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Numerical Analysis of Plasma Combustion Systems for NOX and COX Emissions in Thermal Power Plant Boiler"

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Abstract: In present study mathematical modelling and analysis of conventional and plasma combustion is done using Ansys (Fluent). Performance of two turbulence models, standard k-ε model and SST model, are compared. The effect of particle dispersion on predicted results is found to be insignificant. Pulverized coal fired boilers are basic steam generators in power plants. The conventional start up of this type of boilers require of heavy oil till the pulverised coal burners could start. We compared the both type of combustion on the basic of mass fraction of CO, CO_2, NO NO_2 emissions and stability phenomenon in whole systems. Simulations results gives a clear indication that due to increasing resting time of combustion in plasma type , complete combustion is possible and emission percentages is decreasing as compare to the conventional oil fuel . In plasma combustion there is no need oil for start up operation and flame stabilization, that why it is a cost effective method also. Plasma activation of coal particles instead of using fuel-oil burners promotes more effective and environment friendly combustion.
Key Words: Plasma combustion, power plant, Boiler, Furnaces, Burners, CFD, Mathematical modelling, NOx .

I. INTRODUCTION

The technology of plasma ignition of coal and its realizing plasma-fuel systems (PFS) is electro- thermo-chemical preparation of fuel to burning (ETCPF) [1] – [6]. In this technology pulverized coal is replaced traditionally used for the boiler start up and pulverized coal flame stabilization fuel oil or natural gas. Part of the coal/air mixture is fed into the PFS where the plasma-flame from plasma torch, having a locally high concentration of energy, induces gasification of the coal and partial oxidation of the char carbon. As coal/air mixture is deficient in oxygen, the carbon being mainly oxidized to carbon monoxide. As a result, a highly reactive fuel (HRF) composed of mixture of combustible gases (at a Temperature of about 1300 K) and partially oxidized char particles is obtained at the exit of the PFS. On entry to the furnace, this HRF is easily ignited. Plasma assisted coal combustion is a relatively unexplored area in coal combustion science and only a few references are available on this subject [1]. Coal fired utility boilers face two problems, the first being the necessity to use expensive oil for start-up and the second being the increased commercial pressure requiring operators to burn a broader range of coals, possibly outside the specifications envisaged by the manufacturer's assurances for the combustion equipment. Each of these problems results in a negative environmental impact. Oil firing for start-up increases the gaseous and particulate burden of the plant. The firing of poorer quality coals has two disadvantages: reduced flame stability performance necessitating oil support and its consequential emissions and cost implications; and reduced combustion efficiency due to a increased amounts of carbon in the residual ash, resulting in an increase of emissions per MW of power generated. Plasma aided coal combustion represents a new effective and ecological friendly technology, which is equally applicable to alternative 'green' solid fuels. One of the prospective technologies is Thermo Chemical Plasma Preparation of Coals for Burning (TCPPCB). This technology addresses the above problems in TPP. The realisation of the TCPPCB technology comprises two main steps. The first includes numerical simulations and the second involves full-scale trials of plasma supported coal combustion in a TPP boiler. For both the numerical study and full-scale trials, the boiler of 200 MW power of Gusinoozersk TPP (Russia) was selected. In the framework of this concept some portion of pulverized solid fuel (pf) is separated from the main pf flow and undergone the activation by arc plasma in a special chamber – PFS (Fig.1). The air plasma flame is a source of heat and additional oxidation, it provides a high temperature medium enriched with radicals, where the fuel mixture is heated, volatile components of coal arc extracted, and carbon is partially gasified. This active blended fuel can ignite the main pf flow supplied into the furnace. This technology provides boiler start-up and stabilization of pf flame and eliminates the necessity for additional highly reacting fuel.

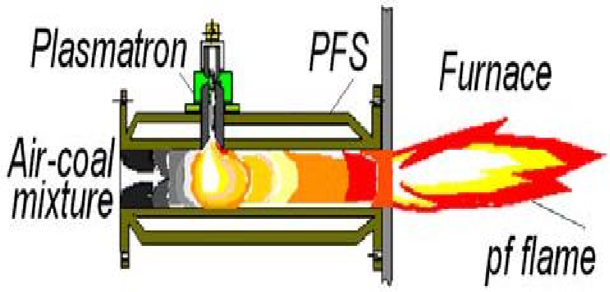

Figure 1 Arch plasma in a special chamber

PFS have been tested for boilers plasma start-up and flame stabilization in different countries at 27 power boilers steam productivity of 75 to 670 TPH equipped with different type of pulverized coal burners [3]. At PFS testing power coals of all ranks (brown, bituminous, anthracite and their mixtures) were used. Volatile content of them varied from 4 to 50%, ash - from 15 to 48% and calorific values - from 6700 to 25100 kJ/kg. In summary, it is concluded that the developed and industrially tested PFS improve coal combustion efficiency and decrease harmful emission from pulverised coal fired TPP. This technology is especially actual one for the countries with high share of coal fired TPP. For example coal output in China is 2.23 billion tonnes in 2005 [2], making China by far the world's largest coal producer (the next largest, the United States, produced 1.13 billion tonnes last year). India's total installed generating capacity in the utility sector in 2005 was 115,000 Mew, of which 67,000 Mew, or 58%, was coal fired. Coal currently accounts for about 70% of total electricity generation in India. The comparable figures in China were about 508,000 Mew of total installed capacity, with coal plants accounting for over 70% of installed capacity and about 80% of generation. As concern the USA, Russia and Kazakhstan, share of coal fired TPP in total electricity generation is about 60%, 30% and 80% respectively. The following advantages of plasma technologies of oil-free boilers kindling and flame stabilization over conventional technologies are:

