archives
of thermodynamics
Vol. **34**(2013), No. 1, 19–39
DOI: 10.2478/aoter-2013-0002

The concept of energy production on the basis of modern alternative fuels

EUGENIUSZ ORSZULIK[*1]
JAN JACHYRA[2]
ANDRZEJ WASYLEWICZ[3]

[1] Central Mining Institute, Plac Gwarków 1, 40-116 Katowice, Poland

[2] Nieruchomości sp. z o.o., Witosa 3, 36-200 Brzozów, Poland

[3] WAFRO S.A., Witosa 3, 36-200 Brzozów, Poland

Abstract The paper presents a concept of producing energy on the basis of modern alternative fuels to be burnt in low- and medium-power stoker-fired boilers. The thermal energy contained in water vapour and hot water will be utilized in producing, in combination, of electrical energy, and for heating of cubature objects. Modern alternative fuels in the form of briquettes and pellets will be produced from hard coals and municipal waste other than hazardous. There have been presented the properties of alternative fuels obtained, and the concept of their utilization in the process of energy production in cogeneration.

Keywords: Waste material; Fuel; Combustionx; Boiler; Emission; Energy

1 Introduction

There has been developed the production technology of modern alternative energy fuels in the form of briquettes and pellets, the process gas obtained from gasification of mixture hard coal MII type, and combustible waste coded as 19 12 10 (alternative fuel) [1]. Obtained fuels will be utilized in the process of thermal and electrical energy production, in combination,

*Corresponding Author. E-mail: soxeo@gig.katowice.pl

based on using a steam boiler adapted to burning of modern alternative energy fuels, and a turbogenerator producing electrical energy [2,5,12,13,24]. In the technology, the waste coded as 19 12 10 was used, the waste produced in the installation for segregation of mixed municipal waste – code 20 03 01.

The assumptions for applying new modern energy fuels for combustion in stoker fired boilers are:

- Reduction of energy acquisition costs.
- Partial substitution of alternative fuel produced of nonhazardous waste, obtained from municipal waste segregation installation, and unsuitable for further recovery, for such a primary fuel as hard coal.
- Ecological effect relying on reduction of:
  - emission of gas and dust substances into the atmosphere, relative to commonly used coal;
  - production of modern alternative energy fuels whose quality will be comparable with the hard coal commonly used.

2 Investigation of raw materials for production of briquettes and pellets

2.1 Production of briquettes and pellets from hard coal and wastes

The implementation of production of briquettes and pellets made from the mixture of MII type hard coal and waste coded as 19 12 10 combustible waste (alternative fuel) is aimed at obtaining a commercial product in the form of a solid fuel to be applied for combustion in water and steam stoker fired boilers. The briquettes and pellets produced should have the fuel parameters better than those of hard coal currently used. They should be characterized by low content of chlorine, fluorine, sulphur, ash, and solid matter, and by high calorific value and heat of combustion [17,21,23].

2.2 Investigation of combustible 19 12 10 waste (alternative fuel)

In the installation for segregation of municipal waste, there was produced the combustible waste – code 19 12 10 (alternative fuel) which is to be a raw material for production of briquettes and pellets with the following composition:

- up to 20% by weight, paper and cardboard:
  codes – 15 01 01, 19 12 01, 20 01 01;
- up to 25% by weight, plastics:
  codes – 15 01 02, 16 01 19, 19 12 04;
- up to 55% by weight, wood:
  codes – 03 01 05, 15 01 03, 19 12 07, 20 01 38.

A representative sample had been taken for analysis, from the fuel produced and then it was subject to testing to the contents of chlorine, fluorine, sulphur, ash, heat of combustion and calorific values [5,8,10]. The results of analysis of the 19 12 10 waste are presented in Tab. 1. The combustible

Table 1. Chemical and technical analysis of alternative fuel – combustible waste coded 19 12 10 (all the markings in the working state).

Parameter	Unit	Value
Heat of combustion	kJ/kg	20768
Fuel value	kJ/kg	15607
Chlorine	%	0.16
Sulphur	%	0.08
Total humidity	%	19.07
Ash	%	17.91
Hydrogen	%	5.81

waste coded 19 12 10 considered as a raw material for production of pellets and briquettes is characterized by a low content of chlorine 0.16%, sulphur 0.08%, average calorific value 15.6 MJ/kg, and high ash content of 17.91%. A low chlorine content enables to use it for burning in the furnaces of boilers which ensure keeping the temperature of flue gas above 850 °C, and maintaining it for at least 2 s.

2.3 Testing of hard coal

Hard coal to be applied for production of briquettes and pellets should be characterized by a low price, low contents of chlorine, fluorine, sulphur, ash, and high calorific value and heat of combustion [17,19,23]. For testing, there was selected the MII type hard coal from Kazimierz-Juliusz mine in Sosnowiec. A representative sample was taken with the aim of making chemical analyses. The results of analyses of selected hard coals are presented in Tab. 2. Hard coal from Kazimierz-Juliusz mine is characterized by a high chlorine content 0.56%, sulphur 1.04%, average calorific value 21.2 MJ/kg, and high ash content 19.28%.

Table 2. Chemical and technical analysis of hard coal from Kazimierz-Juliusz mine.

