DOI: 10.2478/bhee-2017-0010

Professional paper/Stručni rad

ANALYSIS OF THE IMPACT OF STEAM BOILER FURNACE OPERATION PARAMETERS ON ITS GEOMETRIC PROPERTIES

ANALIZA UTICAJA RADNIH PARAMETARA KOTLOVSKOG LOŽIŠTA NA NJEGOVE GEOMETRIJSKE KARAKTERISTIKE

Midhat Osmić[1], Sead Delalić[1], Indira Buljubašić[1]

Abstract: Boiler plants of different constructional design were analyseanalysed in this paper. The setting of "design" and "off-design" simulation models was performed in order to determine the impact of series of operating parameters on the geometric properties of the steam boiler furnace. Within the "design" simulation model, the setting of the simulations was performed. On the basis of these simulations, curves that describe changes of geometric parameters of the boiler furnace were obtained in relation to the given energy properties. In case of the "off-design" simulations the geometric properties were given and the energy properties were "adapted" to the given geometry. After the performed simulations, the impacts of the most important operating parameters on the geometric properties of the combustion chamber were analysed. The results obtained by this analysis could be used when designing new or in revitalization of the existing boiler plants.

Keywords: steam boiler, geometric properties of the furnace, modeling and simulation

Sažetak: U radu su analizirani kotlovi različitih konstruktivnih izvedbi. Izvršeno je postavljanje „dizajn“ i „off - dizajn“ simulacionih modela s ciljem utvrđivanja uticaja radnih parametara na geometrijske karakteristike ložišta. U okviru „dizajn“ simulacionih modela izvršeno je postavljanje simulacija na osnovu kojih su dobijene krive promjene geometrijskih parametara ložišta kotla u odnosu na zadane energetske karakteristike. Kod „off -dizajn“ simulacija geometrijske karakteristike su bile zadane a energetske su se „prilagođavale“ postavljenoj geometriji. Nakon provedenih simulacija analizirani su uticaji radnih parametara na geometrijske karakteristike ložišta. Rezultati dobijeni predmetnom analizom mogli bi se iskoristiti prilikom projektovanja novih ili pri revitalizaciji već postojećih kotlovskih postrojenja.

Ključne riječi: parni kotao, geometrijske karakteristike ložišta, modeliranje i simulacija

INTRODUCTION

The introduction of appropriate assumptions in relation to the processes within the boiler plants related to the irreversibility of the combustion process, the kinetics of combustion, heat transfer and fluid flow have led to the fact that there are significant differences in the performance indicators obtained on the basis of daily measurements compared to those obtained by calculations and planned measurements [1]-[5]. According to the previously mentioned facts, the analysis of the steam boiler started so that the monitoring of individual plant components and the plant as a whole, which is not only about displaying the measured data, but also about selecting a set of relevant information. This provides diagnostic information about the processes in the observed steam boiler as well as the guidelines for improving the efficiency. The purpose of the monitoring the power plants with selecting parameters is actually a measurement procedure with the possibility of reducing the amount of information using appropriate models of the observed system. It should be emphasized that any monitoring system can provide current system status information by the positioned measuring instruments of the power plant [1], [2], [6], [7]. Special attention was given to the processes taking place in furnaces for combustion of solid fuels and their devices due to the use of the fuels of fuels of different quality. Therefore, it is a complex task for designers, constructors and users of the steam boilers, because they must meet the requirements related to economy of the operation on the one hand and protection of the environment on the other hand [5], [8], [9]. Energy steam boilers in the thermal power plants TPP Tuzla and TPP Kakanj were taken as the base for the research of the impact of energy and geometric parameters of the steam boiler furnace on the combustion process. Those are the boilers 5 and 6 in the TPP Tuzla firing a mixture of lignite and brown coal, and the boiler 7 in the TPP

[1]Faculty of Mechanical Engineering, University of Tuzla, Bosnia and Herzegovina
midhat.osmic@untz.ba
Paper submitted: October 2016 Paper accepted: February 2017

Kakanj firing brown coal [8].The aim of the research was to determine appropriate links of the furnace operating parameters with its geometric properties. It is important to note that the geometry or overall concept of the boiler plant depend on the anticipated strength of the boiler and the model of combustion. So, the boiler geometry is defined in designing the plant, and it almost cannot be affected later. There are possibilities of partial change of the boiler concept in the planned revitalization or major change actions of the plant geometric properties.

