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Alternative fuels – the economic and ecological aspects of their use in the cement clinker firing process

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Poland

Abstract: A high-temperature process of firing cement clinker in a rotary kiln creates conditions for waste-free thermal waste utilization, in accordance with the EU requirements. The paper presents methods of using waste fuels in the co-combustion process in a rotary furnace as well as types of alternative fuels and methods of their production. Physical and chemical properties of alternative fuels and their impact on the combustion process were characterized. The example of the furnace tested was used to discuss its properties in the co-combustion process of alternative fuels as well as the obtained technical and ecological indicators.

Keywords: alternative fuel, co-combustion, cement industry, rotary kiln

JEL codes: O31, P18, P28, Q32, Q42

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1. Introduction

Formation of a large amount of municipal and industrial waste, which can be recycled only to a limited extent, definitely is one of the negative effects of contemporary economic development and the increase in living standard. A significant part of the waste that is unsuitable for reuse in the production process is usually stored in landfills or in special settling tanks,

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which is a high risk to the environment. The lack of land for landfills and new EU restrictions on storage of organic waste mean that the current method - deposition at landfills - is significantly limited. Therefore, the problem of limiting the amount of waste and searching for new utilization techniques is still up-to-date. An industry which for years has been using a significant amount of waste from the energetics and metallurgy, is the cement industry. Fly ash from the energetics, blast furnace slag, silica and iron-bearing dusts, coal-waste and Rea gypsum, are often substitutes for natural raw materials in a raw material mix or additives in the cement milling process. A new and developing method of utilization of combustible waste is using them as fuel in the firing process of cement clinker in a rotary kiln. High energy consumption in cement production and fluctuations in natural fuels prices cause the cement industry to look for alternative solutions in order to reduce production costs. One of these actions is usage of combustible waste substitute fuels from the so-called alternative fuels. A great interest of the industry in flammable waste results not only from economic benefits, but also from the need of making a contribution to the difficult problem of waste treatment. In addition, due to the usage of alternative fuels, cement plants "serve" waste management units in a given region. Using clinker burning lines existing in the region allows the administrative units to lower investment spending, which they would have to allocate to construction of a waste incineration plant.

The high-temperature process of burning cement clinker as well as the alkaline atmosphere inside the furnace both create very good conditions for safe and ecological usage of alternative fuels from industrial and municipal waste, serving as a partial replacement of traditional fuel - coal dust. Despite good technological conditions, the cement industry has had many difficulties concerning implementation of coal and alternative fuels co-combustion technology, mainly due to the opposition of local communities. However, thanks to educational campaigns and consultations with the local community and administration responsible for waste management, that standpoint was successfully changed. Starting the process of thermal waste utilization by the cement industry provided a quick (requiring relatively low investment expenditure) solution to the difficult waste management problem in the regions where cement plants are located.

Figure 1 presents the increase percentage in the use of alternative fuels in the cement industry in Poland since 2000. After the first difficult period (community resistance), significant progress may be observed.

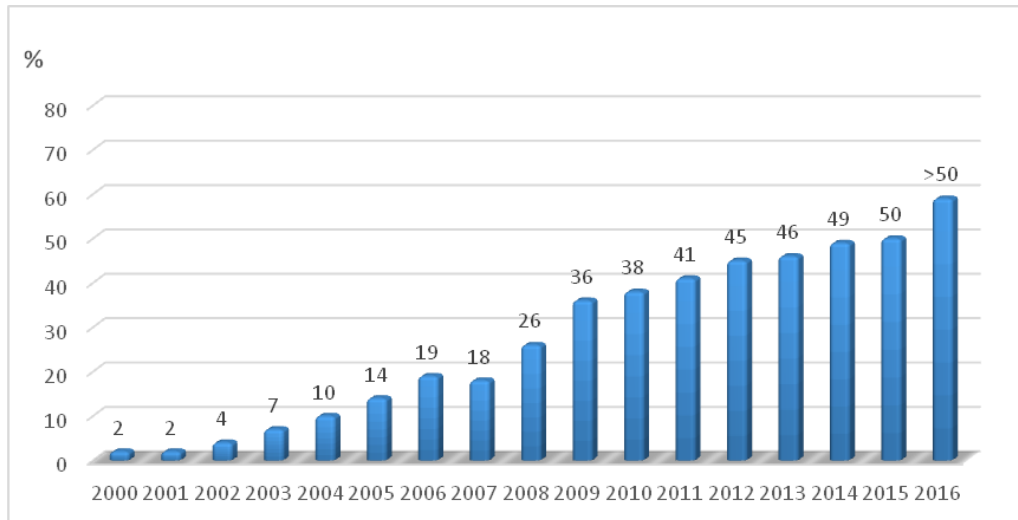


Figure 1. Share of alternative fuels in the clinker burning process

Source: SPC, 2015, 2016 own analysis based on statistics

At the beginning of the 21st century, the use of alternative fuels in the cement industry in Poland was among the lowest in Europe. After about 10 years of usage of these fuels, Poland is now among the European leaders, along with Germany and Austria. The share of alternative fuels in specific cement plants in the country varies between 30 to over 80% of the heat demand in the firing process. The differences result mainly from given firing technology (furnace construction), as well as from availability and type of waste fuel. Nowadays, a problem of the cement industry is fuel logistics, i.e. securing the right quality and continuity of supplies as well as optimizing their use.

