

Thermal destruction kinetics of coal and solid biomass mixtures

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Abstract

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Introduction. The work deals with the research on the kinetics of constituent stages of the combustion process of biomass as an individual fuel and as blends with low reactive anthracite coal from the Donetsk Coal Basin.

Materials and methods. The samples of biomass (including the wastes of agricultural and food industries) and Ukrainian from the coal Donetsk Basin were studied by means of non-isothermal TGA. Kinetic studies of the samples was carried out on the Paulik-Paulik-Erdei Q-1000 system derivatograph with the integrated complex of the synchronous data analysis of the STZ 449 Jupiter NETZSCH in the air atmosphere with the heating rate of 20 °C/min within the temperature interval 25–1000 °C.

Results and discussion. Raw data were processed and generalized within differential and integral approaches. It has been shown that the differential method of data processing has to be used coupled with the determination of current normalized values of mass change rate derivative, which presents a serious difficulty. In this respect the integral approach looks more acceptable. Comparison of approximations has been presented. It has been shown that the Coats-Redfern approximation in a form of a series does not increase the approximation accuracy if an increased number of the series members is taken into account. The appropriate range of correlations has been determined by means of the parameter $E/RT > 4$ which is valid for the dehumidification and devolatilization regions. For the processes of the coke burnout the correlation of Senum-Yang looks more appropriate.

The obtained set of kinetic constants were used with the appropriate form of the Arrhenius type differential equation and the sample mass loss thermal histories were calculated. The deviation between calculated and experimental values of the sample mass loss does not exceed 10% within a whole temperature range 0–700 K.

Conclusions. The methodology of the constituent stages distinguishing and obtained kinetic constants can be used in engineering calculations of the combustion constituent stages duration and fuel components balance as well as development of process sub models for 3-d simulations.

Introduction

The design of high-performance burners and furnaces should be based on the calculations of the current and local distribution of fuel and oxidant components, the intensity of reactions and heat generation across the device's zones. This, in turn, involves the need to determine the duration of individual stages of the combustion process, comprising in succession: dehydration, volatiles release and coke residue burnout. Thus the knowledge of the adequate values of the kinetic constants of separate stages of the overall burning process of solid fuel becomes critical in the design calculations of burners and furnaces. It should be noted that today the topics of the kinetic studies of solid fuels thermal degradation became an undisputed leader among the research in the field of thermophysics of combustion and multidisciplinary studies on the processing and preparation of solid fuels in the energy sector [1–8]. This is due to the involvement of a variety of biomass types which is used as an alternative fuel in the national energy sectors of countries, both for the purpose of substantially expanding the market of energy resources and with the need to utilize a large amount of solid household waste, waste from the agrarian and food industries [1–7]. Wide implementation of co-combustion technologies into the national power sectors renders revitalization effect on the environments, since the said technology allows a significant decrease of harmful substances release primarily into the atmosphere [10]. Knowledge of kinetic parameters becomes especially critical when designing units for co-firing of coal and solid biomass, especially for the pulverized coal combustion, since shredding biomass to the fineness of pulverized coal dust appears cost prohibitive. The technologically attainable sizes of crushed biomass typically surpass typical sizes of coal dust particles by 2–4 orders. Under these circumstances, particular attention should be paid to the proper designing of boiler furnaces and pulverized solid fuel burners to ensure the complete burnout of the coke residue of biomass.

It is obvious that the critical residence time of biomass particles will be determined by the duration of the constituent stages of the overall combustion process, which includes processes of dehydration, release and combustion of volatiles, as well as the burnout of coke residues [4, 5, 11].

Materials and methods

Experimental Materials

The samples of domestic high-ash and low-reactivity coal anthracite grade (type ASHA), pine pellets, wheat straw pellets, soy pellets, saw dust as individual fuels and their blends were investigated. The proportions of coal: biomass 50:50 and 90:10. The data of technical analysis of the studied samples are given in Table 1.

Table 1
Technical analysis of the studied samples

Fuel type	Volatiles (dry) $V^d, \%$	Ash (dry) $A^d, \%$	Moisture $W^r, \%$
Pine Saw Dust 1	82,93	2,90	8,30
Pine Saw Dust 2	83,06	0,90	10,00
Wheat Straw Crushed Pellets	74,52	8,90	9,20
Rape Crushed Pellets	73,08	11,20	9,60
Corn Crushed Pellets	70,55	15,00	10,60
Soy Crushed Pellets	73,82	11,80	11,40
Anthracite Coal (ASHA grade Rus.)	4,690	29,68	1,15

Experimental setup

Kinetic studies of the samples were carried out on the Paulik-Paulik-Erdey Q-1000 system derivatograph with the integrated complex of the synchronous data analysis of the STZ 449 Jupiter NETZSCH in the air atmosphere with the heating rate of 20⁰ C/min. in the temperature range 25–1000 °C.

Primary experimental data were obtained in the form of spread sheets, as well as in graphic form. The thermograms of ASH coal and milled pine pellets are shown in Figure 1 and 2. Apparently, the initial data include the curves of the current mass, temperature, mass change rate (the first derivative $dm(\tau)/d\tau$) and the rate of mass derivative change (second derivative of mass change in time during the experiment).

