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DYNAMICS OF THE EXTRACTION OCCURRENCE OF THE SORTED OUT RESOURCE-VALUED COMPONENTS OF SOLID MUNICIPAL WASTE (SMW) IN VINNYTSIA REGION

During the period of 2013 – 2018 the rate of recycling and reutilization of solid municipal waste in Ukraine increased almost 1.5 times. One of the articles of Ukraine-European Union Association Agreement stipulates the importance of studying the system of solid municipal waste management. That is why, the determination of the regressional dependence describing the dynamics of the extraction occurrence of the sorted out resource- valued components of solid municipal waste in Vinnytsia Region for the solution of the problem of solid municipal waste management is an important scientific-engineering problem.

Aim of the study is the determination by means of the regression analysis the dependence, describing the dynamics of the of the extraction occurrence of the sorted out resource-valued components of solid municipal waste in Vinnytsia Region for the solution of the problem of solid municipal waste management. In the process of the research method of the regression analysis of the results of single factor experiments and other paired dependences with the selection of the most adequate kind of function from 16 most widely spread variants by the criterion of maximum correlation factor was used. Regression was carried out on the base of the linearized transformations, which allow to reduce the non-linear dependence to linear dependence. Determination of the coefficients of regression equation was performed of means of the least squares method, using the developed computer program "RegAnaliz", which is protected by the Certificate of the state Rregistration of the rights to the copyright object.

Adequate regressional dependence, describing the dynamics of the extraction occurrence of the sorted out resource- valued components of solid municipal waste in Vinnytsia Region is obtained. Graphic dependence, describing the dynamics of the extraction occurrence of the sorted out resource- valued components of solid municipal waste in Vinnytsia Region is constructed, this dependence enables to illustrate the dynamics, show sufficient coincidence of the theoretical and actual results. It is established that in the period of 2014 – 2020 the rate of extraction occurrence of the sorted out resource- valued components of solid municipal waste in Vinnytsia Region increased exponentially. It is expected that the extraction occurrence of the sorted out resource- valued components of solid municipal waste in Vinnytsia Region at the existing rate of growth may reach the level of 70 % in 2027.

Key words: *dynamics, statistical data, occurrence, sorting, resource-valued components, solid municipal waste, regression analysis.*

Introduction

Unlike solid industrial waste, subject to recycling [1 – 5], solid municipal waste (SMW) in Ukraine, are mainly buried at the landfills and dumpsites, polluting the environment and only minor part of the waste is recycled and reused [6]. During the period of 2013 – 2018 the occurrence of recycling and reusage of solid municipal waste in Ukraine increased almost 1.5 times. Growth of the occurrence of recycling and reusage is achieved by means of SMW sorting [7], it enabled to extract certain components: scrap paper, glass, ferrous and non-ferrous metals, polymer materials. Technological process of SMW sorting comprises of a sequence of technological operations, performed by the basic and auxiliary technological equipment, according to the stages of the sorting process, this allows to achieve the separation of the total mass of SMW into the components to be recycled and a residue, that can not be recycled. Sorting technology can be introduced as the preprocessing of the raw material prior the application of one of the methods of SMW decontamination. It enables to reduce greatly the negative impact on the environment and obtain profit from the realization of the secondary raw material [8]. For sorting and preparation for further recycling, decontamination and disposal of non-

toxic SMW, collected by indiscriminative mode, material recovery facilities (MRF) are designed [9]. Process of SMW sorting occurs in the following way [10]: SMW from the dust-carts is charged into the bunker, further the conveyor delivers it to the cylindrical trommel, where the small fraction and organics is sorted out. Then SMW is directed to the facility for manual or mechanical sorting. Sorted out waste are pressed to reduce the volume and baled. Solid municipal waste is sorted into the following fractions: metal, glass, plastic, polyethylene, paper. Sorted out waste is sent for the recycling and the unrecyclable residue is buried at the landfill of SMW.

Problem set up

According to the Resolution of the Cabinet of Ministers of Ukraine № 265 organization of the separate waste collection of some components, application of modern high-efficient dust-carts, construction of modern landfills, equipped with the facilities for disinfection of the filtrate and biogas utilization, etc., are among the priority directions of SMW management in Ukraine [11]. In the Law of Ukraine of February 28, 2019 № 2697-VIII "On main fundamentals (strategy) of the state ecological policy of Ukraine for the period until 2030" among the strategic tasks the return into economic turnover materials, containing valuable components is indicated, also it is planned for the period until 2030 to reduce the share of the buried waste to 35 % of the total volume of the formed waste [12]. Thus, the determination of the regressional dependence, describing the dynamics of the extraction occurrence of the sorted out resource-valued components of solid municipal waste in Vinnytsia Region for the solution the problem of solid municipal waste management is an important scientific-engineering problem.

