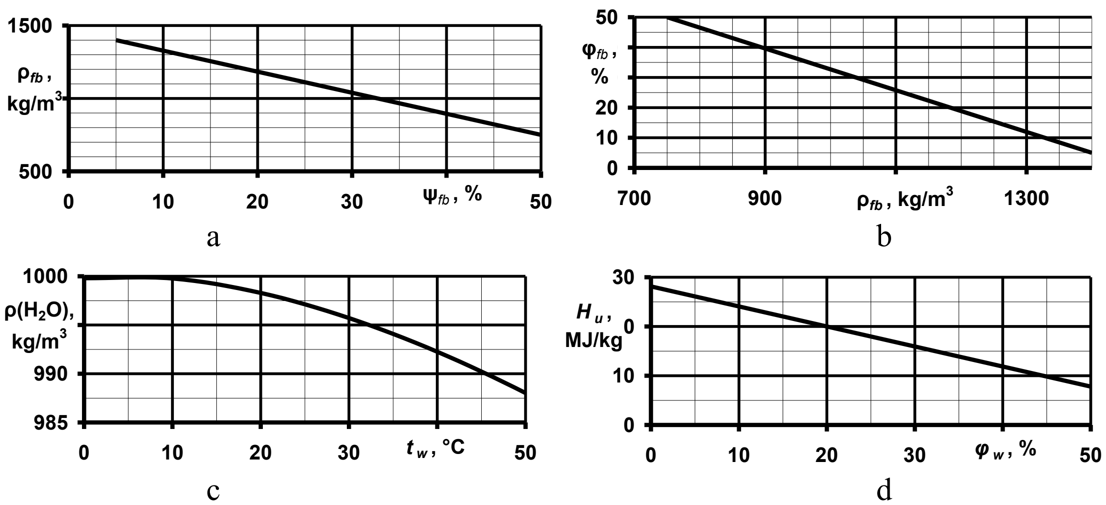


Fig. 2. Dependence of density of fuel briquettes ρ_{fb} on their porosity ψ_{fb} (a), humidity of fuel briquettes φ_{fb} on their density ρ_{fb} (b), density of fresh water ρ_{H2O} on temperature t_w (c) and calorific value of wood waste $H_u(\varphi_w)$ on its humidity φ_w (d)

Thus, for different types of traditional and alternative solid, liquid and gaseous fuels, the calorific value is as follows: diesel fuel $C_{16}H_{34}$ H_u = 42.7 MJ/kg, for gasoline C_8H_{18} 44.0 MJ/kg, for methanol CH_3OH 22.0 MJ/kg, for ethanol C_2H_5OH 27.0 MJ/kg, for natural gas C_2H_6 47.0 MJ/kg, for methane CH_4 55.0 MJ/kg, for hydrogen H_2 120.0 MJ/kg, for motor oil $C_{40}H_{82}$ 41.0 MJ/kg, for fuel oil $C_{60}H_{122}$ 39.0 MJ/kg, for associated petroleum, shale and other types of by-product extractive fuel gas 40.0 MJ/kg, for ammonia NH_3 18.6 MJ/kg, for glycerin $C_3H_5(OH)_3$ 19.0 MJ/kg, for tar and bitumen $C_{250}H_{502}$ 36.0 MJ/kg, for gas oil $C_{25}H_{52}$ 38.0 MJ/kg, for acetone C_3H_6O 29.0 MJ/kg, for kerosene $C_{11}H_{24}$ 35.0 MJ/kg, for coke C 30.0 MJ/kg, for gunpowder 4.0 MJ/kg, for propane C_3H_8 50.5 MJ/kg, for turpentine $(C_5H_8)_n$ 44.0 MJ/kg, for crude oil 43.0 MJ/kg, for peat 17.5 MJ/kg, for anthracite coal 33.5 MJ/kg, for bituminous coal 20.0 MJ/kg, for tree coal other 30.0 MJ/kg, for hard coal 21.0 MJ/kg, for brown coal 16.5 MJ/kg, for ether C_2H_6O 43.0 MJ/kg.

Therefore, the total amount of combustible technical fluids generated at the plant and must be neutralized is determined by formula (5). During the 8-hour work shift, the total amount of TCL that are formed at the enterprise and must be neutralized is formed – according to formula (6). The potential amount of thermal energy released with TCL is determined by formula (7), and during an 8-hour work shift, the amount of such energy is determined by formula (8).