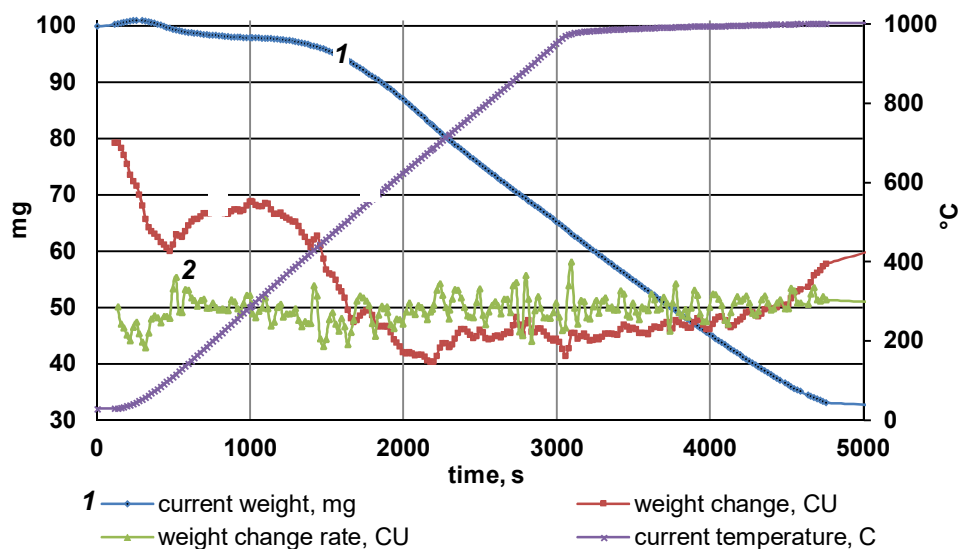


Figure 1. Derivatogravitogram of anthracite coal thermal destruction

The given in Figures 1 and 2 data for two fuels with critically different physical properties have qualitatively similar thermogravitograms which, however, differ considerably. So, assuming that the constituent stages of the general process of thermal destruction (dehydration, volatile yield, coke-coal residue burning) are described by the Arrhenius equation according to the model of the first reaction order, then one should expect a sort of conformity between the sample mass change in time and the character of its derivative [3, 11]. This implies that, if the process can be described by the exponential function and the degree of conversion of a particular component ranges from 0 to 1, then the change of the normalized derivative should be from zero through the local minimum and then back to zero value. The said would hold true if the process has finished completely. If the process is being superseded by the next one, then the derivative of the mass change whilst approaching zero value would not reach it.

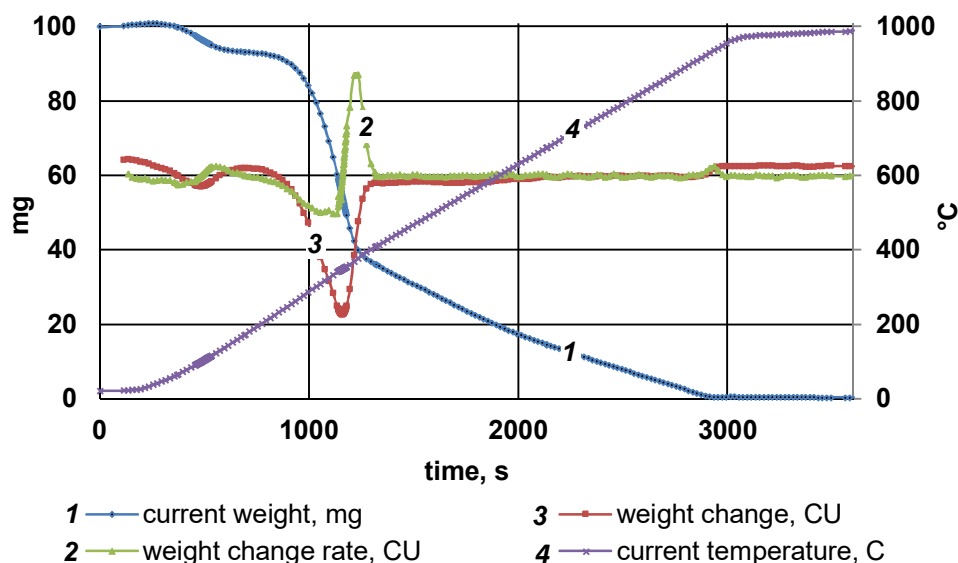


Figure 2. Derivatogravigram of thermal destruction of pine pellet

This can be clearly seen in Figure 2, line 3 which shows two negative local extremums associated with the two consecutive processes – demoisturization and volatiles release. It should be marked that the derivative line 3 whilst coming back to zero value, nonetheless does not reach it, which signifies overlapping these processes.

In fact, this circumstance is clearly observed for processes only in case of coal biomass mixtures. For anthracite, it seems possible to identify as a complete process only the stage of moisture release, since the first derivative curve clearly shows the trend marked above, Figure 1. Unfortunately, the boundary between the stages of volatile yield and the burnout of the coke residue for anthracite cannot be determined at all, since there is neither a change in the mass time change curve, nor a change in the derivative curve past 2000 s (600 °C) can be traced, (see Figure 1). Proceeding from the above, a number of foreign authors tried to analyze the entire process of thermal destruction of coal in the range 200 ÷ 800 °C, as is done in [12], or to correct the constants by choosing the various orders of the reaction, as model fitting methods in [5, 6]. However, the authors [12] provide kinetic equations in two temperature ranges, which indirectly indicate the presence of two distinct processes, and in [4] the whole destruction zone is divided into the region of pyrolysis and the actual burning of coke. This approach was accompanied with the introduction of very complex reaction models. For the pyrolytic region, the authors [4] proposed four separate reactions of the yield of volatile components and two separate reactions for the coke residue burning zone along with the two separate reactions for the oxidation medium.

