

Thermal Analysis of Combustible Components of Municipal Solid Waste

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Abstract. The use of municipal solid waste as a raw material for alternative fuel is a promising direction for waste recycling and substitution of solid fossil fuels. Therefore, selecting of fuel composition and studying of its properties is an urgent task. The aim of this work is thermal characteristics analysis of the combustible components of municipal solid waste, which are the most common in Ukraine, for further selection of a fuel composition that will satisfy the consumer's requirements. The goal is achieved by studying the thermal destruction of samples by thermogravimetry and differential thermal analysis when materials are heated to 1000 °C in the presence of air oxygen. Paper, cardboard, plastic, biodegradable film, textiles, leather, wood were investigated in this work. The most important results are the received data on the characteristic temperatures of destruction stages, content of water, organic and mineral substances, ash, as well as the calculated values of rate and conditional thermal effect of decomposition of organic substances. Strong formation of gaseous substances was registered for samples of polyethylene and biodegradable film, polyethylene terephthalate and cotton fabric. These features should be considered in the technologies of production and combustion of fuel. The significance of the results also lies in the fact that it is recommended to use data on the thermal stability of materials in order to prevent their ignition during drying when developing fuel production technology. In addition, the calculated values of the conditional thermal effect made it possible to evaluate the thermal characteristics of the studied materials as components of solid alternative fuels.

Keywords: thermogravimetry, differential thermal analysis, municipal solid waste, combustible components, decomposition kinetics, heat generation.

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Analiza termică a componentelor inflamabile ale deșeurilor solide menajere

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Rezumat. Scopul lucrării este de a elabora și analiza funcționarea unui circuit termic bazat pe ciclul organic Rankine (ORC) folosind substanțe de lucru cu punct de fierbere scăzut din clasa fluorocarbonilor atunci când funcționează la parametri inițiali de ciclu mari. Acest obiectiv este atins prin analiza energetică a circuitelor termice cu o singură treaptă și mai multe etape ale centralelor electrice cu un circuit de turbină care funcționează pe substanțe de lucru fluorocarbon cu punct de fierbere scăzut, cum ar fi octafluoroprop-pane C3F8 și decafluorobutan C4F10. Se propune integrarea circuitului termic ORC ca extensie la o centrală electrică cu turbină cu gaz de mică capacitate (GTU), care funcționează pe gaz de sinteză după un gazeificator de biomasă. Cele mai importante rezultate ale lucrării sunt posibilitatea implementării unui ciclu cu o temperatură scăzută de condensare a mediului, care permite, la utilizarea fluidelor de lucru cu punct de fierbere scăzut, reducerea semnificativă a temperaturii procesului de îndepărtare a căldurii și, în consecință, creșterea eficiență a ciclului. S-a arătat posibilitatea utilizării substanțelor de lucru enumerate în centralele electrice cu circuit de turbină, care până în prezent au fost utilizate în principal ca agenți frigorifici pentru sistemele de refrigerare și pompe de căldură. Semnificația rezultatelor lucrării constă în faptul că, pe baza analizei complexului energetic, a fost propusă și justificată o soluție de circuit care poate crește eficiența energetică a complexului de alimentare cu energie, crescând volumul de energie electrică generată. și oferind o serie de avantaje tehnologice și de mediu.

Cuvinte-cheie: termogravimetrie, analiză termică diferențială, deșeuri solide menajere, componente inflamabile, cinetică de descompunere, generare.

**Термический анализ горючих компонентов твердых бытовых отходов
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Аннотация. Использование твердых бытовых отходов в качестве сырья для альтернативного топлива является перспективным направлением утилизации отходов и замещения твердого ископаемого топлива. Поэтому подбор состава топлива и изучение его свойств является актуальной задачей. Целью данной работы является анализ термических характеристик горючих компонентов твердых бытовых отходов, наиболее распространенных в Украине, для дальнейшего подбора состава топлива, который будет удовлетворять требованиям потребителя. Поставленная цель достигается путем исследования термической деструкции образцов методами термогравиметрии и дифференциального термического анализа при нагревании их до 1000 °С в условиях доступа кислорода воздуха. В данной работе были исследованы бумага, картон, пластик, биоразлагаемая пленка, текстиль, натуральная и искусственная кожа, древесина. Определены характерные температуры этапов деструкции: дегидратации, разложения органических и минеральных веществ. Наиболее важными результатами являются полученные данные о содержании воды, органических и минеральных веществ, золы, а также рассчитанные величины скорости и условного теплового эффекта разложения органических веществ. Показано, что термическое разложение органических веществ носит стадийный характер. Стадии отличаются как температурными интервалами, так и скоростью разложения. Для образцов полиэтиленовой и биоразлагаемой пленок, полиэтилентерефталата и хлопковой ткани регистрировали мощное образование газообразных веществ. Поэтому в технологиях изготовления и сжигания топлива следует учесть данные особенности термического разложения. Значимость полученных результатов заключается еще и в том, что при разработке технологии производства топлива рекомендуется использовать данные о термической стойкости материалов, чтобы избежать их возгорания при сушке. Кроме того, вычисленные величины условного теплового эффекта позволили оценить термические характеристики исследованных материалов в качестве компонентов твердого альтернативного топлива.