Analysis of the resent studies and publications

Block-diagram of the improved device for SMW sorting, enabling not only to sort out the elastic components from non-elastic components but also elastic components fraction-wise in multi-sectional container, is patented in [13]. Paper [14] contains analytical dependences of the basic kinematic and geometric parameters of the device for sorting out the elastic components of SMW in multi-sectional container; rational values of basic kinematic and geometric parameters of the device for sorting out the elastic components of SMW, using multi-sectional container are obtained. In the works [15, 16] the parameters, influencing the percent portions of SMW, collected differentially in different countries are determined; by means of planning multifactor experiment of the second order mathematical model for the forecasting of the percent portions of differentially collected SMW is constructed. Improved forecasting model of the occurrence of differentiated SMW collection in different countries, that may be applicable to on wider circle of the countries, including Ukraine, is presented in the paper [17]. In the study [18] regressional dependence, describing the dynamics of the involvement of the settlements of Vinnytsia Region in separate waste collection is determined, it enables to forecast the number of settlements, involved in separate waste collection.

In paper [9] in the process of studying the operation of material recovery facility the efficiency of the extraction of secondary raw material, conditions of its profitable operation, composition of SMW, entering the landfill after sorting was assessed. As a result of sorting the volume of SMW, entering the landfill, greatly decreased. Due to this fact the term of the landfill operation can be increased, this will lead to the efficient usage of land resource. As a result of the change of SMW composition (main component became organic waste) loading on the environment greatly reduced. Consequently, the pollution of soils, waters, water-bearing horizons and atmospheric air with harmful for human health and environment particles decreases.

Various tools for sorting out SMW are described in the paper [19]. Article [20] describes the application of image processing in the process of the development of the automated mechanical system of mixed SMW sorting out. First priority stage of the recycling is the separation of plastic and paper waste. Intelligent system is developed by means of computer-optical recognition of the

parts with the specific features on the material recovery facility (conveyor line). System operates without human interference and the efficiency of the correct classification is at least 80%. During the experiment paper and plastic objects of different shape and size were used. The suggested algorithm was experimentally tested by means of the manufactured prototype of paper-plastic system.

Papers [21, 22] contain statistical data regarding the extraction occurrence of the sorted out resource- valued components of solid municipal waste in Vinnytsia Region in the period of 2014 – 2020. However, the authors, after the analysis of the known publications, did not reveal specific mathematical dependences, describing the dynamics of the extraction occurrence of the sorted out resource- valued components of solid municipal waste in Vinnytsia Region.

Aim and tasks of the paper

Aim of the given study is the construction, by means of regression analysis, the regressional dependence, describing the dynamics of the extraction occurrence of the sorted out resource- valued components of solid municipal waste in Vinnytsia Region for the solution of the problem of SMW management.

Methods and materials

For the determination of the regression dependence, describing the dynamics of the extraction occurrence of the sorted out resource- valued components of solid municipal waste in Vinnytsia Region the following methods are used: regression analysis of the single-factor experiments and other pair dependences, computer modeling.

Results of the research

Table 1 shows the dynamics of the extraction occurrence of the sorted out resource-valued components of solid municipal waste in Vinnytsia Region. On the base of the data of Table 1 it was planned to obtain pair regressional dependence, describing the dynamics of growth of the number of material recovery facilities in Ukraine. As the argument of the regressional dependence is a year, the order of its values exceeds by three orders the order of the width of its changes range, then to increase the accuracy of the regressional dependence it is recommended to take the year, which precedes the start of the studied range as the start of the coordinates ($x = t - 2013$).

Table 1

Extraction occurrence of the sorted out resource- valued components of solid municipal waste (SMW) in Vinnytsia Region in different years [21, 22]

Year	2014	2015	2016	2017	2018	2020
Mass of collected and transported SMW, t	201656	259975	277269	234783	239079	271786
Mass of the extracted sorted out resource-valued components of SMW, t	192	197	264	278	935	6071
Extraction occurrence of the sorted out resource-valued components of SMW, %	0.0952	0.0758	0.0952	0.1184	0.3911	2.2338

Regression was performed on the base of the linearized transformations, which enable to reduce the non-linear dependence to linear one. Determination of the coefficients of the regression equations was carried out, applying the method of the least squares by means of the developed computer program "RegAnaliz" [23], protected by the Certificate of the state registration of the rights to the copyright object and is described in details in the works [24, 25].

Program "RegAnaliz" enables to carry out the regression analysis of the results of single-factor experiments and other pair dependences with the selection of the rational type of function from 16 most widely spread variants by the criterion of maximum correlation coefficient, saving the results

in the format MS Excel and Bitmap.

Results of the regressive analysis are shown in Table 2, where the cell with maximum value of correlation coefficient *R* is marked by grey color.