In the paper, using the case study of a firing line which – due to the small size of the furnace – presents a limited possibility of using waste fuels, the method of using them in the co-combustion process, along with coal dust, is presented, as well as some economic and ecological effects resulting from it.

2. Co-combustion of alternative fuels in a rotary kiln

Thermal waste utilization is one of the most effective methods of waste disposal. Still, the technique itself has equally many supporters and opponents. One can agree with the latter who maintain that:

- waste production should be limited,
- non-waste technologies should be developed,
- new recycling methods should be sought,
- waste should be processed and neutralized before storing.

However, for EU countries that have successfully solved the problem of waste, the thermal utilization is often the most effective way to dispose of it, especially partially organic waste. According to the European Parliament and Council Directive 2010/75/UE of 24 November 2010 concerning industrial emissions (domestically the regulation by the Ministry of environment of 4 November 2014 on emissions standards (Dz. U. 2011) and regulation of the Ministry of economy of 21 March 2002 as amended (Dz. U. 2002)) set out conditions of thermal utilization of waste as a potential heat mover. The process may be implemented by different methods, although according to the Minister's of development Regulation of 21 January 2016 (Dz.U. 2014), it must be carried out in an installation which secures conditions of thermal waste destruction and meets requirements concerning legal emission values. According to the aforementioned directive concerning requirements of waste processing, the combustion plant must meet additional requirements that ensure the destruction of toxic compounds of PCDDs and PCDFs (dioxins and furans). Depending on the chlorine content in waste fuels, the thermal utilization process should be carried out in the following conditions:

- 1) incineration of waste containing more than 1% (calculated per chlorine) organochlorine compounds should be carried out at temperature $>1370\text{K}$ and in no less than 2 seconds,
- 2) other waste containing less than 1% chlorine should be incinerated at $>1130\text{K}$.

Figure 2 presents a technological diagram of clinker with marked alternative fuels dosing spots. Clinker firing line makes it possible to dose at both intake side and through the main burner.

High temperature clinker burning process (temperature $> 2000\text{K}$), alkaline atmosphere in the furnace, size of the combustion chamber and the resulting heat capacity and time (approx. 7s) of gas residence at temperature $> 1400\text{K}$ make the rotary kiln a competitive equipment for a professional waste incineration plant. Compared to a professional incinerator or other co-incineration processes, a rotary kiln has a number of additional advantages, the most important being:

- 1) total use of thermal energy from fuel,
- 2) no waste after burning - ash, which is completely absorbed by the clinker,
 - low investment costs of such installation,
 - no pilot burner, which protects combustion as a result of disturbances,
 - possibility of adding fuels in various forms (crumbled, liquid or even whole car tires).

