Study and Comparison of Plasma and Oil Fuel Combustion Systems in Boiler Furnace

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ABSTRACT- *The performance of conventional and plasma combustion is examined in this study utilising Ansys (Fluent) mathematical modelling and analysis. The influence of particle dispersion on projected outcomes is found to be negligible. In power plants, pulverised coal-fired boilers are the most basic steam producers. This type of boiler's traditional start-up procedure necessitates the use of heavy oil until the pulverised coal burners can fire up. On the basis of stability phenomena and mass fractions of CO, CO2, NO, and NO2 emissions in complete systems, we compared the two types of combustion. In comparison to traditional oil fuel, simulation findings show that by increasing the resting time of combustion in the plasma type, complete combustion is possible and emissions are reduced. Because plasma combustion does not require oil for initiation and flame stability, it is also a cost-effective process. Instead of employing fuel-oil burners, plasma activation of coal particles promotes more efficient and environmentally friendly combustion.*

***Keywords*— Boiler furnace, conventional combustion, emissions, oil fuel combustion, power plant, plasma combustion.**

1. INTRODUCTION

The study of the plasma ignition of the coal and its acknowledging plasma fuel frameworks (PFS) is electro-thermo-compound readiness of fuel to consuming (ETCPF) [1] – [6]. Ordinarily, battered coal is used as fuel for the evaporator's fire as well as for the pummeling coal fire adjustment. Plasma-fire from plasma light takes care of most of the coal/air combination in the PFS, where gasification of the coal and mid-convergence of power is produced via plasma-fire. The gas is mostly converted to carbon monoxide, since the coal/air mixture lacks oxygen. The HRF created at the end of the PFS features a combination of burnable gases at around 1300 K and partly oxidised scorch particles. When the heating is turned on, this HRF lights up immediately. To date, little work has been done on plasma-assisted coal igniting, with only a few sources available. Boiler coal use raises two problems for utilities: The first is that oil has to be used in the first place, and the second is that consumption of various types of coal increases as energy providers face higher debt loads. Anything that causes negative ecological impact does so because of one of these factors. Oil fire for firing up raises the mass of the manufacturing plant's vaporous and particulate materials. Wiping out the lower-quality coals will have two notable side effects: lowered dependability of the fire, and an increase in waste and costs. Plasma made coal igniting mirrors an innovative and natural alternative for environmentally conscious individuals, which is relevant to replace "green" alternative strong powers.

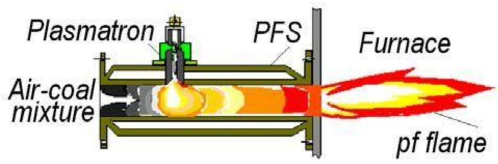


Figure 1 Arch plasma in a special chamber

1.1 BASIC PRINCIPLE OF PLASMA-ENERGY TECHNOLOGY

The little coal particles could be observed during the plasma burst in [4]. Disintegrate, going through a "thermal shock" process, and then form into 5-10 m pieces. This results in much faster de-volatilization and oxidation cycles. [5] was the first to compute the thermodynamic properties of coal species on the basis of temperature changes. Ignitable parts like as CO and H2 are vastly increased as the temperature rises between 900 and 1200 degrees Kelvin (arriving at 50-70 percent by volume). It's also worth mentioning that steam convergence is greatly reduced, probably because to compound interaction between steam and carbon (H2O and CO combine to form CO2, which in turn combines with steam to make a new substance). think of a coal-coal-coal-coal-coal-coal-coal-coal-coal-coal-coal burner with coal-coal-coal-coal-coal-coal-coal-coal-coal-coal It has been calculated that the oxygen for ignition is below 0.5, meaning there is no oxygen for ignition. A plasma source is used to reach the full de-volatilization temperature of the coal/air combination, and the resulting plasma-heated coal/air mixture is then used to gasify one carbon to form a highly sensitive two-stage fuel (flammable gas and burn carbon) (ignitable gas and scorch carbon). This extremely sensitive fuel begins to oxidise leftover coal. Carbon is oxidised to carbon monoxide, which boosts the ignition system's performance. When this mixture is pulled into the heater, it increases the chance of igniting the critical non-plasma-treated coal, which is mixed with optional air, and which is then introduced to the heater via conventional burners. Figure 2 illustrates schematically the plasma thermochemical readiness of coal. The plasmatron curve takes up the left side of the diagram. air is pumped out of copper water-cooled terminals, which, in turn, causes plasma to form (cathode and anode). Its power has increased from 100 kW to 350 kW, thanks to the addition of the plasmatron. It has a height of 0.4 metres and a width of 0.25 metres, and its weight is 25 kilogrammes. The predicted energy change productivity of the plasmatron is approximately 85%. On the right in the figure, you can see the plasma-fuel device (PFS). At once, the plasmatron's sputtering nozzle is changed to a flame-suppressed burner.