$G_{fl} = G(\mathrm{DF}) + G(\mathrm{BF}) + G(\mathrm{MO}) + G(\mathrm{EA}) = 3.0 + 1.0 + 4.0 + 2.0 = 10.0$ kg/h; (5)
$G_{fl8} = 8 \cdot G_{fl} = 8 \cdot 10.0 = 80.0$ kg/day; (6)
$Q_{fl} = G(\mathrm{DF}) \cdot H_u(\mathrm{DF}) + G(\mathrm{BF}) \cdot H_u(\mathrm{BF}) + G(\mathrm{MO}) \cdot H_u(\mathrm{MO}) + G(\mathrm{EA}) \cdot H_u(\mathrm{EA}) =$
$= 3.0 \cdot 42.7 + 1.0 \cdot 44.0 + 4.0 \cdot 41.0 + 2.0 \cdot 27.0 = 390.1$ MJ/h = 0.108 MW. (7)
$Q_{fl8} = 8 \cdot Q_{fl} = 8 \cdot 390.1 = 3120.8$ MJ/day = 0.864 MW. (8)

The amount of sawdust generated at the enterprise and subject to processing into fuel briquettes is $G(\mathrm{W}) = 20$ kg/h or $G(\mathrm{W})_8 = 160$ kg/day, which at constant humidity $\varphi_w = 20$ % and calorific value $H_u(\mathrm{W}) = 20$ MJ/kg (see Fig. 2) potentially gives such an amount of thermal energy in a perfectly organized combustion process is determined by formulas (9) and (10). The total amount of thermal energy that can potentially be obtained by complete combustion of all combustible substances generated at the enterprise – according to formula (11), during an 8-hour work shift, it can be got such a potential amount of thermal energy – according to formula (12).

$Q_W = G(\mathrm{W}) \cdot H_u(\mathrm{W}) = 20 \cdot 20 = 400$ MJ/h = 0.111 MW; (9)
$Q_{W8} = G(\mathrm{W})_8 \cdot H_u(\mathrm{W}) = 160 \cdot 20 = 3200$ MJ/day = 0.888 MW/dey; (10)
$Q_\Sigma = Q_W + G_{fl} = 390.1 + 400 = 790.1$ MJ/h = 0.219 MW; (11)
$Q_{\Sigma 8} = Q_\Sigma \cdot 8 = 790.1 \cdot 8 = 6320$ MJ/day = 1.752 MW/day. (12)

Since all types of TCL are proposed to be mixed during impregnation of porous fuel briquettes from sawdust, it is necessary to determine the molar mass μ_{fl}, calorific value H_{ufl} and density ρ_{fl} of such a mixture as proposed by formulas (13) – (15). The volume of the mixture of TCL is determined by formula (16), and during the 8-hour work shift the volume of the mixture of TCL formed at the enterprise – by (17).

$\mu_{fl} = (\mu(\mathrm{DF}) \cdot G(\mathrm{DF}) + \mu(\mathrm{BF}) \cdot G(\mathrm{BF}) + \mu(\mathrm{MO}) \cdot G(\mathrm{MO}) + \mu(\mathrm{EA}) \cdot G(\mathrm{EA})) / G_\Sigma =$
$= (226 \cdot 3.0 + 114 \cdot 1.0 + 562 \cdot 4.0 + 46 \cdot 2.0) / 10.0 = 313.2$ mol/kg; (13)
$H_{ufl} = (H_u(\mathrm{DF}) \cdot G(\mathrm{DF}) + H_u(\mathrm{BF}) \cdot G(\mathrm{BF}) + H_u(\mathrm{MO}) \cdot G(\mathrm{MO}) + H_u(\mathrm{EA}) \cdot G(\mathrm{EA})) / G_\Sigma =$
$= (42.7 \cdot 3.0 + 44.0 \cdot 1.0 + 41.0 \cdot 4.0 + 27.0 \cdot 2.0) / 10.0 = 39.0$ MJ/kg; (14)
$\rho_{fl} = (\rho(\mathrm{DF}) \cdot G(\mathrm{DF}) + \rho(\mathrm{BF}) \cdot G(\mathrm{BF}) + \rho(\mathrm{MO}) \cdot G(\mathrm{MO}) + \rho(\mathrm{EA}) \cdot G(\mathrm{EA})) / G_\Sigma =$
$= (840 \cdot 3.0 + 750 \cdot 1.0 + 870 \cdot 4.0 + 810 \cdot 2.0) / 10.0 = 837.0$ kg/m^3. (15)
$W_{fl} = W(\mathrm{DF}) + W(\mathrm{BF}) + W(\mathrm{MO}) + W(\mathrm{EA}) = G_{fl} / \rho_{fl} =$
$= G(\mathrm{DF}) / \rho(\mathrm{DF}) + G(\mathrm{BF}) / \rho(\mathrm{BF}) + G(\mathrm{MO}) / \rho(\mathrm{MO}) + G(\mathrm{EA}) / \rho(\mathrm{EA}) =$
$= 3.0 / 840 + 1.0 / 750 + 4.0 / 870 + 2.0 / 810 = 0.012$ m^3/h = 12 l/h. (16)
$W_{fl8} = 8 \cdot W_{fl} = 8 \cdot 12 = 96$ l/day. (17)

Determination of technical and economic indicators of porous fuel briquettes with a new ingredient composition of solid and liquid combustible waste materials

The study suggested that the geometric shape of the fuel briquette obtained after pressing is a parallelepiped with the ratio of the main dimensions as in ordinary bricks, i.e. length A = 250 mm, width B = 125 mm and height C = 63 mm, i.e. A : B : C = 1 : 0.5 : 0.25. Then, the volume of fuel briquette is determined by formula (18), the density of fuel briquette impregnated with a mixture of TCL at standard wood sawdust humidity $\varphi_w = 20$ % and porosity $\psi_{fb} = 20$ % – by formula (19), mass of fuel briquette, impermeable mixture TCL – by formula (20).

