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ASSESSMENT OF THE POSSIBILITIES OF USING ALTERNATIVE FUELS IN THE CEMENT INDUSTRY

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ABSTRACT: The article aims to assess the possibility of using alternative fuels in the cement industry. The research focuses on evaluating the use of alternative fuels, considering their calorific value, the share of biomass content, the impact on the CO2 emission factor, and the possibility of achieving possible economic benefits. The methodology includes the analysis of production data and the calculation of savings resulting from the use of alternative fuels. On this basis, ecological aspects were also indicated that should be taken into account when analysing the profitability of the investment. The conclusions show that by using alternative fuels, CO2 emissions and production costs are reduced, while there is no negative impact on efficiency and production volume. For practice, it was important to confirm that alternative fuels can also find practical application in the cement industry, and investing in renewable energy sources by cement production plants fits into the goals and directions of development related to sustainable management of resources according to the win-win principle.

KEYWORDS: alternative fuels, environmental protection, cement industry, economic dimension

Introduction

Inherent problems of constantly progressing economic development and civilisation are the growing amount of waste generated by industry, such as households, constantly rising energy costs and increasing demand for energy, the conventional sources of which are increasingly exposed to exhaustion. It turns out that the waste generated by humanity can be a very important source of energy for the cement industry, which significantly contributes to global greenhouse gas emissions and fuel consumption, accounting for 5% of global greenhouse gas emissions and is one of the main industrial sources of carbon dioxide emissions carbon (Benhelal et al., 2021; Paul et al., 2021). By using alternative fuels from rainfall as fuel instead of coal, cement plants can thus reduce pollutant emissions, contributing to reducing the impact of ongoing climate change, and in addition, reduce production costs by reducing emission fees (Sahoo & Kumar, 2022; AbdeL-Hay et al., 2020).

In the era of ever-increasing urbanisation, especially in developing countries, the demand for cement will continue to grow. Total annual cement consumption is expected to increase to 4.68 Gt/year by 2050 (Schneider, 2019; Mohamad et al., 2022). As cement production increases, the amount of greenhouse gases emitted will also increase, therefore, many countries and international organisations, such as the European Union, place great emphasis on the policy of sustainable development and reduction of harmful gas emissions, for example, by introducing the EU-ETS system.

In light of the described conditions, more and more cement plants in Poland have decided to implement investments aimed at modernising production technology and enabling the use of alternative fuels such as municipal waste, biomass or other alternative raw materials as the main fuel material feeding the clinker furnace (Smol et al., 2019). In this context, examining the effectiveness of alternative fuels in the cement industry becomes extremely important not only to achieve environmental protection goals but also to increase production efficiency and improve the profitability of this industry sector.

High CO2 emissions from the cement industry resulted in the development of strategies to reduce these emissions by improving production processes, modernising equipment, replacing primary fuels with alternative fuels from waste, optimising cement composition, and recovering thermal energy from production processes. In addition, Industry 4.0 solutions enable CO2 monitoring, monitoring the source of its emissions and methods of calculating these emissions at the plant and group level. The authors in their works (Niekurzak et al., 2023; Elżbieciak, 2022) show how the fourth industrial revolution 4.0 contributes to the development of the process of technological transformation of energy-intensive enterprises (Ritchie & Roser, 2020). The implementation of these solutions is possible thanks to the use of new digital technologies and data resources and ensuring communication in the cooperation network of machines, devices and people (Kobyłka et al., 2023; Kościółek, 2023). The factors driving the transformation towards Industry 4.0 are the increasing individual needs of customers, the growing trend of personalisation of products and services and environmental and regulatory requirements related to the energy transition (SBTi, 2022).

The scientific aim of the work is to assess the effectiveness of the use of alternative fuels in the cement industry. The subject of the research was to obtain high-quality fuels with a reduced emission index. This study is a continuation of existing research towards mandatory energy transformation of production plants. The research was carried out to demonstrate that the use of alternative fuels in the clinker production process will not hurt the environment and may bring measurable economic benefits. To our knowledge, this is the first approach to this topic analysing the use of alternative fuels in this market sector, which certainly constitutes an added value of the presented considerations.

