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The possibility of reducing emissions from households by using coal briquettes

ABSTRACT: The expected demand for hard coal intended for the households will progressively be decreasing. This is directly related to the introduced anti-smog resolutions, as well as the growing level of environmental awareness. However, it should be noted, that the use of the modern home heating boilers will result in an increase in the demand for medium coal sizes. The shortfall of this type of coal is already observed on the market. Therefore, its import is necessary. One of the solutions to increase the supply of the medium coal sizes is the production of coal briquettes. Moreover, their use will consequently lead to reduced emissions.

The paper presents a comparison of emissions from the combustion of coal briquettes and hard coal in home heating boilers. The briquettes were characterized by significantly lower emissions than hard coal (by 52% on average). The particulate matter emissions were lower by 70%. This may significantly contribute to improving air quality in Poland and in addition, limit the occurrence of smog. The possibility of further emission reduction by using low-emission fuels as briquette components was presented. The average relative emission reduction compared to hard coal for the analyzed fuels was estimated as follows: 62% for coal char, 57% for coke, 51% for charcoal/bio-carbon, 49% for anthracite, 45% for torrefied biomass, and 33% for peat.

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Furthermore, the issue of the mercury content in the analyzed fuels was discussed. The lowest mercury content was found in biomass fuels, in particular biomass after thermal treatment (torrefied biomass, biocarbon, and charcoal). Fuels produced from hard coal in the pyrolysis process (coal char and coke) were characterized by very low mercury content as well.

KEYWORDS: households, emissions, solid fuels, coal briquettes

Introduction

The fuel consumption forecasts show that coal will remain the primary energy source by 2040 (IEA 2019), although the consumption of hard coal in Poland will decrease by nearly a half (ME 2019). The specificity of the Polish hard coal consumption pattern is related to the relatively high usage by the non-commercial combustion installations sector, i.e. 16.7%. In 2018, this consumption reached 12.37 million Mg (of which the households 10.05 million Mg, the agriculture 1.46 million Mg) (GUS 2019). The main reason for such a high consumption of hard coal in this sector is the low heating price, which remains the lowest among the available fuels and other heating methods (Stala-Szlugaj 2017). However, it is expected that the demand for coal intended for households will be also progressively decreasing. This results from the anti-smog resolutions (Stala-Szlugaj 2018) as well as the growing level of environmental awareness. Despite the decrease in demand for the coarse coal sizes by 68%, the demand for the medium coal sizes will increase by 27% (Rogus et al. 2019). This is closely related to the changes in the pattern of the used home heating boilers, i.e. the replacement of older appliances with modern of 5th class or EcoDesign.

It should be noted that there is currently a shortage of medium coal sizes on the Polish market (Stala-Szlugaj 2019). In the Polish hard coal distribution pattern, only 9% are coarse coals sizes, 5% are medium coal sizes, and the majority – 83% – are the fine coal sizes (Baic et al. 2019). Their shortfall in the Polish mining industry requires their import, mainly from Russia. The price of imported coal is even lower than domestic coal (Stala-Szlugaj 2019). The solution allowing for increasing supply of the medium coal sizes is the production of coal briquettes as well as coal pellets. Coal briquettes in comparison to coal and firewood are characterized by significantly lower emissions (EEA 2006; Kim Oanh et al. 1999). Therefore, they are classified as the low-emission solid fuel (Dzik et al. 2012; Kubica 2007) and anthracite briquettes as smokeless fuel (Mitchell et al. 2016).

This paper studies the possibility of reducing emission from the households by burning coal briquettes in home heating boilers. The further possibility of emission reduction by using low-emission fuels such as briquette components was proposed. Additionally, the issue of mercury content in the analyzed fuels was discussed.

1. Emissions from the combustion of coal briquettes

The comparison of emission factors for coal, briquettes, and wood is shown in Figures 1 and 2. For most of the presented parameters, the emission factors for coal briquettes are lower than for hard coal (except for nitrogen dioxide) and wood (except for nitrogen dioxide and sulfur