Parameter	Unit	Value
Heat of combustion	kJ/kg	23485
Fuel value	kJ/kg	21215
Chlorine	%	0.558
Sulphur	%	1.04
Total humidity	%	10.77
Ash	%	19.28

2.4 Testing of binder

For production of briquettes and pellets, apart from MII type hard coal and 19 12 10 waste, the binder was used to bond the raw materials. For testing as a binder, the liquid product was selected, obtained from the process of gasification of MII type hard coal and 19 12 10 waste. To perform the analyses, a representative sample was selected and analyzed. Table 3 presents the results of analyses. The binder, in spite of lacking energy values, being the waste other than hazardous, produced in the installation, was qualified for further testing relative to the properties of mechanical bonding of raw materials.

2.5 Testing of mixture

There were performed the tests on energy and emission properties for an optimal flammable mixture with the raw material composition being by weight: 80% coal from Kazimierz-Juliusz mine, 17% of the 19 12 10 waste and 3% binder. Representative samples were taken for the mixture, with the aim of making chemical analyses. The results of analyses of flammable mixture to be used for production of briquettes and pellets are presented in Tab. 4.

The flammable mixture based on the hard coal from Kazimierz-Juliusz mine had a composition of low chlorine content being 0.46%, sulphur 0.93%, low calorific value 21.2 MJ/kg, and high ash content of 21.70%. The flammable mixture has good characteristics of ash fusibility. They should not cause cindering and slagging of the boiler furnace chambers.The mixture has the

Table 3. Analysis of the liquid product obtained from the gasification process of flammable mixture of MII type hard coal and 19 12 10 waste.

Indicator	Unit	Value
Suspension	mg/dcm^3	8990
Reaction	pH	7.65
ChZT	mgO_2/dcm^3	63300
Total nitrogen	mgN/dcm^3	610
Nitrite nitrogen	mg/dcm^3	10.70
Nitrites	mg/dcm^3	35.1
Chlorides	mg/dcm^3	1130
Sulphates	mg/dcm^3	144
Sum Cl + SO_4	mg/dcm^3	1270
Ether extract	mg/dcm^3	810
Zinc	mg/dcm^3	38.5
Cadmium	mg/dcm^3	0.07
Iron	mg/dcm^3	1860
Manganese	mg/dcm^3	26.5
Cobalt	mg/dcm^3	0.26
Copper	mg/dcm^3	16.3
Lead	mg/dcm^3	0.36
Chromium	mg/dcm^3	–
Nickel	mg/dcm^3	2.40

Table 4. Chemical and technical analysis of flammable mixture of hard coal 19, 12 10 waste and binder for production of briquettes and pellets.

Parameter	Unit	Value
Heat of combustion	kJ/kg	22151
Calorific value	kJ/kg	21203
Chlorine	%	0.46
Sulphur	%	0.93
Total humidity	%	4.93
Ash	%	21.70
Hydrogen	%	3.79
Ash fusibility Temperature characteristics: – sintering point – softening point – melting point – flow temperature	 °C °C °C °C	 1150 1240 1280 1310

properties being comparable to MII type power coals currently used for firing power boilers.

3 Investigation of emission of flammable mixture to be used for production of briquettes and pellets

The investigation relied on conducting thermal tests, performing measurements of concentrations and computing the emissions of dust and gas substances emitted from the test boiler being fired with the briquettes in the form of a cylinder of $\phi\,50 \times 100$ mm (Fig. 1). The briquettes were made of the flammable mixture with the composition by weight: 80% coal from Kazimierz-Juliusz mine, 17% of 19 12 10 waste and 3% binder.

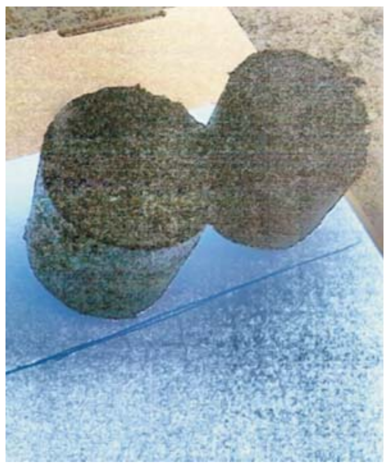

Figure 1. View of the briquettes obtained from the flammable mixture.

The thermal and emission tests of dust and gas substances were performed on the water boiler type EKO GT-KWR 22, fitted with a fixed grate of 25 kW power, fired with the flammable mixture [7–10]. The water boiler tested is a heating unit being commonly used for heating cubature objects in the low and medium-temperature heating installations up to 95/75 °C, with automatic operation and control system, depending on the thermal load. The view of the test station is shown in Fig. 2. The parameters of the boiler used in the tests are listed in Tab. 5. The scope of tests and measurements in the process of flammable mixture combustion included the following:

- analysis of chemical composition of gases,
- determining concentrations of dusts and gases in the waste gases,

Table 5. Technical parameters of tested water boiler of type EKO GT-KWR 22.

Specification	Unit	Data
Calorific effect	kW	25
Heating surface	m^2	2.85
Working pressure	MPa	0.10
Working temperature	^oC	100
Temperature of flue gas/fuel	^oC	200

Figure 2. View of testing stand with water boiler of EKO GT – KWR 22 type.

- computing the values of emissions of pollutants,
- analyses of fuel used,
- computing thermal load,
- determining the energy effectiveness of the boiler.

