THE ELECTRIC ARC FURNACE OFF-GASSES MODELING USING CFD

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ABSTRACT

This article includes basic information about the functioning of electric arc furnace (EAF) and a modern research method - Computational Fluid Dynamics (CFD) - used among other things in metallurgy. The paper also contains a few samples how CFD helped solve and analyse problems strictly combined with the work of EAF. Sample computer model of an off-gas duct was defined for the purposes of this article. Based on this model a series of numerical simulations was conducted. These calculations aim at solving the problem of fumes flow inside the cooling duct taking into account the CO combustion process. The results of the described above CFD simulations in the fumes temperature distribution range and their brief analysis were included into this article.

Key words: CFD, electric arc furnaces, off-gas model

1. INTRODUCTION

The modern electric arc furnace together with the technology intensifying the steelmaking process results in the emission of substantial amounts of off-gases and dust. In order to comply with environmental requirements the construction of the steel bowl of the furnace has to possess an efficient off-gas system which sucks out the gases and dust. The OGS (off-gas system) is responsible for intercepting gases and dust from the working section of the furnace as well as for the post-combustion of CO, cooling and filtering. The choice of the OGS and its parameters is decisive when it comes to its effectiveness, i.e. the contents of the undesirable gases and dust emitted to the atmosphere and natural environment. The off-gas system modelling makes it possible to choose a proper construction and technological parameters. One of the ways of modelling is to use Computational Fluid Dynamics (CFD). On the basis of the structure parameters of the OGS a sample computer model of an off-gas duct of an electric arc furnace having the capacity of 140mg was defined. The defined model was then used in a series of simulations aiming at analysing the technological parameters of the flowing gases. Assuming the changing temperatures as well as the changing speed of the flow and the changing chemical content of the gases entering the system, the following were calculated: temperature distribution, the speed of flow and the content of carbon monoxide in the cross-section and horizontal section of the modelled duct. This study presents only the results of the calculations concerning the temperature distribution range in the cross-section of the duct from the furnace in focus.

2. USING CDF TO ANALYSE THE OFF-GAS SYSTEM IN ELECTRIC ARC FURNACES

CFD was also used in the analysis of the phenomena occurring in electric arc furnaces in off-gas systems handling gases and dust [1, 2]. The calculations made during the simulations allow one to point precisely to a range of important factors which influence the metallurgical processes as well as to structure parameters, physical and chemical parameters of gases and dust in the system, all of which have a substantial effect on the production costs and the improvement of the purity of natural environment.

CFD was used to solve the main problems such as the widely understood control of gases emitted by arc furnaces to the atmosphere as well as the optimisation of the work of these appliances. Computational methods can also be used to conduct simulations of gas emission and chemical reactions which the gases take part in. CFD is used to simulate the process of obtaining nitric oxides NO_x. The mechanisms of production of these harmful compounds have been known for many years. The complexity of this process, however, makes it necessary to conduct further research into this matter in order to reduce their harmful effect [3].

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Thanks to using a 3D model of the electric arc furnace, CFD analysis provides a better understanding of the process of scrap metal smelting and a possibility of assessing the amount of energy which is emitted by the electric arc and then absorbed by the charge and other elements of the furnace itself. The obtained profiles of the intensity of radiation inside the furnace allow a detailed assessment of the amount of energy used in the smelting process as well as the amount of energy received by the furnace's walls, roof and electrodes. Precise calculations help predict the speed of the smelting process and they help choose the optimal parameters of the furnace which can ensure its long and reliable work. Computer simulations help establish the technical and operational parameters of the system cooling the furnace's elements which are subject to high temperatures [4].

Numerical fluid dynamics allows a precise prediction of the processes taking place in the electric arc furnaces and by means of such knowledge it also makes it possible to optimise the metallurgical processes with relatively low costs. Modern numerical methods minimise the time-consuming aspect of such studies or of experimental measurement. CFD is a field of science which is developing extremely dynamically. Particular models used in those programmes are constantly being improved and developed. Several year long observations allow one to claim that the computational methods like these will in future replace the more expensive and time-consuming experimental studies [5].

