

Iliyana NAYDENOVA<sup>1</sup>, Ognyan SANDOV<sup>2</sup>

## Shrinking characteristics of a single biomass particle in oxidation conditions

**ABSTRACT:** In the context of the Net Zero Emission, using of biomass of different origins is assumed to be an acceptable alternative to fossil fuel thermo-chemical conversion for power generation or goods production. Biomass combustion is characterised by heterogeneous kinetics, where the oxidised substance is in a solid state. The reaction takes place primarily along the surface separating the two phases. The rate of combustion can be expressed by the amount of reacted substance per unit surface area or, alternatively, by the diameter or mass loss profile. The present investigation aimed to study shrinking characteristics during single particle combustion of spherically shaped solid (softwood) particles. The experiment was conducted in a laboratory scale Horizontal Tube Furnace (HTF) type reactor. The initial and resulting particle mass and diameter were experimentally measured, based on which the fuel particle density, surface, and volume were estimated for each biomass particles. The dimensional evolution of the fuel particle was investigated in terms of the effect of temperature and residence time of the fuel particles in the reaction zone. The experiments were carried out at atmospheric pressure, constant air flow rate, and at two different temperatures (700 and 800°C). The particle shrinkage improved with increasing the residence

---

✉ Corresponding Author: Iliyana Naydenova; e-mail: [inaydenova@tu-sofia.bg](mailto:inaydenova@tu-sofia.bg)

<sup>1</sup> Technical College – Sofia, Department of Energy and Mechanical Engineering, Technical University of Sofia, Bulgaria; ORCID iD: 0000-0001-7174-1971; e-mail: [inaydenova@tu-sofia.bg](mailto:inaydenova@tu-sofia.bg)

<sup>2</sup> Technical College – Sofia, Department of Energy and Mechanical Engineering, Technical University of Sofia, Bulgaria; e-mail: [o.sandov@tu-sofia.bg](mailto:o.sandov@tu-sofia.bg)



© 2024. The Author(s). This is an open-access article distributed under the terms of the Creative Commons Attribution-ShareAlike International License (CC BY-SA 4.0, <http://creativecommons.org/licenses/by-sa/4.0/>), which permits use, distribution, and reproduction in any medium, provided that the Article is properly cited.

time, until the process reached its final stage of residual combustion. The studied temperature range showed faint but distinct temperature dependence.

KEYWORDS: biomass conversion, single particle combustion, solid biofuel particle shrinking

## Introduction

In the context of the Net Zero Emission Roadmap (Net Zero Roadmap 2023) the utilisation of biomass is assumed to be an acceptable alternative to the fossil fuel thermo-chemical conversion (Iontchev et al. 2020; Ivanov et al. 2022; Kostov et al. 2022; Kostov 2023). Although scarcely implemented due to numerous techno economic problems, in case of large availability, woody biomass is utilised in different industrial conversion processes. The available technical equipment generally uses fuel particles sized on the centimeter-scale (Caposciutti et al. 2019).

During the combustion process fuel particles are rapidly pyrolysed to coke/char and other volatile organic compounds. Their fast ignition and combustion are carried out in the gaseous phase, while the char particles' combustion is characterised by the slower complex process that involves homogeneous and heterogeneous kinetics and transport phenomena (Lackner 2004; Sadukhan et al. 2010; Pereira and Costa 2017). The reaction takes place primarily along the surface separating the two phases, and the burning rate can be expressed in terms of the amount of reacted substance per unit surface area (Oberberger et al. 2006). The combustion of the residual char provides a significant part of the energy compared to the combustion of volatile matter, but the heterogeneous reactions are much-slower than the homogeneous ones, thus it often is assumed to be the rate limiting stage (Lackner 2004). According to (Caposciutti et al. 2019), the biofuel characteristics are of crucial importance for the choice of parameters providing control of the combustion process, such as the air excess and displacement, as well as for controlling the combustion stages, the emissions, and the boilers' thermal behaviour. On the other hand, to mathematically describe the course of the non-catalytic reaction of the particles with the surrounding medium, semi-empirical models are often adopted, such as the progressive conversion model, shrinking-core model, and particle shrinkage model (Levenspiel 1998). The required prerequisite for adopting such models is the experimental examination of key physical parameters that characterise the particle shrinking behaviour during single particle thermo-chemical decomposition of solid biofuels. Therefore, studying the single particle biomass dimensional evolution during a conversion process is essential for the process control and the development of models capable of accurately predicting emissions (Caposciutti et al. 2019; Bryden and Hage 2003; Davidsson and Pettersson 2002; Kwiatkowski et al. 2014). Furthermore, in terms of reactor design and optimization, both size distribution and particle size are important parameters to be considered (Caposciutti et al. 2019).