The testing stand was provided with the control-measuring equipment for continuous and periodical measurements of:

- temperature of water feeding the boiler,
- temperature of water returning from the boiler,
- pressure of water in the boiler,
- intensity of water flow through the boiler,

- analyses of flue gases, i.e., O_2, CO_2, CO, NO_2, SO_2, hydrogen chloride, hydrogen fluoride, organic matter in the form of gases and vapours expressed as total organic coal, heavy metals and their compounds expressed as metal,
- dust concentration in flue gas.

The control-measuring system was equipped with the devices being necessary to perform thermal tests of the boiler. The duty of the control-measuring system was to enable to control the parameters of the process of flammable mixture combustion, and their recording to allow further analysis. Figure 3 presents the schematic diagram of the control-measuring system in testing the EKO GT-KWR 22 – type water boiler.

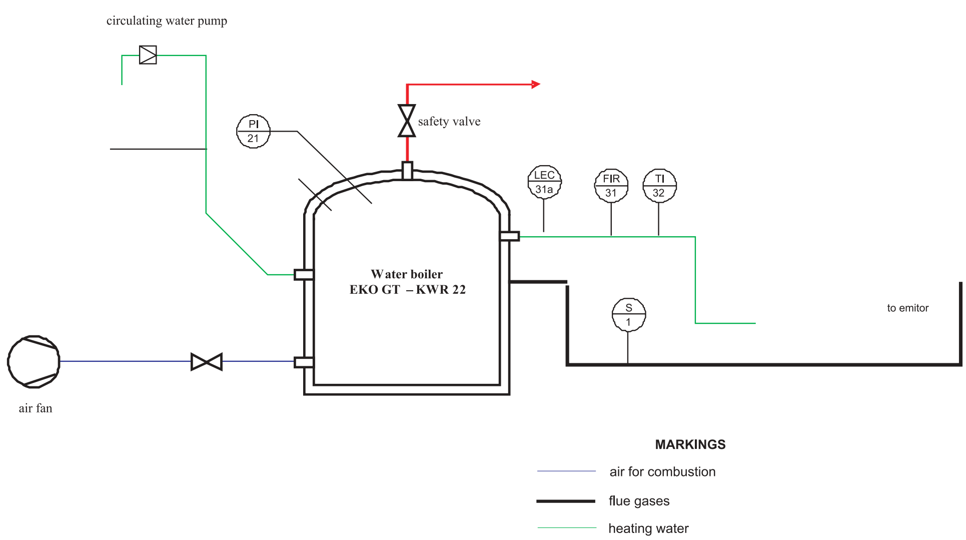

Figure 3. Schema of control-measuring system of the installation for testing of water boiler of type EKO GT-KWR 22.

The energy efficiency (gross) of the boiler during the combustion of briquettes, in relation to a given load of the boiler (in a specified measuring moment), and to the fuel applied, taking into account the stream of energy being fed as chemical energy contained in the fuel was found from the definition being in accordance standard [26], according to the formula

$$\eta = \frac{Q_N}{Q_Z}\,, \tag{1}$$

where:

Q_N	=	$\dot{m}_p(h_2) - h_1$ – specified effective thermal power, kW,
Q_Z	=	$\dot{m}_F[(H_{(N)} + h_F)/(1 - l_u) + J_{(N)A}]$ – stream of energy being fed (in accordance with PN-EN 12952-15 standard), kW,
$\dot{m}_p$	–	mass stream of hot water, kg/s,
h_2	–	enthalpy of water at average outflow temperature t_2, kJ/kg,
h_1	–	enthalpy of water at average temperature at the inlet t_1, kJ/kg,
$\dot{m}_F$	–	mass stream of fuel, kg/s,
$H_{(N)}$	–	calorific value of fuel at the reference temperature t_r, kJ/kg,
h_F	–	enthalpy of fuel $h_F = c_F(t_F - t_r)$, kJ/kg,
c_F	–	specific thermal capacity of fuel, kJ/kgK,
t_F	–	temperature of fuel, ^{o}C,
t_r	–	reference temperature, ^{o}C,
l_u	=	m_{Fu}/m_{Fo} – proportion of mass stream of unburnt fuel, m_{Fu}, to mass stream of fuel being fed, m_{Fo},
$J_{(N)A}$	=	$\mu_A C_{pA}(t_A - t_r)$ – enthalpy of air for combustion, kJ/kg,
C_{pA}	–	specific thermal capa city of air, kJ/(kgK),
μ_A	–	proportion of mass of air to mass of fuel,
t_A	–	temperature of air at the boundary of balance partition, ^{o}C.

The efficiency of the boiler defined in such a way is referred to a specified point of boiler load (in a specified measuring moment).

The results of tests obtained in the course of combustion are listed in Tab. 6. Figures 4 and 5 present the plots of the amount of energy produced, consumption of flammable mixture, changes of the excess air number, and emissions of gas and dust substances depending on the time of combustion of briquettes in the EKO GT-KWR 22 type water boiler. The energy efficiency of the boiler obtained in the tests on burning the briquettes was $\eta = 80\%$.