Initial data of the dewatering process for anthracite, pine pellets and their mixtures are shown in Figure 3.

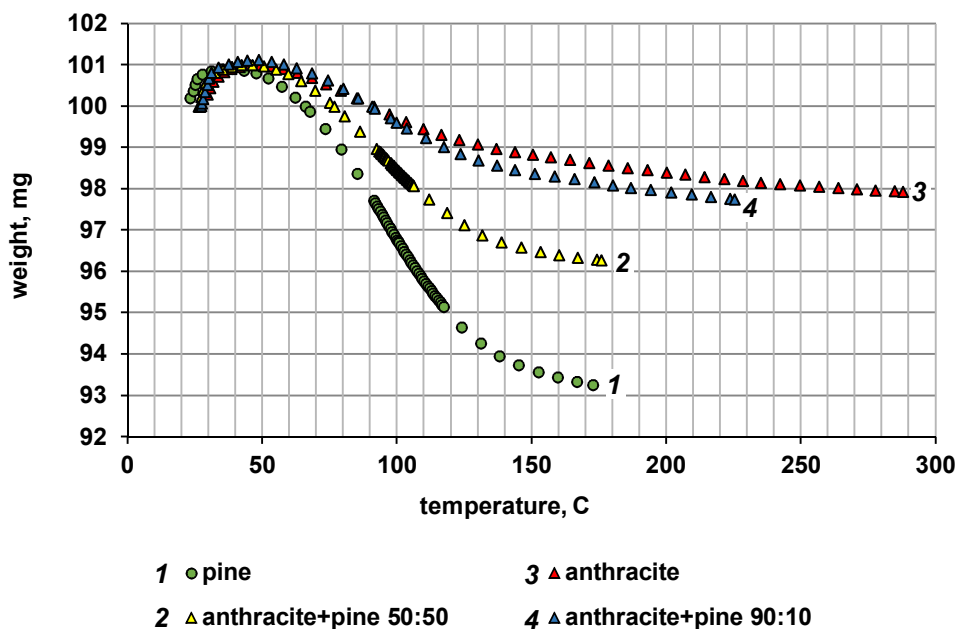


Figure 3. Gravigrams of sample mass change in time at a heating rate 20⁰ C/min

For the stage of dewatering, the gravigrams for the significantly different types of fuel vary quantitatively, although they have similar character. For both individual fuels, an initial mass increase is observed, which is explained by the absorption of moisture from air, followed by a decrease in the mass of the sample, the rate of which gradually reaches the maximum, and then – decreases. The mixtures of two heterogeneous fuels show an intermediate nature, shifting towards anthracite as its share in the mixture grows. The comparison of gravigrams and derivatiograms for anthracite and pine pellets is shown in Figure 4 and 5. The given data are obtained under similar conditions in an oxidizing medium at a constant sample heating rate of 20 °C/min. As can be seen from Figure 4, the curve of the derivative of weight change, normalized to the interval from 0 to -1, is characteristic of the derivative of the exponential function, but does not reach the 0-th value at the end of the process, having a specific negative value that testifies to the further progress of the sample mass loss. This may be attributed to the parallel development of the next process which would be the stage of devolatilization.

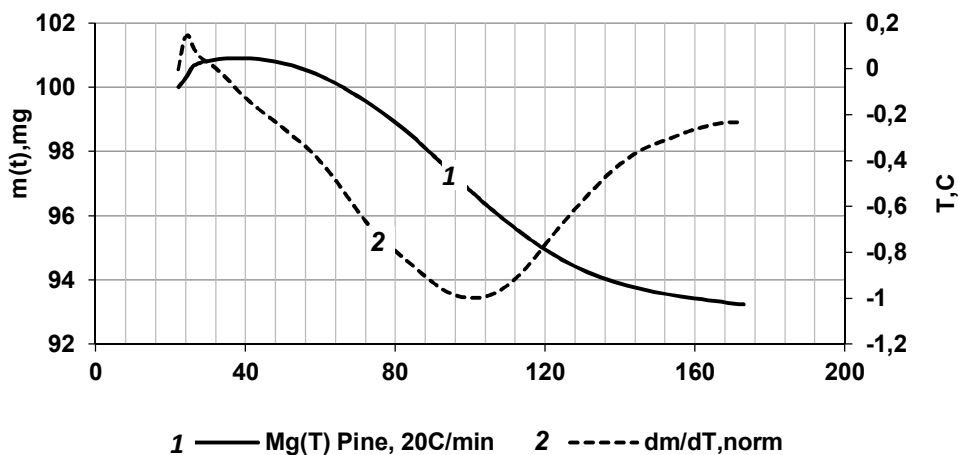


Figure 4. Thermogravigram and Derivatogram of moisture release at thermal destruction of pine pellets