1. ANALYSIS OF STEAM BOILER FURNACE GEOMETRIC PROPERTIES

Experimental setup base for the simulation models are data taken from the normative tests boiler systems, on the one hand, and data obtained by daily measurements of the relevant boiler parameters necessary for creating the model [8]. Each created model hasthe basic, project “design” version, as well as a series of exploitation “off-design” versions. The project model version defines physical quantities such as the surface of the heat exchanger, while the exploitation model versions are used for analyzing performances of the observed plant in the event of a change in operation conditions.

1.1. Creating simulation models

The data obtained by normative tests on boiler plants are used as the basis for setting up the simulation models, and the same data were used in order to verify the simulation model [4]. Figure 1 provides the overview of the project model of one of the boilers, where graphical elements can be noticed symbolically representing the boiler elements such as: the furnace, feed water inlet into the boiler drum, water steam outlet from the evaporator, water steam outlet from the drum, feed water inlet into the boiler, air inlet, and flue gases outlet from the furnace. The red lines mark the flue gases and air flow, green line represents the water steam flow, and the blue lines represent the feed water flow [6], [8], [10]. In the software package Gate Cycle (the software made for the use on a PC, used both to design and to estimate the performancesof the thermo-energetic systems in the design and the exploitation phase) the setting up of the simulation model for the observed boilers [6], [10]. It should be noted that in this case the effects of large number of quantities were analysedand some of them will be shown diagrammatically. Figure 2 shows the value of the steam amount at the outlet of the boiler evaporator obtained by measuring, and the steam amount obtained from the model and the plant power. It can be seen that the plant power value follows the change in steam amount obtained by measuring, which is not the case with the steam amount obtained from the model. The steam amount obtained from the model does not follow the plant power change in a number of points, because larger amount of coal was put in the boiler in those moments to cover the losses of the lower quality of the coal. However, it was not possible to be done as a model, so for this reason at few places in a diagram, the clear deviationof steam amount obtained by measuring can be seen with those obtained from the model.

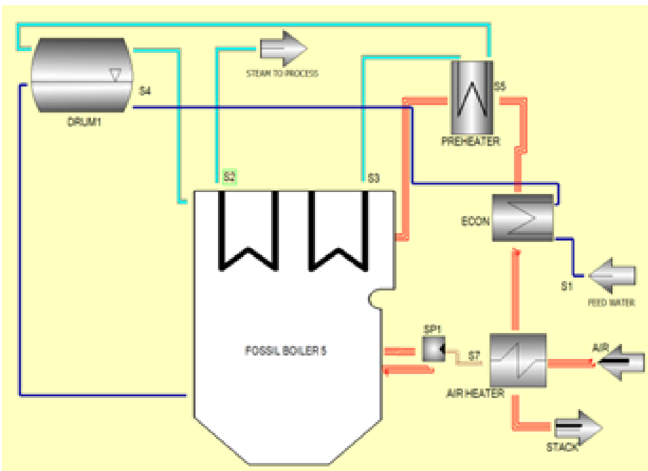

Figure 1: Display of the design model of the boiler

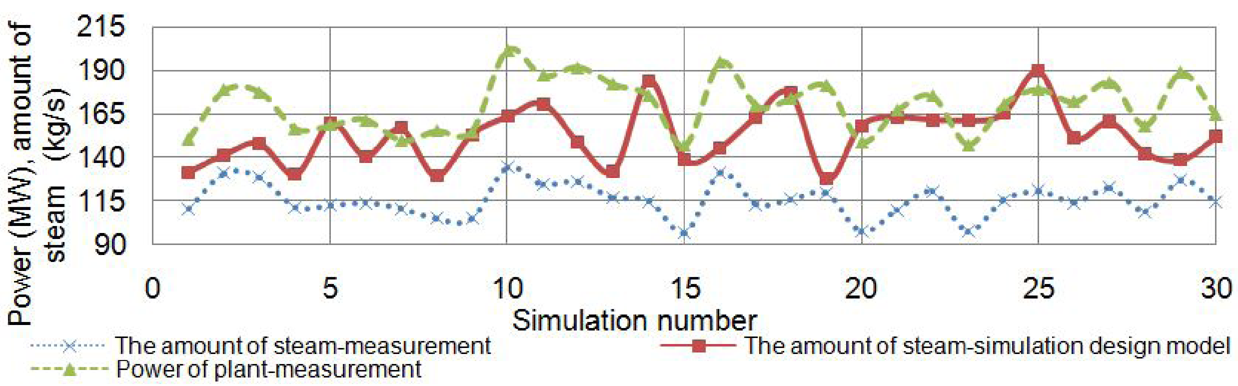

Figure 2: Change in plant power with a display of the deviation of the steam quantity obtained by modelling in relation of the steam amount obtained by measuring at the boiler 5 in the plant

Figure 3 presents the change in the air amount obtained by measuring in relation to the one obtained from the model. Again, the fact is expressed on the change of the lower calorific value of coal during the process, which cannot be predicted in the simulation model itself. This leads to the apparent discrepancies between these two air amounts.