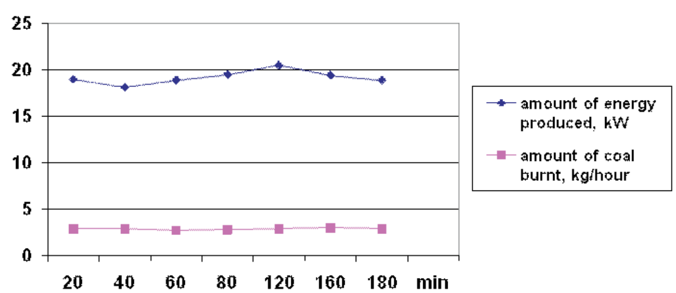

Figure 4. Amount of energy produced, consumption of briquette as well as the value of the the air excess number versus time of combustion.

Table 6. Test results of the boiler EKO GT-KWR 22 obtained during the combustion of briquettes.

Time [min]	Water temperature [°C]		Stream of water [Mg/h]	Amount of energy produced [kW]	Amount of fuel consumed [kg/h]	Excess air number [-], λ	Emission						
	feeding	return					O_2 [%]	CO_2 [%]	SO_2* [mg/m^3]	NO_2* [mg/m^3]	CO* [mg/m^3]	Dust* [mg/m^3]	t_s /** [°C]
0	63.8	51.4	1.33	19.1	2.865	1.58	7.70	11.7	689	379	168	123	161.2
20	61.0	40.8		19.0	2.850	1.47	6.70	12.6	709	391	248	120	143.0
40	51.6	39.9		18.1	2.715	1.72	8.80	10.8	715	292	153	190	126.5
60	52.2	40.1		18.9	2.835	1.52	6.75	13.5	761	332	880	175	169.8
80	53.8	41.2		19.5	2.925	1.43	6.40	12.9	772	330	709	186	151.0
120	55.5	42.2		20.5	3.075	1.54	7.40	12.9	787	297	378	180	127.8
160	55.2	42.6		19.4	2.910	1.43	6.40	12.0	710	326	423	184	145.0
180	54.9	42.9		18.9	2.835	1.51	5.16	14.6	724	332	214	160	187.0

* At oxygen content in flue gas of 10% in the contractual conditions at 273 K and 101.3 kPa ** t_s – exhaust temperature

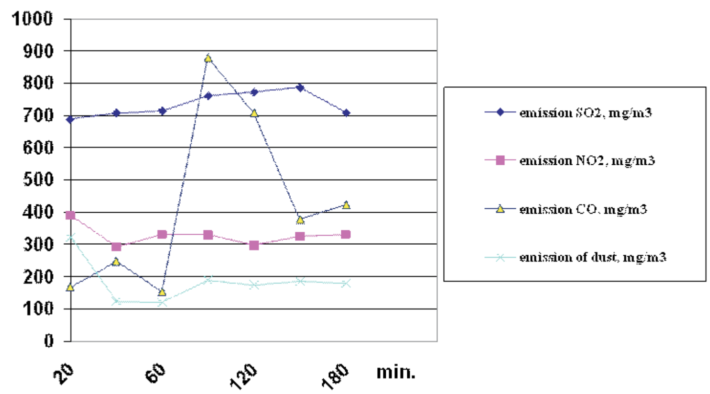

Figure 5. Emission of gaseous substances and dust versus time of briquette combustion.

4 Investigations of gasification process of mixture of hard coal MII type and 19 12 10 waste

The assumption for basic investigations was the choice of a method to produce gas from inflammable mixture by low-temperature gasification, which were aimed at [5,20,22,23]:

- selection of optimal technological parameters of gasification process (temperature, pressure, efficiency)
- carrying out physical and chemical analyses of gas obtained from the gasification process of inflammable mixture
- assessment of the effects of waste utilisation process on the condition of the environment.

The assumptions made in this way enabled to:

- apply the same raw materials as for the production of briquettes, pellets and gas
- use, in the gasification process, of the pellets and briquettes which are so-called the production waste (cracking, lack of size, lack of commercial properties).

The inflammable mixture was subjected to thermal tests of thermogravimetric techniques (with thermobalance) on the stand for the thermal analysis of the Mettler-Toledo company [27]. In the conducted tests there has been measured the change of the sample mass of the inflammable mixture applied, depending on the temperature changes and the passage of time. The sample in the small container was placed in the small stove, which was connected with the thermobalance. The sample was heated to temperature of 900 °C. The measurement of a given temperature was made by means of the thermocouple, which was placed directly next to the small container of the sample. There have been applied the following parameters of the thermal tests using the thermogravimetric technique of the inflammable mixture under test: initial and final temperature 25 and 900 °C, respectively, rate of temperature rise (linear) 10 °C/min, atmosphere inert nitrogen. The results of tests are presented in Tab. 7. On the basis of performed thermogravimetric analyses (TGA), Fig. 6, it should be stated that:

- maximum of exothermic effects in the process of sample gasification that occur is the temperature between 50 to 600 °C,
- the biggest sample mass loss occurs up to the temperature of 350 °C,
- rate of sample mass loss proceeds slowly up to the temperature of 86 °C, and up to the temperature of 349 °C takes place a slow release of gaseous products which ends at the temperature 453 °C,
- the most rapid mass change happens in the temperature of approx. 453 °C,
- optimal temperature of inflammable mixtures gasification is the temperature of 450 °C,
- sample mass loss connected with the release of gaseous products proceeds up to the temperature of 460 °C with the mass loss being 24%.