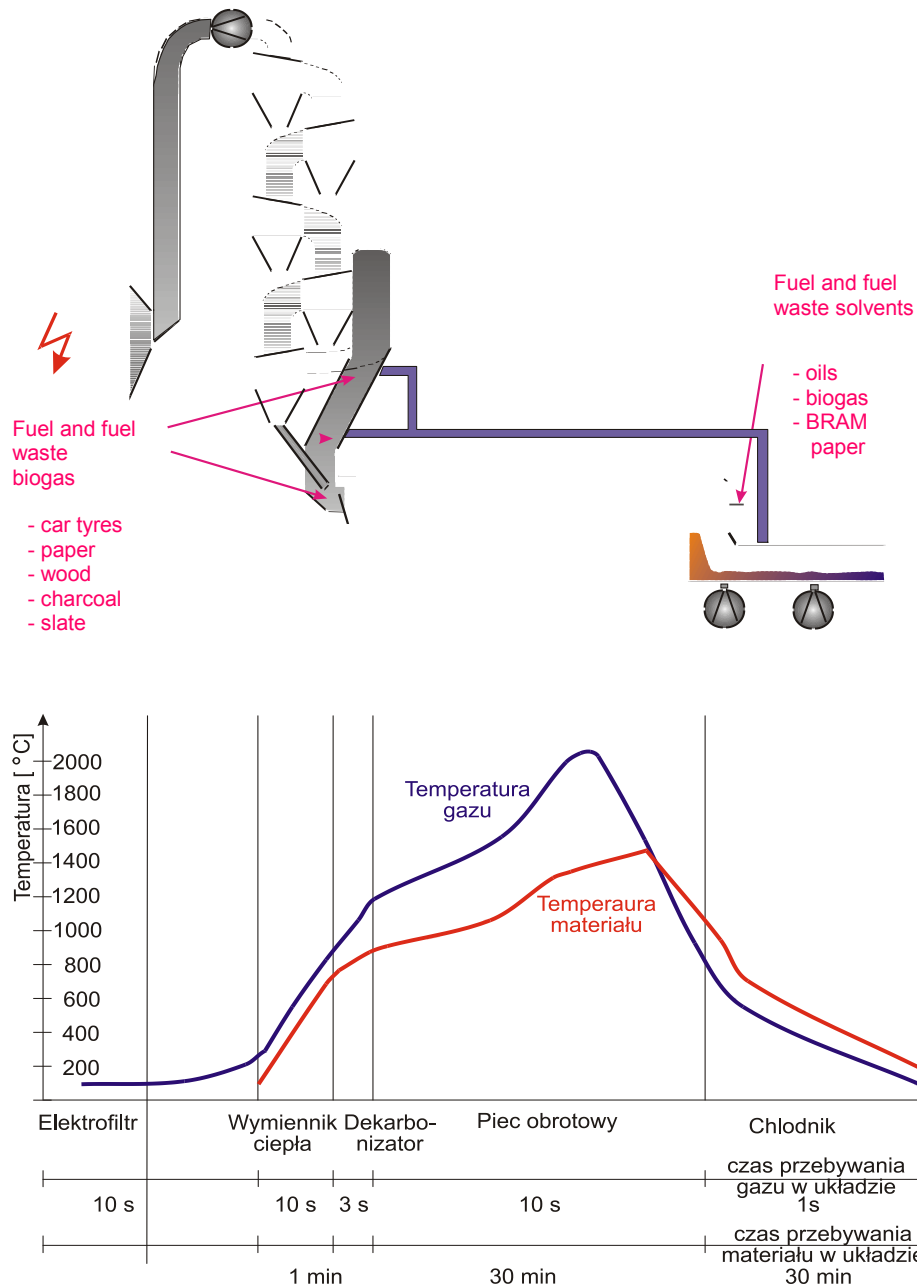


Figure 2. Methods of using alternative fuels and temperature distribution in typical rotary kilns operating in the country

Source: Duda, 2004: 149

An important part in the co-combustion of alternative fuels along with coal in the clinker firing process, in addition to furnace design and type of burner, is played by a type of fuel, the method of its preparation and its physical and chemical parameters.

3. Alternative fuels

Figure 3 presents types of fuels used in the firing process of cement clinker in a rotary kiln.

