

Model and Method of Solid Household Waste Sorting for Their Effective Thermal Disposal

Hanna Lysiuk^{a,*}, Oksana Maksymova^b

^a*Odesa Polytechnic National University, 1 T. Shevchenko Avenue, Odesa, 65044, Ukraine*

^b*National University "Odesa Maritime Academy", 8 Didrichsona St., Odesa, 65052, Ukraine*

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Abstract

The work considers the development of a simulation model and an automated method of sorting solid household waste based on the identification of a portion of the studied raw material with further classification according to accepted groups of characteristic chemical composition. A method of classification of municipal solid waste (MSW) and a method of their identification was proposed, which made it possible to identify groups that produce acid gases. The basis of the method is a simulation model, which is represented by a tabular form of the gross formulas of possible compounds. The identified compounds are identified both qualitatively by the isoenthalpic method and quantitatively by the express gravimetric method. The sequential chain of identification makes it possible to search for substances that form acid gases during further processing by thermal destruction methods. A method of sorting solid household waste has been developed for the possibility of further processing of each group with maximum efficiency and compliance with ecological indicators. The method is based on: technological method of sorting; the method of sorting raw materials-processing in which measuring devices are integrated to ensure the specified characteristics of identification according to the classification features of the simulation model; the principle of using measuring devices depending on the type of identification task by qualitative or quantitative indicator.

Keywords: municipal solid waste; thermal utilization; sorting; gross formula; identification.

1. Introduction

The development trend of modern civilization is the rational use of natural resources and environmental protection. But at the same time, the consumption capacity of the population, which is characterized by a high quality of life, is also growing, which is one of the main factors in the accumulation of municipal solid waste (MSW). "The future of humanity, as part of a single system of the biosphere, depends on when it understands its connection with Nature and takes responsibility not only for the development of society, but the biosphere as a whole", this expression in the modern world is accepted as an axiom, which was first formulated by Academician Vernadskyi at the beginning of the 20th century.

A feature of current waste from high-tech industries is their low rate of biochemical decomposition. For example, the time interval for complete decomposition of most plastics and composite carbon plastics is hundreds of years, the only natural process that allows accelerating this term is solar insolation [1].

There is not a single developed country in the world where the problem of solid waste accumulation and processing has been completely solved. The goal of economically developed industrialized countries is environmental

* Corresponding author. Email address: lysiukann@gmail.com

friendliness in the management of household waste during their processing and elimination of them as pollutants of the ecosystem, due to their transformation into a source of endless secondary raw materials.

When choosing a system for the secondary use of solid waste, first of all, effective technologies of systems of collection and sorting, transportation and processing of waste are determined, which in turn depend on the chemical composition of materials and their physical properties. Currently, in most cases, the most applicable methods of waste processing include: natural decomposition in the surrounding natural environment; burial at solid waste landfills; sorting and recycling [1].

The analysis of many ways of recycling MSW allowed us to come to the disappointing conclusion that of all the technologies used, thermal destruction shows the highest consumer properties according to the criterion of efficiency. The main advantages of this technology are: effective disposal of waste, including complete destruction of pathogenic microflora; reducing the volume of waste by one order of magnitude; use of the energy potential of waste of organic origin [3].

In addition, thermal destruction meets the requirements of business technologies, namely: the production of the maximum amount of a valuable end product and ensuring the minimum amount of emissions into the natural environment of harmful substances. In the practice of thermal destruction, four methods of thermochemical transformation of MSW have become the most widespread: incineration, gasification, pyrolysis, and thermal modification. Pyrolysis, in turn, is divided into slow and fast [2].

Each technology has its own purpose [7]. When burning raw materials, the possibility of maximum heat release is determined by excluding under-burning of raw materials or supplying excess air. The goal of gasification is to minimize energy costs for the process of converting raw materials, provided that a mixture of combustible gases with the highest possible calorific value is obtained. In order to organize the process of pyrolysis of raw materials, it is necessary to supply energy in the form of heat and the absence of air or oxidizing gases. As a product of the pyrolysis process, a carbonaceous residue, condensed substances and non-condensed gases appear. It should be noted that any technology of thermal destruction in order to ensure the given environmental and technical performance indicators requires the stability and certainty of the composition of the processed raw materials [7].

Analysis of the composition of industrial volumes of solid waste is a random set of homogeneous and heterogeneous substances with known properties. This state of affairs makes it practically impossible to directly use MSW as a raw material for any thermal destruction technology without additional consideration of two aspects.

First of all, for the use of industrial volumes of solid waste as raw material for thermal destruction technologies, it is necessary to consider methods of crushed sorting of waste with simultaneous identification according to accepted classification features. Secondly, it is necessary to adopt the criteria on the basis of which, based on the results of the sorting, an appropriate method of thermal destruction of solid waste and a corresponding method of automatic control of such a process should be applied [7]. It follows from the above that consideration of the issues of sorting, identification and processing of solid waste is a relevant direction in modern research.

2. Analysis of literary data and formulation of the problem

For the possibility of using MSW as a raw material in thermal destruction technologies, their composition was analyzed. It should be noted that various studies conducted over the past five years have shown significantly different results.

Research results [2] revealed that the morphological composition of MSW for Ukraine in 2018 was: food waste – 54.2%, paper and cardboard – 16.3%, wood – 3.5%, metals – 4.2%, textiles – 6.7%, glass – 4.3%, plastic – 6.3%. The morphological composition of solid waste of alternative studies is shown in Table 1.

The given research results clearly allow us to conclude that the composition with a high degree of probability has a random nature of distribution, and even more so, the number of morphological groups is also random. It should be noted the study [2] where the principle of classification of MSW into four groups is proposed based on the conditional formula of the substance or the gross formula.

For simulation modeling of various morphological groups of MSW, models based on the known mass or volume fractions of constituent organic compounds, as well as their chemical formulas, were considered as a conditional formula. Despite the diversity of organic substances and compounds, they can be described using a single model.

Table 1. Morphological composition of MSW according to data [2].

Composition by mass, %													
Food waste and organic matter	Paper and cardboard	Packaging	PET container	Black metals	Non-ferrous metals	Textile	Glass	Wood	Leather, rubber	Min. remainder	Plastic	Polymer film	Hazardous solid waste
53.68	14	0.96	2.09	0.94	0.17	2	13	1	1	4.31	3	2.09	0.02

The number of atoms (C, H, O, N) in an organic compound, which is characteristic of certain types of solid waste, became a classification feature. The first group includes waste that can conditionally be classified as hydrocarbon waste. The basis of such solid waste is primarily polyethylene film, polypropylene and polyester elements of artificial structures. The second group includes hydrocarbon and oxygen-containing waste. The basis of such solid waste is primarily paper, cardboard, wood, PET containers, artificial textiles (cellulose triacetate and viscose). The third group included hydrocarbon waste containing oxygen and nitrogen. The basis of such solid waste is primarily protein waste, nylon, wool, leather. Hydrocarbon wastes containing active elements (F, Cl, S) were assigned to the fourth group. The basis of such MSW consists primarily of polyvinyl chloride and vinyl defluoride structural elements, rubber.