Ключевые слова: термогравиметрия, дифференциальный термический анализ, твердые бытовые отходы, горючие компоненты, кинетика разложения, генерация теплоты.

INTRODUCTION

The amount of municipal solid waste (MSW) is constantly increasing because of a general increase in the planet's population, an improvement in the quality of life and widespread industrial development. Improperly utilised waste is environmentally hazardous and takes up too much land. Therefore, the European Commission requires a reduction in landfills to reduce pollution of surface and ground water, soil and air, as well as to reduce the greenhouse effect [1].

Traditional methods of disposal and recycling of MSW include landfilling, combustion, and biological treatment. However, these methods have certain disadvantages [2, 3]. There are many problems associated with decreasing landfill areas, strict environmental regulations, and rising disposal costs [4]. In the Ukraine, more than 90% of MSW is subject to disposal at landfills. However, in most cases they are overcrowded and do not meet environmental requirements. Therefore, safe disposal and recycling of MSW has become an urgent task throughout the world. It encourages the development of new ways of waste disposal [5]. Waste-to-energy technologies are used in developed countries. In the USA, Great Britain, Germany, and Italy, MSW is disposed of in waste

incineration plants to produce energy and is converted into fuel [6].

Refuse derived fuel (RDF) is an alternative solid fuel containing the combustible part of the waste remaining after separation of secondary raw materials [7]. Secondary raw materials usually amount to 20–40 wt. % MSW [8]. Combustion of the RDF has higher efficiency in contrast to direct combustion of the MSW due to higher calorific value and less negative impact on the environment.

The RDF is used as an alternative to fossil fuels mainly in cement plants and coal-fired power plants [7]. Between 30% and 60% of traditional fuels have been replaced by the RDF in cement and waste recycling plants in Europe [9]. The RDF is combusted by mixing it with coal or biomass [10–11]. At the same time, the emission reduction is 0.4 tons of CO₂/ton of coal when coal is replaced by the RDF, the moisture content of which is less than 15% [12]. And combustion together with biomass can reduce the total amount of recorded CO₂ emissions, since biomass is considered carbon neutral [13, 14].

The possibility of using the RDF of a certain composition is finally determined in the combustion process. The defining characteristics are the heat of combustion and the number of emissions.

The RDF properties are actively being researched in the world. However, there are difficulties associated with ensuring quality and accurately determining the thermal characteristics of the fuel due to its heterogeneous composition. It was also found that the properties of the RDF have significant differences depending on the location of waste storage area [6]. It is possible to predict the characteristics of the fuel using the results of thermal analysis of its components.

Most researchers have focused their attention on studying the pyrolysis kinetics of the MSW components and their mixtures using thermogravimetric analysis (TGA). Some of the studies presented in the literature are complemented by the study of thermal characteristics using differential scanning calorimetry (DSC). In particular, in [15] the thermogravimetric characteristics and kinetic behavior of mixed plastic, mixed paper, textiles, and the RDF mixtures based on them were studied. In [16], studies were carried out on the kinetic parameters of pyrolysis (by the TGA method) and thermal characteristics (by the DSC method) of paper (receipts, cotton wool), cardboard (cardboard, egg carton), textiles (cotton, leather), plastics (polyethylene, polyurethane), hygiene waste (diapers, leno), and biodegradable waste (chicken meat, potato peel) for optimizing the combustion process and determining the energy intensity of low-temperature pyrolysis. The authors of the work [17] performed a cluster analysis, including thermogravimetric characteristics of 26 components of the MSW, in particular food residue (chinese cabbage, rice, potato, tangerine peel, banana peel, pakchoi, celery, orange peel, spinach), wood waste (poplar wood, poplar leaf, chinar leaf, ginkgo leaf), paper (blank printing paper, tissue paper, newspaper), textiles (cotton cloth, absorbent cotton gauze, terylene), plastics (low-density polyethylene, high-density polyethylene, polyvinyl chloride, polypropylene, polyethylene terephthalate), and rubber. In [18], samples of wood, paper, textiles and polyethylene terephthalate were selected to study the thermogravimetric and calorimetric characteristics of their interaction during pyrolysis. In [19], ten main components of the MSW, such as yard waste, food waste, textile, paper, rubber, low-density polyethylene, high-density polyethylene, polypropylene, polyethylene terephthalate, and polystyrene, were studied by thermogravimetric method. As a result, the interaction between the components was quantified, and the kinetic parameters of pyrolysis were calculated.

