

*This experimental study has confirmed that during thermal decomposition of polymeric waste samples at a temperature of 850 °C, without oxygen access, there is a 90 % drop in the mass of this waste with the release of a large volume of gaseous products. This feature should be taken into consideration in the engineering calculations of reaction chambers, reactors, and connecting gas pipelines. The analytical study was carried out by a method of thermodynamic analysis using the universal estimation system Astra (TERRA). It has been shown that with an increase in reaction temperature there is a change in the composition of the products of thermal destruction of polymeric waste by reducing the mole fraction of CH<sub>4</sub> and increasing the proportion of H<sub>2</sub>. The calorific value was calculated according to Mendeleev's empirical formula. The experimental study (a pyrolysis-gas chromatography method) has confirmed the calculation results regarding an increase in the proportion of hydrogen in the gaseous products of destruction with an increase in process temperature. As a result, due to the lower volumetric heat of hydrocarbon combustion, the total caloric content of the synthesis gas obtained is significantly reduced. For the experiments, a laboratory installation of low-temperature pyrolysis of polymers with external supply of thermal energy was built, and synthesis gas was used as an energy carrier.*

*At the experimental-industrial installation, by a low-temperature pyrolysis method, the synthesis gas of a stable composition with a lower heat of combustion of 24.8 kJ/m<sup>3</sup> was obtained. The reliability of the results of the proposed estimation method to the results of instrumental measurements has been shown.*

*Promising areas of further studies have been determined, including the optimization of processes of thermal destruction of chlorine-containing polymer waste; the effective use of hydrogen from the composition of the synthesis gas obtained*

**Keywords:** solid household waste, destruction, pyrolysis, synthesis gas, hydrocarbons, polymers

UDC 628.475:678.06

DOI: 10.15587/1729-4061.2021.238952

# THERMAL DESTRUCTION OF POLYMERS: ANALYSIS OF THE PROCESS PHYSICOCHEMICAL PARAMETERS

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Received date 24.06.2021

Accepted date 17.08.2021

Published date 30.08.2021

**How to Cite:** Sezonenko, O., Vasechko, O., Aleksyeyenko, V. (2021). thermal destruction of polymers: analysis of the process physicochemical parameters. *Eastern-European Journal of Enterprise Technologies*, 4 (10 (112)), 31–37. doi: <https://doi.org/10.15587/1729-4061.2021.238952>

## 1. Introduction

In the modern world, solid household waste confidently gains the status of one of the renewable energy sources [1]. This process is facilitated by the following factors:

- the high energy intensity of technological processes to create elements of everyday human life;
- the high rates of accumulation of the deposited solid household waste (SHW);
- awareness by an increasing number of national governments of the depth of environmental damage and irreversibility of anthropogenic and man-made environmental impact. An essential component of SHW are various polymeric materials (plastics).

According to the Plastic – The Facts 2020 statistics [2], in Europe 24.9 % of polymers are exported to landfills.

The peculiarity of polymer waste is that they practically do not decompose in nature, more precisely, it takes a hundred or more years. At the same time, harmful chemical reagents (styrene, phenol, formaldehyde, urethane, etc.) are released in the environment in contact with plastic (air, water, soil).

Accordingly, the equipment and technology for processing such groups of polymers (the so-called «residues», or «tails»)

have been actively developed, for example, Enerkem Alberta Biofuels (Canada), Sierra's FastOx Pathfinder (USA) [3].

The processes of thermal destruction and disposal of polymers of various kinds as a component of solid household waste (SHW) and gaseous products of thermal decomposition of such wastes are considered. This is important because such waste is a fairly significant component of SHW and has a significant energy value. Standard storage of such waste at solid waste landfills poses a significant threat to the environment. Technologies for the thermal disposal of the specified waste should take into consideration the peculiarities and dependence of the amount and composition of substances in gasification products on temperature and time.