The article presents many important theoretical issues and practical implications. The considerations contained in the work are as follows. Section 2 presents waste management and analysis of the waste market in Poland. Moreover, the types of waste processed for the production of alternative fuels are described in detail from the perspective of the currently used production technology. Section 3 contains a description of the research methods used in response to the stated aim of the work. Section 4 presents the economic assessment of the effectiveness of processed waste for the production of alternative fuels based on legal provisions and currently applicable environmental standards. The article ends with conclusions indicating current research limitations and future research directions.

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Literature review of the problem

Principles of waste management and the waste market in Poland

All rules and regulations applicable in Poland regarding municipal waste management are specified in the following acts (Styś & Foks, 2014):

- Act of December 14, 2012, on waste,
- Act of January 25, 2013, amending the Act on maintaining cleanliness and order in municipalities,
- Regulation of the Minister of Climate of January 2, 2020, on the waste catalogue.

The Act of December 14, 2012, on waste defines the key principles of waste management, which are aimed at protecting the environment, as well as human life and health, by preventing the generation of waste and limiting its quantity and harmful impact on the environment, and also improving the efficiency of resource use. to transform the system towards a circular economy (Albin, 2021; Popiół, 2022). The main objectives of these principles include the reduction of waste generation in various economic sectors and human activities, the reintroduction of post-production residues into the production cycle, the recovery of raw materials from collected waste, the judicious use of waste disposal processes and the orderly storage of all remaining waste in a way that minimises environmental damage. Following the above-mentioned guidelines aims to develop a system promoting the so-called 3R principle (reduce-reuse-recycle), which defines sustainable development through reduction, that is, reducing the amount of waste generated, reusing items or materials that would be thrown away as waste, and recycling resources to the greatest extent possible (Smol et al., 2019; Kopeć, 2023).

The Waste Directive introduces a waste hierarchy, which is the basis for modern waste management. The system hierarchises activities in law and policy related to waste prevention and general waste management to achieve the greatest possible environmental benefits. Derogations from this hierarchy may apply to certain waste streams if justified, for example, due to technological limitations, insufficient economic viability or insufficient environmental protection (Zalewska, 2019). The cited course of action is consistent with the European waste hierarchy, prioritising waste prevention and preparation for reuse as the most desirable approach (Bień, 2021).

Because waste is an inevitable result of human activity, it is necessary to develop an effective waste management system to minimise their negative impact on the environment in the form of water, air and soil pollution, degradation of landscapes and the management of agricultural and forest land for waste landfills. The aim to achieve this goal is to introduce a selective waste collection system and transform the economy into a circular economy (Niekurzak et al., 2023). These changes are crucial due to the constantly increasing amount of waste generated. In 2022 alone, 128.4 million tons of waste were generated, including 10.4 tons of municipal waste (GUS, 2023; Dolatowski & Wasiak, 2020).

Unfortunately, the selective waste collection system is not perfect and encounters certain problems, for example, the increasing monopolisation of the municipal waste collection market from residents to municipalities and inter-municipal associations, which may result in an increase in collection fees due to a lack of competition. Another problem is the fact that not all waste processed in municipal installations is subjected to further recovery or recycling processes for technological or economic reasons (Głodek-Bucyk et al., 2018). Another problem is the fact that too little emphasis is placed on preventing the generation of waste, the amount of which increases every year, and there is a lack of appropriate economic mechanisms forcing producers to limit the generation of packaging waste (Albin, 2021). Only some of the shortcomings of this system have been mentioned, and the relevant authorities should make efforts to solve them, for example, by introducing fees in the form of deposits for reusable packagings, such as in some European Union countries (Ministerstwo Klimatu i Środowiska, 2023; Yuliya et al., 2022). Therefore, in the authors' opinion, it is important to look for new market sectors to fully use the generated waste. One of them may be the construction sector, including cement production.