The presented studies are mainly devoted to determining the kinetic parameters of pyrolysis using different methods. This leads to a wide range of research and calculations. In addition, the study of the thermal characteristics of the process is carried out using differential scanning calorimetry, which requires additional equipment and data processing. Therefore, it is advisable to carry out a preliminary assessment of the components of the MSW as fuel using a technique that allows you to calculate the kinetic and thermal characteristics of components without the involvement of additional methods (DSC) and complex calculations of the kinetic parameters of the process. A simplified calculation of the kinetics of the process, namely the calculation of average decomposition rates and the assessment of the conditional thermal effects of the decomposition process, allows us to determine the possibility of using the investigated combustible components of the MSW as the RDF components.

The largest part of the MSW consists of food waste, paper and cardboard, plastic, glass, and textiles [20]. Recycling of the MSW into the RDF involves sorting waste and separating combustible components. The main combustible components of the MSW can be identified by analysing the morphological composition of waste in the Ukraine. Paper, cardboard, plastic, textiles, leather and rubber products, and wood can be used to produce the RDF [21].

MATERIALS AND RESEARCH METHODS

A thermal analysis of the most common types of combustible components of the MSW was carried out to determine the prospects for their use as a fuel and to study the kinetics of thermal decomposition during combustion. The study was carried out in the derivatograph "Q-1000" of the Paulik-Paulik-Erdey system (MOM company, Hungary) [22] modernized at the IET of NAS of the Ukraine. The derivatograph implements methods of thermogravimetry and differential thermal analysis. These methods contribute to deepening knowledge on the kinetics of thermal destruction and heat generation [23].

The subjects of the study were packaging paper, 4 types of cardboard from packaging boxes and disposable tableware, fragments of a polyethylene terephthalate (PET) bottle, polyethylene film and biodegradable film based on corn starch from food bags, 3 types of textiles

of different origins, 2 types of genuine leather, faux leather, and pine wood (Table 1). Before the study, all materials were kept for a long time in the air environment of the laboratory at 20 °C and relative humidity of 45%, and were crushed to a linear particle size of ≤ 0.5 mm.

Thermal destruction of materials was studied in a conical platinum crucible without a lid when heated from ambient temperature to 1000 °C at a rate of 7.4 K/min and the resolution of the scales is 0.5 mg in the presence of air oxygen. Data collection and processing was carried out using “Derivatograph” computer application program.

Based on the results of thermal analysis, data on changes in temperature (T) and mass (TG) of the sample, rate of change of mass (DTG) and heat generation (DTA) (Fig. 1–5) were obtained during the heating process. Processing and analysis of experimental data made it possible to determine the temperature ranges of dehydration and thermal decomposition of organic (OS) and mineral substances (MS), moisture and ash content in the samples (Table 1), and the rate of decomposition of OS (Table 2).

Conditional specific thermal effects (STE) of thermal decomposition of OS (Table 1) were determined for estimating heat generation in the process of thermal decomposition of combustible components of the MSW using the “Deri-

vatograph” program. STE is the part of the area (mV s) of the integral thermal effect divided by the mass (mg) of the OS of the sample. The integral thermal effect was calculated as the area determined by the trapezoidal method between the DTA curve and the predicted baseline. The straight line connecting the points of complete dehydration and completion of heat release on the DTA curve was taken as the baseline.

RESEARCH RESULTS AND DISCUSSION

Figure 1 shows a complete derivatogram of a thin packaging cardboard sample, as an example for better understanding of the processes that occur during the heating of samples of combustible components of municipal solid waste, represented by the DTG and DTA curves in Figs. 2–5.

The thermal destruction of paper and cardboard samples (Table 1, Fig. 2) is the same type. Dehydration is completed between 163 and 176 °C, depending on the type of material. It is accompanied by heat absorption (DTA curves, Fig. 2). Cardboard from a cup has the narrowest dehydration range, and corrugated cardboard has the widest.

