

# Analysis of thermal conversion of non-homogeneous solid recovered fuels

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## Abstract

*Solid Recovered Fuel (SRF) is produced from households and industrial solid waste. Due to European Union regulation, which prohibits the disposal of waste with calorific value higher than 6 MJ / kg by storage on landfills, there is a need of utilizing it in different way. SRF's in times of increasing demand of energy could be used as an alternative fuel due to its energy attractiveness. The aim of this work is to verify the suitability of waste as a fuel. For this purpose, samples of waste were collected from three waste treatment plants located in Poland. Detailed physicochemical properties have been obtained by the proximate, ultimate and ash analysis. To evaluate the combustion behavior, thermogravimetric analysis was used. Using the results of the TGA, the kinetic model for the process of combustion and gasification of SRF had been created. In this thesis, energy usefulness of tested samples was confirmed and compared with other studies of the literature. Thermogravimetric analysis allowed to observe a similar behavior between the samples. Additionally, the activation energy, based on designed kinetic models, was obtained.*

*Keywords: SRF, solid recovered fuel, waste, combustion, TGA, kinetic model.*

## 1. Introduction

At the beginning it is worth to mention what are Solid Recovered Fuels (SRF) and Refused Derived Fuels (RDF). SRF and RDF terms are often used alternatively. Refused Derived Fuels RDF are produced from Municipal Solid Waste (MSW) which according to Directive 2010/75/EU [1] means waste from households as well as commercial, industrial and institutional waste which, because of its nature and composition, are similar to waste from households. SRF can be produced only from non-hazardous waste namely those which are not a threat to life and health of humans and the environment.

Amount of waste comparison was created according to Confederation of European Waste-to-Energy Plants (CEWEP) country report for Poland [2] and Portugal [3]. In Poland, in 2010, the production of waste was 315 kilograms per inhabitant and in Portugal was 511 kilogram per inhabitant. Therefore, the total amount of waste, in the respectively country, was 12.04 and 5.47 million tones. These large quantities of garbage are treated in different ways. In Poland treatment of waste by landfilling in 2010 was 73% and was much higher than in Portugal where it was 62%. Portugal

disposes 19% of produced waste using incineration where Poland disposed in this way only 1% of waste. Recycling and composting respectively for Poland were 18 and 8%, for Portugal 12 and 7%. Besides Poland and Portugal, the waste issues occur in the whole Europe.

Nowadays, with the entry into force of the new Act of 14 December 2012 [4] the storage of waste of calorific value greater than 6 MJ/kg will be prohibited. With the growing demand for energy and plans to increase production of energy from renewable sources till 2030 [5], it is needed to consider other and more effective methods of waste disposal.

The main objective of this work was to determine the physicochemical properties of the sieve fraction of municipal waste of Poland. The proximate and ultimate analysis was performed. The thermochemical behavior of waste was assessed by thermogravimetry simulating combustion and gasification conditions. Kinetics studies of waste were performed using thermogravimetry data obtained for different heating rates. The kinetic models were based on three separate fitting methods. The environmental issues were also studied. The mercury, chlorine and fluorine as well as heavy elements were analysis in order to prevent danger coming from their toxicity.

## **2. Treatment methods**

As previously mentioned, there are many different ways to manage the waste utilization. Two main groups of methods can be distinguished: mechanical-biological (MBT) and thermal treatment. In the present work only thermal treatment was used.

Thermal Treatment is a group of waste treatment methods which include all processes converting the waste into gas, liquid and solid products with release of thermal energy (pyrolysis, gasification and combustion) [6]. Pyrolysis is a thermal transformation of carbon-rich organic substances, which takes place at increased temperatures with absence of air. The gasification occurs at a temperature close to 1000 °C in the presence of oxidizing agent, which may be air, oxygen, CO<sub>2</sub> and water vapor [7]. Combustion is usually understood as a reaction of oxidation of organic fuel components, related with the release of significant amounts of heat. The purpose of the combustion process is to obtain energy (heat) for industrial energy processes or heating. On the other hand the incineration process is to eliminate or only reduce the volume of harmful waste for the environment. It is also possible to combine these two objectives by the use of waste energy. An important benefit of thermal waste treatment processes is the ability to generate significant amounts of heat, thus saving non-renewable fuel and reduces emissions to the environment of the combustion products [8].