In the present study, shrinking characteristics of spherically shaped solid biofuel (softwood) particles were experimentally measured in the case of single fuel particle oxidation in a labo-

ratory scale Horizontal Tube Furnace (HTF) type reactor. The initial and resulting shrinking characteristics, such as: mass and diameter were experimentally measured for each of the investigated biomass samples. The results were used to estimate the fuel particles' density, surface, and volume. The effects of temperature and particle residence time in the reaction zone were investigated. The observations confirmed that the larger residence time led to greater particle conversion and shrinking, but negligible temperature dependence was obtained at the considered temperature range.

## 1. Biomass chemical composition

In the present work spherically shaped particles of softwood were oxidised at the HTF, in air. The biomass chemical composition was obtained through proximate (БДС EN ISO 18134-2:2024; БДС EN ISO 18122:2023; БДС EN ISO 18123:2023), ultimate (БДС EN ISO 16948:2015; ETC 7.3-4:2014), ash (EN ISO 16968:2015) and calorimetric (EN ISO 14918:2009) analysis. The results were listed in Table 1. The currently obtained results corresponded well with the literature data of a large number of biomass types of animal and plant origin (Vassilev et al. 2010) as well as with those reported by (Brezin et al. 2013; Vassilev et al. 2013a, 2013b; Bai et al. 2017).

TABLE 1. Biomass chemical composition and higher heating value (HHV)

TABELA 1. Skład chemiczny biomasy i wyższa wartość opałowa (HHV)

No.	Parameter	This work	Vassilev et al. 2010	Parameter*	This work	Vassilev et al. 2010
1	Moisture [wt. %] (a)	7.0	3–63	CaO	33.3	1–83
2	Ash [wt. %] (db)	0.65	0.1–46	MgO	7.4	0.2–16
3	Volatiles [wt.] (db)	78.8	48–86	Na <sub>2</sub> O	1	0.1–30
4	Fixed carbon [wt.%] (by difference)	13.65	1–38	K <sub>2</sub> O	15.8	0.2–64
5	Carbon [wt. %] (daf)	47.8	42–71	TiO <sub>2</sub>	0.3	0.01–28
6	Hydrogen [wt. %] (daf)	6.4	3–11	SrO	0.01	–
7	Sulfur [wt. %] (daf)	0.02	0.01–2.3	Fe <sub>2</sub> O <sub>3</sub>	0.3	0.2–36
8	Nitrogen [wt. %] (daf)	0.13	0.1–12	Al <sub>2</sub> O <sub>3</sub>	0.2	0.1–54
9	Oxygen [wt. %] (by difference)	38	0.01–0.9	SiO <sub>2</sub>	2.7	1.44–64.08
10	HHV [kJ/kg]	19,300	15,000–25,000	P <sub>2</sub> O <sub>5</sub>	5.8	0.2–41

as – as received.

db – dry basis.

daf – dry ash free basis.

\* normalised to 100 wt% ash analysis.

According to (Ahmad et al. 2020) the typically measured chemical compositions in terms of cellulose, hemicellulose, and lignin content vary, as follows: 40–44 wt. %; 30–32 wt. % and 25–32 wt. %, respectively, as well as the typical organic extractives are usually about 5 wt. %.

## 2. Experimental setup

The oxidation of the spherically shaped single fuel particles was carried out in the laboratory scaled tubular reactor – HTF. Its general characteristics are described elsewhere (Sandov 2019; Sandov et al. 2021, 2022). Schematic interpretation of the experimental set-up, used in the present study, is presented in Figure 1.