3. COMPUTER MODEL OF AN OFF-GASS DUCT IN THE ELECTRIC ARC FURNACE

Computational Fluid Dynamics (CFD) was used to conduct an analysis of the off-gases from the arc furnace having the capacity of 140Mg. On the basis of the technical specification a geometrical model of a duct was prepared. It was then used during the computer simulation (Figure 1).

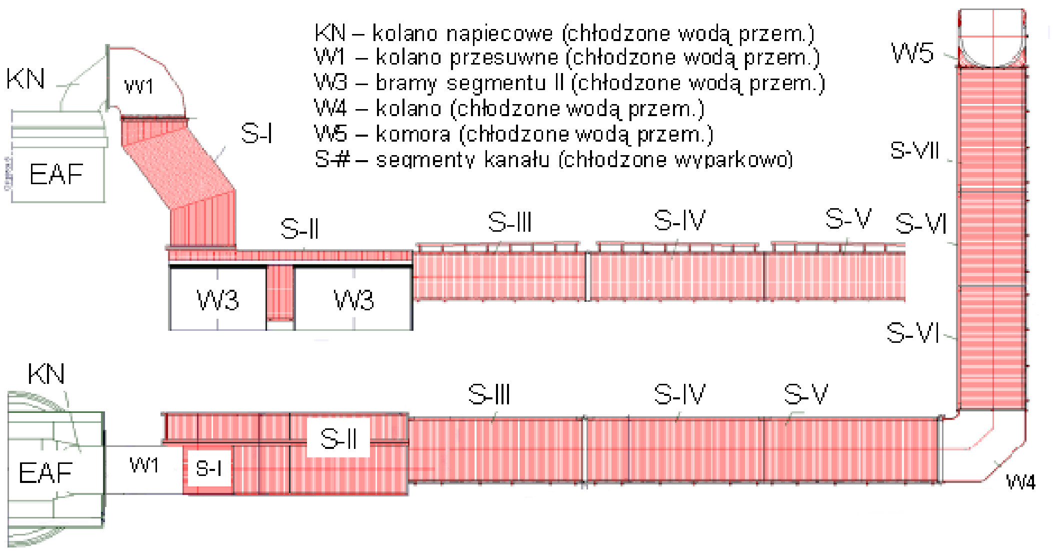

Figure 1. A simplified design of the off-gas duct of the arc furnace having the capacity of 140Mg.

KN – voltage joint (cooled by industrial water)
W1 – movable joint (cooled by industrial water)
W3 – the gates of segment II (cooled by industrial water)
W4 – joint (cooled by industrial water)
W5 – chamber (cooled by industrial water)
S# - the segments of the duct (cooled by means of an evaporator)

Table 1 presents data concerning the calculation grid as well as the information concerning the models used in the computer analysis. The flowing and thermal character of the simulation was assumed, which resulted in implementing a layer next to the wall in order to correctly determine the profile of the flowing gas and the exchange of the energy between the walls of the duct and the fumes.

Table 1. Numerical parameters of the computer model of the off-gas duct of the furnace.

Grid	• Elements	1,4mln – hex
	• Nodes	1,5mln
Solver	• Fluent 6.1	Solver – segregated, time - steady
	• Models: Energy Turbulence Chemistry	 k-epsilon Finite-rate/Eddy-dissipation

Simulative calculations for two different stages of the smelting process having entirely different marginal conditions were conducted. Simulation I was conducted for the marginal conditions existing in the period of the least favourable conditions in the off-gas system. Simulation II, on the other hand, was conducted for the marginal conditions existing during pouring off the molten metal batch, i.e. in the period of the most favourable conditions in the off-gas system.

In the real system measurements were made. In selected points the following were measured: the temperature, chemical content of the gases as well as the temperature of the water supplied for cooling the duct's segments during the smelting process in the furnace.

The results of the measurements of temperature and chemical content served as marginal conditions for the medium. The information concerning the cooling water temperature and the design parameters of the cooling system of the duct allowed the assessment of the temperature of the duct's walls at the given stage of the analysed smelting process.

The assumed marginal conditions used in the simulations were presented in table 2. Marginal pressure conditions determining the intensity of the off-gas flow were specially selected so that the mass flow at the duct exit would be similar to the value resulting from the measurement.

