STUDY OF SELECTED BURNER PARAMETERS ON THE GAS-AIR MIXTURE COMBUSTION

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The study of the combustion of a gas-air mixture using burners opens possibilities for further research, in which it is possible to modify the parameters of existing burners (geometry, method combustion air distribution, ...). Flame length can be influenced by changing some of the burner parameters to achieve the best possible conditions in the combustion chamber. The topic of the article is to study the effect of changing burner parameters on the length and nature of the flame in the combustion chamber. For this, an existing burner simulation model was modified. The properties of the proposed changes were investigated using the ANSYS simulation software. Simulation confirmed the suitability of the proposed system for reducing the flame length and intensifying the mixing of gaseous media. Also, the results show that the effect of changing the angle of combustion air supply along the longitudinal axis of the burner significantly affects the mixing of the fuel and, consequently, the nature of the flame with the combustion products.

KEYWORDS

burner, combustion, CFD simulation model, vortex mixing

1 INTRODUCTION

The modern situation in the energy and fuel sector is directed towards the development of new production technologies and their applications with the aim of reducing emissions and increasing the energy efficiency of equipment [Blozon 2012, Liptakova 2012, Bialik 2014, Kuznetsov 2020]. The main priority of every process is to reduce production costs by making production more efficient, which also makes the equipment more energy efficient [Man 2011, Trpcevska 2015, EP 2021].

Based on the priorities and goals of the Energy Policy not only of Slovakia but also of the EU, increasing the energy efficiency of the operation of thermal aggregates is currently one of the main priorities of every process. As stated in it is one of main pillars. It results at the same time the reduction of produced greenhouse gas emissions and also the carbon footprint of the given technology [EP 2021, Holubcik 2022a,b]. Therefore, it is necessary to make a thorough analysis of energy needs for each thermal unit and derive appropriate guidelines, as it was state in [Bialik 2014, Trpcevska 2015].

In recent years, various studies have been devoted to the development of burners and burner systems, which focused mainly on reducing emissions, e.g. in [Liptakova 2012, Bialik 2014] and more efficient use of energy from fuel [Variny 2019, Jablonsky 2015]. In [Variny 2019], the authors focused on energy saving, both internal and external heat saving, by optimizing the entire technology using mathematical models [Baukal 2004]. Upgrades of existing burners require input from existing systems and technologies. The burners used in industry are well described in [Lazic 2011]. Upgraded burner systems are more suitable for large applications or thermal aggregates of greater power (flue gas recirculation, reburning, flux and flat burning, ...), where the burners work rather in groups or zonally, such as e.g. in [Durdan 2014]. It is important to regulate the burners or burner systems also by means of indirect measurement of some parameters, as in [Ozdemir 2016]. Some applications in the smaller heat aggregates remain problematic, where these systems are not a cheap matter and due to various limitations (especially the dimensions of the working space) it is possible to use even simpler combustion devices with appropriate temperature regulation in the working space.

An important parameter when applying a particular burner is the length and nature of the flame. In [Zarvandi 2022], a system of partial mixing of the combustion mixture is interestingly described. In [Lin 2022], the authors focused on the geometry and nature of the flame in a micro-burner. Those were rather low power burners. In [Poskart 2016], the authors focused on an experimental and numerical study of a two-stage swirl burner, where the authors focused on the low production of NOx emissions by optimizing the design parameters of the burner.

In order to save energy, it is possible to increase the temperature in the combustion chamber or to more efficiently use fuel energy during combustion by partially enriching the combustion air by oxygen [Baukal 2001, Dzurnak 2019, Variny 2019]. This idea is not new, but nowadays is increasingly relevant. A very discussing topic is the use of hydrogen energy as an additive to methane [Rimar 2020] or natural gas or to pure methane [Reyes 2022].

It is necessary to focus on the influence of inert components [Barabas 2022, Hudak 2022] of the gaseous fuel, which affect both combustion and the character of the flame when burning gaseous fuels, especially technological gases. In such cases, it is appropriate to focus on the overall energy balance and the description of the heat exchange process, as in [Varga 2013] [Ferstl 2011, Kozubkova 2011]. It is appropriate to use not only the creation of computational mathematical models, but also modeling using a simulation tool in CFD software.

Figure 1. Physical model of a melting furnace with co-current supply of fuel and combustion air to the burner.