II. LITERATURE

Beyca n Ibrahim oglu, M. Zeki Yilmazoglu, Ahmet Cucen[1] In this study, numerical analyses of repowering of a thermal power plant boiler using plasma combustion systems were performed. In order to reduce the energy consumption of the power plant, fuel-oil burners were disassembled and plasma combustion systems were installed on t e surfaces of the boiler. The integration procedure, design data, and boundary conditions were given in detail. Super heater, economizer tubes (dome) were modeled as porous media and the pressure losses of each section were compared with design data. The power plant was modeled according to the design parameters using the Thermo flex commercial software, in order to find the heat loads of each boiler section. These results were used as input data in CFD (Computational Fluid Dynamics) code. ANSYS Fluent was used for numerical analyses. Temperature contours, velocity vectors, and iso surfaces of temperature in the furnace were compared. According to the results, the integration of the plasma combustion systems to the boiler slightly decreases the velocities at the inlet of each domain. Additional energy from the plasma combustion system has no reverse effect in the case of overheating, especially for convective surfaces. V. E. Messerle, A. B. Ustimenko, and O. A. Lavrichshev[2] Application of direct-flow and vortex plasma-fuel systems (PFS) for coal-fired boilers of thermal power plants (TPP) at Ust-Kamenogorsk, Shakhtinsk, and Almaty (TPP-2 and TPP-3) (Kazakhstan) is discussed. In the plasma technology coal replaces traditionally used for the boiler start up and pulverized coal flame stabilization fuel oil or natural gas. Part of coal/air mixture is fed into the PFS where the plasma-flame from plasma torch induces gasification of the coal and partial oxidation of the char carbon. As coal/air mixture is deficient in oxygen, the carbon being mainly oxidized to carbon monoxide. As a result, a highly reactive fuel (HRF) composed of mixture of combustible gases and partially oxidized char particles is obtained at the exit of the PFS. On entry to the furnace, this HRF is easily ignited. Simulation and testing of PFS at existing pulverized coal-fired boilers of TPP confirmed the technical feasibility, environmental and energy efficiency of no-fuel oil boilers start-up and pulverized coal flame stabilization using PFS. E.I. Karpenko, V.E. Messerle, A.B. Ustimenko[3] Plasma supported solid fuel combustion is promising technology for use in thermal power plants (TPP). This technology was realised through full-scale trials of plasma supported coal combustion using plasma-fuel systems (PFS) mounted on a TPP boiler. PFS have been tested for boilers plasma start-up and flame stabilization in different countries at 27 power boilers steam productivity of 75 to 670 tons per hour equipped with different type of pulverized coal burners. At PFS testing power coals of all ranks (brown, bituminous, anthracite and their mixtures) were used. Volatile content of them varied from 4 to 50%, ash - from 15 to 48% and calorific values - from 6700 to 25100 kJ/kg. In summary, it is concluded that the developed and industrially tested PFS improve coal combustion efficiency and decrease harmful emission from pulverised coal fired TPP. Arkadiusz Dyjakon[4] Ignition of fuel-air mixtures is an important topic in combustion science from both fundamental and practical points of view. Some of the applications of ignition phenomenon include reliable ignition of fuel-air mixture in engines, burners and other devices. The electrical discharge has been the ignition source of choice for most types of propulsion and automotive combustion engines for over 100 years. It has many advantages including simplicity, low cost, size and weight of the electronic elements and it produces sufficiently high temperatures to dissociate and partially ionize air-fuel mixture. Nevertheless, there are also few disadvantages of electrical discharges, like: limited size of the discharge, the necessity for supporting electrodes that may interfere with the flow or combustion process, and quite high energy input efficiency (ratio of energy deposited in the gas to the electrical energy consumed in producing the discharge). There are many types of electrical discharges: dark, corona, spark, arc and others, however their application depends on process parameters and expected results. Zhao Feng TIAN*, Peter J. WITT, M. Phillip SCHWARZ and William YANG[5] A CFD model of a 375 MW tangentially-fired furnace located in Australia's Latrobe Valley has been developed. Coal feed rates, air flow rates, coal particle size distribution and coal properties, obtained from plant data, are taken as input conditions in the CFD simulation. A level of confidence in the current CFD model has been established by carrying out a mesh independence test and comparing simulated results against power plant measurements. Performance of two turbulence models, standard k-ε model and SST model, are compared.