Table 2 The marginal conditions assumed during simulative calculations

Condition	**Features**	**Value/ Source**	
		Simulation 1	**Simulation 2**
Exit EAF (Duct entry)	• Intensity of the flow	Determined by pressure	Determined by pressure
	• Pressure	Atmospheric	Atmospheric
	• Temperature	1893 °K (measurements)	Assessment
	• Chemical content: CO_2 CO O_2	(measurements) 19.0 % 19.3 % 0.0 %	(measurements) 3.2 % 1.1 % 17.7 %
Air split	• Intensity of the flow	Determined by pressure	Determined by pressure
	• Pressure	Atmospheric	Atmospheric
	• Temperature	323 °K	323 °K
	• Chemical content	Atmospheric air	Atmospheric air
	• Width	400mm	200mm
Duct exit	• Intensity of the flow	(measurements)	(measurements)
	• Pressure	Assessment	Assessment
Industrial water	• Intensity of the flow Joint W1 Chamber's gates S2 Joint W4 Chamber W5	Technical specification	Technical specification
	• Temperature	(measurements)	(measurements)
Water from the evaporator	• Intensity of the flow Segment I-VII	Technical specification	Technical specification
	• Temperature	(measurements)	(measurements)
Duct segments	• Temperature	Assessed on the basis of the temperature measurement of the industrial water and the water from the evaporator	

For the purposes of this article only the analysis results of the off-gas temperature in the off-gas system were presented. The results of simulation I conducted for the off-gas temperature distribution range from voltage joint to segment III were presented in figure 2 while the results for the off-gas temperature distribution range from segment IV to the duct exit were presented in figure 3. The measurement points and the measured temperature values were also marked in the pictures.

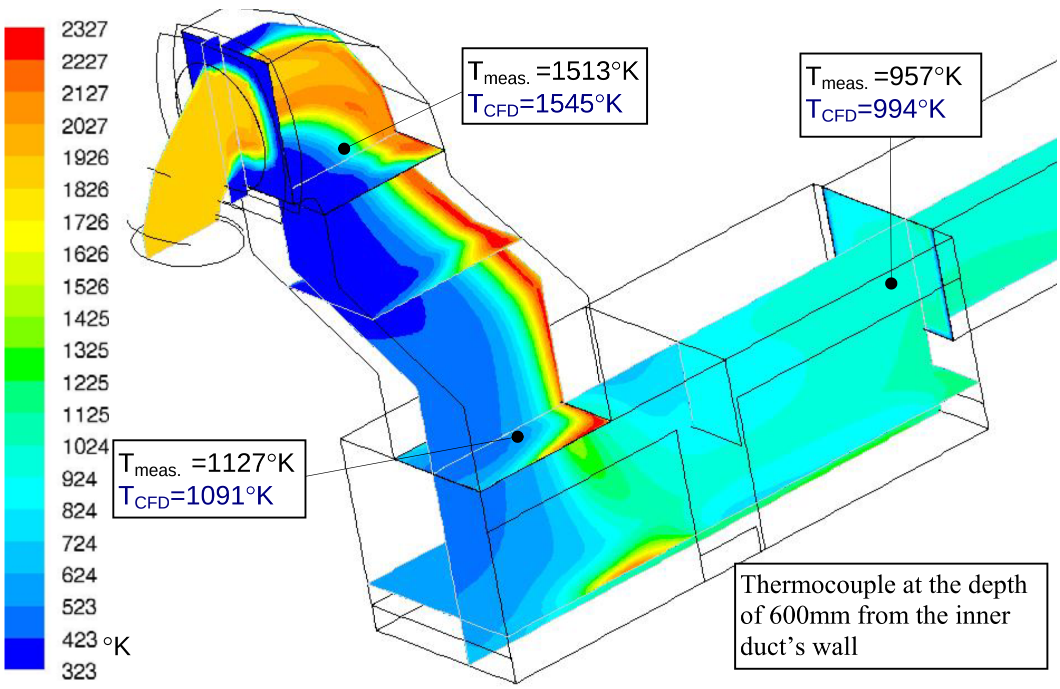

Figure 2. The temperature distribution range of the off-gases in the part from voltage joint to segment III (simulation I)

