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EXPERIMENTAL DETERMINATION OF THE COMPRESSION CHARACTERISTICS OF THE MUNICIPAL SOLID WASTE IN THE WASTE DISPOSAL VEHICLE TAKING INTO ACCOUNT THEIR RELATIVE HUMIDITY

Analysis of literature sources, devoted to the problem of the municipal solid waste treatment proved the necessity of their compaction. The paper contains the results of the experimental study of the compaction process of pre-dewatered and packed the municipal solid waste by means of experiment planning by Box-Wilson method. Adequate regression models of the compression characteristics of the municipal solid waste in the waste disposal vehicle, taking into account their relative humidity have been obtained. The validity of the regression models was tested on the basis of Fisher's variance ratio and the significance of the regression coefficients – by Students criterion. The suggested mathematical models can be used in the process of mathematical modeling of the prepacked and dewatered solid waste compaction in waste disposal vehicle and for the development of the technique of the engineering calculations of the machines and mechanisms parameters used for compaction, as the component of scientific engineering fundamentals of the design of highly efficient actuating organs of the machines for the collection and primary processing of the solid waste. Response surfaces of the objective functions – compaction pressure, density and relative humidity of the completely compacted and dewatered solid waste and two-dimensional sections of the waste in the parametric planes of the impact have been constructed, this enables to illustrate the dependence of the objective functions on separate impact parameters.

Key words: *municipal solid waste, waste disposal vehicle, compression characteristic, compaction pressure, relative deformation, density, relative humidity.*

Introduction

Solid municipal waste (SMW) threaten the health of people and safety of the environment [1, 2]. Every year more than 54 mil. m^3 of solid municipal waste are accumulated in populated areas of Ukraine. Unlike solid industrial waste [3, 4], greater part of solid domestic waste is buried on 4530 landfields and disposal sites, their total area is almost 7700 hectares and only partially is recycled or disposed at waste incineration plants, unlike the developed countries, where modern technologies of solid municipal waste disposal and recycling are widely used [5]. To decrease the rate of the landfields area increase, technological operation of solid municipal waste compaction is carrying out in the process of waste loading into the waste disposal vehicle. High compaction coefficient of solid municipal waste promotes efficient usage of the landfield area. Transportation of the solid waste by the waste disposal vehicles to the site of the disposal at minimal distance of 30 km, that corresponds to the dimensions of the sanitary protection zone, in Ukraine is connected with the considerable financial expenditures, as annually more than 45 thousand tons of the fuel is spent. The degree of wear of the waste disposal vehicles pool in Ukraine is approximately 70 % [6].

Problem set-up

Among the priority directions of SMW treatment in Ukraine is to provide the usage of high efficient waste disposal vehicles according to the Decree of the Cabinet of Ministers of Ukraine № 265 [7]. One of the promising directions of the waste disposal vehicles efficiency increase is the increase of the compaction coefficient of the waste. That is why, the construction of the mathematical models of the compression characteristics of the solid municipal waste in the waste disposal vehicles, taking into account their relative humidity is the important scientific-engineering problem as one of the components for the solution of the problem, dealing with the creation of the scientific-engineering fundamentals for the design of highly efficient actuating organs of the machines, intended for the collection and primary processing of the solid municipal waste.