The potential amount of thermal energy released during the complete combustion of one fuel briquette, impregnated with a mixture of TCL, is determined by formula (21), the number of fuel briquettes received at the plant per hour and 8 hours per shift – by formulas (22) and (23), the potential amount of thermal energy released during the complete combustion of n_{fbd} and N_{fbd} fuel briquettes, impregnated with a mixture of TCL – according to formulas (24) and (25).

$W_{fbd} = \mathrm{A} \cdot \mathrm{B} \cdot \mathrm{C} = 0.250 \cdot 0.125 \cdot 0.063 = 1.969 \cdot 10^{-3}$ m^3. (18)
$\rho_{fbd} = \rho_w(\varphi_w) \cdot (100 - \psi_{fb}) / 100 = 520 \cdot (100 - 20) / 100 = 416$ kg/m^3. (19)
$m_{fbd} = \rho_{fl} \cdot W_{fl} = 416 \cdot 1.969 \cdot 10^{-3} = 0.819$ kg. (20)
$Q_{fbd} = m_{fbd} \cdot Q_{20} = 0.819 \cdot 20 = 16.4$ MJ; (21)
$n_{fbd} = G(\mathrm{W}) / m_{fbd} = 20 / 0.819 = 24.4$ psc/h; (22)
$N_{fbd} = n_{fbd} \cdot 8 = 24.4 \cdot 8 = 195$ psc/day. (23)
$Q_{fbd}(n_{fbd}) = Q_{fbd} \cdot n_{fbd} = 16.4 \cdot 24.4 = 400$ MJ/h; (24)
$Q_{fbd}(N_{fbd}) = Q_{fbd} \cdot N_{fbd} = 16.4 \cdot 195 = 3200$ MJ/day. (25)

In the case of impregnation of fuel briquettes with porosity $\psi_{fb} = 20$ % mixture of TCL, the mass of liquid in the briquette should be determined by formula (26), the mass of fuel briquette impregnated with a mixture of TCL – by formula (27), in this case impregnated with a mixture of TCL, can be determined by the formula (28).

The potential amount of thermal energy released during the complete combustion of one fuel briquette impregnated with a mixture of TCL is determined by formula (29), the potential amount of thermal energy released during complete combustion of n_{fbd} and N_{fbd} fuel briquettes impregnated with a mixture of TCL according to formulas (30) and (31).

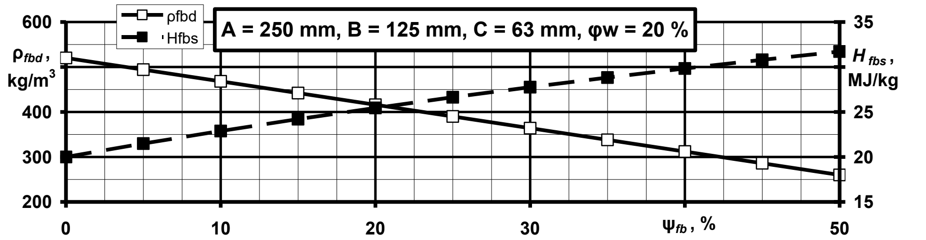
$m_{flb} = \rho_{fl} \cdot W_{fbd} \cdot \psi_{fb} / 100 = 837 \cdot 1.969 \cdot 10^{-3} \cdot 20 / 100 = 0.330$ kg; (26)
$m_{fbs} = m_{fbd} + m_{flb} = 0.819 + 0.330 = 1.149$ kg; (27)
$H_{fbs} = (H_{fbd} \cdot m_{fbd} + H_{fl} \cdot m_{flb}) / m_{fbs} = (20 \cdot 0.819 + 39 \cdot 0.330) / 1.149 = 25.5$ MJ/kg. (28)
$Q_{fbs} = m_{fbs} \cdot H_{fbs} = 1.149 \cdot 25.5 = 29.3$ MJ. (29)
$Q_{fbs}(n_{fbd}) = Q_{fbs} \cdot n_{fbd} = 29.3 \cdot 24.4 = 715$ MJ/h; (30)
$Q_{fbs}(N_{fbd}) = Q_{fbs} \cdot N_{fbd} = 29.3 \cdot 195 = 5720$ MJ/day. (31)

For another limit value of porosity of fuel briquette – $\psi_{fb} = 40$ % – we have the following results of calculations: $\rho_{fbd} = 312$ kg/m^3, $m_{fbd} = 0.614$ MJ, $Q_{fbd} = 12.3$ MJ, $n_{fbd} = 32.6$ psc/h, $N_{fbd} = 260.6$ psc/day, $Q_{fbd}(n_{fbd}) = 401.0$ MJ/h, $Q_{fbd}(N_{fbd}) = 3206.4$ MJ/day, $m_{flb} = 0.660$ kg, $m_{fbs} = 1.274$ kg, $H_{fbs} = 29.8$ MJ/kg, $Q_{fbs} = 38.0$ MJ, $Q_{fbs}(n_{fbd}) = 971.5$ MJ/h, $Q_{fbs}(N_{fbd}) = 7765.9$ MJ/day. Therefore, having performed research for the interval of porosity values $\psi_{fb} = 0…50$ %, we obtain the dependences of the above values, shown in Fig. 3.