Figure 2 shows that significant changes in temperatures were observed only after the air split which can be found between the voltage joint and the movable joint W1. It is the result of the mixing of cool atmospheric air sucked in by the split together with hot gases coming from the furnace. The temperature distribution range suggests that the gasses reach the highest temperature (approx. 2300°K) in the movable joint W1 and segment I. It is the result of a reaction consisting in post-combustion of carbon monoxide in the oxygen rich air. The area of high temperature is clearly moved toward the walls of W1 and segment I which are closer to the exit. It is determined by the geometry of the duct and, what is more important, by the positioning of the exit of the chamber (segment II). Inside the first part of the chamber there is a clearly visible gas whirl caused by a barrier blocking the flow. The barrier, which is being cooled by water, is responsible for disturbing the gas flow and in this way for preventing the hot fumes from getting away quickly from the chamber. The intensification of the post-combustion of carbon monoxide and reception of the heat by a large surface of the walls is the result of this process. The fall in temperature of fumes in the said part of the duct amounts to approx. 900 °K. The maximum difference between the CFD results and the measurements in the said part of the duct amounts to 4%.

Figure 3. presents the temperature distribution of gases in the farther part of the duct, i.e. from segment IV to the duct exit. The temperature profiles show that the flow inside this part of the duct is regular and without whirls. Contrary to the above mentioned part of the duct, here the process of the post-combustion of carbon monoxide does not occur. What takes place is the reception of thermal energy of the off-gasses by the walls of the segments cooled by water. The fall in the fume temperature in this part of the duct amounts to 100 °K. The difference between the CFD results and the measurements conducted near the duct entry amounts to 3%. Table 3 summarises other parameters of the duct exit, such as the intensity of the flow and the chemical content obtained as a result of simulation I.

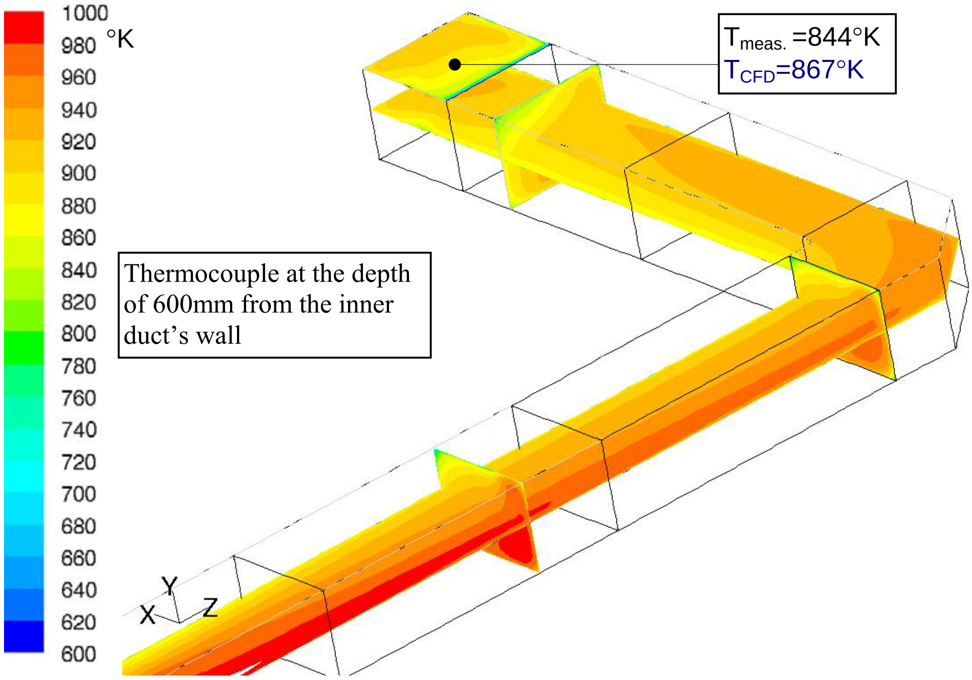

Figure 3. The temperature distribution range of the off-gases in the part from segment IV to the duct exit (simulation I)

Table 3. Parameters of the off-gases at the duct exit obtained during the simulation