It should be noted that standard structural solutions for equipment are not suitable for complete and safe thermal decomposition of polymers. For example, the gasification chambers of furnaces-incinerators for medical waste are designed for caloric content up to 4,000 kcal/kg, while polymer waste has a caloric content 2 times higher. In addition, an important feature is the rapid reduction of the weight of polymers when heated with the release of more than 90 % of volatile substances in the first 10–15 minutes of heating. These factors are the main ones that predetermine the relevance of

scientific research into the thermal destructive processes of polymers of different origins.

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## 2. Literature review and problem statement

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Paper [4] provides information on the composition of the basic polymeric materials in the composition of SHW, which are interesting in terms of energy use. At the same time, the filling of polymers with nanomaterials adds some difficulties [5].

Taking into consideration the dynamics of continuous growth of packaging materials production, the European Commission devised a «strategy for plastic masses in the closed-loop economy» [6], establishing that by 2030 all plastic packaging in Europe should be re-usable or processed at minimal cost.

In the review of existing technologies for the processing of plastic waste by gasification methods [3], the focus is on the technologies of joint processing of polymers and biomass, and gasification with «agents». A limited amount of oxygen and water vapor are considered as gasification agents. At the same time, the processes of thermodynamics of thermal polymers without artificial impurities are not sufficiently considered. The same applies to work [7].

Paper [8] emphasized that using existing, standard methods of thermal neutralization of polymers such as combustion in special installations significantly increases the load on dust and gas catching equipment. In pyrolysis processing of certain groups of polymers, for example, polyurethanes, the current methods are unstable. Much attention is paid to the search for new methods of processing polymeric materials and biomass.

The importance of the study of the compositions of synthesis gases obtained from waste and the impact on their composition exerted by the parameters of the gasification chambers, working conditions, and temperature levels is shown in work [9].

An additional feature of polymers is the process of phase transition stages with the release of energy, in a given case, the exothermic depolymerization reaction. In general, the areas of modern research are focused on the search for new, effective, environmentally safe means and technologies of thermal destruction of polymers, as a rule, with the addition of an additional working body (water vapor or oxygen). At the same time, insufficient attention is paid to the «non-energy» use of synthesis gases.

The authors of [10] carried out a comprehensive analysis of the mechanisms for the formation of harmful components in waste combustion products, including hazardous ones. It has been shown that violation of the normative values of indicators of work of waste recyclers leads to emissions of highly toxic substances: dioxins, furan, etc. That further confirms the relevance of work on improving waste disposal processes and equipment.

Paper [11] provides an overview of the technology of polymer neutralization as part of infected medical waste. As an energy efficiency solution, it is proposed to carry out recuperative heating of the reaction air and thermal destruction components. Such a solution could to some extent reduce energy consumption for the process but would lead to early melting of polymers (in the preheat chamber).

A wider range of wastes disposed of by thermal destruction is set out in paper [12]. The caloric content of various groups of waste is mutually compensated inside the reaction chamber (moisture from liquid waste evaporates due to the use of part of the energy of synthesis gas from polymers). Only the

energy component is used without taking into consideration the possible technological use of synthesis gas components.

It should be emphasized that polymer waste is an important renewable energy source that can be used either by burning or by burning waste pyrolysis products. In both cases, it is extremely important to study in detail the conditions of the thermal decomposition of polymer waste and products released when they are heated. And such a study could make it possible to move to the most effective implementation of industrial designs.

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## 3. The aim and objectives of the study

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The purpose of this study is to analytically and experimentally determine the physical and chemical indicators of the process of thermal destruction of polymers from waste (household waste, industrial waste). That could make it possible to improve the thermal-technical and environmental indicators of existing equipment, as well as take into consideration the results of research in the design of new tools.

To accomplish the aim, the following tasks have been set:

- to investigate the effect of temperature on a change in the initial mass of representative samples of waste during external energy supply;
- to check the accuracy of the selected analytical method for determining the composition and caloric content of thermal destruction products through a series of experimental studies.