In case of using for the formation of fuel briquettes by pressing wood sawdust with a different from standard (20 %) humidity φ_w from 0 % (completely dry wood) to 50 % (maximum possible value according to the standard), at a constant value of the volume of the briquette W_{fbd} mass of the wood part of briquette m_{fbw} will remain unchanged (see formula (33)) and will correspond to such mass $m_{fbw}(20)$ at the standard value of humidity $\varphi_w = 20$ %, the mass of moisture in the briquette m_{fbh} (see formula (34)) and the mass of the briquette m_{fb} (as the sum the first two components – see formula (32) and (35)) will be a function of humidity φ_w. The dependences of the values of m_{fb}, m_{fbw} and m_{fbh} on the humidity φ_w are shown in Fig. 4.

$m_{fb} = m_{fbw} + m_{fbh}$, kg; (32)
$m_{fbw} = m_{fbw}(20) = m_{fb}(20) - m_{\mathrm{H2O}}(20) = m_{fb}(20) \cdot (1 - 20 / 100) =$
$= W_{fbd} \cdot \rho_{20} \cdot (1 - 20 / 100) = 1.969 \cdot 10^{-3} \cdot 520 \cdot 0.80 = 0.819$ kg; (33)
$m_{fbh} = m_{fbw} \cdot \varphi_w / 100 / (1 - \varphi_w / 100)$, kg; (34)
$m_{fb} = W_{fbd} \cdot \rho_{20} \cdot (1 - 20 / 100) + m_{fbw} \cdot \varphi_w / 100 / (1 - \varphi_w / 100)$, kg. (35)

We will consider that at drying of wood sawdust the volumes occupied by moisture will be released and added to volumes of pores in a fuel briquette after its formation by pressing, and at use of sawdust with higher humidity, than standard, the additional volumes occupied by moisture will be deducted from the pore volume. It should be noted that the moisture content of wood φ_w and the porosity of the briquette ψ_{fb} are fundamentally different physical quantities, which are determined by formulas (36) and (37). Then, the increase or decrease in the pore volume of the fuel briquette due to the change in humidity of its sawdust relative to its standard value is determined by formula (38).



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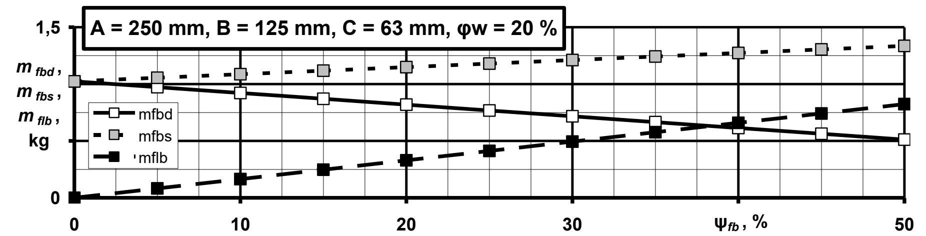

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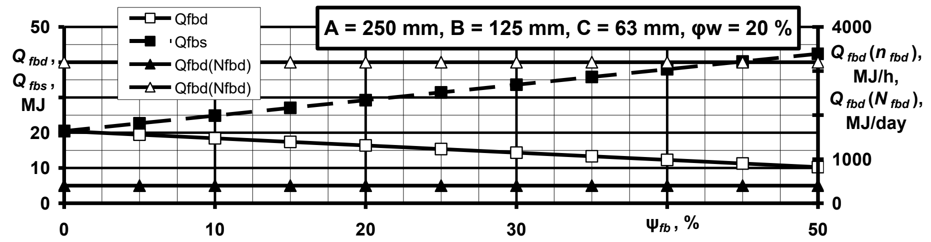

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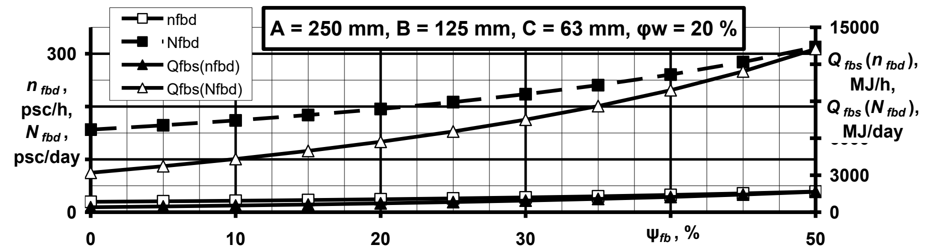


d

Fig. 3. Dependencies of values of ρ_{fbd} and H_{fbs} on the porosity of the fuel briquette ψ_{fb} (a), such dependences for the values of m_{fbd}, m_{flb} and m_{fbs} (b), for the values of Q_{fbd} and Q_{fbs} and $Q_{fbd}(n_{fbd})$ and $Q_{fbd}(N_{fbd})$ (c) and for the values of n_{fbd} N_{fbd} and $Q_{fbs}(n_{fbd})$ and $Q_{fbs}(N_{fbd})$ (d)

