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PARTICULATE MATTER MEASUREMENTS IN INDOOR AIR

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Abstract: *The paper presents results concerning indoor air measurements of particulate matter with mean diameters 10 μm and 2.5 μm. The tests are performed with experimental module for particulate matter emission control based on optical principle. The work compares the data from measurements which are conducted with different types of biofuels burned out at the same conditions.*

Keywords: *Particulate matter, Biofuels, Combustion.*

INTRODUCTION

Recently, Bulgaria has been increasingly using the biomass waste generated by agriculture. The Ministry of Energy axcepted in 2008 a National long-term programme for encouraging the use of the biomass for period 2008-2020 (Ministry of Energy, 2008). Nowadays, the producers are offering large choice of biofuels. Utilization of the biomass residue can be processed in different ways – simultaneous wheat production and residues transforming into pellets; simultaneous sunflower oil production and residues conversion into pellets; even directly burnout of the fruit stones in local heating systems or in manufacturing processes, etc. A tendency is currently

observed of inceased number of end users of those biofuels for residential heating instead of using the classical furnancies operating with coal or wood. However, in Bulgaria, there is scarse data about the concentration of primary particulate matter (PM) with mean diameter 2.5μm ($PM_{2.5}$) and 10μm (PM_{10}), in the indoor air during solid biofuel combustion.

The $PM_{2.5}$ and PM_{10} levels are being monitored and controled because of its harmful effects on the human health and the ecosystems (Directive 2008/50/EO, 2008). Those levels have been mainly monitored in the outdoor air. Some governments have published guidances for decreasing the PMs in the indoor air (Environmental Protection Agency Victoria, 2014) and (Government of Canada, 2012). According to (Bo, M., Salizzoni, P., Clerico, M., & Buccolieri, R., 2017) and (Gupta, A., Bhandari, M., 2011) the main pollution sources of the indoor air, after smoking and cooking, are the heating systems.

Detailed study of the indoor air PM in Bulgaria is needed merely because of the large number of household heating systems, relying on solid fuel comsbution (Executive Environment Agency, 2016)

The main goal of this research is to investigate the indoor air PM, which were emitted during biofuel combustion. For that purpose, the indoor air concentration of $PM_{2.5}$ and PM_{10} was experimentally measured during the combustion of four different types of pellets, produced from agricultural biomass residue: colza, lucerne, wheat straw and sunflower husks. This work is still in progress and the article presents some preliminary results. Due to the particular characteristics of the experimental equipment and the analytical methods applied, the work pretends to provide a qualitative study of the issue and needs to be further developed.

EXPOSITION

Solid biofuels characterization

The used biofuels were chemically characterized in term of the following analyses: proximate, ultimate and ash analyses. In addition, the high heating value (HHV) was obtained with bomb calorimeter. The main results are summarized in Table 1.

It has been observed that there is relation between the particular physical and chemical characteristics of the solid biofuels and the emissions of harmful substancies (Obernberger, I., Brunner, T., Baernthaler, G., & Thurnes J., 2007). Currently, the appropriate analyses for the considered biofuels are being carried out internally and in external laboratories.

Table 1. Chemical characteristics of the biofuels

Parameter	Colza pellets	Lucerne pellets	Wheat straw pellets	Sunflower husk pellets
Proximate analyses (wt%, as analyzed)				
Volatiles	78.53	73.01	72.53	76.93
Fixed carbon	4.59	2.79	8.02	12.67
Moisture	9.86	8.58	9.62	7.52
Ash	4.59	15.62	9.8	2.88
Ultimate analysis (wt%, as analyzed)				
Carbon	49.64	47.96	48.39	54.04
Hydrogen	8.24	8.74	8.59	8.45
Nitrogen	2.67	4.81	3.25	3.00
Sulphur	<0.05	<0.05	<0.05	<0.05
Oxygen	24.85	14.14	20.20	23.96
Chlorine	<0.10	<0.10	<0.10	<0.10
High heating value (MJ/kg, dry basis)	18.69	18.25	16.79	20.28
Ash analysis (wt%, dry basis)				

Parameter	Colza pellets	Lucerne pellets	Wheat straw pellets	Sunflower husk pellets
SiO_2	2.47	28.86	57.79	1.01
Al_2O_3	0.97	5.78	3.93	0.15
Fe_2O_3	0.25	1.45	1.37	0.92
MnO	0.06	0.06	0.17	0.02
CaO	29.07	12.06	8.12	20.44
MgO	9.36	3.56	2.82	11.95
BaO	0.05	0.04	0.01	0.01
Na_2O	2.48	1.31	0.93	0.57
K_2O	17.80	19.72	12.11	28.78
Cr_2O_3	<0.01	0.01	0.01	0.07
TiO_2	0.08	0.20	0.20	0.14
ZnO	0.01	0.06	0.07	0.06
CuO	0.01	0.01	0.04	0.03
SrO	0.01	0.03	0.04	0.02
P_2O_5	11.67	4.78	2.57	5.88
Moisture at 105 ^{0}C	0.23	2.44	2.04	4.40
Loss on ignition	25.68	21.82	9.50	29.51