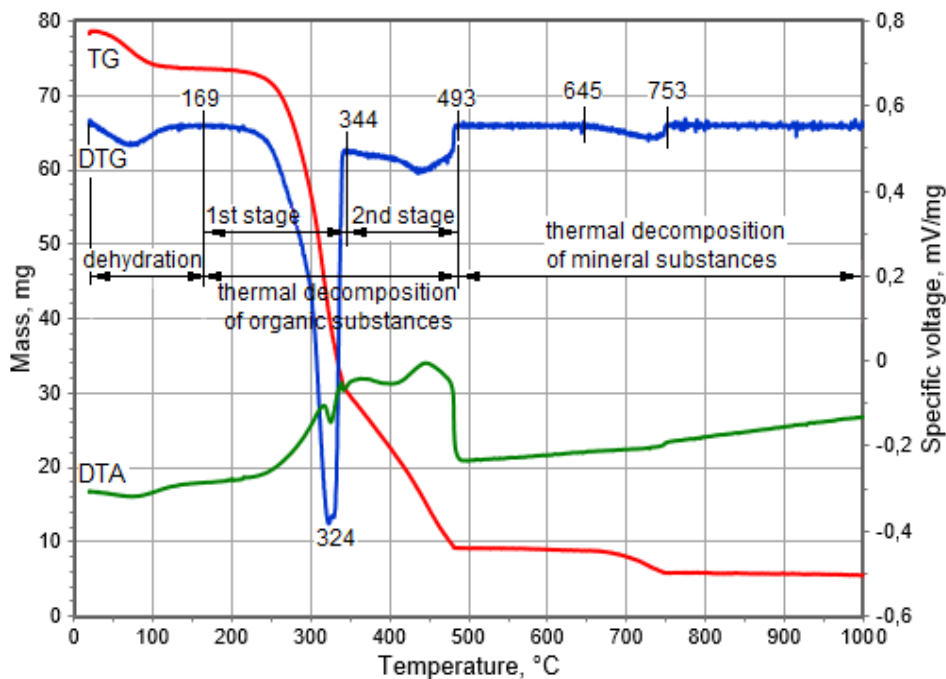


Fig. 1. Derivatogram of the sample of thin packaging cardboard.

Table 1

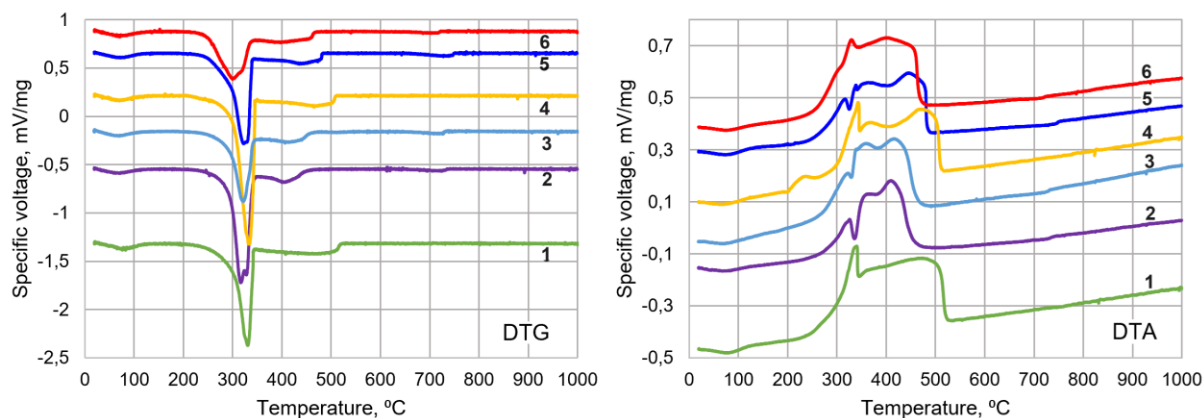
Thermal characteristics of MSW components