Then the porosity of the fuel briquette from sawdust with different from the standard humidity can be obtained from the formula (39). The dependences of the values of ΔW_{por} and $\psi_{fb}(\varphi_w)$ at φ_w = 20 % on the value of φ_w are shown in Fig. 4. The dependences of the magnitudes of values $\psi_{fb}(\varphi_w)$ on the values of φ_w and ψ_{fb} are shown in Fig. 4.

$$\varphi_w = m_{fbh} / m_{fb} \cdot 100 = m_{fbh} / (m_{fbh} + m_{fbw}) \cdot 100, \%; \quad (36)$$

$$\psi_{fb} = W_{por} / W_{fb} \cdot 100 = W_{por} / (W_{fbw} + W_{por}) \cdot 100, \%. \quad (37)$$

$$\Delta W_{por} = (m_{\mathrm{H2O}}(20) - m_{\mathrm{H2O}}(\varphi_w)) / \rho_{\mathrm{H2O}}(t_w) = (0.205 - m_{\mathrm{H2O}}(\varphi_w)) / 998.3, \mathrm{m}^3. \quad (38)$$

$$\psi_{fb}(\varphi_w) = (W_{por}(\varphi_w{=}20) + \Delta W_{por}(\varphi_w)) / W_{fb} \cdot 100 =$$
$$= (W_{fb} \cdot \psi_{fb} / 100 + \Delta W_{por}(\varphi_w)) / W_{fb} \cdot 100, \%. \quad (39)$$

The main results of this study are the data shown in Fig. 5 and 6. It is following data – dependences of the value of $\psi_{fb}(\varphi_w)$ on the values of φ_w and ψ_{fb}, such dependences for the values of m_{fb}, m_{fbw} and m_{fbh}, for the values of H_{fbs} and Q_{fbs}, for the values of $Q_{fbd}(n_{fbd})$ and $Q_{fbd}(N_{fbd})$ and for the values ΔH_{fbs}, Δm_{flb} and Δm_{fbs}.

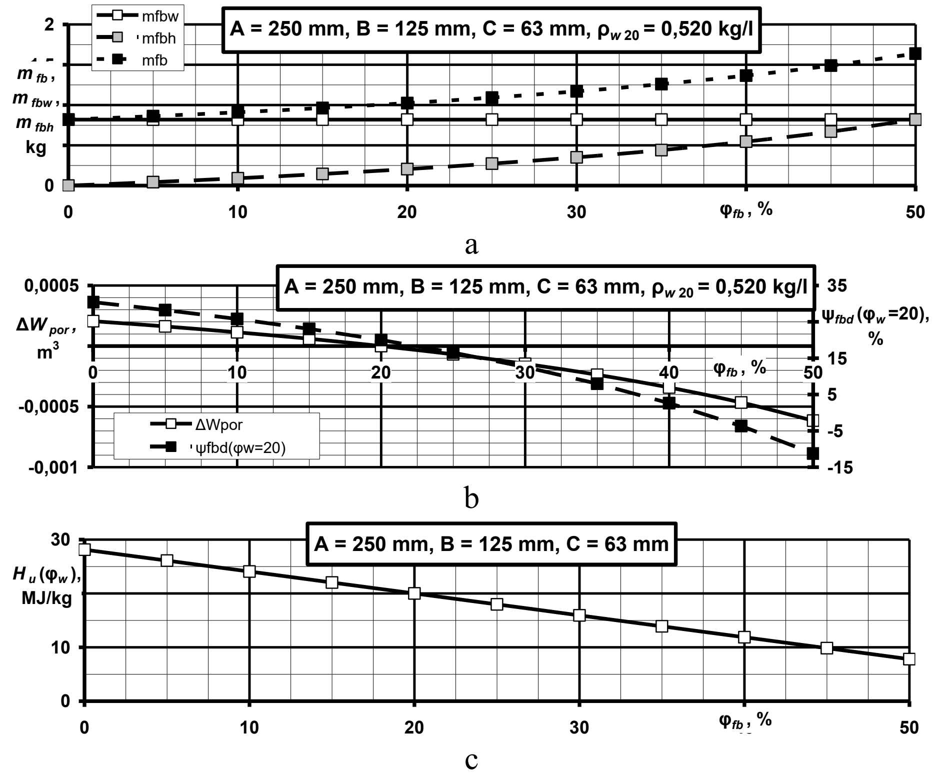


Fig. 4. Dependences of values of m_{fb}, m_{fbw} and m_{fbh} on humidity φ_w (a), such dependences for values of ΔW_{por} and $\psi_{fb}(\varphi_w)$ at φ_w = 20 % (b) and for value of $H_u(\varphi_w)$ (c)