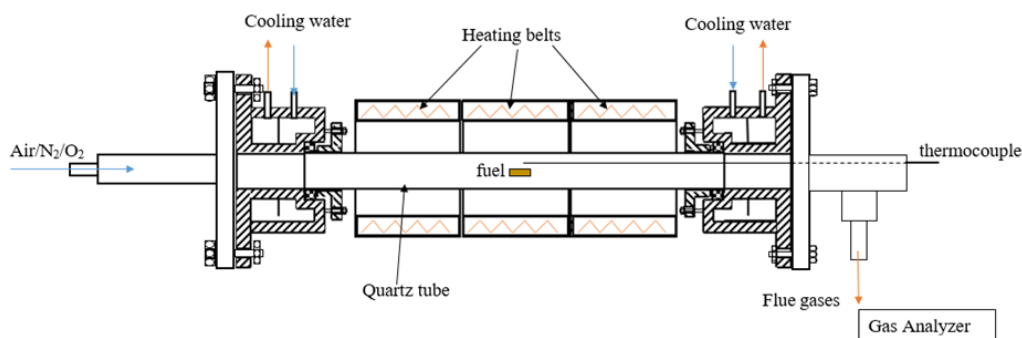


Fig. 1. Experimental set-up The sample was adjusted in the middle of the reaction zone of the HTF, using specifically designed stand (Fig. 2) with thermocouple placed in the spherical center of the fuel particle

Rys. 1. Układ eksperymentalny Próbkę została dostosowana w środku strefy reakcji HTF, przy użyciu specjalnie zaprojektowanego stanowiska (rys. 2) z termoparą umieszczoną w kulistym środku cząstki paliwa



Fig. 2. Single fuel particle positioning in the center of the reaction zone (a) before; (b) after the conversion process

Rys. 2. Pojedyncza cząstka paliwa ustawiona w środku strefy reakcji (a) przed; (b) po procesie konwersji

The temperature in the reaction zone was 700 and 800°C. The single fuel particle oxidation was performed at constant atmospheric pressure and an airflow rate of 3 l/min. The investigated fuel particle samples were with initial diameter ( $d_{fuel,init}$ ) of 17 mm and initial particle mass ( $m_{fuel,init}$ ) of 1.37–1.62 g. At given time intervals (30, 60, 120, 360 and 480 s) the biomass particles were extracted from the reaction zone and placed in a quartz crucible with lid, then tempered in a desiccator up to room temperature. The experimentally measured fuel particle diameter and mass thereafter, were used to calculate the effect of the residence time and temperature on the fuel particle surface, volume, and density (see eq. 1–3).

### 3. Reactivity measurements

The dimensional evaluation of the fuel particle volume, surface area, and density was estimated (using eq. 1–3), during single particle biomass oxidation in the HTF. For that purpose the biomass particle shape was assumed to be ideally spherical. The initial and resulting (after the oxidation) volume ( $V$ ), surface ( $S$ ) and density ( $\rho$ ) of spherically shaped biomass particles were estimated through the following equations:

$$V = 3/4 \cdot \pi \cdot r^3 \quad (1)$$

$$S = 4 \cdot \pi \cdot r^2 \quad (2)$$

$$\rho = m/V \quad (3)$$

where:

- $V$  – the volume of a sphere [ $\text{cm}^3$ ],
- $r$  – the radius of a sphere [ $\text{cm}$ ],
- $S$  – the surface of a sphere [ $\text{cm}^2$ ],
- $\rho$  – the density [ $\text{g}/\text{cm}^3$ ],
- $m$  – the mass of a sample [ $\text{g}$ ].

### 4. Results and discussion

The experimentally measured and estimated results for the shrinking characteristics of oxidised biomass particles were summarised in Table 2 and Figures 3 to 6.

TABLE 2. Effect of residence time and temperature on the measured biofuel's characteristics  
 TABELA 2. Wpływ czasu przebywania i temperatury na charakterystykę mierzzonego biopaliwa