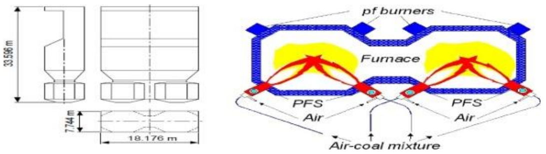


Fig. 2. Illustration of the plasmatron (left side) and PFS (right side).

Fig. 3 depicts the important characteristics of fuel-air mixture interaction with arc plasma in a PFS. Even dust particles of about 50 to 100 micrometres in size can experience a thermal shock upon entering a plasma. Because of this, the pieces are quite small; the pieces are usually around 5-10 µm in size. Because of this, fuel de-volatilization is carried out more intensively and the oxidation of fuel combustibles is 3-4 times quicker.

Table 1. Thermotechnical characteristics of coals.

Coal Type	W^r, %	A^d, %	V^{daf}, %	Q^r_i, kJ/kg
Brown	25-35	15-20	35-50	12500-16000
Shale	40-50	75-80	48-50	6700-8500
Bituminous	5-12	20-45	15-40	16500-21000
Anthracite	5-8	25-35	4-10	18000-26000
Mixture of coals	10.4	48.5	38.2	13150

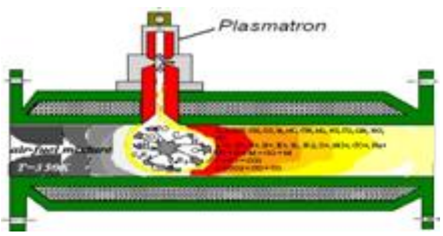


Figure 3. In the coal ignition plasma-fuel system, characteristics of arc plasma interaction with air-fuel mixture.

Under laboratory and industrial conditions, the PFS has been used to assess the characteristics of many types of power generation coals (shale, brown coal, bituminous coal, and anthracite, including lignite and high-ash anthracite coal) (brown coal, shale, bituminous coal and anthracite, including mixtures of lignite and high-ash anthracite coal). This results in yield volatility that ranges between four and fifty percent, ash content that is equal to fifteen to eighty percent, and calorific values that are between 6700 to 26000 Kilojoules per kilograms.

1.2 INDUSTRIAL TESTS

Some of the TPP's coal-terminated extra combustors have adopted the PFS [7]. The idea was successfully implemented on 27 battered and bulging coal boilers that produced steam at a range of productivity levels, including 75 to 670 TPH at 16 PTU in seven nations (Russia, Korea, Kazakhstan, Ukraine, Mongolia, Slovakia, and China). There were different fire-control frameworks fitted on these heat exchangers.

For example, the PFS is included in the heater of a 640 TPH steam full-scale steam rising kettle, which is in operation in Eastern Siberia, Russia (Gusinoozersk TPP, Eastern Siberia, Russia) (Gusinoozersk TPP, Eastern Siberia, Russia). Here, you have an illustration of the heater with the PFS, as well as estimates for it. The heater has two (semi)heaters, each of which has eight carefully-controlled pf burners, positioned in two layers. The focal section that connects the burning chambers Every stove has a primary air delivery and an auxiliary air scattering area. When considering the four lower layer burners in Figure 3, the condition as viewed on the correct side is considered. While the evaporator is warming up, the plasmatrons operate. When the evaporator yield is figured out, the plasmatrons are put out of commission and the PFS are adjusted to function as normal pf burners. The plasmatrons are restarted in the event of a fire. The fuel used in the BKZ 640-140 heater was Tugnuiski bituminous coal [6].