Experimental equipment

The measurements were carried out with an experimental module for PM emission control, which is described in (Petrova, Ts., Naydenova, I., Sandov, O., Velichkova, R., & Simova, I., 2018). The SDS011 sensor is sensitive to two types of particulate matter (PM): $PM_{2.5}$ and PM_{10}.

The measurement procedure employed by the PM sensor is schematically described on Fig. 1. The air enters into the measuring chamber where a laser diode periodically generates light emission impulses. The fallen laser beams are scattered by the available in the sampled volume of air PM depending on its size. The light transducer picks up and transforms the collected light in signals with different intension. The entire measurement procedure is described in detail e.g. in (Genikomakis, K., Galatoulas, N., Dallas, P., Ibarra, L., Margaritis, D., & Ioakimidis, Ch., 2018).

The biofuel was burned out at mild temperature in a programmable burnout furnace Dentamatic 6000 at well controlled temperature of 550^{0}C (± 10^{0}C), atmospheric pressure and residence time of 41 min. The used biofuels were as follows: colza pellets, sunflower husk pellets, lucerne pellets and wheat straw pellets. The amount of biofuel used for each test run was 10 grams. The mean particle size of the fuel was with nominal top size of 1mm or less.

The $PM_{2.5}$ and PM_{10} concentrations were experimentally measured in the indoor air of the Laboratory of Combustion Technique and Technologies, College of Energy and Electronics at Technical University – Sofia. The measurments were carried out during the autumn period, at dry and sunny days and at the following conditions of the indoor laboratory environment: temperature of 12 ^{0}C, relative humidity of 48 % and atmospheric pressure of 94 700 Pa.

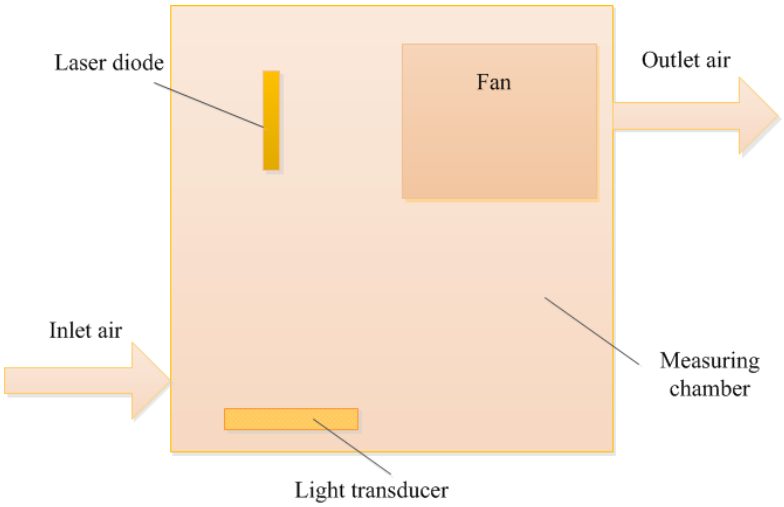

Fig. 1. The sensor's principle of work

Experimental results

The average concentrations of the emitted $PM_{2.5}$ and PM_{10} in $\mu g/m^3$ per biofuel are given on Fig. 2. The highest average value was obtained during the lucerne pellets combustion, followed by the colza, sunflower husk and wheat straw pellets.

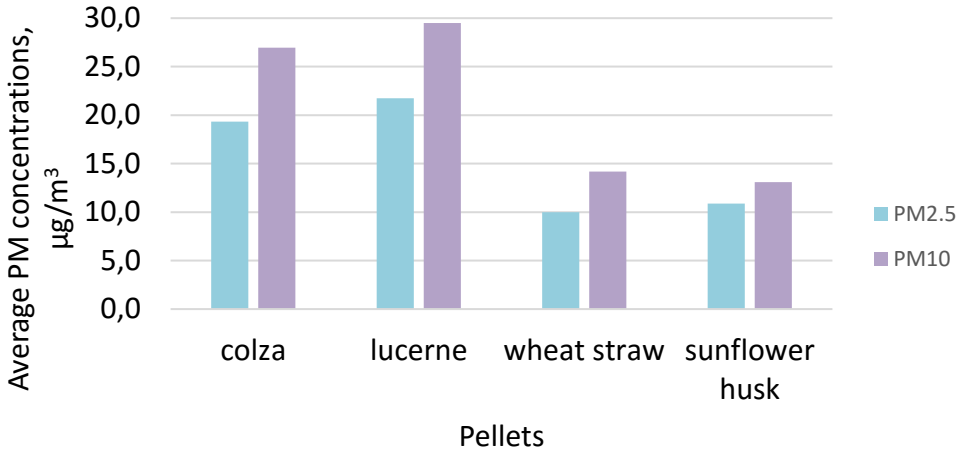

Fig. 2. Average values of the measured $PM_{2.5}$ and PM_{10} concentrations in indoor air during the combustion of four types of pellets

