Proceedings of ECOpole
DOI: 10.2429/proc.2012.6(1)008 2012;6(1)

Sebastian WERLE[1]

ANALYSIS OF THE POSSIBILITY OF THE SEWAGE SLUDGE THERMAL TREATMENT

ANALIZA MOŻLIWOŚCI ENERGETYCZNEGO WYKORZYSTANIA OSADÓW ŚCIEKOWYCH

Abstract: Promoting of the renewable energy is one of the priorities of the Polish energy policy until the year of 2030. It is believed that the co-combustion of sewage sludge in the Polish conditions is especially attractive. The paper contains two parts of research. The first one concerns a theoretical analysis of the possibility of direct co-combustion of solid municipal sewage sludge with hard coal in power station boilers. Numerical simulation of indirect co-combustion process of gas from sewage sludge gasification in coal-fired boiler has been done in the second part of the work. The conclusions show that the thermal methods of sewage sludge utilisations provide a great opportunity for application in Polish conditions.

Keywords: co-combustion, sewage sludge

According the Polish Regulation and the objectives of the National Waste Management Plan 2014 [1] and the National Urban Wastewater Treatment Program [2] the quantity of sewage treated in Poland is systematically increasing. Currently, the predominant method for the disposal of sewage sludge is its storage and agricultural application [3]. The main problems are the high percentage of stored sewage sludge and a lack of installations for its thermal utilization. Thermal processes can be used for the conversion of large quantities of sewage sludge (eg, in large urban areas) into useful energy. There is a wide range of analysed and proposed solutions for municipal sewage sludge utilization. Nevertheless, there are serious legal constraints determining this choice. One of the most important Regulation is the Regulation of the Minister of Economy and Labour [4], which introduced a ban of the storage of sewage sludge from the date of January 1, 2013.

In view of the presented facts, there is a large and pressing need for the development of thermal methods (combustion, co-combustion, gasification and pyrolysis) of disposal of sludge.

Taking into consideration Polish specificity of the power engineering sector which is based on the coal-fired boilers, the most promising method of sewage sludge treatment in Poland is co-combustion. Basically, it is mainly possible to distinguish the use of sewage sludge in fossil fired power plants in three different co-combustion concepts, which are as follows:

1. Direct co-combustion: Sewage sludge and coal are burned in the same boiler or gasifier, using the same or separate mills and burners, depending principally on the sewage sludge fuel characteristics. Coal and sludge can be mixed before milling or coal and sludge are fed and milled by separated supply chains.

[1] Institute of Thermal Technology, Silesian University of Technology, ul. Konarskiego 22, 44-100 Gliwice, phone 32 237 29 83, fax 32 237 28 72, email: sebastian.werle@polsl.pl

2. Indirect co-combustion: In gasifier sewage sludge is converted into a fuel gas, which after cooling and cleaning can be burned in the coal boiler furnace. As an alternative the produced syngas can also directly be burnt in a joint steam boiler without further cooling or cleaning.

The aim of the work is - first of all - theoretical analysis of the possibility of direct co-combustion of solid municipal sewage sludge with hard coal in power station boilers (WR-25, CFB-420 and OP-230) and - secondly - numerical simulation of indirect co-combustion process of gas from sewage sludge gasification in coal-fired boiler.

Methods and materials

First part of the present work consist theoretical analysis of the possibility of the direct co-combustion of dried sewage sludge in different types of the coal-fired boilers (fluidized bed boiler CFB-420, stoker fired boiler WR-25 and pulverized coal boiler OP-230). The analysis takes into consideration wide range of mass fraction of sewage sludge (0÷20%) in the fuel (hard coal) mixture and wide range of air excess ratio in the combustion chamber (1.1÷1.5). Boiler efficiency in all analysed examples was calculated. Energy balance of all analysed boilers was done. Composition of the analysed fuels blends are presented in Table 1.