Figure 1 shows a burner with co-current supply of fuel and combustion air, which is more described in previous research [Dzurnak 2019, Rimar 2020]. The parameters of the burner were used for further study of the flow in the burner and the combustion chamber when some parameters were changed [Reyes 2022]. CFD modeling was used to further study the combustion process of the gas-air mixture, which is described in the following chapters of the article.

2 EXPERIMENTAL

The authors proposed a new burner system for mixing enriched air with gaseous fuel, which is based on the existing burner system for melting aluminium described in [Variny 2019].
The authors focused on two main design tasks:

1. Change the supply of oxidizing agent from co-current to tangential and thus change the dynamics of the mixing of gaseous media.
2. Redistribution of the oxidizing agent for gradual mixing with gaseous fuel by changing the geometry of the air nozzle. Modification of the burner geometry consists of placing the dividing insert cylindrical part in the air nozzle.
3. Analise and compare usually used burner with 90° air inlet with the 45° air inlet burner.

According to Equation (1) in [Ozdemir 2016], the burner geometry was designed based on the flame length. This relationship is especially valid for co-current supply of gaseous media for combustion in the burner. The validity of this relationship was confirmed on the basis of temperature field measurements by the authors in [Zarvandi 2022] [Čajová 2011] in the combustion chamber of the experimental equipment.
The co-current burner of [Ozdemir 2016], designed for the melting chamber of the drum furnace, proves to be unsuitable for the short length of the melting chamber. Therefore, when increasing the power, it is necessary to shorten the flame length.
Figure 2 schematically shows the modifications of the burner also with the location of the dividing insert part in the air nozzle.

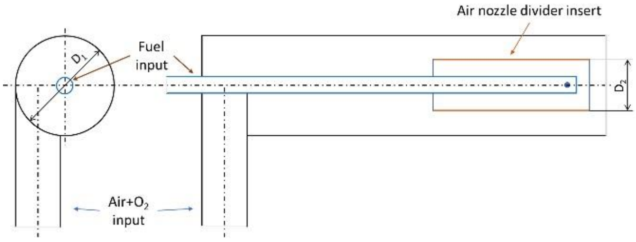

Figure 2. Schematic design of burner modifications

The dividing insert part is located in the mouth of the burner. Proposed burner adjustment solutions could address this shortcoming.

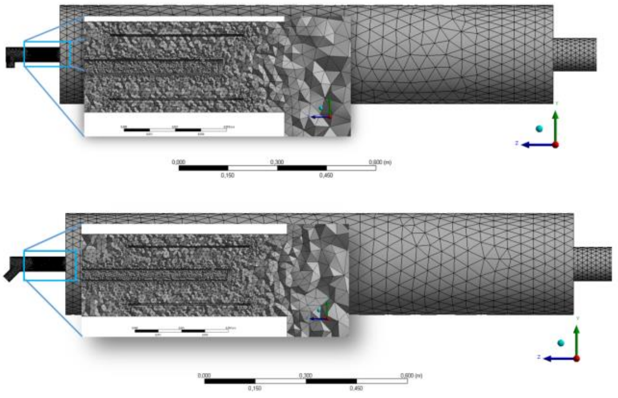

Figure 3. The simulation results shown a different combustion behaviour of the 90° and 45° burners

The simulation models were made in ANSYS 19 Fluent. The geometries of the models were made in Design Modeller. The drawings of the burners with combustion chamber are at the Figure 3. Simulation models consists by three main parts:

- Burner
- Combustion chamber
- Exhauster

The meshes were made in ANSYS Mesh using the proximity and curvature advanced size function due the model geometric specialities. The inflation setting was used for gas and air inlets. Mesh growth parameter were chosen at ratio 0.272 for two layers to reach the best Mesh quality. The mesh of the models is shown in Figure 3.
The quality of the Mesh was considered by two main parameters – orthogonal quality and skewness. The mesh quality parameters are in the Table 1.