No.	$d_{fuel,init}$ [mm]	$m_{fuel,init}$ [g]	$T_{residence}$ [sec.]	$T^{\circ}C$	$d_{fuel,res}$ [mm]	$m_{fuel,res}$ [g]	$V_{fuel,init}$ [cm <sup>3</sup> ]	$V_{fuel,res}$ [cm <sup>3</sup> ]	$S_{fuel,init}$ [cm <sup>2</sup> ]	$S_{fuel,res}$ [cm <sup>2</sup> ]	$\rho_{fuel,init}$ [g/cm <sup>3</sup> ]	$\rho_{fuel,res}$ [g/cm <sup>3</sup> ]	
1	17	1.5165	30	800	16	0.3123	2.571	2.144	9.075	8.038	0.590	0.146	
2	17	1.389	120		12.2	0.1012	2.571	0.950	9.075	9.075	4.674	0.540	0.106
3	17	1.5488	180		11.8	0.0711	2.571	0.860	9.075	9.075	4.372	0.602	0.083
4	17	1.466	240		10	0.0464	2.571	0.523	9.075	9.075	3.14	0.570	0.089
5	17	1.376	300		6	0.0068	2.571	0.092	9.075	9.075	0.985	0.5352	0.061
6	17	1.4839	60	700	15.5	0.2639	2.571	1.949	9.075	7.544	0.577	0.135	
7	17	1.441	120		13.6	0.1328	2.571	1.316	9.075	9.075	5.808	0.560	0.101
8	17	1.5232	120		14	0.1957	2.571	1.436	9.075	9.075	6.154	0.592	0.136
9	17.1	1.6223	145		14	0.1736	2.617	1.436	9.182	9.182	6.154	0.620	0.121
10	17	1.5732	180		12.7	0.1153	2.571	1.072	9.075	9.075	5.065	0.612	0.108
11	17	1.5245	240		11	0.0669	2.571	0.697	9.075	9.075	3.799	0.593	0.096
12	17	1.5755	300		10.8	0.031	2.571	0.660	9.075	9.075	3.663	0.613	0.047
13	17	1.4642	360		6	0.004	2.571	0.034	9.075	9.075	0.502	0.570	0.035
14	17	1.6175	450	6	0.004	2.571	0.014	9.075	9.075	0.283	0.629	0.035	

As expected, the experimentally measured fuel particle shrinkage, in terms of continuous mass- and diameter-loss (Fig. 3–4) was larger with increasing the residence time of the sample in the reaction zone of the HTF. The results were also confirmed also for the estimated parameters, e.g., the fuel particle density (Fig. 5). The negligible effects, observed at residence time of above 300 sec. were associated with the final stage of the process, the so called residue combustion.

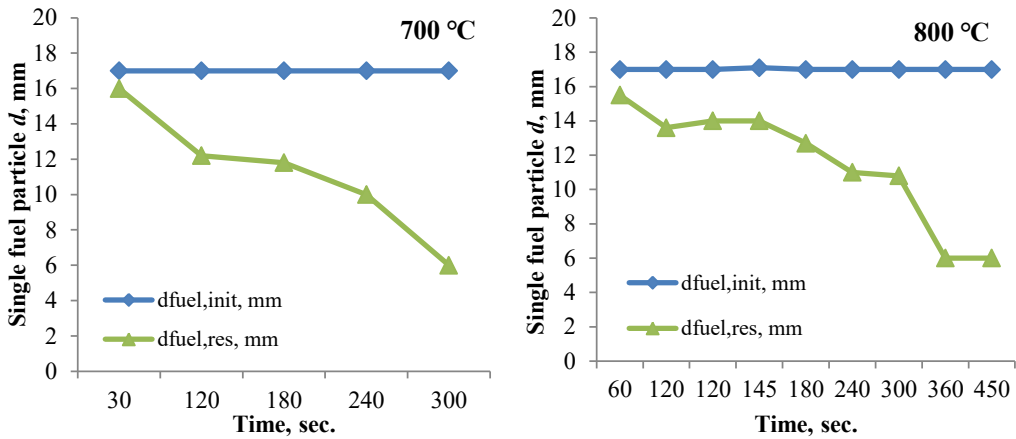


Fig. 3. Effect of particle residence time ( $t_{res}$ ) and oxidising temperature ( $T$ ) on the diameter shrinkage of a single fuel particle

Rys. 3. Wpływ czasu przebywania cząstek ( $t_{res}$ ) i temperatury utleniania ( $T$ ) na kurczenie się średnicy pojedynczej cząstki paliwa