Analysis of the recent studies and publications

In [8] unifactor regressional dependence of the SMW compaction coefficient on the height of the landfield is suggested. In the paper [9] main characteristics of SMW, including the compression characteristic of the waste, without taking into consideration the initial relative humidity, are given. In the research [10] the necessity of solid municipal waste dewatering during the loading into the waste disposal vehicle is determined for the greater part of the considered methods of waste treatment. In the paper [11] the compressibility and shear strength of SMW is studied in the laboratory conditions. Tests for compaction, dry and non-dry triaxial compression were carried out in the reconstructed samples of the waste of large dimensions and with different specific weights of the saturated samples and samples, tested at natural content of the humidity. In the work [12] the dependence between the compaction pressure of SMW and the parameters of the process: relative deformation and piled up density without taking into account the initial relative humidity of solid municipal waste. In the paper [13] the impact of the relative humidity of SMW on the process of the compaction is studied. Optimal content of the humidity during waste compaction – 10...12 % is determined. Higher content of the humidity in the briquette led to the longer duration of the compaction process, lower density of the briquette in the internal layer, lower strength of the briquette , possibility of layering and swelling. The advantages of low humidity content are the following: lack of the adhesion of SMW particles to the walls of the matrix and more homogeneous distribution of the density along the thickness of the briquette. In [14] the dependence of SMW density on the content the humidity, joint effort and season effects in the process of compaction in the laboratory and field conditions, as well as the mechanism of waste compaction is analyzed. The duration of the hydration of SMW 16...24 hours resulted in more uniform compaction curves, than for the wasted compacted without the hydration. In the paper [15] the possibility of SMW disposal at the available municipal thermal plants, of 12 MW generating capacity, which can operate on energy fuel (mixture of SMW, dewatered to 20 % of the relative humidity and coal with weight fraction of 16 %) with the calculated lower combustion value of 10.99 MJ/kg is considered. In the research [16] it is determined that the humidity content and compaction pressure of the fuel ingredients of SMW were two key parameters for obtaining quality fuel briquette which have the calorific value not less than 20 MJ/kg, equivalent to the calorific value of lignite and can be burnt together with coal at electric power plants. The studies were carried out at room temperature without using the bonding agents at the pressure of 69...138 MPa and relative humidity of SMW of 6...20 %, as a result of the studies, carried out, it was determined that the content of the humidity must not exceed 15 % for the obtaining of high quality briquettes, made of the mixture of paper and other inflammable materials in SMW.

Thus, the analysis of literature sources, devoted to the problem of SMW treatment, proved the necessity of their compaction.

Aim and task of the paper

Aim of the paper is to construct, by the results of multifactoral experimental research, mathematical models of the compression characteristics of the solid municipal waste in the waste disposal vehicle, taking into account their relative humidity.

Methods and materials

For the investigation of the compression properties of solid municipal waste the experimental installation in the form of the vertical screw press with the maximum force of 6 tons is used, general view of the installation is shown in Fig. 1a. For the measurement of the relative humidity of SMW

[17] the moisture meter (see Fig. 1b) with the measurement accuracy of ±0,5% is used, it is described in details in the paper [18]. Determination of the density of SMW was performed by weighting, using the digital scales Mirta SKE325O (see Fig. 1c) with the measurement accuracy of ±1 g of the certain volume of the waste.

Compaction pressure of SMW p_w was determined by the formula [19]

$$p_w = F/S \quad (1)$$

where F – is pressing force, H; S – is the area of the pressing plate, m^2.

Relative deformation of SMW ε was determined by the expression

$$\varepsilon = \Delta h/h = Nt/h \quad (2)$$

where Δh – is the absolute deformation of SMW, mm; h – is the height of the bunker with SMW, mm; N – is the number of the press screw turns, q-ty ; t – is the screw pitch, mm.

For the determination of the coefficients of multifactural regression dependences the original computer program "PlanExp" is used, it is protected by the certificate of the state registration of the rights to the copyright object [20] and is described in details in the work [12].

Regression models adequacy was tested on the basis of Fisher's variance ratio and the significance of the regression coefficients was verified by Student's t-test [21, 22].