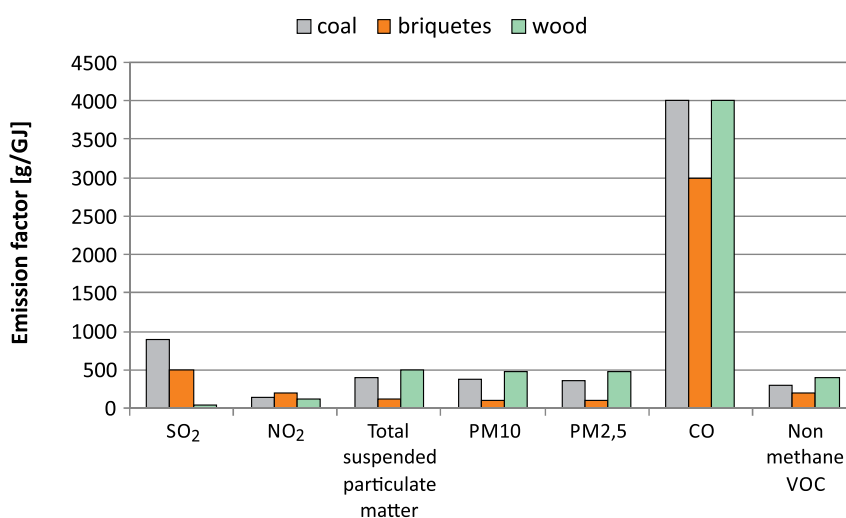


Fig. 1. The comparison of emission factors for coal, briquettes, and wood for a home heating boiler – part 1 (data derived from (EEA 2006))

Rys. 1. Porównanie wskaźników emisji dla węgla, brykietów oraz drewna dla domowego kotła grzewczego – część 1

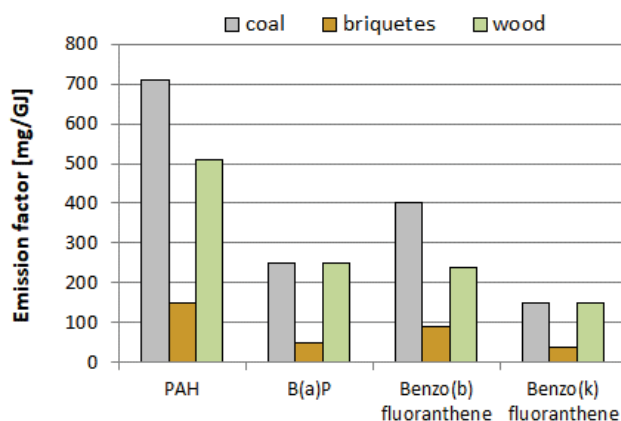


Fig. 2. The comparison of emission factors for coal, briquettes, and wood for a home heating boiler – part 2 (data derived from (EEA 2006))

Rys. 2. Porównanie wskaźników emisji dla węgla, brykietów oraz drewna dla domowego kotła grzewczego – część 2

dioxide). The average emission reduction for briquettes in relation to hard coal was achieved at the level of 52%. Significantly lower emissions of particulate matter (by 70%), gaseous compounds as well as hydrocarbons may contribute to the reduction of the occurrence of smog. This applies in particular to those areas of Poland where the environmentally friendly methods of heating are not available or are too expensive.

It should be noted that the ecological effect of using briquettes can only be achieved if an eco-friendly binder is used. Moreover, the binder must ensure the formation of a strong and water-resistant briquette, create a strong structure during combustion as well as have a relatively low price (Licznarski 1970). The inappropriate selection of the binder can increase emissions, while the low strength of the briquette can cause high fuel loss.

The ecological effect of using coal briquettes can be enhanced by using relevant additives – the catalysts for combustion (Chyc 2012). Such additives, as a result of complete fuel combustion, allow to reduce fuel consumption, increase the thermal efficiency of the boiler as well as to eliminate the formation of chimney soot. The catalysts for combustion may be dosed on a layer of burning coal in the furnace (direct method), dosed mixed with the coal (indirect method) as well as dosed as a component of briquettes (Hilse et al. 2011). The best effect can be achieved by dosing catalysts as a component of briquettes.

2. Comparison of solid fuels considered as potential components of coal briquettes

An additional possibility to increase the ecological effect of coal briquettes is to use low-emission fuels as components of coal briquettes. A comparison of selected solid fuels is given in Table 1. They were classified into three groups:

- ◆ biomass-based fuels: torrefied biomass, biocarbon and charcoal,
- ◆ hard coal-based fuels (coal char, coke),
- ◆ fossil fuels other than hard coal (anthracite, peat).

In order to eliminate the influence of moisture on the interpretation of the results, the parameters were presented on a dry basis.

Torrefied biomass is a product of a torrefaction process, i.e. the low-temperature pyrolysis of biomass at 200–300°C. In the torrefaction process, the fibrous structure of the biomass is destroyed (Basu 2018), which enhances its grinding ability. The biomass becomes hydrophobic (Tumulur et al. 2015), which simplifies its storage and transport. Moreover, the lower heating value of torrefied biomass, in comparison to the raw biomass, may increase even by 38% (Arias et al. 2008).

