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СИСТЕМНЫЙ АНАЛИЗ ЭФФЕКТИВНОСТИ ИСПОЛЬЗОВАНИЯ ВТОРИЧНЫХ ЭНЕРГОРЕСУРСОВ В КРУГОВОЙ ЭКОНОМИКЕ

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Целью статьи является исследование уровня и динамики энергоемкости полимерной продукции, оценка потенциала использования полимерных отходов в качестве источника тепловой энергии в экономике замкнутого цикла. В качестве основных методов исследования предложен авторский методический инструментарий, использован системный подход, методы дескриптивной статистики, графического анализа, причинно-следственных связей. Произведен анализ текущих тенденций с расчетом уровня энергоемкости полимерной продукции, позволивший отнести исследуемые производства к 1 классу энергоемкости «Высокая энергоемкость». В производстве полимерной продукции выделены три вида отходов (пластик, резина, термореактивные смолы), являющиеся потенциальным сырьем для получения вторичной тепловой энергии. Показано, что значения теплоты сгорания отходов (31-45 ГДж/т), способы получения энергии и их эффективность (45-70%) позволяют использовать данные виды отходов для разработки решений по альтернативным источникам энергии. Определен масштаб образования отходов полимеров на российских предприятиях, позволяющий сделать вывод о целесообразности разработки решений по альтернативным источникам энергии. Разработан алгоритм расчета объема вторичной тепловой энергии, направленный на решение двух задач: задачи определения объема, полученного тепла путем энергетического рециклинга отходов; задачи определения возможного объема продукции, произведенной на основе вторичной тепловой энергии. Апробация алгоритма на примере отходов пластика и использования тепловой энергии от их сжигания показала возможность выработки из отходов 56467,2 Гкал тепловой энергии и производства с ее использованием 26516,7 т синтетических смол и пластмасс. Рекомендовано при организации энергетического рециклинга соблюдать приоритет использования отходов непосредственно в производственном цикле в качестве вторичного сырья с учетом экологической и экономической целесообразности.

Ключевые слова: источники энергии, устойчивое развитие, энергоемкость, отходы производства, энергетический рециклинг отходов, класс энергоемкости, алгоритм, полимерная продукция

SYSTEM ANALYSIS OF THE EFFICIENCY OF SECONDARY ENERGY RESOURCES USE IN CIRCULAR ECONOMY

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The purpose of the article is to study the level and dynamics of the energy intensity of polymer products, to assess the potential for using polymer waste as a source of thermal energy in a closed-cycle economy. As the main research methods, the author's methodological tools are proposed, a systematic approach, methods of descriptive statistics, graphical analysis, and cause-and-effect relationships are used. The analysis of the current trends with the calculation of the level of energy intensity of polymer products, which made it possible to classify the investigated industries as the 1st class of energy intensity "High energy intensity". In the production of polymer products, three types of waste are identified (plastic, rubber, thermosetting resins), which are potential raw materials for obtaining secondary thermal energy. It is shown that the values of the heat of combustion of waste (31-45 GJ/t), methods of energy production and their efficiency (45-70%) allow using these types of waste to develop solutions for alternative energy sources. The scale of the formation of polymer waste at Russian enterprises has been determined, which makes it possible to draw a conclusion about the advisability of developing solutions for alternative energy sources. An algorithm for calculating the volume of secondary heat energy has been developed, aimed at solving two problems: the problem of determining the volume of heat received by waste energy recycling; the task of determining the possible volume of products produced on the basis of secondary heat energy. Approbation of the algorithm using the example of plastic waste and the use of thermal energy from their combustion showed the possibility of generating 56467.2 Gcal of thermal energy from waste and producing 26516.7 t of synthetic resins and plastics using it. When organizing energy recycling, it is recommended to observe the priority of using waste directly in the production cycle as a secondary raw material, taking into account environmental and economic feasibility.

Key words: energy sources, sustainable development, energy intensity, production waste, energy waste recycling, energy intensity class, algorithm, polymer products

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INTRODUCTION

Chemical production high energy intensity conditions the continuous development and implementation of innovative solutions aimed at increasing energy efficiency in order to ensure the competitiveness of products. Reducing resource intensity of production is possible not only through the introduction of new chemical technology, but also through the use of various organizational and technological methods that ensure energy savings.

One of the directions for sustainable production models development in developed countries, including framework of EU action plan for the implementation of a circular economy, is balanced waste recycling, including incineration for energy generation. At the same time, an increase in the volume of polymer processing is extremely important for the transition to a circular economy.