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## 4. The study materials and methods

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The object of our study is a chamber (pyrolysis, gasification, reactionary), in which the process of decomposition of polymers takes place. New batches of waste are periodically loaded into the chamber after unloading the ash residue. The chamber is externally supplied with the thermal energy obtained during the combustion of hydrocarbon fuel (synthesis gas, pyrolysis oil, etc.).

The subject of the study is the gas environment formed during the decomposition of polymers.

The main research hypothesis assumes that the phase transition of solid polymeric waste to a gaseous state occurs in a short period of time. At the same time, up to 98 % of the mass of waste in the chamber accounts for the steam-gas mixture, from which, after separation of the condensing part, synthesis gas is obtained. The caloric content of synthesis gas, depending on the composition, is in the range from 20 to 30 MJ/nm<sup>3</sup>. Caloric content is adjusted by the temperature level of the process and, to a certain extent, the initial composition of polymers.

To simplify the calculations, we do not take into consideration the residual oxygen remaining in the chamber after loading it with waste.

The research involved the following:

- analytical methods of calculation by a thermodynamic analysis method using the universal estimation system Astra (TERRA);
- an experimental method of pyrolysis-gas chromatography;
- a laboratory pyrolysis installation with a hermetic stationary retort (Fig. 1);
- an experimental-industrial single-retort pyrolysis unit of periodic action (Fig. 2, 3);
- the precision technical platform scales Mettler Toledo ME2002T.

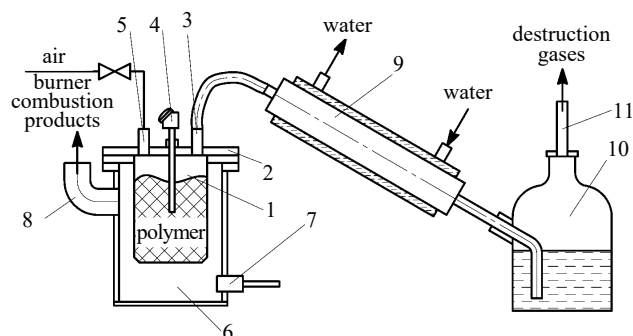


Fig. 1. Schematic of the laboratory set-up



Fig. 2. General view of the experimental-industrial installation



Fig. 3. Loaded waste

The main difficulties in calculating the equilibrium state are the uncertainty of the numerical value of quantity  $n$ , which depends on the brand, manufacturing technique, etc. That does not allow us to determine the necessary indicators for analysis: heat of formation, calorific value, etc. The data given in various papers have significant differences that affect the accuracy of further calculations. For example, the calorific value of polyethylene combustion, depending on the brand, ranges from 44.0 to 47.2 MJ/kg.

Important indicators, in this case, are also the ignition temperature of polyethylene (306 degrees) and the temperature of self-ignition (417 degrees). Conclusions drawn from a wide overview of various papers are as follows: the range of values of the lower calorific value of unprocessed polymer waste is 22.9...41.0 MJ/kg. In general, these plastics are a good source of alternative energy but, in practice, such a range of values significantly complicates calculations.

An approximate assessment of the calorific value is derived from a known empirical formula by Mendeleev, which is widely used in the calculations of the lower calorific value

of unconventional fuels with a known elemental composition. In a given case, the advantage of that formula is that the calculation result does not depend on the value of  $n$ , as shown below using an example of polyethylene.

At the first stage, we obtained the representative samples of waste – screening or «tails» from one of the Ukrainian specialized enterprises, a waste management operator, and from the garbage collection station in Nur-Sultan (Astana), Republic of Kazakhstan. Samples of high-density polyethylene, low density polyethylene, and polyvinyl chloride were received. At the second stage, the samples were loaded into the retort of the laboratory unit, with a volume of 1 dm<sup>3</sup>, and in the retort of the experimental-industrial installation, with a volume of 1 m<sup>3</sup>. Both plants were heated by external energy. In the process of decomposition of polymers, samples of the resulting synthesis gas were selected with a gas pipette with a three-way valve at one end, at the second – a two-way valve according to GOST 18954-73. At the third stage, the analysis of the composition of synthesis gases by pyrolysis-gas chromatography was carried out. At the fourth stage, calculations were made to determine a calorific value. During the decomposition process, samples of the material were weighed. Samples from the laboratory unit were weighed on electronic scales with an error of 0.01 grams. The experimental-industrial installation, namely the reactor, was weighed by the method of tensometry with an error of 1.0 g.