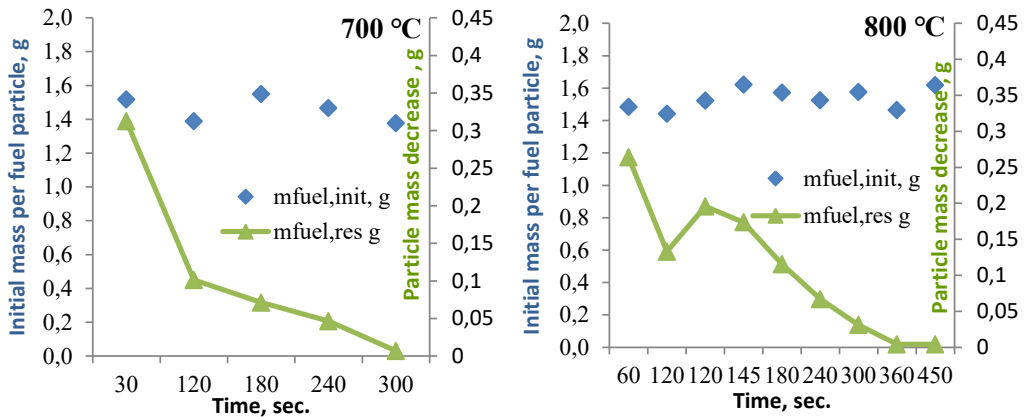


Fig. 4. Effect of  $t_{res}$  and  $T$  on the rate of fuel particle mass decrease

Rys. 4. Wpływ czasu przebywania cząstek i temperatury utleniania na szybkość zmniejszania się masy cząstek paliwa

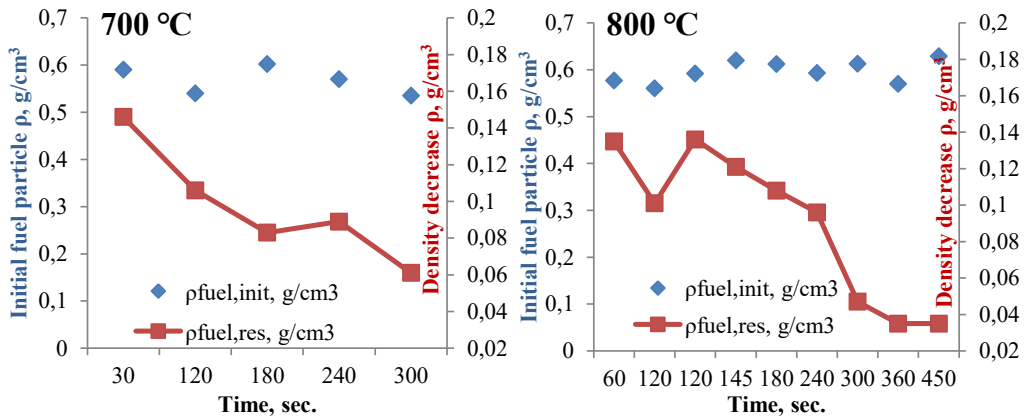


Fig. 5. Effect of particle residence time and oxidising temperature on the rate of fuel particle density decrease

Rys. 5. Wpływ czasu przebywania cząstek i temperatury utleniania na szybkość zmniejszania się gęstości cząstek paliwa

Relatively weak temperature dependence of the particle mass-loss rate was observed in the present experiment (Fig. 6), showing a shorter induction period. These results were found to correlate with the general observations of (Sadhukhan et al. 2010; Caposciutti et al 2019). The authors investigated the dimensional evolution of biomass fuel (beech wood) in pyrolytic and combustion conditions using an image analysis tool. The same research teams study also the effect of the fuel particle size and observed that similar volume reduction (60–66%) is determined during the pyrolysis. However, for the smaller particles with minor intra-particle gradients, the shrinkage occurred mainly at the end of the conversion, while for the bigger particles, the size variation pattern showed linear behaviour. According to (Pereira and Costa 2017) two general stages of biomass conversion typically govern fuel particle combustion, where maximum co-

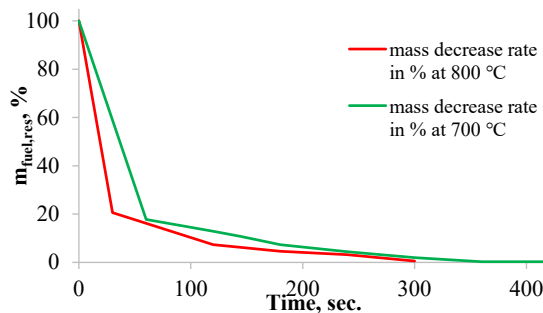


Fig. 6. Temperature dependence of the rate of mass-loss during single biomass particle combustion at  $p = \text{atm.}$ ,  $T = 700$  and  $800^\circ\text{C}$ , residence time between 30 and 450 sec.