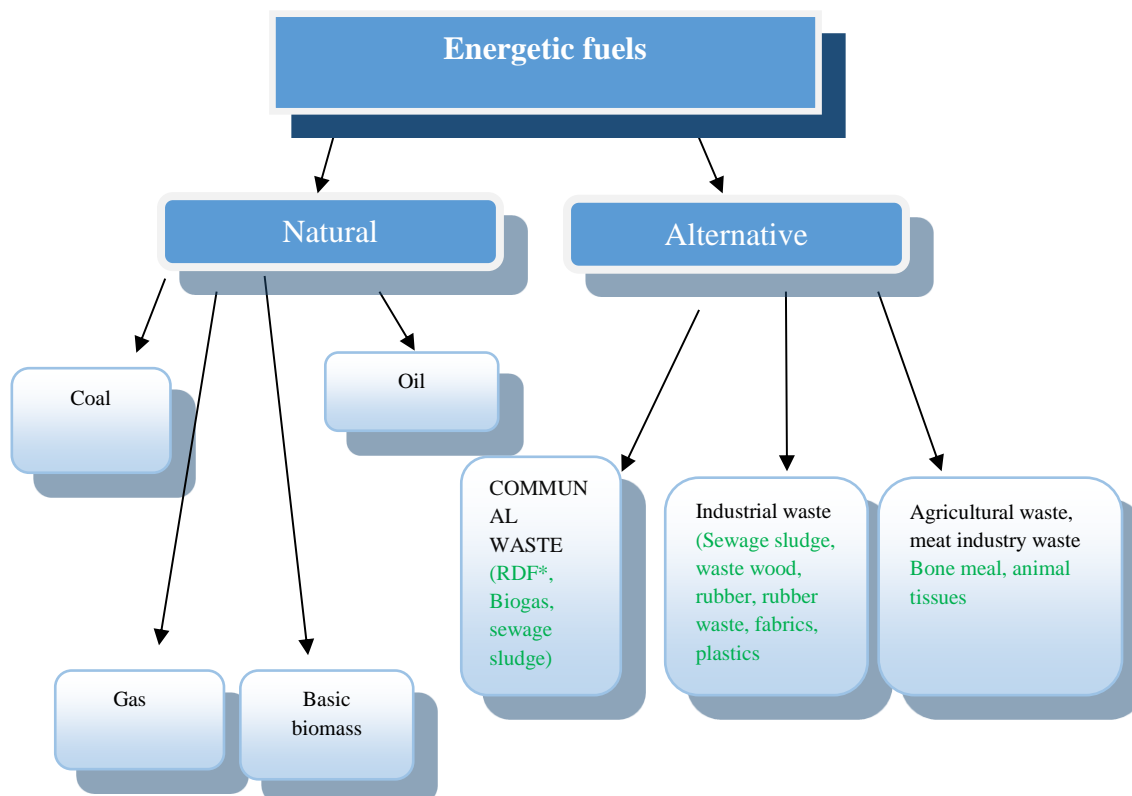


Figure 3. Natural and alternative fuels used in the cement industry

Combustible waste presents a large variety in terms of physical and chemical properties, which means that preparation of an appropriate alternative fuel, in accordance with requirements of a cement plant, is a complex process, requiring control by both a fuel producer and a customer-cement plant. The parameter that determines the possibility of using waste as an alternative fuel is its minimal thermal value. The experience of countries associated in CEMBUREAU (European Association of Cement Producers) shows that alternative fuels in a clinker burning process must be characterized by the following parameters:

- average thermal value > 13 MJ/kg ,
- humidity < 30 %,
- CL < 0,3 %
- S < 22.5 %,
- heavy metals < 2500 ppm,
- PCB + PCT < 50 ppm,
- Hg < 10 ppm,
- Cd + Tl +Hg < 100 ppm

Preparation of an alternative fuel of specific physical and chemical properties often requires mixing of several types of waste. Depending on the type of waste and the method of

fuel preparation, the following types of alternative fuels can be distinguished in the domestic market: (Walendziewski, 2007):

- **PASr** - Alternative solid fuel, similar to RDF fuel (Refuse Derived Fuel) and BRAM (germ. Brennstoff aus Müll - fuel from municipal waste). Production of this fuel involves mixing and grinding of solid waste like: fabrics, paper, rubber waste, plastics, cleaning cloths - thermal value **15-22 MJ/kg**.
- **PASi** – alternative solid impregnated fuel, created as a result of mixing liquid waste with substances of absorbent properties like: sawdust, tobacco, cellulose dust, paper - thermal value **20 MJ/kg**.
- **PAP** – alternative liquid fuel; a mixture of liquid flammable waste like: used oils, solvents and paints, sludge from paint and varnish plants - high thermal value of **30MJ/kg**.

Table 1 presents features of waste fuels used in the cement industry in Poland.

Table 1. Features of waste fuels

Required parameters	Alternative fuels 19 12 10 / 11*	Sewage sludge 19 08 05	Bone meals 19 02 10	Liquid waste
Thermal value [MJ/kg]	>17	>11	>18	>24
humidity [%]	<15	<10	<5	<5
Cl content [%]	<0.7	<0.7	<0.7	<0.7
S content [%]	< 1	< 1	< 1	< 2
Heavy metals overall [ppm]	<2000	<2000	<2000	<2000
Fragmentation [mm]	<30	Granulated/dust	Granulated/dust	-

Source: Sładeczek, 2011

Alternative fuel coded 19 12 10, i.e. flammable waste produced after municipal waste sorting; waste coded 19, 12, 11* - other waste (including mixed waste and objects) coming from waste mechanical processing including dangerous substances.

The parameter that determines the use of waste fuel in the clinker firing process is its thermal value. Theoretically, the lower limit of the thermal value of an alternative fuel, which can be burned in a rotary kiln, is the value ensuring an autothermal combustion ($W_d > 6,5$

MJ/kg). Since the primary objective of this process is to produce high-quality cement clinker and not to utilize waste, the used waste fuel must have the appropriate thermal value which, along with heat from coal combustion, will provide the technologically required conditions in the furnace. To secure the conditions for the clinker burning process, the thermal value of the fuel burned in the furnace's main burner should be approx. 25MJ/kg. Each reduction will result in a decrease in the efficiency of the furnace and an increase in heat consumption. Clearly, co-combustion of coal and alternative fuels (low thermal) shall make it difficult to obtain the right thermal value of the combusted mixture. The impact of the thermal value of fuel combusted in the clinker firing process on furnace efficiency and heat consumption is shown in Figure 4.