## **3. Sample preparation**

The samples were collected at two waste treatment plants located in the Silesia province and one waste treatment plant in the Łódź province. From each of them one sample was taken weighing about 50 kg from fraction above sieve mesh 80 mm sieve. The samples were pre-treated due to the fact that the material is not unitary. Then, samples were pulverized to 0.1 mm for thermogravimetric

analysis. Figure 1 shows the samples SRF1, SRF2 and SRF3. These samples were used in the analysis described in the following sections.



Figure 1. Samples of waste from three waste treatment plants in sequence SRF 1, SRF 2, SRF 3.

## 4. Morphology

Morphology of samples was determined in accordance with PN-93/Z-15006 [9]. This standard recommends testing waste composition consisting in collecting the sample mean of the waste in the landfill and then separation by hand into individual fractions and weighing them [10]. Table 1 shows the results of morphology composition of samples.

Table 1. Morphological composition of samples.

No.	Name of component	SRF 1 (%)	SRF 2 (%)	SRF 3 (%)
1	Fraction below 10 mm	0	0	0
1	Food waste of vegetable origin	6.48	4.93	3.00
2	Food waste of animal origin	0.49	0.73	4.29
3	Paper and cardboard waste	40.61	23.94	37.92
4	Plastic waste	36.22	45.06	28.62
5	Waste textile materials	13.64	21.40	14.17
6	Glass waste	0.62	1.26	1.70
7	Metal waste	0.53	1.92	1.60
8	Other organic waste	0.75	0.68	8.43
9	Other non-organic waste	0.66	0.08	0.27

In Table 1 can be verified that the samples have a high percentage of paper and cardboard from 23.94 to 40.61% and plastic between 28.62 and 45.06%. Both of these components can have a great impact on the calorific value of the mixture. Therefore, it is important to analyze morphological composition of the material to know the impact of the individual components on the fuel properties.

## 5. Analysis of SRF laboratory samples

Waste analyses were carried out according to the procedures of Institute for Chemical Processing of Coal (Zabrze-Poland) based on the European Union standards and experience of employees of the Institute.

### 5.1 Proximate, ultimate, calorific value and ash analysis

Proximate analysis is measurement of technical properties of fuel following the procedures Q/LP/18/A:2011 [11], Q/LP/28/A:2011 [12] and Q/LP/20/A:2011 [13] Q/LP/19/A:2011 [14]. Table 2 shows the result of proximate analysis of waste.

Table 2. Result of proximate analysis of waste.

Proximate analysis (wt %, as received)	SRF 1	SRF 2	SRF 3
Volatiles	63.1	73.7	67.6
Fixed Carbon	11.4	10.6	12.0
Moisture	3.1	4.6	3.2
Ash	22.4	11.1	17.2

The obtained results are accordingly with values present in the literature. Studies of Wagland et al. (2011) [15], and Bosmans et al. (2014) [16], shows related proximate analysis results of waste.

Content of volatile matter in their studies was respectively 79.6 and 69.3%, ash content was 11.1 and 22.1%, moisture content was 3.0 and 4.6%. It is possible to verify a small correlation between morphological composition and proximate analysis. Content of volatiles matter is higher when in composition of SRF is a great amount of plastic waste and ash content can depend on content of paper and cardboards in waste.

Ultimate analysis was measurement following the procedures: Q/LP/22/B:2011 [17] and Q/LP/21/A:2011 [18] Table 3 shows the result of ultimate analysis of waste.

Table 3. Results of ultimate analysis of waste.

Ultimate analysis (wt %, dry ash free)	SRF 1	SRF 2	SRF 3
Carbon	65.6	60.6	61.1
Hydrogen	8.3	4.8	8.1
Nitrogen	1.2	0.9	1.2
Sulphur	0.5	0.9	0.5
Oxygen	24.4	32.8	29.1

The high content of carbon and hydrogen in the samples can increase calorific value. In studies of Pinto et al. (2014) [19], and Zhou et al. (2013) [20], related ultimate analysis results of waste. Content of carbon in their studies was 67.9 and 63.3%, respectively. Content of hydrogen was respectively 5.1 and 8.9%.

