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ENERGY EFFICIENCY AND ECOLOGICAL EFFICIENCY OF LOW POWER FURNACE POWERED WITH DEPOLYMER SECONDARY FUEL

Key words

Combustion, liquid fuel furnace, alternative fuel, depolymer, energy efficiency, ecological efficiency.

Abstract

The use of oil fraction, derived from the depolymerisation of waste plastics, as a fuel is becoming increasingly important, because apart from being a source of energy, it can solve the problem of disposing of waste that is harmful to the environment. Based on the study, the effect of the use of depolymer is based on the values of the basic parameters of the combustion process in a low-power furnace. The variation of value of excess air ratio and the value of flue gas temperature and value of the concentrations of toxic substances in fumes during combustion processes were assessed. The amounts of heat generated in the furnace during combustion of depolymers and its fuel mixtures with heating oil were established. Controlled changes in process parameters of the combustion conditions of depolymer and the selected mixtures of fuel oil allow the ecological operation of the processes of combustion in commercial low-power furnaces.

Introduction

In recent years, there have been extensive efforts performed for the introduction into practical use of furnaces powered with fuel other than heating oil. Unconventional fuel, which is conquering more and more recognition, is the oil fraction derived from the depolymerisation of waste plastics [3, 4, 8, 10, 13, 14, 15, 21]. The use of depolymers as a fuel is becoming increasingly important because, besides being a source of energy, they can also solve the problem of the disposal of environmentally harmful waste [5, 6, 7, 11, 12, 25, 26].

Plastic wastes have become one of the main environmental problems of the contemporary environment due to their high resistance to natural degradation. Attempts have been made to solve the problem by destructive processing of such waste into the hydrocarbon fraction with a wide boiling temperature range with possible application as a component of motor and heating fuels [2, 3, 4, 13, 21, 24]. Most of the methods involve recuperation of energy from waste polymers by decomposition into low molecular weight compounds by catalytic cracking or pyrolysis [1, 2, 3, 12, 14, 15, 23]. Thermal or catalytic processes for the decay of macromolecular polymers produce compounds of lower molecular weight. The most preferred seems to be the processing of olefin plastic (that contain no heteroatoms); therefore, hydrocarbon fractions can be derived having similar properties as fractions derived from crude oil processing [1]. One of the great advantages of this type of depolymers is that the compounds are devoid of impurities that adversely affect the environment (sulphur, chlorine, nitrogen) when combusted.

The most commonly used group of plastic materials are the following: polyethylene (PE), including low-density polyethylene (LDPE), linear low-density polyethylene (LLDPE), high-density polyethylene (HDPE), polypropylene (PP), polyvinyl chloride (PVC), polystyrene solid (PS) and expandable polystyrene (EPS), polyethylene terephthalate (PET), and polyurethane (PU). These polymers represent 80% of global production of plastics [1]. The largest share in the production and consumption are found in the most industrialized countries, including the US, Japan, and Germany.

An important part of used plastics (62%) are [1] polyolefins, 23% PP, 11% PELD, 11% LLDPE, and 17% HDPE. It is estimated that, in 2050, the global plastics market will reach its saturation point – 200 mln Mg. Waste plastic, due to occupation of a significant volume in relation to its weight, are a major component collected in landfills; in Poland – as much as 91%, and, e.g., in Austria – only 26% [1].

Making liquid fuels from plastic is not a process that is viable from an economic point of view, but it allows the use of a large mass of waste and thus brings Poland closer to achieving a mandatory level of recycling resulting from EU regulations on waste management [5, 6, 25, 26].

1. The aim of the work

The first aim of this research is the identification of the possibilities and the range of the applications of secondary fuel, originating from a process of the depolymerisation of waste plastics for the supply of low-power furnaces. The second aim is the determination of the impact of the fuel used for energy and the nature of the emissions of the furnace.

The task was accomplished by conducting our own experimental research aimed at the determination of the impact of the composed fuel on the level of toxic exhaust emissions and the energy of the furnace tested.

2. The test stand

The study was conducted on a test stand for studying the combustion of liquid fuels. Because of the need to conduct research on liquid fuels meeting the requirements of PN-96024: 2011 for light heating oils, a stand was constructed using a low power furnace with a burner adapted to burn such fuels.

To perform the combustion processes, a Wertich WO 15 furnace from Ulrich was used that has a rated output of 13.8 kW.

The construction of the furnace was modernised by installing a water jacket and special heat-resistant sleeves to allow the installation of temperature sensors.