The study highlights a research gap, i.e. whether the use of alternative fuels in Polish conditions for the clinker production process will negatively affect their quality of use and the environment.

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Research methods

The main goal of the article is to provide knowledge about the possibilities of waste management as an alternative fuel in the production of cement plants. The authors analysed this method of waste management in several key areas from an economic and environmental perspective during the selected period. As part of the research, a qualitative and comparative analysis of the impact of the use of alternative fuels on production parameters and costs was performed. A laboratory station at the cement plant was used for the tests. On its basis, it was determined The degree of use of alternative fuels in cement, GJ costs of alternative fuels compared to coal, and the impact of the TSR biomass content on the emission index of a given industry sector. The analysis assumes a constant percentage of fuels supplied to the furnace in the cement plant and the biomass index, CO_2 emission costs. Figure 1 shows a flowchart of the research methodology.

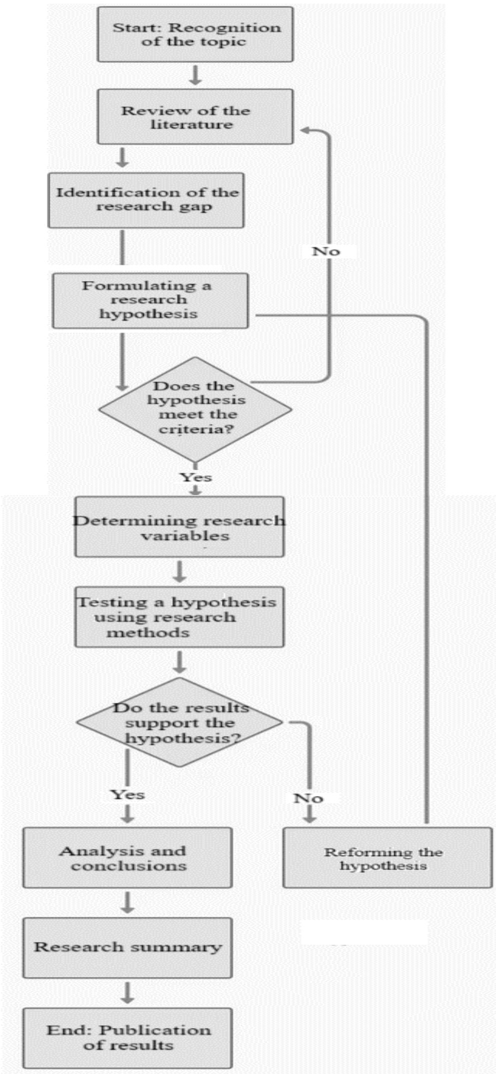

Figure 1. Flowchart of the research methodology

The following research methods were used in the research: data analysis based on data obtained from the cement plant, expert interviews with production technologists, analytical work (qualitative and quantitative analyses), analysis of current scientific literature, research on waste management methods for industrial purposes within the framework of the principles of the circular economy.

The article gives a new perspective and complements the current literature in the areas of technology, innovative technological solutions, circular economy, environmental protection and economics. The presented research complements knowledge about ecological production with a diversified nature of production as part of the ongoing energy transformation of production plants.

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Results of the research

Alternative fuels used in the cement industry in the light of a sustainable economy

In December 2018 The European Parliament and the Council of the European Union adopted Directive/2018/2001 on the promotion of the use of energy from renewable sources, known as the RED II Directive (Geocycle Polska, 2024). This provision introduces more stringent targets for the share of renewable energy sources in the energy sector by 2030, the main one being the requirement that at least 32% of the energy consumed in the EU comes from renewable sources. As a result of the implementation of the above-mentioned directive, the global KZR system (Sustainable Development Criteria) of the Oil and Gas Institute has expanded the certification area of solid biomass fuels and biogas. The mechanism of this system is based on the certification of all entities involved in the entire biomass fuel production process, from raw material acquisition to final use. Certificates are awarded separately to each entity. The KZR system certificate guarantees compliance with the sustainable development standards set out in the RED II directive. It is worth mentioning that the KZR system is voluntary (System KZR INiG, 2024).