Rys. 6. Zależność temperaturowa szybkości utraty masy podczas spalania pojedynczej cząstki biomasy przy  $p = \text{atm.}$ ,  $T = 700$  i  $800^\circ\text{C}$ , czasie przebywania między 30 a 450 sek.



nversion rate is observed during stages two and three (the devolatilisation, volatiles ignition and oxidation, and the stage of fixed carbon decomposition). It is also confirmed (Oberberger et al. 2006; Naydenova et al. 2020) that the fraction of volatile organic compounds often vary between 60 and 85 wt. % of the proximate solid biofuel content (see also Table 1). In addition, following (Wesenauer et al. 2021; Pereira and Costa 2017), the devolatilisation stage should account for the major part of the total mass conversion of biomass at the temperature interval applied in the present work.

## Conclusion

A comprehensive experimental study was carried out during the thermal decomposition of spherically shaped single particles of softwood. Generally the effect of temperature and residence time on the fuel particle mass and diameter were studied in oxidative media (21 vol. % O<sub>2</sub> and airflow rate of 3 l/min) at atmospheric pressure and at two different temperatures (700 and 800°). The experimentally measured initial and resulting fuel particle mass and diameter allowed for estimating the particles' density, surface, and volume, applying the general assumption that the fuel particles are of ideally spherical shape. The general stages of the combustion process (devolatilisation and fixed carbon oxidation) were assumed to show the most pronounced effects on the fuel particle conversion. The fuel particle shrinkage was expressed through the gradual mass- and diameter-loss with increasing the residence time of the sample in the reaction zone of the chemical reactor until the process reached its final stage (residual combustion). The same tendency was confirmed for the estimated parameters. Such experimentally measured data are usually needed for solving particular technical problems related e.g., to the design and/or optimization of the combustion chamber. Numerous appliances are benefiting from such experiments in the context of model development and validation, combustion chamber upgrade, process control, and emission monitoring and reduction.

This work has been carried out in the framework of the National Project “Aerosols and their Organic Extractives, derived during Biomass Conversion – Cytotoxic and Oxidative Response of Model Systems of Pulmonary Cells”, Contract № КП-06-H44-5/14.07.2021, National Science Fund, Ministry of Education and Science. The laboratory equipment was supported through the local administrative and technical support, provided from the Research and Development Centre at the Technical University of Sofia, Bulgaria (Contract No. 23IIP0007-10/2023 and 24IIP0016-10/2024).

The Authors have no conflicts of interest to declare.