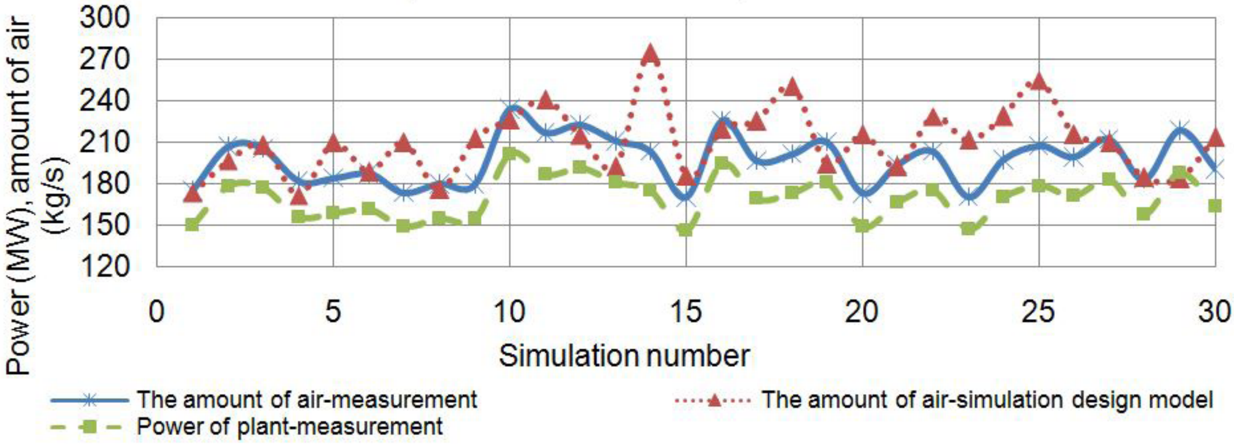

Figure 3: Change in plant power with display of deviation of the model amount in relation to the measured air amount at the inlet to the boiler 5

It can be seen in Figure 4 that the apparent volume of the boiler furnace changes at the boiler inlet. With the increased amount of coal, the apparent volume of the boiler furnace largely increases.

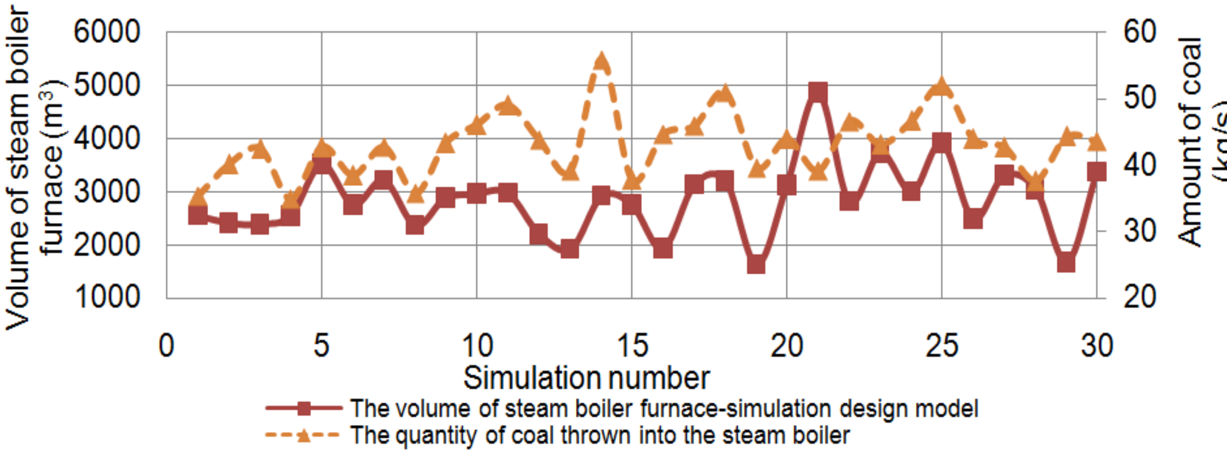

Figure 4: Display of the apparent volume change of the steam boiler furnace for different values of the coal quantity thrown into the boiler 5

Figure 5 presents the change of the apparent volume of the boiler furnace in relation to the change of flue gases temperature at the outlet of the furnace, where it is more clearly seen what the actual impact of the temperature is on the specified quantity.