The installation includes retort 1, in which the experimental sample of polymeric waste are placed. From above, the retort is tightly closed with lid 2, which hosts the outlet nozzle 3 for destruction gases, thermocouple 4, as well as air supply nozzle 5. The retort is placed in heating reactor 6 with gas burner 7, which heats the walls of the retort, and the combustion product drainage nozzle 8. Outlet nozzle 3 is connected by a bypass hose to gas cooler 9 with a water jacket, which, in turn, is connected by tubes to water capacity 10. The tubes enter the container below the water level. On top of the tank, there is a discharge nozzle for cooled gases of destruction 11, from where samples are taken.

Thus, the polymer waste, by the flame from burner 7, is heated in the retort, where an adjustable amount of air is supplied through the nozzle 5. Separation of the polymer waste from the burner flame with a metal wall of the retort is necessary to prevent the combustion products of the burner from mixing with waste disposal gases. It is also necessary to prevent the suction of air into the retort, which would lead to early combustion of combustible destruction gases. After the retort, the destruction gases are cooled in cooler 9 to a temperature acceptable for sampling, after which they are washed in water tank 10.

To determine the number of experimental measurements, a sequential analysis of statistical hypothesis testing was used (the number of measurements is determined in the process of testing).

When processing the experimental data, the normal law of distribution of random measurement errors was applied. The random value distribution function was determined from the Gaussian formula.

## 5. The results of studying polymer thermal destruction processes

### 5.1. Determining the effect of temperature on a change in the output mass of waste

A characteristic feature of polymer waste is the high rate of decomposition of this waste at the temperatures

recommended for incinerators. Fig. 4 shows the established experimental dependence of the rate in the drop of the mass of waste at a temperature of 850 °C on the time of aging. In turn, this leads to a short-term peak release of gaseous products, which must be taken into consideration in the development of industrial samples of gasification chambers and thermal-destruction reactors.

During the experimental study of changes in the relative mass of waste at a fixed temperature, the laboratory reactor (pos. 6, Fig. 1) was installed on a platform of precision scales with a system of fully automatic calibration (allowable load up to 2,200 g; variance 0.01 g; error ±0.02 g) under the mode of dynamic weighing. The results on weight change were obtained through a computer interface in steps of 10 s. The weight in grams is converted as a percentage. Based on the results of our data on the similar batches of HDPE, LDPE, PVC, the Excel software was used to build the dependences of the change in mass on time (Fig. 4).

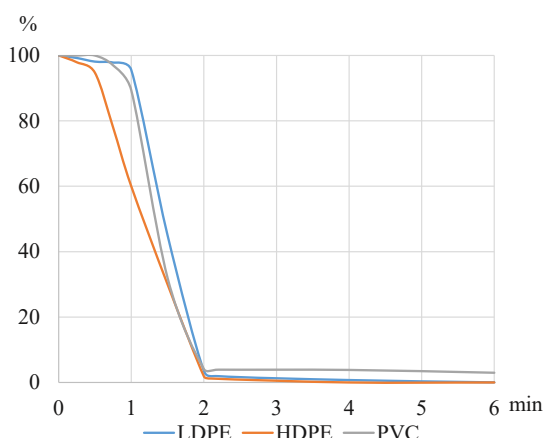


Fig. 4. Change in the relative mass of waste at a temperature of 850 °C dependent on aging time for high-density polyethylene (HDPE), low-density polyethylene (LDPE), polyvinyl chloride (PVC)

The nature of curves in the plot leads to a conclusion that, independent of the type, polymers almost equally lose weight in the first 2...6 minutes from the onset of the reaction. The lost mass likely transforms into the volume of the working chamber in the gas phase.