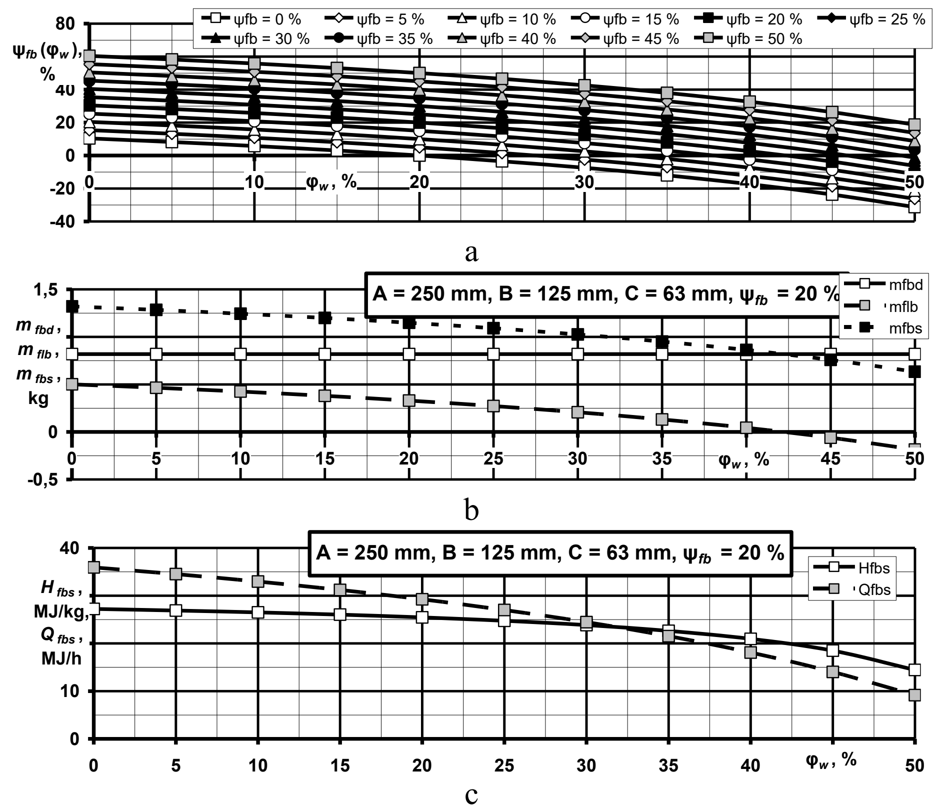
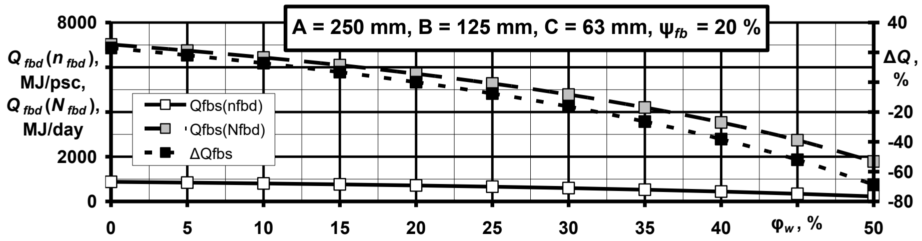
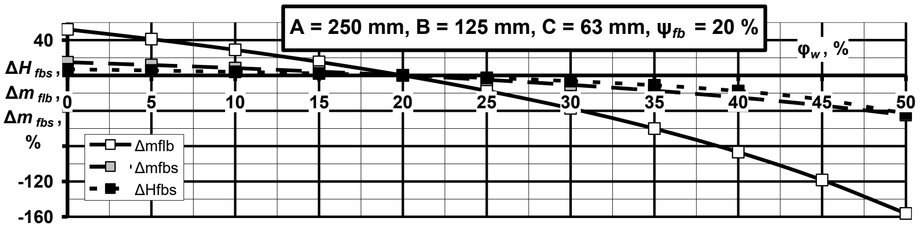


Fig. 5. Dependences of the value of $\psi_{fb}(\varphi_w)$ on the values of φ_w and ψ_{fb} (a), such dependences for the values of m_{fb}, m_{fbw} and m_{fbh} (b), for the values of H_{fbs} and Q_{fbs} (c)



a



b

Fig. 6. Dependences of the value of of $Q_{fbd}(n_{fbd})$ and $Q_{fbd}(N_{fbd})$ on the values of φ_w (a) and such dependences for the values of ΔH_{fbs}, Δm_{flb} and Δm_{fbs} (b)

So, it can be concluded that the decrease in the moisture content of sawdust in fuel briquettes with a constant value of their theoretical porosity, which provides the briquette press with a certain value of its effort (and hence mechanical energy consumption), causes an increase in actual porosity and, consequently, the content of TCL impregnated with briquettes.

Increasing the humidity, on the contrary, reduces the value of the actual porosity, because the standard value of moisture of sawdust is set provided that full saturation of cellulose capillaries with moisture at the recommended air temperature in the room where the sawdust is stored. Excess moisture is adsorbed on the outer surface of the sawdust particles and occupies volumes between them in the briquette, thereby reducing the amount of pores occupied by the air, which must receive a mixture of flammable liquids when the briquette is impregnated.