Table 1. The quality of the Mesh of the simulation model

	90° air inlet		**45° air inlet**
	D 44	**D 26**	
Number of elements	318139	324345	312090
Number of nodes	461142	471582	452245
Orthogonal quality	min – 0.2, avg – 0.77	min – 0.21, avg – 0.77	min – 0.2, avg – 0.77
Skewness	max – 0.79, avg – 0.22	max – 0.79, avg – 0.23	max – 0.79, avg – 0.22

The boundary conditions of the walls are adiabatic. The input of fuel and oxidizer is solved through the flow inlet from the direction perpendicular to the cross-sectional area. The output of combustion products from the simulation model is solved using a pressure output.
As settings for the Ansys Fluent simulation software were used the energy equation model, turbulence realizable k-ε model, and radiation p1 model. The combustion process was made via PDF table. Fuel composition for simulation is in the Table 2.

Table 2. Fuel composition for simulation

	Methane	Propane	Butane
%	95	3	2

The input parameters for simulation are in the Table 3.

Table 3. Simulation input parameters Parameter and values for the simulations performed

Parameter	Value	
Air nozzle diameter – D_1, m	0.44	0.26
Fuel flow, m^3/h	1.32	1.32
Air flow, m^3/h	14.33	12.03
Oxygen mass fraction, %	21.00	25.00
Excess air	1.1	1.1

Baukal [Baukal 2001] stated in his review paper that industrial applications use oxygen enrichment to less than 30 vol.%. For this reason, a maximum air enrichment to an O2 content of 25 vol.% was considered for the simulations. This limit was determined due to the performed experimental measurements according to [Poskart 2016] and supplemented in [Ozdemir 2016] by own measurements. Increasing the oxygen content would lead to an increase of the combustion temperature and, as noted by the authors in [Dzurnak 2019], also to an increase of the formation of NOx emissions.

3 RESULTS AND DISCUSSION

The design of the burner was based on the existing burner system for melting aluminium in a model of the tilting rotary furnace. The aim of the authors was to design a new burner system for mixing enriched air with gaseous fuel.

In the first simulations, the authors focused on unenriched air and the diameter of the air nozzle D1 = 44 mm. In the original burner, a co-current air supply is considered. In the design for the simulations, the oxidant supply is tangential (Figure 2).

Figure 4 shows the results of a simulation of the flow of gaseous media with a tangential supply to the air nozzle. According to the speed of the streams calculations, it can be concluded that there was an intensive mixing of the gaseous fuel with the oxidizing agent.

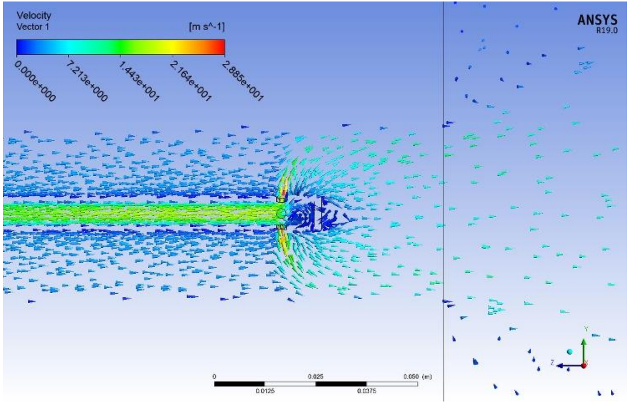

Figure 4. Simulation of the flow of gaseous media without insert part (D1 = 44 mm)

Another research objective of the authors was, based on the redistribution of the oxidizing agent, to simulate the gradual mixing with gaseous fuel. The length of the partition insert was selected 65 mm and a diameter D2 = 20 mm. The location of the insert part is at the mouth of the burner so that there is a gradual mixing of the divided stream of the oxidizing agent.

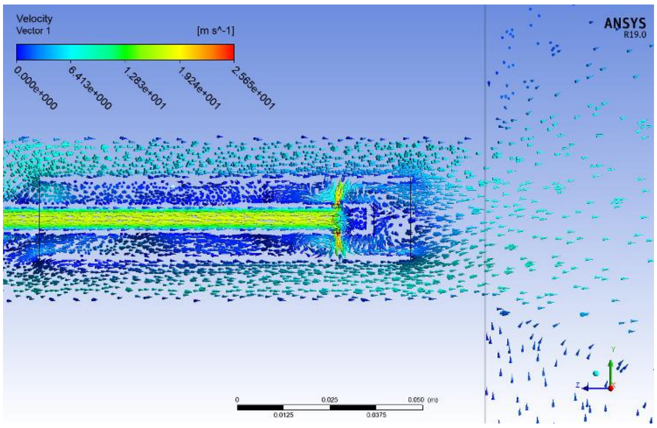

Figure 5. Simulation of the flow of gaseous media with insert part (D1 = 44 mm, D2 = 20 mm - Ver.1.1)

From the simulation in Figure 5, it is possible to observe a change in the flow in the insert part. The flow of gaseous media inside the insert part does not coincide with the direction of the gases exit from the burner. The oxidizing agent is sucked into the interior of the dividing insert part and mixed with the gaseous fuel, thereby shifting the combustion to the fuel nozzle. This is an undesirable phenomenon that had to be eliminated due to possible damage to the burner mouth. For this reason, a new diameter of the dividing inserts D2 = 30 mm was chosen.