Table 1

Composition of analysed fuel mixtures [5]

Mass fraction of main components in mixture	**Mass fraction of sewage sludge in fuel mixture [%]**				
	0	**5**	**10**	**15**	**20**
C	0.6867	0.6542	0.6246	0.5977	0.5730
H	0.0083	0.0087	0.0091	0.0094	0.0097
S	0.0466	0.0468	0.0469	0.0470	0.0472
O	0.0849	0.0932	0.1070	0.1076	0.1141
N	0.0178	0.0205	0.0230	0.0252	0.0272
H_2O	0.0493	0.0517	0.0539	0.0559	0.0577

Equilibrium calculations of fuel mixtures complete combustion in analysed boilers were done. Energy balance illustration is presented in Figure 1.

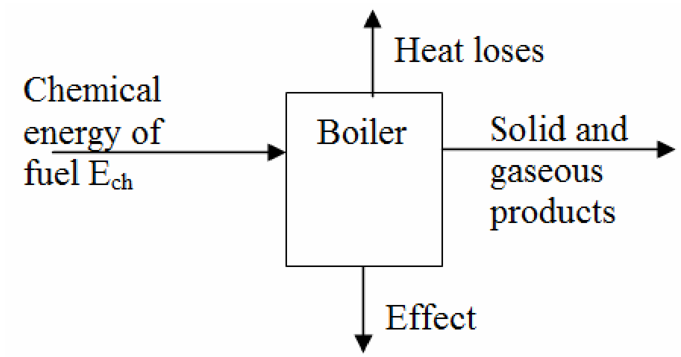

Fig. 1. Illustration of energy balance

Energy balance solution using real operating parameters of all analysed boilers (capacity, operating temperatures and pressures etc.) leads to determination of the flow of combusted fuel $\dot{P}$. Thanks to it, boilers efficiency using eq. (1) can be determined:

$$\eta = \frac{\text{Effect}}{E_{ch}} = \frac{\dot{Q}}{\dot{P} \cdot W_d} \tag{1}$$

where: $\dot{Q}$ - boiler capacity [kW], $\dot{P}$ - flow of the fuel [kg/s], W_d - lower heating value [kJ/kg].

In the second part of the work, numerical simulation of the indirect co-combustion of sewage sludge gasification gas in coal-fired boiler NO_x reduction efficiency has been calculated. The calculations were modelled using the GRI-Mech 2.11 mechanism, plug flow reactor model. The molar flow rate ratio of the additional fuel to the whole exhaust was assumed to be 5.0, 7.5, 10.0, 12.5 and 15.0%. The simulations were conducted at a constant pressure equal to 1atm and at temperatures ranging from 600 to 1400ºC, with typical residence times of 0.0÷0.4 s and local air excess ratio ranging from 1.0 to 2.0.

Results and discussion

Direct co-combustion

The calculated values of boiler efficiency are presented in Table 2. Analyzing those results it can be concluded that, taking into consideration constant value of boiler capacity, both increasing of mass fraction of sewage sludge in fuel mixture and increasing of air excess ratio causes decreasing of boiler efficiency. Nevertheless, it should be emphasis that this decrement is not very high and mainly causes by high value of exhaust loss. It can be concluded, that direct co-combustion of sewage sludge in different types of coal-fired boilers does not negative affect on boiler efficiency.