In practice, thanks to the use of certification of alternative biomass fuels, it is possible to reduce costs related to carbon dioxide emissions. If alternative fuels from biomass without a certificate were used in the cement production process, then the plant would have to purchase more emission allowances for the CO2 generated in the combustion process by the system (Jaworski & Wajda, 2022). EU-ETS. Further in the work, it was calculated how a 1% reduction in biomass consumption affects the increase in carbon dioxide emission costs. The calculations were made based on formula (1) provided later in the article. Table 1 shows the division of alternative fuels used in the cement industry, giving the average calorific value of each fuel.

Table 1. Division of alternative fuels used in the cement industry with detailed calorific value

<table>
<tr><th></th><th colspan="2">Fuel Type</th><th>Calorific value [MJ/kg]</th></tr>
<tr><td rowspan="14">Solid fuels</td><td colspan="2">Fuel from used tyres</td><td>24.2-37.6</td></tr>
<tr><td colspan="2">Fuel from wood waste</td><td>11-20</td></tr>
<tr><td colspan="2">Fuel from waste plastics</td><td>36</td></tr>
<tr><td colspan="2">Fuel from sewage sludge</td><td>13.3</td></tr>
<tr><td colspan="2">Fuel from waste from the paper industry</td><td>14-16</td></tr>
<tr><td colspan="2">Fuel from waste from the meat and fat industry</td><td>14.4-16</td></tr>
<tr><td colspan="2">AWDF fuel</td><td>15-23</td></tr>
<tr><td colspan="2">Fuel from agricultural waste</td><td>13.8-15.9</td></tr>
<tr><td colspan="2">PASr alternative fuel</td><td>24.38</td></tr>
<tr><td colspan="2">PASi alternative fuel</td><td>10.9</td></tr>
<tr><td colspan="2">Profuel fuel</td><td>20</td></tr>
<tr><td rowspan="3">Fuels produced from municipal waste</td><td>RDF fuel</td><td>16-18</td></tr>
<tr><td>BRAM fuel</td><td>13.1-18.9</td></tr>
<tr><td>INBRE fuel</td><td>18-19</td></tr>
<tr><td rowspan="3">Liquid fuels</td><td colspan="2">Emulsion fuel</td><td>18.8-25.1</td></tr>
<tr><td colspan="2">ECOFLUID fuel</td><td>25.9</td></tr>
<tr><td colspan="2">PAP fuel</td><td>25</td></tr>
<tr><td>Gas fuels</td><td colspan="2">Biogas</td><td>16-22</td></tr>
</table>

Source: authors' work based on Mokrzycki and Uliasz-Bocheńczyk (2009).

For comparison, the calorific value of coal ranges from 15 MJ/kg to 30 MJ/kg, while the average value is assumed to be 21 MJ/kg. Therefore, from the table above it can be read that there are alternative fuels with a higher calorific value than coal, for example, PASr and PASi fuel. PASr fuel, i.e. fuel produced by grinding waste to granulation of 0÷70 mm or 0÷40 mm, such as papers, cardboard, foils, rags, textiles, plastic packaging, tapes, cables, and cleaning cloths. PASi fuel, i.e. fuel produced by mixing a sorbent in the form of sawdust or tobacco dust with waste: paints, varnishes, heavy distillation fractions, diatomaceous earth soaked in petroleum waste, etc., which is characterised by the highest calorific value (Wasilewski & Nowak, 2019).