The result of the simulation is shown in Figure 6 using velocity vectors of gaseous media. From the simulation, it is possible to observe a change in the flow of the oxidizing agent in the insert part in the direction of the burner exit.

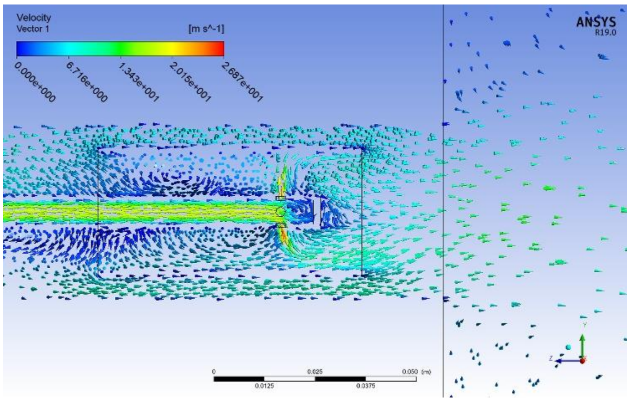

Figure 6. Simulation of the flow of gaseous media with insert part (D1 = 44 mm, D2 = 30 mm - Ver.1.2)

For the further simulations, a smaller air nozzle diameter was considered due to air enrichment to 25 vol.% O2 content. As in the first case, a simulation of the flow of gaseous media without insert part was performed. The result of the simulation is shown in Figure 7.

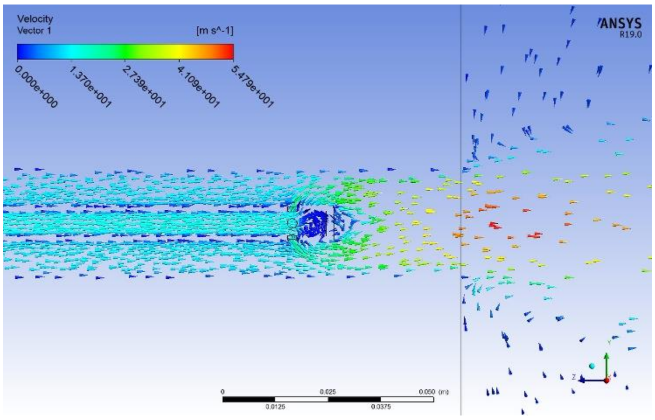

Figure 7. Simulation of the flow of gaseous media without insert part (D1 = 26 mm)

Figure 7 shows the result of a simulation of the flow of gaseous media with a tangential supply to the air nozzle. Here again, the flux rates of the gaseous media can be concluded that there was more intense mixing of fuel gas with an oxidizing agent on the burner orifice.

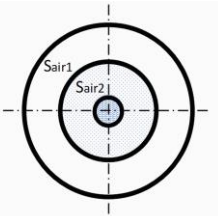

Figure 8. Burner cross-section - divided areas of the air nozzle

For the design of the insert part, a criterion was sought that would ensure correct flow in the insert part. Table 4 shows the ratio of diameters and areas (Figure 8) in the air nozzle.

Table 3. Ratios of diameters and areas in the air nozzle

	Ver.1.1	Ver.1.2	Ver.2.1
D_1, mm	44	44	26
D_2 / D_1	0.4545	0.6818	0.6923
S_{air2} / S_{air1}	0.2892	1.0526	1.2174

From the values given in Table 3 for the first air nozzle (Ver.1.1 and Ver.1.2), it was found that if the ratio of the areas

Sair2/Sair1 is greater than 1, then the flow in the manifold should be correct.