Table 2

Efficiency of analysed boilers

λ	WR-25					CFB-420					OP-230				
	Mass fraction of sewage sludge in fuel mixture [%]														
	0	**5**	**10**	**15**	**20**	**0**	**5**	**10**	**15**	**20**	**0**	**5**	**10**	**15**	**20**
1.10	90.8	90.8	90.7	90.7	90.6	92.6	92.5	92.5	92.5	92.4	82.7	82.6	82.5	82.4	82.3
1.15	90.5	90.5	90.4	90.4	90.4	92.3	92.3	92.3	92.2	92.2	82.0	82.0	81.8	81.8	81.7
1.20	90.2	90.2	90.1	90.1	90.1	92.1	92.1	92.0	92.0	92.0	81.4	81.3	81.2	81.2	81.1
1.25	90.0	89.9	89.9	89.8	89.8	91.9	91.9	91.8	91.8	91.8	80.8	80.7	80.6	80.5	80.4
1.30	89.7	89.6	89.6	89.6	89.5	91.7	91.6	91.6	91.6	91.5	80.2	80.1	80.0	79.9	79.8
1.35	89.4	89.4	89.3	89.3	89.2	91.5	91.4	91.4	91.4	91.3	79.6	79.5	79.4	79.3	79.2
1.40	89.1	89.1	89.0	89.0	89.0	91.2	91.2	91.2	91.1	91.1	79.0	78.9	78.7	78.7	78.6
1.45	88.9	88.8	88.8	88.7	88.7	91.0	91.0	90.9	90.9	90.9	78.3	78.2	78.1	78.0	78.0
1.50	88.6	88.5	88.5	88.4	88.4	90.8	90.8	90.7	90.7	90.6	77.7	77.6	77.5	77.4	77.3

Indirect co-combustion

In Figure 2, relative amount of NO_x as a function of temperature is shown. NO reduction efficiency of the gasification gas is strongly dependent on temperature. Temperature in the additional fuel injection zone is a key variable in the process because it determines the degree of conversion of the additional fuel and thus the formation of hydrocarbon radicals, as well as the rates of important reactions involved in the reburning mechanism. The reduction of NO increases with increasing temperature - presumably through its reaction with CH_i - until it reaches a maximum. At temperatures between 600 to 800ºC, the sewage sludge-derived syngas does not affect the NO concentration. At higher temperatures, the reburning efficiency of the analysed reburning fuel increases. The strongest NO reduction occurs at temperatures higher than 1000ºC; however, the best temperature for the reburning process is 1200ºC. In general, as seen in Figure 2, increasing the molar ratio of reburning fuel results in a decrease in the temperature for optimal NO reduction.

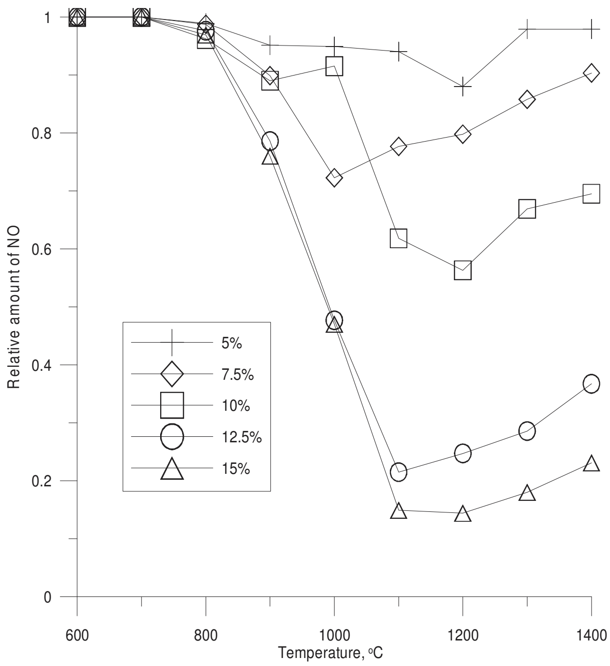

Fig. 2. Relative amount of NO_x as a function of the temperature for different values of the molar ratio of reburning fuel; λ - 1.1; τ = 0.4 s

Figure 3 shows the dependence of relative amount of NO as a function of the air excess ratio for a reburning zone temperature and residence time of 1200ºC and 0.4 s. As shown in this figure, an air excess ratio equal to 1.0, reburning fuel has no influence on the reduction of NO. The reduction of NO increases up to a maximum as the stoichiometry becomes more fuel-rich. Such conditions favour the formation of CO and CO_2 via the oxidation mechanism of the reburning fuel instead of the formation of hydrocarbon radicals active in NO reduction.

