Analysis of Plastic Waste Processing Methods

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Abstract **- The article summarizes the arguments and counterarguments within the scientific discussion on the current state of environmental pollution. The main purpose of the study is to update and promote the processing industry of plastic waste. Systematization of literary sources and approaches to solving the problem of environmental protection has shown that today the problem of plastic recycling is one of the most important facing humanity. The article presents the results of empirical analysis of the main indicators of production, use and processing of plastic, which showed the need to stimulate and develop enterprises in the processing industry.**

Keywords **– environmental protection, plastic recycling, plastic waste.**

1. Introduction

The invention of plastic has given a major breakthrough in the economy. The first plastic was obtained by the British metallurgist and inventor Alexander Parks in 1855 [6].

Plastic is a very cheap material for production, which has made the production cheaper and the demand for it has grown. But plastic manufacturing has many negative consequences that scientists are still trying to solve. Plastic is used throughout toys, tableware, containers, tools and other household products.

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About 30-50% of all products are reused, other products need recycling. Lack of plastic recycling leads to environmental pollution, wildlife deaths, poisoning of nature. It is very dangerous to reuse plastic because it releases toxic substances that are harmful to humans and the environment.

So, humanity is faced with a problem - how to get rid of plastic trash. This question is beginning to worry every person who thinks about the future of their planet. Recently, there has been a significant deterioration of ecology in the world as a result of human activity, as an example of global warming. Climate change can lead to global, large-scale changes in natural and social systems [17], [23].

It should also be added that the reduction of production and consumption of plastic is impossible without reviewing existing mechanisms to meet the needs of mankind.

As of today, scientists have proven that there are many alternatives to addressing this problem through its processing and disposal. Burning plastic is a cheap solution, but poisonous substances get into the environment. And plastic processing requires more financial, material and other costs. Plastic processing will somewhat halt the growth of plastic waste, but plastic will still account for 50-70% of the packaging market.

Thus, an effective mechanism to combat this problem is to ban the use of plastic in a particular area. You can prohibit the use of plastic at the legislative level. But this step will not be enough - it is necessary to develop an alternative to the plastic.

The problem of polymer waste processing is of urgent importance not only in the context of environmental protection, but also in the context of the scarcity of polymeric raw materials, plastic waste is a powerful additional raw material and energy resource [8].

Therefore, the "plastic problem" needs to be addressed in an integrated approach as a matter of urgency, as every minute more than 1 million plastic garbage appears and the ecological status of the planet is rapidly deteriorating [16].

1.1. Novelty of the Research

The novelty of the study is beyond doubt because of the significant environmental degradation caused by human activity. Mankind draws on natural resources not always thinking about the consequences. Climate change and global warming are evidence of disruption to the normal functioning of our planet. Nature provides ecosystem services to humanity worth $ 125 trillion a year [15].

The ecological crisis is forcing to find ways of economically sustainable production and sustainable development [18].

Plastic has certainly become an effective material in meeting human needs. At the same time, the ways of its further use and processing require considerable attention.

As of today, campaigns have been launched around the world to limit the use of plastic products and look for alternatives [10].

1.2. Setting Objective

The purpose of the study is to analyze the existing approaches to the processing of plastic waste and the existing prospects for technological development of the industry, while promoting the said issues among the scientific community.

1.3. Methodology

To ensure the achievement of the purpose of the article, it is proposed to decompose the research objective and to carry out separately.

First, to understand the issues of the study, to analyze the main indicators of the volume of production, use and processing of plastic.

Secondly, to analyze the existing technological approaches to the processing of plastic waste and prospects for their development.

During the research, the following methods of scientific knowledge were used: system approach, analysis, synthesis, and grouping.

2. Results

2.1. For the consistency of material presentation, it is necessary to pay attention to some of the chemical and physical properties of polymers.

According to experts, in the structure of polymeric waste 34% is polyethylene (film, beer boxes, buckets, pallets and other products), 20,4% - polyethylene terephthalate (bottles of various drinks and other liquids), 17% - laminated paper, 13,6 % - polyvinyl chloride (pipes, film, panels), 7.6% - polystyrene (cases of electronic equipment, disposable tableware), 7.4% - polypropylene (household products, battery cases, various containers) [13].

Plastic particles are usually grouped according to their size (measured by their diameter). The table summarizes some standard ranges for this category of particles (Table 1.).