Conclusion

Thus, in this study, a calculated study was conducted to develop a new ingredient composition of fuel briquettes and improve the technology of their storage with a feasibility study for an improved approach.

To simultaneously solve the problem of utilization of solid and liquid combustible non-recyclable waste generated at the enterprise for the production of industrial electronics, and increase the energy autonomy of the enterprise by utilizing thermal energy from burning porous fuel briquettes produced from these wastes, environmental technology has been developed.

It is determined that when burning one fuel briquette with measuring of 250 × 125 × 63 mm and weighing 0.819 kg, made on a briquetting press from wood waste sawdust with a standard humidity of 20 % calorific value of 20 MJ/kg and a porosity of 20 % of the total amount of 160 kg/day potentially 16.5 MJ of thermal energy is released. From the available amount of wood waste generated daily at the enterprise, such briquettes can be produced 24 units/hour and 195 units/day.

When impregnating such a briquette with a mixture of combustible liquid waste with a molar mass of 313 g/mol, calorific value of 39 MJ/kg and a density of 837 kg/m^3, a total volume of 96 l/day, in the amount of 0.330 kg/briquette increases its calorific value to 25.5 MJ/kg. The dependences of technical and economic indicators of such briquettes on their porosity and humidity are obtained.

Scientific novelty of results of the study. Approaches to development of technology of production and storage of porous fuel briquettes with the improved ingredient structure from solid and liquid combustible waste of the enterprise on production of industrial electronics have received further development.

Practical value of results of the study. The offered approaches to development of technology of production and storage of these porous fuel briquettes are suitable for application at the enterprises with needs of increase of energy autonomy of the main and auxiliary divisions.

References

[1] O.M. Kondratenko, V.Yu. Koloskov, Yu.F. Derkach, S.A. Kovalenko, Physical and mathematical modeling of processes in particulate matter filter in practical application of criteria based assessment of ecological safety level: Monograph, Styl-Izdat, Kharkiv, 2020. ISBN 978-617-7912-64-3.

[2] M.M. Zatserkvlyanny, O.M. Zatserkvlyanny, T.B. Stolevych, Environmental protection processes: textbook, Odesa, Fenix, 2017.

[3] S.O. Apostolyuk, V.S. Djygirey, I.A. Sokolovsky, Industrial ecology: tutorial, 2nd ed., Kyiv, Znannya, 2012.

[4] A.G. Vetoshkin, K.R. Tarantseva, Environmental protection technology (theoretical foundations). Tutorial, Penza, PTI, 2004.

[5] V.M. Gutsulyak, N.V. Maksymenko, T.V. Dudar, Landscape ecology: a textbook for students of higher educational institutions, Kharkiv, KhNU, 2015.

[6] I.V. Semenova, Industrial Ecology: A Study Guide for University Students, Moscow, Akademiya, 2009.

[7] A.G. Vetoshkin, Engineering protection of the atmosphere from harmful emissions. Educational and practical guide, 2nd ed. add. and rework, Moscow, Infra-Inzheneriya, 2016.

[8] S.O. Vambol, V.V. Vambol, V.Yu. Koloskov, Design and construction of environmental safety systems. Methodical instructions for performance of control (modular) works, Kharkiv, NUCDU, 2018.

[9] Ya.A. Zhylinskaya, I.S. Glushankova, M.S. Dyakov, M.V. Byskov, Calculation and design of security systems: a tutorial, Perm, PNIPU, 2012.

[10] L.F. Dolina, Modern equipment and technologies for wastewater treatment from salts of heavy metals: Monograph, Dnepropetrovsk, Kontinent, 2008.

[11] Yu.S. Rybakov, Processes and devices for environmental protection. Lecture notes for students of all forms of education in the specialty 280202 – Environmental Engineering, Yekaterinburg, 2005.

[12] S.O. Vambol, I.V. Mishchenko, V.Yu. Koloskov, O.M. Kondratenko, Ecological safety management systems. Lecture notes, Kharkiv, NUCDU, 2018.

[13] O.M. Kondratenko, S.O. Vambol, O.P. Strokov, A.M. Avramenko, Mathematical model of the efficiency of diesel particulate matter filter, Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu. 6 (2015) 55-61.

[14] S. Vambol, V. Vambol, O. Kondratenko, Y. Suchikova, O. Hurenko, Assessment of improvement of ecological safety of power plants by arranging the system of pollutant neutralization, EasternEuropean Journal of Enterprise Technologies. 3(10-87) (2017) 63-73. DOI: 10.15587/1729-4061.2017.102314.

[15] O. Kondratenko, I. Mishchenko, G. Chernobay, Yu. Derkach and etc., Criteria based assessment of the level of ecological safety of exploitation of electric generating power plant that consumes biofuels, 2018 IEEE 3rd International International Conference on Intelligent Energy and Power Systems (IEPS–2018): Book of Papers (10–14 September 2018, National Technical University «KhPI», Kharkiv, Ukraine) (2018) 185-189. DOI: 10.1109/IEPS.2018. 8559570.