III. OBJECTIVE OF THE STUDY

Pulverized coal fired boilers are basic steam generators in power plants. The conventional start up of this type of boilers require of heavy oil till the pulverised coal burners could start. The procedure is oil consuming (20-50 tons of oil for a single boiler kindling) and often causes environment problems. Heavy oil can be replaced by light oil. However, the use of this fuel rises the cost of electrical energy generation. For these reasons, some effort is paid to develop oil free boiler kindling systems fed with pulverized coal. The problem is difficult because pulverized coal requires much more energy for ignition than oil. Moreover, it is not possible to maintain pulverized coal flame in cold surrounding. The most promising idea is the use of thermal plasma for stabilization of the auxiliary pulverized coal flame (<1MW), which secures the operation of main pulverized coal burner of 10-30 MW. Purpose of this investigations reported was to consider basic operation modes of the plasma assisted pulverized coal burner (PAPCB) of the cyclone type. In previous research conventional coal combustion and plasma combustion was compared with CFD simulation on the basic of Temperature, Velocity and is surfaces of temperature in the furnaces. In present study we will compare the both oil-fuel and plasma based combustion system on the basic of emissions like COx and NOx with the help of mathematical modelling and simulation using ANSYS (Fluent). This study can be helpful for investigating the combustion efficiency of different fuel and reducing the emissions percentages of power plants so that the environmental issues can be solved in future.

IV. METHODOLOGY

A. *Basic Steps to Perform CFD Analysis*

1) *Pre-processing:* CAD Modeling: Creation of CAD Model by using CAD modeling tools for creating the geometry of the part/assembly of which you want to perform FEA.CAD model may be 2D or 3d.
2) *Meshing:* Meshing is a critical operation in CFD. In this operation, the CAD geometry is discretized into large numbers of small Element and nodes. The arrangement of nodes and element in space in a proper manner is called mesh. The analysis accuracy and duration depends on the mesh size and orientations. With the increase in mesh size (increasing no. of element), the CFD analysis speed decrease but the accuracy increases
3) *Type of Solver:* Choose the solver for the problem from Pressure Based and density based solver.
4) *Physical model:* Choose the required physical model for the problem i.e. laminar, turbulent, energy, multi-phase, etc.
5) *Material Property:* Choose the Material property of flowing fluid.
6) *Boundary Condition:* Define the desired boundary condition for the problem i.e. temperature, velocity, mass flow rate, heat flux etc.

B. *Solution*

1) *Solution Method :* Choose the Solution method to solve the problem i.e. First order, second order
2) *Solution Initialization:* Initialized the solution to get the initial solution for the problem.

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3) *Run Solution:* Run the solution by giving no of iteration for solution to converge.
4) *Post Processing:* For viewing and interpretation of Result. The result can be viewed in various formats: graph, value, animation etc.

C. Cfd Method Applied

The model was simulated and the required geometry configurations were pre-processed in ANSYS 14.5. This following section illustrates the method used in the CFD simulations in this particular study.

D. Geometry Or Model Formation

The study focuses on the to calculate the NOx percentage and the geometry used for the simulations is therefore only a part of the whole exhaust gas system in order to save computational time. The generation of the model by using ANSYS shown below:-

1) *.STEP I – Cad Model Generation:* The study focuses on the to calculate the NOx percentage and the geometry used for the simulations is therefore only a part of the whole exhaust gas system in order to save computational time. The generation of the model by using ANSYS shown below:-

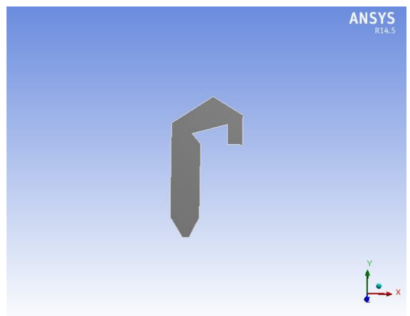


Figure 4.1 Cad Model

2) *STEP 2*

Mesh file –To be Meshed

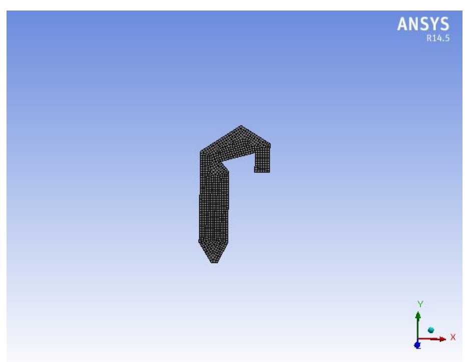


Figure 4.2 Mesh Model

3) *Step 3 Checks The Mesh*

Various checks on the mesh and reports the progress in the console. Also check the minimum volume reported and make sure this is a positive number select mesh to mm.

a) METHODS- 1. Pressure based
b) 3D Model is used
c) Gravity is enabling

E. Model

1) Energy equation is enabled.
2) K-Epsilon turbulence model used.

3) P-1 radiation model is used, since it is quicker to run. However DO radiation model can be used for more accurate results in typical models.
4) Finite rate / eddy dissipation in turbulence chemistry. Interactions are used for species model.

a) STEP 4 Simulation Setu

b) Boundary conditions

Operation conditions[a]	1	2	3	4	5
Turbine power [MW]	7	12	17	22	NA
Water/Steam Pressures [bar]					
Inlet of Economizer	62	62.6	65.7	70	72
Outlet of dome	59.6	61.5	64	68	69.8
Outlet of Superheater	59.4	60.7	62.4	65	66.2
Temperatures [°C]					
Steam temperature at outlet of superheater	489.7	487.7	487	486.5	486.4
Water temperature at inlet of economizer	139	165	180	192	196
Water temperature at outlet of economizer	197	216	230	242	245
Gas temperature at inlet of superheater	826	872	922	980	1000
Gas temperature at outlet of economizer	239	261	278	296	302
Air temperature at outlet of air pre-heater	206.5	213	222.5	226.5	228
Stack temperature	129	142	152	160	162.5
Mass flow rates [t/h]					
Fuel	6.96	11.4	15.6	20.3	22
Combustion gas	60.6	93.3	121.4	150.8	161.5
Steam mass flow rate	30	51	72	96	105

Table 1

Comparison of mass flow rates of coal, primary air, and secondary air at the inlet of the burners.