Furthermore, another important aspect in assessment of the fuel behavior is the determination of calorific value, which represents the amount of heat that the fuel produces in a process of combustion. Higher Heating Value (HHV) was measured and Lower Heating Value (LHV) was calculated according to Institute for Chemical Processing of Coal procedure number Q/LP/23/A:2011 [21]. Table 4 shows the result of calorific value of waste.

Table 4. Results of calorific value.

Heating value (wt MJ/kg, analytical state)	SRF 1	SRF 2	SRF 3
Low	19.0	22.9	20.0
High	20.4	23.9	21.5

The caloric value is close to the calorific value of the biomass. These results illustrate us the opportunity to use waste as a fuel to combustion or co-firing. In study of Luo et al. (2010) [22], results revealed that higher

heating value of SRF was found to be 21.3 MJ/kg. Calorific values of SRF's are comparable to Luo et al. (2010) studies.

The melting temperature of ash and the content of oxides in the ash were analyzed according to Institute for Chemical Processing of Coal procedure Q/LP/35/A:2011 [23] and Q/LP/65/A:2011 [24], respectively. Tables 5 and 6 show the results of ash melting temperatures and content of oxides in the ash, respectively.

Table 5. Results of ash melting temperatures.

Oxidizing atmosphere (°C)	SRF 1	SRF 2	SRF 3
Temperature of sintering	1160	1140	1120
Temperature of softening point	1190	1190	1150
Temperature of melting	1200	1210	1230
Temperature of flow	1210	1240	1250
Half-reduction atmosphere (°C)	SRF 1	SRF 2	SRF 3
Temperature of sintering	1060	1030	1070
Temperature of softening point	1150	1150	1170
Temperature of melting	1180	1180	1180
Temperature of flow	1210	1190	1200

Table 6. Results of content of oxides in the ash.

Ash analysis (wt %, dry basis)	SRF 1	SRF 2	SRF 3
SiO <sub>2</sub>	35.7	33.4	35.1
Al <sub>2</sub> O <sub>3</sub>	16.2	12.0	17.3
Fe <sub>2</sub> O <sub>3</sub>	14.4	7.0	8.8
CaO	20.4	22.6	24.5
MgO	2.8	2.3	2.8
P <sub>2</sub> O <sub>5</sub>	1.0	1.9	1.1
SO <sub>3</sub>	3.6	11.9	4.8
Mn <sub>3</sub> O <sub>4</sub>	0.2	0.1	0.2
TiO <sub>2</sub>	1.6	2.4	2.2
BaO	0.2	0.2	0.2
SrO	0.1	0.6	0.1
Na <sub>2</sub> O	2.4	3.8	1.8
K <sub>2</sub> O	1.4	1.8	1.1

Studies [25] show that the melting temperature is also influenced by the chemical composition of ash. Larger contents ash components such as: SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, K<sub>2</sub>O caused an increase in the melting temperature ash. Components: Fe<sub>2</sub>O<sub>3</sub>, CaO, MgO, SO<sub>3</sub>, Mn<sub>3</sub>O<sub>4</sub> have more complex effect on the temperatures. There is a weak relationship between the melting temperature of ash and the ash content in material. With increasing ash content, the fusion temperature of ash slightly increases.

All these measurements are needed to be able to predict behavior of waste during combustion and to determine if the waste is suitable as fuel from which energy can be produced, and to understand the process of combustion and consequently, could design of appropriate installations for the disposal of waste as well as check the impact of incineration on the environment.

## 5.2 Thermogravimetry

The three samples of waste were analyzed by thermogravimetry. For each tested material 8 samples of 20 mg each were prepared.

The degree of conversion ( $\alpha$ ) for tested material was calculated using the equation [26]:

$$\alpha = \frac{m_0 - m_t}{m_0 - m_f}$$

where  $m_0$  mass of sample at the beginning,  $m_t$  mass of sample at time  $t$  and  $m_f$  is the final mass of the sample.

First thermogravimetric analysis was measured in two stages process; in the first, non-isothermal stage heating rate was 10 °C min<sup>-1</sup> in the atmosphere of Ar with flow rate of 25 ml/min; after reaching assumed temperatures of 475, 600, 800 °C the heating was stopped and the atmosphere was changed to synthetic air (N<sub>2</sub>/O<sub>2</sub>) with flow rate 100 ml/min, to enable isothermal combustion process. Figure 2 and 3 shows comparison of non-isothermal stage, isothermal combustion and conversion at 475, 600 and 800 °C for SRF 1, SRF 2, SRF 3.