In work [2], the results of various morphological classifications were summarized and, based on the proposed simulation model, a classification by characteristic chemical composition was obtained, the results of which are presented in Table 2.

Table 2. Morphological composition of MSW according to its characteristic chemical composition.

The composition of solid waste by mass of the conventional formula, %			
$CH_w O_q N_k$	$CH_n O_f$	$CH_a F_x; CH_b Cl_y; SN_d Sz;$	CH_m
54	16	22	8

From the point of view of industrial technology, it is necessary to separate a discrete amount of solid waste, which is classified according to criteria according to chemical composition, see table 2. The process of organizing a discrete volume of MSW is based on the fact that the chemical composition is identified in any constant minimum volume. The quantitative composition of the analyzed volume of solid waste is determined by the intensity of the signal received from the meter, the change of which is recorded instrumentally. Quantitative analysis can be carried out by physical or chemical methods.

In physical methods of analysis, the information signal is obtained using special measuring equipment. Physical methods of analysis include atomic emission spectroscopy, infrared spectroscopy, and nuclear magnetic resonance. These laboratory methods are devoid of the disadvantages inherent in chemical methods, but require expensive equipment and cannot be used for real time in industrial conditions.

In chemical methods of solid waste analysis, an information signal is obtained as a result of a chemical reaction study. Weight and volumetric methods of analysis belong to chemical methods. The main disadvantages of the chemical method of solid waste analysis are: the need to separate the component that is determined from others, and from components that have similar properties and a large sample volume when determining small amounts of impurities. Chemical methods are characterized by high selectivity, ease of implementation, reliability, but great difficulties during the analysis in time when automating the process [2].

For industrial productions producing plastics, polymers, organic-element compounds, pharmaceuticals, pesticides, industrial products of heavy organic synthesis, processing oil, natural gas, coking coal, a reliable industrial method of analysis of raw materials, semi-finished products and finished products is used by production - the "express gravimetry" method. Diverse in their individual properties, MSW in the form of organic compounds pose a task for their identification, which boils down to complete decomposition and conversion of the specified elements into a single form; registration of the information signal and processing of the analysis results.

The method of determining the mass fraction of carbon, hydrogen and nitrogen in organic compounds on automatic analyzers by the "express gravimetry" method can be used to identify MSW. This method makes it possible

to determine C, N and H, to analyze volatile compounds, unstable or combustible substances, determining three to five elements in them at the same time. The basis of the method is the pyrolytic combustion of the substance in an empty tube, within the quartz container, which is washed by a stream of inert gas.

Numerous variants of simultaneous determination of several elements in one sample have been developed on the basis of express gravimetry. The simultaneous determination of carbon, hydrogen and one or more elements is a reliable method of elemental analysis only if the carbon and hydrogen content found corresponds to the required gross formula of the compound. However, in many cases, the knowledge of the mass of the residue after burning and in the case of discrepancy between the data found and the expected gives essential information that helps to determine the true gross formula of the obtained substance.

A very similar method was proposed in [6], [8], only in real time and based on the isenthalpy of the pyrolysis process to determine the elemental composition, which is integrated into the automated control system in real time. The calculation of the composition of combustion products is based on the conventional fuel formula, which includes fuel and oxidizer. The composition of the mixture of gases is determined from the quantitative ratio of substances formed as a result of combustion. The mathematical model of the analyzed method is determined by the equations of chemical equilibrium for each of these substances, the law of acting masses, the law of conservation of energy, and Dalton's law. Relative errors of calculations correspond to reference data [4] <10%, which corresponds to the permissible accuracy of engineering calculations.

The mathematical model for identifying the conditional formula was further developed in work [7] and served as the basis of a single model for identifying the composition of hydrocarbon compounds in different aggregate states as a single model for identifying the composition of combustion, gasification, and pyrolysis products.

The property of the identity of the gross formulas of the starting substance and reaction products can be the basis of the method of determining the composition of hydrocarbon substances in the sorting of solid waste based on the thermochemical processing of the portion of the raw material under investigation.

3. The purpose and objectives of the research

The purpose of this article is to develop a simulation model and an automated method of sorting household solid waste based on the identification of a portion of the studied raw material with further classification according to accepted groups of characteristic chemical composition, which are determined by the gross formula for their further processing by effective methods of thermal destruction in compliance with environmental indicators.

To achieve the given goal, the following tasks must be solved:

- 1) To consider the method of classification of solid household waste and the method of their identification, which allows singling out groups that produce acid gases, and on this basis adopting a simulation model of solid household waste, which will allow for the identification by thermochemical method.
- 2) Develop a method of sorting solid household waste for the possibility of further processing of each group with maximum efficiency and compliance with ecological indicators, depending on the given characteristics of identification of each component.

4. Models and methods of determining the composition of solid waste

In [6], the described method of calculating the composition of combustion products with a known composition of the hydrocarbon substance is summarized. The list of substances representing this type is wide, but still limited. Taking into account additional oxygen and nitrogen in their composition significantly expands the number of substances, changes the combustion process and the calculated composition of combustion products. In addition, there are combustible mixtures of gases, the composition of which can include oxygen in the form of an active chemical element. The model and method of determining the composition of the combustible substance are given [12].

Despite such a variety of combustible substances, the process of formation of combustion products and determination of their temperature can be described using a model in the form of a gross formula.. Let's define the model of the combustion process on the example of artificial textile (nylon-66), the conditional formula of which is $(\text{CH}_{1.8332}\text{O}_{0.166}\text{N}_{0.166})_n$, which includes atoms [C], [H], [N], [O] in its composition. It is a typical representative of solid waste of a wide class of organic waste, the composition of which can be presented in the form of compounds of the following combinations of elements: the first – [C], [H]; second – [C], [H], [O]; the third– [C], [H], [N], [O].

Detection and separation of such compounds will allow to obtain a residue, the constituent elements of which are the characteristic active elements [F], [Cl] and [S] found in solid waste.

Thus, additional consideration of active elements [F], [Cl] and [S] found in MSW allows simulating almost all organic compounds that can be decomposed isoenthalpically or burned with a lack or excess of atmospheric air. Based on the conditions of building the model, there is no need to take into account the structure of this substance. In this case, the conditional fuel formula looks like this:

$$C_{b_C}H_{b_H}N_{b_N}O_{b_O}, \tag{1}$$

where b_C, b_H, b_N, b_O is the number of corresponding atoms in the conditional formula of solid waste.

Consider air as an oxidizer. Combustion reactions are not necessarily carried out in a stoichiometric ratio. This is taken into account by introducing the oxidant excess factor α , and all reaction ratios are constructed using the molar ratio of the components

$$\chi^W = \alpha \cdot \chi_0^W. \tag{2}$$

It is the non-stoichiometric combustion of MSW that allows changing the concentrations of the gases produced and thereby ensuring data redundancy when measuring for the analysis of the current substance [9]. In general, for any MSW burning in air, the conventional formula for MSW will look like this

$$C_{b_C}H_{b_H}N_{(b_N+\alpha \cdot \chi_0^W \cdot 1.518)}O_{(b_O+\alpha \cdot \chi_0^W \cdot 0.419)}. \tag{3}$$

List of substances and ions that can be formed in the process of solid waste burning:

$$[CO], [CO_2], [H_2], [O_2], [H_2O], [OH], [N_2], [NO], [C], [H], [O], [N]. \tag{4}$$

Determining the composition of combustion products consists in finding the quantitative ratio of gases from this list. The number of unknowns in the model is determined by the list of substances.