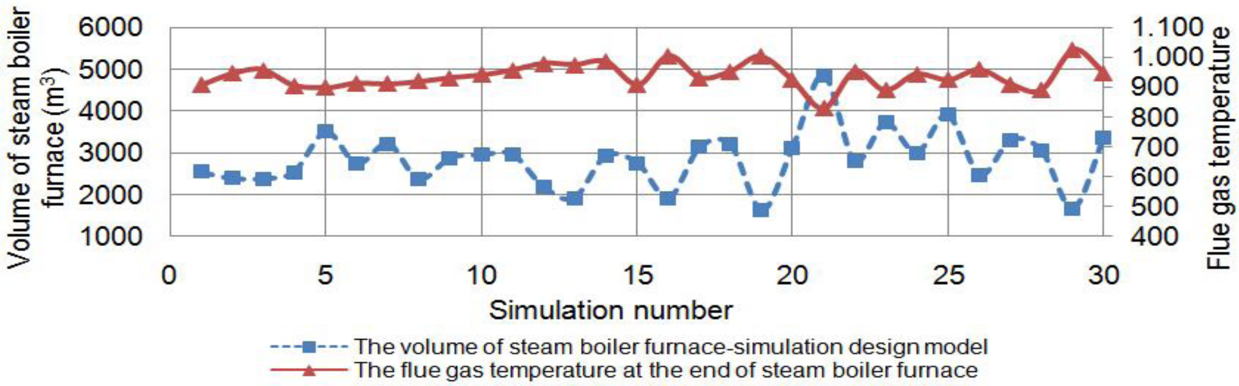

Figure 5: Display of the apparent volume change of the boiler furnace depending on the temperature of flue gases at the end of the boiler 5 furnace

After previously conducted comparison of the measured and model-derived values of the observed parameters it was noticed that the temperature of the flue gases at the end of the furnace, taking into consideration appropriate limitations, has on the geometric properties. In order to prove the impact of the furnace geometric properties on the combustion process, the process in the boiler furnace was analysed in a manner to set the appropriate number of “off design”, that is the exploitation simulations in which the geometry locking was made. As the starting point for the creation of “off design” simulations, the normative boiler model was used with the geometry whose value of the boiler walls area deviated from the project in 0,15%, then the height of the boiler furnace deviated in 9,2%, the furnace depth deviated in 1,3%, the furnace width which deviated in 5%, and the furnace volume deviated from the project in 7,5%. In fact, the parameters value of steam, temperature, flue gases and other factors necessary for the process in the boiler furnace had to be “adjusted” to the already set limitation, i.e. inability to change geometric properties. In this way it can be clearly seen which quantities depend on the geometric properties of the boiler furnace. What should be noted is that the values of the air amount, flue gases amount, air enthalpy, adiabatic temperature in the furnace, coal amount at the inlet in the furnace and the content in the same as in the design model. Figure 6 presents the correction of the steam production obtained in the design model,with variable geometric properties in relation to the one obtained in the off design model in which the geometric properties of the furnace were fixed. It has been shown that the change of steam production, for example in the interval of 130-180 kg/s would cause an apparent correction of the furnace wall area within approximately 1200-1700 m^2.