Table 1. Plastic particle size categories

Particle category (mm = millimetres)	***Diameter range***
Nanoplastics	*< 0.0001 mm (0.1μm)*
Small microplastics	*0.00001 – 1 mm*
Large microplastics	*1 – 4.75 mm*
Mesoplastics	*4.76 – 200 mm*
Macroplastics	>200 mm

Most plastic products, containers and packaging retain their properties for a long time and are reusable.

However, today only 20% of polyethylene, 17% of polypropylene, 12% of polyethylene terephthalate, 12% of polystyrene, 10% of polyvinyl chloride are collected and processed. Moreover, today the industry is able to process several times more recyclables from waste than it is produced .

If we analyze the dynamics of distribution by industry of polymers we will have the following indicators (Fig. 1.) [11].

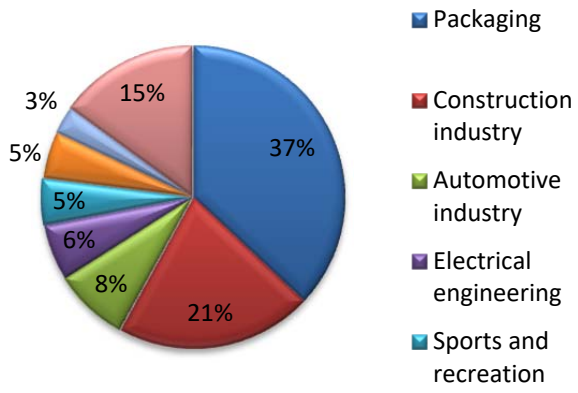

Figure 1. Distribution of polymers by industry

The total amount of plastic ever produced by mankind is 8.3 billion tons, and the big problem here is that most plastic products are used for a short period of time before landing, such as plastic bags or packages.

There are also a number of facts regarding the use of plastic as defined in the following values [2]:

- humanity has produced 8.3 billion tons of plastic throughout history;
- half of these volumes have been manufactured in the last 13 years;

- about 30% of these volumes are still in use;
- less than 9% was recycled from the landfill plastic;
- 12% were burned, another 79% are in landfills;
- the most commonly used packaging plastic is on average less than a year;
- the longest time plastic products are used is in construction and machine equipment;
- current trends predict that by 2050, humanity will produce 12 billion plastics;
- in 2014, 30% of plastic was recycled in Europe, 25% in China and 9% in the US.

None of the widely used types of plastic decompose. The only way to permanently get rid of it is to heat it up to destructive temperatures, that is, either to undergo a process known as pyrolysis, or to simply burn it, although the second option carries harmful emissions and negative health effects.

Particularly dangerous are cellophane bags, which in large quantities contain polyethylene - one of the most active sources of methane and ethylene. It has been estimated that more than eight billion tons of plastic bags have been manufactured since 1950. It is expected that in the next 20 years their annual production will double (*ecolog-ua.com*).

Annual global production of polymer resins and fibers (plastic production), is measured in metric tons per year [5].

In 1950, the world produced only 2 million tons per year. Since then, annual production has increased almost 200 times, reaching 381 million tons in 2015. In the context, this is roughly equivalent to the mass of two-thirds of the world's population. The chart shows the increase in global plastic production, measured in tons per year, from 1950 to 2015. (Fig. 2.).

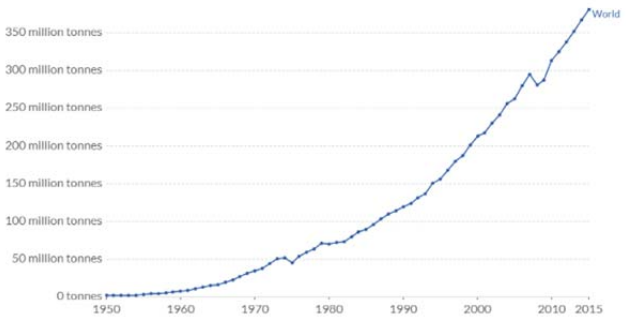

Figure 2. Indicators of world plastic production from 1950 to 2015

The short decline in annual production in 2009 and 2010 was largely the result of the global financial crisis of 2008 - a similar trend is observed in several indicators of production and consumption of resources [24].

Since the beginning of the mass production of plastic in the 1950s, more than 8.3 billion tons of this material have been produced worldwide, which subsequently turned into nearly 6 billion tons of plastic waste, of which only about 9% was recycled. The scale of the problem is astounding.

As plastic production grows every year, forecasts are also disappointing. It is expected to triple in 2050 compared to 2014 and account for 20% of global oil consumption [19].