## References

- AHMAD et al. 2020 – AHMAD, Z., AL DAJANI, W.W., PALEOLOGOU, M. and XU, C. 2020. Sustainable Process for the Depolymerization/Oxidation of Softwood and Hardwood Kraft Lignins Using Hydrogen Peroxide under Ambient Conditions. *Molecules* 25(10), DOI: 10.3390/molecules25102329.
- BAI et al. 2017 – BAI, X., LU, G., BENNET, T., SARROZA, A., EASTWICK, C., LIU, H. and YAN, Y. 2017. Combustion behavior profiling of single pulverized coal particles in a drop tube furnace through high-speed imaging and image analysis. *Experimental Thermal and Fluid Science* 85, pp. 322–330, DOI: 10.1016/j.expthermflusci.2017.03.018.
- BREZIN et al. 2013 – BREZIN, V., ANTOV, P. and KOVACHEVA, A. 2013. *Organic biomass – source for production of biogenic fuels (Rastitelna biomasa – iztochnik za poluchavane na biogenni goriva)*. University of Forestry – Sofia (in Bulgarian).
- BRYDEN, K.M. and HAGGE, M.J. 2003. Modeling the combined impact of moisture and char shrinkage on the pyrolysis of a biomass particle. *Fuel* 82(13), pp. 1633–1644, DOI: 10.1016/S0016-2361(03)-00108-X.
- CAPOSCIUTTI et al. 2019 – CAPOSCIUTTI, G., ALMUINA-VILLAR, H., DIEGUEZ-ALONSO, A., GRUBER, T., KELZ, J., DESIDERI, U., HOCHENAUER, C., SCHARLER, R. and ANCA-COUCÉ, A. 2019. Experimental investigation on biomass shrinking and swelling behaviour: Particles pyrolysis and wood logs combustion. *Biomass and Bioenergy* 123, pp. 1–13, DOI: 10.1016/j.biombioe.2019.01.044.
- DAVIDSSON, K. and PETTERSSON, J. 2002. Birch wood particle shrinkage during rapid pyrolysis. *Fuel* 81(3), pp. 263–270, DOI: 10.1016/S0016-2361(01)00169-7.
- IVANOV et al. 2022 – IVANOV, I., KOSTOV, K., ATANASOV, K., DENEV, I. and KRISTEV, N. 2022. Analysis of the air exchange in livestock building through the computational fluid dynamics. *EUREKA: Physics and Engineering* 3, pp. 28–39, DOI: 10.21303/2461-4262.2022.002349.
- IONTCHEV et al. 2020 – IONTCHEV, E., MILETIEV, R., YORDANOV, R. and DAMYANOV, I. 2020. Measurement and Analysis of PM Particles Emitted by Automotive Brakes. *55<sup>th</sup> International Scientific Conference on Information, Communication and Energy Systems and Technologies (ICEST)*, Niš, Serbia, pp. 231–234, DOI: 10.1109/ICEST49890.2020.
- KOSTOV, K.V. 2022. Analysis and assessment of risk in the implementation of a cogeneration installation at a livestock farm. *Polityka Energetyczna – Energy Policy Journal* 25(3), pp. 123–132, DOI: 10.33223/epj/153026.
- KOSTOV et al. 2023 – KOSTOV, K.V., IVANOV, I.I. and ATANASOV, K.T. 2023. The analysis of the energy index and the application of equivalent distillation productivity as criteria for identification of the energy efficiency of a petroleum refinery. *Polityka Energetyczna – Energy Policy Journal* 26(1), pp. 133–144, DOI: 10.33223/epj/161625.
- KWIATKOWSKI et al. 2014 – KWIATKOWSKI, K., BAJER, K., CELIŃSKA, A., DUDYŃSKI, M., KOROTKO, J. and SOSNOWSKA, M. 2014. Pyrolysis and gasification of a thermally thick wood particle – effect of fragmentation. *Fuel* 132, pp. 125–134, DOI: 10.1016/j.fuel.2014.04.057.
- LACKNER et al. 2004 – LACKNER, M., LOEFFLER, G., TOTSCHNIG, G., WINTER, F. and HOFBAUER, H. 2004. Carbon conversion of solid fuels in the freeboard of a laboratory-scale fluidized bed combustor – application of in situ laser spectroscopy. *Fuel* 83(10), pp. 1289–1298, DOI: 10.1016/j.fuel.2003.12.012.
- LEVENSPIEL, O. 1998. *Chemical Reaction Engineering, 3<sup>rd</sup> Edition*, Publisher: Wiley; pp. 688.
- NAYDENOVA et al. 2020 – NAYDENOVA, I., SANDOV, O., WESENAUER, F., LAMINGER, T. and WINTER, F. 2020. Pollutants formation during single particle combustion of biomass under fluidized bed conditions: An experimental study. *Fuel* 278, DOI: 10.1016/j.fuel.2020.117958.