а) б) в)

Fig. 1. Experimental installation for studying the compression properties of SMW: a) general view, b) moisture meter, c) scales

Previous experiments showed that the dependence of the compacting pressure of SMW p_w on the relative deformation ε, density ρ_1 and relative humidity w_1 of precompacted and dewatered SMW can not be adequately described neither by linear nor quadratic regression model, that is why, the decision was made regarding the determination of the regression model from the impact factors in the exponential form. The validity of the selection of the exponential form of the dependence $p_w = f(\varepsilon)$ is proved by the fact that in the paper [23] the inverse dependence $\varepsilon = f(p_w)$ is logarithmic one. The values the coefficients have been obtained as a result of the preliminary search experiments. Thus, the forms of the mathematical models of the SMW compression characteristics in the waste disposal vehicle are the following:

$$p_w = f(e^{6,094\varepsilon}, e^{-0,07908\rho_1}, e^{1,658w_1}); \quad (3)$$

$$\rho_2, w_2 = f(p_w, \rho_1, w_1), \quad (4)$$

where p_w – is compacting pressure of SMW, MPa; ε – relative deformation of SMW; ρ_1 – is the density of precompacted and dewatered SMW, kg/m^3; w_1 – is the relative humidity of the precompacted and dewatered SMW, %; ρ_2 – is the density of the finally compacted and dewatered SMW, kg/m^3; w_2 – is the relative humidity of the finally compacted and dewatered SMW, %.

The number of the experiments in the centre of the experiment plan was defined according to the recommendations [24, 25].

In the process of the research the value of the relative deformation of SMW changed within the range of ε = 0.05...0.975, maximum compaction pressure of SMW – within the range of p_w = 4.187...26.515 MPa and the ranges of the values of two other factors are stipulated by the results of the experiment on precompaction and dewatering of SMW [17]: ρ_1 = 384.6...665.3 kg/m^3; w_1 = 15.5...42.54 %. The choice of the functions factors variation ranges (3), (4) was accompanied by the verification, its aim is that any their set in the ranges, provided by the plan of the experiment could be realized and would not lead to the discrepancies. The searching experiments were carried out for the determination of the area, where the necessity combinations of the factors levels could be realized.

Results of the experimental studies

Using the experiment planning method by means of the central composite rotatable design of the second order, applying the developed software, protected by the certificate [20] and described in details in the work [12], after dropping by Student's t-test the nonfactors and interaction effects, the following regression dependences will be obtained:

$$p_w = 1,356 + 0,04669e^{6,094\varepsilon} - 1,162 \cdot 10^{13} e^{-0,07908\rho_1} - \\ - 1,267 \cdot 10^{-31} e^{1,658w_1} - 5,198 \cdot 10^{11} e^{6,094\varepsilon} e^{-0,07908\rho_1} \text{ [MPa]}; \quad (5)$$

$$\rho_2 = 1964 p_в + 211,4\rho_1 + 31,65w_1 - 9,276 p_в \rho_1 + 81,15 p_в^2 - 0,06183\rho_1^2 - 67226 \text{ [kg/m}^3\text{]}; \quad (6)$$

$$w_2 = 8,906 p_в - 0,2711\rho_1 + 4,074w_1 - 0,02712 p_в \rho_1 - \\ - 6,93 \cdot 10^{-3} p_в w_1 + 0,1564 p_в^2 + 8,758 \cdot 10^{-4} \rho_1^2 - 53,06 \text{ [\%]}. \quad (7)$$

Verification of the regression models (5) – (7) validity was carried out by means of Fisher's variance ratio.

The obtained regression dependence (5) can be used in the process of mathematical modeling of the compaction of the prepacked and dewatered SMW in the waste disposal vehicle and regression dependences (5) – (7) – can be used for the development of the technique of engineering calculations of the machine and mechanisms parameters, intended for SMW compaction. In particular, regression dependences (6), (7) are needed for the determination of the properties of the completely compacted and dewatered SMW.