Table 7. Test results of the thermogravimetric analysis of flammable mixture.

Mass of sample [mg]		12.9
Residue at 900 °C [%]		59
Temperature range [°C]	T_{max}/DTG [°C]	Weight change [%]
52.0–197.0	86	– 4.7
197.0–381.6	349	– 6.3
381.2–648.6	453	– 22.3
648.6–871.9	721	– 6.3

Note: The minus sign denotes loss of mass;
T_{max}/DTG – waste of mass of sample in function of temperature.

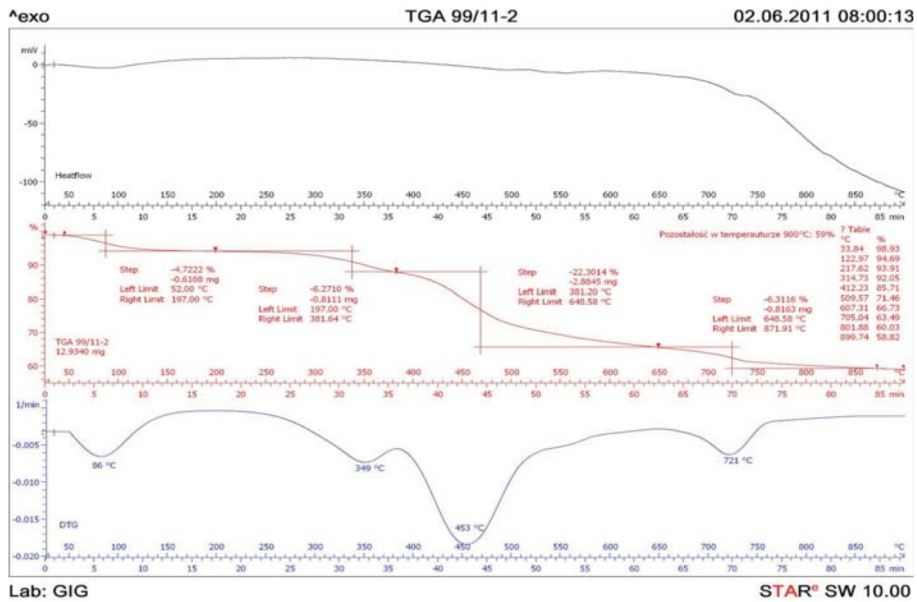

Figure 6. Characteristics for thermogravimetric analysis (TGA) of flammable mixture.

In order to confirm the obtained results of tests made by the thermogravimetric technique (with thermobalance), there have been carried out the tests of gasification in a laboratory. Installation featured the throughput up to 2.5 kg of inflammable mixture. The laboratory installation consisted of: reactor for waste gasification made of steel, equipped with protective fittings, with the capacity up to 3.0 kg mixture/processed units and dimensions 550×1200 mm; blower with the efficiency of 0.15–3.5 m^3/h to produce current of air fed to the process of kindling and gasification of mixture in the reactor; control and measuring equipment of the process (temperature, pressure, gas productivity, analysis of fumes). The schema of laboratory installation has been presented in Fig. 7.

The tests on installation have been carried out periodically in the following cycle:

- loading of inflammable mixture in the amount up to 3.0 kg to the reactor,
- initiating the combustion phase by lighting the part of loaded mixture and feeding air for combustion,
- phase of the thermal gasification process, the course of which was controlled with the inflow of air forced by the blower to the reactor,

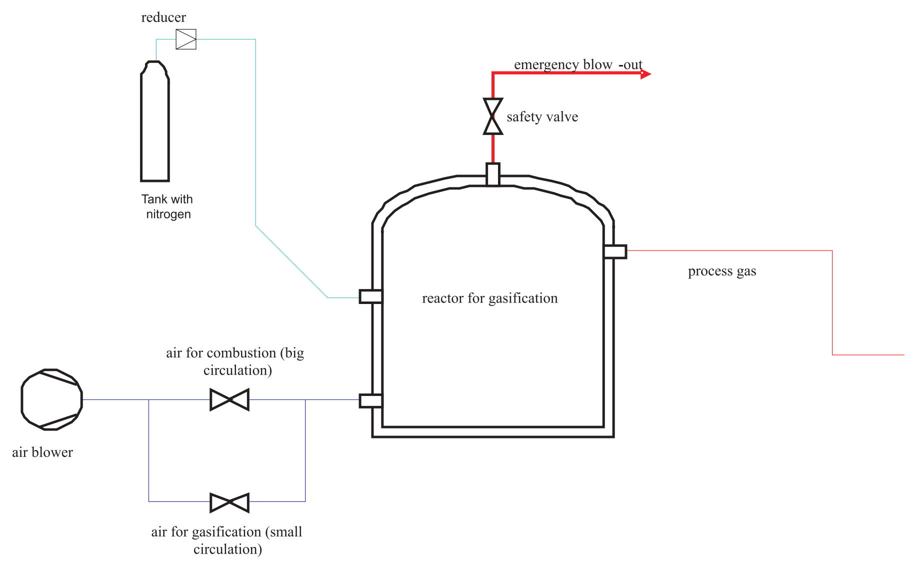

Figure 7. Schema of laboratory system for gasification of flammable mixture.

