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SELECTED ECOLOGICAL ASPECTS OF CO-INCINERATION OF GLYCERIN PHASE WITH COAL IN GRATE FURNACES

WYBRANE ASPEKTY EKOLOGICZNE WSPÓŁSPALANIA FAZY GLICERYNOWEJ Z WĘGLEM W PALENISKACH RUSZTOWYCH

Abstract: The prospect of depletion of reserves of fossil fuels and concerns about the environment have significantly increased the interest in renewable energy sources and have consequently led to a large increase in their use, both in Poland and in other EU countries. One of the important sources of renewable energy is biomass, which can be used, inter alia, for the production of biofuels and bioliquid, including esters. The applicable rules impose increasing consumption of such substances and, as a result, increase in their production. Ester production is accompanied by the production of glycerol phase whose management in an efficient manner poses a number of problems. The problems arise from the large variability in the glycerol phase depending on the technology and materials used in the production of esters, as well as the relatively large mass of glycerol phase waste produced in the country. The paper presents the results of research on selected environmental aspects of co-incineration of glycerin phase with coal in grate furnaces. The specificity of national power utilities is the existence of a relatively large number of boilers with travelling grates. The research which was done includes the study of the incineration of compounds with the mass fraction of the glycerol phase ranging from 5 to 20%. The paper presents the methodology of the study and the outcomes of the resulting emissions of CO and NO.

Keywords: glycerin phase, co-incineration, grate furnaces, emission

Introduction

The prospects of the depletion of fossil fuel resources and concerns for the condition of the environment have significantly increased the interest in renewable energy sources. Consequently, it led to a significant increase in the use of renewable energy sources in Poland and in other highly-developed countries. This increase has also forced measures of a legal nature, including obligations arising for instance from Directive 2009/28/EC [1] obliging Poland to reach in 2020 at least 15% share of energy from renewable sources in the consumption of gross final energy (20% at the EU level). Apart from the main objective, Poland is to achieve intermediate objectives: 9.54% until 2014, 10.71% until 2016 and 12.27% until 2018.

An important source of renewable energy in Poland, available for quick use, is biomass. One of biomass applications is the production of biomass-based liquid fuels. In the case of this biomass application, there are also legal regulations that enforce the increase in its application. Pursuant to the provisions of the "Act on Biocomponents and Liquid Biofuels" [2], entrepreneurs operating business activity within the scope of manufacture, import or purchase of fuels or liquid biofuels, who sell them in the territory of Poland, have been obliged (since 2008) to ensure in a given year at least a minimum share of biocomponents and other renewable fuels in the total quantity of fuels and liquid biofuels

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sold. And the minimum share, as mentioned hereinabove, is calculated according to the calorific value of individual biocomponents. The minimum share of biocomponents in subsequent years is stipulated in the Regulation of the Council of Ministers on National Indicative Targets for the years 2008-2013 [3]. Accordingly, National Indicative Targets (*ie* minimum shares of biocomponents) amount to: from 2013 - 7.10%, in 2017 - 7.80% and in 2018 - 8.50% (in 2008 - the first year when the regulation came into force, it amounted to 3.45%). The implementation of the provisions of the aforementioned legal acts resulted in the increase in the production of bioethanol and esters. Figure 1 presents changes in the production volume of biocomponents and biofuels in Poland in the years 2008-2014.

It is worth mentioning that in Poland up to 5 percent of bioethanol is added to standard petrol and up to 7 percent of esters is added to diesel oil.