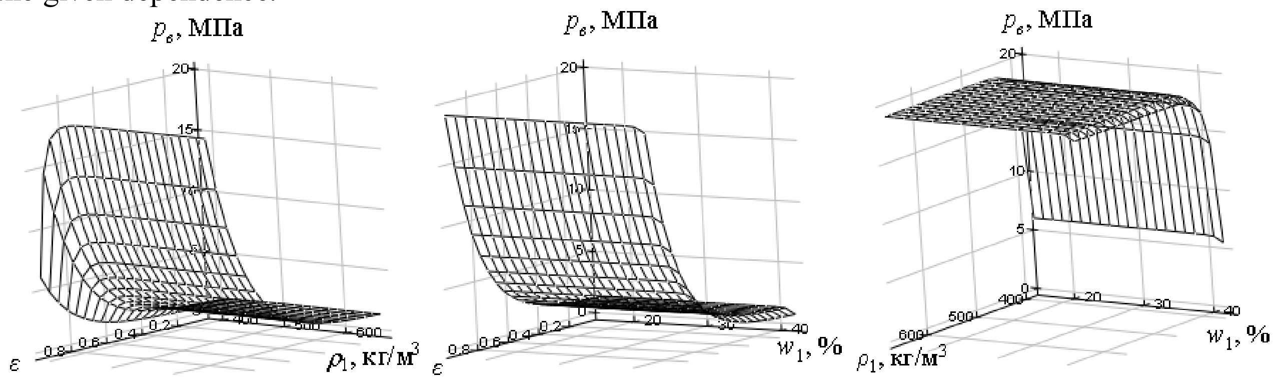
By the Student's t-test it was determined that among the studied factors of impact relative deformation of SMW has the greatest impact on the compaction pressure, and the least impact – relative humidity of prepacked and dewatered SMW.

Fig. 2 shows the response surfaces of the objective function – compaction pressure of SMW p_w

in the planes of the impact parameters, which enable to illustrate this dependence.

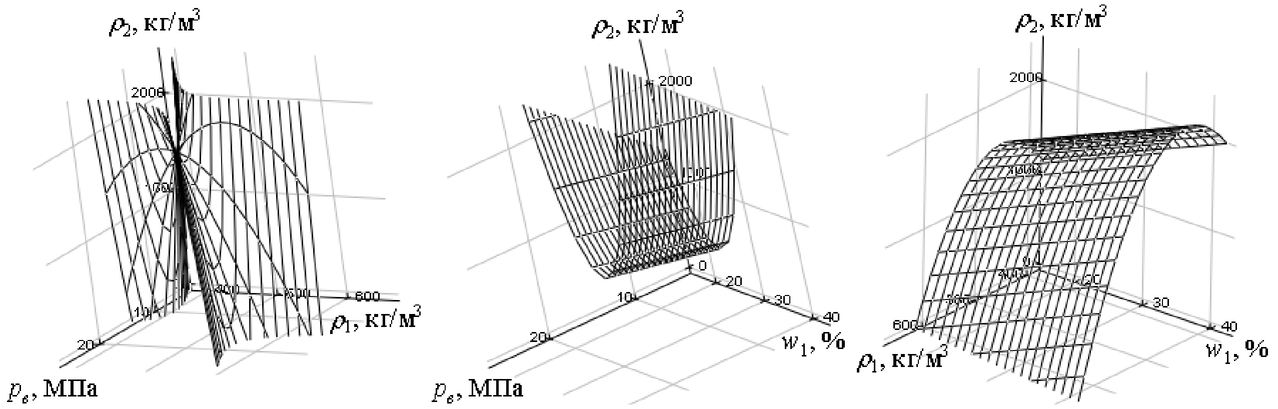
By Student’s t-test it was determined that among the studied factors of impact the density of the prepacked and dewatered SMW exercised the greatest impact on the density of the completely packed and dewatered SMW and the least impact – relative humidity of prepacked and dewatered SMW.

Fig. 3 shows the response surfaces of the objective function – the densities of the completely packed and dewatered SMW ρ_2 in the planes of the impact parameters, which enable to illustrate the given dependence.



a) b) c)

Fig. 2. Response surfaces of the objective function – SMW compaction pressure p_w in the planes of the impact parameters: a) $p_w = f(\varepsilon, \rho_1)$; b) $p_w = f(\rho_1, w_1)$; c) $p_w = f(\varepsilon, w_1)$