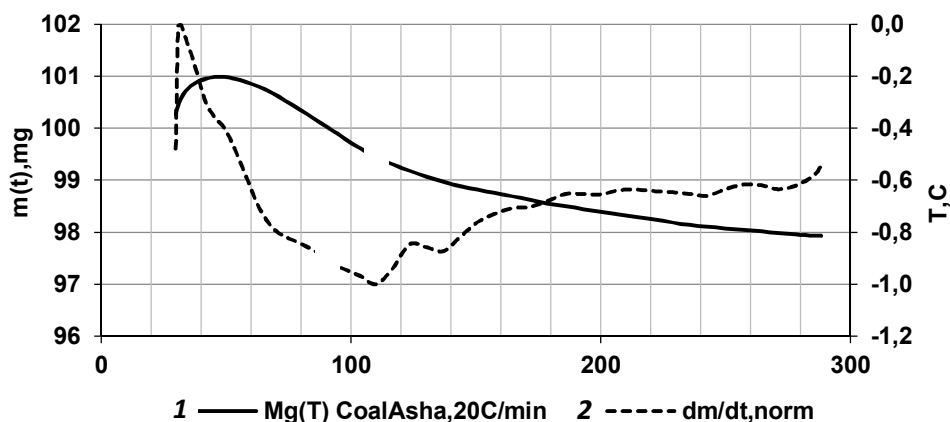


Figure 5. Thermogravigram and Derivatogram of moisture release at thermal destruction of anthracite coal (ASH)

It is quite probable that such a change in the da/dt curve may be attributed to the beginning of the coke burout. It is worth noticing, that even a slight share of highly volatile biomass in the mixture causes a noticeable change in the gravitograms and derivatograms profile. In Figure 7, all derivatograms have clear minimal values positioned within a temperature range of 340–350° C. It is also evident that the lower the share of biomass in mixture, the closer the curve approaches “0”, which signifies that preceding process practically approaches its end with the complete exhausting volatiles. Only after this, the coke burnout starts, which is being proven by the following mass loss of samples.

According to the analysis of the primary experimental data the following conclusions may be drawn up:

- the derivatograms and gravitograms of anthracite, biomass and their mixtures differ significantly; for the process of moisture release the curves for all substances retain a

- similar trend with a characteristic minimum of derivatograms, after which the da/dt curve approaches the 0 value, which signifies exhaustion of moisture in a sample;
- for all samples of individual fuels and their mixtures the completion of dehydration process coincides with the beginning of the following process of devolatilization, which is proven by the residual values of da/dt not equal to 0;
 - the process of volatiles release for biomass and mixtures retain certain similarities insofar all derivatograms show local minimum, after which the derivatives approach zero, which signifies the completion of the process. For anthracite samples no such trends have been marked, since the derivatogram does not show any marked extremum within a whole range 350–1000 °C;
 - the gravitograms and derivatograms of anthracite coal thermal destruction do not allow to identify and separate the processes of volatiles release and coke burnout.

Data analysis and processing

Modern TGA and DTG methods coupled with the application of infrared spectroscopy and differential calorimetry are widely used in almost all physical and technical branches of science [1–3, 10–14], the substances ranged from food products, polymers and solid household wastes, biofuels and fossil fuels were analyzed with these methods. Such diversity caused the need for the development of perfect methods of processing and generalization of experimental data [3, 5, 11, 13–15]. Following [11, 14], it is possible to provide the following classification of analysis methods (see Table 2).

Table 2

Main methods of kinetic constants determination [1,12]

Model Methods		Model Free Methods	
Isothermal	Dynamic	Isothermal	Dynamic
Standard	Differential: Freeman-Carrol Coats-Redfern	Friedmann	Kissinger-Akahira-Sunose Flinn-Wall-Ozawa

The advantage of a non-isothermal (dynamic) method is that a single non-isothermal thermogravimetric experiment allows obtaining a set of data related to the sample mass loss as a result of its heating, which in turn, allow calculating the kinetic constants of a process, and thus replaces the receipt and processing of a series of isothermal curves. We used non-isothermal methods of TG analysis for the study of kinetic characteristics of processes of thermal degradation of fuels, including dehydration and volatile yield and coke residue burnout. The dynamic TG analysis is applied with further processing of experimental data by means of one of the following: differential, integral and isoconversional [3,14] methods. The change in the mass of a solid in a certain process can be mathematically described by one equation, using physical constants and corresponding model functions [2, 3, 11]:

$$\frac{dm(\tau)}{d\tau} = -k \cdot f(m(\tau)) \quad (1)$$

where: $\frac{dm(\tau)}{d\tau}$ - the current at the time of mass of a certain component in the experimental sample; k – constant of the reaction rate; $f(m(\tau))$ – a function that describes a particular reaction model.

The degree of conversion is determined on the basis of taking into account the change in the mass of a sample at the beginning of the process, at the end of the process and at the time (τ):

$$\alpha = (m_0 - m_\tau) / (m_0 - m_\infty), \quad (2)$$

where: m_0 - the initial mass of the sample; m_∞ - sample mass at the end of the process under consideration; m_τ - sample mass at (τ).