When the coefficient of excess oxidant α is varied, the amount and composition of substances that are formed will change. The composition of combustion products may include other more complex substances, but at any value α their amount will be significantly small. Therefore, they are not taken into account in the calculations. Thus, (4) gives a list of substances covering practically important cases.

Consider the equation of chemical equilibrium for substances from the list (4). Their list is given in Table 3.

Table 3. Basic equations of chemical equilibrium of dependent substances.

1	$CO \leftrightarrow C+O$
2	$CO_2 \leftrightarrow C+2O$
3	$H_2O \leftrightarrow 2H+O$
4	$OH \leftrightarrow H+O$
5	$H_2 \leftrightarrow 2H$
6	$O_2 \leftrightarrow 2O$
7	$N_2 \leftrightarrow 2N$
8	$NO \leftrightarrow N+O$

For the equations given in the table, it is possible to write down the law of active masses, which is the ratio of partial pressures [8]. When using the partial pressures of substances, another variable was additionally introduced M_T – the number of considered moles of fuel. Thus, the model includes a total of 13 unknown quantities: 12 partial pressures of gases (4) in the combustion products and the number of moles of the M_T amount of fuel under consideration.

The first eight equations of the model will be represented by the partial pressures of the combustion products due to the law of active masses for reactions from Table 3:

$$\frac{P_C \cdot P_O}{P_{CO}} = K_{CO}(T); \quad (5)$$

$$\frac{P_C \cdot P_O^2}{P_{CO_2}} = K_{CO_2}(T); \quad (6)$$

$$\frac{P_H^2 \cdot P_O}{P_{H_2O}} = K_{H_2O}(T); \quad (7)$$

$$\frac{P_H \cdot P_O}{P_{OH}} = K_{OH}(T); \quad (8)$$

$$\frac{P_H^2 \cdot P_O}{P_{H_2}} = K_{H_2}(T); \quad (9)$$

$$\frac{P_O^2 \cdot P_O}{P_{O_2}} = K_{O_2}(T); \quad (10)$$

$$\frac{P_N^2 \cdot P_O}{P_{N_2}} = K_{N_2}(T); \quad (11)$$

$$\frac{P_N \cdot P_O}{P_{NO}} = K_{NO}(T). \quad (12)$$

The constants of chemical equilibrium are presented in tabular form in the relevant reference books and in the calculations for the corresponding temperature can be selected or calculated using approximation polynomials. In addition, they can be calculated on the basis of enthalpies and entropies of formation of substances included in the reactions under consideration, and which, in turn, are also presented in tabular form, or can be calculated on the basis of approximation polynomials [4].

The following four equations were compiled on the basis of the law of conservation of matter in the form of the equality of the number of atoms of the corresponding chemical element in fuel and combustion products. The number of atoms in the fuel is calculated on the basis of expression (3) taking into account the number of its molecules considered M_T :

$$\text{for [C]} \quad b_C \cdot M_T = P_{CO} + P_{CO_2} + P_C; \quad (13)$$

$$\text{for [H]} \quad b_H \cdot M_T = 2 \cdot P_{H_2O} + P_{OH} + 2 \cdot P_{H_2} + P_H; \quad (14)$$

$$\text{for [O]} \quad (b_O + \alpha \cdot \chi_0^W \cdot 0.419) \cdot M_T = P_{CO} + 2 \cdot P_{CO_2} + P_{H_2O} + P_{OH} + 2 \cdot P_{O_2} + P_{NO} + P_O; \quad (15)$$

$$\text{for [N]} \quad (b_N + \alpha \cdot \chi_0^W \cdot 1.581) \cdot M_T = 2 \cdot P_{N_2} + P_{NO} + P_N. \quad (16)$$

To close the system, we will use Dalton's law as the basis of the last equation, which expresses the equality of the sum of the partial pressures of the combustion products of the pressure in the furnace of a steam boiler P_Σ :

$$P_\Sigma = P_{CO} + P_{CO_2} + P_{H_2O} + P_{OH} + P_{H_2} + P_{O_2} + P_{N_2} + P_{NO} + P_C + P_H + P_O + P_N. \quad (17)$$

The recorded model is a system of nonlinear algebraic equations. To solve it, Newton's method was used, which consists in linearizing the equations of the system and solving them with respect to corrections of unknown quantities. A feature of the system obtained in the process of linearization is its poor conditioning. This is caused by the very small value of some terms (partial pressures) and the large difference in values between them, which can reach 10...15 orders of magnitude. This leads to instability and a large decision error.

To increase accuracy, the original system of equations (5) – (17) was logarithmized. This led to the fact that the members of the system modified in this way will remain nonlinear, but will differ from each other by no more than 10...15 times. But this approach does not completely solve the problem of a large difference between the members of the equations of the system subjected to linearization. In the case of linearization, which is carried out in the usual way, using as arguments the required values (partial pressures of combustion products), for which corrections will be determined. Therefore, they can differ from each other by the same 10...15 orders of magnitude. To avoid this, logarithms of the sought arguments (partial pressures and magnitudes) were M_T used as arguments during differentiation [6], [13]. To explain the transformations, consider equation (6). After logarithmization, we have:

$$\ln(P_C) + 2 \cdot \ln(P_O) - \ln(P_{CO_2}) = \ln(K_{CO_2}(T)). \quad (18)$$

After linearization:

$$1 \cdot \Delta[\ln(P_C)] + 2 \cdot \Delta[\ln(P_O)] - 1 \cdot \Delta[\ln(P_{CO_2})] = (-1) \cdot \{\ln(P_C) + 2 \cdot \ln(P_O) - \ln(P_{CO_2}) - \ln[K_{CO_2}(T)]\}^0. \quad (19)$$

Here, the superscript ⁰ indicates that the expression in curly brackets is an initial approximation.

In order to slightly reduce the cumbersomeness of entries, in the future, the expression of the species $\Delta[\ln(P_O)]$ will be represented as Δ_0 , and, for example, $\Delta[\ln(P_{CO_2})]$, as Δ_{CO_2} .