Undoubtedly, the priority is the return of waste polymer products to the production cycle for use as secondary raw materials. However, with the availability of appropriate equipment and the feasibility of integrating technological processes, it is possible to process unused waste into energy resources. At the same time, method choice and reserves for increasing energy efficiency and their practical use should be based on reliable data from monitoring energy consumption at the enterprise, system analysis and forecasting the production and consumption of energy.

The foregoing determines the expediency of studying polymer production energy intensity, the scale of the formation and nature of waste turnover, the potential for using polymer waste as a source of thermal energy in a closed production cycle. We believe that the obtained scientific and practical knowledge and results will make a new contribution to the theory development of sustainable production models and consumption of industrial waste.

LITERATURE REVIEW

Numerous works of foreign and domestic researchers are devoted to the issues of increasing chemical industries energy efficiency and the search for alternative energy sources. The interest in this topic is due to the importance of sustainable energy-saving industries development based on the scientific knowledge obtained, the derived principles and patterns. The main areas of rational use of energy resources research field are determined by the work of the following scientists: Sembiring and Krishna developed a business strategy model for technological services in the field of renewable energy sources [1]; Sergeev et al. examined the flow distribution and thermal efficiency of coil heat exchangers [2]; Cabello Eras et al. studied the problems of energy management of compressed air systems in industry [3]; Meha, Pfeifer and Duic investigated the integration of variable renewable energy sources into a coal-fired power system using energy-to-heat technologies [4]; Wan and Luo conducted economic optimization of chemical processes based on zone predictive control with redundancy of variables [5]; Rahman assessed the reality and prospects of generating electricity from renewable sources in Arab countries [6]; Malysheva et al. also identified trends in the formation of production energy intensity and the structure of the "energy portfolio" [7].

In order to develop organizational approaches to the introduction of a circular economy, Blomsma et al. developed a system of circular strategies for manufacturing companies to support innovation focused on a cyclical economy [8]; Kozlov et al. analyzed the main types of chemical products [9]; Laila et al. conducted an extensive bibliometric survey on energy economics [10]; Hahladakis and Iacovidou explored the challenges and tradeoffs in closing the plastic waste cycle for recycling [11]; Nilsen built a hierarchy of resource use for a sustainable circular economy [12]; Desing et al. considered the issues of ensuring sustainable circular economy in the projection of an engineering approach to assessment of renewable energy sources potential [13]; Shinkevich et al. developed an algorithm for optimizing energy consumption in chemical production based on descriptive analytics and neural network modeling [14]; Allakhverdieva studied the physical and mechanical properties of composite materials [15].

The ecological problems of energy-saving are considered by research teams Meshalkin et al., who presented an intelligent logical informational algorithm for choosing energy and resource-saving chemical technologies [16]; Bahreini et al., who studied anaerobic digestion of primary sludge for the simultaneous recovery of resources and energy [17]; Kolesnikov et al. proposed an integrated approach to wastewater disposal [18]; Berardi et al. carrying out an analysis of a waste-based fuel strategy [19]; Malav et al. providing an overview of solid waste as a renewable energy source for a waste-to-energy project [20]. To develop the direction of processing waste into energy, Zhang et al. proposed new technologies for converting waste to energy based on anaerobic digestion [21]; Liu et al. reviewed the state of the art in organic solid waste and coal co-firing technology [22]; Savini investigated the circular economy of waste, including recovery, incineration and reuse [23].

Nevertheless, despite the availability of significant theoretical and methodological material, analytical data, there is a lack of research to solve the problems of using alternative energy sources in the chemical industry, the potential and feasibility of using production waste as energy resources.

RESEARCH METHODS

The methodological basis of the study included general scientific econometric methods, as well as research methods adequate to the specifics of the task of assessing the potential of using polymer waste as a source of thermal energy in a closed production cycle.

The energy intensity of production, expressed as the consumption of electrical energy required for the production of a unit of production, is determined by the formula:

$$Cep^i = \frac{Ve^i}{Vp^i}$$

where Cep^i is product energy intensity, kWh / t;

Ve^i is the volume of electrical energy used in production, kWh;

Vp^i - volume of products, tons;

i is the type of product being manufactured.

Product heat capacity of production, expressed as the consumption of thermal energy required for the production of a unit of product, is determined by the formula:

$$Chp^i = \frac{Vh^i}{Vp^i}$$

where Chp^i is product heat capacity, kcal / t;

Vh^i is the volume of heat energy used in production, kcal.