- Net Zero Roadmap. A Global Pathway to Keep the 1.5°C Goal in Reach 2023. *International Energy Agency. Flagship report*, September 2023. [Online] <https://www.iea.org/reports/net-zero-roadmap-a-global-pathway-to-keep-the-15-0c-goal-in-reach> [Accessed: 2023-11-16].
- OBERNBERGER et al. 2006 – OBERNBERGER, I., BRUNNER, T. and BAERNTHALER, G. 2006. Chemical properties of solid biofuels – significance and impact. *Biomass Bioenergy* 30, pp. 973–982, DOI: 10.1016/j.biombioe.2006.06.011.
- PEREIRA, S. and COSTA, M. 2017. Short rotation copies for bioenergy: From biomass characterization to establishment – a review. *Renewable Sustainable Energy Rev* 74, pp. 1170–1180, DOI: 10.1016/j.rser.2017.03.006.
- SADHUKHAN et al. 2010 – SADHUKHAN, A.K., GUPTA, P. and SAHA, R.K. 2010. Modelling of combustion characteristics of high ash coal char particles at high pressure: Shrinking reactive core model. *Fuel* 89, pp. 162–169, DOI: 10.1016/j.fuel.2009.07.029.
- SANDOV, O. 2019. Construction of a flow reactor for the combustion/pyrolysis of biomass fuels. *Proceedings of XXIV Scientific conference with international participation FPEPM 2019*, pp. 258–268.
- SANDOV et al. 2021 – SANDOV, O., NAYDENOVA, I. and VELICHKOVA, R. 2021. Primary gaseous emissions during biomass combustion, *2021 6th International Symposium on Environment-Friendly Energies and Applications (EFEA)*, Sofia, Bulgaria, pp. 1–6, DOI: 10.1109/EFEA49713.2021.9406230.
- SANDOV, O. 2022. Dynamics of the Process of Combustion and Generation of Harmful Substance Using Alternative Fuels. *Ph.D. Thesis, Technical University of Sofia*, Sofia, Bulgaria, 2022.
- VASSILEV et al. 2010 – VASSILEV, S.V., BAXTER, D., ANDERSEN, L.K. and VASSILEVA, C.G. 2010. An overview of the chemical composition of biomass. *Fuel* 89, pp. 913–933, DOI: 10.1016/j.fuel.2009.10.022.
- VASSILEV et al. 2013a – VASSILEV, S.V., BAXTER, D., ANDERSEN, L.K. and VASSILEVA, C.G. 2013a. An overview of the composition and application of biomass ash. Part 1. Phase–mineral and chemical composition and classification. *Fuel* 105, pp. 40–76, DOI: 10.1016/j.fuel.2012.09.041.
- VASSILEV et al. 2013b – VASSILEV, S.V., BAXTER, D., ANDERSEN, L.K. and VASSILEVA, C.G. 2013b. An overview of the composition and application of biomass ash. Part 2. Potential utilisation, technological and ecological advantages and challenges. *Fuel* 105, pp. 19–39, DOI: 10.1016/j.fuel.2012.10.001.
- WESENAUER et al. 2021 – WESENAUER, F., FREI, A., JORDAN, C., PICHLER, M., WINTER, F. and HARASEK, M. 2021. A three-stage reaction model for the conversion of organic and inorganic carbon in clay brick firing. [In:] *Proceedings of the 10th European Combustion Meeting 2021*, held on 14–15 April 2021, Naples, Italy.

# Charakterystyka kurczenia się pojedynczej cząstki biomasy w warunkach utleniania

## Streszczenie

W kontekście zerowej emisji netto wykorzystanie biomasy różnego pochodzenia jest przyjmowane jako dopuszczalna alternatywa dla termochemicznej konwersji paliw kopalnych w celu wytwarzania energii lub produkcji towarów. Spalanie biomasy charakteryzuje się heterogeniczną kinetyką, w której utleniona substancja znajduje się w stanie stałym. Reakcja zachodzi głównie wzdłuż powierzchni oddzielającej dwie fazy. Szybkość spalania można wyrazić ilością reagującej substancji na jednostkę powierzchni, alternatywnie również średnicą koryta lub profilem utraty masy. Niniejsza analiza miała na celu zbadanie charakterystyki kurczenia się podczas spalania pojedynczych cząstek sferycznych cząstek stałych (drewna miękkiego). Eksperyment przeprowadzono w reaktorze w skali laboratoryjnej typu pieca rurowego poziomego (HTF). Początkową i wynikową masę i średnicę cząstek zmierzono eksperymentalnie, na podstawie czego oszacowano gęstość, powierzchnię i objętość cząstek paliwa dla każdej cząstki biomasy. Ewolucję wymiarową cząstek paliwa zbadano pod kątem wpływu temperatury i czasu przebywania cząstek paliwa w strefie reakcji. Eksperymenty przeprowadzono przy ciśnieniu atmosferycznym, stałym natężeniu przepływu powietrza i w dwóch różnych temperaturach (700 i 800°C). Skurcz cząstek poprawiał się wraz ze wzrostem czasu przebywania, aż proces osiągnął końcowy etap spalania resztkowego. Badany zakres temperatur wykazywał słabą, ale wyraźną zależność temperaturową.

**SŁOWA KLUCZOWE:** konwersja biomasy, spalanie pojedynczych cząstek, kurczenie się cząstek biopaliw stałych