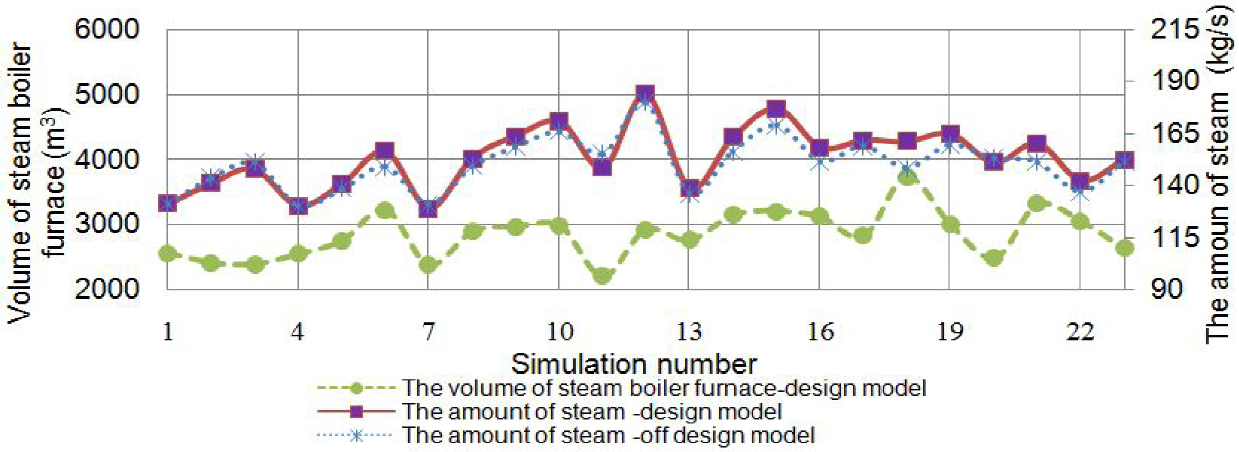

Figure 6: The correction of the steam production from the design model in relation to the steam amount obtained in off-design model with different coal amount and fixed furnace volume

Figure 7 shows the correction of the flue gases temperature at the end of the furnace for the design model in relation to the same temperature obtained in the off design model. There has been an intensivedeviation of these two temperatures especially for the experiments which in the design model had great deviation of the geometric properties of the furnace in relation to their values defined by the project. So, in order to maintain the project values of the furnace geometric properties it is inevitable to change the process parameters. For example, it can be seen in the Figure 7 that, for example, the flue gases temperature is corrected for 60 °C, so on the other side the furnace walls area would be corrected for approx. 300 m^2 in relation to the design model.

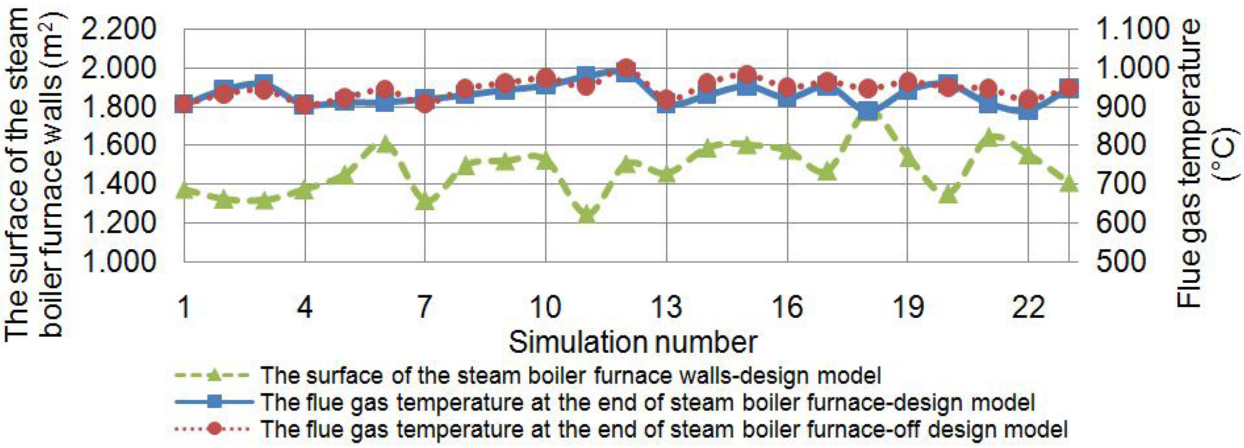

Figure 7: The correction of the flue gases temperature from the design model in relation to the flue gases temperature obtained in the off design model with different coal amount and fixed wall area

2. RESULTS OF MODELLING

By the analysis of the adequate number of experiments, setting the simulation model and the off design model it has been established that the greatest impact on the furnace geometric properties of the subject steam boilers has the flue gases temperature at the end of furnace. The same level of the interval of the observed parameter was selected for each of the mentioned steam boilers. Table I provides minimum and maximum value of the parameter and the interval of its change.

Table I: The interval of the observed parameters

Parameter	Minimum value	Maximum value	Interval
Flue gas temperature	800 °C	1200 °C	100°C

The value of flue gases temperature of 800 - 1200 °C was included in the existing simulation models, without changing other parameters within the simulation model. After creating the simulation models obtained in this way, the impact of the furnace shape factor (*F*) on the observed properties was analysed.The shape factor was observed in limits of 2 to 6 with step 1, where it represents the ratio of the boiler furnace height and depth. The geometric parameters whose change was analysed in case of the change of operating parameters in this case are the boiler furnace volume and the area of its cross section. The result comparison was made after the same procedure was done on the boilers 5, 6 and 7.