Because biodegradable plastics do not occur, about eight million tons of plastic waste is released into the oceans annually [14].

Next, we need to consider the main indicators of plastic waste recycling in several countries [7], [26].

42% of plastic packaging waste was recycled in the EU in 2017. In seven EU Member States, more than half of the waste generated in plastic packaging was recycled in 2017. Compared to 2005, the level of recycling of plastic packaging waste in the EU increased by 18 percentage points (from 24% in 2005 to 42% in 2017). This upward trend is observed at different levels in all EU Member States except Croatia.

The dynamics of plastic processing in EU countries is as follows (Table 2.).

Table 2. The dynamics of plastic processing in EU countries

TIME	2015	2015	2016	2016	2017	2017
GEO/WST_OPER	Waste generated	Recycling - material	Waste generated	Recycling - material	Waste generated	Recycling - material
European Union 28 countries (2013-2020)	15 924 959	6 356 960	16 298 447	6 905 615	16 758 000	7 022 000
Belgium	339 690	144 583	343 161	149 034	345 342	153 566
Bulgaria	99 532	60 537	108 247	56 959	119 962	77 771
Czech	247 328	152 622	236 891	140 282	248 585	146 408
Denmark	197 030	60 065	214 593	77 477	218 107	83 946
Germany	3 052 200	1 445 700	3 097 700	1 498 280	3 184 900	1 528 100
Estonia	61 125	17 006	64 601	15 894	65 799	17 465
Ireland	282 148	83 678	275 510	86 032	280 673	85 657
Greece	183 800	67 700	186 600	71 220	188 200	77 860
Spain	1 474 731	649 343	1 526 347	693 935	1 608 873	771 269
France	2 133 626	543 152	2 178 758	561 590	2 328 662	616 205
Croatia	51 959	24 072	54 744	22 479	60 582	22 588
Italy	2 128 496	875 827	2 214 672	938 918	:	:
Cyprus	16 099	10 255	16 470	10 255	:	:
Latvia	41 362	14 582	40 261	14 966	39 438	14 433
Lithuania	65 495	35 902	65 611	48 824	68 742	51 038
Luxembourg	27 663	8 824	28 183	8 675	28 847	9 644
Hungary	299 790	81 993	308 994	97 164	315 526	100 902
Malta	12 475	3 564	14 544	3 420	:	:
Netherlands	492 000	245 000	503 000	259 000	512 000	258 000
Austria	294 888	99 015	297 837	100 006	302 306	101 006
Poland	935 755	288 580	1 007 369	472 847	1 041 124	360 577
Portugal	369 751	158 953	378 505	158 186	400 239	139 647
Romania	359 036	167 554	348 794	162 351	:	:
Slovenia	45 090	28 600	46 350	28 758	50 164	30 275
Slovakia	106 417	57 861	119 409	61 706	124 158	65 112
Finland	116 530	27 588	122 849	31 214	130 309	34 565
Sweden	230 943	113 263	238 447	120 917	240 654	116 445
United Kingdom	2 260 000	891 141	2 260 000	1 015 226	2 260 000	1 044 363
Iceland	14 806	5 511	15 028	6 411	15 611	4 644
Liechtenstein	786	133	803	168	782	143
Norway	184 132	68 350	193 200	75 834	220 614	79 616

In 2017, the highest recycling rate of plastic packaging waste was recorded in Lithuania (74%), ahead of Bulgaria (65%), Cyprus (62%, 2016 data), Slovenia (60%), Czech (59%), Slovakia (52%) and the Netherlands (50%).

In contrast, less than one third of plastic packaging waste was recycled in Malta (24%, 2016 data), Estonia, France and Finland (each 27%), Ireland (31%), Hungary (32%), Luxembourg and Austria (33%) [25].

The analysis of the information in the table shows that in the EU countries as a whole, the percentage of recycled plastic waste to the total amount of garbage is: in 2015 - 39%, in 2016 - 42% and in 2017 - 41%.

However, given the current positive dynamics in some EU countries, the overall level of plastic processing does not exceed 50% of the material produced.

In addition, if we analyse the recycling of plastic waste in some European countries for recycling and energy, we can determine that only in Germany recycling prevails over energy (Table 3.) [12].

Table 3. Disposal of plastic waste in European countries

Country	Total processing, %	Recycling for secondary use, %	Energy processing, %
Denmark	**85**	**19**	**66**
Germany	**70**	**51**	**19**
France	**69**	**22**	**47**
Italy	**62**	**42**	**20**
United Kingdom	**57**	**41**	**16**

As of today, five of the following methods are applicable to the science of plastic processing, namely:

Pyrolysis - the effect on a substance with or without oxygen temperature [22].