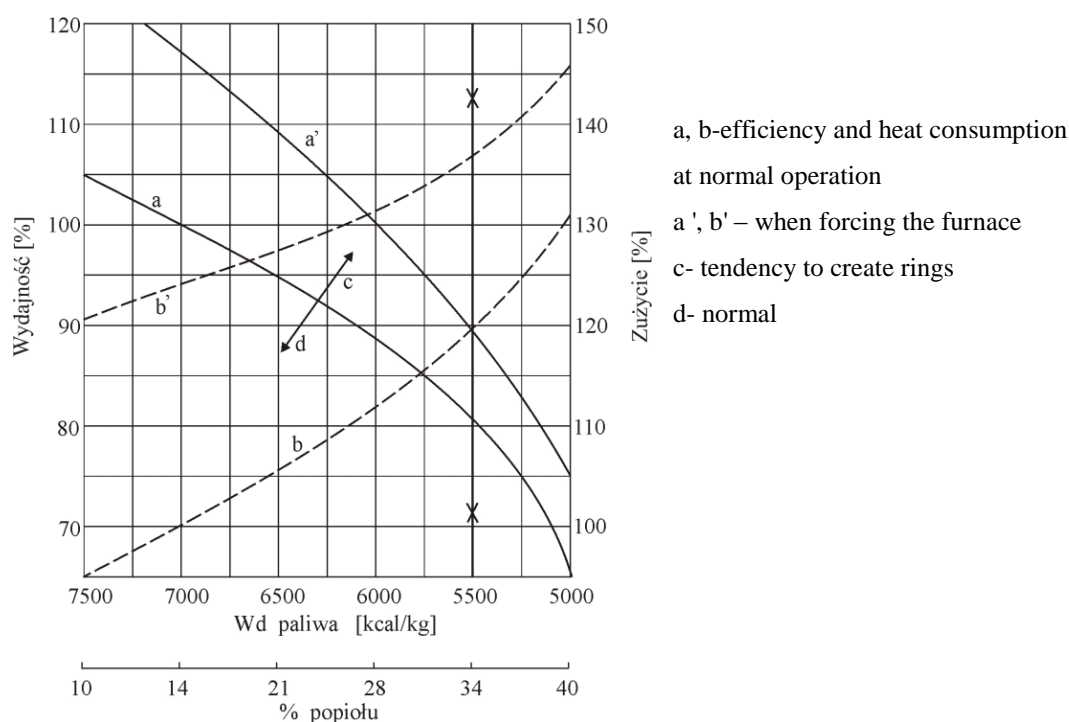


Figure 4. Impact of fuel thermal value on heat consumption and furnace efficiency

Source: Kurdowski, 1981

The development of new firing technologies must be mentioned here, during which, due to the use of an additional burner in the sheer chamber or in a separate calciner (initial decarbonisation), a significant reduction of the endothermic process of carbonate dissociation in the rotary kiln was achieved. This change has enabled a reduction of the heat generated in the furnace at the expense of heat generated at an additional burner in the decarbonisation zone (calciner). The effect of these changes is a possibility of using a fuel of lower thermic value, approx. 23MJ/kg at the main burner. Such a calorific value ensures the correct process of clinker firing, but according to the data in the chart (Fig. 4), it will result in an additional heat

consumption increase and a decrease in efficiency. To reduce losses resulting from the increase in heat consumption, coal of higher calorific value can be used in the co-combustion process or the share of alternative fuels can be reduced. On the other hand, at the so-called additional burner located in the decarbonation zone, due to the much lower temperatures required (about 1200K) than at the kiln sintering zone (about 2000K), the calorific value of the fuel used there may be lower. For example, by using coal of a calorific value approx. 27MJ/kg (typical cement plant coals) and alternative fuel of $W_d=13\text{MJ/kg}$ in the co-combustion process it will be possible to reduce the amount of coal burned for waste fuel consumption at the range of 10-20%. However, in case of ensuring the calorific value of an alternative fuel at the level of 18 MJ/kg, it will be possible to reduce the coal share by 20-40%.

Figure 5 shows the influence of an alternative fuel share in the clinker firing process on the heat consumption.