The installed system for measurement and recording the temperature in the combustion chamber of the furnace allowed temperature measurements at six points (4 sliding type K thermocouples in the combustion chamber and 2 in the exhaust system). Signals from the temperature sensors were recorded with a universal recorder KD7 from Kobold. The registration system of temperatures allowed the export of data to a computer.

The combustion chamber of the furnace is equipped with a system for measuring the amount of air supplied to the combustion. To measure the amount of air, a Hoffer turbine was used (RPR-51S HO sensor) with flow laminators and mass flow computers Masstrol ST2L10P from KEP.

To measure the amount of fuel, gear flow meters from KEM were used together with type F110P meters from FLUIDWELL.

For the analysis of exhaust gases, a microprocessor gas analyser GA-21 Plus from Madur was used, which allows the measurement of the composition of the exhaust gases, including the content of oxygen, carbon monoxide and dioxide, nitrogen monoxide and dioxide, and sulphur dioxide. The analyser allows the measurement of the excess air ratio λ, chimney loss SL, combustion efficiency η, and the losses by incomplete combustion IL.

To measure the concentrations of hydrocarbon, a MC-218 Hermann analyser was used.

The stand is equipped with a system for measuring and recording the energy produced by the furnace during combustion. Measurements of the energy performance of the furnace were made by an electronic energy meter PolluTerm from SENSUS, recording the energy of heating medium (GJ), the instantaneous power (kW) and other parameters.

3. The test results

In the study, the fuel components were used that are characterised by the features presented in the list below (Table 1). Naming style in the description of research results was adopted in the form of, e.g., D20 (20% share of depolymer mixed with heating oil), D100 (pure depolymer), OO100 (pure oil).

Table 1. Selected parameters of fuels used for supplying the furnace

No.	Parameters	Heating oil	Depolymer
1	Ignition [°C]	88	91
2	Calorific value [MJ/kg]	39.8	41.5
3	Density in 15°C [g/cm³]	830	807
4	Viscosity in 40°C [mm²/ s]	2.64	3.5
5	Sulphur content [mg/kg]	776	2

In Figures 1 to 4, the results of changes in toxic exhaust emissions are presented. Figures 5 to 8 present the results of the efficiency of the combustion processes of depolymer fuel components and heating oil.

D20 fuel combustion requires a lower excess air ratio $\lambda = 2.1$ compared to the combustion of heating oil ($\lambda = 2.37$), which, with a slight increase of exhaust gas temperature to 177°C (166°C for oil), reduces the concentration of carbon monoxide by almost 20% and nitrogen oxides by 15%. In addition, a decrease in sulphur dioxide concentration by 20% was indicated. The limitation of the concentrations of toxic exhaust is proportional to content of depolymer in the heating oil, which testifies that the recorded changes are due to the fuel type rather than to thermal changes.

The efficiency of the furnace supplied with D20 fuel (86.8%) was at a comparable level to the efficiency of the furnace supplied with heating oil (85.5%) – Fig. 5.

Further increasing the percentage of depolymer mixed with heating oil changes the nature of the combustion process. For the D50 fuel (Fig. 2), the excess air ratio ($\lambda = 2.23$) is indeed smaller than for the heating oil, but higher than that of the D20 fuel, which, with the same exhaust gas temperature (180°C), indicates the transition of the combustion process from the kinetic to diffusive. The concentration of carbon monoxide measured using D50 is higher

than the concentration using the D20 fuel, resulting in a limitation on the concentrations by about 8% compared to heating oil. The concentrations of nitrogen oxides decrease by 24% and sulphur dioxide by 55%, which testifies about the fuel-type nature of those changes.

With the supply of D50 fuel, a 5% increase in furnace efficiency was observed – Fig. 6.