Biocarbon is produced by the pyrolysis of biomass at temperatures between 250 and 800°C (Gładki 2017). Any type of biomass can be used, i.e.: wood, wastes from the agri-food industry,

TABLE 1. Characteristics of selected solid fuels (dry basis)

TABELA 1. Porównanie charakterystyki wybranych paliw stałych (stan suchy)

Parameter	Biomass-based fuels			Hard coal-based fuels		Fossil fuels	
	Torrefied biomass ¹	Biocarbon ²	Charcoal ³	Coal char ⁴	Coke ⁵	Anthracite ⁶	Peat ⁷
Ash, A ^d [%]	0.4–10.2	2.9–21.0	1.0–7.7	4.5–7.8	<11.0	2.5–2.9	3.2–10.6
Volatile matter, V ^d [%]	59.6–80.5	5.8–25.5	9.4–30.0	3.8–5.9	<1.4	3.0–7.7	69.0
Fix carbon, FC ^d [%]	13.3–39.1	48.4–87.2	67.7–89.6	86.3–91.5	>87.6	89.4–94.5	22.6
Lower heating value, LHV ^d [MJ/kg]	17.8–24.7	20.3–30.9	28.1–33.9	32.4	27.6–28.3	33.9–40.3	19.1–21.6
Carbon, C ^d [%]	47.5–62.2	56.9–88.9	75.6–92.0	91.2	85–90	88.9–94.4	50.3–55.6
Hydrogen, H ^d [%]	5.2–6.3	0.7–3.3	2.4–3.3	1.5	0.5–1.0	1.7–3.4	4.5–6.3
Oxygen, O ^d [%]	27.2–42.7	0.6–16.5	3.0–18.4	1.0	0.2–1.5	1.0–2.5	32.3–38.5
Nitrogen, N ^d [%]	0.1–0.9	0.3–2.0	0.2–1.5	1.5	0.3–1.5	0.1–1.5	0.2–1.6
Sulfur, S _t ^d [%]	<0.1	0.03–0.41	0.04–1.00	0.27–0.44	<0.7	0.2–0.8	0.10–0.67

¹ (Arias et al. 2008; Bridgeman 2008); ² (Phyllis2 2020); ³ (Phyllis2 2020); ⁴ (Matuszek et al. 2016b; Niesler et al. 2017; Stelmach et al. 2018); ⁵ (Nowa 2017; Szeszko 2017); ⁶ (Phyllis2 2020; Środa et al. 2015); ⁷ (Cunico 2015; Gaze et al. 2019; Kowalczyk-Juśko et al. 2016).

municipal sewage sludge, solid organic fractions of municipal wastes, as well as manure. The variety of the input material, as well as the temperature, affect the diverse quality of the final product. The ash content in biocarbon ranges from 2.8 to 44.6% and the lower heating value ranges from 12.1 to 31.6 MJ/kg (Gładki 2017). Charcoal is a special case of biocarbon. It is a product of the pyrolysis process of the wood logs at the temperature up to 600°C (Lewandowski and Milchert 2011).

Coal char is the product of the pyrolysis process of hard coal at 450–500°C. It's commonly called a semi-coke. Coal char, in comparison to the raw coal, is characterized by significantly lower volatile matter and sulfur content, higher carbon content as well as higher calorific value (Stelmach et al. 2018). It is classified as a low-emission fuel. In Table 1 the properties of coal char are presented on the example of the so-called *blue coal*.

In turn, coke is the product of the pyrolysis process of hard coal at a temperature of 1000°C and higher. As a component of the coal briquettes, the coke breeze can be especially useful (Helmann and Pietrasik 2005). It is a product of the coking process with a grain size below 10 mm. Coke dust, the byproduct of the dry and wet coke quenching, can also be used (Hycnar et al. 2015). Coke is characterized by the lowest content of volatile matter among the presented fuels. It results in the very low emissions of the particulate matter as well as the organic compounds. Therefore coke is classified as a smokeless fuel.