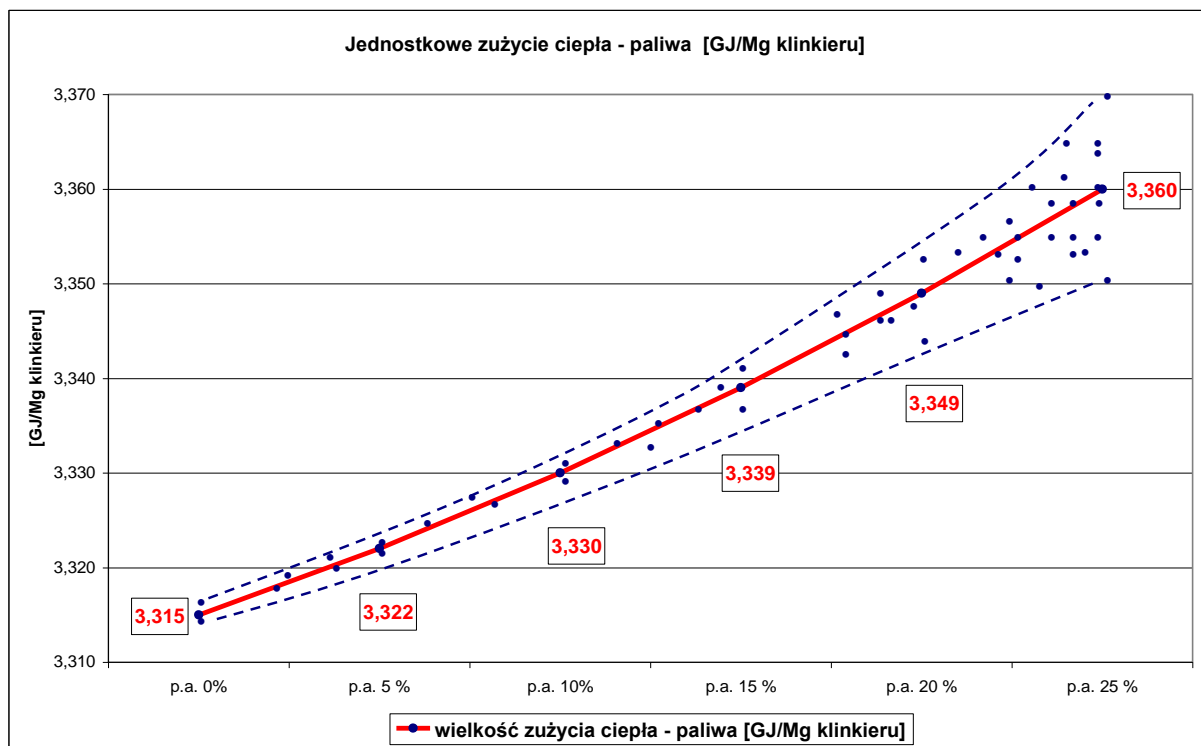


Figure 5. Heat consumption depending on alternative fuel consumption level

The presented data show that the use of alternative fuels always increases the heat consumption. Even a relatively small, 10% share of alternative fuels may cause an increase in the heat consumption by approx. 5-8%. Therefore, the choice of alternative fuel for a given furnace, its share in the clinker firing process must be supported by a detailed assessment of economic efficiency and environmental impact. The current increase in the share of these fuels

in the firing process indicates that advantages prevail over the disadvantages. In order to improve the efficiency of alternative fuels use, the ways are sought to increase the calorific value by drying them using the waste heat from the firing process.

4. Economic and ecological aspects resulting from the use of alternative fuels in the process of cement clinker firing

To assess the economic and ecological efficiency of a co-combustion process of waste fuels and coal in a rotary kiln, an installation, which due to the dimensions of the kiln is a structural solution with limited possibilities of using alternative fuel, was chosen. It is the smallest rotary kiln in the country, with a diameter of 3.4m and a length of 48.4m, significantly different from other kilns, characterized by diameters 4-5.7m and lengths ranging 60-100m. This kiln, like other dry method modernized furnaces in the country, is equipped with an external heat exchanger. It is a 5-stage heat exchanger consisting of 4 stages of cyclone exchangers and a pear-shaped lifting chamber, which is the fifth stage of the exchanger.

The dimensions of this kiln give it a relatively short sintering zone and the time the material spends at high temperature. Therefore, the firing process requires a short, very sharp flame which is unachievable when using a typical alternative fuel, e.g. only PASr. Limited for technological reasons is also the possibility of using replacement fuels at an additional burner in the elevation chamber. A short rotary kiln also limits the possibility of burning whole used car tires (danger of incomplete combustion), which are the basic fuel on other rotary kilns in the country. High calorie value and the possibility of burning entire tires without their fragmentation causes that the cement industry is unchallenged in utilization of used tires. Taking into account the aforementioned limitations of the possibility of using replacement waste fuel, it was decided to limit co-combustion only to the burner of the main furnace, where the mixture: coal dust + alternative fuel is combusted. In the combustion chamber of the additional burner, only coal dust is burned.

In order to provide the required flame and burning time, a special alternative fuel with high thermic value (about 28MJ / kg) was used, which was a mixture of rubber waste ($W_d > 30$ MJ/kg) and PASr fuel ($W_d > 19$ MJ/kg). After the first technological tests (2015) and removal of the identified malfunctions in the dosing system, the desired effects of limiting the coal dust in the process of firing, were obtained.