The fuel consumption of production, expressed as the fuel consumption required to produce a unit of production, is determined by the formula:

$$Cfp^i = \frac{Vf^i}{Vp^i}$$

where Cfp^i is product fuel capacity, t of fuel equivalent/t;

Vf^i is the volume of fuel used in production, t.e.

Calculation of combustion heat of waste value taking into account the parameter of the efficiency of its processing is determined by the formula

$$Qwe^j = \frac{Qw^i}{Ep^k}$$

where Qwe^j is waste heat of combustion, taking into account the parameter of processing efficiency depending on the method of obtaining energy, kcal / t;

Qw^j is waste heat of combustion due to its physicochemical properties, kcal/t;

Ep^k - coefficient of efficiency of waste processing, due to one or another method of obtaining energy,%;

j is the type of waste to be converted into energy;

k is the way to get energy.

Calculation of thermal energy volume obtained by waste energy recycling is determined by the formula:

$$Ehr^{jk} = Qwe^j \cdot W^j$$

where Ehr^{jk} is the volume of thermal energy obtained by waste energy recycling, kcal/t;

W^j is the potential volume of waste to be converted into energy, tonnes.

Calculation of production volume based on heat energy obtained by waste energy recycling is determined by the formula:

$$Phr^i = \frac{Ehr^{jk}}{Chp^i}$$

where Phr^i is production volume of products based on heat energy obtained by waste energy recycling, tons.

In addition, to achieve this goal, the article uses dialectical and systematic approach, methods of descriptive statistics, graphical analysis, cause-and-effect relationships, logical-structural analysis.

DESCRIPTION OF DATA

To determine the energy intensity level and trends in energy consumption of polymer products production, five types of products are considered: synthetic resins and plastics, synthetic rubber, ethylene and propylene, and tire products. Table 1 shows the dynamics of the actual consumption in electrical energy per unit of products made of polymeric materials. As can be seen from the table, the production of synthetic rubber has the highest electrical capacity (2027.2 kWh per ton) due to significant energy consumption for plasticizing, mixing and subsequent processing of mixtures. For 8 years, there has been a positive tendency to reduce the level of electricity consumption in polymer products production by 20-30% (the average rate of reduction in consumption is 82%). An exception is the production of tires for trucks (consumption growth rate 142.7%), which is probably due to the stagnation of this production, namely, unstable demand for products due to increased competition in world markets (Table 1).

Table 1

Actual consumption level of electrical energy per unit of products made of polymeric materials at Russian enterprises, kWh

Таблица 1. **Уровень фактического расхода электрической энергии на единицу продукции из полимерных материалов на российских предприятиях, кВт·ч**

Production types	Electricity consumption per unit of production, kWh		Energy consumption growth rate, 2019/2011, %
	2011	2019	
Synthetic resins and plastics, t	733.9	560.0	76.3
Synthetic rubber, t	2600.2	2027.2	78.0
Ethylene and propylene, t	481.4	412.3	85.6
Tires for trucks, pcs.	52.0	74.2	142.7
Tires for passenger cars, pcs.	18.7	16.5	88.2

Thermal energy accounts for predominant share in polymer production energy portfolio. Similarly to electrical energy, the specific consumption of heat energy has a negative trend in four product positions, where the average rate of decrease in resource consumption in 2011-2019 is 76.9% (Table 2). At the same time, the growth rate of specific heat consumption in tires for trucks production reaches 130%. The most resource-intensive in terms of thermal energy consumption is also synthetic rubber due to specific physical and chemical properties and characteristics of chemical technology (11693 thousand kcal per ton).

For individual operations in polymer production technology, including the preparation and movement of raw materials and products along the technological line, various types of fuels are used. The total specific fuel consumption in conventional units is presented in Table 3, where the maximum level of resource consumption was also noted in the production of synthetic rubber – 652.7 kg c.u. t., ethylene and propylene – 302.5 kg of c.u. t. (Table 3).

Table 2

Actual consumption level of heat energy per unit of products made of polymeric materials, thousand kcal

Таблица 2. **Уровень фактического расхода тепловой энергии на единицу продукции из полимерных материалов, тыс. ккал**

Production types	Heat consumption per unit of production, thousand kcal		Energy consumption growth rate 2019/2011, %
	2011	2019	
Synthetic resins and plastics, t	2827.0	2129.5	75.3
Synthetic rubber, t	15357.2	11693.0	76.1
Ethylene and propylene, t	2583.9	2322.5	89.9
Tires for trucks, pcs.	191.3	248.7	130.0
Tires for passenger cars, pcs.	61.1	40.5	66.3

Table 3

Actual fuel consumption level per unit of polymer products, kg c.u. t.