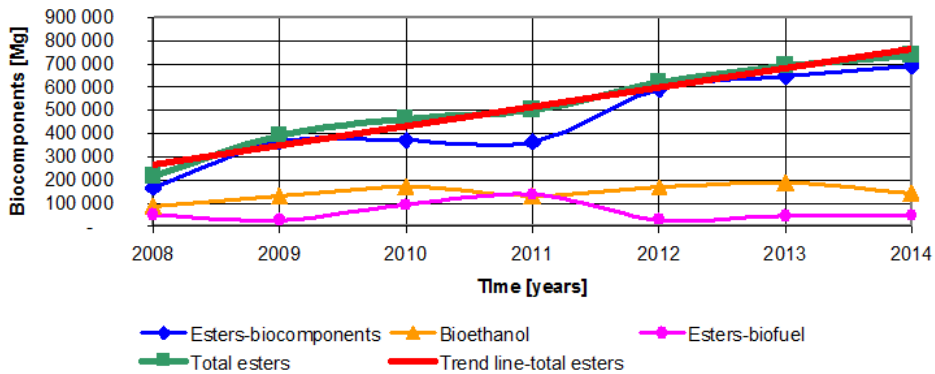

Fig. 1. Production volume of biocomponents and biofuels in Poland in the years 2008-2014 (own work based on data [4])

From the point of view of the research presented in the paper, the volume of esters production is important, as their production is accompanied by the creation of the glycerine phase. As a result of the process of vegetable oil esterification for fuel purposes, a relatively considerable quantity of glycerine phase is produced. The glycerine phase production amounts from several to twenty percent of the weight of esters produced.

According to the data presented in Figure 1, in the last five years in Poland there has been a rapid increase in the production of esters. Their production increased from the level of about 200 000 Mg to the value of nearly 700 000 Mg. Due to the further increase in obligatory National Indicative Targets, further increase in ester production is to be expected. With the increase in the quantity of produced esters, the quantity of produced glycerine phase will be also increasing.

It can be estimated that during the production of the mass of esters produced in 2014, about 80-130 thousand Mg of glycerine phase was created. The issue of effective management of the currently produced glycerine phase causes a number of problems. They result both from high changeability of glycerine phase properties depending on technology and raw materials used for ester production, and from the relatively high weight of this waste produced at the national level. There are several possibilities of managing the glycerine fraction. However, for majority of them, the glycerine fraction needs to be treated

to pure glycerine first, and this is an expensive process. Other applications include the use in agriculture or in thermal processes, *eg* in co-combustion processes.

In Poland, hard coal is still the basic fuel and its share in the structure of covering demand on primary energy will continue to be significant for a few decades.

One of the technologies for using coal is its combustion in stoker fired boilers, including with a mechanical grate. Boilers with mechanical grates are basic structures in Poland used for combusting coal in medium output facilities. They are present in boiler rooms, heat generating plants and municipal and industrial heat and power stations. A large tolerance of these boilers for parameters of combusted fuel causes that they are predisposed to carry out processes of fuel co-combustion. In addition, their prevalence causes that they can be used in the place where biomass or waste is produced. It is also relatively easy to perform modernisation in these boilers, *eg* of the fuel feeding system. The weak point of this type of structure is the relatively low energy efficiency and problems with adapting to the growing legal requirements in terms of environmental protection.

Testing methodology

As part of the testing presented, technical possibilities and selected environmental effects of the co-combustion process of hard coal with the glycerine phase in the stoker-fired boiler furnace were checked. Testing was conducted at a laboratory station allowing for conducting laboratory testing in a relatively large scale as the fuel mixture combusted at the station can have the maximum capacity of over 40 dm^3 and the weight of over 20 kg.

The basic element of the laboratory station is a boiler with a special design that allows for the simulation of combustion processes occurring in water boilers with a permanent grate and with a mechanical travelling grate. The boiler is composed of two basic parts:

- the lower one, with adjustable temperature,
- the upper one, equipped with a water jacket.

The lower part of the system, in connection with the possibility of being heated up to the assumed temperature, allows, inter alia, for the simulation of the operation of the ignition arch of the stoker-fired boiler. The heated chamber walls also simulate the impact of further parts of the boiler on the combusted fuel sample.

The upper part of the boiler allows for flue gas cooling in a manner similar to the one occurring in the upper part of combustion chambers in water boilers.