It should be borne in mind that the term "conversion" in this case applies exclusively to the process under consideration. That is, in the case of considering the process of moisture release when the particle is heated, it is about the conversion of moisture, while in considering the process of release of volatile – this will mean the conversion of the combustible mass of the sample with the release of combustible gases. The corresponding quantities in (2) relate solely to a particular process. In this case, the difference in the denominator of formula (2) is determined by the value of that component of the fuel involved in the transformation. Obviously, for example for moisture release, it is critical to determine precisely the time of the process beginning, along with precise values of respective masses of components, process completion and the start of the next (release of volatile) process and, accordingly, determining the mass balance of the next reacting component. For dehydration completion, for example, this is the point where the second derivative of the mass change function passes through a zero value in the range 170–200 °C, changing the sign from "+" to "-", that is, where the local reaction rate becomes the minimum value, but would not reach zero precisely, since the final stages of demineralization coincide with the beginning of the next process. The constant of the reaction rate is given in the form of the Arrhenius equation:

$$k = A \cdot \exp(-E / RT)$$

where: A – the pre-exponential multiplier, 1/s; E – activation energy, J/mol; R – universal gas constant – 8,314 J/(mol·K); T – temperature, K.

Taking into account the Arrhenius equation and (2), equation (1) acquires the form:

$$\frac{d\alpha}{d\tau} = A \cdot \exp(-E / RT) \cdot f(\alpha). \quad (3)$$

A detailed analysis of the methods for applying the equation (2) for processing the experimental data of the TG analysis and the analysis of reaction models is given in [1,3,4,11,12],

When the sample is heated at a constant rate, the dependence of temperature change over time:

$$T = \beta \cdot \tau + C, \quad (4)$$

where β is the heating rate.

Combining (3) and (4) and adopting the first-order reaction model, we obtain

$$\frac{d\alpha}{dT} = -\frac{A}{\beta} \cdot \exp\left(\frac{-E}{RT}\right) \cdot (1 - \alpha), \quad (5)$$

or, after logarithm:

$$\ln\left(\frac{\beta}{1 - \alpha} \frac{d\alpha}{dT}\right) = -\frac{E}{RT} + \ln A. \quad (6)$$

Equation (6) forms the methodological basis of the differential approach to the kinetic constants determination on the basis of thermogravimetric studies and is the basis of the well-known Friedmann method [9, 14].

Despite its apparent simplicity, the Friedmann method has significant drawbacks related to the need of determining the left side of (6) by the values of current conversion rates and the derivative of the time-varying mass change function. As stated above, the definition of the current conversion rate requires not only the measurement of the current sample mass, but also the determination of the initial content of the component and its total content in the mixture. In many cases gravitograms show initial increase in mass associated with the absorption of moisture when biomass is heated. Moreover, it is often impossible to determine exactly the content of the target component at the end of the process insofar the final stage of the process coincides with the beginning of the consecutive one. The next critical point of this methodology is also the need to scale the value of the derivative $\frac{d\alpha}{dT}$, based on the actual mass loss curve, which becomes extremely complex due to the above mentioned.

In accordance with the integral approach, which has become widespread [7, 9, 14] in recent years, equations (6) is being integrated

$$\beta \int_0^\alpha \frac{d\alpha}{1-\alpha} = \beta \cdot \ln(1-\alpha) = -A \int_0^T \exp\left(-\frac{E}{RT}\right) dT. \quad (7)$$

Since the expression on the right side (7) does not integrate analytically, a large number of expressions are proposed for obtaining acceptable approximations, usually in the form of series or rational fractions [6, 10–12, 15]. In [11] it is proposed to apply the method of integration by parts. Having introduced a new variable $x = \frac{E}{RT}$, one obtains.

$g(\alpha) = -\frac{AE}{\beta R} \int_\infty^x \frac{\exp(-x)}{x^2} dx$. Let us analyze the function $p(x) = \int_\infty^x \frac{\exp(-x)}{x^2} dx$ which we then integrate by parts several times:

$$\begin{aligned} \int_\infty^x \frac{\exp(-x)}{x^2} dx &= \frac{e^{-x}}{x^2} - \int_\infty^x \frac{2e^{-x}}{x^2} dx, \\ \int_\infty^x \frac{2e^{-x}}{x^3} dx &= \frac{-2e^{-x}}{x^3} + \int_\infty^x \frac{6e^{-x}}{x^4} dx, \\ \int_\infty^x \frac{6e^{-x}}{x^4} dx &= \frac{6e^{-x}}{x^4} - \int_\infty^x \frac{6 \cdot 4e^{-x}}{x^5} dx, \end{aligned}$$

or in general:

$$p(x) = \frac{e^{-x}}{x^2} \left(1 - \frac{2}{x} + \frac{6}{x^2} - \frac{24}{x^3} + \dots + (-1)^{n-1} \frac{n!}{x^{n-1}} \right)$$

Having taken two members of the series, one obtains the well-known approximation of Coats-Redfern [7], which leads to the following:

$$\ln \left[\frac{-\ln(1-\alpha) \cdot \beta}{T^2 \left(1 - \frac{2RT}{E} \right)} \right] = \ln \left(\frac{AR}{E} \right) - \frac{E}{R} \frac{1}{T}. \quad (8)$$

Using n-members of the series leads to the general form of equation:

$$\ln \left[\frac{-\ln(1-\alpha) \cdot \beta}{T^2 \left(1 + \sum_2^n (-1)^{n-1} \frac{n!}{x^{n-1}} \right)} \right] = \ln \left(\frac{AR}{E} \right) - \frac{E}{R} \frac{1}{T}. \quad (9)$$

The equations (9) and (10) allow determining of the kinetic characteristics based on the results of TG experiments using only the current mass loss data, without resorting to the complicated determination of the mass change derivatives over time.