Having transformed the original system (5) – (17) in the described way, we obtain a system of equations over which linearization was carried out:

$$1 \cdot \Delta_C + 1 \cdot \Delta_O - 1 \cdot \Delta_{CO} = (-1) \cdot \{\ln(P_C) + 2 \cdot \ln(P_O) - \ln(P_{CO}) - \ln[K_{CO}(T)]\}^0; \quad (20)$$

$$1 \cdot \Delta_C + 2 \cdot \Delta_O - 1 \cdot \Delta_{CO_2} = (-1) \cdot \{\ln(P_C) + 2 \cdot \ln(P_O) - \ln(P_{CO_2}) - \ln[K_{CO_2}(T)]\}^0; \quad (21)$$

$$2 \cdot \Delta_H + 1 \cdot \Delta_O - 1 \cdot \Delta_{H_2O} = (-1) \cdot \{\ln(P_H) + 2 \cdot \ln(P_O) - \ln(P_{H_2O}) - \ln[K_{H_2O}(T)]\}^0; \quad (22)$$

$$1 \cdot \Delta_H + 1 \cdot \Delta_O - 1 \cdot \Delta_{OH} = (-1) \cdot \{\ln(P_H) + 2 \cdot \ln(P_O) - \ln(P_{OH}) - \ln[K_{OH}(T)]\}^0; \quad (23)$$

$$2 \cdot \Delta_H - 1 \cdot \Delta_{H_2} = (-1) \cdot \{2 \cdot \ln(P_H) - \ln(P_{H_2}) - \ln[K_{H_2}(T)]\}^0; \quad (24)$$

$$2 \cdot \Delta_O - 1 \cdot \Delta_{O_2} = (-1) \cdot \{2 \cdot \ln(P_O) - \ln(P_{O_2}) - \ln[K_{O_2}(T)]\}^0; \quad (25)$$

$$2 \cdot \Delta_N - 1 \cdot \Delta_{N_2} = (-1) \cdot \{2 \cdot \ln(P_N) - \ln(P_{N_2}) - \ln[K_{N_2}(T)]\}^0; \quad (26)$$

$$1 \cdot \Delta_N + 1 \cdot \Delta_O - 1 \cdot \Delta_{NO} = (-1) \cdot \{\ln(P_N) + 2 \cdot \ln(P_O) - \ln(P_{NO}) - \ln[K_{NO}(T)]\}^0. \quad (27)$$

$$\text{For [C]} \quad \frac{P_{CO}}{A} \Delta_{CO} + \frac{P_{CO_2}}{A} \Delta_{CO_2} + \frac{P_C}{A} \Delta_C - 1 \cdot \Delta_{M_T} = (-1) \cdot [\ln(A) - \ln(M_T) - \ln(b_C)]^0, \quad (28)$$

where $A = P_{CO} + P_{CO_2} + P_C$.

$$\text{For [H]} \quad \frac{2 \cdot P_{H_2O}}{L} \Delta_{H_2O} + \frac{P_{OH}}{L} \Delta_{OH} + \frac{2 \cdot P_{H_2}}{L} \Delta_{H_2} + \frac{P_H}{L} \Delta_H - 1 \cdot \Delta_{M_T} = (-1) \cdot [\ln(L) - \ln(M_T) - \ln(b_H)]^0, \quad (29)$$

where $L = 2 \cdot P_{H_2O} + P_{OH} + 2 \cdot P_{H_2} + P_H$.

$$\begin{aligned} \text{For [O]} \quad & \frac{P_{CO}}{G} \Delta_{CO} + \frac{2 \cdot P_{CO_2}}{G} \Delta_{CO_2} + \frac{P_{H_2O}}{G} \Delta_{H_2O} + \frac{P_{OH}}{G} \Delta_{OH} + \frac{2 \cdot P_{O_2}}{G} \Delta_{O_2} + \frac{P_{NO}}{G} \Delta_{NO} + \frac{P_O}{G} \Delta_O - 1 \cdot \Delta_{M_T} = \\ & (-1) \cdot [\ln(G) - \ln(M_T) - \ln(b_O + \alpha \cdot \chi_0^W \cdot 0.419)]^0, \end{aligned} \quad (30)$$

where $G = P_{CO} + 2 \cdot P_{CO_2} + P_{H_2O} + P_{OH} + 2 \cdot P_{O_2} + P_{NO} + P_O$.

$$\text{For [N]} \quad \frac{2 \cdot P_{N_2}}{J} \Delta_{N_2} + \frac{P_{NO}}{J} \Delta_{NO} + \frac{P_N}{J} \Delta_N - 1 \cdot \Delta_{M_T} = (-1) \cdot [\ln(J) - \ln(M_T) - \ln(\alpha \cdot \chi_0^W \cdot 1.581)]^0, \quad (31)$$

where $J = 2 \cdot P_{N_2} + P_{NO} + P_N$.

$$\begin{aligned} \text{For [P}_\Sigma] \quad & \frac{P_{CO}}{R} \Delta_{CO} + \frac{P_{CO_2}}{R} \Delta_{CO_2} + \frac{P_{H_2O}}{R} \Delta_{H_2O} + \frac{P_{OH}}{R} \Delta_{OH} + \frac{P_{H_2}}{R} \Delta_{H_2} + \frac{P_{O_2}}{R} \Delta_{O_2} + \frac{P_{N_2}}{R} \Delta_{N_2} + \frac{P_{NO}}{R} \Delta_{NO} + \frac{P_C}{R} \Delta_C + \\ & + \frac{P_H}{R} \Delta_H + \frac{P_O}{R} \Delta_O + \frac{P_N}{R} \Delta_N = (-1) \cdot [\ln(R) - \ln(P_\Sigma)]^0, \end{aligned} \quad (32)$$

where $R = P_{CO} + P_{CO_2} + P_{H_2O} + P_{OH} + P_{H_2} + P_{O_2} + P_{N_2} + P_{NO} + P_C + P_H + P_O + P_N$.

The solution is based on the assumption of isoenthalpy of the process. For the selected pair, MSW-oxidizer with known enthalpies for them $I^{(MSW)}$ and the $I^{(O)}$ given value χ^W (2) of the molar ratio of the components calculates the enthalpy of the fuel:

$$I^{(F)} = I^{(MSW)} + \chi^W \cdot I^{(O)}. \quad (33)$$

Next, the search for a solution is carried out step by step:

Step 1. Some temperature is chosen T^0 (initial approximation). It is considered realized at the considered moment during combustion $T_i = T^0$.

Step 2. Using an iterative process based on the linearized model, (20) – (32), the composition (partial pressures P_i and, therefore, molar fractions) of the combustion products corresponding to the current considered temperature is determined T_i . As mentioned earlier, the values of chemical equilibrium constants required for this calculation can be taken from the tables or calculated using approximation polynomials similar to those given in [4].

Step 3. The enthalpies of combustion products I_i corresponding to the currently considered temperature are determined T_i . These values can also be taken from the tables or calculated using approximation polynomials similar to those given in [4].

Step 4. Using the values of the partial pressures as the values of the mole fractions of the corresponding gases included in the composition of the combustion products, their enthalpy is calculated I_{CP} :

$$I_{CP} = \sum_i (P_i \cdot I_i). \quad (34)$$

Step 5. The enthalpies of fuel and combustion products at the current temperature under consideration are compared. It should be taken into account that the I_{CP} values of partial pressures used for calculation are numerically equal to molar concentrations only in the case when M_T moles of fuel are considered. In other words, the comparison of enthalpies should take place in the form of a ratio: $M_T \cdot I^{(T)} \Leftrightarrow I_{CP}$.

