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Analitical paper / Praca analityczna

Analysis of the use of green chemistry principles in the production of gasless pyrotechnic compositions
Analiza wykorzystania zasad zielonej chemii w produkcji bezgazowych kompozycji pirotechnicznych

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Abstract: *The article deals with the issue of a rather unusual component of green chemistry, namely green pyrotechnics. The complexity and danger of the production, storage and usage of pyrotechnic compositions carry a significant ecological threat. An analytical study of the peculiarities of using green chemistry principles in gasless pyrotechnic composition production was carried out. Research in this area will help to find empirical approaches to the application of relevant green chemistry principles, which will help bring gasless pyrotechnic compositions into the green chemistry domain and make these productions environmentally safer and contemporary.*

Streszczenie: *Artykuł porusza zagadnienie dość nietypowego składnika zielonej chemii, jakim jest zielona pirotechnika. Należy zauważyć, że złożoność i niebezpieczeństwo produkcji, przechowywania i stosowania kompozycji pirotechnicznych niesie ze sobą istotne zagrożenie ekologiczne. Przeprowadzono analityczne badanie specyfiki wykorzystania zasad zielonej chemii w produkcji bezgazowych kompozycji pirotechnicznych. Dalsze badania w tej dziedzinie pomogą znaleźć podejścia empiryczne do zastosowania odpowiednich zasad zielonej chemii, które pomogą wprowadzić bezgazowe mieszaniny pirotechniczne do klastra zielonej chemii i uczynić te produkcje bardziej bezpiecznymi dla środowiska i zmodernizowanymi.*

Keywords: *gasless composition, green chemistry, production*
Słowa kluczowe: *skład bezgazowy, zielona chemia, produkcja*

Abbreviations and symbols

PC	Pyrotechnic composition
PP	Pyrotechnic production
GC	Gasless composition
GCP	Green chemistry principle

1. Introduction

Green chemistry, as an interdisciplinary science, has become one of the essential elements of production process planning [1]. Considering the modern trends of creating "eco-friendly" technologies and products, green chemistry finds more specific production areas for application.

Pyrotechnics is one of the promising production areas for green chemistry applications [2]. The technology of producing, storing and using pyrotechnic products and compositions has always been dangerous to both the environment and human health. The use of PP and PC causes the release of toxic substances into the atmosphere, lithosphere, and hydrosphere, and the production processes can lead to chronic diseases among workers [3].

Gasless pyrotechnic compositions are one of the largest classes of pyrotechnic substances. They are used in pyrotechnic products for various purposes in the industrial sphere [4].

The main problem is the misconception concerning the environmental safety of GCs. It is believed that since these compositions emit almost no gases, they do not damage the environment. However, the main components of most GCs are toxic substances, for example, lead oxides of various valences, salts of chromic and perchloric acids, etc. [4]. The production of such compositions can be hazardous to human health and the environment due to the high toxicity of these components, according to NFPA 704 [5].

This analytical article considers the theoretical aspects of using green chemistry principles in the processes of gasless pyrotechnic compound production.

2. Theoretical

2.1. Green chemistry principles

The object of research is the green chemistry principles for the production of gasless pyrotechnic compositions. The purpose is an analytical study of the use of green chemistry principles in gasless pyrotechnic composition production. There are twelve principles of green chemistry in the planning of a technological process. They are shown in Fig. 1 and are the basis for further analysis. It is worth noting that they have different wording in different sources but have the same meaning.

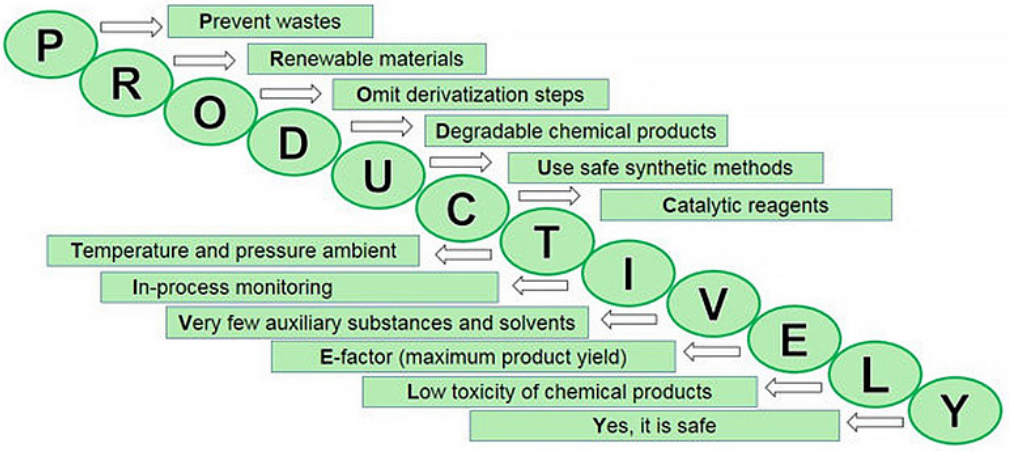

Figure 1. Green chemistry principles [6]

2.2. Features of the analysis

Planning and technical operations of GC production were analysed. These operations include the selection of components and their parameters, the process of obtaining the mixture, and waste disposal technologies. The process of obtaining the required mixture consists of the following stages [7]:

1. Grinding of components.
2. Drying of components.
3. Sieving.
4. Dosage.
5. Preparation of the mixture (mixing), granulation, drying.
6. Formation of final products (charges, cast products, etc.).