**5. 2. Determining the composition and caloric content of destruction products by conducting calculated, experimental, and industrial studies**

To assess the composition of thermal decay products, we thermodynamically calculated the equilibrium state of decomposition of polyethylene (C<sub>2</sub>H<sub>4</sub>)<sub>n</sub>, polypropylene (C<sub>3</sub>H<sub>6</sub>)<sub>n</sub>, and polystyrene (C<sub>8</sub>H<sub>8</sub>)<sub>n</sub>.

Thermodynamic analysis was carried out using the Astra software package (TERRA).

In the (C<sub>2</sub>H<sub>4</sub>)<sub>n</sub> formula, the masses of elements are as follows: C=24n, H=4n; the total mass is 28n, hence the mass shares of elements are: C=24n/28n=85.71, H=4n/28n=14.29 (% by weight); the lower calorific value is calculated from formula (1):

$$Q_n^p = 339 \cdot C + 1,030 \cdot H - 109 \cdot (O - S) = 339 \cdot 85.71 + 1,030 \cdot 14.29 - 109 \cdot 0 = 43,775 \text{ [kJ/kg]}. \quad (1)$$

It should be remembered that despite the relatively high calorific value of polymeric waste, its direct combustion

poses environmental risks and additional costs. When disposing of polymeric waste, depending on their composition and processing technique, various harmful substances may form in combustion products, including sulfur anhydride, hydrogen chloride, benzopyrene, dioxins, and other resistant organic compounds. To minimize this process, it is necessary to maintain a high oxygen content in the combustion chamber for complete combustion and a consistently high temperature, in order to maintain which, it is necessary to use third-party heat sources (fuel, electricity). The high rate of decomposition of these wastes at the temperatures recommended for incinerators, specifically, +850 °C in the gasification chamber, and +1,100 °C in the combustion chamber, leads to the jump-like release of gaseous products when loading waste into the combustion chamber. The products of the process are formed when reactions progress towards an equilibrium state, characterized by equality of the speeds of direct and reverse reactions. Thermodynamic analysis implies 2 variants of calculations:

- at specified composition and temperature; the calculation determines the composition of the products of the process;
- with the predefined composition and calorific value of fuel; in this case, the composition of products and their temperature in a state of adiabatic equilibrium (autothermic process) are determined by calculation. In both cases, the calculated indicators characterize the ideal state of the system, to which the actual state is approaching at fairly high temperatures and/or the presence of a catalyst, which provides high reaction rates.

At the first stage of analysis, the composition of products is calculated at the predefined temperature: 550 °C (823 K); it is given in Table 1.

Table 1

Equilibrium composition of olefin thermal destruction products

Substance and mass, g	T	H <sub>2</sub>	C(c)	CH <sub>4</sub>
	mole fractions			
C <sub>2</sub> H <sub>4</sub> =100	823	0.314238	0.5	0.185759
C <sub>6</sub> H <sub>12</sub> =100	823	0.314238	0.5	0.185759
C <sub>10</sub> H <sub>20</sub> =100	823	0.314238	0.5	0.185759

Hydrocarbons in the left column are taken as an example; similar results are obtained for any hydrocarbon of the C<sub>n</sub>H<sub>2n</sub> series; hence, it follows that the equilibrium composition of the products of thermal destruction is not dependent on the number n.

The change in the equilibrium composition of products at elevation of temperature is traced by calculation (Table 2) and illustrated by the plot in Fig. 5.

When the temperature rises, the amount of free carbon is stable – 0.5 (mole fractions); at the same time, there is an increase in the degree of methane destruction and, due to this, the mole fraction of hydrogen.

The results of similar calculations for any hydrocarbon of the C<sub>n</sub>H<sub>2n</sub> series are identical at the same temperatures and, therefore, also do not depend on the number n.