- phase of gas production,
- phase of cooling to the temperature of the environment and removal of the remains after gasification from the reactor.

In the laboratory tests of the low-temperature process of flammable mixture gasification, the flammable gas was obtained with the properties as included in Tab. 8. In the gasification process, the mass of flammable mixture was transformed into a gaseous phase, which consisted mainly of water vapour, hydrogen, methane, ethane, carbon monoxide and dioxide as well as other gaseous compounds such as: H_2S, NH_3, HCl, HF. The composition of gas produced during gasification process was dependent on the range of temperatures of the process. Owing to application of gas produced from the flammable mixture of hard coal of MII type and 19 12 10 waste, it will be possible to obtain very good control characteristics of the boiler and its high efficiency, higher by about 8% than that of conventional energy systems.

Table 8. Properties of gas from gasification of flammable mixture.

Property	Unit of measure	Result
Average productivity of gas yield	$Nm3/kg_{inflammable\ mixture}$	1.50
Calorific value of gas	MJ/m^3	< 25.0
Sulphur content in gas	mg/m^3	0.02
Dust content in gas	mg/m^3	0.099
Hydrogen chloride content	mg/m^3	< 0.10
Ammonia content	mg/m^3	1.23
Hydrogen fluoride content	mg/m^3	< 0.20
Content of CO	%	25.0
Content of CO_2	%	17.0
Content of H_2	%	9.9
Content of CH_4	%	3.8
Content of H_2O (water vapour)	%	25.0
Content of O_2	%	4.5
Gas density	kg/m^3	0.95
Lower limit of explosiveness DGW	%	6.26
Upper limit of explosiveness GGW	%	42.46
$DGW < \sum n\% < GGW \cup (O_2)VO_{2\,min}$	%	nonexplosive mixture
Sums of inflammable components $\sum n$	%	22.23

Note: DGW – bottom border explosion,
GGW – overhead border explosion,
O_2, O_{2min} – from contents of oxygen.

5 Investigations of the combustion process of gas produced from the gasification of flammable mixture in the boiler

The gas produced was burnt in the burner installed in the same boiler in which all briquettes and pellets were burned [7–10]. The gas was burning evenly, and there were no signs observed of explosion (detonation) character of gas ignition in the burner. The process of burning in the boiler ensured keeping the temperature of flue gases above 850 °C, and obtained composition of flue gas during the process of gas combustion was included in Tab. 9.

Table 9. Composition of flue gas obtained in gas combustion from gasification of flammable mixture. Source of emission: boiler EKO GT-KWR 22 with the oxygen content in flue gas 11%.

Specification of pollution	Value of emission gasification phase [mg/m^3_u]
Airborne dust, total	0.00
Organic substance in the form of gases and vapours, expressed as the total organic carbon	5.00
Hydrogen chloride	0.45
Hydrogen fluoride	0.04
SO_2	0.00
Carbon monoxide	140
NO_2	324
Heavy metals and their compounds expressed as metal:	
Cd + Tl	0.00
Hg	0.00
Sb + As + Pb + Cr + Co + Cu + Mn + Ni + V + Sn	0.00

Gasification of flammable mixture with the transformation into gaseous fuel gives:

- possibility of deep (above 95%) recycling and transformation of 19 12 10 waste;
- without their energy-consuming and technically difficult transformation by using the other methods and, and without ecological and economical effects of long-term storage municipal waste landfils;
- possibility because of production and burning gaseous fuel almost completely and in the optimal conditions without the emission of soot; aliphatic and aromatic hydrocarbons, aromatic compounds of chlorine, with low emission of nitrogen oxides, sulphur and organic substance in the form of gases and steams expressed as the total organic coal;
- obtaining flue gas from burning with the composition enabling their emission into the atmosphere without additional chemical cleaning;
- acquisition of energy sources protecting highly the environment;

- possibility of utilising in the installation, without any modifications, of any kind of biomass in any form for energy production from renewable resources in the form of gas from gasification waste other than hazardous;
- reducing the consumption of primary fuel being the hard coal.

6 Conclusions

The implementation of the technology will serve to provide waste neutralization services by using their energy potential, and in the innovative and intensive way, the chemical enthalpy contained in the neutralized waste and in hard coal.

The concept of energy production based on modern alternative fuels relies on:

- producing the flammable mixture with the composition by weight: 80% of coal from Kazimierz-Juliusz mine, 17% of 19 12 10 waste, and 3% of binder;
- application of installation for low-temperature gasification of flammable mixture and gas production,
- production of briquettes and pellets obtained from the flammable mixture,
- coburning of briquettes and pellets as well as gaseous fuel, being the process gas, in a way enabling their complete transformation, being safe for the environment, into thermal and electrical energy.

Systems of thermal and electrical energy production will be able to work in three independent variants:

I. Thermal energy production in the steam boiler (technological steam) as well as electric energy, in association, in which there will be burnt the pellets or briquettes produced from the hard coal and 19 12 10 waste.

II. Thermal energy production (technological steam) as well as electric energy, in association, in the installation based on the process of gas combustion from the low-temperature gasification of hard coal and 19 12 10 waste .

III. Thermal energy production in the steam boiler (technological steam) as well as electric energy, in association, in which there will be co-burnt pellets or briquettes and gas from the low-temperature gasification of hard coal and 19 12 10 waste.