Temperature [°K]		Intensity of the flow [kg/s]		**Chemical content** [% volume]					
				CO_2		CO		O_2	
Measurement	CFD	Measurement	CFD	Measurement	CFD	Measurement	CFD	Measurement	CFD
844	867	103	104	-	11	0.0005	0	23	16

The conditions of simulation II were presented in figures 4 and 5. The former figure contains the temperature profiles of the off-gases in the part from voltage joint to segment III. Taking into consideration the stage of the smelting process, i.e. pouring off steel which is simulated in the second case, one can notice lower temperatures of the fumes. Lower temperatures of the flame in the duct are mainly the effect of a radically lower content of carbon monoxide. The area of lower temperatures in segment I, which is smaller than in simulation number 1, was caused by reducing the air split from 400mm to 200mm and what follows by reducing the amount of cool atmospheric air which is sucked into the system. The gases reach the peak temperatures inside the movable joint W1 and the voltage joint. The fall of gas temperature in this part of the duct amounts to approximately 450 °K. The maximum difference between CFD results and measurements in the said part of the duct amounts to 8%.

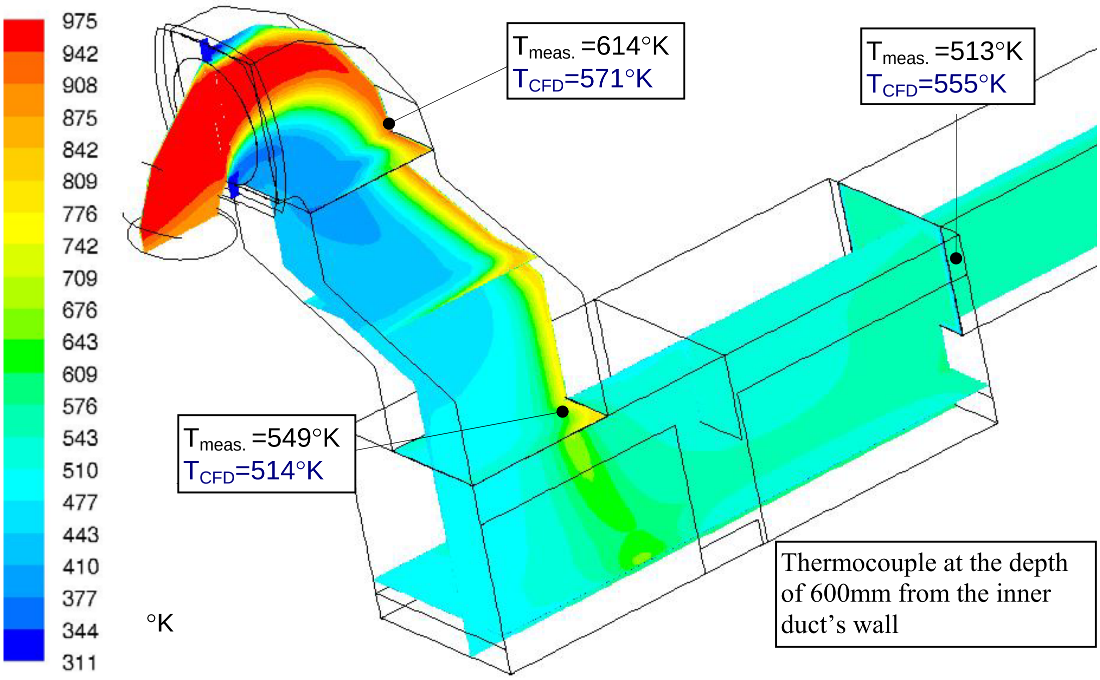

Figure 4. The temperature distribution range of the off-gases in the part from voltage joint to segment III (simulation II)