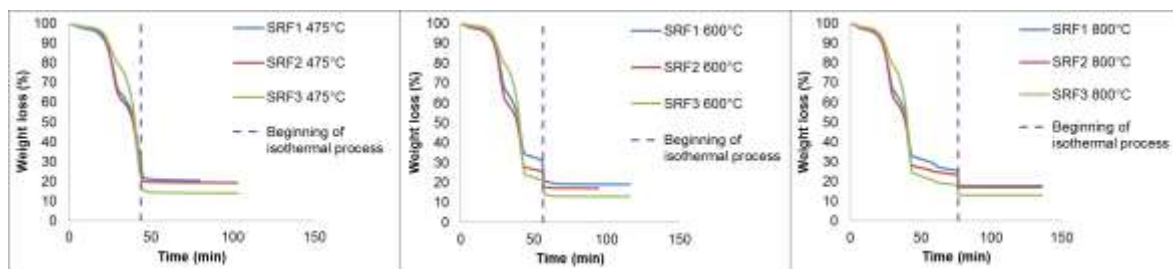


Figure 2. Comparison for non-isothermal stage and isothermal combustion at 475, 600 and 800 °C for SRF 1, SRF 2, SRF 3.

Results shows that in non-isothermal stage occurs the biggest weight loss (from 94 to 40%), which can be observed between 20 and 40 minute of measurement. This may be caused by moisture vaporization and release of volatile matter as well as conversion of higher hydrocarbons into simpler chains. Isothermal process SRF began, for three assumed temperatures (beginning of the process was marked by dash line), sequentially in 44, 56.5, 76.5 minute. Mass become constant after 46, 60, 78 minutes of measurement, respectively. In first minutes swift weight loss can be observed. Below 20% of weight loss are residues, which were burn out. In all three figures can be observed that curves for SRF 1 and SRF 2 in non-isothermal stage are almost similar. In case of SRF 3 which weight loss is

slower between 30 and 40 minute, this may be due to higher content of other organic waste in this sample, which need more time for vaporization and devolatilization.

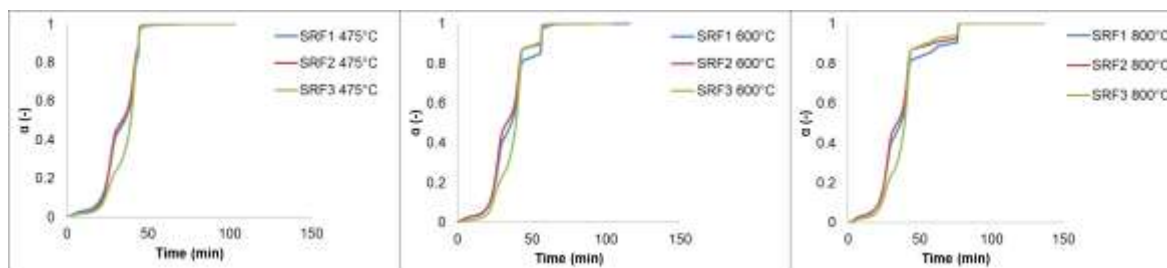


Figure 3. Comparison for the degree of conversion at 475, 600 and 800 °C for SRF 1, SRF 2, SRF 3.

Figure 3 shows that the degree of conversion increased with time. The largest increase can be observed between 20 and 40 minute from 0.1 up to 0.9. Curves for SRF 1 and SRF 2 are almost similar, but in case of SRF 3 the increase of conversion is slower in this time. In the second graph in Figure 3 between 44 and 56.5 minute and in the third graph in Figure 3 between 44 and 76.5 minute can be observed stable grown of conversion. In 44, 56.5 and 76.5 minute respectively for 475, 600 and 800 °C swift increase of conversion can be observed.

Second thermogravimetric analysis for three samples was performed for gasification for different heating rates. Analysis conditions were in an atmosphere of Ar with flow rate 25 ml/min and CO<sub>2</sub> with flow rate of 100 ml/min in three assumed heating rates 5, 10, 20 °C min<sup>-1</sup>. Process was carried out to a temperature of 1100 °C. Figures 4 and 5 shows comparison of gasification and conversion in three heating rates 5, 10, 20 °C min<sup>-1</sup> for SRF1, SRF2 and SRF3.