To ensure quick feeding of the fuel sample into the furnace chamber and to allow for the placing of fuel on the grate, it is possible to insert the grate into the lower chamber.

The combustion chamber is equipped in a number of nozzles, which enables performing temperature measurements and sampling in the different points of the chamber. The installation is equipped with a system of equipment, which makes it possible to control the size of the air stream supplied and to measure it.

Before starting tests, samples of the combusted fuel were prepared. The glycerine phase was mixed with coal in proportion by weight of 10 and 20%. Then the prepared mixture was poured on the travelling grate. After the lower part of the furnace was heated up to 900°C, the grate was inserted into the combustion chamber. The fuel was combusted in a 50 mm-thick layer. As a result of the combustion chamber cooling during the insertion

of the fuel sample, the process was carried out from the temperature of about 700-750°C. The temperature measurement was registered at the level of 200 mm above the combusted fuel layer.

Table 1 presents basic fuel parameters of substances used in testing.

Table 1

Selected fuel parameters of substances used in testing

Item	Unit	Hard coal*	Glycerine phase*
c	[%]	63.88	43.12
h		3.71	7.15
n		1.17	0.03
s		0.94	1.75
cl		0.11	-
o		6.34	48.02
p		18.47	0.12
w		6.51	0.29
Calorific value	[MJ/kg]	25.3	16.4

* Over 100% summary contents of components result from uncertainty in measurement and from the fact that oxygen was measured and not calculated

Further in the article, combustion results for coal and mixtures with 10 and 20% of glycerine phase content are presented. These results are compiled with the results obtained during hard coal combustion. Every fuel (coal and mixtures) combustion was repeated three times. These processes were defined respectively as: “Test I”, “Test II” and “Test III”.

During presented testing, the mixture was obtained by thorough mixing of the glycerine phase with coal. As a result of such mixing, the glycerine phase occurred only on coal grains, providing them with clear gloss. Therefore, the phenomenon of the flow of the glycerine phase down the fuel layer did not occur. Moreover, such creation of the mixture caused that, de facto, there was no increase in their capacity (in relation to the combustion of coal alone). The glycerine phase filled the irregularity of grains and spaces between them.

Measurements were started at the moment of the ignition (adopted to be the moment when over 0.5% of CO_2 in flue gas was reported); testing was conducted for the period of 90 minutes. During testing, air was supplied to the combustion chamber in the quantity ensuring the mean value (for the entire combustion process) of the excess air ratio λ equal to 1.5.

Test results

Ones of the most important flue gas parameters in terms of environmental protection are their concentrations and emissions of CO and NO. These combustion process compounds are largely affected by control factors, such as, *eg* quantity and time of air supply.

A more detailed analysis of changes in these concentrations during the combustion of tested fuels (coal and mixtures) is presented below.

Figure 2 presents changes in time of CO concentrations reported during the implementation of three repetitions of the combustion of the mixture with 20% of glycerine

phase content. In the figure, there is also a curve presenting changes in time of the mean concentration values from these three repetitions.