Sample	Water removal		Thermal decomposition of OS		Thermal decomposition of MS		Ash content, % DM	STE, mV·s·mg ⁻¹ DM
	range, °C	moisture content, %	range, °C	content, % DM	range, °C	content, % DM		
Paper	20-166	6.02	166-495	90.05	495-1000	3.68	6.27	315.52
Thin packaging cardboard	20-169	6.0	169-493	87.64	493-1000	4.89	7.47	395.62
Corrugated cardboard from packaging boxes	20-176	6.81	176-488	86.82	488-1000	4.58	8.60	479.87
Cardboard from a cup	20-163	6.73	163-517	96.65	517-1000	1.59	1.76	437.77
Cardboard from a plate	20-169	5.83	169-545	78.76	545-1000	5.16	16.08	468.51
Pine wood	20-171	6.94	171-525	98.47	525-1000	0.68	0.85	488.61
Polyethylene film	–	0	211-516	95.86	516-1000	2.16	1.98	456.86
PET bottle material	–	0	247-572	98.76	572-1000	1.06	0.18	339.68
Biodegradable film	23-122	1.77	122-573	81.61	573-1000	8.37	10.02	327.02
Wool fabric	19-149	8.62	149-646	96.93	646-1000	1.75	1.32	522.44
Synthetic fabric	20-178	7.96	178-542	97.05	542-1000	1.90	1.05	496.99
Cotton fabric	19-162	4.30	162-513	97.53	513-1000	1.35	1.12	365.23
Cotton fibers	20-169	4.04	169-465	98.0	465-1000	1.11	0.89	471.57
Genuine thick leather	20-156	10.08	156-595	95.32	595-1000	1.42	3.26	622.92
Genuine thin leather	20-152	10.79	152-501	94.03	501-1000	2.09	3.88	533.44
Faux leather	–	0	141-597	69.57	597-1000	16.78	13.65	293.02

The thermal decomposition of OS occurs in stages in the range of 163–545 °C and conventionally includes low-temperature and high-temperature stages. The maximum rate of OS decomposition is registered at the first stage in the range of 300–336 °C for all samples (Fig. 2). The determined average rate of OS decomposition is ~2% of dry material (DM) per minute for most samples (Table 2). Only cardboard from a plate has a 1.3 times lower decomposition rate compared to other samples of paper and cardboard. In paper and cardboard, the low-temperature stage is characterized by a greater intensity of decomposition.

Thermally unstable MS present in the samples decompose in the range from 488 to 1000 °C

(Table 1). The highest content of decomposing MS is observed in cardboard from a plate (5.16% DM), and the lowest amount is observed in cardboard from a cup (1.59% DM). An increase in of the decomposition rate is observed at a temperature of 645–750 °C in samples of cardboard and paper, except for the cardboard from a cup. This is accompanied by an endothermic effect. This temperature range corresponds to that of the temperature of thermal dissociation of calcium carbonate (chalk) used in the technology of manufacturing paper products. The ash content varies from 1.76 (cardboard from a cup) to 16.08% DM (cardboard from a plate).



1 – pine wood; 2 – paper; 3 – cardboard from a plate; 4 – cardboard from a cup; 5 – thin packing cardboard; 6 – corrugated cardboard from packaging boxes.

Fig. 2. Combined DTG and DTA curves of samples.

Table 2

Temperature ranges, proportions of decomposed OS and average rates of decomposition of MSW components

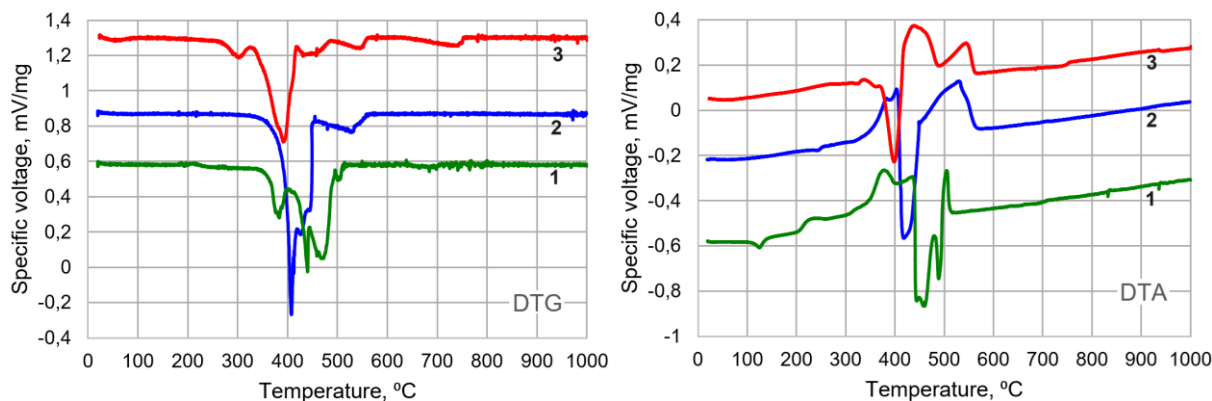
Sample	First stage			Second stage			Average rate of decomposition, % DM/min
	range, °C	proportion of OS, %	decomposition rate, % DM/min	range, °C	proportion of OS, %	decomposition rate, % DM/min	
Paper	166-349	70.65	2.94	349-495	29.35	1.18	2.04
Thin packaging cardboard	169-344	66.82	2.80	344-493	33.18	1.29	2.01
Corrugated cardboard from packaging boxes	176-347	65.68	2.77	347-488	34.32	1.40	2.08
Cardboard from a cup	163-346	66.49	2.91	346-517	33.51	1.28	2.04
Cardboard from a plate	169-360	69.38	2.28	360-545	30.62	0.90	1.55
Pine wood	171-346	59.55	2.75	346-525	40.45	1.52	2.07
Polyethylene film	211-402	21.24	0.85	402-516	78.76	4.42	2.33
PET bottle material	247-456	84.74	3.07	456-572	15.26	0.92	2,26
Biodegradable film	122-419	76.06	2.29	419-573	23.94	0.86	1.35
Wool fabric	149-398	46.83	1.39	398-646	53.17	1.52	1.45
Synthetic fabric	178-338	48.70	2.33	338-542	51.30	1.74	1.98
Cotton fabric	162-378	80.18	2.79	378-513	19.82	1.01	2.07
Cotton fibers	169-359	70.37	2.89	359-465	29.63	1.83	2.47
Genuine thick leather	156-367	43.45	1.56	367-595	56.55	1.67	1.62
Genuine thin leather	152-350	53.97	2.08	350-501	46.03	1.95	2.02
Faux leather	141-346	71.40	1.83	346-597	28.60	0.59	1.14