Recently, a number of the Arrhenius temperature integral approximations have been proposed on the basis of polynomial fractions [6, 13, 15]. The most promising appears the Senum – Yang approximation [11]:

$$p(x) = \frac{e^{-x}}{x^2} \left(\frac{x^4 + 18x^3 + 86x^2 + 96x}{x^4 + 20x^3 + 120x^2 + 240x + 120} \right), \quad (10)$$

Having introduced (10) into (7), one obtains

$$\ln \left[\frac{-\ln(1-\alpha) \cdot \beta}{T^2 \frac{x^4 + 18x^3 + 86x^2 + 96x}{x^4 + 20x^3 + 120x^2 + 240x + 120}} \right] = \ln \left(\frac{AR}{E} \right) - \frac{E}{R} \frac{1}{T}. \quad (11)$$

Thus, in general the determination of kinetic constants by either integral or differential methods consists in analyzing correlations in the form $Y=f(1/T)$. Where Y is taken equal:

$$\ln \left(\frac{1}{1-\alpha} \frac{d\alpha}{dT} \right), \ln \left(\frac{\beta}{T_{\max}^2} \right) \text{ or right hand side of (8), (9), (11). Experimental data would be}$$

approximated by linear function of $1/T$ with the slope of $\frac{E}{R}$ and an intercept – a function of the frequency factor. Since the correction multipliers in the denominators of (9) and (11) are the functions of the sought values E and A , the application of (9) and (11) can be utilized through the iterative approach, whereas at first one assumes the values of correction functions in (9,11) equal unity and determines respective values E_1 and A_1 , which then are to be used for determination of correction multipliers for equations (9) or (11) and further allow to determine the new paired values of E_2 and A_2 . The procedure may be repeated until the stated precision has been reached.

Results and discussion

Data Generalization

The primary data of the derivatograms were processed according to the differential method which allowed determining the temperature ranges and mass loss of the individual stages of samples thermal degradation (Table 3).

Table 3
Temperature ranges and mass loss of individual stages of thermal decomposition of biomass samples

Fuel	Thermal Destruction Stage								
	Dehumidification			Volatiles Release			Coke Burnout		
	Range, °C	Maximum, °C	Mass Loss, %	Range, °C	Maximum, °C	Mass Loss, %	Range, °C	Maximum, °C	Mass Loss, %
Pine Saw Dust 1	27–120	65	7,20	120–416	301	79,80	416–697	n/a	13,00
Pine Saw Dust 2	32–136	56	6,80	136–404	307	77,20	404–610	n/a	16,00
Wheat Straw Pellets	24–187	100	6,18	187–440	290	62,60	440–920	n/a	31,19
Rape Pellets	23–194	103	9,54	194–418	303	57,98	418–872	n/a	32,32
Corn Pellets	24–186	99	9,44	186–416	281	58,02	416–940	n/a	32,51
Soy Pellets	23–161	98	9,23	161–404	294	56,79	404–898	n/a	33,89

As can be seen from the data in Table 3, the coke-ash residue burnout stage reaches a temperature of 1000 °C. For moderate values of the variable x in (9–11), for which the temperature integral was approximated, may decrease to 3–3.5. Since the accuracy of the approximation of the temperature integral (7) depends on the value of the variable and decreases when the values are lower than 5–6, it is necessary to estimate the approximation error and the applicability of the Coates-Redfern method for data processing for the kinetics of burning of the coke residue, that is, at the temperature range greater 600–800 °C. To evaluate the accuracy of the approximation, the integral (7) was calculated numerically in Mathcad and compared with the calculated approximation values. In addition, the 1st, 2nd and 3rd members of the series (10) were taken into account successively. The proposed Senum and Yang equation (13) is also calculated. Comparison of results in the form of the dependence of the relative error module on the parameter x are shown in Figure 6.

As it can be seen from the above, the accuracy of the temperature integral approximation by the series derived above sharply drops down when x lowers below 5. Moreover, since the series is a sign changing one, the accuracy of the approximation does not increase when the number of series members taken into account increases. At the same time the accuracy of the Senum-Yang approximation appears the most reliable even within the range of x lesser than 5.

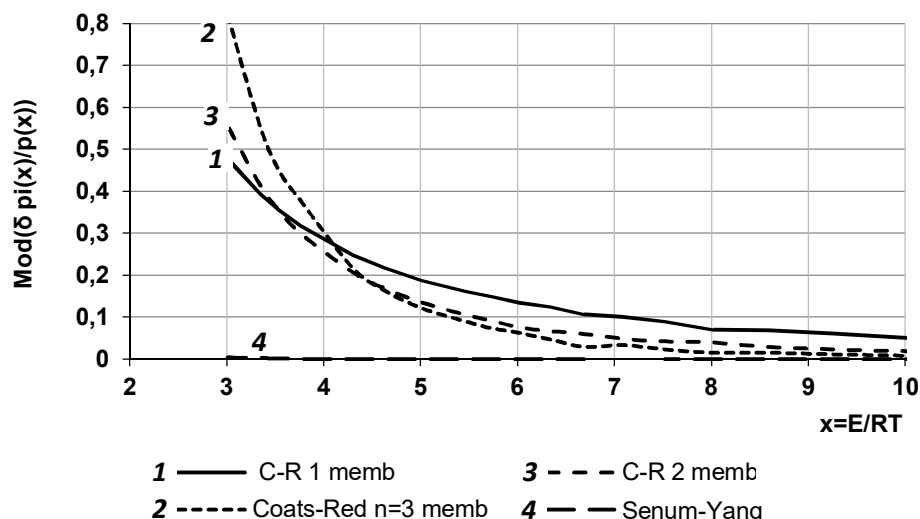


Figure 6. Module of Relative Error of Temperature Integral Series Approximation depending on the number of series members