The Polish cement industry has seen a significant increase in the use of alternative fuels and various types of waste instead of coal as a fuel material used in the clinker production process. The average percentage of alternative fuels is currently approximately 65% and is expected to continue to increase (Kurdowski & Zajd, 2022; Daya et al., 2021). It is worth mentioning that the use of alternative fuels in cement production may affect the amount of undesirable chemical elements, such as chromium, zinc and other heavy metals, in the final product, i.e. cement, and consequently deteriorate its properties. For the above reason, research is being conducted around the world on how an increased amount of certain elements affects not only the properties of cement but also the production process and wear of equipment (Chatterjee & Sui, 2019) and (Głodek-Bucyk et al., 2018). Therefore, it is very important to test the quality of introduced alternative fuels and control the quality of produced cement.

Analysing the literature on the subject, the authors conclude that the technology of using alternative fuels in the cement industry has not yet been described, developed and implemented on an industrial scale. Experiments described in the literature often do not reveal specific values of the basic parameters of this process and have not been tested in Polish industrial conditions. The problem of the ecological use of alternative fuels for such an important industry sector prompts the authors to develop effective, economical and pro-ecological methods of assessing the profitability of their use within the framework of a sustainable economy based on the win-win principle.

Analysis of the GJ cost of alternative fuels to traditional coal

As part of this part of the research and analysis, the cost of heat production was calculated in GJ of alternative fuels about the cost of GJ of coal. The price per tonne of alternative fuel is negative because currently, waste suppliers pay for the waste collection service provided by the cement plant, which is a direct result of the fact that alternative fuels are considered waste by law and not traditional fuel.

Table 2. Calculation of savings from using alternative fuels instead of coal

Price per ton of alternative fuels for cement plants with dosing	-19	EUR/t
Average calorie content	18,8	GJ/t
	-1	EUR/GJ
The price of coal	86	EUR/t
Calorific value	26	GJ/t
	4	EUR/GJ
TSR	78,64	%
Total heat utilization	4 965 387	GJ
Including fuels	3 904 780	GJ
Made of coal	1 060 607	GJ
Savings from using alternative fuels instead of coal	17	EUR

Source: authors' work based on data from Geocycle Polska (2024).

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However, coal is purchased at market prices, and, as a result, the difference in the cost of producing 1 GJ of heat is EUR 4.19. Due to the price of coal and the fact that cement plants are charged for waste collection, savings from using alternative fuels instead of coal may amount to approximately EUR 16,279,070 per year, as shown in Table 2. Alternative fuel is obtained mainly from plastics, which are not suitable for recycling. These are often residues and waste from production processes of various industries such as automotive, paper, food, packaging and furniture production. Alternative fuel can also be old furniture and other bulky waste, as well as all kinds of biomass – these include waste from wood processing, sewage sludge, residues from agricultural production or even roasted coffee husks. This waste should not be processed and, therefore does not generate additional costs. The most important thing is that the waste we want to obtain is stored properly because this affects the quality of the fuel.

TSR bio biomass content and impact on the emission factor

As part of this part of the research, the change in TSR bio, i.e. the rate of heat consumption from biomass, by 1%, and the impact on the cost of carbon dioxide emissions were calculated. The TSR bioindicator was determined based on the formula:

$$TSR\ bio = \frac{total\ energy\ from\ biomass(GJ)}{total\ energy\ consumption\ in\ the\ furnace} * 100\ \%. \quad (1)$$

Table 3 presents the results of testing the impact of the loss of 1% TSR bio on the cost of CO2/t clinker.

Table 3. Study of the impact of the loss of 1% TSR bio on the cost of CO2

BIO TSR		2023	2024
STEC	MJ/t clinker	3 262	3262
	GJ/t clinker	3,26	3,26
Reduction	%	1	1
	GJ/t clinker	0.0326	0.0326
Carbon emission rate	$kgCO_2/GJ$	95.76	95.76
Emission CO_2	$kgCO_2/t$	3.1234	3.1234
	tCO_2/t clinker	0.0031	0.0031
Price CO_2	EUR/t CO_2	25.66	84.28
Cost CO_2	EUR/t clinker	0.08	0.2632417
Exchange rate	EUR	4.4	4.4
Cost CO_2	**EUR/t clinker**	**54**	**73**

Source: authors' work based on data from Geocycle Polska (2024).