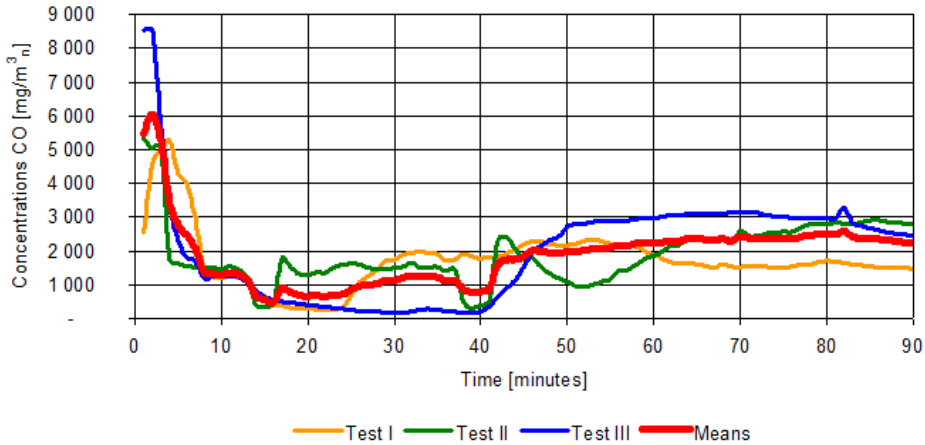

Fig. 2. CO concentrations during the combustion of the mixture with 20% of glycerine phase content

According to the data presented in Figure 2, for all tests we can observe that after the initial very significant increase in concentrations, they decrease very quickly (this stage lasts until c. 15th minute). At this stage, for all three repetitions of the mixture combustion process, maximum values were observed. Then, there is the stage of relatively low concentration values, and then their repeated increase. However, the duration of the last two stages of CO concentrations are very diversified for individual tests.

Despite relatively significant differences in the slopes of individual curves, the mean values of concentrations observed during individual repetitions are similar. These values are presented in Table 1.

Figure 3 presents mean CO concentrations obtained during the combustion of tested fuels.

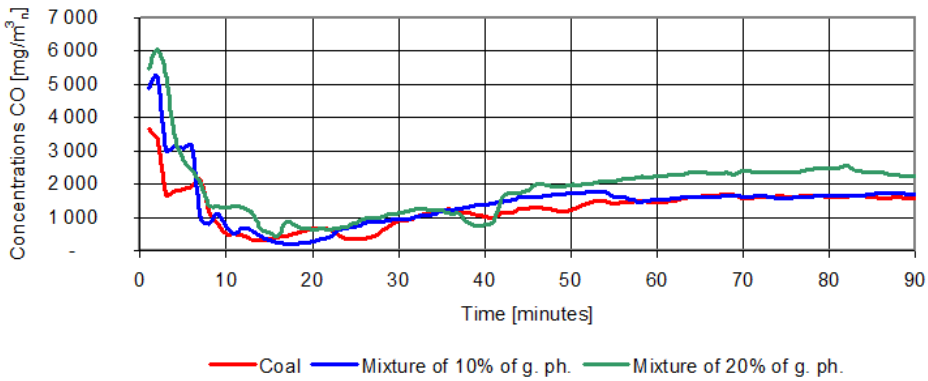

Fig. 3. Mean CO concentrations during the combustion of tested fuels (g. ph. - glycerine phase)

According to the data presented in Figure 3, in case of combustion of all tested fuels, a sudden increase and a very fast drop in CO concentrations in the period of the first 10 minutes is visible. In the second period, lasting for about 15 minutes, concentrations are of relatively low values. Then, there is an increase in concentrations, which continues till the end of testing.

The initial increase in CO concentrations results from the very intense process of volatile matter releasing. At the second stage, the fuel is combusted intensely, and CO is burned to CO_2. At the third stage, hydrogen radicals necessary for burning CO to CO_2 have already been used up. At the same time, there is a temperature drop, which also affects significantly CO burning.

Figure 3 also demonstrates that during the combustion of coal and mixture with 20% of glycerine phase content, starting from the 10th minute, we can observe relatively similar changes in concentration values. For the combustion of the mixture with 20% of glycerine phase content, increased (in relation to combustion processes of the other two fuels compared) CO concentrations at the first and at the last stage (from about 45th minute) of the combustion process were observed.

When comparing the mean values of concentrations reported during combustion of individual fuels (values presented in Table 2), it can be concluded that the least repeatable CO concentration results were characteristic for the coal combustion process, for which the relative error was over 30% (for the combustion of other fuels 11.0 and 7.3%). Along with the increase in the glycerine fraction content, CO concentrations are growing, and in the case of the combustion of the mixture with 10% of glycerine phase content, the increase is insignificant. For the combustion of the mixture with 20% of glycerine phase content the increase is over 30% (in relation to the concentrations observed during coal combustion).