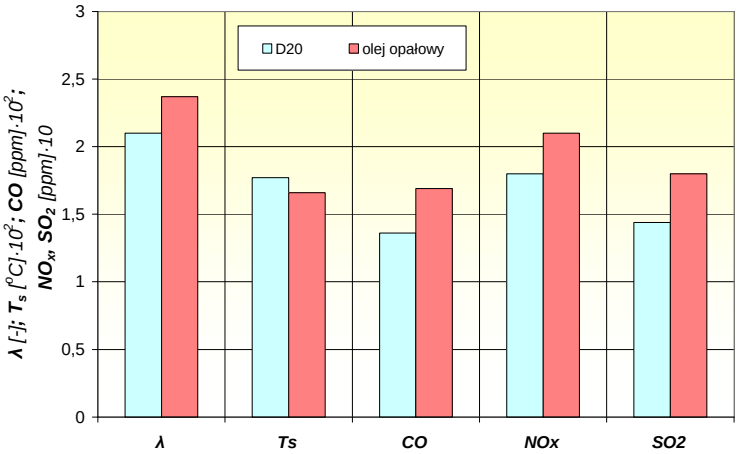

Fig. 1. Comparison of results of combustion of D20 fuel and heating oil

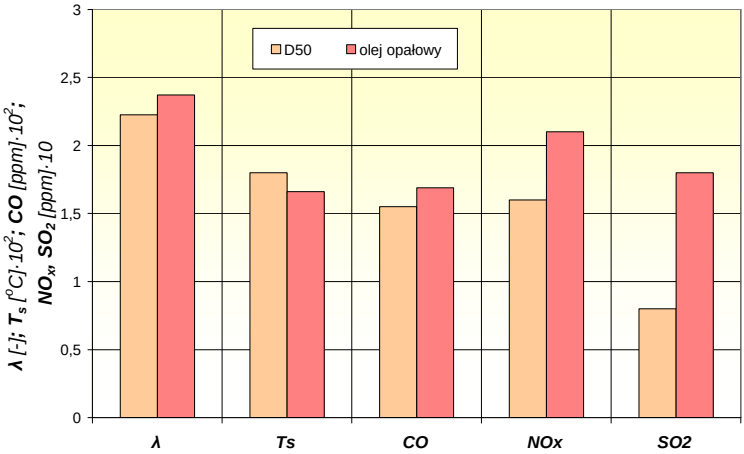

Fig. 2. Comparison of results of combustion of D50 fuel and heating oil

Supplying the furnace with a fuel containing more than 50% polymer results in significant changes in the combustion process. A significant change in the viscosity of the fuel mixture (D70 fuel) causes that the injector of the furnace is not able to spray the fuel supply properly; therefore, the propagation

speed of the oxidation front would be similar to conventional heating oil. Changing the nature of the combustion from kinetic to diffusion causes the reduction of intensity of oxidation despite the increased excess air ratio (λ = 2.7 – an increase by 14% compared with heating oil), which strongly increases the temperature of the exhaust gas (25%) and combustion becomes incomplete – an increase in the concentration of carbon monoxide by 15% compared to the heating oil supply – Fig. 3. An increase by 10% of the concentration of nitrogen oxides in the exhaust gas has a typical thermal nature – high temperature, a lot of oxidant, and a slowly moving front of oxidation.

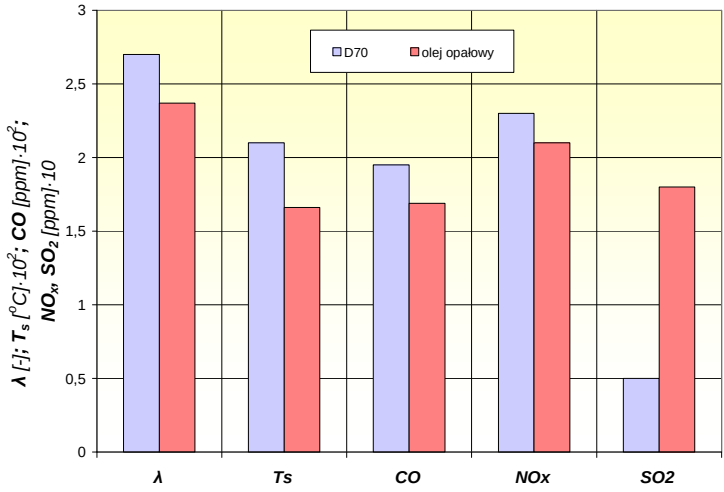

Fig. 3. Comparison of results of combustion of D70 fuel and heating oil

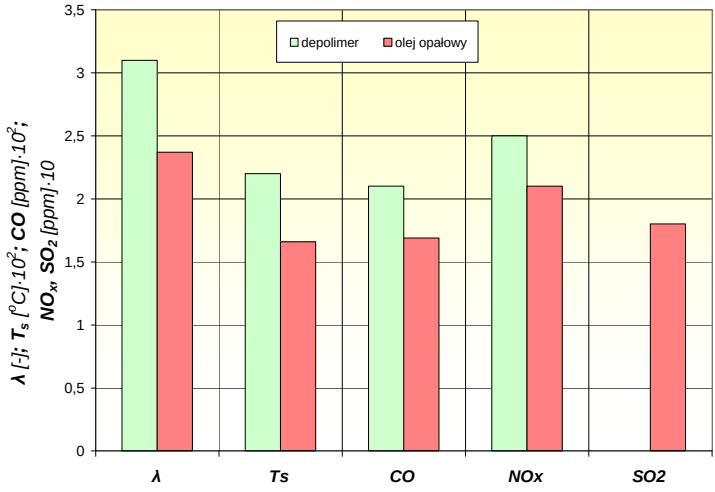

Fig. 4. Comparison of results of combustion of depolymer and heating oil

A decrease by more than 70% in the concentration of sulphur dioxide was observed in the case of the combustion of D70, which is typically the fuel's nature, since the mixture contains in its elemental composition with 70% less sulphur.