The calculations show how important the use of alternative biomass fuels is from the point of view of reducing production costs. Assuming, for example, the average amount of clinker produced in July 2023, i.e. 141,171 tons, as a constant production volume for all months in 2023, the loss of 1% TSR bio would involve a cost of almost EUR 139,534,883 per year, and in 2024 it would be almost EUR 465,116 per year.

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CO2 emission cost analysis and trend

As part of this part of the research, an analysis was made of CO2 costs and savings due to the use of alternative fuels, which contribute to reducing carbon dioxide emissions, in the years 2017-2030 with a constant percentage of fuels fed to the furnace in the cement plant and the biomass index. The calculation results are presented in Table 6.

Table 6. CO2 emission costs in 2017-2030

	CO2 savings in tonnes due to the use of alternative fuels in the Kujawy Cement Plant in 2023	158634						
	Euro exchange rate	4.4						
	Years	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**
	CO2 price [t] in EUR	6.35	18.11	25.85	25.66	55.37	81.35	84.28
	Savings in EUR	1,023,256	2,930,233	4,186,047	4,162,791	8,976,745	13,209,303	13,674,419
Forecast	**Years**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
	CO2 price [t] in EUR	100.00	115.00	140.00	155.00	160.00	165.00	170.00
	Savings in EUR	16,232,559	18,674,419	22,720,931	25,162,791	26,046,512	26,744,187	27,674,419

Source: authors' work based on data from Geocycle Polska (2024).

As can be seen in Tabel, the price for CO2 emission allowances will increase significantly from 2023 and will also increase in the future. It can also be noted how much savings result from the use of alternative fuels (Szykowska & Walewska, 2021). Currently, reducing carbon dioxide emissions is not only pro-ecological but also profitable.

Important parameters from the point of view of assessing the effectiveness of the use of alternative fuels are the following indicators: fuel use, biomass heat consumption and CO2 savings. The scope of data in terms of furnace input has a significant impact on calorific value, energy obtained and emission factor. The calculated CO2 savings of 16,698.5 tons means that if alternative fuels were not used and coal was burned instead, carbon dioxide emissions would be higher by almost 16,700 tons, which would increase CO2 emission fees. CO2 savings with ash are negative because it is ash with a high carbon content separated from fly ash; therefore, carbon dioxide emissions are not reduced.

The research shows that the use of alternative fuels results in a reduction in carbon dioxide emissions and, as a result, in a reduction in production costs through savings due to lower fees for CO2 emission allowances and the negative cost of obtaining 1 GJ of heat resulting from the fact that waste suppliers pay the cement plant for their reception. Additionally, it has been shown that feeding alternative fuels to the furnace does not negatively affect the efficiency and volume of clinker produced. It also shows how significantly the amount of biomass contained in alternative fuels affects the cost of CO2 per tonne of clinker.

Project management, including those financed from public funds and European funds, requires the use of appropriate tools and methods for planning tasks, monitoring their implementation and controlling effects. Both at the stage of project planning, implementation and settlement of the project (applying for project financing), it is important to estimate expenditures and costs). Project cost management does not end with estimating costs and preparing their budget. During the implementation of the project, it is necessary to monitor costs and determine possible deviations of the incurred costs from the assumed amounts. The example of project modernisation presented in the article due to the ongoing energy transformation is of significant strategic importance and is economically justified. However, accurate estimation of project costs is only possible based on correctly determined expenditures and unit costs of resources, which will be the subject of subsequent publications.