Table 2

Results the regression analysis of the dynamics of the extraction occurrence of the sorted out resource- valued components of solid municipal waste (SMW) in Vinnytsia Region

№	Type of regression	Correlation factor R	№	Type of regression	Correlation factor R
1	$y = a + bx$	0.81718	9	$y = ax^b$	0.75365
2	$y = 1 / (a + bx)$	0.91094	10	$y = a + b \cdot \lg x$	0.64292
3	$y = a + b / x$	0.46008	11	$y = a + b \cdot \ln x$	0.64292
4	$y = x / (a + bx)$	0.39967	12	$y = a / (b + x)$	0.91094
5	$y = ab^x$	0.90801	13	$y = ax / (b + x)$	0.60792
6	$y = ae^{bx}$	0.90801	14	$y = ae^{b / x}$	0.56262
7	$y = a \cdot 10^{bx}$	0.90801	15	$y = a \cdot 10^{b / x}$	0.56262
8	$y = 1 / (a + be^{-x})$	0.54594	16	$y = a + bx^n$	0.99855

Thus, according to the results of the regression analysis on the base of the data of the Table 1, the following regression dependence is finally accepted as the most adequate

$$S_{esrve.smw} = 0,04326 + 1,295 \cdot 10^{-4} (t - 2013)^5 \text{ [\%]}, \quad (1)$$

where *Sesrve.smw* – is the extraction occurrence of the sorted out resource-valued components of SMW in Vinnytsia Region, %; *t* – year.

Fig. 1 shows actual and theoretical graphic dependence, which describes the dynamics of the extraction occurrence of the sorted out resource-valued components of SMW in Vinnytsia Region.

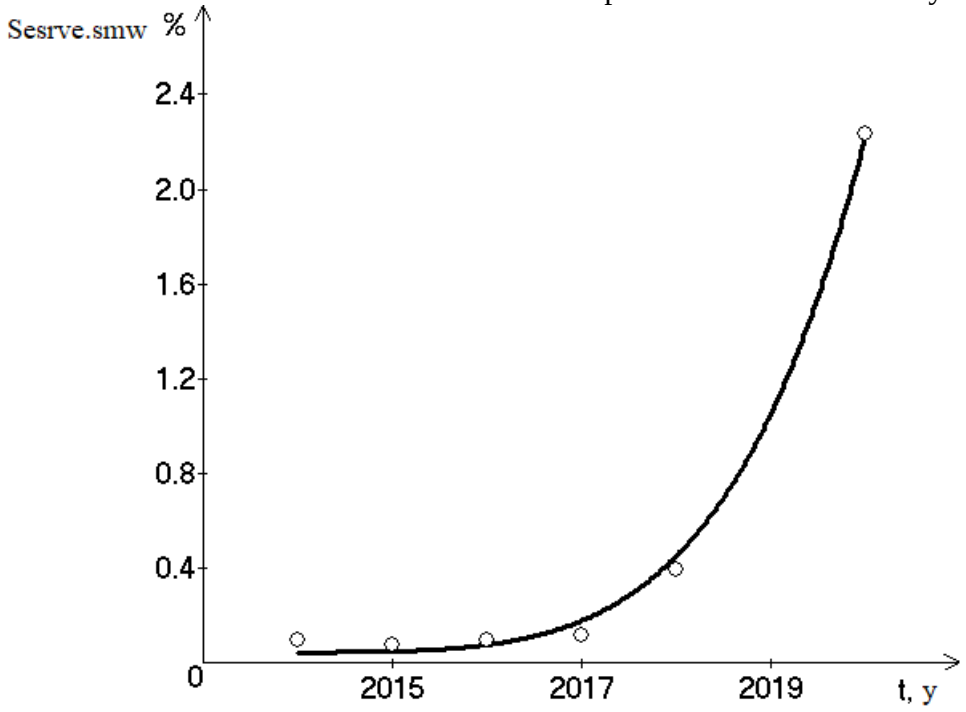

Fig. 1. Dependence, which describes the dynamics of the extraction occurrence of the sorted out resource-valued components of SMW in Vinnytsia Region in the period of 2014 - 2020: actual ○, theoretical —

Comparison of actual and theoretical data showed that theoretical dynamics of the extraction occurrence of the sorted out resource-valued components of SMW in Vinnytsia Region, calculated

by means of the regression equation (1), does not differ greatly from the data, presented in works [21, 22], this proves the accuracy of the obtained dependence.

Using the dependence (1) it can be forecast that the extraction occurrence of the sorted out resource-valued components of SMW in Vinnytsia Region in 2027 will grow up to 70% at the existing rate of growth.

Conclusions

1. Regression dependence, describing the dynamics of the extraction occurrence of the sorted out resource-valued components of SMW in Vinnytsia Region is determined, this dependence enables to forecast the dynamics that is necessary for the solution of the problem of solid municipal waste management.
2. Graphic dependence, describing the dynamics of the extraction occurrence of the sorted out resource-valued components of SMW in Vinnytsia Region is constructed, it allows to illustrate the given dynamics and show the sufficient coincidence of theoretical with actual results.
3. It is established that in Ukraine during the period of 2014 – 2020 the extraction occurrence of the sorted out resource-valued components of SMW in Vinnytsia Region increased in accordance with the exponential law.
4. It is forecast, that the extraction occurrence of the sorted out resource-valued components of SMW in Vinnytsia Region at the existing rate of growth may reach the level of 70 % in 2027.

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