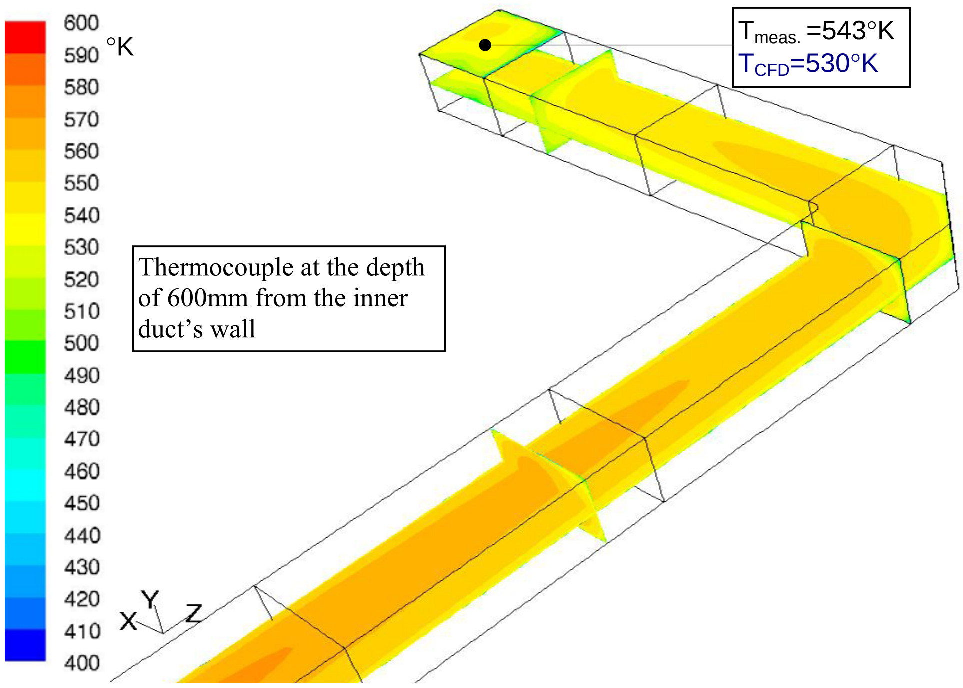

Figure 5. The temperature distribution range of the off-gases in the part from segment IV to the duct exit (simulation II)

Figure 4 presents the temperature distribution range of the off-gases in the part from segment IV to the exit of the duct. Similarly as in simulation I, the flow in this part of the duct is stable and not subject to any whirls. The post-combustion of carbon monoxide does not occur as the result of low content of carbon monoxide in the off-gases during pouring off steel. The gas temperatures do not exceed 600 °K. The fall in gas temperature in the above described part of the duct amounts to approx. 30 °K. The difference between CFD results and measurements near the duct exit amounts to 3%. Table 4 summarises other parameters of the duct exit obtained during simulation II.

Table 4 Off-gas parameters at the duct exit obtained during simulation II

Temperature [°K]		Intensity of the flow [kg/s]		Chemical content [% volume]					
				CO_2		CO		O_2	
Measurement	CFD	Measurement	CFD	Measurement	CFD	Measurement	CFD	Measurement	CFD
543	530	108	109	-	1.8	0.0002	0.005	24	19.4

4. SUMMARY

Computational Fluid Dynamics (CFD) is one of the methods of modelling the off-gases duct in the electric arc furnace. The method was used to analyse the work of the off-gas system in the electric arc furnace having the capacity of 140mg. On the basis of structure parameters of the system a computer model of the duct was presented and simulative calculations were conducted considering changing temperatures, the speed of the flow and the chemical content of the gases entering the system.

The temperature distribution range as well as the speed of the flow and carbon monoxide content in the cross-section and horizontal section of the modelled duct were then calculated. In order to verify the accuracy of the temperature results obtained by means of the CFD method, a series of numerical calculations for two different stages of the smelting process followed. Marginal conditions for simulation I are equivalent to the conditions existing in the off-gas system during the process of smelting the scrap metal. Marginal conditions for simulation II, on the other hand, are equivalent to the conditions existing during the process of pouring off steel. The choice of the simulated stages of the technological process depended on the least favourable and the most favourable conditions in which the system operates.

The verification of the obtained results was conducted by means of a series of temperature measurements made at selected point of the duct during real operating conditions. Relatively small differences between the simulated results and the actual measurements suggest that the off-gas system designed according to the CFD method was a success. Such a system can be used with great precision to simulate the temperatures in its various parts and other technological stages of the steel making process.

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Work subsidised by the AGH statutory research fund no. 11.11.110.564