Таблица 3. **Уровень фактического расхода топлива на единицу продукции из полимерных материалов, кг у. т.**

Production types	Fuel consumption per unit of production, c.u. t.		Fuel consumption growth rate 2019/2011, %
	2011	2019	
Synthetic resins and plastics, t	143.7	113.3	78.8
Synthetic rubber, t	679.5	652.7	96.1
Ethylene and propylene, t	313.7	302.5	96.4
Tires for trucks, pcs.	0.1	0.1	100.0
Tires for passenger cars, pcs.	0.08	1.2	150.0

The largest reduction in fuel consumption is observed in the production of synthetic resins and plastics (the rate of decline is 78.8%). In the production of rubber, ethylene and propylene, there was a slight decrease in resource consumption (96%). In the production of automobile tires, the use of fuel in production is insignificant, and therefore, the dynamics of resource consumption is not very informative.

RESULTS AND DISCUSSIONS

1. Analysis of Energy Resources Consumption Level in the Production of Polymer Products and its Compliance with the Class of Energy Intensity

Energy resources play an important role in polymer production, and are used for heating materials, carrying out chemical reactions, carrying out thermal and mechanical processes, transporting materials and other procedures. Traditionally, Russian enterprises use both electric energy and heat energy and various types of fuel (natural gas, coal, fuel oil, gasoline, diesel fuel, etc.).

Chemical production is conventionally classified into three classes by the level of energy consumption:

1 class "High energy intensity" – energy consumption of more than 2 t of standard fuel per ton of manufactured products;

2nd class "Average energy intensity" – energy consumption from 1 to 2 t of standard fuel per ton of manufactured products;

Class 3 "Low energy consumption" – energy consumption is less than 1 t of standard fuel per ton of manufactured products.

To determine the class of polymer products studied production energy consumption, we will calculate the total consumption of energy resources in units of equivalent fuel. Figure 1 shows the dynamics of energy resources total specific consumption in the production of products from polymer materials. Confirming the above analysis results, the graph demonstrates the dominant position of thermal energy in polymer production, the curve of which is located in the zone above 2 t (range of values ΔCh = [2.692; 3.006] t of fuel equivalent). The second largest resource is fuel, the curve of which is located in the zone from 1.0 to 2.0 t of fuel equivalent. tons (range of values ΔCf = [1.137; 1.233] t of fuel equivalent). The minimum specific weight in the energy portfolio of polymer production is occupied by electrical energy, which has a range of values ΔCe = [0.410; 0.478] t.

The specific consumption of resources in general for energy portfolio of the studied types of industries is presented in Table 4. Integration of data in types of polymer products and types of energy resources made it possible to obtain a single value for resource intensity in 2011-2019. The dynamics of the indicator shows a steady decrease in values from 4.62 t of c.u. t. up to 3.80 t. At the same time, throughout the entire time series, the values of production energy intensity exceed 2.0 t of c.u. t., which makes it possible to classify the investigated polymer production as class 1 according to the level of energy consumption "High energy intensity".

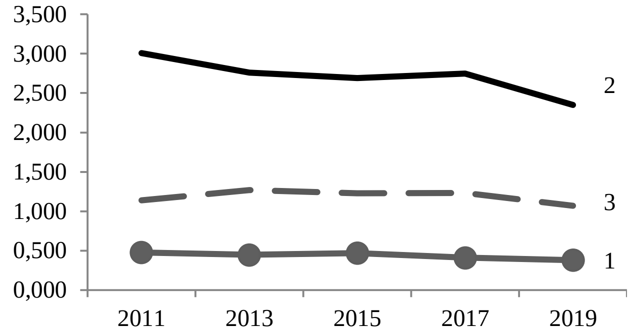

Fig. 1. Dynamics of energy resources total specific consumption in the production of products from polymer materials, tons of fuel equivalent: (1) total specific consumption of electrical energy, tons of fuel equivalent; (2) total specific consumption of heat energy, tons of fuel equivalent; (3) total specific fuel consumption, tons of fuel equivalent

Рис. 1. Динамика суммарного удельного потребления энергетических ресурсов в производстве продукции из полимерных материалов, тонн условного топлива

Thus, relatively high consumption of energy resources in polymer production, corresponding to the 1st class of energy consumption, in a priority order requires continuous improvement of resource-saving technologies, the search for new alternative energy sources, organizational and managerial decisions aimed at increasing energy efficiency.