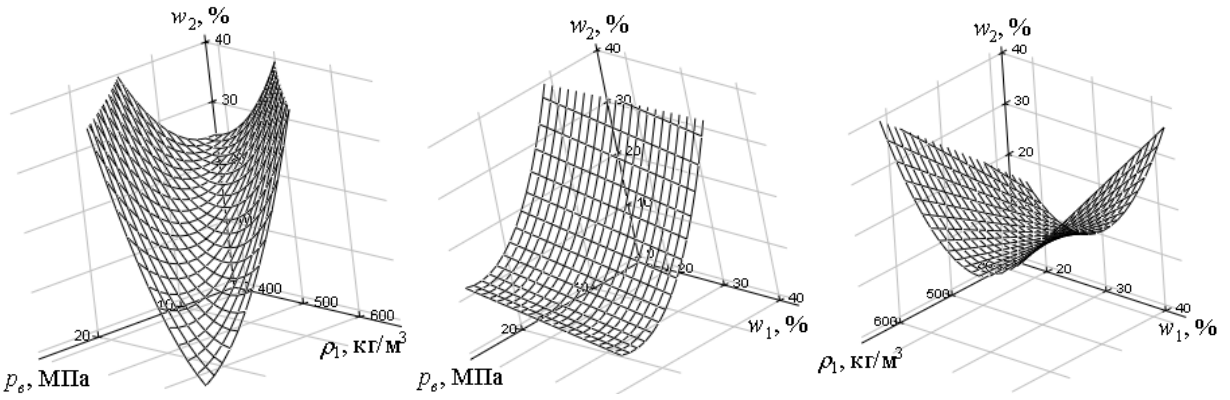


a) b) c)

Fig. 3. Response surfaces of the objective function – the densities of the completely compacted and dewatered SMW ρ_2 in the planes of the impact parameters: a) $\rho_2 = f(p_w, \rho_1)$; b) $\rho_2 = f(p_w, w_1)$; c) $\rho_2 = f(\rho_1, w_1)$

By the Student’s t-test it was determined that among the studied factors of impact the compaction pressure influences most on the relative humidity of the completely compacted and dewatered SMW, and the least action is exercised by the relative humidity of pre-compacted and dewatered SMW.

Fig. 4 shows the response surfaces of the objective function relative humidity of the completely compacted and dewatered SMW w_2 in the planes of the impact parameters, which allow to illustrate visually the given dependences.



a) b) c)

Fig. 4. Response surfaces of the objective function relative humidity of the completely compacted and dewatered SMW w_2 in the planes of the impact parameters: a) $w_2 = f(p_w, \rho_1)$; b) $w_2 = f(p_w, w_1)$; c) $w_2 = f(\rho_1, w_1)$

Conclusions

Analysis of the literature sources, devoted to the problem of the solid municipal waste treatment proved the necessity of the waste compaction. Experimental research of the compaction processes of the prepacked and dewatered solid municipal waste by means of the experiment planning was carried out, the research enabled to determine the valid regression models of the compression characteristics of solid municipal waste in the waste disposal vehicle, taking into account the relative humidity of the waste that can be used in the process of the mathematical modeling of the compaction of the prepacked and dewatered SMW in the waste disposal vehicle as well as development of the scientific-engineering fundamentals of the design of the efficient working organs of the machines, intended for the collection and primary processing of the solid municipal waste. By the Student's t-test it was determined that among the studied factors of impact the relative deformation of SMW has the greatest impact on the compaction pressure, and the least impact – relative humidity of prepacked and dewatered SMW; the density of the prepacked and dewatered SMW exercised the greatest impact on the density of the completely packed and dewatered SMW and the least impact – relative humidity of prepacked and dewatered SMW; the compaction pressure influences most on the relative humidity of the completely compacted and dewatered SMW, and the least action is exercised by the relative humidity of pre-compacted and dewatered SMW.

The response surfaces of the objective functions – compaction pressure, density, relative humidity of the completely packed and dewatered solid municipal waste and their 2D sections in the planes of the impact parameters which allow to illustrate visually the dependence of the given objective functions on separate impact parameters have been constructed.

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