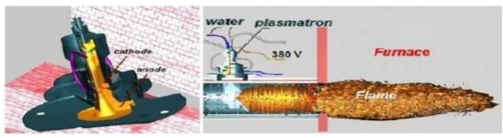


Figure 4. Scheme of the industrial furnace of BKZ 40-140 boiler and the boiler furnace equipped with four PFS (top view)

As a result, four of the boilers in the TPP were outfitted with sixteen PFS. According to calculations, some 21,000 tonnes of fuel oil have been saved at this factory since 1995. This equates to a 13000 tonne reduction in annual nitrogen and sulphur oxide emissions, carbon monoxide emissions, and vanadium pentoxide emissions. In the boiler combustor BKZ-420 in Ulan-Bator TPP-4, Figure 4 illustrates the PFS arrangement. (horizontal view). There are twelve corner-fired burners at three different heights. Two PFS were used on the bottom layer in a cornerwise configuration. PFS was used to start all eight boilers in the power plant. After being lighted with the PFS, the temperature of both pulverised coal flames rose to 1100-1150°C in 2-3 seconds. After an hour, the flames were approximately 7–8 m long and were up to 1260–1290°C in temperature. Operating instructions say the boiler was run for a total of four hours.

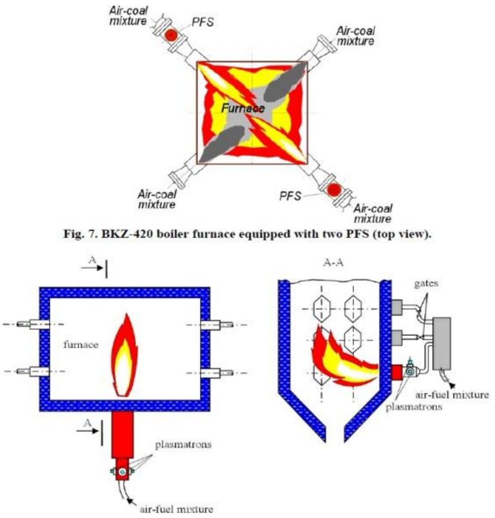


Figure 5: Burner and PFS configuration on the BKZ-640 boiler (Gusinoozersk TPP).

This is seen in the image above, which shows three plasma generators placed on a direct-jet flat flame pulverised-coal burner on the BKZ-640 boiler at Gusinoozersk TPP (from the left it is the top view; from the right it is the cross section). The figure in figure 5 illustrates the operation plan for two plasma generators and two vortex burners installed on two low-layer vortex burners in an evaporator that generates 160 t/h of steam (at Neryungry TPP, Russia) (Russia). A plan of operation for a plasma generator is shown in Figure 10, which illustrates a chamber for thermochemical power treatment surrounded by blend snails. Table 5 shows the specific listings of plasma-coal burners used at nuclear power plants in Russia, China, and Slovakia for second-rate coal igniting. The temperature of the fire ranged from 1150 to 1400 degrees Celsius, and its span ranged from 2.5 to 6 metres, as shown in the table. The awareness of a plasmatron's fundamental force usage is expected to be used to evaluate PFS execution. In the PFS, this boundary is known as the plasmatron electric capacity to plasma fuel usage ratio.

2. LITERATURE REVIEW

Beyca n Ibrahimoglu , M. Zeki Yilmazoglu , Ahmet Cucen[1] Formalized paraphraseA numerical trial of repowering a nuclear energy station kettle utilising plasma burning frameworks was conducted in this study. To reduce the force plant's energy consumption, the fuel-oil burners were removed, and plasma ignition frameworks were installed on the evaporator's surfaces. The interrelationship of coordination, plan information, and limit conditions were all described in great detail. The permeable media of the super heater and economizer tubes (vault) were displayed, and the pressing factors causing disasters in each part were compared and planned information. The heat heaps of each kettle division were discovered using the Thermoflex business application, which was demonstrated by the plan limits. These findings were incorporated into the CFD code. ANSYS Familiar was used for the computational tests. We examined the shape, velocity, and isotherms of the heater. A plasma burning framework connected to a kettle reduces the speed in the bay by a small amount. For convective surfaces, the extra energy released from the plasma burning system has no detrimental consequences, especially if it is concentrated at the source.