Step 6. In the case of equality of these values or the permissible value of deviation, the temperature and composition of combustion products are considered determined. The calculation stops. Otherwise, proceed to the next item.

Step 7. Depending on the excess of the left or right part of the expression $M_T \cdot I^{(T)} \Leftrightarrow I_{CP}$, the value of the current temperature T_i under consideration is adjusted in the direction of its increase or decrease. With the new value of the quantity, T_i we go to step 2 and repeat all the calculations.

The considered method is based on the assumption of isenthalpy of the combustion process. This condition is observed only in some power plants. In the vast majority of energy devices, the isoenthalpy conditions of the combustion process are not feasible. For this reason, a special device [10] was developed for research, which will be used to identify the composition of the gross solid waste formula.

5. The method of sorting solid household waste based on thermochemical processing

5.1. Simulation model of solid waste

For simulation modeling of different groups of solid waste that are formed after the separation of the total volume, it is also possible to use the model of the mixture of formed compounds by a conditional formula. The work

[2] presents the results of the classification of solid waste into four groups of various compounds included in each group. Averaging the compounds in each group made it possible to obtain the conditional formulas of each group of the gross formula. The results are presented in Table 4.

Table 4. Classified morphological composition of solid waste through representation by conventional formula through averaging compounds.

No	Group name according to [2]	Average group name	Conditional formula of the averaged compound
1	Hydrocarbons	A	CH _{1.8}
2	Hydrocarbons that contain oxygen	B	CH _{1.7} O _{0.76}
3	Hydrocarbons containing oxygen and nitrogen	C	CH ₂ O _{0.51} N _{0.2}
4	Hydrocarbons containing selective active elements	D	CH _{1.6} Cl _{0.5} F ₂ S _{0.444}

In the open information sources for conditions in Ukraine, no results of systematic studies of the morphological composition of solid waste were found, which would have a dependence on the conditions of their occurrence. The only sources of statistical data were studies conducted by solid waste operators and relevant associations at one time or another in certain regions. Their results differ significantly from each other. Discrepancies in the data are most likely due to the limited sample size. Data processing [2] made it possible to obtain the following results on the morphological composition of MSW for Ukraine in 2018, namely group A – 12%, B – 19%, C – 58%, D – 11%.

The total volume of solid waste is formed by natural mixing of all types of solid waste. Therefore, in the solid waste sample, which is analyzed, there will be very high probability of different groups in the ratio that was presented in [2].

Isothermal decomposition of a substance will be used to obtain classification features of one or another group [12]. During isothermal decomposition, the four defined groups that make up the total volume of MSW can form 11 variants of various mixtures. Conventional formulas of such mixtures are given in Table 5.

Table 5. Composition of individual groups and mixtures of solid waste generated and their conventional formula.

Group No	A group of mixtures that can be formed	Conditional formula of the averaged mixture
1	A	CH _{1.8}
2	B	CH _{1.7} O _{0.76}
3	C	CH ₂ O _{0.51} N _{0.2}
4	D	CH _{1.6} Cl _{0.5} F ₂ S _{0.444}
5	A + B	CH _{1.744} O _{0.427}
6	A + C	CH _{1.957} O _{0.4} N _{0.157}
7	A + D	CH _{1.737} Cl _{0.158} F _{0.633} S _{0.141}
8	B + C	CH _{1.922} O _{0.575} N _{0.148}
9	B + D	CH _{1.673} Cl _{0.133} F _{0.531} S _{0.118}
10	C + D	CH _{1.955} O _{0.453} N _{0.177} Cl _{0.056} F _{0.225} S _{0.05}
11	A + B + C	CH _{1.901} O _{0.478} N _{0.123}
12	A + B + D	CH _{1.955} O _{0.453} N _{0.177} Cl _{0.056} F _{0.225} S _{0.05}
13	B + C + D	CH _{1.72} O _{0.355} N _{0.001} Cl _{0.084} F _{0.337} S _{0.074}
14	A + C + D	CH _{1.925} O _{0.364} N _{0.143} Cl _{0.045} F _{0.181} S _{0.04}
15	A + B + C + D	CH _{1.88} O _{0.443} N _{0.114} Cl _{0.036} F _{0.145} S _{0.032}

Thus, Table 5 represents a tabular form of a simulation model of different groups of solid waste, which will allow for the implementation of a classification method for the identification of solid household waste samples. This method of identification will make it possible to distinguish groups that form acid gases.

5.2. The method of sorting solid household waste

In general, the volume of solid waste is formed by natural mixing of all types of solid waste, so its distribution into components consists of the following methods and algorithms. First, from the technological method of sorting solid waste. Secondly, the method of sorting raw materials-processing, in which measuring devices are integrated to ensure the given characteristics of identification by classification signs. Thirdly, the principle of application of measuring devices depending on the type of identification task by qualitative or quantitative indicators. As errors of the first and second kind were accepted. To identify a quantitative indicator, the error of the first kind can belong to

the interval 0.7...0.9, and the error of the second kind – 0.05...0.01. To identify a qualitative indicator, the error of the first kind can belong to the interval 0.95...0.99, and the error of the second kind – 0.001...0.005.

The technological method of solid waste sorting consists of the following steps. To understand the method, it is not indicated which technological operation is performed on which type of equipment.

Step 1. Determining the mass of a discrete volume of solid waste that is industrially processed. Determination of the minimum mass from the current state of the raw material from which a heterogeneous or homogeneous sample will be extracted, which depends on the adopted analysis criterion, on the basis of which qualitative or quantitative identification of the composition of the substance will be carried out. The boundary condition of the minimum mass is its ratio to the total mass of the processed volume. The ratio should be less than one ppm.

Step 2. In the current sample, the qualitative or quantitative composition of the raw material is determined by its identification. The isenthalpic method of determining the total composition in the device [12] through the gross formula is used for qualitative composition. For the quantitative composition, the express gravimetry method of simultaneous determination of several elements in one sample is used, which also makes it possible to obtain the gross formula.

Step 3. Regardless of the adopted method of determining the composition, compare the obtained gross formula from the list of gross formulas of the simulation model, see table 4 taking into account the errors of identification methods [9]. According to the gross formula of the simulation model, the types of classified components of solid waste are identified and a conclusion is drawn about the presence of a composition that can form acid gases during its processing by thermal destruction methods.

Step 4. We give the value of the obtained composition to the minimum mass and, in accordance with the identified gross formula, send it to the place of collection of the classified type of raw material.

Step 5. We determine the possibility of conducting the next cycle. If there is still a current minimum mass, we analyze and measure it. If not, the entire amount of solid waste is processed and the algorithm is exited.

Let's consider the method of sorting industrial volumes of raw materials for the purpose of their further processing by methods of thermal destruction. The method consists of the derived name of the accepted variables, the rule of composition of constants and the sorting algorithm of the current portion of raw materials.