2. *Assessment of Waste Scale From the Production of Polymer Products that Can Be used in a Closed Cycle as Energy Resources*

The production of energy from waste supports the development goals of a cyclical economy. Energy recycling of polymer waste is considered by Russian and foreign scientists and practitioners as the most efficient way of using waste within production cycle of enterprises. Over the past five years, in developed countries, against the background of a decrease in the disposal of plastic waste, their incineration has increased for the purpose of using the obtained heat in technological production processes.

Table 5 shows energy value and efficiency of recycling waste from the production of polymer products based on data from Russian information and technical reference books on the best available technologies.

Table 4

Correspondence of the actual fuel consumption per unit of polymer products to the class of energy consumption of production, t

***Таблица 4*. Соответствие фактического расхода топлива на единицу продукции из полимерных материалов классу энергоемкости производства, т**

Class of energy intensity production	Energy intensity value(Cr), correponding to energy intensity class, t of fuel equivalent	Actual energy consumption of polymer production, t				
		2011	2013	2015	2017	2019
1 class «High Energy Intensity»	**Cr > 2.0**	**4.621**	**4.477**	**4.389**	**4.389**	**3.800**
2 class «Mid energy intensity»	1.0 > Cr > 2.0					
3 class «Low energy intensity»	Cr < 1.0					

Table 5

Energy indicators of waste polymer products for the purpose of their reuse as heat energy

***Таблица 5.* Энергетические показатели отходов полимерной продукции для целей их повторного использования в качестве тепловой энергии**

Waste type	Calorific value, GJ/t	Method of obtaining heat energy	Processing efficiency,%
Plastic	34.2	Bulk layer incineration	70
		Pyrolysis	55
		Incineration of compressed waste	45
Rubber	31.0	Pyrolysis	55
		Incineration of small fractions	50
Thermosetting resins	45.0	Thermal destruction	70

There are three types of polymer waste (plastic, rubber, thermosetting resins), capable of being reused in the production cycle as energy resources.

So, by the method of thermal destruction of one ton of waste of thermosetting resins or thermosetting plastics, 45.0 GJ/t of thermal energy may be obtained. At the same time, the efficiency of waste processing reaches 70%. Thermal treatment of plastic waste allows to obtain up to 34.2 GJ/t of heat with different productivity, depending on the method of obtaining energy. The most effective in this case is the burning of plastic in a bulk layer, which allows you to recycle up to 70% of waste. Receiving heat energy from rubber waste in the amount of 31.0 GJ/t is possible by pyrolysis (processing efficiency 55%) or by burning small fractions (processing efficiency 50%).

In addition to the listed types of waste in petrochemical production, it is promising to use petroleum coke as a fuel for a combined heat and power plant located in the territorial vicinity. Industrial waste from the combustion of solid fuels, such as coal, oil shale, peat, is a promising raw material for the production of energy resources at thermal power plants.

Thus, a significant amount of heat may be obtained by incinerating waste. Undoubtedly, this requires the organization of waste accumulation, a technological unit or adaptation of the existing equipment.

A study of accumulated waste scale, which is a potential raw material for generating thermal energy, showed significant resources of plastic and rubber waste at Russian enterprises in 2019 (Table 6).

Table 6

Waste, which is a potential raw material for obtaining heat energy, accumulated at Russian enterprises in 2019

Таблица 6. **Отходы, являющиеся потенциальным сырьем для получения тепловой энергии, накопленные на российских предприятиях в 2019 г**

Receipt of waste from other organizations, t	Waste utilized in our own production, t	Waste disposal to other organizations, t	Accumulated waste residue, t
Thermosetting resins (synthetic resins hardened substandard, waste products from thermosetting plastics)			
251.054	0.204	262.640	0.251
Plastic (ABC plastic, waste polymer in the production of rubbers BK and GBK, waste from the production of plastic products, waste from the production of plates, sheets, films and polymer tapes)			
1928.332	1510.883	8538.487	1405.093
Rubber (waste from the production of vulcanized rubber, waste from the production of rubber tires, tires and tubes, waste from rubber-asbestos products)			
10003.54	4401.899	11992.527	3582.707

The volume of plastic waste, including ABC-plastic, waste from the production of butyl rubbers, plastic products, polymer tapes, amounted to 1.4 thousand tons at the end of 2019. At the same time, 8.5 thousand tons of waste were sold by enterprises to third-party organizations for various purposes. If production wastes are not sold, but will be used by enterprises for internal purposes, then the potential volume for obtaining secondary energy resources will be 9.9 t.