The water vapour produced in accordance with the variants I, II and III in the steam boiler will be driving the turbogenerator. Figure 8 presents the schema of installation for production of thermal and electrical energy, in association, originating from the waste other than hazardous coded 19-12-10 and hard coal.

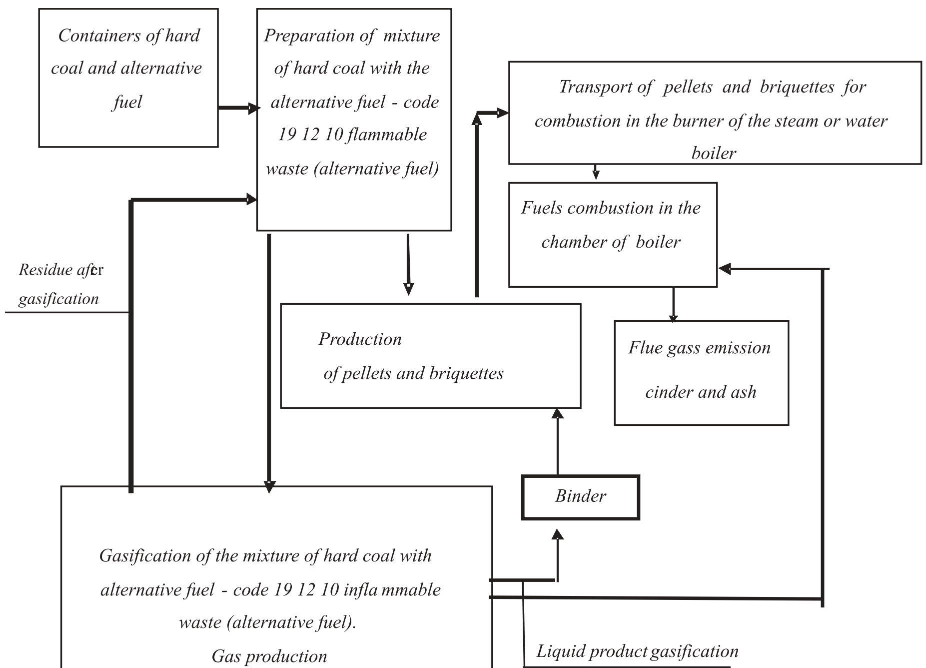

Figure 8. Flow diagram of the system for advanced alternative fuel production.

The conception worked out of energy production on the basis of modern alternative fuels allows, to a high degree (nearly 90%), to transform into heat and electric energy by using all the products created during the production process of pellets, briquettes and gas from gasification of flammable mixture. Figure 9 presents an analysis of equipment operation, i.e., boiler and turbine generator in the cogeneration.

The preliminary economical analysis performed of energy production and modern alternative fuels production on the basis of flammable mixture made from MII type hard coal and 19 12 10 waste demonstrated that:

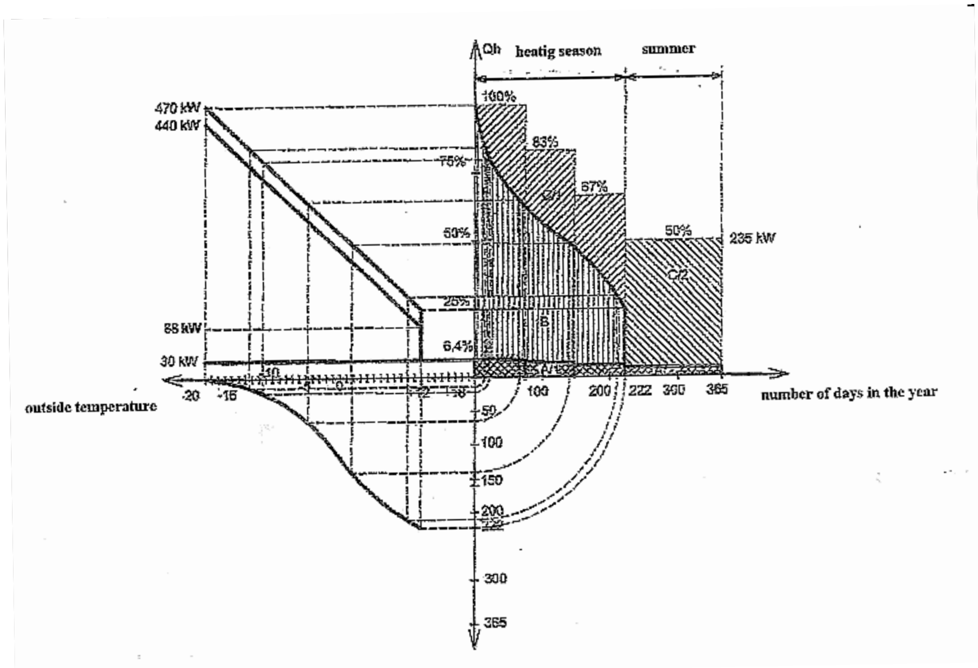

Figure 9. Analysis of operation of the unit boiler-turbogenerator in cogeneration: A/1 – electric energy produced during the heating season (222 days), A/2 – electric energy produced outside the heating season (143 days), B – amount of the thermal energy for heating purposes during the heating season (222 days), C/1 – amount of waste energy directed to the cold store during the heating season (222 days), C/2 – amount of waste energy directed to the cold store outside the heating season (143 days).