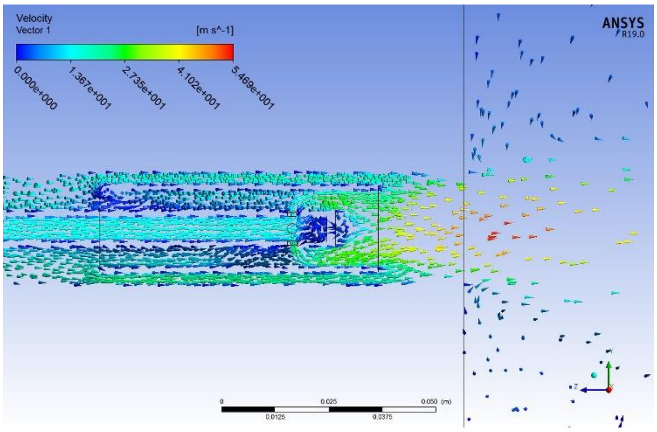

Figure 9. Simulation of the flow of gaseous media with insert part (D1 = 26 mm, D2 = 18 mm - Ver.2.1)

Figure 9 shows the result of a simulation where ratio of areas of the insert part air nozzle was greater than 1. From the analysis of the velocity vectors, it can be concluded that the flow direction in the insert part is correct and that the gaseous fuel with the oxidizing agent is intensively mixed at the burner orifice.

Table 4. Obtained results from simulations for 2 types of burner and 2 different oxygen contents in the oxidizing agent; a) without insert part b) with insert part (65 mm)

O_2 content in the air, %	21	21	25	25
Air nozzle diameter D_1, mm	44 $^{a)}$	44 $^{b)}$	26 $^{a)}$	26 $^{b)}$
The highest temperature, °C	1600	1694	1669	1727
Medium temperature, °C	1258	1574	1617	1627
Flame length, mm	1000	700	350	250
CO_2, mg/m^3	20250	20200	20250	20250
CO, mg/m^3	42	35	28	28
NO, mg/m^3	29	18	33	36
O_2, mg/m^3	6400	6940	13750	13650

Table 4 shows the results obtained from simulations of the burners without and with the insert part.

Owing to the insert part the highest temperature behind the burner as well as the mean temperature is increased. Comparing the flame length in both cases, the flame was shortened due to the more intensive mixing of gaseous media in the burner orifice.

In terms of emerging emissions, it can be observed that in the case without air enrichment, to reduce CO and NO emissions. This can be explained by the more intensive mixing of the gaseous media and a shorter mixing zone at the burner orifice.

In the case of air enrichment, it can be stated that although the flame length was shortened by more intensive mixing, the increase in temperature increased the amount of thermal NO emissions. The amount of CO, in this case, is even lower, and with using the partition insert is unchanged.

The models of 90° and 45° inlet burners were compared by next parameters:

- Flame temperature
- Flame length
- Flame velocity
- Flame orientation
- Fuel utilization efficiency
- Emissions

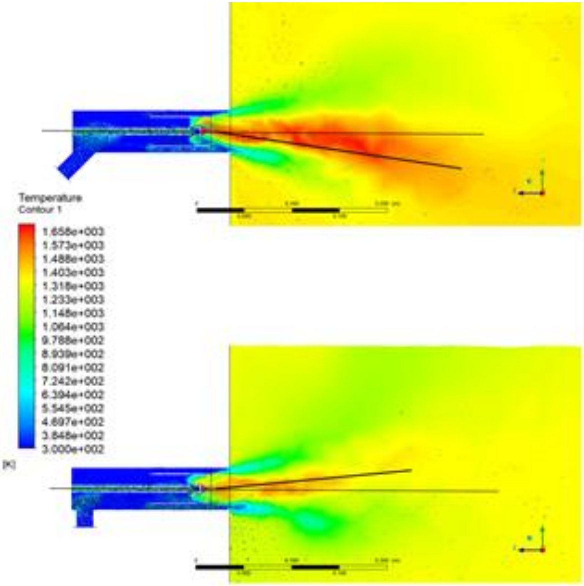

Figure 10 The simulation results shown a different combustion behaviour of the 90° and 45° burners

The simulation results shown a different combustion behaviour of the 90° and 45° burners (Fig. 10). The 90° burner had lower flame temperature (90°-1600K, 45°-1750K), lower flame length (90°-0.2m, 45°-0,3m) and another flame orientation (90° has 6°angle upside from the axis, 45° has 8°angle downside from axis).