Hydrolysis is a method of processing using extremely high temperatures and pressure. The output is higher quality raw materials than using Pyrolysis [1].

Glycolysis is a way in which very high temperatures and pressures are applied using ethylene glycol and a catalyst to help obtain a pure and high-quality product [9], [20].

Methanolysis - the processing of plastic waste using methanol. This method is the most common [21].

Mechanical recycling is a method whose essence consists in the mechanical grinding of plastic waste for the purpose of further heat treatment and production of quality raw materials.

All these methods pursue a common goal - to obtain quality raw materials that could be used in production. One of the required forms of raw material is plastic pellets (secondary pellets).

The secondary pellet is the result of the recycling of primary plastic, that is, plastic waste. Today, plastic pellets are the basic material for the production of various plastic products. Plastic granulation technology is quite simple and not very expensive; many companies specialize in the processing of plastic into granules.

According to these methods, there are the following main areas of disposal of plastic waste:

- recycling or using the waste in different compositions; thermal schedule to obtain the target products;
- thermal neutralization with heat recovery;
- development of photo- and bio-destructive plastics, capable of being degraded to low molecular weight compounds after the end of their service life, absorbed by microorganisms and incorporated into a closed biological cycle, without creating a negative environmental impact.

Today, almost all complexes involved in the processing of plastic products are operating according to a typical technological scheme (Fig. 3.) [25] with some possible modifications due to specific features of production, consisting of several main stages:

1. Sorting of raw materials, whereby synthetic polymers are separated from other wastes and classified by type, colour;
2. Grinding of plastic raw materials;
3. Plastic washing;
4. Seals (agglomeration) to facilitate further operations with raw materials;
5. Granulation of agglomerated material.

In the future, the pellets (the so-called PET-flex) enter industrial plants, where by means of extrusion they produce the final products.

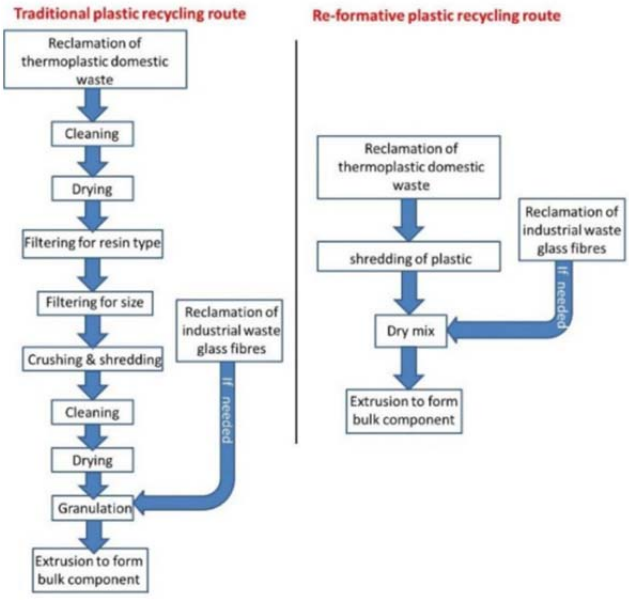

Figure 3. The schematic of the traditional plastic recycling process and the novel re-formative process

The process line for washing and granulating plastic can be graphically depicted as follows (Fig. 4.) [27]:

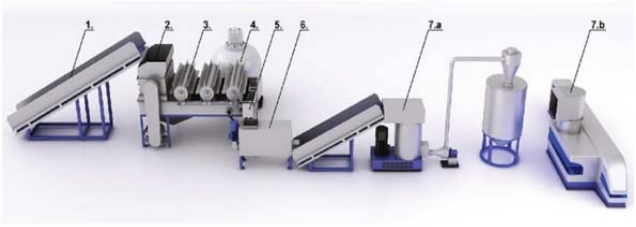

Figure 4. where: 1 - belt conveyor; 2 - crusher; 3 - sedimentary bath with a sieve; 4 - water filtration with chemical treatment; 5 - drainage screw; 6 - auger for squeezing; 7a - agglomerator + silo; 7b is a line of subsequent granulation

In the US and Western Europe, the PET flex is used mainly to produce fibers and nonwovens. This is due to the fact that the viscosity of the dark green PET flex marks decreases significantly during the recycling process (from 0.8 to 0.4 - 0.6), especially with insufficient material drying. Technology and equipment for forming multilayer bottles using 80% secondary PET flex as a middle layer have been developed, and such bottles are already on the market.