The following changes were adopted:

A, B, C, D – designation of selected I -th components of the morphological composition for analysis (character – capital letter); designation of J components after analysis, which are impurities in the analysis of only one of the selected ones;

a, b, c, d – designation of selected i -th components from the composition after analysis (character-uppercase letter); designation of the j -th components after the analysis, which remained unextracted as a result of the extraction of one of the selected ones;

M – total mass of the mixture to be analyzed;

M_I – mass of the first component of the mixture to be analyzed;

m_i – mass of the i -th component of the mixture after the analysis of the component itself;

R_I – percentage content of the I -th component in the total mass of the mixture before analysis;

R_i – percentage content of the i -th component left for analysis after the extraction of the i -th component from the total mass;

P_I – parameter of identification of the I -th component of the mixture to be analyzed;

i_{ost} – the remainder of the i -th component of the mixture after analysis;

j_{ost} – the remainder of the j -th component of the mixture after analysis.

We will introduce the rules for compiling variables for the method of sorting industrial volumes of raw materials .

$k(i_{ost})$ – coefficient for determining the share of impurities in the remainder of the i -th component after analysis;

mi_{ost} – the mass of the i -th component residue after analysis;

$R(i_{ost}(J))$ – percentage content of component J in the remainder of component i ;

$m(i_{ost}(J))$ – the mass of the impurity component J in the remainder of the components i ;

$m(i_{ost}(j))$ – the mass of the impurity component j in the remainder of the components i ;

$m(i_{ost}(j_{ost}))$ – the mass of the remaining impurity component j in the remainder of the components i ;

$m(i_{ost}j_1j_2j_3)$ – mass of the mixture remaining after the I -th (one) component has been extracted from it for further analysis, which is used to extract the next component in the current cycle;

$m(i_{1ost}i_{2ost}j_1j_2)$ – similarly to the previous one, only after the I -th (two) component is selected from it;

$m(i_{1ost}i_{2ost}i_{3ost}j_1)$ – similarly to the previous one, only after the I -th (three) component is selected from it;

$m(i_{1ost}i_{2ost}i_{3ost}i_{4ost})$ – similarly to the previous one, only after the I -th (four) component is selected from it.

Let's show the rules for adding constants:

MA, MB, MC, MD – mass, respectively, component A, B, C, D to analysis ;

RA, RB, RC, RD – percentage content, respectively, component A, B, C, D to analysis ;

PA, PB, PC, PD – identification parameter (qualitative or quantitative) of the relevant component A, B, C, D for analysis.

Let's show the rules for adding constants from the example of component A:

MA_{start} – mass concentration of A before analysis;

$k(a_{ost})$ – coefficient for determining the percentage content of impurities B, C, D in the remaining component a after analysis;

$R(a_{ost}(B)), R(a_{ost}(C)), R(a_{ost}(D))$ – percentage content, respectively, components B, C, D in the remainder of the components a after analysis;

ma_{ost} – the mass of the remaining component a after analysis;

$m(a_{ost}(B)), m(a_{ost}(C)), m(a_{ost}(D))$ – the mass of the admixture, respectively, the components B, C, D in the remainder of the components a after analysis;

mb, mc, md – mass, respectively, components b, c, d without the portion remaining as an impurity in the remainder a ;

$m(a_{ost}bcd)$ – the mass of the mixture remaining after the separation of component A , the remaining components a_{ost}, b, c, d in the mixture, which are sent to the next step for further separation of a new component.

Algorithm for sorting the current batch of raw materials.

Step 1. Calculation of the mass of the component A and detection of impurities in it B, C, D .

Action 1.1. Calculation of the mass of MA component A before analysis :

$$MA = M * RA. \tag{35}$$

Action 1.2. Calculation of the mass concentration of MA_{start} components before analysis:

$$MA_{start} = MA * PA. \tag{36}$$

Action 1.3. Calculation of the mass of the residue of ma_{ost} component A after analysis :

$$ma_{ost} = M - MA_{start}. \tag{37}$$

Action 1.4 . Calculation of the percentage content of each impurity component j received for processing: in Step1, these are the initial parameters RB, RC, RD .

Action 1.5. Calculation of the mass of impurities B, C, D in the residue a .

Calculation of the coefficient of $k(a_{ost})$ determination of the percentage content of impurities B, C, D in the remaining component a :

$$k(a_{ost}) = \frac{1}{RB+RC+RD}. \tag{38}$$

Calculation of the share of impurities B, C, D in the remaining component a :

$$R(a_{ost}(B)) = RB * k(a_{ost}), R(a_{ost}(C)) = RC * k(a_{ost}), R(a_{ost}(D)) = RD * k(a_{ost}). \quad (39)$$

Calculation of the mass of impurities B, C, D in the residue a :

$$m(a_{ost}(B)) = ma_{ost} * R(a_{ost}(B)), m(a_{ost}(C)) = ma_{ost} * R(a_{ost}(C)), m(a_{ost}(D)) = ma_{ost} * R(a_{ost}(D)). \quad (40)$$

Action 1.6. Checking the material balance Step 1:

$$MA = MA_{start} + m(a_{ost}(B)) + m(a_{ost}(C)) + m(a_{ost}(D)). \quad (41)$$

Action 1.7. Calculation of the mass of components b, c, d without the fraction remaining as an impurity in the residue a :

$$mb = MB - m(a_{ost}(B)); \quad mc = MC - m(a_{ost}(C)); \quad md = MD - m(a_{ost}(D)). \quad (42)$$

Action 1.8. Determination of the mass of the mixture transferred to Step 2:

$$m(a_{ost}bcd) = ma_{ost} + mb + mc + md. \quad (43)$$

Step 2. Separation of component B from the total mass and detection of impurities in it a, c, d .

Action 2.1. Calculation of mass concentration mb_{start} components b :

$$mb_{start} = mb * PB. \quad (44)$$

Action 2.2. Calculation of the remaining mass of mb_{ost} component b after analysis:

$$mb_{ost} = mb - mb_{start}. \quad (45)$$

Action 2.3. Calculation of the percentage content of each component a_{ost}, c, d received for processing:

$$Ra_{ost} = ma_{ost}/m(a_{ost}bcd), \quad Rc = mc/ m(a_{ost}bcd), \quad Rd = md/ m(a_{ost}bcd). \quad (46)$$

Action 2.4. Calculation of the mass of impurities a, c, d in the residue b .