The character of curves substantiates mentioned above. The divergence between the curves becomes apparent in the region of $1/T$ lower than 0.0012, which corresponds to the values of x (Figure 6) lesser than 5. At the same time, when approximating data within the lower temperature range, it would be expedient to use the Coats-Redfern method as it is simpler. It should be mentioned specifically that despite a noticeable difference in the values of the apparent activation energies, found from data in Figure 7, the respective values of the frequency factor would render the opposite effect, when used in the Arrhenius equation (3) for the calculations of the degree of conversion rate.

Our experimental data processed as shown above by the successive approximations method are presented on Figure 7.

Figure 8 shows a series of data for the dewatering stage for anthracite coal grade, crushed pine pellets and their mixtures. As it is clearly seen, the lines that approximate data for mixtures are localized between such for individual fuels, which is quite natural. Coupled kinetic constants are easily derived from the equations presented in Figure 8. It should be pointed out that all experimental data tend to diverge from the straight lines, which proves that the complex processes of dehumidification, volatiles release and coke burnout can hardly be depicted by the first order reactions. Despite marked above divergence, the determined kinetic constants, being used in calculations by (3) the degree of conversion rate and the history of sample thermal degradation at heating, show their reliability. The results of Mathcad calculations of mass loss curves of heated samples are shown in Figure 9.

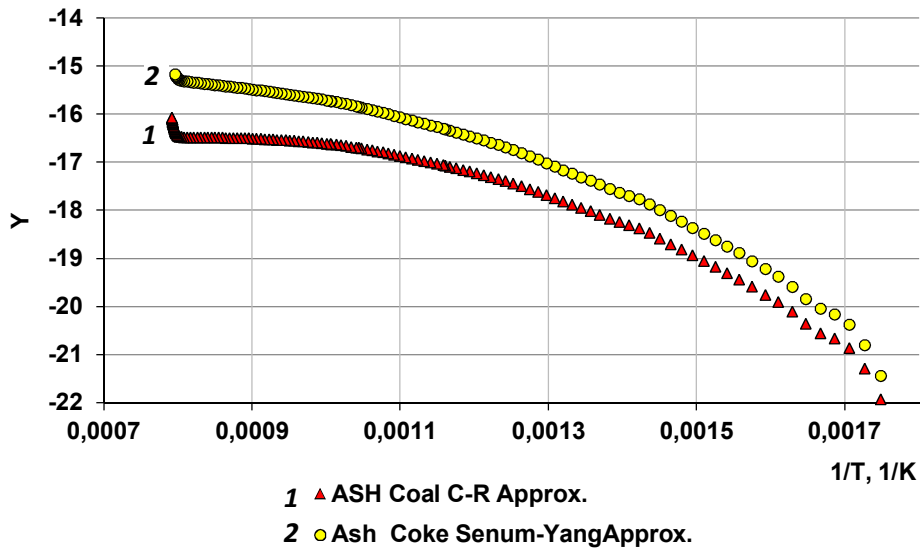


Figure 7. Comparison of data approximated by Coats-Redfern and Senum-Yang methods. Anthracite, coke burnout