Purified and crushed PET flex can be mixed with other polymers and fillers to produce new composites with a range of new properties [12].

Today, a global problem can become a global source of income and a real salvation for all living things. While plastic garbage mountains occupy entire landfills, there are more and more people making money from recycling. It is important to understand that if you do not set up a timely process for collecting, sorting and recycling plastic waste, it will soon go far beyond landfills.

Chinese scientists have taken a step forward in the fight against plastic waste by offering a water-soluble plastic technology. Due to the addition of water-soluble compounds to biodegradable polyesters, and in the presence of radicals, the plastic decomposition process takes 10 days and is non-toxic. Scientists from the Chinese Academy of Sciences said that four plants will be converted to this technology. Thus, the production of plastic bags and disposable tableware will continue, and it is planned to receive 75 thousand tons of water-soluble plastic goods annually. However, many people point out that such material is half the price of conventional material, so it can be a barrier to mass production.

Sweden is called one of the world's leaders in waste management, where energy-from-garbage is particularly effective. Currently, there are dozens of waste processing plants in the country. 99% of the waste is used either as fuel for power plants or as raw material for production. This is a lot for a 10 million country.

Also, in Vienna, the capital of Austria, the waste incineration plant has simultaneously become a thermal power plant and an art object, and today, 265 thousand tons of garbage is converted into thermal energy per year.

In Poland, a modern garbage processing plant was built [4]. The capacity of the complex is 180 thousand tons per year, so the plant can easily serve its own and neighboring city. Around € 100 million was spent on the construction of the plant. After burning the waste, the slag remains, which is not burned. First it is dried, later sorted out, using a magnet to remove the metal parts. Also, the slag is crushed and mechanically filtered. Later, construction material is obtained from the remains. In Western Europe, this slag is commonly used for road construction [3].

3. Conclusion

Polymer waste processing companies have a positive impact on the economic performance of the locality or region of operation. An increase in jobs in the area of work, which does not always involve higher education, will be of benefit to the low-skilled unemployed.

The gradual abandonment of plastic for household needs without an urgent need will inevitably affect the conservation of the environment, where the use of repeatedly existing raw materials without producing new ones is an economically viable technology for meeting public needs.

With sufficient attention from the state and non-governmental organizations and funds to the processing plants, the result may be the unconditional ability to recycle the landfill accumulated over the years and, by switching to the green economy concept, in the first stages, to reduce the need for the production of new artificial materials.

The need for recycling of plastic waste is caused not only by the large amount of garbage, but also by the need of many modern enterprises for recycling. Thus, a business built on plastic waste recycling and recycling is one of the most promising today.

Due to its physical and chemical properties, plastic can undergo an infinite number of production and processing cycles. The opening of processing plants and their continuous work will help to solve the problem of excess plastic waste, and in the future to eliminate the need to produce new plastic products.

In view of the foregoing, we can draw the following conclusions:

1. The problem of plastic waste will not be solved without public policy, so the government and parliament, in partnership with various stakeholders, need to accelerate the development and adoption of a legislative framework to implement the extended producer responsibility principle, creating the conditions for developing a cyclical economy and encouraging new investment and innovation in development plastic processing and new quality plastic packaging.
2. On the basis of regional plans, city authorities and integrated territorial communities begin to create important infrastructure facilities for garbage collection, transportation and recycling, through inter-municipal cooperation tools.
3. Prohibit the free distribution of plastic bags in supermarkets and impose appropriate sanctions in case of violation.
4. Educate consumers, from school desk, on the negative impact of waste and plastic in particular on the environment and encourage the creation of initiatives and innovations to solve the problem.
5. Citizens - do not expect that someone will solve this problem for them, but to start from their own homes, simply reducing the use of plastic in everyday life. Start collecting and sorting waste, mobilize and actively participate in similar community projects and initiatives.

But the most significant factor that hinders the development of recycling in many countries is the complexity of the plastic waste collection phase. Processing complexes that require a constant flow of raw materials in the form of synthetic polymers do not have the ability to independently collect them throughout the city. The existence of such a problem is conditioned by the lack of a proper waste management culture among the population. Partially this defect is solved by the installation of sorting bins, and, as noted earlier, this requires a high level of cooperation between private enterprises and city government, which is quite difficult to achieve in our country's realities.

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