Table 2

Equilibrium compositions of ethylene thermal destruction products as a function of temperature

T, K	H <sub>2</sub>	C(c)	CH <sub>4</sub>
	Mole fractions		
323	0	0.5	0.500
423	0.002	0.5	0.498
523	0.015	0.5	0.485
623	0.065	0.5	0.435
723	0.174	0.5	0.326
823	0.314	0.5	0.186

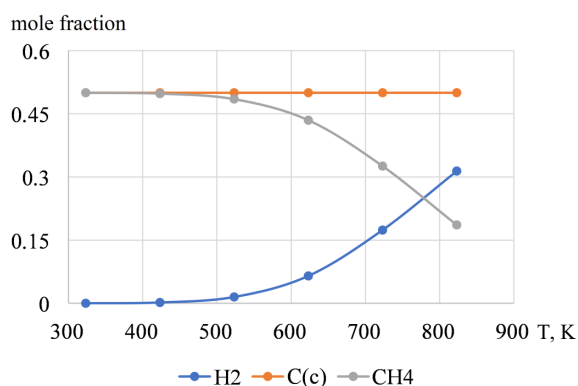


Fig. 5. The plot of function  $i = f(T)$  for the  $C_nH_{2n}$  hydrocarbon series, where  $i$  is the component of the equilibrium composition of thermal destruction products

The observed reduction of carbon content in the system, that is, the reduction of the mole fraction of CH<sub>4</sub> with unchanged C(c), can be explained when considering the composition of equilibrium products, expressed in mass fractions. At the same time, the decrease in the concentration of methane with an increase in the value of  $T$ , the released carbon atoms transform into C(c), as well as into neglected particles – into residual ethylene and boundary hydrocarbons of the  $C_nH_{2n+2}$  series, as shown in Table 3 and in Fig. 6, a, b.

Equilibrium compositions of ethylene thermal destruction products as a function of temperature

Process temperature, K	Component mass share, g/g						
	H <sub>2</sub>	C(c)	CH <sub>4</sub>	C <sub>2</sub> H <sub>4</sub>	C <sub>2</sub> H <sub>6</sub>	C <sub>3</sub> H <sub>8</sub>	C <sub>4</sub> H <sub>10</sub>
323	0	35.65	35.64	$2.7 \cdot 10^{-18}$	0	$3.7 \cdot 10^{-12}$	$1.4 \cdot 10^{-17}$
423	0.13	35.71	35.58	$1.9 \cdot 10^{-13}$	0	$1.9 \cdot 10^{-10}$	$2.91 \cdot 10^{-15}$
523	1.10	36.19	35.10	$1.92 \cdot 10^{-10}$	0	$2.2 \cdot 10^{-9}$	$7.7 \cdot 10^{-14}$
623	4.98	38.13	33.16	$2.0 \cdot 10^{-8}$	0	$1.0 \cdot 10^{-8}$	$6.2 \cdot 10^{-13}$
723	15.04	43.17	28.13	$5.0 \cdot 10^{-7}$	0.0003	$2.2 \cdot 10^{-8}$	$1.8 \cdot 10^{-12}$
823	32.7	51.98	19.31	$4.5 \cdot 10^{-6}$	0.0003	$2.2 \cdot 10^{-8}$	$2.0 \cdot 10^{-12}$