The DTG and DTA curves of paper and cardboard repeat the nature of the curves of pine wood (Fig. 2, curve 1). This is quite natural, since cellulose is the main raw material component in the production of paper and cardboard.

Cardboard from a cup is the closest to wood in terms of the nature of thermal destruction.

Wood dehydration occurs in the range from 20 to 171 °C, with a maximum rate at 77 °C. At the second stage, OS decomposes in two stages (low temperature (171–346 °C) and high temper-

ature (346–525 °C)). This is accompanied by intense heat generation. The maximum average rate of decomposition (2.75% DM/min.) is registered at the first stage. A further temperature increase causes the decomposition of a small amount of mineral substances (0.68% DM) within the range of 525–1000 °C. The ash content in the pine wood sample was determined to be 0.85% DM.



1 – polyethylene film; 2 – PET bottle material; 3 – biodegradable film.

Fig. 3. Combined DTG and DTA curves of samples.

Thermal destruction of polyethylene film begins with a glass transition at 126 °C, at which polyethylene transforms into an elastic state. Thermal decomposition with the loss of mass of the sample begins at 211 °C and has a staged nature (Tables 1 and 2). The first stage is completed at 402 °C and has a maximum decomposition rate at 381 °C. At this stage, only 21.24% of OS is decomposed at a relatively low rate (0.85% DM/min). A further increase in temperature causes intensive formation of gaseous substances. They leave the crucible at a certain temperature (~436 °C).

This leads to a sharp loss of heat and a decrease in the temperature of the crucible with the sample. This is reflected in the DTA curve as an endothermic peak with a maximum at 459 °C. The second stage is characterized by a significantly higher average rate (4.42% DM/min) and depth of OS decomposition of 78.76% DM.

Mineral substances were found in the polyethylene film. Their decomposition is observed in the range of 516–1000 °C (Table 1). Most of MS (1.62% of DM) decomposes in the range of 638–713 °C and has a pronounced endothermic character (DTA curve).

This is most likely due to the dissociation of calcium carbonate.

Plastic waste is on the same level as paper and cardboard in terms of content in the MSW. Fragments of a PET bottle and a polyethylene film were used in the study (Fig. 3). Thermogravimetric analysis showed the absence of water in the plastic samples within the used sensitivity limits of the scales (Table 1).

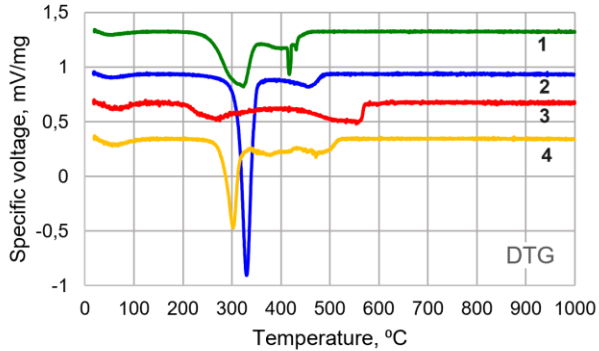
The thermal decomposition of a sample from a PET bottle (Tables 1 and 2, Fig. 3) begins simultaneously with the achievement of the glass transition at 247 °C and occurs in two stages. A higher intensity of decomposition is observed at the first stage with a maximum rate at 407 °C. Intense gas formation occurs in the range of 387–456 °C. It was found that the content of decomposing mineral substances of the sample is 2 times less, and the ash content is 11 times less than in the sample from polyethylene film.