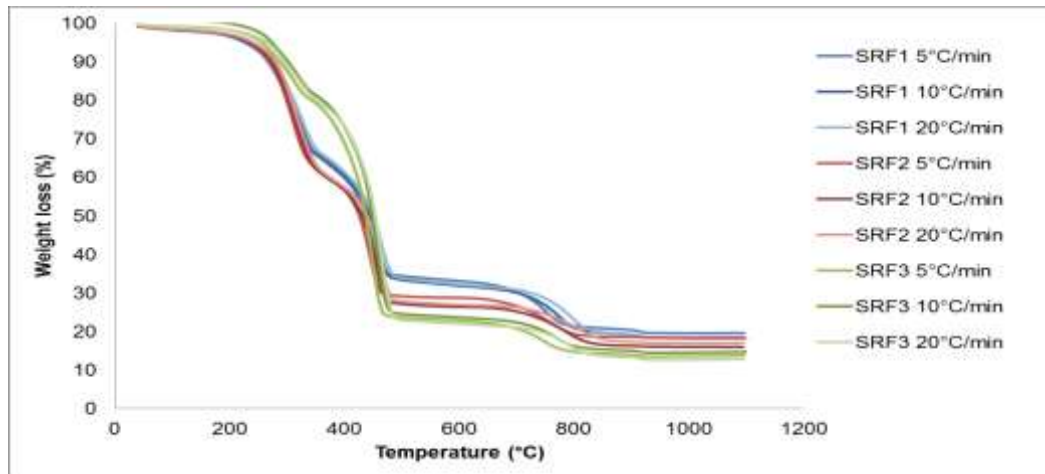


Figure 4. Thermogravimetric analysis for gasification in three heating rates 5, 10, 20 °C min<sup>-1</sup> for SRF1, SRF2 and SRF3.

Looking at all nine curves in Figure 4 approximately the same weight loss is observed. The gasification process began in 190 °C. The higher weight loss (95-70%) was observed from 190 °C to 325 °C corresponding to the moisture vaporization. Following, the second weight loss (70-35%) occurs between 325 and 470 °C and may correspond to the devolatilization of hydrocarbons. The gasification process terminates between 470 and 1100 °C, where residues of material were degraded.

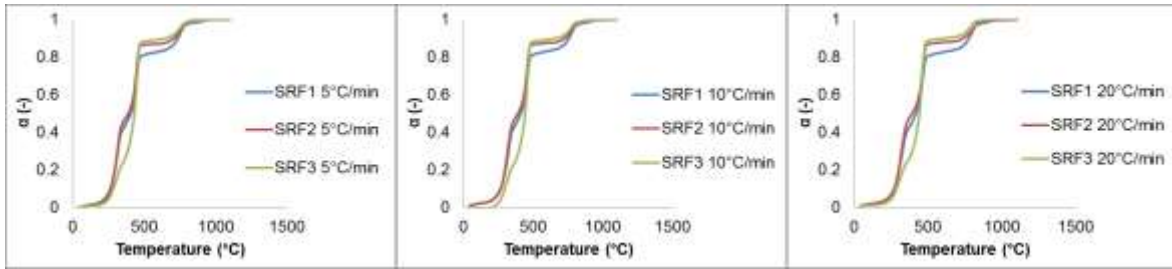


Figure 5. Degree of conversion of gasification in heating rate 5, 10 and 20 °C min<sup>-1</sup> for SRF1, SRF2 and SRF3.

In Figure 5 it can be seen the dependence of degree of conversion to temperature for three different heating rates, which had the largest increase between 190 and 470 °C from 0.1 up to 0.8 for curves of SRF 1 and up to 0.9 for curves of SRF 2 and SRF 3. In this temperature zone it can be noticed a slower conversion of SRF 3. Between 470 and 1100 °C progressively heading to 1 can be noticed.