Similarly, the potential volume of waste energy recycling from the production of vulcanized rubber, tires and tires, rubber asbestos products is 15.6 t, including 3.6 t of accumulated residue and 12.0 t of waste transferred to third parties. Clearly, the volume of various polymer waste types generated at Russian enterprises in 2019, and in terms of physical and chemical properties suitable for generating heat energy, is shown in Fig. 2.

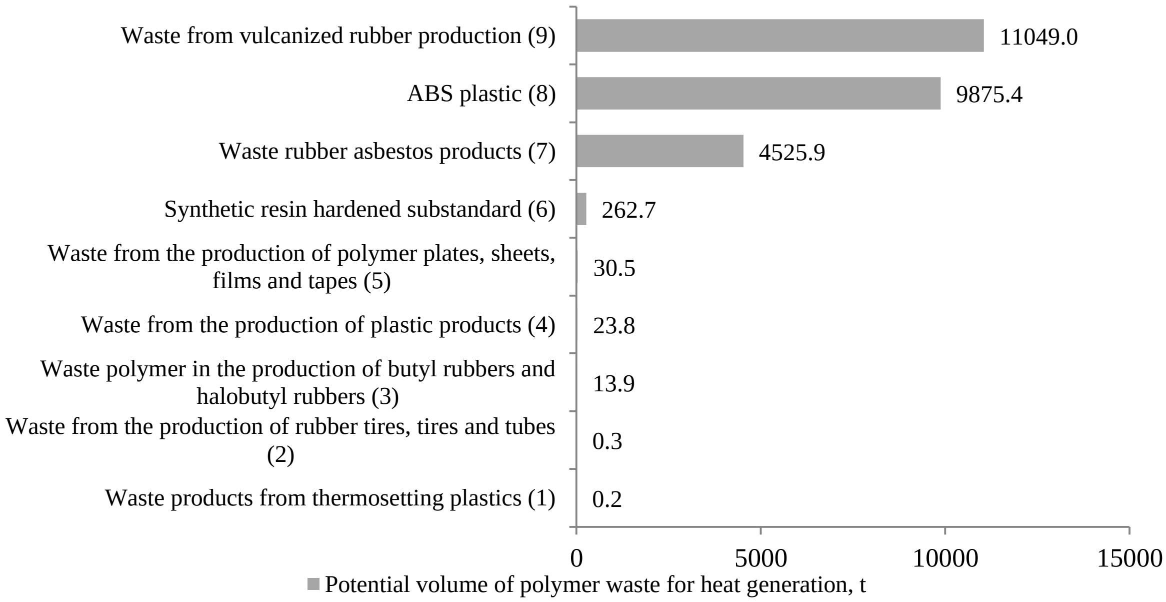

Fig. 2. Potential residual volume of polymer waste at Russian enterprises in 2019 for heat generation, t

Рис. 2. Потенциальный остаточный объем полимерных отходов на российских предприятиях в 2019 г для выработки тепловой энергии, т

The most energy-efficient waste products of thermosetting plastics (phenoplast, aminoplast, textolite, getinax, polyurethane, faolite, fiberglass) in the amount of 262.7 tons are sold by manufacturers to other organizations and today are not considered as their own secondary energy resources. The accumulated residual waste of thermosetting resins is only 251 kg.

Thus, a probable reserve or source of thermal energy is located in the polymer waste accumulated at the enterprises and may be recycled with the level of waste processing efficiency up to 45-70%. The incineration of waste with a limited thermal energy output (up to 45%) is considered by us as energy utilization.

It should be noted that the planning of operations with waste-to-energy facilities should be consistent and maintain a hierarchy of waste management, taking into account the potential of new and emerging waste recycling technologies in the main production.

3. *Development and Testing of an Algorithm for Calculating the Volume of Secondary Heat Energy and Production of Products Based on Resources Obtained by Energy Recycling of Waste*

The next step towards achieving the purpose of the study is to determine possible saving of energy resources due to use of secondary thermal energy obtained by energy recycling of waste. In this direction, we see the solution of two sequential tasks:

task 1 - calculating the amount of thermal energy that may be obtained as a result of waste energy recycling in one way or another;

task 2 - a conditional calculation of the volume of products produced on the basis of thermal energy obtained as a result of energy waste recycling.