Calculation of the coefficient of $k(b_{ost})$ determination of the percentage content of impurities a, c, d in the remaining component b :

$$k(b_{ost}) = \frac{1}{Ra_{ost} + Rc + Rd}. \quad (47)$$

Calculation of the share of impurities a, c, d in the remaining component b :

$$R(b_{ost}(a_{ost})) = Ra_{ost} * k(b_{ost}), R(b_{ost}(c)) = Rc * k(b_{ost}), R(b_{ost}(d)) = Rd * k(b_{ost}). \quad (48)$$

Calculation of the mass of impurities a, c, d in the residue b :

$$m(b_{ost}(a_{ost})) = mb_{ost} * R(b_{ost}(a_{ost})), m(b_{ost}(c)) = mb_{ost} * R(b_{ost}(c)), m(b_{ost}(d)) = mb_{ost} * R(b_{ost}(d)). \quad (49)$$

Action 2.5. Checking the material balance Step 2:

$$mb = mb_{start} + m(b_{ost}(a_{ost})) + m(b_{ost}(c)) + m(b_{ost}(d)). \quad (50)$$

Action 2.6. Calculation of the mass a, c, d without the fraction remaining as an impurity in the residue b :

$$ma_{ost} = mb_{ost} - m(b_{ost}(a_{ost})), mc = mc - m(b_{ost}(c)), md = md - m(b_{ost}(d)). \quad (51)$$

Action 2.7. Determination of the mass of the mixture transferred to Step 3:

$$m(a_{ost}b_{ost}cd) = ma_{ost} + mb_{ost} + mc + md. \quad (52)$$

Step 3. Separation of component C from the total mass and detection of impurities in it **a, b, d**.

Action 3.1. Calculation of mass concentration mc_{start} components:

$$mc_{start} = mc * PC. \quad (53)$$

Action 3.2. Calculation of the mass of the remaining mc_{ost} component after analysis :

$$mc_{ost} = mc - mc_{start}. \quad (54)$$

Action 3.3. Calculation of the percentage content of each component a_{ost}, b_{ost}, d received for processing:

$$Ra_{ost} = ma_{ost}/m(a_{ost}b_{ost}cd), Rb_{ost} = mb_{ost}/m(a_{ost}b_{ost}cd), Rd = md/m(a_{ost}b_{ost}cd). \quad (55)$$

Action 3.4. Calculation of the mass of impurities a, b, d in the residue c .

Calculation of the coefficient of $k(c_{ost})$ determination of the percentage content of impurities a, b, d in the remaining component c :

$$k(c_{ost}) = \frac{1}{Ra_{ost} + Rb_{ost} + Rd}. \quad (56)$$

Calculation of the share of impurities a, b, d in the remaining component c :

$$R(c_{ost}(a_{ost})) = Ra_{ost} * k(c_{ost}), R(c_{ost}(b_{ost})) = Rb_{ost} * k(c_{ost}), R(c_{ost}(d)) = Rd * k(c_{ost}). \quad (57)$$

Calculation of the mass of impurities a, b, d in the residue c :

$$m(c_{ost}(a_{ost})) = mc_{ost} * R(c_{ost}(a_{ost})), \quad m(c_{ost}(b_{ost})) = mc_{ost} * R(c_{ost}(b_{ost})), \\ m(c_{ost}(d)) = mc_{ost} * R(c_{ost}(d)). \quad (58)$$

Action 3.5. Checking the material balance Step 3:

$$mc = mc_{start} + m(c_{ost}(a_{ost})) + m(c_{ost}(b_{ost})) + m(c_{ost}(d)). \quad (59)$$

Action 3.6. Calculation of the mass a, b, d without the fraction remaining as an impurity in the residue c :

$$ma_{ost} = ma_{ost} - m(c_{ost}(a_{ost})), mb_{ost} = mb_{ost} - m(c_{ost}(b_{ost})), md = md - m(c_{ost}(d)). \quad (60)$$

Action 3.7. Determination of the mass of the mixture transferred to Step 4:

$$m(a_{ost}b_{ost}c_{ost}d) = ma_{ost} + mb_{ost} + mc_{ost} + md. \quad (61)$$

Step 4. Separation of component D from the total mass and detection of impurities in it **a, b, c**.

Action 4.1. Calculation of mass concentration md_{start} components d :

$$md_{start} = md * PD. \quad (62)$$

Action 4.2. Calculation of the remaining mass of md_{ost} component d after analysis :

$$md_{ost} = md - md_{start}. \quad (63)$$

Action 4.3. Calculation of the percentage content of each component $a_{ost}, b_{ost}, c_{ost}$ received for processing:

$$Ra_{ost} = ma_{ost}/m(a_{ost}b_{ost}c_{ost}d), Rb_{ost} = mb_{ost}/m(a_{ost}b_{ost}c_{ost}d), Rc_{ost} = mc_{ost}/m(a_{ost}b_{ost}c_{ost}d). \quad (64)$$

Action 4.4. Calculation of the mass of impurities a, b, c in the residue d .

Calculation of the coefficient of $k(d_{ost})$ determination of the percentage content of impurities a, b, c in the remaining component b :

$$k(d_{ost}) = \frac{1}{Ra_{ost} + Rb_{ost} + Rc_{ost}}. \quad (65)$$

Calculation of the share of impurities a, b, c in the remaining component d :

$$R(d_{ost}(a_{ost})) = Ra_{ost} * k(d_{ost}), R(d_{ost}(b_{ost})) = Rb_{ost} * k(d_{ost}), R(d_{ost}(c_{ost})) = Rc_{ost} * k(d_{ost}). \quad (66)$$

Calculation of the mass of impurities a, b, c in the residue d :

$$m(d_{ost}(a_{ost})) = md_{ost} * R(d_{ost}(a_{ost})), \quad m(d_{ost}(b_{ost})) = md_{ost} * R(d_{ost}(b_{ost})), \\ m(d_{ost}(c_{ost})) = md_{ost} * R(d_{ost}(c_{ost})). \quad (67)$$

Action 4.5. Checking the material balance Step 4:

$$md = md_{start} + m(d_{ost}(a_{ost})) + m(d_{ost}(b_{ost})) + m(d_{ost}(c_{ost})). \quad (68)$$

Action 4.6. Calculation of the mass a, b, c without the fraction remaining as an impurity in the residue d :

$$ma_{ost} = ma_{ost} - m(d_{ost}(a_{ost})), \quad mb_{ost} = mb_{ost} - m(d_{ost}(b_{ost})), \quad mc_{ost} = mc_{ost} - m(d_{ost}(c_{ost})). \quad (69)$$

Action 4.7. Determination of the mass of the mixture transferred to Step 5:

$$m(a_{ost}b_{ost}c_{ost}d_{ost}) = ma_{ost} + mb_{ost} + mc_{ost} + md_{ost}. \quad (70)$$

Step 5. Determination of the possibility of conducting the next cycle. If there is still a current analyzed portion, we analyze and measure it. If not, the entire volume of MSW is processed, output from the algorithm. It should be noted that in case of technological organization of detection and separation of various components at each stage, the current error of the material balance is taken into account in the technological balance.

According to the presented method of sorting solid waste and a simulation model in the form of a gross formula, a simulation of one composition of solid waste was carried out according to [2]: A – 12%, B – 19%, C – 58%, D – 11% by the two methods considered. The obtained results showed that identification by the isoenthalpic method does not take into account the composition, if the element under consideration is less than 5% by mass of the entire sample, and the method of identification by the express gravimetric method takes into account. To confirm this opinion, modeling of such a composition was carried out where three out of four components had a mass content of at least 5%. The simulation results are summarized in Table 6. The second composition corresponded to the maximum allowable (hypothetical) value of one component and the same value of the other three: A – 85%, B – 5%, C – 5%, D – 5%. The simulation results are summarized in Table 7.