A third thermogravimetric analysis was performed for pyrolysis and combustion conditions. Both processes were carried out from 40 °C to a temperature of 1100 °C. Heating rate was 10 °C/min. Pyrolysis was carried out in an atmosphere of Ar with flow rate of 25 ml/min. Combustion was carried out in an atmosphere of Ar with flow rate 25 ml/min and synthetic air (N<sub>2</sub>/O<sub>2</sub>) with flow rate 100 ml/min. Figures 6 and 7 show comparison of pyrolysis, combustion and their conversions for all three samples.

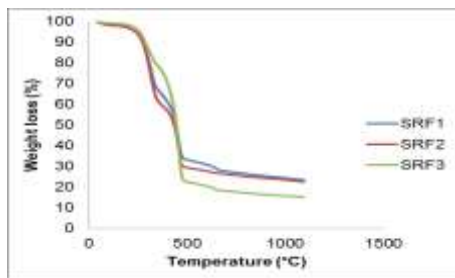


Figure 6. Comparison of pyrolysis for SRF 1, SRF 2 and SRF 3.

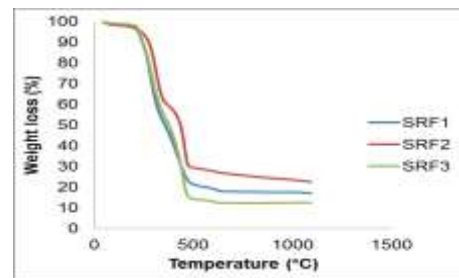


Figure 7. Comparison of combustion for SRF 1, SRF 2 and SRF 3.

As it can be seen in Figure 6 thermogravimetric analysis shows pyrolysis conducted from 40 to 1100 °C. The largest weight loss can be observed between 200 and 470 °C (from 90 to 50%), which is related with vaporization and devolatilization. Process terminates between 470 and 1100 °C. Figure 7 shows weight loss of samples during temperature growth. Between 200 and 470 °C the biggest weight loss can be observed. Between 470 and 1100 °C difference in curves can be noticed, which could be due to various percentages content of ash and fixed carbon in the samples.

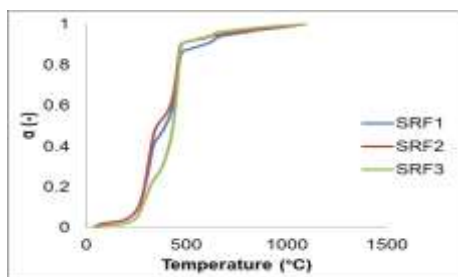


Figure 8. Comparison of conversion of pyrolysis for SRF 1, SRF 2 and SRF 3.

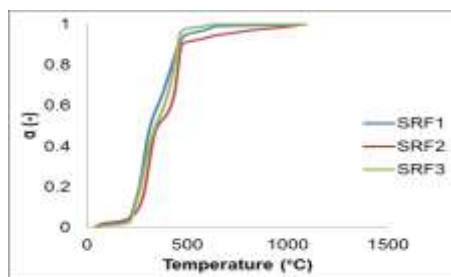


Figure 9. Comparison of conversion of combustion for SRF 1, SRF 2 and SRF 3.

In Figure 8 the growth of conversion depending on temperature could be observed. The largest increase may be observed between 200 and 470 °C. At temperature between 470 to 1100 °C conversion gradually was heading to 1. In Figure 9 curves for conversion for combustion of all samples were almost similar. Combustion process began earlier than pyrolysis process. This fact occurs because the pyrolysis was performed with absence of air or oxygen. Instead in combustion, high amount of oxygen can help and accelerate heating process. Considering the weight loss (from 70 to 35%), it is possible to verify differences between pyrolysis and combustion curves which could correspond to a faster release of volatile matter and/or a different behavior of material in combustion process. Both processes can be divided in three steps. Step 1 is drying, step 2 is devolatilization and step 3 is burnout residues.

In the figure 10 the conversion degree was compared for non-isothermal pyrolysis till assumed temperatures, gasification, pyrolysis and non-isothermal combustion in heating rate 10 °C min<sup>-1</sup> for SRF 1, SRF 2 and SRF 3.