A thermal analysis of the biodegradable film of Conserv Ukraine LLC, made from modified corn starch and biodegradable petroleum products, was performed. Packages from such a film are quite common in the Ukraine.

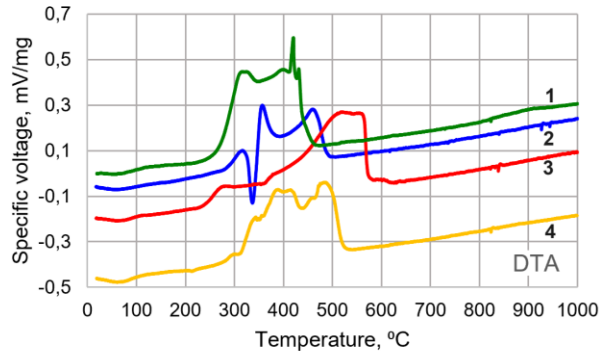
Dehydration of the biodegradable film is observed up to 122 °C (Fig. 3, Table 1). After the water is removed, the decomposition of OS begins immediately. It occurs in several stages, differing in decomposition rates (DTG) and associated thermal effects (DTA). The maximum rate of decomposition was registered at 392 °C. Intense gas formation is observed in the range of 325–419 °C. The decomposition of OS ends at 573 °C. The endothermic process is registered reaching 636 °C during the decomposition of MS. Its rate increases up to 740°C and ends at 760°C. The temperature range of the registered

endothermic peak coincides with the temperatures of thermal dissociation of calcium carbonate. The ash content of the studied biodegradable film is quite high (~10% DM) compared to polyethylene film (Table 1).

The thermal destruction of textiles was studied on samples of cotton, wool and synthetic fab-



rics (Table 1 and 2, Fig. 4). Wool fabric has the most narrowest dehydration temperature range (19–149 °C), while synthetic fabric has the widest range (20–178 °C). At the same time, the longest decomposition of organic compounds was registered in wool fabric.



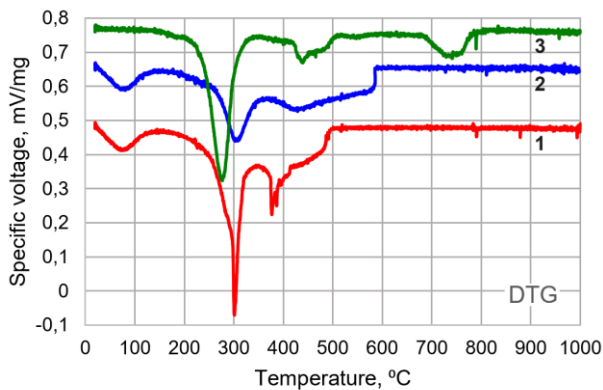
1 – cotton fibers; 2 – cotton fabric; 3 – wool fabric; 4 – synthetic fabric.

Fig. 4. Combined DTG and DTA curves of samples.

Destruction of cotton fabric begins immediately after dehydration at a temperature of 162 °C (Fig. 4, curve 2). The first stage is characterized by greater intensity due to powerful gas formation in the range of 280–357 °C with a maximum rate at 331 °C. Comparison of the obtained results with data on the decomposition of cotton fibers (Fig. 4, curve 1) as a raw material for the fabric production showed that the decomposition range of OS is narrower by 55 °C, and intensive gas formation is not registered. This is most likely due to the presence of synthetic impurities in cotton fabric.

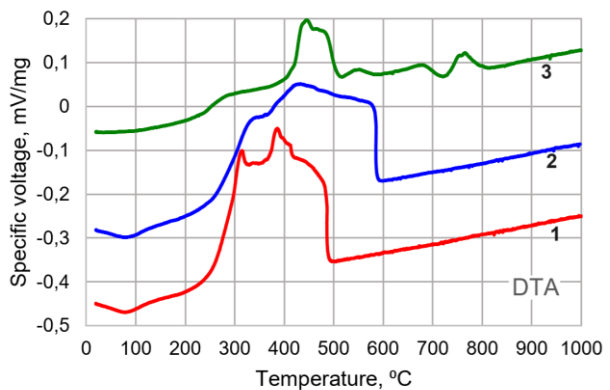
The ash content in the textile samples is in the range of 1.05–1.32% DM.