Table 6. Results of modeling of solid waste composition according to [2].

The composition of solid waste and the calculated gross formula		
The starting mixture	After sorting the mixture during identification by the express gravimetric method	After sorting the mixture during identification by the isoenthalpic method
A = 120 B = 190 C = 580 D = 110	A=108; b=2.6; c=7.9; d=1.5 CH _{1.799} O _{0.034} N _{0.005} Cl _{0.009} F _{0.035} S _{0.008}	A=109; b=0; c=7.9; d=0 CH _{1.81} O _{0.026}
	B=169; a=0.3; c=15.5; d=2.9 CH _{1.712} O _{0.687} N _{0.003} Cl _{0.006} F _{0.023} S _{0.005}	B=171; a=0; c=15.5; d=0 CH _{1.723} O _{0.741} N _{0.016}
	C=501; a=4.7; b=7.7; d=43.2 CH _{1.974} O _{0.453} N _{0.177} Cl _{0.006} F _{0.025} S _{0.005}	C=505; a=4.7; b=7.7; d=43.2 CH _{1.972} O _{0.481} N _{0.184} Cl _{0.026} F _{0.105} S _{0.023}
	D=56.1; a=0.6; b=0.9; c=4.7 CH _{1.636} O _{0.004} N _{0.001} Cl _{0.0410} F _{1.641} S _{0.364}	D=103.8; a=0; b=0; c=0 CH _{1.6} Cl _{0.5} F ₂ S _{0.444}
	a=6.3; b=10.1; c=50.9; d=6.2 CH _{1.799} O _{0.024} N _{0.004} Cl _{0.006} F _{0.025} S _{0.006}	a=6.3; b=10.1; c=50.9; d=6.2 CH _{1.911} O _{0.461} N _{0.137} Cl _{0.028} F _{0.112} S _{0.025}

Table 7. Results of modeling of solid waste composition to confirm the obtained conclusion.

The composition of solid waste and the calculated gross formula		
The starting mixture	After sorting the mixture during identification by the express gravimetric method	After sorting the mixture during identification by the isoenthalpic method
A = 850	A=765; b=28.3; c=28.3; d=28.3	A=850; b=0; c=0; d=0
B = 50	CH _{1.88} O _{0.443} N _{0.114} Cl _{0.036} F _{0.145} S _{0.032}	CH _{1.8}
C = 50	B=19.5; a=1.4; c=0.4; d=0.4	B=50; a=0; c=0; d=0
D = 50	CH _{1.88} O _{0.443} N _{0.114} Cl _{0.036} F _{0.145} S _{0.032}	CH _{1.7} O _{0.760}
	C=19.2; a=1.66; b=0.04; d=0.4	C=50; a=0; b=0; d=0
	CH _{1.88} O _{0.443} N _{0.114} Cl _{0.036} F _{0.145} S _{0.032}	CH ₂ O _{0.51} N _{0.2}
	D=18.8; a=2; b=0.05; c=0.05	D=50; a=0; b=0; c=0
	CH _{1.88} O _{0.443} N _{0.114} Cl _{0.036} F _{0.145} S _{0.032}	CH _{1.6} Cl _{0.5} F ₂ S _{0.444}
	a = 79.9; b=2.05; c=2.05; d=2.1	a = 0; b=0; c=0; d=0
	CH _{1.88} O _{0.443} N _{0.114} Cl _{0.036} F _{0.145} S _{0.032}	

Analysis of the results of modeling the sorting of raw materials with specified characteristics through identification and classification allows us to make a sequence for sorting industrial volumes of solid waste. The first qualitative sorting is carried out on the basis of identification by the isenthalpic method, which makes it possible at the second stage to sort by a quantitative method based on the express gravimetric method. A qualitative method allows, first of all, to sort out raw materials, which with a high probability will form 80 ... 85% of one type of initial mixture, which significantly reduces the sorting volume. Residues of compounds that can form acid gases of less than 0.1% by weight can be effectively neutralized by special purification technologies during direct combustion in industrial boilers. If, as a result of a quantitative method, groups of compounds are detected that can form acid gases, such raw materials can be processed using pyrolysis technology. In this technology, acid gases that enter the synthesis gas are bound on alkaline filters. But most compounds in a bound form will remain in the so-called carbonaceous residue.

The results obtained during the modeling confirmed the fundamental possibility of dividing the industrial volume of MSW into five possible independent components with different morphological composition. A chain of analyses formed by qualitative and quantitative methods makes it possible to identify MSW with an error of no worse than 1% and to find the gross formula of each component of the MSW morphological composition.

6. Conclusion

The development of the method of classification of solid household waste and the method of their identification was proposed, which made it possible to distinguish the groups that form acid gases. The basis of the method is a simulation model, which is represented by a tabular form of gross formulas of possible compounds from which volumes of solid household waste are formed. According to accepted data, 15 compounds were formed in the form of gross formulas. Identification of certain compounds, both qualitative and quantitative, is done by thermochemical method, which makes it possible to search for substances that form acid gases during processing by methods of thermal destruction.

A method of sorting solid household waste has been developed for further processing of each group with maximum efficiency and compliance with ecological indicators. The method is based on: technological method of sorting; a method of sorting raw materials in which measuring devices are integrated to ensure the specified characteristics of identification according to the classification features of the simulation model; the principle of using measuring devices depending on the type of identification task by qualitative or quantitative indicator.

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Модель та метод сортування твердих побутових відходів для їх ефективної термічної утилізації

Ганна Лисюк^a, Оксана Максимова^b

^aНаціональний університет «Одеська політехніка», просп. Т. Шевченка, 1, м. Одеса, 65044, Україна

^bНаціональний університет «Одеська морська академія», вул. Дідріхсона, 8, Одеса, 65052, Україна

Анотація

В роботі розглядається розробка імітаційної моделі та автоматизованого методу сортування твердих побутових відходів (ТПВ) на основі ідентифікації порції досліджуваної сировини з подальшою класифікацією за прийнятими групами характерного хімічного складу. Запропоновано метод класифікації ТПВ та способу їх ідентифікації, який дозволив виділити групи, що утворюють кислі гази. Основу метода складає імітаційна модель яку представлено табличною формою бруто-формул можливих сполук. Ідентифікація визначених сполук відбувається, як якісна – ізоентальпійним способом так і кількісна за рахунок експрес-гравіметричного способу. Послідовний ланцюг ідентифікації робить можливим пошук речовин які утворюють кислі гази при подальшій переробці методами термічної деструкції. Розроблено метод сортування твердих побутових відходів для можливості подальшої переробки кожної групи з максимальною ефективністю та дотриманням екологічних показників. В основу метода покладено: технологічний спосіб проведення сортування; метод сортування сировини-переробки в якій інтегровано вимірювальні пристрої для забезпечення заданих характеристик ідентифікації за класифікаційними ознаками імітаційної моделі; принципу застосування вимірювальних пристроїв в залежності від типу задачі ідентифікації за якісним або кількісним показником.

Ключові слова: тверді побутові відходи; термічна утилізація; сортування; бруто-формула; ідентифікація.