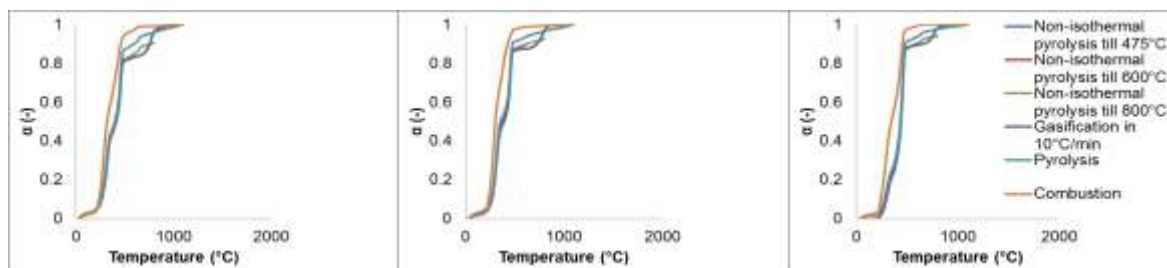


Figure 10. Comparison of conversion of all processes in heating rate 10 C min<sup>-1</sup> respectively for SRF 1, SRF 2 and SRF 3.

In Figure 10 it could be seen that all curves except non-isothermal combustion were overlapped until they reached 0.8 conversion degree. In case of pyrolysis after reaching this conversion point the different stages of pyrolysis can be distinguished. For gasification can be concluded that at the beginning of the process, pyrolysis occurred. For non-isothermal combustion for all three samples, conversion swiftly increases, which in comparison with other processes may be caused by an oxidizing agent.

Thermogravimetric analyzes show the behavior of the tested material during the individual processes under assumed parameters. They show the variable behavior of the samples which could be caused by the differences seen in proximate and ultimate analysis as well as in morphological composition.



### 5.3 Kinetic models

A kinetic model is used for better knowing behavior of the material in thermal processes and to calculate the activation energy of the material. Kinetic modeling in this work is based on the results obtained on section 5.2 and it is divided in three different processes.

Table 7. Activation energy and correlation coefficient calculated using standard isoconversional method for isothermal combustion.

	SRF 1		SRF 2		SRF 3	
	Ea (kJ/mol)	R <sup>2</sup>	Ea (kJ/mol)	R <sup>2</sup>	Ea (kJ/mol)	R <sup>2</sup>
475 °C	268.49	0.9245	282.65	0.9501	258.04	0.922
600 °C	636.41	0.9446	641.92	0.961	628.09	0.959
800 °C	717.71	0.9562	806.47	0.9529	883.59	0.959

The first process is isothermal combustion at three different temperatures. Table 9 shows activation energy and correlation coefficient. At the temperature of 475 °C the activation energy was the highest for SRF 2 and almost similar for SRF 1 and SRF 3. At the temperature 600 °C the activation energy was almost similar for all three samples. The large difference in activation energy can be observed at temperature 800 °C, The Ea for SRF 1 was 717.71 kJ/mol, for SRF 2 was 806.47 kJ/mol and for SRF 3 was 883.56 kJ/mol. For all three samples it can be possible to observe that the activation energy increases with the increase of temperature.

Table 8. Activation energy and correlation coefficient for SRF 1, SRF 2 and SRF 3 calculated using Ozawa-Flynn-Wall method for gasification.

$\alpha$ (-)	SRF 1		SRF 2		SRF 3	
	Ea (kJ/mol)	R <sup>2</sup>	Ea (kJ/mol)	R <sup>2</sup>	Ea (kJ/mol)	R <sup>2</sup>
0.1	80.83	0.9625	166.24	0.7772	62.91	0.0804
0.2	107.66	0.7147	73.55	0.9999	37.51	0.0103
0.3	73.13	0.9985	114.81	0.836	235.63	0.6239
0.4	74.03	0.9936	61.57	0.8448	268.32	0.6369
0.5	83.24	0.981	109.58	0.262	279.93	0.6645
0.6	85.32	0.9194	87.86	0.9743	409.37	0.5606
0.7	89.72	0.9223	67.84	0.9983	465.62	0.5951
0.8	73.68	0.9981	61.92	0.8852	311.27	0.6536
0.9	60.92	0.9984	61.61	0.9595	-	-