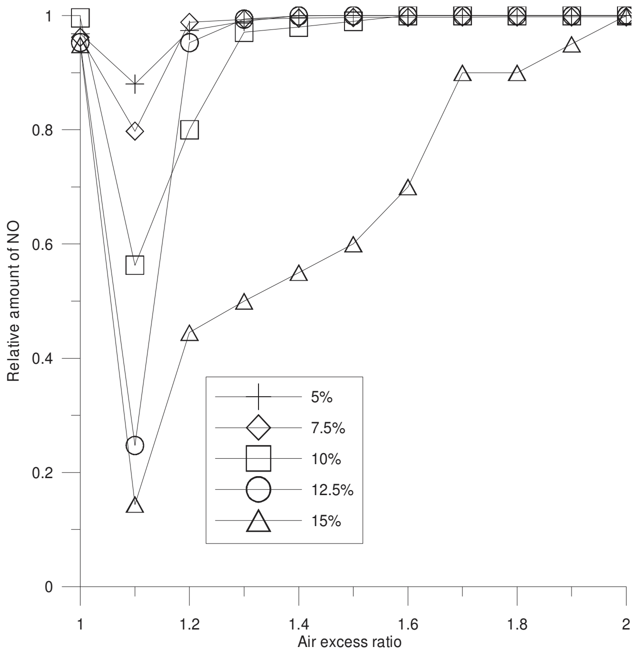

Fig. 3. Relative amount of NO_x as a function of the air excess ratio for different values of the molar ratio of reburning fuel; t = 1200ºC; τ = 0.4 s

For each molar ratio of reburning fuel, the relative amount of NO initially decreases at the beginning as the air excess ratio begins to increase. As seen in this figure, there is a value of the air excess ratio for which the efficiency of the NO reduction reaches a maximum. Above this value, NO reduction decreases.

Conclusions

Alternative methods for the thermal utilization of sewage sludge are an important element in the wider problem of sludge disposal. Their undoubted advantage, in addition to the disposal of sludge, is that it becomes possible to obtain a product that can be effectively used for the generation of energy. Polish conditions also appear to present a good opportunity to utilize this group of waste-disposal technologies.

References

[1] The National Waste Management Plan 2014, Project. Warsaw 2010.
[2] The National Urban Wastewater Treatment Program, Regulation of the Ministry of Environment. Warsaw 2003.
[3] Werle S, Wilk RK. Renew Energ. 2010;35:1914-1919, DOI: 10.1016/j.renene.2010.01.019.
[4] Regulation of the Minister of Economy and Labor on the admission criteria and procedures for the storage of waste in the landfill of the type of waste. DzU 28 IX 2005, 7 IX 2005.
[5] Werle S. Unieszkodliwianie komunalnych osadów ściekowych na drodze współspalania. Gaz, Woda i Technika Sanitarna. 2011;2:58-62.

ANALIZA MOŻLIWOŚCI ENERGETYCZNEGO WYKORZYSTANIA OSADÓW ŚCIEKOWYCH

Instytut Techniki Cieplnej, Politechnika Śląska, Gliwice

Abstrakt: Promowanie wykorzystania odnawialnych źródeł energii jest jednym z priorytetów polskiej polityki energetycznej do roku 2030. Uważa się, iż współspalanie osadów ściekowych w warunkach polskich zasługuje na szczególną uwagę. W pracy zaprezentowano dwa główne nurty badawcze. Pierwszy z nich dotyczy analizy możliwości współspalania komunalnych osadów ściekowych z węglem kamiennym w obiektach energetyki zawodowej. Drugi nurt dotyczy symulacji numerycznych procesu współspalania gazu ze zgazowania osadów ściekowych w kotle opalanym węglem kamiennym. Wnioski wskazują, iż energetyczne sposoby wykorzystania osadów ściekowych dają duże szanse na zastosowanie w polskich warunkach.

Słowa kluczowe: współspalanie, osady ściekowe