Such differences must be a reason of different kinetic of the fuel mix due to the angle of the air inlet. In 90° burner air made 1.5 rotation before it will mixed with fuel while in 45° burner it made only 0.75. Due to a higher air rotation level of the 90° burner and as a reason, lower velocity of the flame, it has worse fuel-air mixing. Combustion in the 90° burner comparing to 45° burner is less intensive, leads to increasing of the unburned fuel directly in flame (85% of the fuel burned directly in flame, 15%-oxidise in the chamber). On the other hand, it also leads to decreasing of the prompt and thermal NOx production. Comparing to the 45° burner 90° burner has by 10% lower NO prompt molar reaction rate and by 30% lower NO thermal molar reaction rate.

Combustion in 45° burner is more intensive as 98% of the fuel burned directly in flame. Such combustion can be characterised by higher flame temperature what results increasing the thermal radiation intensity.

4 CONCLUSIONS

The results of computer simulations confirmed the effect of changes in the oxidant supply and air nozzle geometry on the mixing intensity of gaseous media and the generation of emissions.

The analysis of simulation results confirms that:

- Insertion of the separating insert part into the air nozzle helped to adjust the flow of the oxidizing agent so as to shorten the flame and intensify the mixing of the gaseous media. The proof is the increased temperature behind the burner using a separating insert.
- Changing the dynamics of the flow in the air nozzle, by adjusting the supply of oxidizing agent, adjusted the flow of the resulting flue gases behind the burner. This change could intensify the circulation with flue gases on the charge and thus increase the intensity of heat exchange.
- Air inlet angle significantly affects flame kinetic. Air rotation by Z axis has significant influence on the flame direction. In

90° burner air rotation was approximately 1.5 circle while 45° burner had only 0.75. This led to the different flame length and orientation.

- Increasing of the air path due to rotation in 90° burner also, led to decreasing of the air velocity and pressure before it mixed with fuel. This fact results worse combustion parameters due to the impropriate fuel-air mixing. Otherwise, 90° had lower NO production what a reasonable factor for some production technologies may be.

The performed simulations are only a partial solution of the proposed change of the burner construction. The addition of oxygen influences the geometry and structure of the flame and therefore further research is needed.

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REFERENCES

[Barabas 2022] Barabas, J., Jovicic, V., Delgado, A. Simulation of a Hydrogen-Air Diffusion Flame under Consideration of Component-Specific Diffusivities. Applied Sciences, 2022, Vol. 12, 3138.

[Baukal 2001] Baukal, CH.E. Combustion Handbook. CRC Press, John Zink company LLC, 2001.

[Baukal 2004] Baukal CH.E., Industrial burners handbook, 1st ed. CRC Press, Boca Raton, USA, 2004.

[Bialik 2014] Bialik, W., Gil, S., Rozpondek, M. A Study on Emissions from Afterburning Chambers Included in Metallurgical Thermal Equipment. Arch. Metall. Mater., 2014, Vol.59, No. 2, pp.785-788.

[Blozon 2012] Blozon B. More efficient aluminium melting. [online] ATP journal, 2012. Available at: www.atpjournal.sk/rubriky/aplikacie/efektivnejsie-tavenie-hlinika.html?page_id=14223 (in Slovak)

[Durdan 2014] Durdan, M., Mojzisova, A., Laciak, M., Kacur, J. System for indirect temperature measurement in annealing process. Measurement, 2014, Vol. 47, pp. 911-918.

[Dzurnak 2019] Dzurnak, R., Varga, A., Kizek, J., Jablonsky, G., Lukac, L. Influence of Burner Nozzle Parameters Analysis on the Aluminium Melting Process. Applied Sciences, 2019, Vol. 9, 1614.

[EP 2021] European Parliament. Energy efficiency. [online] Downloaded October 21, 2021. Available at: www.europarl.europa.eu/factsheets/en/sheet/69/energy-efficiency

[Ferstl 2011] Ferstl, K., Masaryk, M. Heat transfer book. STU Bratislava, 2011. (in Slovak)

[Holubcik 2022a] Holubcik, M., Cajova Kantova, N., Jandacka, J., Caja, A. The Performance and Emission Parameters Based on the Redistribution of the Amount of Combustion Air of the Wood Stove. Processes, 2022, Vol. 10, 1570.