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The research focuses on assessing the use of alternative fuels in terms of their impact on greenhouse gas emissions, production efficiency and the impact on reducing the costs of the production process. The methodology includes the analysis of production data and the calculation of savings resulting from the use of alternative fuels. However, challenges were also identified related to the need to monitor the quality of the alternative fuels themselves and the cement produced, as well as to supervise the operation of the kiln. It should also be remembered that the CO2 emission decomposition modelling we developed also has its limitations. Firstly, the model only partially takes into account the progress in production technology and, consequently, the decrease in energy consumption of the analysed industries. This does not take into account, for example, the possibility of launching emission-neutral cement production technology or the use of CO2 capture and storage technology. Secondly, the model does not take into account changes in the environmental regulatory framework, which may result in the closure or severe limitation of the activities of selected industry sectors. Third, the model assumes a constant, linear improvement in energy carbon intensity. Therefore, this type of analysis will be the subject of future work aimed at defining and identifying key factors in the implementation of such an ambitious plan for the cement industry, in which environmental protection and production are not mutually exclusive. As part of further work, models should be built using artificial intelligence methods. The use of these methods would make it possible to obtain even better results and develop more efficient models. For this purpose, a hybrid approach should be considered, combining elements of effective management tools and artificial intelligence based on expert knowledge models.

Conclusions and Discussion

In today's market realities, both the demand and supply sides should not doubt that in the coming years, environmental requirements will change the functioning of every market sector, including those related to cement production. The cement industry, which is essentially a waste-free industry, can play an important role in the economic system of waste management in Poland. This branch of the economy uses (in recycling processes) significant amounts of waste and products by-products (e.g. fly ash, blast furnace slag and rea-gypsum) as ingredients of mixtures of raw materials for the production of clinker, cement and concrete. Significant amounts of waste, including special waste, are used as energy carriers for clinker-burning prepared mixtures called alternative fuels (RDF). They constitute now in the energy balance of the clinker production installation, over 70% of the energy necessary to burn the clinker. The cement industry, therefore, contributes to both saving and improving natural resources' quality environment, including by reducing the amount of waste deposited in landfills.

The authors put forward the thesis that the cement industry fits perfectly into the European idea of a closed-loop economy. However, it is an energy-intensive industry and a source of large carbon dioxide emissions. Due to requirements resulting from the European Union's climate policy, the cement industry, therefore faces major challenges challenges that will require combined efforts of the entire sector and readiness to cooperate with scientific and research units. To achieve the desired win/win relationship.

Based on a study of the literature and own research, the following conclusions can be drawn:

1) The use of alternative fuels from waste as fuel in a cement plant furnace reduces CO2 emissions into the atmosphere, which results in benefits in the form of reduced production costs.
2) Alternative fuels made from waste do not have a fixed composition, which requires routine laboratory tests to control their basic parameters and price and whether they can be used as fuel for a cement plant furnace.
3) Because alternative fuels are made from various waste fractions, their calorific value is not constant.
4) The high rate of use of alternative fuels in the mixture feeding the furnace does not negatively affect the production volume and its efficiency.
5) It is necessary to constantly monitor the fuel combustion process in a cement furnace, and if the alternative fuel provided has too low a calorific value, increase the coal dosage at the expense of the amount of fuel fed in to maintain constant production efficiency.

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6) The amount of biomass contained in the alternative fuel supplied has a significant impact on production costs.
7) The use of alternative fuels significantly reduces production costs due to the constantly increasing prices for CO2 emission allowances in connection with the EU-ETS system.
8) The use of alternative fuels affects the content of undesirable chemical compounds in the produced cement, therefore, it is important to control both the alternative fuels themselves and the produced cement.

Like any study, the one presented by the authors also has its limitations. Future research directions should include an account of technological changes that could contribute to reducing carbon dioxide emissions from cement plants. These are: removal of carbon dioxide from the system (CCS) through the use of post-combustion techniques (removal of CO2 after the combustion process – this method is the most popular and often used in industry, especially in power plants powered by fossil fuels, hydrogen technologies, low-temperature heat recovery, e.g. for electricity production, other, currently being researched (under the "New Energy" program of the National Center for Research and Development). The key postulate in this matter also seems to be to pay attention to economic and environmental analyses covering the entire spectrum of benefits and threats to the implementation of the presented solutions in practice.