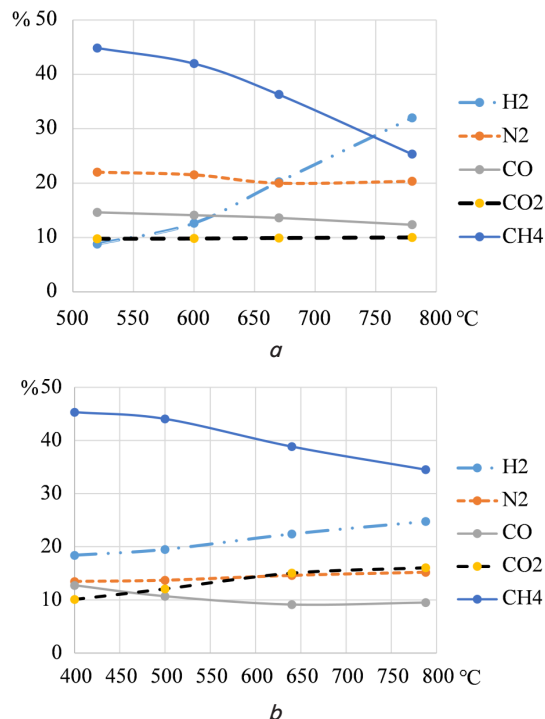


Fig. 6. Mass fraction of thermal polyethylene destruction products as a function of temperature: a – for low-density polyethylene; b – for high-density polyethylene

At the same time, temperature unevenness would always be present in an actual combustion chamber of the incinerator or in the pyrolysis chamber, which would determine the nature and speed of the thermal destruction process.

The composition of solid household waste, which mainly requires the detection of polymeric waste, has a very wide morphology and is variable depending on the region and even the time of year. In practice, components of so-called RDF, Refuse-Derived Fuel, namely: paper, wood, polymers, small screening, are most often identified from the waste composition.

Therefore, for industrial research, a series of experiments on the processing of various combinations of RDF components was carried out using a pilot industrial installation (Fig. 2, 3) [13].

The study results for this composition of raw materials are given in Table 4.

The calculated lower calorific value of a given mixture is  $Q_p^n = 24758 \text{ kJ/m}^3$  ( $5,914 \text{ kcal/m}^3$ ).

Table 3

Results of industrial research at a pilot industrial installation

No. of entry	Component name	Value, %
1	Hydrogen H <sub>2</sub>	22.404
2	Nitrogen N <sub>2</sub>	4.681
3	Carbon oxide CO	10.675
4	Carbon dioxide CO <sub>2</sub>	3.737
5	Methane CH <sub>4</sub> +heavy hydrocarbons	58.503
TOTAL:		100

## 6. Discussion of results of studying the polymer thermal destruction processes

Our results that were obtained during the research are related to the following set of reasons. First is the instability of «heavy» hydrocarbon molecules. At a regulated temperature in the thermal waste disposal chamber of 850 °C, in the first 3 minutes, more than 90 % of waste passes into the gas phase.

These data are correlated with the composition of gaseous products during the pyrolysis of polymers from open literary sources. Thus, with low-temperature pyrolysis, gaseous destruction products would represent hydrocarbon gases, mainly CH<sub>4</sub>, H<sub>2</sub>, CO, as well as with a certain amount of CO<sub>2</sub>, N<sub>2</sub> and O<sub>2</sub>. The presence of carbon monoxide indicates the presence of oxygen in polyethylene, that is, the presence of carbonyl groups. The presence of N<sub>2</sub> and O<sub>2</sub> is associated with air suction along the gas tract of the installation. The liquid phase would represent a wax-like product with a molecular weight of about 700 atomic mass units, mainly paraffins and olefins. Solid product is soot, coke particles, mineral inclusions.

With an increase in the temperature of the process, the proportion of gaseous and solid components increases due to the liquid phase. At the same time, while at the low-temperature pyrolysis mainly the C-C bonds were destroyed, at the high-temperature pyrolysis, the destruction of C-N bonds would significantly increase, which leads to an increase in the proportion of hydrogen in gaseous products [14]. The rate of thermal decomposition significantly increases, as illustrated in Fig. 2.

At the same time, with an increase in the temperature of the destruction, the calorific value of the resulting gas changes as follows:

- for LDPE, it decreases from 19.37 to 13.78 MJ/m<sup>3</sup>;
- for HDPE, it decreases from 20.5 to 14.2 MJ/m<sup>3</sup>.