Table 2 presents data about consumption of alternative fuels in this furnace

Table 2. The amount of coal dust and the amount of alternative fuels used to fire clinker in Odra Cement Plant between May 2015 and October 2017

Month	2015			2016			2017		
	Coal dust used to fire clinker [Mg]	Alternative fuels used to fire clinker 19 12 10 [Mg]	The proportion of alternative fuel in relation to coal dust [%]	Coal dust used to fire clinker [Mg]	Alternative fuels used to fire clinker 19 12 10 [Mg]	The proportion of alternative fuel in relation to coal dust [%]	Coal dust used to fire clinker [Mg]	Alternative fuels used to fire clinker 19 12 10 [Mg]	The proportion of alternative fuel in relation to coal dust [%]
01	5 055.36	0.00	0.00	2 170.40	3 291.00	151.63	3 304.09	2 492.00	75.42
02	3 513.94	357.76	10.18	1 197.13	2 001.98	167.23	2 024.67	2 310.00	114.09
03	153.00	0.00	0.00	1 019.68	93.50	9.17	693.39	1 069.00	154.17
04	4 392.82	0.00	0.00	2 553.46	2 679.88	104.95	2 343.64	1 737.00	74.12
05	3 642.81	598.00	16.42	2 590.56	2 563.34	98.95	2 362.67	3 049.00	129.05
06	4 960.80	630.00	12.70	2 418.99	2 574.00	106.41	2 068.69	3 632.00	175.57
07	4 414.91	566.00	12.82	2 287.72	2 344.00	102.46	2 185.51	3 253.00	148.84
08	4 277.79	798.00	18.65	2 886.88	2 432.00	84.24	2 265.92	3 204.00	141.40
09	4 431.29	1 425.00	32.16	2 700.18	1 789.00	66.25	2 113.48	3 403.00	161.01
10	2 926.43	2 679.00	91.54	3 048.92	2 218.00	72.75	1 779.23	2 701.00	151.81
11	2 651.95	2 974.92	112.18	2 979.28	2 103.00	70.59			
12	3 022.17	2 712.28	89.75	3 386.85	1 711.00	50.52			
TOTAL	43 443.26	12 740.96	29.33	29 240.06	25 800.70	88.24	21 141.28	26 850.00	127.00

Source: data of Odra cement plant

Clinker production in the given years was as follows:

2015 – 393 116 Mg

2016 – 368 087 Mg

2017 (for 10 months) – 316 349 Mg

In 2016, the alternative fuels provided over 49% of the heat required in the clinker burning process, which allowed reducing the annual coal dust consumption by 22 000 Mg. The resulting costs (the cost of buying coal + milling - the cost of an alternative fuel) exceeds 2 million PLN. However, in the analyzed period in 2017 (10 months) alternative fuels have already provided over 59% of the required heat, which allowed reducing the consumption of coal dust by about 23 000 Mg. The expected financial profit of this activity is approximately 5 million PLN. It is clear that despite considerable limitations in using alternative fuels, the plant achieves effects similar to those achieved on large kilns with pre-decarbonisation systems. The existing positive experience to date encourages a further increase in the share of alternative fuels at this kiln. The solution enabling an increase in the amount of these fuels in the process may be building a third air installation and creating a typical calciner chamber.

In addition to the measurable economic effects at the plant, the use of alternative fuels was also of great ecological importance both at the cement plant and for the environment. The

process of co-combustion of alternative fuels in this kiln has already eliminated over 60 000 Mg of waste thus decreasing landfill storage. Combustion of alternative fuels in clinker burning process brings is no threat to the environment. The emission limit values in accordance with the BREF (BAT Reference Document - best available techniques that do not cause excessive cost increase, preventing or reducing air pollution) are not exceeded.

Table 3 presents results of emission measurements on the examined kiln and kilns in Warta II cement plant, which uses similar firing technology. The difference is only in the size of the furnaces (ϕ 5m \times 92m), which results in the fact that various substitute fuels can be used in them.

Table 3. Results of emission measurements in "Odra" and "Warta" cement plants

Substance	Unit	Emission standards in accordance with the Regulation	ODRA		WARTA kiln no 5		WARTA kiln no 6	
			2015	2016	2015	2016	2015	2016
			Coal dust Pal. alter 19 12 10	Coal dust Pal. alter 19 12 10	Coal dust Alt. fuel 19 12 04 07 02 80 Tyres 16 01 03	Coal dust Alt. fuel 19 12 04 07 02 80 Tyres 16 01 03	Coal dust Alt. fuel 19 12 04 07 02 80 Tyres 16 01 03	Coal dust Alt. fuel 19 12 04 07 02 80 Tyres 16 01 03
Dust	mg/m ³ _u	30	3.7	5.4	7.25	7.83	4.77	4.32
SO ₂	mg/m ³ _u	50	14.84	13.8	8.66	3.88	28.3	4.85
NO _x	mg/m ³ _u	500	410.0	439.7	487.1	423.8	465.2	337.2
CO	mg/m ³ _u	2000	1087	1837	1408	1538	1529	1907
HCl	mg/m ³ _u	10	3.6	3.2	2.11	2.6	2.67	1.21
HF	mg/m ³ _u	1	<0.12	<0.16	0.36	0.32	0.5	0.6
Hg	mg/m ³ _u	0.05	0.03	0.002	0.02	0.03	0.016	0.03
Sb+As+Pb+Cr+Co+Mn+Ni+V	mg/m ³ _u	0.5	0.02	0.005	0.004	0.002	0.001	0.003

mg/m³_u - values expressed in terms of dry gas with a 10% oxygen content in waste gases