The nature of the derivatographic curves of thermal decomposition of genuine leather



(Fig. 5) is similar to the curves of cardboard and fabric. Water removal occurs up to 152 and 156 °C, depending on the type of skin (Table 1). Due to hydrophilicity, genuine leather has a fairly high equilibrium moisture content (10.08–10.79%) and relatively low thermal stability (152–156 °C).

The organic substances of the leather also decompose in two stages. In comparison with thick leather, thin leather has a narrower decomposition range by 90 °C and, accordingly, a 1.2 times greater rate of OS decomposition (Table 2). Decomposition of a small amount of MS is observed in samples of thin skin after 501 °C and thick skin after 595 °C. The ash content directly depends on the thickness of the leather (Table 1).



1 – genuine thin leather; 2 – genuine thick leather; 3 – faux leather.

Fig. 5. Combined DTG and DTA curves of samples.

The decomposition of faux leather begins with thermal destruction of OS at 141 °C and has 2 stages. Moreover, the rate of decomposition is 3 times higher at the first stage than in the second (Table 2). Decomposition of MS occurs upon reaching 597 °C. The content of thermally unstable MS in faux leather is quite high compared to all studied samples. A significant content of chalk was registered; therefore, the ash content is also high (Table 1).

The studies have shown that dehydration of moisture-containing combustible components of the MSW can be observed up to 178 °C. However, each of the components has its own temperature of complete dehydration, after reaching which thermal decomposition begins (Table 1). The temperature of the beginning of thermal decomposition is often called thermal stability.

Thermal stability is an important characteristic of a material that must be considered when developing fuel production technology to avoid ignition during drying.

Due to the long stay of the samples in the laboratory, their moisture content reached equilibrium values in the range of 0–10.8% and depends on the type of components.

Thermal decomposition of organic compounds occurs in several stages, which differ in kinetics and magnitude of accompanying thermal effects.

At a certain temperature, in some samples (polyethylene and biodegradable films, PET and cotton fabric), gaseous substances are intensively formed, which quickly leave the boundaries of the crucible. This is reflected in the DTA curves as endothermic and leads to an underestimation of the actual thermal effects of thermal decomposition.

Thermally unstable MS, such as CaCO_3 , MgCO_3 , etc., which are present in among the investigated components of the MSW as fillers, decompose in the range from 488 to 1000 °C and not only increase the ash content of the fuel, but also reduce its calorific value due to heat consumption on their thermal dissociation.

Analysis of the kinetics of thermal decomposition of organic substances of the MSW components (Table 2) showed that most samples decompose more intensively at the first stage, at lower temperatures. Only polyethylene film, wool fabric and genuine thick leather are characterized by intensive decomposition in the second stage. Under the same heating conditions, PET bottle material has the highest decomposition

rate in the first stage, and polyethylene film has in the second.

If we compare the overall average rate of decomposition, it turned out to be the highest in the samples of polyethylene film and cotton fibers (2.33% and 2.47% DM/min, respectively), and the lowest in the faux leather (1.14 % DM/min).

Analysis of the calculated values of STE showed that genuine thick leather has the largest value, and faux leather has the smallest value, which is a consequence of its high ash content and thermally unstable MS (Table 1). The values of STE calculated from the area under the DTA curves are clearly underestimated in samples of PET bottles, polyethylene and biodegradable films, as well as cotton fabric due to the loss of heat of thermal decomposition with gases. Therefore, it is necessary to determine the calorific value of MSW components in a calorimetric bomb [24] for the final thermal assessment of them as raw components of fuel.

However, the conditional STE of the thermal decomposition of a sample of pine wood (Table 1), the thermal characteristics of which are known (in particular, the heat of combustion) [25], was compared with the values of the STE of all investigated combustible components of the MSW. This comparison made it possible to verify that almost all samples, except faux leather, have satisfactory properties and can be used as the RDF components.

CONCLUSIONS

The thermal analysis of the combustible components of municipal solid waste made it possible to determine the characteristic temperatures of dehydration, thermal decomposition of organic and mineral substances.

The content of water, organic and thermally unstable mineral substances, and ash was determined by the method of thermogravimetry. Data on the kinetics of thermal decomposition of organic substances were obtained.

Differential thermal analysis made it possible to evaluate the thermal effects of thermal decomposition of combustible components of municipal solid waste and the kinetics of heat generation.

Knowledge of conditional specific thermal effects and kinetics of thermal decomposition of organic substances of the MSW components make it possible to select fuel with certain thermal characteristics. During the development of the RDF, certain characteristics will make it pos-

sible to satisfy the needs of fuel consumers both in terms of calorific value and combustion kinetics.

The obtained results indicate the possibility of using the investigated combustible components of the MSW as components of the RDF.

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