Table 2

Mean values, standard deviations and relative errors, characteristic for the course of fuel combustion processes (coal and mixtures with 10 and 20% of glycerine phase content)

Gas	Mean values [mg/m^3_n]			Mean value for tests I to III [mg/m^3_n]	Standard deviation [mg/m^3_n]	Relative error [%]
	Test I	Test II	Test III			
	Coal					
CO	1462	951	1831	1415	442	31.2
NO	90	99	59	83	21	25.3
	Mixture with 10% of glycerine phase content					
CO	1423	1323	1636	1460	160	11.0
NO	92	50	57	66	22	33.3
	Mixture with 20% of glycerine phase content					
CO	1741	1904	2014	1887	137	7.3
NO	40	67	92	67	26	38.8

As in the case of CO, analyses conducted for NO lead to the conclusion that mean concentration values obtained are characterised by much less repeatability (relative error amounted from about 25 to nearly 40%). At the same time, adding the glycerine fraction resulted in the reduction in observed concentrations by about 20%. And concentrations observed during the combustion of mixtures with 10 and 20% of glycerine phase content were similar.

Conclusions

In Poland, in recent years, we have been observing a dynamic increase in ester production. The growing ester production is accompanied by an increasing production of the glycerine phase. Thus, the problem with the management of the glycerine fraction in a cheap and effective manner starts to occur. One of the methods meeting these criteria is the possibility of co-combusting the glycerine phase with coal. Testing conducted leads to the conclusion that combustion of mixture based on coal, characterised by a significant glycerine phase content (20% mass fraction), in the grate furnace, is possible. Glycerine does not cause the filling of spaces among the grains. And the co-combustion of the glycerine phase stabilises the process and increases its repeatability. Unfortunately, this co-combustion process is accompanied by an increase in concentrations, and thus, in CO emission.

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WYBRANE ASPEKTY EKOLOGICZNE WSPÓŁSPALANIA FAZY GLICERYNOWEJ Z WĘGLEM W PALENISKACH RUSZTOWYCH

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Abstrakt: Perspektywa wyczerpania się zapasów paliw kopalnych oraz obawy o stan środowiska naturalnego znacznie zwiększyły zainteresowanie odnawialnymi źródłami energii i w konsekwencji doprowadziły do dużego wzrostu ich wykorzystania zarówno w Polsce, jak i w pozostałych krajach Unii Europejskiej. Jednym z istotnych źródeł energii odnawialnej jest biomasa, która może być wykorzystana m.in. do produkcji biopaliw i biokomponentów płynnych, w tym estrów. Obowiązujące obecnie przepisy wymuszają rosnące zużycie tych substancji, a więc i rosnącą ich produkcję. Produkcji estrów towarzyszy produkcja fazy glicerynowej, której zagospodarowanie w sposób efektywny przysparza szereg problemów. Wynikają one zarówno z dużej zmienności właściwości fazy glicerynowej w zależności od technologii i surowców wykorzystywanych do produkcji estrów, jak i stosunkowo dużej masy tego odpadu powstającego w skali kraju. W pracy przedstawiono wyniki badań nad wybranymi aspektami środowiskowymi procesu współspalania fazy glicerynowej z węglem w paleniskach rusztowych. Specyfiką krajowej energetyki komunalnej jest występowanie stosunkowo dużej liczby kotłów z rusztami taśmowymi. W ramach prezentowanych badań zbadano proces spalania mieszanek o udziale masowym fazy glicerynowej wynoszącym od 5 do 20%. W pracy przedstawiono metodykę prowadzonych badań oraz wyniki dotyczące powstających emisji CO i NO.

Słowa kluczowe: faza glicerynowa, współspalanie, paleniska rusztowe, emisja