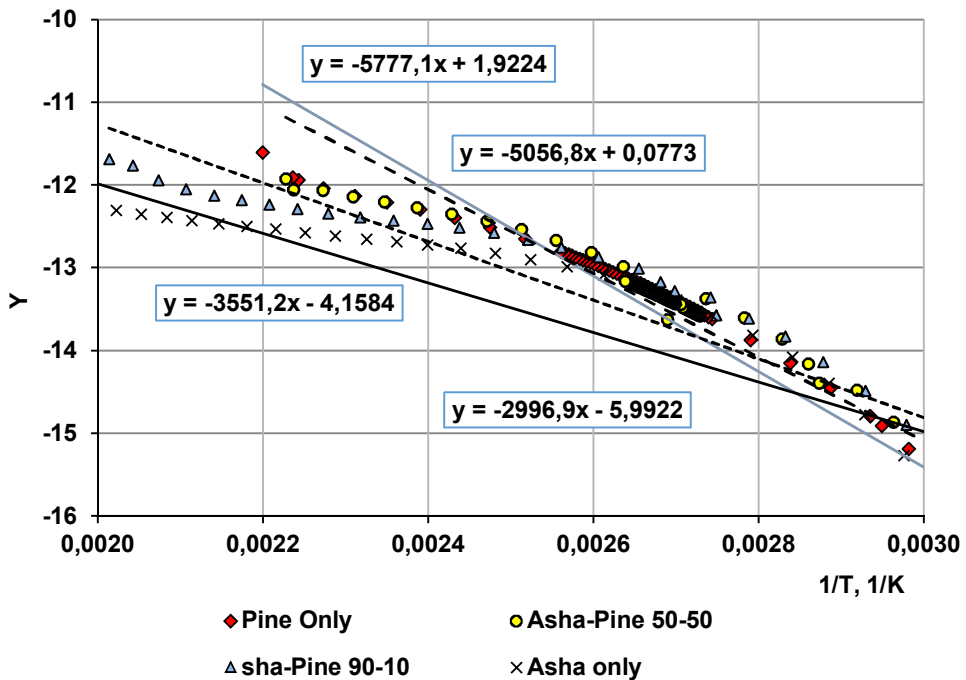


Figure 8. Correlation of Coats-Redfern parameter $Y = f(1/T)$

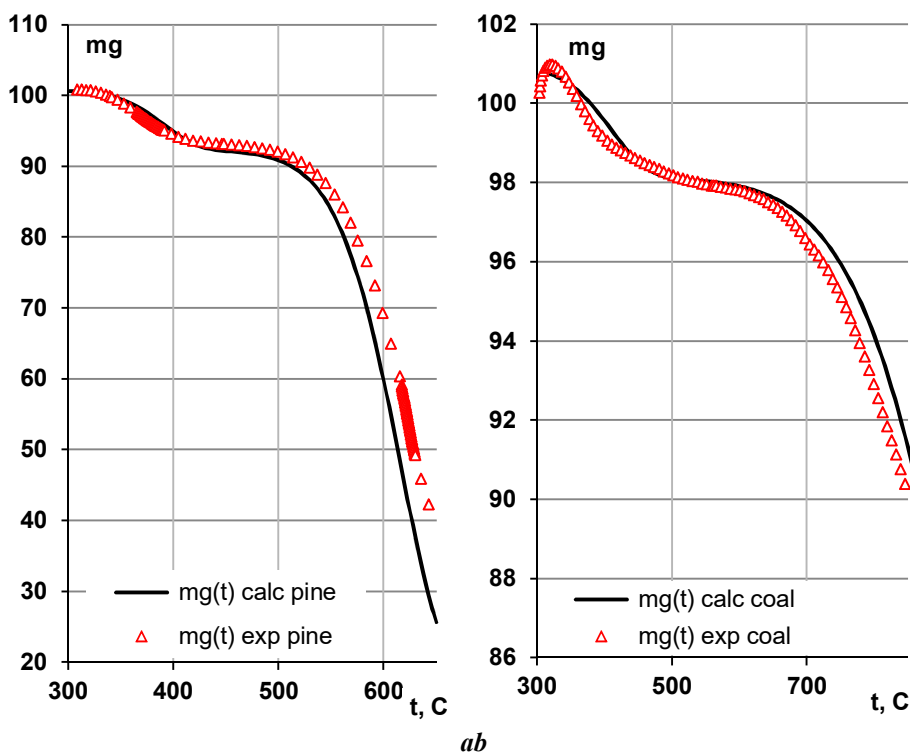


Figure 9. Sample mass loss at thermal destruction curves:
a – pine pellets; b – ASH coal

A system of differential equations $\frac{d\alpha_i}{dT} = \frac{A_i}{\beta} \exp\left(-\frac{E_i}{RT}\right) \cdot (1 - \alpha_i)$ has been solved according to the experimental conditions for dehumidification and devolatilization stages with further determination of current in temperature mass loss curve. As it may be seen, the obtained kinetic constants allow for the calculations of data in close correspondence with experimental data. The obtained kinetic constants are presented in Tables 4 and 5.

Table 4
Kinetic constants for the dehumidification stage (Coal ASH, biomass and mixtures)

Fuel	Frequency Fact., 1/s	Activ. Energy, J/(mol·K)	Temp. Range, °C
ASH Coal	7,432	24917,06	61,6-288,0
Pine Pellet	39483,565	48030,26	46,1-172,9
Straw Pellets	2848,674	40735,27	66,1-166,2
Mix. ASH Pin50/50	5465,239	42043,06	46,8-176,1
Mix. ASH Pin90/10	56,4754	29531,06	50,9-225,5
Mix. ASH Straw90/10	7652,619	45699,56	82,3-185,7

Table 3

Devolatilisation kinetics of ASH coal, biomass and their mixtures

Fuel	Frequency Fact., 1/s	Activ. Energy, J/(mol·K)	Temp. Range, °C
Pine Pellet	20833,67	76562,79	172,9-411,2
Straw Pellets	5,861945	36527,56	166,2-407,6
Mix. ASH Pin50/50	27603,07	76559,47	176,1-407,1
Mix. ASH Pin90/10	267478,2	89092,82	225,5-400,6
Mix.ASH_Straw90/10	34136,62	75422,95	185,7-379,9

Conclusions

Detailed investigations of the kinetics of individual stages of solid fuel (coal of the anthracite grade and certain types of solid biomass) thermal destruction have been carried out.

It has been established that the Coats-Redfern method can be used to determine the kinetic constants of the process of dehumidification and volatile release during thermal decomposition of biomass, coal and their mixtures.

It is shown that for the high-temperature processes (burning of the coke residue) a combined method Coats-Redfern and Senum-Yang of iterative approximation should be used.

The obtained kinetic constants allow enough precise calculations of mass loss history of the studied fuels in the determining of the duration of their thermal destruction stages.

The resulting constants can be used in calculations of burners and furnaces.

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