2.1. Change of geometric parameters of the steam boiler furnace depending on the flue gases temperature at the end of steam boiler furnace

The comparison of the furnace volume change in boilers 5, 6 and 7 depending on the flue gases temperature at the end of the furnace, and for different values of the furnace shape factor it is shown in Figure 8. It is about the exponential change of parameters which is valid for the observed boilers. It is noticeable that at the temperatures lower that the normative for the given boilers, the apparent volume increases, that is, its value drastically increases comparing to the mentioned normative value. However, this is not the case for flue gases temperatures higher than the normative. It should be emphasized that by increasing the furnace shape factor for the same values of the flue gases temperatures, the apparent volume increased in less intensity, which shows that with the optimal choice of the geometric properties the errors which might occur between the project and the real used furnace volume can be reduced. The volume value which is in the appropriate measure close to its normative or project value can be read for every value of the furnace shape factor of that normative value of the flue gases temperature from the diagram.

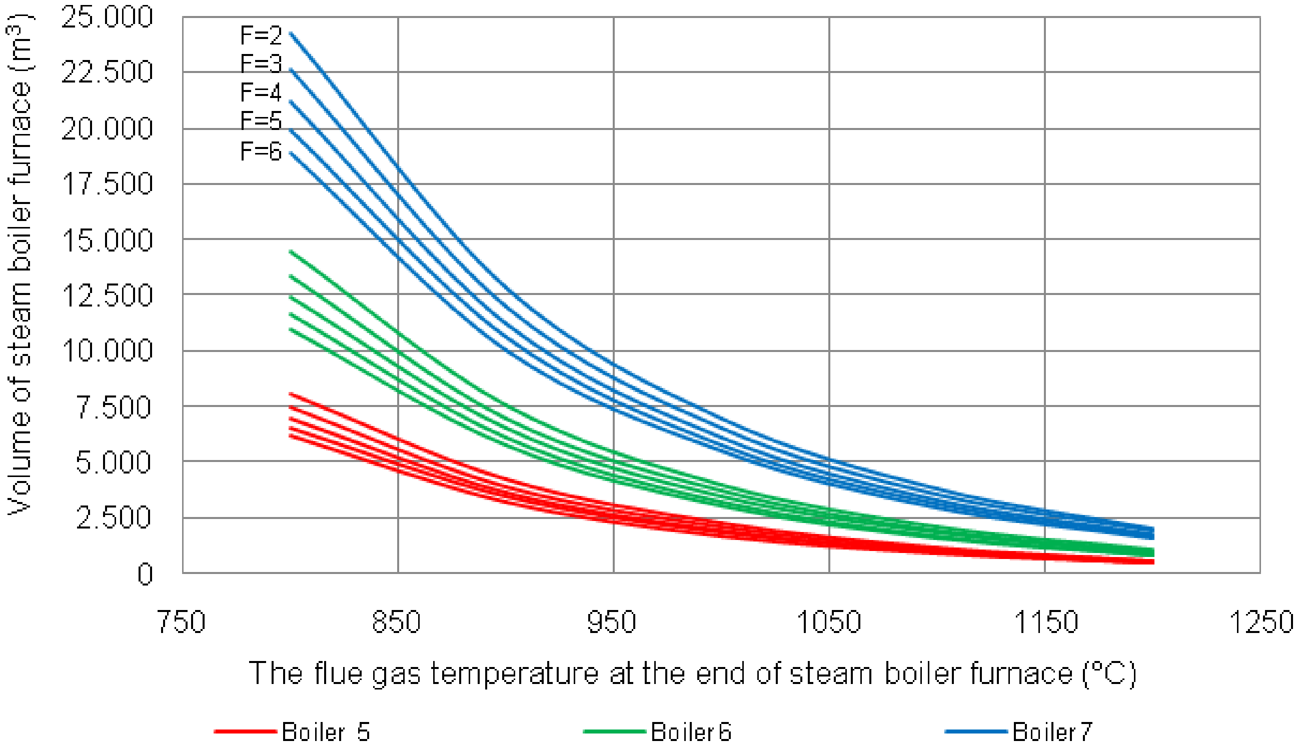

Figure 8: The comparison of the volume of the three furnaces in case of the change of flue gases temperature at the end of the furnace and for the shape factors of the furnaces 2, 3, 4, 5 and 6

Figure 9 shows the comparison of the changes of the furnace cross-section for the boilers 5, 6 and 7, and for different values of the furnace shape factors and observed interval of the flue gases temperature. The mentioned parameter changed exponentially. Identical to the change of the furnace volume, the area of its cross-section intensively changed at lower flue gases temperature. The curves for the boilers 5 and 6 are a lot less severe, while the curves of the boiler 7 are steeper. It is reversed with the flue gases temperatures, which are higher than the normative values. The curves are much gentler and the deviations from the project values of the cross-section areas are much smaller.