[Holubcik 2022b] Holubcik, M., Jandacka, J., Nicolanska, M. Design of a wireless monitoring system with emission analysis integration for solid-fuel based heating devices in households of SmartCity. Wireless Networks, 2022. https://doi.org/10.1007/s11276-021-02859-w.

[Hudak 2022] Hudak, I., Skryja, P., Bojanovsky, J., Jegla, Z., Krnavek, M. The Effect of Inert Fuel Compounds on Flame Characteristics. Energies, 2022, Vol. 15, 262.

[Jablonsky 2015] Jablonsky, G., Pastor, M., Dzurnak, R. Enrichment of combustible mixture with oxygen in practice. TU Kosice, 2015. (in Slovak)

[Kozubkova 2011] Kozubkova, M., Blejchar, T., Bojko, M. Modeling of heat transfer, mass and momentum. VSB-TU Ostrava, 2011. (in Czech)

[Kuznetsov 2020] Kuznetsov, E., Nahornyi, V., Krenicky, T. Gas Flow Simulation in The Working Gap of Impulse Gas-barrier Face Seal. Management Systems in Production Engineering, 2020, Vol. 28, No. 4, pp. 298-303.

[Lazic 2011] Lazic, L., Brovkin, V.I., Gupalo, V., Gupalo, E.V. Numerical and experimental study of the application of roof flat-flame burners. Applied Thermal Engineering, 2011, Vol. 31, pp. 513-520.

[Lin 2022] Lin, J., Li, H., Zhang, Y., Yang, J. Experimental and Numerical Study of a Two-Stage Swirl Burner. Energies, 2022, Vol. 15, 1097.

[Liptakova 2012] Liptakova, T., Jandacka, J., Malcho, M., Vojsovicova, M. Corrosion-erosion waste of metals in the duct system of the recycling aluminium. Communications - Scientific Letters of the University of Zilina, 2012, Vol.14, No. 4, pp. 37-42.

[Man 2011] Man, M., Modrak, V., Grabara, J.K. Marginal Cost of Industrial Production. Polish Journal of Management Studies, 2011, Vol. 3, pp. 62-69.

[Ozdemir 2016] Ozdemir, I.B., Kantas, M. Investigation of partially-premixed combustion in a household cooker-top burner. Fuel Processing Technology, 2016, Vol. 154, pp. 107-116.

[Poskart 2016] Poskart A., Radomiak H., Niegodajew P., Zajemska M., Musial D. The Analysis of Nitrogen Oxides Formation During Oxygen - Enriched Combustion of Natural Gas. Arch. Metall. Mater., 2016, Vol. 61, pp. 1925-1930.

[Reyes 2022] Reyes, M., Sastre, R., Gimenez, B., Sesma, C. Experimental, Kinetic Modeling and Morphologic Study of the Premixed Combustion of Hydrogen/Methane Mixtures. Energies, 2022, Vol. 15, 3722.

[Rimar 2020] Rimar, M., Kizek, J., Kulikov, A. Numerical Modelling of Gaseous Fuel Combustion Process with the Stepwise Redistribution of Enriched Combustion Air. MATEC Web of Conf., 2020, Vol. 328, 02001.

[Trpcevska 2015] Trpcevska, J., Laubertova, M. Metal waste and its processing. TU of Kosice, 2015.

[Varga 2013] Varga, A., Jablonsky, G., Lukac, L. Kizek, J. Thermal technology for metallurgists. TU of Kosice, 2013. (in Slovak)

[Variny 2019] Variny, M., Blahusiak, M., Janosovsky, J., Hruska, M., Mierka, O. Optimization study on a modern regeneration boiler cold end operation and its feedwater system integration into energy system of a paper mill. Energy Efficiency, 2019, Vol. 12, No. 6, pp. 1595-1617.

[Zarvandi 2022] Zarvandi, J., Baigmohammadi, M., Tabejamaat, S. A Numerical Study on the Effects of the Geometry and Location of an Inserted Wire on Methane–Air Flames in a Micro-Burner. Energies, 2022, Vol. 15, 93.

[Čajová 2011] Čajová Kantová, N., Čaja, A., Patsch, M., Holubčík, M., Ďurčanský, P.: Dependence of the flue gas flow on the setting of the separation baffle in the flue gas tract. Applied sciences, 2021, Vol.11, No. 7, pp. 1-13. ISSN 2076-3417 (online).

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