Anthracite is a valuable solid fuel, which is also classified as a smokeless fuel (Kubica 2014). It is the most metamorphosed type of coal, characterized by a very low volatile content and a high calorific value. Another fossil fuel that can be considered for the production of coal briquettes is peat. Peat is a deposit of partially decomposed organic matter of plant origin. In the process of peat formation, the physical, chemical, as well as microbiological changes of plant matrix occur (PGI 2019). Although peat is built of the incompletely decomposed plant matter, according to EU legislation, it is not classified as biomass (EC 2017). Peat is the only renewable fossil fuel, but its renewability is relatively slow, i.e. 1–2 mm per year (Bęben 2007). The operative peat resources in Poland were estimated at 35.93 mln Mg (PGI 2019). The great advantage of peat is the high strength of the pellets/briquettes produced from them with no need for binder application. The costs of heating and hot water preparation resulting from use in a domestic heating boiler are attractive as well (Gaze et al. 2019).

3. Comparison of emissions from combustion of the analyzed fuels by households

A comparison of emission reduction resulting from the combustion of the analyzed fuels by households in relation to hard coal is given in Figure 3. Additionally, the emissions from the combustion of firewood and wood pellets have been presented. The results were provided

as a relative reduction of emissions in comparison to hard coal. This method was adopted because there were significant methodical differences in the literature data used:

- ◆ various measurement methods,
- ◆ various heating appliances,
- ◆ various units,
- ◆ various forms of fuel burnt.

The literature data, in which apart from the analyzed fuels hard coal was also examined, were selected for the investigation. This allowed for the determination of a reliable change of emission factors.

Due to the lack of available data on the organic compound emissions from the combustion of the torrefied biomass, they were calculated. According to Mitchell (Mitchell 2017), the torrefaction process allows for a reduction in the content of volatile matter and a reduction

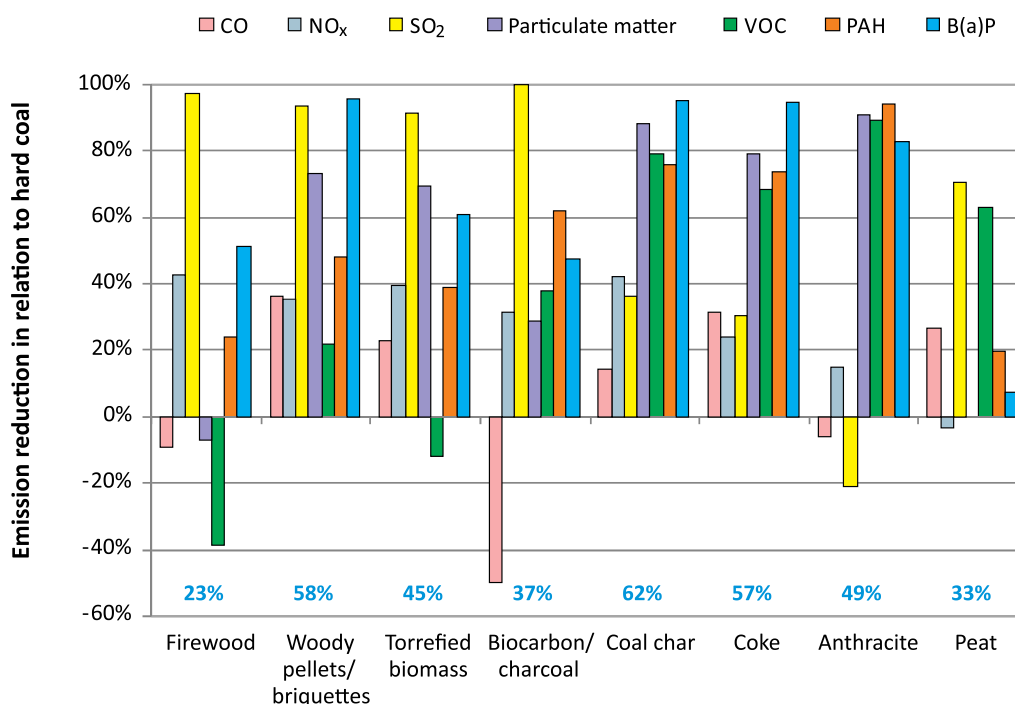


Fig. 3. Comparison of the emission reduction from households by burning the analyzed fuels in relation to hard coal (a negative value means an increase in emissions). The average of the relative emissions reduction is given in bold, blue font

(data derived from: Bhattacharya et al. 2002; EEA 2006; Gaze et al. 2019; IChPW 2017; Kim Oanh et al. 1999; Kubica 2014; Matuszek et al. 2016a, 2016b; Maxwell et al. 2020; Mitchell et al. 2016; Mitchel 2017; Rokni et al. 2018; Seljeskog et al. 2017; Szeszko 2017; Tian et al. 2018; WHO 2010)