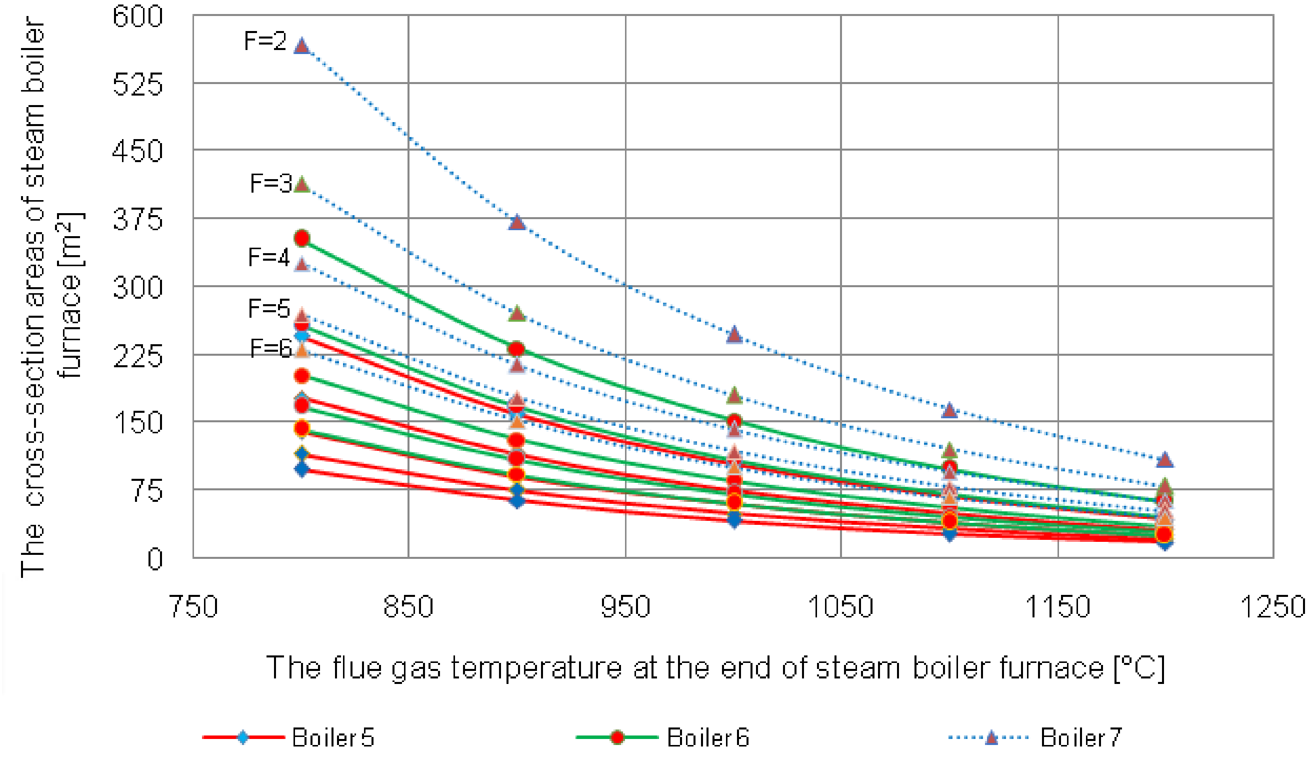

Figure 9: The comparison of the cross-section areas of the three furnaces in case of the change of flue gases temperature at the end of the furnace and for the shape factors of the furnaces 2, 3, 4, 5, and 6

3. CONCLUSION

After selecting the relevant number of measurements, the number of experiments, it was started with creating the “design” and “off design” simulation model. By comparing the obtained results, it turned out that the flue gases temperature at the end of the furnace has the greatest impact on the geometric properties of the furnace. The basic properties of the furnace analysed in this case were: the furnace volume and the area of its cross-section. When comparing the changes of the furnace volume for the boilers 5, 6 and 7 depending on the flue gases temperature and the furnace shape factor (*F*) it was clear that it is an exponential change of parameters. It was very clearly revealed that the apparent furnace volume distinctively increases, that is, its value drastically increases in relation to its project values, at the temperatures lower than the normative for the given boilers. As a result, the boiler with the lowest value of the normative flue gases temperature used for model verification is also the one whose values of the observed properties had the smallest deviations from their project-defined values. In this case it was the boiler 5 with the normative flue gases temperature of 975 °C. Also, in the case of the boiler 5, the smallest impact of the furnace shape factor was recorded on the change of its volume, and it has been shown that its impact noticeably weakens it the increase of the flue gases temperature at the end of the furnace.