[16] O. Kondratenko, V. Koloskov, S. Kovalenko, Yu. Derkach, O. Strokov (2020) Criteria based assessment of efficiency of conversion of reciprocating ICE of hybrid vehicle on consumption of biofuels, 2020 IEEE KhPI Week on Advanced Technology, KhPI Week 2020 – Conference Proceedings, 2020. Kharkiv, Ukraine, pp. 177–182, DOI: 10.1109/KhPIWeek51551.2020.9250118.

[17] O.M. Kondratenko, Taking into account the emissions of CO_2 as a toxic pollutant and as a greenhouse gas in fuel and ecological complex criteria-based assessment of diesel-generator operation process, Technogenic and Ecological Safety. 6(2/2019) (2019) 12-23. DOI: 10.5281/zenodo. 3558960.

[18] S. Vambol, V. Vambol, V. Sobyna, V. Koloskov, L. Poberezhna, Investigation of the energy efficiency of waste utilization technology, with considering the use of low-temperature separation of the resulting gas mixtures, Energetika, Vol 64. No 4 (2018) 186-195.

[19] M.I. Vasiliev, I.O. Movchan, O.M. Koval, Diminishing of ecological risk via optimization of fire-extinguishing system projects in timber-yards, Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu. 5 (2014) 106-113.

[20] V.V. Tiutiunyk, H.V. Ivanets, I.A. Tolkunov and E.I. Stetsyuk, System approach for readiness assessment units of civil defense to actions at emergency situations, Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu. 1 (2018) 99-105.

[21] Y. Otrosh, A. Kovalov, O. Semkiv, I. Rudeshko, V. Diven, Methodology remaining lifetime determination of the building structures, MATEC Web of Conferences. 230 (2018) 02023.

[22] A.M. Levterov, A.A. Levterov, Thermodynamic properties of fatty acid esters in some biodiesel fuels, Functional Materials. 25(2) (2018) 308-312. DOI: https://doi.org/10.15407/fm25.02. 308.

[23] List and codes of substances that pollute the atmospheric air. Sixth edition, revised. and add., Sankt Petersburg, 2005.

[24] Methodology for determining emissions of pollutants into the atmosphere when burning fuel in boilers with a capacity of less than 20 Gcal per hour, Moscow, State Committee of the Russian Federation for Environmental Protection, 1999.

[25] A.S. Bystrov, V.V. Varankin, M.A. Bilensky, Temporary standard methodology for determining the economic efficiency of environmental protection measures and assessing the economic damage caused to the national economy by environmental pollution, Moscow, Ekonomika, 1986.

[26] Law of Ukraine «On Environmental Protection» of June 25, 1991 № 1264-XII as amended on October 12, 2018, URL: http://zakon.rada.gov.ua/laws/show/1264-12.

[27] State sanitary rules of protection of atmospheric air of settlements (from pollution by chemical and biological substances) (DSP-201-97), approved by the order of the Ministry of Health of Ukraine from 09.07.1997 № 201, URL: https://zakon.rada.gov.ua/rada/show/v0201282-97.

[28] Order of the Ministry of Health of Ukraine «On approval of methodological recommendations «Risk assessment for public health from air pollution» dated 13.04.2007 № 184, URL: http://old.moz.gov.ua/ua/portal/dn_20070413_184.html.

[29] Official site of LLC NGO «Vertical», URL: https://npo-vertical.com.ua.

[30] Ecological passport of the region. Kharkiv region. 2020. URL: https://menr.gov.ua/files/docs/eco_passport/2017/Харківської%20області%20за%2020%20рік.pdf.

[31] Kharkiv Regional Center for Hydrometeorology. Official information server, URL: http://kharkiv.meteo.gov.ua/klimat-kharkova.

[32] A.A. Dobrachev, Yu.V. Yefimov, Harvesting and rational use of fuel wood. Teaching aid for students in the direction 35.03.02 «Technology of logging and wood processing industries». Full-time and part-time forms of study, Yekaterinburg, UGLTU 2019.

[33] V.V. Korobov, N.P. Rushnov, Processing of low-quality raw materials (problems of waste-free technology), Moscow, Ekologiya, 1991.

[34] S.O. Vambol, I.V. Mishchenko, O.M. Kondratenko, Technical mechanics of liquids and gases. Textbook, Kharkiv, NUCDU, 2016.

[35] V.P. Sykhanov, Oil refining. 2nd ed. revised and add., Moacow, Vysshaya shkola, 1979.

[36] P.N. Lavrushko, V.M. Muraviev, Exploitation of oil and gas wells, Moscow, Nedra, 1974.

[37] G.F. Bolshakov, Recovery and quality control of petroleum products, Leningrad, Nedra, 1982.

[38] F.Sh. Khafizov, A.V. Krasnov, Saturated vapor pressure of petroleum products, Electronic scientific journal «Oil and Gas Business», 2012, № 3, pp. 406 – 413.