Rys. 3. Porównanie relatywnego obniżenia emisji zanieczyszczeń generowanych przez użytkowników domowych w wyniku spalania analizowanych paliw odniesionej do emisji ze spalania węgla kamiennego (wartość ujemna oznacza wzrost emisji). Średnie relatywne obniżenia emisji podano czcionką pogrubioną, kolorem niebieskim

in the reactivity of the torrefied biomass. This results in a decrease in the amount of organic compounds released during combustion which leads to reduction of the soot formation as well. Therefore, the organic compound emissions were determined based on the decrease in the content of the volatile matter in the torrefied biomass (Arias et al. 2008; Bridgeman et al. 2008; Rokni et al. 2018).

Based on the presented results, it can be concluded that all of the analyzed fuels (presented in section 2) can contribute to a significant reduction of emissions. The average relative emission reduction compared to hard coal was estimated as follows: 62% for coal char, 57% for coke, 49% for anthracite, 45% for torrefied biomass, 37% for charcoal/biocarbon and 33% for peat. The fuels with the lowest particulate matter emissions were coal char, coke as well as anthracite. These fuels also provided a significant reduction in the organic compound emissions. The low particulate matter emission obtained for the torrefied biomass resulted both from its good properties as well as its form (the briquettes). A positive effect of fuel compacting on reducing these emissions is also observed for biomass pellets. It should be noted, however, that in order to achieve a desired effect in emissions reduction, installing modern heating appliances may be necessary (Mirowski and Orzechowska 2015).

In the case of the SO₂ emissions, the highest reduction was achieved for biomass fuels (wood, pellets, torrefied biomass, biocarbon/charcoal). This is directly related to the low sulfur content in the biomass. In the case of anthracite and peat, the effect of reducing SO₂ emissions will be affected by the sulfur content in them. This can change within quite a wide range from 0.1 to 0.8% (Table 1).

The noticeable increase in CO emissions obtained for charcoal resulted both from a lower reactivity of that type of fuel as well as from the simple design of the stoves and fireplaces used in the research. It should be expected that the use of charcoal in the form of briquettes can contribute to significantly lower emission (as noted for the torrefied biomass). Excluding the CO emissions, the average relative emission reduction for the charcoal/biocarbon was 51%.

It is worth mentioning that the torrefied biomass can be a suitable solution for using straw. In the torrefaction process, chlorine is partially removed from biomass, and its emissions can be reduced by 76% (Rokini et al. 2018).

4. Comparison of mercury content in the fuels analyzed

At present, the emission of ecotoxic elements is increasing in importance. A special emphasis is placed on reducing mercury emissions. It is characterized by very toxic properties and can bioaccumulate in living organisms. Moreover, mercury is a transboundary air pollutant. In 2017, the Polish sector of the non-commercial combustion installations (mainly the households) was responsible for mercury emissions of 0.93 Mg, which represented 9.7% of total emissions

(KOBiZE 2019). Taking the fact that the introduced regulations (BAT-LCP 2017) will force a reduction in mercury emission from the sector of power generation into account, the share of the households will increase.

The relatively high mercury emissions from the combustion of solid fuels in the home heating boilers are caused by its high volatility. In the boiler, mercury is nearly completely released from the fuel and passes into the flue gas. Only small amounts of mercury remain in the ash. The release rate of mercury from hard coal was 98.3–99.1% and from woody biomass 99.5–99.9%, respectively (Dziok et al. 2018b). Some of the released mercury is adsorbed by the deposits in the boiler heater as well as by the soot in breeching and chimney (Dziok et al. 2018a, 2019). In contrast to the coal-fired power plants (Wichliński et al. 2014), the households have no further possibility to remove mercury from the flue gas. Therefore, reducing mercury emissions from this source requires the use of fuels with the lowest possible mercury content. A comparison of mercury content in the analyzed fuels is given in Table 2.

TABLE 2. Comparison of mercury content in the analyzed fuels

TABELA 2. Porównanie zawartości rtęci w analizowanych paliwach

Fuel	Mercury content	
	[µg/kg]	[µg/MJ]*
Biomass	2–52	0.3–3.1
Torrefied biomass	0.5–33	0.1–1.6
Biocarbon/charcoal	16–24	0.6–0.8
Hard coal (Poland)		
◆ overall	34–228	1.4–9.9
◆ fuel for the households	7–83	0.3–3.3
Coal char	18–32	0.7–1.2
Coke	7–21	0.3–0.8
Anthracite	20–340	0.5–9.2
Peat	66–187	3.2–9.2

* In the calculation the average calorific value according to Table 1 was assumed.