Each of these stages was analyzed for the possibility of integrating GCPs in further prospects of reducing the technogenic load on the environment from the pyrotechnic domain. The analysis was based on literature sources.

3. Analytics, results and discussion

The results of the analysis of the possibility of applying the GCP in GC production are shown in Table 1.

Table 1. Analysis of the GCP for the production of GC by relevance

Letter	Principle	Relevance for manufacturing GC
P	Prevent waste	Relevant
R	Renewable materials	Particulary relevant
O	Omit derivatization steps	Irrelevant
D	Degradable chemical products	Particulary relevant
U	Use safe synthetic methods	Irrelevant
C	Catalytic reagents	Irrelevant
T	Temperature and pressure ambient	Particulary relevant
I	In-process monitoring	Relevant
V	Very few auxiliary substances and solvents	Irrelevant
E	E-factor (maximum product yield)	Irrelevant
L	Low toxicity of chemical products	Relevant

Let us consider the use of each of these principles separately, based on their relevance.

Irrelevant principles are those which are directly related to chemical reactions. The production of GC does not include stages with chemical reactions [7]. Therefore, the principles, *"Omit derivatization steps"* (O), *"Use safe synthetic methods"* (U), *"Catalytic reagents"* (C), *"E-factor (maximum product yield)"* (E), and *"Very few auxiliary substances and solvents"* (V) cannot be applied, as they refer solely to chemical synthesis.

Partially relevant principles are specific enough for the production of GC but may find their application in certain conditions. These principles include *"Renewable materials"* (R), *"Degradable chemical products"* (D), and *"Temperature and pressure ambient"* (T).

Renewable energy is a useful technological and economic prospect for most industries [8]. Taking into account the use of several stages during the drying process (which is a highly energy-consuming process), obtaining electricity utilising solar and wind power plants is the optimal solution to the energy issue of the enterprise for the production of GC. However, such features are not always easy to implement due to the specificity of climatic conditions, so it is necessary to conduct preliminary calculations of the energy efficiency of such installations.

The use of safely degradable chemical products is a modern ecological trend [9]. Although it refers to

safe material destruction, GCs decompose into various products while burning. Creating a pyrotechnic composition with safe final products is one of the most significant tasks in production planning. However, some specific GCs contain toxic components in their mixture, which are difficult or impossible to replace due to a narrow field of application [4]. Therefore, this principle is only partially relevant.

Using ambient temperature and pressure is an energy-efficient ecological solution. As a rule, the production of GCs uses atmospheric pressure (with the exception of the stage of formation of charges) and standard temperature (with the exception of the stages of drying) [7]. The standard conditions at these stages will significantly lengthen the technological process, so it is worth applying the other forms of the final product and optimizing the drying process.

The relevant principles are suitable for the production of GCs. They include *"Prevent waste"* (P), *"In-process monitoring"* (I), and *"Low toxicity of chemical products"* (L).

Waste prevention is the principal goal of creating waste disposal technology. Since most non-recyclable waste in a GC's production is disposed of by incineration, this is a good area for research [10]. Optimizing the renovation of returnable waste is also a relevant area for research.

In GC production, constant in-process monitoring is the main element of occupational health and safety. Innovations in this area are a relevant direction for research.

The use of low-toxic substances in production is an actual problem for GCs. Since most GCs contain heavy metals, chromic and perchloric acid salts, and other hazardous substances in their mixtures, the creation of eco-friendly GCs is one of the most relevant and promising research areas [11].

Analyzing the GCP's relevance, the following conclusions can be drawn:

1. Only six principles of green chemistry can be applied in the production of GCs.
2. There are more relevant and less relevant areas of research and introduction of innovations in the production of GCs.
3. Application of relevant principles of green chemistry will help to bring GCs into the domain of green chemistry and make these products more ecologically safer and contemporary.

4. Conclusions

- An analytical study of the use of the principles of green chemistry in the production of gasless pyrotechnic compositions was conducted. Relevant, partially relevant and non-relevant green chemistry principles for this field were established. The peculiarities and usage of each green chemistry principle in the pyrotechnic sphere was analyzed.
- Further research in this area will help to find empirical approaches in applying relevant green chemistry principles, which will help bring gasless pyrotechnic compositions into the green chemistry domain and make their production environmentally safe and contemporary.

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