	Level	Coal [kg/s]	PA [kg/s]	SA [kg/s]
Conventional CS	First stage	2.4375	2.403	13.617
	Second stage	2.4375	2.403	13.617
Conventional and Plasma CS	First stage	2.1615	2.037	11.543
	Second stage	2.1615	2.037	11.537
	Plasma stage	0.552	4.88	

Table 2

F. Material

Properties of SOMA/EYNES coal.

Proximate analysis (as received) [wt.%]	
Moisture	25.22
Volatile matter	32.83
Fixed carbon	23.55
Ash	18.4
Ultimate analysis (dry basis) [wt.%]	
C	39.48
H	2.95
N	0.59
O	12.83
S	0.53
Lower heating value [kJ/kg]	14,248

1) Step 5 Solutions

G. Method

1) Coupled
2) Presto model is used:

Presto model is often used for buoyant flows where velocity vector near walls may not align with the wall due to assumption of uniform pressure in the boundary layer so presto can only be used with quadrilateral or Hexahedral.

3) *Solution Initialisation:* -The solution is initialized
4) *Run Calculation:* -Start the calculation for 2500 iterations.

V. RESULTS AND CONCLUSION

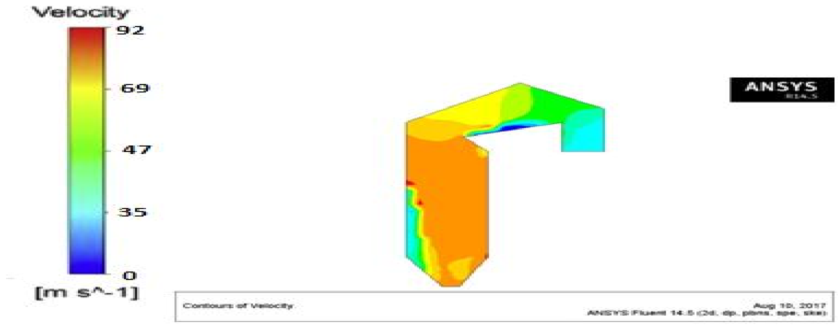


Figure 1 Velocity contour in conventional oil-fuel method

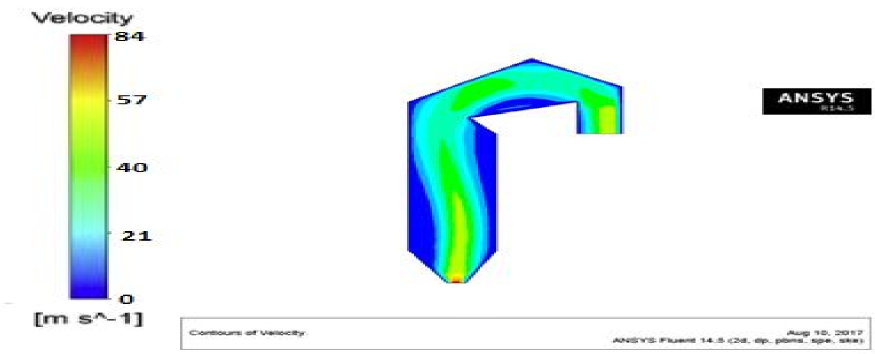


Figure 2 Velocity contour in plasma method

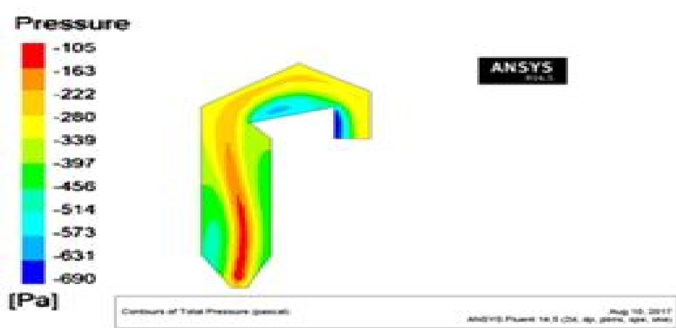


Figure 3 pressure contour in conventional oil-fuel method

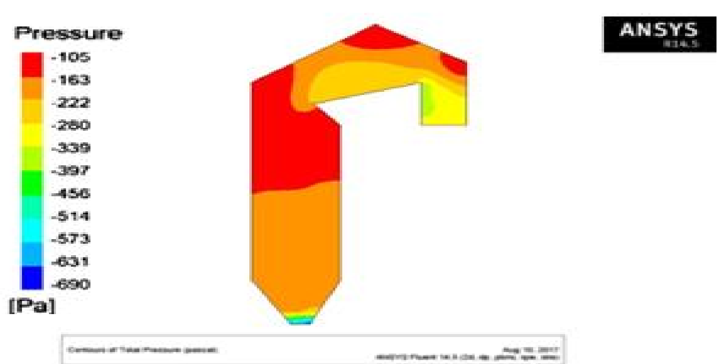


Figure 4 Pressure contour in plasma method

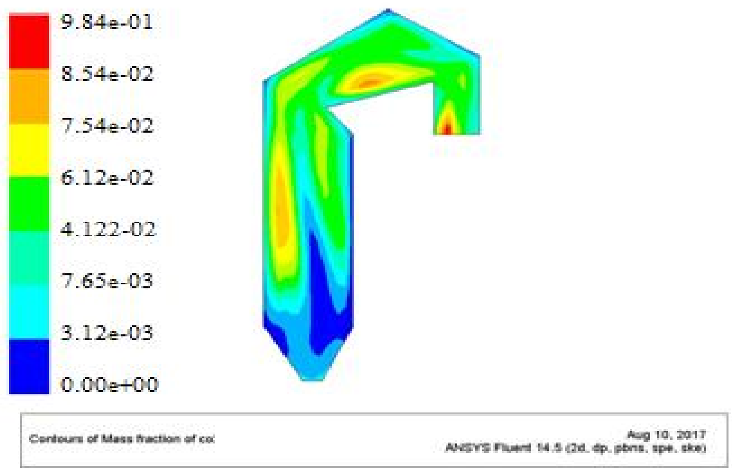


Figure 5 Mass fraction of CO in conventional oil-fuel method

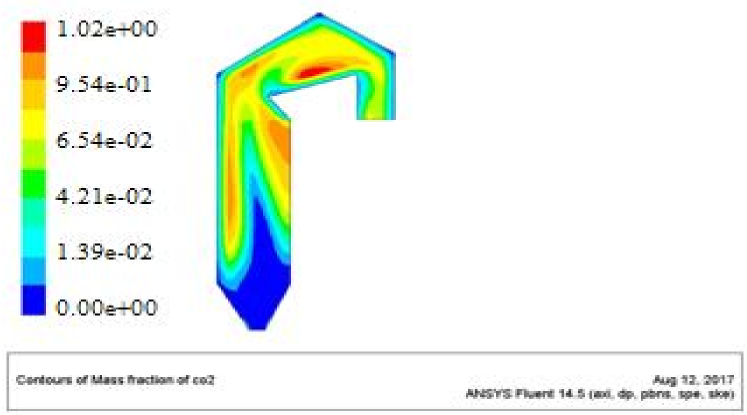


Figure 6 Mass fraction of CO_2 in conventional oil-fuel method

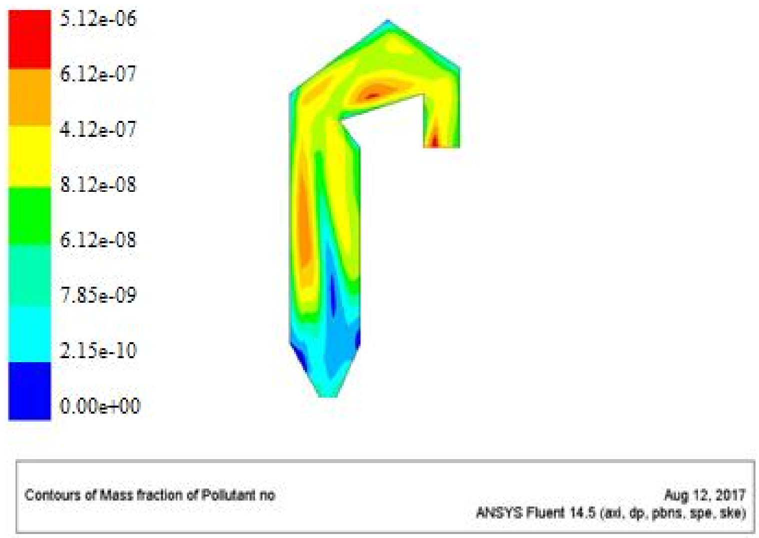


Figure 5 Mass fraction of NO in conventional oil-fuel method