Source: Dziok et al. 2015, 2018b, 2020; Dziok 2019; Friedli et al. 2001; Kłojzy-Karczmarczyk and Mazurek 2013; Koniecznyński et al. 2012; Liu et al. 2003; UN Environment 2016; Wichliński and Kobyłecki 2019.

The highest mercury content was found in the unprocessed fossil fuels (hard coal, anthracite, and peat). However, hard coal intended for the households (the coarse and medium coal sizes) is characterized by a much lower mercury content. It is also possible to significantly reduce the mercury content in hard coal using a combination of the cleaning process and the thermal

pre-treatment process at 250°C. This method allows the mercury content in hard coal to be reduced to less than 4.8 µg/MJ (Dziok et al. 2020). The lowest mercury content was recorded for biomass fuels, in particular after thermal treatment (torrefied biomass, biocarbon, and charcoal) as well as for fuels produced from hard coal in the pyrolysis process (coal char and coke).

Conclusions

Despite the decreasing demand for hard coal for the households, the demand for medium coal sizes will increase. This is due to the shortfall of this type of coal. One of the solutions to increase the supply of this type of fuel is to produce coal briquettes.

Coal briquettes, in comparison to hard coal, are characterized by lower emission (by 52% on average), including lower emission of the particulate matter by 70%. Therefore, their use can significantly contribute to improving air quality as well as reducing the smog occurrence. A further possibility to reduce emissions is the use of low-emission fuels as the briquettes component. The average relative emission reduction compared to hard coal for the analyzed fuels was estimated as follows: 62% for coal char, 57% for coke, 51% for charcoal/biocarbon, 49% for anthracite, 45% for torrefied biomass, and 33% for peat.

The lowest mercury content was recorded for biomass fuels, in particular after thermal treatment (torrefied biomass, biocarbon, and charcoal) as well as for fuels produced from hard coal in the pyrolysis process (coal char and coke). The highest mercury content was found in unprocessed fossil fuels (hard coal, anthracite, and peat).

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Możliwość ograniczenia emisji w sektorze użytkowników domowych poprzez zastosowanie brykietów węglowych

Streszczenie

Prognozuje się, że zapotrzebowanie na węgiel kamienny w polskim sektorze użytkowników domowych będzie sukcesywnie malało. Jest to bezpośrednio związane z wprowadzanymi uchwałami antysmogowymi i rosnącą świadomością ekologiczną społeczeństwa. Niemniej jednak wymiana kotłów grzewczych na nowoczesne spowoduje wzrost zapotrzebowania na średnie sortymenty węgla kamiennego. Już dziś obserwuje się niedobór tego sortymentu na rynku, co stwarza konieczność importu. Jednym z rozwiązań pozwalających na zwiększenie podaży tego typu paliwa jest wytwarzanie brykietów węglowych. Ponadto ich zastosowanie pozwala na ograniczenie emisji przez gospodarstwa domowe.

W artykule przedstawiono porównanie emisji zanieczyszczeń generowanej przez spalanie brykietów węglowych i węgla kamiennego w domowych kotłach grzewczych. Brykiety te w porównaniu do węgla kamiennego charakteryzują się znacznie niższą emisją zanieczyszczeń (średnio o 52%), w tym niższą emisją pyłów o 70%. Może to w sposób znaczący przyczynić się poprawy jakości powietrza w Polsce i ograniczenia występowania smogu. Zaprezentowano dodatkową możliwość ograniczenia emisji zanieczyszczeń w wyniku stosowania w brykietach dodatku niskoemisyjnych paliw. Oszacowany średni relatywny stopień obniżenia emisji względem węgla kamiennego dla analizowanych paliw wynosił odpowiednio: karbonizat węglowy 62%; koks opałowy 57%; węgiel drzewny/biowęgiel 51%; antracyt 49%; toryfikat 45%; torf 33%.

Dodatkowo omówiono kwestię zawartości rtęci w analizowanych paliwach. Najniższą zawartość rtęci odnotowano w paliwach z biomasy, w szczególności w przypadku biomasy po obróbce termicznej (toryfikat, biowęgiel i węgiel drzewny). Niską zawartością rtęci charakteryzowały się również paliwa wytwarzane z węgla kamiennego w procesie pirolizy (węgiel i koks).

SŁOWA KLUCZOWE: sektor komunalno-bytowy, emisja, paliwa stałe, brykiety węglowe