V. E. Messerle, A. B. Ustimenko, and O. A. Lavrichshev [2] At the Nuclear Power Plants in Kazakhstan, coal-terminated boilers utilise direct-stream and vortex plasma-fuel frameworks (PFS) (TPP-2 and TPP-3). Instead of using fuel oil or gaseous petrol, coal is employed in plasma technology as a fuel for heater fire start and for coal-fire correction. A single carbon (i.e. carbon monoxide, CO) is fractionally oxidised in the PFS, which leads to coalification and the production of carbon dioxide gas. The gas is practically converted to carbon monoxide due to a shortage of oxygen in the coal/air mixture. As a result, the final few feet of the PFS will have a high-reactivity fuel (HRF), which is mostly comprised of flammable gases and contains large amounts of oxidised scorch particles. When access to the heater is gained, this HRF is rapidly triggered. PFS reproduction and testing at existing PFS-operated coal-terminated boilers was used to confirm the specific fire adjustment, as well as the boiler efficiency, of no-fuel oil boilers.

E.I. Karpenko, V.E. Messerle, A.B. Ustimenko [3] The potential for plasma-assisted strong fuel ignition as a new technology for nuclear power reactors appears considerable (TPP). Plasma-fuel frameworks (PFS) were tested on a TPP evaporator employing full-scale preliminaries for plasma-supported coal burning. It has been tested in several nations, including the U.S., Canada, China, Russia, Japan, and many other countries, for plasma fire up and fire adjustment in 27 force boilers with steam productivity ranging from 75 to 670 tonnes per hour. When PFS evaluated the power coals, everything was scrutinised (earthy coloured, bituminous, anthracite, and their mixtures). Content was between 4% and 50%, with debris coming in at 15% to 48%, and calorific energy in the 6700 to 25100 kJ/kg range. The developed and tested PFS have been shown to improve the efficiency of coal ignition while lowering the emission of harmful vapours from coal in pounded coal.

Arkadiusz Dyjakon [4] The starting of fuel-air mixtures is an important topic in burning science from both a theoretical and practical standpoint. Some of the applications of start marvel include consistent start of fuel-air mixtures in motors, burners, and other devices. For more than a century, the electrical release has been the preferred starting source for the majority of drive and car ignition motors.It offers a number of advantages, including ease of use, size and weight of electronic components, and the ability to deliver sufficiently high temperatures to separate and mostly ionise air-fuel mixtures. By the by, there are a few disadvantages to electrical releases, such as the limited size of the release, the requirement for supporting cathodes that may interfere with the stream or burning interaction, and extremely high energy input proficiency (proportion of energy retained in the gas to the electrical energy burned-through in creating the release) (proportion of energy stored in the gas to the electrical energy burned-through in delivering the release). Electrical discharges come in a variety of forms, including dim, crown, dazzle, bend, and others; nevertheless, their application is dependent on measurement bounds and expected consequences.

3. OBJECTIVE OF THE STUDY

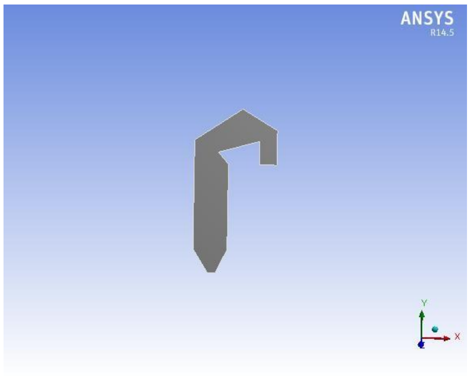
Base steam turbines in power plants are powdered coal terminated boilers. Substantial oil is required for the conventional beginning up of this sort of kettle before the powdered coal burners can start. Oil use (20-50 tons of oil for a solitary kettle start) is the component which likewise makes natural issues. It is important to operate weighty oil with light oil. The use of this fuel, notwithstanding, builds the cost of creating electrical power. For these reasons, some efforts are being made to assemble powdered coal took care of without oil kettle encouraging frameworks.

The objective of the current work is to comprehend the working plasma and oil fuel combustion and compare their combustion parameters also to analyze the combustion on basis of emissions. This study will be valuable in contemplating the ignition execution of numerous fills and decreasing the contamination rates of boiler furnace with the end goal that natural difficulties can be tended to later on.