- Production cost of 1 Mg steam at pressure of 170 kPa and temperature 220 °C is as follows:
  - from hard coal: 45.00 PLN/Mg_{steam},
  - from briquettes and pellets: 30.25 PLN/Mg_{steam} .
- Fuel cost:
  - hard coal with the range of eco-pea coal: 720.00–1053 PLN/Mg,
  - briquette: 524.00 PLN/Mg_{steam},
  - pellet: 630.25 PLN/Mg_{steam}.

Received 12 November 2011

References

[1] *Regulation of the Minister of Environment of 27 September 2001 on Waste Catalogue*. Dz.U. 01.112.1206 (in Polish).

[2] *Regulation of the Minister of Economy of 29 January 2002 on the types of non-hazardous waste and types of installations and equipment, in which there is allowed their thermal transformation*. Dz.U. 02.18.176 (in Polish).

[3] *Act of 27 April 2001 Environmental Law*, Dz.U. 01.62,627, (see also Dz.U. 08.25.150 of 23.01.2008) (in Polish).

[4] *Act of 27 April 2001 on waste*, Dz.U. 01.62.628 (see also Dz.U. 07.39.251) (in Polish).

[5] *Regulation of the Minister of Economy, Labour and Social Policy of 22.12.2003 amending Regulation on requirements for the process of thermal conversion of waste*. Dz.U. 03.1.2 (in Polish).

[6] *Regulation of the Minister of Environment of 9 September 2002 on standards for soil quality and ground quality standards*. Dz.U. 02.165.1358 (in Polish).

[7] *Polish Standard PN-Z-04030-7: 1994 Measurement of the concentration and mass flux of dust in exhaust gases by the gravimetric method* (in Polish)

[8] *Regulation of the Minister of Environment of 23.12.2004 on the requirements for emission measurements*. Dz.U. 04.283.2842 (in Polish).

[9] *Polish Standard PN-ISO 10396: 2001 Emission from stationary sources. Sampling for the automated measurement of concentrations of gaseous components* (in Polish).

[10] *Regulations of the Minister of Environment of 04.11.2008, on the requirements for emission and water intake measurement*. Dz.U. 08.206.1291 (in Polish).

[11] Furtak D.: *Is there a chance in Poland to gain energy from biomass in large power boilers*. Energetyka **57**(2004), 4, 235–240 (in Polish).

[12] Golec T.: *Mass co-firing in power boilers*. Energetyka **57**(2004), 7/8, 437–445 (in Polish).

[13] Jesionek J. Soliński I.: *Biomass – renewable organic fuel of twenty-first century*. Energy Policy J. **7**(2004), 1, 37–119.

[14] Juszczak M.: *Research on float of pollution from burning coal and wood dust chemically contaminated*. Ochrona Powietrza i Problemy Odpadów **34**(2000), 3, 103–106.

[15] Mirowski T., Wielgosz G.: *Utilisation of coal and biomass in Electric Power Plant Stalowa Wola join stock company*. Energ. Policy J., Supplement **7**(2004), 451–461.

[16] Kruczek H., Rączka P., Tatarek A.: *Installation and method of burning wood waste*. Ochrona Powietrza i problemy Odpadów **37**(1997), 5, 171–172 (in Polish).

[17] Nocuń A., Ostrowski W., Rabsztyn A., Żbik M., Miklas E., Łyb B.: *Renewable energy generation through biomass co-combustion of fuels in PKE SA*. Energetyka **57**(2004), 11, 709–713 (in Polish).

[18] Wójcik W., Kotyra A.: *Use of the flame image for evaluation of the stability of coal dust and biomass mixtures combustion*. Measurement, Automation and Monitoring, PAK 2005, 3, 34–36.

[19] Strozik G.: *Selected ecological ways of energy production from fossil fuels with biomass*. Zesz. Nauk. PŚl. Górnictwo **258**(2003), 333–344.

[20] Malkow T.: *Novel and innovative pyrolysis and gasification technologies for energy efficient and environmentally sound MSW disposal*. Waste Management **24**(2004), 53–79.

[21] Pronobis M.: *The influence of biomass co-combustion on boiler fouling and efficiency*. Fuel **85**(2006), 4, 474–480.

[22] Mirosław J., Dobrzycki T.: *Installation of the thermal transformation of municipal waste in view of the Polish and European Union regulations*.

[23] Błaszczyk J., Błagowska K., Rajewski A.: *Production of energy from waste*, Arch. Energ., **XL**(2010), 1–2, 19–29.

[24] *Regulations of the Minister of Environment of 02 June 2010. on the specific technical conditions of eligibility of energy recovered from municipal waste thermal conversion*. Dz.U. 10.206.1291 (in Polish).

[25] *Regulation of the Minister of Economy of 14 August 2008. on the detailed scope of duties to obtain and present to the redemption of certificates of origin, substitute fee, purchase of electricity and heat generated in renewable*. Dz.U. 08.156.969 (in Polish).

[26] *European Standard BS EN 12952-15, Water-tube boilers and auxiliary installations Part 15: Acceptance tests*.

[27] *Investigative documentation*. Central Mining Institute, No 09 128001 – 322, August 2011.