Implementation of the combustion process on the fuel D70 causes more than a 5% decrease in furnace efficiency – Figure 7.

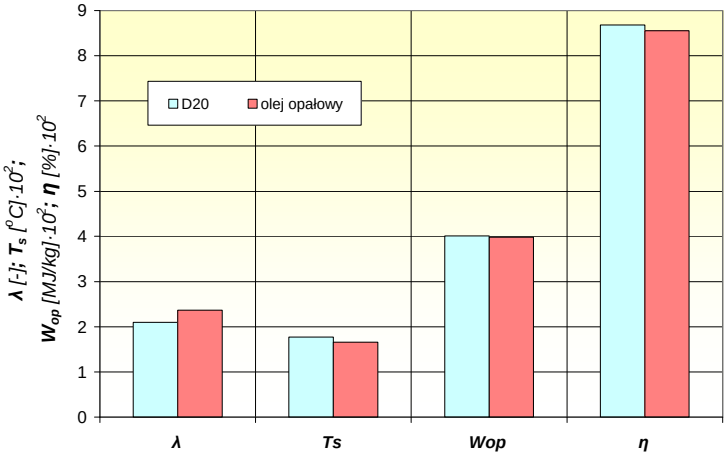

Fig. 5. Comparison of the energy efficiency of the combustion of D20 fuel and heating oil

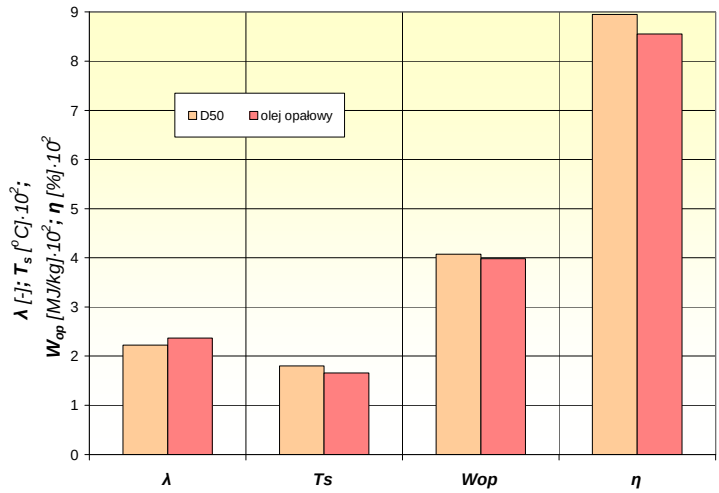

Fig. 6. Comparison of the energy efficiency of the combustion of D50 fuel and heating oil

Carrying out the combustion process in the furnace supplied with pure polymer is possible (see Fig. 4), but suffers from shortcomings resulting from a failure to ensure proper spray of fuel (penetration depth, size of the fuel

droplets). The combustion of pure depolymer in the test furnace requires a much higher excess air ratio λ = 3.1 (30% higher than for heating oil). The intensity of oxidation decreases causing a 25% increase in the concentration of carbon monoxide (as a result of incomplete combustion), and a 20% increase in the nitrogen oxides emissions of the thermal type. The efficiency of the furnace is lower by 12% (see Figure 8) compared to the efficiency when supplied with heating oil. The only advantage of the supply of the test furnace with pure depolymer is zero emissions of sulphur dioxide in the exhaust gases.

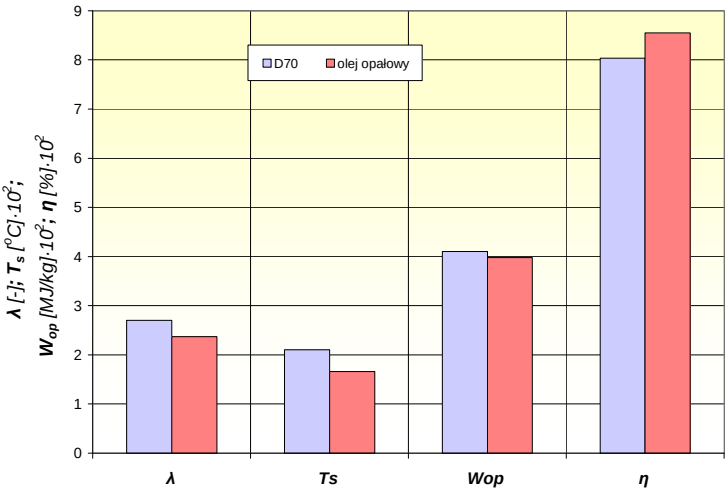

Fig. 7. Comparison of the energy efficiency of the combustion of D70 fuel and heating oil