The decrease in the calorific value of the gas obtained is explained by an increase in the share of H<sub>2</sub> whose lower combustion heat is only 10.79 MJ/m<sup>3</sup> (for comparison, other combustible gas components have a lower combustion heat value: CO=12.64 MJ/m<sup>3</sup> and CH<sub>4</sub>=35.88 MJ/m<sup>3</sup>).

Thus, with an increase in the temperature of the destruction, the calorific value of the resulting gas is significantly reduced but the total amount of gas would be greater, that is, the energy balance is not disturbed.

In the industrial disposal of polymer waste, it should always be remembered that, unlike experimental conditions, it is extremely difficult to work on the disposal of one particular type of waste. Even sorted waste would contain different types of plastics, as well as different moisture content and solid non-combustible inclusions, which could significantly affect the composition of the output products.

As an option for possible industrial use, by applying existing, worked-out methods, it is possible to isolate hydrogen for its further use in other areas. That increases the calorific value of synthesis gas to the values of 65...77 % of the calorific value of natural gas.

Certain limitations of our study are as follows.

- in practice, polymer waste can have high contamination with mineral admixtures, and high moisture content;
- in the research, we used periodic-action equipment, both laboratory and experimental.

The use of hydrogen at the modern level of industry development is of priority importance. The main sectors are

ferrous and non-ferrous metallurgy, and chemical industry. Ukraine, with the participation of the EU, is currently developing a Roadmap for the use of hydrogen in various sectors of the economy.

To isolate hydrogen from the composition of thermal waste disposal gas, a series of technologies are proposed, among which the Technology of short-loop adsorption under variable pressure (SLA) deserves attention. It is based on the principle of absorption of impurities of gas, which contains hydrogen in its composition at the surface of the specially designed adsorbing materials. This technology makes it possible to separate hydrogen with high purity. Mandatory certification of technology is not stipulated by the current legislation of Ukraine. Absorption of impurities with the adsorbent depends on pressure. Using this effect, SLA systems adjust the process of adsorption of impurities and the regeneration of the adsorbent by changing pressure. Adsorption is realized at high pressure, and desorption – at low pressure. Under optimal parameters, the purity of commodity hydrogen reaches 99.9999 % by volume [15].

There are obvious advantages of using hydrogen isolated from the composition of thermal waste disposal gas:

- low specific cost;
- absolute «environmental friendliness» of the process – the hydrogen is released from the waste composition and returns to the natural environment in the form of water vapor after targeted use.

The use of such hydrogen ensures rational and complete utilization of the potential of thermal decomposition of hydrocarbon-containing waste from solid waste.

The development of new, autothermal processes of waste recycling make it possible to use recycling components in:

- energy aspect (obtaining heat and/or electricity);
- technological (reduction of metals, production of substances, for example, ammonia). This direction is expedient, promising, and in line with national development strategies of the leading world powers.

Further research may be aimed at the processes of thermal destruction of mixed waste, using mainly chlorine-containing waste, and waste from rubber-technical products, with the study of the dynamics of the formation of chlorine-containing and sulfur-containing components.

## 7. Conclusions

1. Our study has found that when burning polymer waste at temperatures recommended for incinerators, that is, above 850 °C, there is a rapid drop in the mass of such waste with the rapid release of a large volume of gaseous products. This is due to the peculiarity of the structure of polymer molecules. Our waste was chosen precisely from the composition of solid household waste as the most typical in world practice.

2. The peculiarities of the thermal destruction of polymers relate to the fact that with an increase in the temperature of the process, the composition of the thermal destruction products of polymer waste changes by reducing the mole share of CH<sub>4</sub> from 45 % to 25 % and increasing the share of H<sub>2</sub> from 8 % to 32 %. As a result, the total calorific value of the gas obtained is significantly reduced (to 13.78 MJ/m<sup>3</sup>). We have confirmed a lower combustion heat of the synthesis gas *Q<sub>lower working</sub>* at the level of 24 758 kJ/m<sup>3</sup>, with a hydrogen content in the gas composition of 22 %.

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