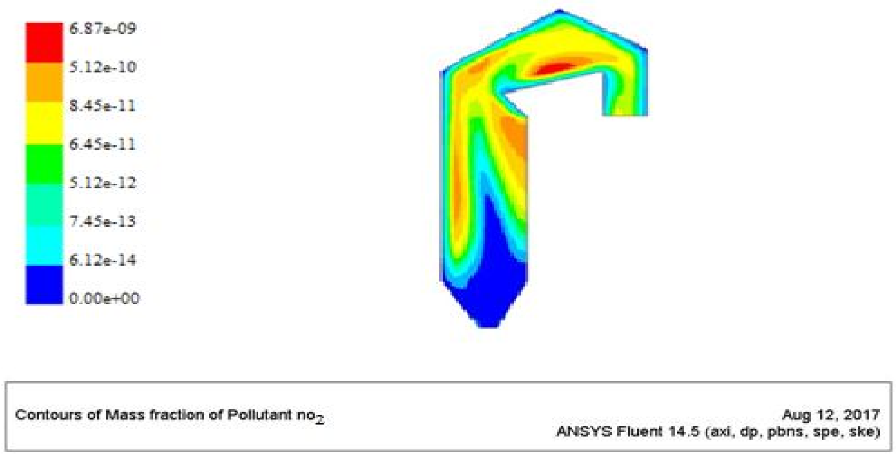


Figure 7 Mass fraction of NO_2 in conventional oil-fuel method

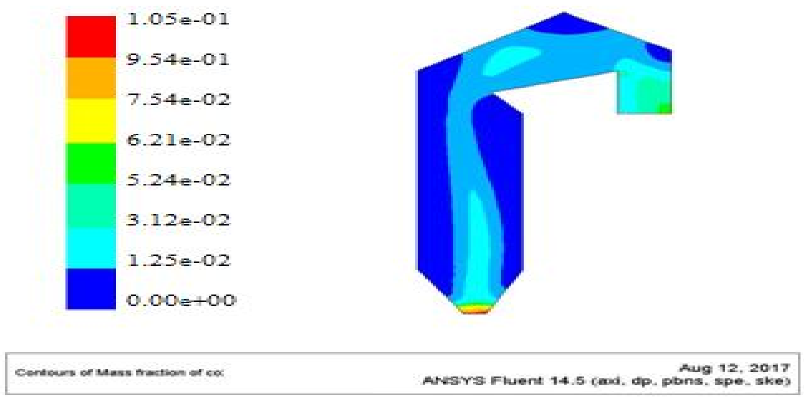


Figure 5 Mass fraction of CO in plasma combustion method

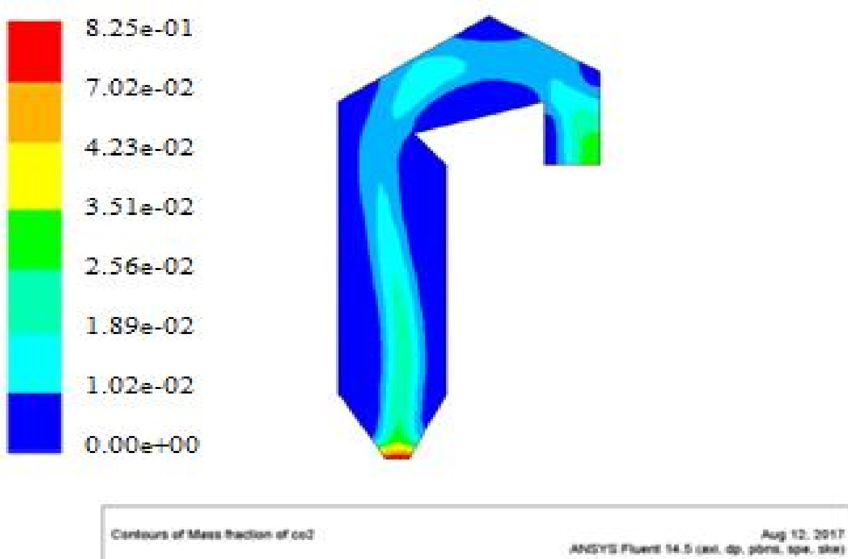


Figure 5 Mass fraction of CO_2 in plasma combustion method

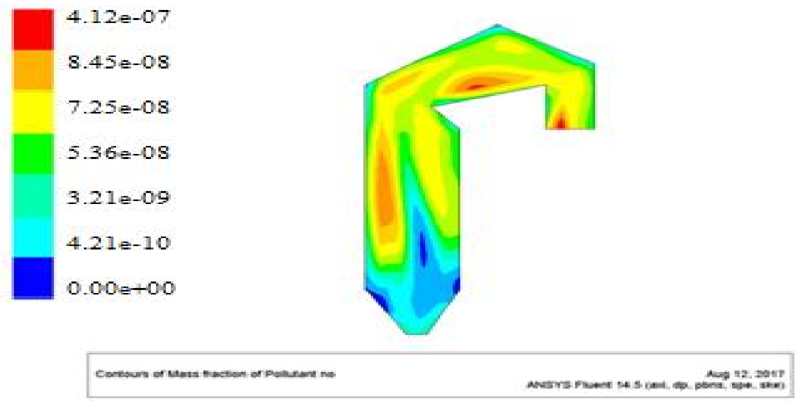


Figure 5 Mass fraction of NO in plasma combustion method

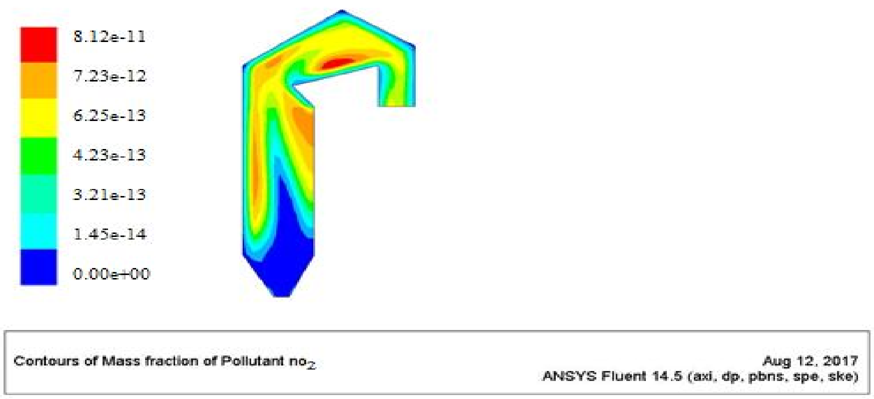


Figure 5 Mass fraction of NO_2 in plasma combustion method

RESULTS TABLE

Fluid Variables And Emissions	Conventional Oil fuel combustion	Plasma combustion
Velocity (m/s)	92	84
Pressure Drop (Pa)	85	100
Mass fraction of CO	9.84e-01	1.05e-01
Mass fraction of CO2	1.02e+00	8.25e-01
Mass fraction of NO	5.12e-06	4.12e-07
Mass fraction of NO2	6.87e-09	8.12e-11