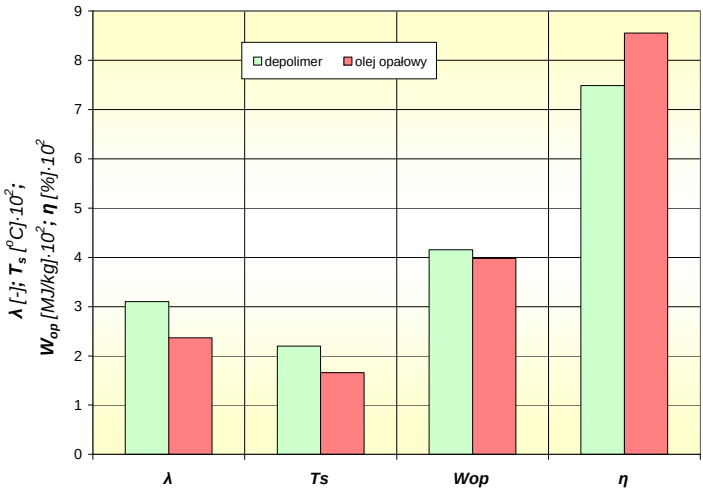

Fig. 8. Comparison of the energy efficiency of the combustion of depolymer and heating oil

Conclusion

Based on the study and analysis the following conclusions may be stated:

- Over 20% of depolymer mixed with heating oil produces a significant effect on the reduction of toxic exhaust emissions. The biggest energy effects (5% increase in furnace efficiency) were obtained for 50% of depolymer in the mixture.
- The addition of 50% depolymer to heating oil is the limiting value at which you can reduce NOx emissions to a level close to 15%, SO2 emissions by 55%, and the reduction of the concentration of CO by 8%.
- The increase in the share of depolymer over 50% in a mixture with heating oil changes the nature of the combustion process in the furnace chamber, caused by changes in fuel viscosity, so that the injector in the furnace is not able to spray the fuel supply properly; therefore, the propagation speed of the oxidation front would be similar to a conventional speed for heating oil. The intensity of oxidation is reduced despite the higher rate of excess air and furnace efficiency decreases.
- Carrying out the combustion process in the furnace powered with pure depolymer is possible, but it is subjected to shortcomings resulting from a failure to ensure proper spray of fuel. The only advantage in supplying the furnace with pure depolymer is zero emissions of sulphur dioxide in the exhaust gases.
- The optimal implementation of the injection process of depolymer (fuel atomisation quality and range of its stream in the combustion chamber) by an injector with a greater "tolerance" on the viscosity of fuel will reduce emissions of CO and NOx, which is similar to the typical thermal efficiency of the boiler.

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Efektywność energetyczna i ekologiczna kotła małej mocy zasilanego depolimerowym paliwem wtórnym

Słowa kluczowe

Spalanie, kocioł na paliwo płynne, paliwo alternatywne, depolimer, sprawność energetyczna i ekologiczna.

Streszczenie

Zastosowanie frakcji olejowej pochodzącej z depolimeryzacji odpadowych tworzyw sztucznych jako paliwa nabiera coraz większego znaczenia, ponieważ oprócz tego, że może być źródłem energii – rozwiązuje również problem utylizacji uciążliwych dla środowiska odpadów. Na podstawie przeprowadzonych badań określono wpływ depolimeru na przebieg podstawowych parametrów procesu spalania w urządzeniu kotłowym małej mocy. Określono zmiany współczynnika nadmiaru powietrza, zmiany temperatur gazów spalinowych, zmiany stężeń toksycznych składników spalin w trakcie procesów spalania. Ustalono ilości energii cieplnej wytworzonej w instalacji kotłowej w trakcie spalania depolimeru i jego mieszanin paliwowych z olejem opałowym. Kontrolowane zmiany parametrów procesowych warunków spalania depolimeru i wybranych mieszanin z olejem opałowym pozwalają na ekologiczne prowadzenie procesów spalania w komercyjnych kotłach małej mocy.