The areas of the furnace cross-sections for the boilers 5, 6 and 7 changed exponentially, identically to the furnace volume. Its value intensively changed at lower flue gases temperatures. It was shown that the curves for the boilers 5 and 6 are quite mild, while the curve for the boiler 7 is much steeper, with apparent areas of cross-section which are up to two times higher than those given in the project documentation. Furthermore, it was shown that with the increase of the furnace shape factor occurs the weakening of its impact on the area of the furnace cross-section, but that the same impact is much more expressed than with the furnace volume.

It should be noted that the error of the simulation model in relation to the measured values or the values taken from the normative in case of the change of the flue gases temperature was below 10%.The results of these and similar researches, for the most part, can be used in designing new plants, and to a lesser extent during revitalization of the existing systems.

REFERENCES

[1] N. Khaldi, Y. Chouari,H. Mhiri,P. Bournot: CFD investigation on the flow and combustion in a 300MWe tangentially fired pulverized-coal furnace,Heat and Mass Transfer, pp 1-10, Springer Berlin Heidelberg, 2015
[2] W. Songhao, L. Syun-Cheng, Y. Yu-Ching: Geometry estimation for the inner surface in a furnace wall made of functionally graded materials, Heat and Mass Transfer, Elsevier, Volume 67, Pages 1–7, 2015
[3] N. Yanqing, L. Xing, Z. Yiming, T. Houzhang, W. Xuebin: Combustion characteristics of a four-wall tangential firing pulverized coal furnace, Applied Thermal Engineering, Elsevier, Vol. 90, 471–477, 2015
[4] M. Osmić: Influence of the constructional characteristics of steam boiler combustion chamber on the combustion process of coal dust,doctoral thesis, Mechanical Faculty of Tuzla, 2016
[5] M. Gulič, Lj. Brkić, P. Perunović: Steam boilers, Faculty of Mechanical Engineering in Belgrade, 1988
[6] R. R. Gay, C.A. Palmer, M. R. Erbes: Power Plant Performance Monitoring, R-Squared Publishing, P.O. Box 8520, Woodland, CA 95776, 2004
[7] I. Buljubašić, S. Delalić: Improvement of steam boiler plant efficiency based on results of on-line performance monitoring, Technical Gazette, Vol. 15, no. 3, 2008
[8] Technical Documentation with Normative Tests for Boilers in TPP Tuzla and TPP Kakanj, 2010, 2004
[9] Lj. Brkić, T. Živanović: Steam boilers, Faculty of Mechanical Engineering in Belgrade, 1997
[10] GE Energy:GateCycleTM, Getting started & installation guide, SAD, 2006

BIOGRAPHY

Midhat Osmić was born in Tuzla. He graduated from the Faculty of Mechanical Engineering in Tuzla, in 2007. After the graduation, he worked at the Institute for Ecology, Protection and Education in Tuzla at the position of a vocational mechanical engineer, and starting with the 4thof October 2008, he has been workingas a teachingassistant at the Faculty of Mechanical Engineering in Tuzla. He got his Master's degree in 2011 at the Faculty of Mechanical Engineering in Tuzla and therefore earned the title of the Master of Technical Sciences. He participated in 8 research projects and 6 professional projects. In his teaching and scientific work he has published 7 scientific papers. Since 2016 he has been employed at the Facultyof Mechanical Engineering as an assistant professor in the field of "Energy Plants and Ecology".

Sead Delalić was born in Živinice. He graduated from the Faculty of Mechanical Engineering in Sarajevo in 1979. After the graduation, he was employedatthe TPP Tuzla where he worked as a shift engineer, and later as a lead engineer for boiler, pump and turbine plants. He finished the postgraduate study at the Faculty of Mechanical Engineering in Sarajevo in 1990. He defended his doctoral thesis at the Faculty of Electric Engineering in Tuzla in 1996. In the 2008/09 academic year he was elected a professor in the department of "Energy Mechanical Engineering" at the Faculty of Mechanical Engineering in Tuzla.

Indira Buljubašić was born in 1971 in Mostar. After completing undergraduate studies at the Faculty of Mechanical and Electrical Engineering of the University of Tuzla in 1997, she completed post-graduate study programme in 2001 and defended her doctoral thesis at the Faculty of Mechanical Engineering of the University of Tuzla in 2008, becoming the Doctor of Technical Science in the field of mechanical engineering. She is an associate professor in Energy Plants and Ecology, at the Faculty of Mechanical Engineering in Tuzla, where she pasionatly teaches and carries out scientific work and research.