VI. CONCLUSION

In results table comparison between conventional oil- fuel combustion and plasma combustion is shown. In plasma combustion velocity of the profile is slow down so the residence time combustion is increased which is helpful for NOx reduction because complete combustion can be achieved with increasing residence time and pressure drop is also decreasing in stable system. The velocity profile of each burner stage was investigated before and after the integration of the plasma combustion systems. The flame has to be a rotational characteristic to ensure the mixing and turbulence. As a result of mixing and turbulence, a complete combustion can be achieved. Finally we calculate the emissions of COx and NOx from CFD simulation and using chemical kinetics mechanism for NOx evaluation. Comparison between conventional and plasma combustion is clearly shown on results table that all the emissions (Cox & NOx) have a lower value in case of plasma type combustion and this is happened due to the complete combustion as compare to conventional oil fuel combustion . In plasma combustion there is no need oil for start up operation and flame stabilization , that why it is a cost effective method also. Plasma activation of coal particles instead of using fuel-oil burners promotes more effective and environment friendly combustion.

REFERENCES

[1] Beyca n Ibrahimoglu , M. ZekiYilmazoglu , AhmetCucen Numerical modeling of repowering of a thermal power plant boiler using plasma combustion systems. Article history: Received 5 May 2015 Received in revised form 12 February 2016 Accepted 22 February 2016.

[2] V. E. Messerle, A. B. Ustimenko, and O. A. Lavrichshev Plasma-assisted ignition and combustion of pulverized coal at thermal power plants of Kazakhstan Proceedings of the 2014 International Conference on Power Systems, Energy, Environment.

[3] E.I. Karpenko, V.E. Messerle, A.B. Ustimenko PLASMA-FUEL SYSTEMS APPLICATION IN HEAT-AND-POWER ENGINEERING Branch Centre of Plasma-Power Technologies of Russian J.S.Co. “UPS of Russia”, Gusinoozersk, Russia, Research Institute of Experimental and Theoretical Physics, Research Department of Plasmotechnics, Almaty, Kazakhstan:

[4] ArkadiuszDyjakon[4] “PLASMA IGNITION SYSTEM FOR LIQUID FUELS ” Institute of Heat Engineering and Fluid Mechanics, Wroclaw University of Technology, Wyb. Wyspiańskiego 27, 50-370 Wrocław, POLAND

[5] Zhao Feng TIAN*, Peter J. WITT, M. Phillip SCHWARZ and William YANG “NUMERICAL MODELLING OF BROWN COAL COMBUSTION IN A TANGENTIALLY-FIRED FURNACE ” Seventh International Conference on CFD in the Minerals and Process Industries CSIRO, Melbourne, Australia 9-11 December 2009.

[6] Dr Ian A B Reid “Retrofitting lignite plants to improve efficiency and performance” IEACCC Ref: CCC/264 ISBN: 978–92–9029–587-7 Copyright: © IEA Clean Coal Centre Published Date: April 2016.

[7] A.S. Askarova “Mathematical modeling of heat and mass transfer in the presence of physicalchemical processes” Bulgarian Chemical Communications, Volume 48, Special Issue E (pp. 272 - 277) 2016

[8] P. Gomes Angela O. Nieckele, Monica F. Naccache, Marcos Sebastião” Combustion performance of an aluminum melting furnace operating with natural gas and liquid fuel Applied Thermal Engineering, Volume 31, Issue 5, April 2011, Pages 841-851

[9] Renzo Piazzesi, Maria Cristina Cameretti, RaffaeleTuccillo, “ Study of an exhaust gas recirculation equipped micro gas turbine supplied with bio-fuels’ Applied Thermal Engineering, Volume 59, Issues 1–2, 25 September 2013, Pages 162-173

[10] AbdulazizAlsairafi, Abbas Khoshhal, MasoudRahimi, Ammar CFD study on influence of fuel temperature on NOx emission in a HiTAC furnace International Communications in Heat and Mass Transfer, Volume 38, Issue 10, December 2011, Pages 1421-1427

[11] D.J.E.M. Roekaerts, B. Danon, E.-S. Cho, W. de Jong, “ Numerical investigation of burner positioning effects in a multi-burner flameless combustion furnace” Applied Thermal Engineering, Volume 31, Issues 17–18, December 2011, Pages 3885-3896

[12] JafarGhafouri, Amin Maghbouli, Rahim KhoshbakhtiSaray, SinaShafee, “Numerical study of combustion and emission characteristics of dual-fuel engines using 3D-CFD models coupled with chemical kinetics”Fuel, 106, April 2013, 98-105