The algorithm of sequential actions for solving the assigned tasks includes four key blocks for performing data operations, as well as blocks for entering and processing data, branching the algorithm (Fig. 3). The four key blocks of the algorithm are as follows:

1) After setting the problem and determining type of waste, data on combustion heat (Qw) is entered with the specification of method for obtaining heat energy and the corresponding level of processing efficiency (Ep). Under the true condition of waste processing efficiency Ep > 45%, the movement along the tree of the algorithm continues. If this condition is not met, the cycle is exited to correct the set task associated with the choice of waste type and the method of its processing.

2) For further actions, the data on calorific value (Qw) is converted from J/t to kcal/t. After that, the value of waste heat combustion is calculated taking into account parameters of the processing efficiency (Ep) according to the proposed method. This completes the preparation of data on the calorific value of waste.

3) Data is entered on the volumes of waste (W) that are subject to energy recycling, followed by the calculation of the value of secondary heat energy (Ehr). This result is a solution to problem 1. The received volume of secondary heat energy (Ehr) is also considered by us as the value of the possible saving of primary energy resources.

4) To determine the volume of production using secondary resources, data is entered on the consumption of heat energy for production of a unit of production (Chp). After preparing the data, a conditional calculation of production volume is made based on heat energy obtained by energy waste recycling (Phr). This result is a solution to Problem 2.

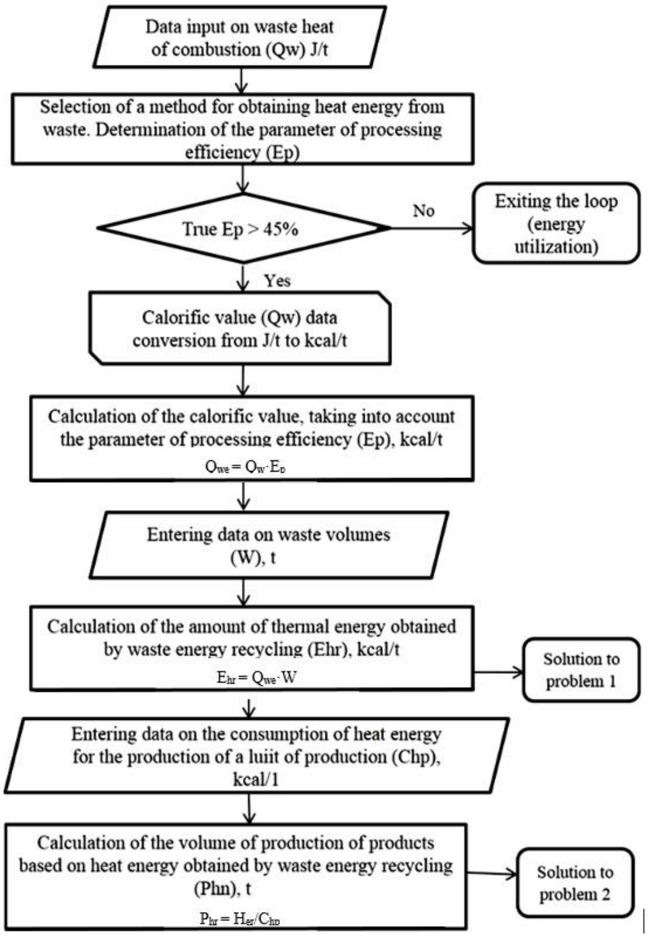

Fig. 3. Algorithm for calculating heat energy volume (task 1) and the volume of production (task 2) based on the resources obtained by energy waste recycling

Рис. 3. Алгоритм расчета объема тепловой энергии (задача 1) и объема производства продукции (задача 2) на основе ресурсов, полученных путем энергетического рециклинга отходов

We tested the algorithm using the example of plastic waste and thermal energy use from their combustion in the production of synthetic resins and plastics. The sequence of calculation according to the algorithm tree is shown in Table 7.

The combustion heat of plastic according to its physical and chemical properties is 34.2 gJ/t or 8168529.4 kcal/t. Energy recycling of waste by the method of incineration in a bulk bed gives a recycling efficiency of 70%. Thus, when burning 1 t of plastic waste by the above method, 5,717,970.6 kcal of thermal energy can be obtained.

At the end of 2019, at Russian enterprises, the potential volume of plastic waste, including waste sold to third-party organizations, amounted to 9875.4 t. It is this amount of waste that can be processed into secondary heat energy within the framework of our own production.