Table 10 shows activation energy and correlation coefficient for gasification. In the case of gasification at three different heating rates it is possible to see that for SRF2 the highest activation energy of the 166.24 kJ/mol can be verified in conversion 0.1. The highest value of activation energy was observed for sample SRF 3, which could be due to morphological composition as well as low correlation coefficient. At conversion points 0.6, 0.7 and 0.9, it could be observed the highest activation energy of 409.37, 465.62 and 311.27 kJ/mol, respectively. Activation energy for SRF 1 and SRF 2 were almost similar. In comparison with the results of studies of Ren et al. (2012) [27] performed on mixture of coal and plastic waste respectively 60 and 40%, the activation energy of SRF 1 and SRF 2 for the specified conversion degree was twice smaller. In studies Naskar et al. (2010) [28] carried out on mixture of bitumine/plastic blend (7% of plastic), the activation energy of SRF 1 and SRF 2 was smaller. In case of SRF 3 activation energy is larger than in Ren et al. (2012) and Naskar et al. (2010) studies.

Table 9. Activation energy, frequency factor and correlation coefficient calculated using Coats-Redfern method for pyrolysis.

	SRF 1			SRF 2			SRF 3		
	Ea (kJ/mol)	A (1/sec)	R <sup>2</sup>	Ea (kJ/mol)	A (1/sec)	R <sup>2</sup>	Ea (kJ/mol)	A (1/sec)	R <sup>2</sup>
Step 1	37.34	2.04*10 <sup>3</sup>	0.8497	34.36	8.72*10 <sup>2</sup>	0.9065	31.1	2.36*10 <sup>2</sup>	0.9376
Step 2	62.11	1.49*10 <sup>3</sup>	0.992	55.47	1.60*10 <sup>2</sup>	0.9097	60.06	1.38*10 <sup>3</sup>	0.9846
Step 3	92	1.93*10 <sup>4</sup>	0.9381	65.16	1.71*10 <sup>2</sup>	0.9065	81.68	2.67*10 <sup>3</sup>	0.9481

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Third is comparison of pyrolysis and combustion in 1100 °C. Table 11 and 12 show activation energy, frequency factor and correlation coefficient for pyrolysis and combustion, respectively. In case of pyrolysis, in step 1, activation energy was 37.34, 34.46 and 31.10 kJ/mol, respectively. The biggest

difference of activation energy could be verified in step 3, where it was 92 kJ/mol for SRF 1, 65.16 kJ/mol for SRF 2 and 81.69 kJ/mol for SRF 3. For all three samples it can be observed regularly that together with the next process step, the activation energy increases.

Table 10. Activation energy, frequency factor and correlation coefficient calculated using Coats-Redfern method for combustion.

	SRF 1			SRF 2			SRF 3		
	Ea (kJ/mol)	A (1/sec)	R <sup>2</sup>	Ea (kJ/mol)	A (1/sec)	R <sup>2</sup>	Ea (kJ/mol)	A (1/sec)	R <sup>2</sup>
Step 1	36.66	2.01*10 <sup>3</sup>	0.9082	31.78	4.27*10 <sup>2</sup>	0.9019	30	1.65*10 <sup>2</sup>	0.9388
Step 2	70.91	2.10*10 <sup>4</sup>	0.9881	70.41	1.71*10 <sup>4</sup>	0.9808	73.24	3.61*10 <sup>4</sup>	0.9795
Step 3	76.7	2.53*10 <sup>4</sup>	0.9648	74.52	2.23*10 <sup>3</sup>	0.9526	77.49	2.30*10 <sup>3</sup>	0.9494

In combustion, step 1 and step 2 were characterized by the lowest activation energy, while the highest was observed in step 3. For all three samples the activation energy in each step is almost similar. For all three samples it can be noticed regularly that together with the next process step, the activation energy increases.

## 6. Conclusion

The main aim of the study was to provide the necessary data for the modeling of the process of combustion and gasification, as well as to evaluate the usefulness of energy and influence on environment of three SRF samples taken from three waste treatment plants from Poland. According to the analysis carried out on samples SRF 1, SRF 2 and SRF 3 it can be concluded a promising usefulness of waste in energy field. Thermogravimetry analysis of tested material showed that the behavior of the pyrolysis, gasification and combustion depends on the conditions under which those analysis were conducted as well as the composition of the tested material. The activation energy calculated using kinetic models for thermogravimetric data shows that the processes that samples have been carried do not need high energy input. In future research, the analysis of exhaust gases and also the impact of waste combustion on environment should be performed to fulfill characterization of samples, which will help in the design of flue gas purification systems.

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