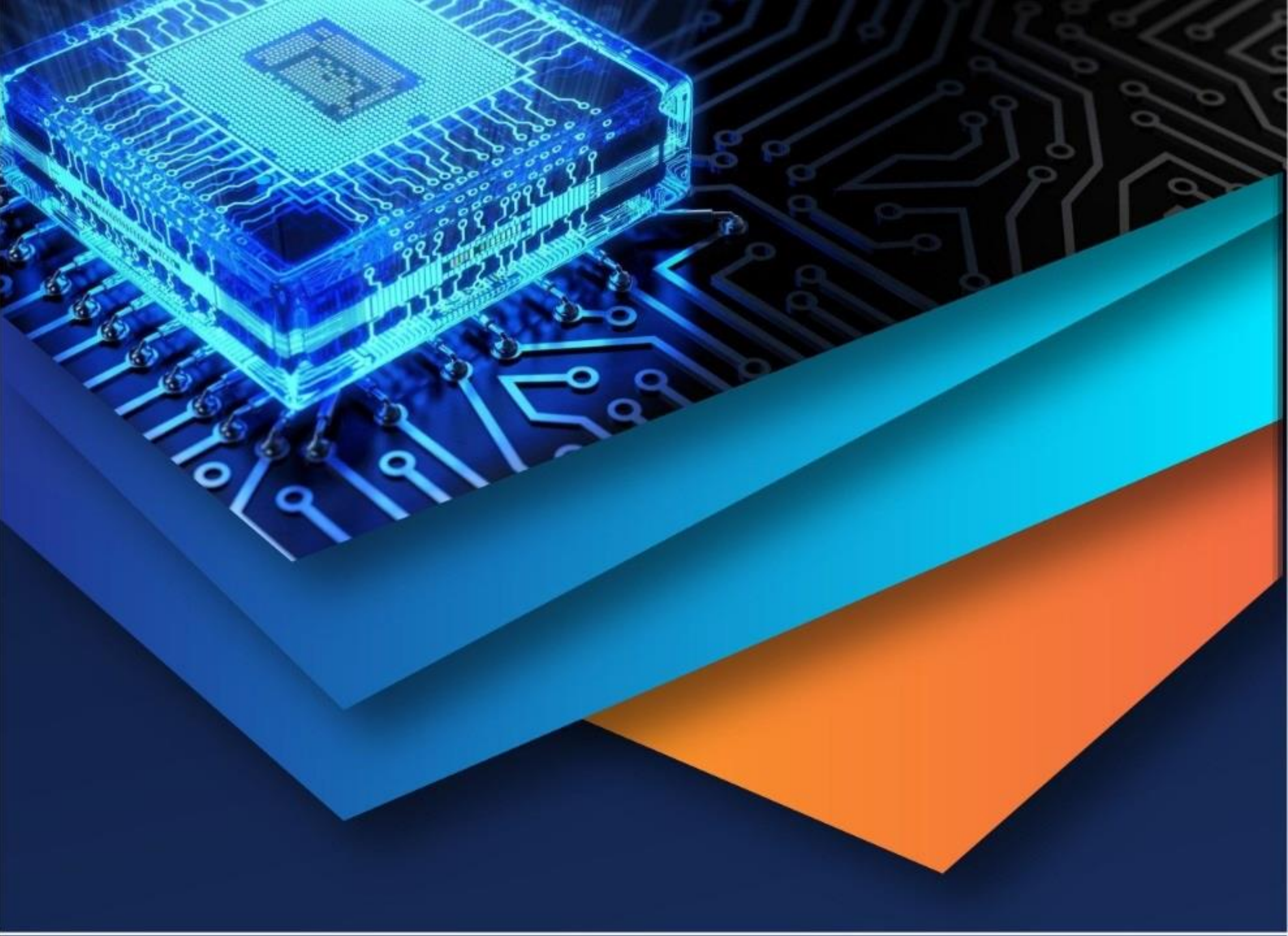
[13] E.G. Pariotis, C.D. Rakopoulos, G.M. Kosmadakis, Evaluation of a combustion model for the simulation of hydrogen spark-ignition engines using a CFD code International Journal of Hydrogen Energy, 35, Issue 22, November 2010, 12545-12560

[14] AnandOdedra, Gasser Hassan, Mohamed Pourkashanian, Derek Ingham, Lin Ma, Paul Newman,” Predictions of CO and NOx emissions from steam cracking furnaces using GRI2.11 detailed reaction mechanism – A CFD investigation” Computers & Chemical Engineering, Volume 58, 11 November 2013 68-83

[15] IngwaldObernberger, Ali Shiehnejadhesar, Kai Schulze, Robert Scharler, “A new innovative CFD-based optimisation method for biomass combustion plants” Biomass and Bioenergy, 53, June 2013,48-53

[16] S. Verhelst, G.M. Kosmadakis, C.D. Rakopoulos, J. Demuynck, M. De Paepe, “ CFD modeling and experimental study of combustion and nitric oxide emissions in hydrogen-fueled spark-ignition engine operating in a very wide range of EGR rates” International Journal of Hydrogen Energy, Volume 37, Issue 14, July 2012, Pages 10917-10934

[17] David Dodds, Audai Hussein Al-Abbas, Jamal Naser,” CFD modeling of air-fired and oxy-fuel combustion in a large-scale furnace at Loy Yang A brown coal power station” Fuel, Volume 102, December 2012, Pages 646-665



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