The figures below reveal the time distribution of the experimentally measured concentrations of $PM_{2.5}$ (Fig. 3) and PM_{10} (Fig. 4) during the combustion process of the investigated four types of biofuels. In all four cases, the highest values of the PM concentration were measured during the first fifteenth minutes of the experiment, which was dedicated to the volatilization stage of the combustion process. During the stage of the char combustion, the pollution levels gradually decreased.

The measurements show the highest $PM_{2.5}$ level for the case of lucerne pellets burnout and the lowest $PM_{2.5}$ - for the wheat straw pellets burnout. During the entire experiment, the measured values for colza and lucerne pellets were more than twice higher in comparison to those for the wheat straw and the sunflower husk pellets. Apparently bimodal time distribution was observed for $PM_{2.5}$ (Fig. 3) and PM_{10} (Fig. 4) during the combustion of colza and suflower husk pellets.

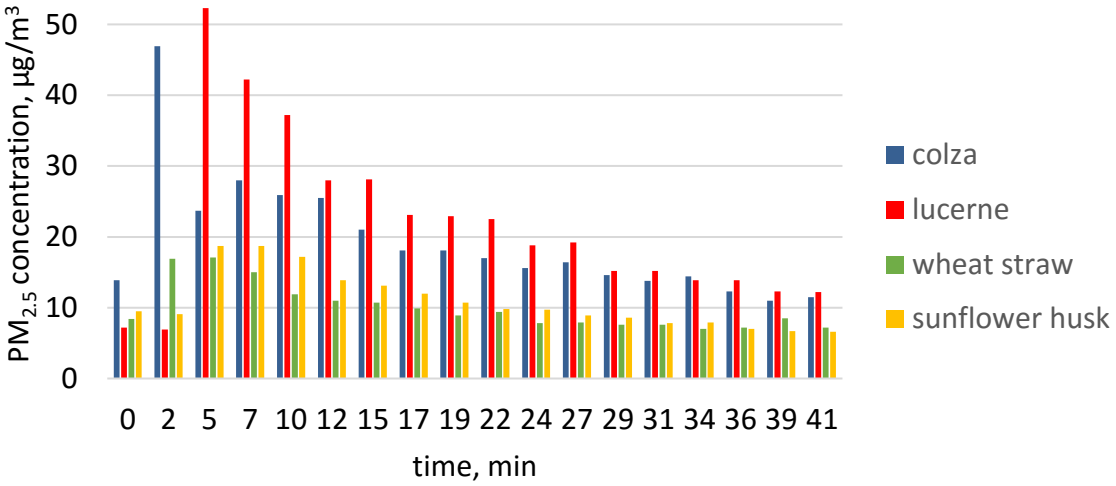

Fig. 3. Time distribution of the $PM_{2.5}$ during the experiments

The measurements performed with the experimental module for PM emission control show that during the lucerne pellets combustion, within the first half of the test period, the PM_{10} level was about three times higher than the one, obtained during the wheat straw and the sunflower husk pellets combustion.