Taking into account the conditions presented above that affect the difficulties in reducing emissions of carbon dioxide from production processes in the cement industry, the importance of cooperation should be emphasised in cement plants (or groups of cement plants) with scientific and research units. Research is necessary for basic (including economic aspects) and testing of pilot installations. It comes with risks, but the risks must be accepted for the sake of potential achievements and if the cement industry wants to participate in achieving the goals resulting from the European Union's climate policy. Perhaps the result of cooperation between cement plants and research units will not only be elimination techniques or significantly reducing carbon dioxide emissions from currently operating installations but also new, low-emission and energy-saving technologies for obtaining clinker, cement or concrete.

To sum up, as the authors pointed out above, the presented research does not fully exhaust the research problem raised and certainly constitutes a basis for further scientific polemics on this rarely discussed topic.

List of more important symbols and abbreviations

- AWDF – solid fuel produced from animal waste, mainly from slaughterhouses.
- PASr – solid fuel produced by grinding waste such as paper, cardboard, foil, plastic packaging, etc., to granulation of 0-40 mm or 0-70 mm.
- PASi – solid fuel produced by mixing sawdust or tobacco dust sorbent with waste paints, varnishes, etc.
- RDF – solid fuel produced from a flammable fraction of municipal waste, which is briquetting (briquette size: 32 x 32 cm).
- BRAM – solid fuel produced from household waste and industrial waste with similar characteristics to those mentioned earlier. This fuel is used in combination with conventional fuel and constitutes approximately 10% of the mixture.
- INBRE – solid fuel produced from flammable fractions of municipal waste.
- PAP – liquid fuel produced as a result of the homogenisation process of liquid flammable waste, e.g.: fuel oils, solvents, paints, etc.
- Ppm – (parts per million) a unit expressing the concentration of the components of a given substance in a solution.
- PASr HCV – a high-calorie fraction of alternative fuel used in the Kujawy cement plant from external suppliers (calorific value above 20 MJ/kg).
- TSR – alternative fuel use rate.
- TSR bio – biomass heat consumption rate.

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The contribution of the authors

Conception, M.N., J.M. and W.L.; literature review, M.N., J.M. and W.L.; acquisition of data, M.N., J.M. and W.L.; analysis and interpretation of data , M.N., J.M. and W.L.

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OCENA MOŻLIWOŚCI WYKORZYSTANIA PALIW ALTERNATYWNYCH W PRZEMYŚLE CEMENTOWYM

STRESZCZENIE: Celem artykułu jest ocena możliwości wykorzystania paliw alternatywnych w przemyśle cementowym. Badania koncentrują się na ocenie wybranych parametrów w tym, udziału zużycia paliw alternatywnych w cementowi, wpływu na współczynnik emisji CO_2 oraz możliwości osiągnięcia ewentualnych korzyści ekonomicznych. Metodologia obejmuje analizę danych produkcyjnych oraz obliczanie oszczędności wynikających z faktu stosowania paliw alternatywnych. Na tej podstawie wskazano również aspekty ekologiczne, które należy wziąć pod uwagę przy analizie opłacalności realizowanej inwestycji. Wnioski wykazują, że poprzez stosowanie paliw alternatywnych następuje obniżenie emisji CO_2 i kosztów produkcji przy jednoczesnym nie stwierdzeniu negatywnego wpływu na wydajność i wielkość produkcji. Dla praktyki ważne było potwierdzenie, że paliwa alternatywne mogą znaleźć swoje praktyczne zastosowanie także w branży cementowej a inwestowanie w odnawialne źródła energii przez zakłady produkcyjne cementu wpisuje się w cele i kierunki rozwoju związane ze zrównoważonym gospodarowaniem zasobami w myśl zasady win-win.

SŁOWA KLUCZOWE: gospodarka o obiegu zamkniętym, paliwa alternatywne, ochrona środowiska, przemysł cementowy

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