Table 7

Calculation of thermal energy volume (task 1) and the volume of production of synthetic resins and plastics (task 2) based on resources obtained by energy recycling of plastic waste

Таблица 7. **Расчет объема тепловой энергии (задача 1) и объема производства синтетических смол и пластмасс (задача 2) на основе ресурсов, полученных путем энергетического рециклинга отходов пластика**

Calculation algorithm procedure name	Parameter value
Plastic combustion heat (Qw), gJ/t	34.2
Method of obtaining heat energy from waste	Bulk layer incineration
Waste processing efficiency,%	70.0
Plastic combustion heat (Qw), kcal/t	8168529.4
Heat of plastic combustion, taking into account the parameter of processing efficiency (Ep), kcal/t	5717970.6
Waste plastic volume (W), t	9875.4
Result 1 **Thermal energy obtained by energy recycling of plastic waste (Ehr), thousand kcal/t**	**56467246.9**
Heat consumption for the production of 1 ton of synthetic resins and plastics (Chp), thousand kcal/t	2129.5
Result 2 **Production volume of synthetic resins and plastics based on thermal energy obtained by energy recycling of plastic waste (Phr), t**	**26516.7**

The calculation based on the proposed methodological tools showed the amount of heat energy in 56467.2 Gcal, which may be obtained as a result of burning plastic waste in a bulk layer in the amount of 9875.4 t.

With the consumption of thermal energy for production of 1 ton of synthetic resins and plastics 2129.5 thousand kcal, the conditional calculation of products volume produced on the basis of thermal energy obtained as a result of energy recycling of plastic waste will be 26516.7 t.

It should be kept in mind that for an effective implementation of processes for processing of waste into energy, it is necessary to use advanced energy efficient technologies, objectively assess the utilization of production facilities and provide combined supplies of electricity and heat. In addition, it is important to correctly determine technology and process that has the greatest potential for optimizing the output energy, taking into account possible changes in the secondary raw materials for processes of obtaining energy from waste.

CONCLUSION AND RECOMMENDATIONS

Thus, the study of potential for using polymer waste as an energy source in a closed production cycle allows us to draw the following conclusions:

1. Analysis of energy consumption level and dynamics per unit of polymer products showed a positive tendency to reduce energy intensity in 2011-2019 at Russian enterprises for such types of products as synthetic resins and plastics, synthetic rubber, ethylene and propylene, tires for passenger cars. The decrease in specific consumption of energy resources amounted to 25% for electric energy, up to 33% for thermal energy, and up to 22% for various types of fuel. It was determined that the predominant share (60%) in "energy portfolio" of the studied polymer products, due to the peculiarities of chemical technology, is heat energy. In this regard, the present study is aimed precisely at solving the problem of reducing heat consumption in the production of polymer products.

2. Total consumption assessment of energy resources required for the production of a unit of polymer products has been made. Calculations show the value

of energy intensity indicator from 3.8 to 4.6 t of standard fuel during 2011-2019. According to classification of chemical industries by energy intensity classes, the production of polymer products is assigned to the 1st class "High energy intensity" with energy consumption exceeding 2 t of fuel equivalent per ton of manufactured products. High consumption of energy resources in the production of polymers requires continuous improvement of resource-saving technologies, the search for new alternative energy sources.

3. It has been determined that one of development goals of a cyclical economy is the generation of energy from production wastes. In the field of polymer production, three types of waste are identified (plastic, rubber, thermosetting resins), which are potential raw materials for production of secondary thermal energy. The given values of combustion heat of waste (31-45 GJ/t), methods of generating energy and their efficiency (45-70%) allow using the data to develop solutions for alternative energy sources. A study of the scale of the formation of polymer waste at Russian enterprises showed a significant potential for their use in production of secondary thermal energy (up to 9.9 thousand t of plastic, 15.6 thousand t of rubber, 263 t of thermosetting plastics).

4. An algorithm has been developed for calculating the volume of secondary heat energy and the volume of production based on resources obtained by energy recycling of waste. The proposed algorithm allows solving two problems: calculating heat energy volume obtained by waste energy recycling and calculating products volume produced on the basis of secondary heat. Approbation of the algorithm using an example of plastic waste and the use of thermal energy from their combustion in the production of synthetic resins and plastics showed the possibility of generating 56467.2 Gcal of thermal energy from plastic waste. At the same time, 26516.7 t of synthetic resins and plastics may be produced on the basis of secondary heat obtained as a result of waste energy recycling.

As recommendations for organizing the production of secondary energy resources, the following should be noted: decisions made on energy recycling of waste should be balanced with the use of waste directly in production cycle as a secondary raw material. At the same time, according to principles of a cyclical economy, it is necessary to promote the full realization of waste potential, taking into account environmental and economic feasibility. More attention needs to be paid to processes such as anaerobic digestion of biodegradable waste, where recycling of materials is combined with energy production.

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