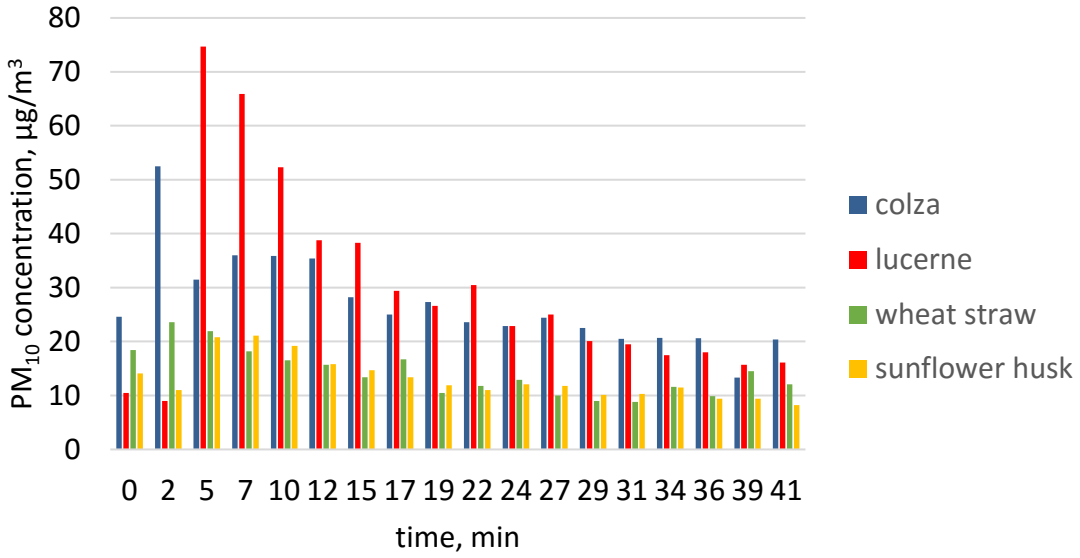

Fig. 4. Time distribution of the PM_{10} during the experiments

CONCLUSION

The PM measurements were conducted during the combustion of four different types biofules produced in Bulgaria and freely available at the national energy maket: colza pellets, lucerne pellets, wheat straw pellets and sunflower husk pellets. Based on the obtained results it can be concluded that in the frame of the chosen experimental conditions and the characteristics of the available experimental equipment:

- The highest $PM_{2.5}$ and PM_{10} levels were measured during the lucerne pellets burnout;
- The lowest $PM_{2.5}$ level was measured during the wheat straw pellets burnout;
- The lowest PM_{10} level was measured during the sunflower husk pellets burnout;

- The amount of $PM_{2.5}$ and PM_{10} emitted during the combustion process varied in relatively wide range depending on the used type of biofuel.

In addition, bimodal time distribution was observed for both ($PM_{2.5}$ and PM_{10}) in the combustion of colza and suflower husk pellets.

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REFERENCES

Bo, M., Salizzoni, P., Clerico, M., & Buccolieri, R. (2017). *Assessment of Indoor-Outdoor Particulate Matter Air Pollution: A Review.* Atmosphere, 8 (8), 136; doi:10.3390/atmos8080136. URL: https://www.mdpi.com/2073-4433/8/8/136/htm.

Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe (2008), URL: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32008L0050&from=EN.

Environmental Protection Agency Victoria (2014), *Air quality in the home.* URL: https://www.epa.vic.gov.au/your-environment/air/air-quality-in-the-home.

Executive Environment Agency (2016), National State of the Environment Report in the Republic of Bulgaria, *Emissions of harmful substances and quality of the atmospheric air*, http://eea.government.bg/bg/soer/2016/air/index.

Genikomakis, K., Galatoulas, N., Dallas, P., Ibarra, L., Margaritis, D., & Ioakimidis, Ch. (2018). *Development and On-Field Testing of Low-Cost Portable System for Monitoring PM2.5 Concentrations*. Sensors, 18 (4), 1056, doi:10.3390/s18041056. URL: https://www.mdpi.com/1424-8220/18/4/1056/htm.

Government of Canada (2012). *Guidance for fine particulate matter (PM2.5) in residential indoor air*. URL: https://www.canada.ca/content/dam/canada/health-canada/migration/healthy-canadians/publications/healthy-living-vie-saine/fine-particulate-particule-fine/alt/fine particulate-particule-fine-eng.pdf.

Gupta, A., Bhandari, M. (2011). *Monitoring and control of particulate matter in indoor air: A revew*. Journal of Applied and Natural Science 3 (1): 139-150. URL: https://www.researchgate.net/publication/264531785_Monitoring_and_control_of_particulate_matter_in_indoor_air_A_review.

Ministry of Energy of Bulgaria (2008), *National long-term programme for encouraging the use of the biomass for period 2008-2020*. URL: https://www.me.government.bg/bg/library/nacionalna-dalgosrochna-programa-za-nasarchavane-izpolzvaneto-na-biomasata-za-perioda-2008-2020-g-178-c174-m0-1.html.

Obernberger, I., Brunner, T., Baernthaler, G., & Thurnes, J. (2007). *Feinstaubemissionen aus Pelletfeuerungen – aktueller Stand der Erkenntnisse*. In: Proceedings zur Europaiische Pelletkonferenz, 28.02-02.03.2007, Wels, Oesterreich.

Petrova, Ts., Naydenova, I., Sandov, O., Velichkova, R., & Simova, I. (2018). *Constructing and testing of experimental module for particulate matter emission control.* Proceeding of XXIII Scientific Conference with International Participation FPEPM 2018, 17th-20th September, 2018, Sozopol, Bulgaria, ISSN 1314-5371, 164-171.