Source: Dz. U. 2014, data of "Odra" and "Warta" cement plants

The measuring and technological data presented in the Table 3 show that the combustion of alternative fuels not only did not increase the emission of harmful dusts and gases, but also contributed to the reduction of greenhouse gases CO₂ and NO_x emission. The decrease in CO₂ emission is a result of reduction of coal combusted in the process of coal dust - a fuel of high CO₂ emission factor and substituting it with an alternative fuel of lower emission. The additional reduction of CO₂ emission is a result of a relatively high (30-40%) content of zero-emission combustible biomass in municipal waste fuels. Because of this the use of alternative fuels indirectly affect a reduction of greenhouse gas emission. According to the data obtained from the German cement industry, while using 3.91 million Mg of alternative fuels, 3.03 million Mg of CO₂ was emitted to the atmosphere, during burning of 2.34 million Mg of coal, the

emission of CO₂ to the atmosphere was 5.18 million Mg. Thanks to the co-combustion of waste alternative fuels, a consumption reduction of over 2.3 million Mg of coal was achieved, while the reduction of CO₂ emission was by 2.15 million Mg (Oerter, 2015).

The relatively low NO_x reduction rate that can be seen on the tested kiln results from the aforementioned problems of a short furnace and the required short, sharp flame. An increase in temperature causes an increase in the amount of NO_x, whereas a short zone of high temperatures and an excess air low ratio limit NO_x. As a result of these divergent factors and burning of high-calorie fuels, the reduction rate is lower than that obtained at kilns, e.g. in Warta cement plant, using alternative fuels with a high moisture content – low-calorie. Such fuels have a beneficial effect on the NO_x reduction, because the endothermic water evaporation reaction reduces the flame temperature, which results in lower thermal NO_x emissions.

5. Conclusions

The high-temperature technology of firing cement clinker in a rotary kiln creates good conditions for safe, thermal waste utilization. Co-combustion of alternative fuels is a beneficial process for both cement plants and the environment. A cement plant which replaces high-CO₂ coal with cheap alternative fuels of lower CO₂ emission, not only achieves significant financial effects but also reduces greenhouse gas emissions. This process, due to clinker mass production and the resulting high demand for fuel, to a large extent solves the difficult economic problem regarding utilization of industrial and municipal waste. The assessment of co-firing on a short kiln shows that, while being not the most beneficial device for co-firing waste fuels, but due to the appropriate selection of alternative fuel quality and the way of usage, it was possible to obtain technical and technological indicators similar to large kilns equipped with preliminary calcination systems. Both the high quality of produced clinker and the control of emission measurements confirmed that the use of alternative fuels has no detrimental effect either on the process or on the environment. There are also significant ecological effects of thermal utilization of a significant amount of waste, more than 60,000 Mg was utilized in less than 3 years. The rate of 59% heat protection obtained in the last year (for 10 meters) in the waste incineration process (avg. national approx. 55%) is very good. The current exploitation has confirmed that this indicator can be further improved at relatively low cost. All these activities, in addition to the benefits for a cement plant, are very important for the country's waste management and for environmental protection. The industry which used to belong to those particularly harmful to the environment, nowadays, due to its contribution to solving the problem of industrial and municipal waste disposal, plays an important part in protecting it.

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PALIWA ALTERNATYWNE – ASPEKTY EKONOMICZNE I EKOLOGICZNE ICH UŻYWANIA W PROCESIE WYPAŁU KLINKIERU

Streszczenie

Wysokotemperaturowy proces wypalania klinkieru cementowego w piecu obrotowym stwarza warunki do bezodpadowej, termicznej utylizacji odpadów, zgodnie z wymaganiami wynikającymi z Dyrektyw UE. W pracy przedstawiono metody wykorzystania paliw z odpadów w procesie współspalania w piecu obrotowym oraz rodzaje stosowanych paliw alternatywnych i sposób ich wytwarzania. Scharakteryzowano własności fizyko-chemiczne paliw alternatywnych oraz ich wpływ na proces spalania. Na przykładzie badanego pieca omówiono jego własności w procesie współspalania paliw alternatywnych oraz uzyskane wskaźniki techniczno-ekologiczne.

Słowa kluczowe: paliwo alternatywne, współspalanie, przemysł cementowy, piec obrotowy.

JEL codes: O31, P18, P28, Q32, Q42

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