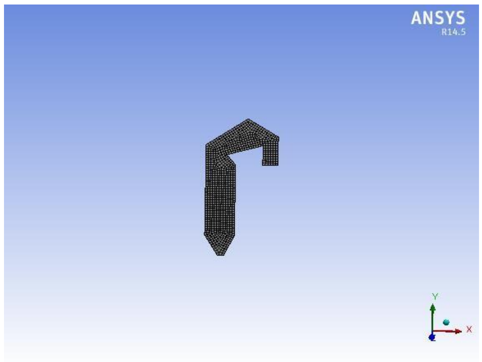
4. METHODOLOGY

4.1. How to Perform a CFD Analysis in Basic Steps

4.1.1 Pre-processing: CAD Modeling: CAD Modeling is the process of developing the geometry of a part or assembly that will be used in a FEA simulation. The CAD model can be 2D or 3D. In the diagram below, the entire exhaust gas system is depicted to reduce computational time.



4.1.2 Meshing: In CFD, meshing is a crucial step. The CAD geometry is discretized into a huge number of tiny elements and nodes in this technique. Mesh refers to the appropriate organisation of nodes and elements in space. The mesh size and orientations affect the accuracy and time of the analysis. The CFD analysis speed decreases as the mesh size (number of elements) grows, while the accuracy increases.



4.1.3 Type of Solver: Choose from Pressure Based and Density Based Solvers to solve the problem.

METHODS

- Pressure based
- 3D Model is used.
- Gravity is enabling

4.1.4 Physical model: Select a physical model for the problem, such as laminar, turbulent, energy, multi-phase, and so on.

MODEL

- The energy equation is turned on.
- The turbulence model K-Epsilon was utilised.
- The P-1 radiation model is employed since it is easier to use. In typical models, however, the DO radiation model can be utilised to get more accurate results.
- Turbulence chemistry: finite rate / eddy dissipation The species model is based on interactions.

4.1.5 Material Property: Select the flowing fluid's Material property.

For NOx evaluation, the mixing law and chemical kinetic mechanism are applied.

Define two polynomial coefficients
(a) 0.0083676 (b) 6.3317*10-5 for thermal conductivity.

1. Viscosity polynomial coefficient

(a) 7.8136e-06 (b) 4.2780e-8

2. Select a stable domain for the absorption coefficient.

3. 1e-9 is the scattering coefficient.

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

4.1.6 Boundary Condition: Define the problem's desired boundary conditions, such as velocity, temperature, heat flux, mass flow rate, and so on.

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

4.2 SOLUTION

Solution Method: To solve the problem, you must choose an approach such as the First-order, Second-order.

Solution Initialization: Initialization of the solution had solved the problem for the problem that was presented.

Run Solution: Run the solution by giving no of iteration for solution to converge. Start the calculation for 500 iterations.

4.3 Post Processing: For the purpose of examining and interpreting the result. The output can be displayed in a variety of formats, including graphs, values, and animations.

5. RESULTS

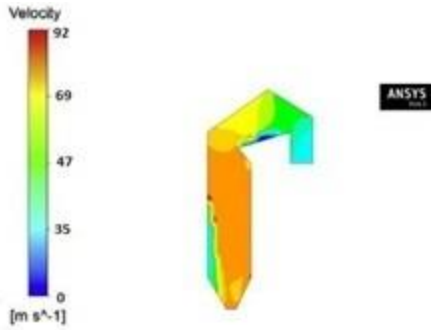


Figure 5.1: Velocity contour in the traditional oil-fuel method.

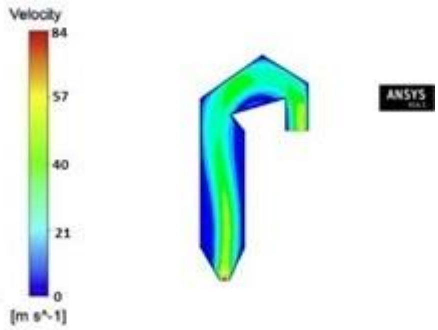


Figure 5.2 Velocity contour in plasma method

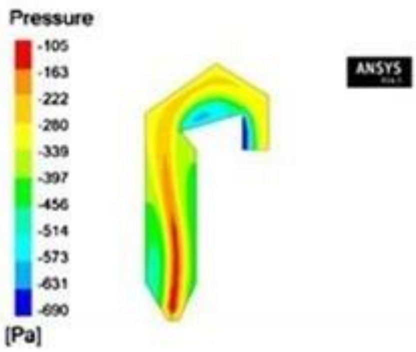


Figure 5.3 shows the pressure curve in the traditional oil-fuel approach.

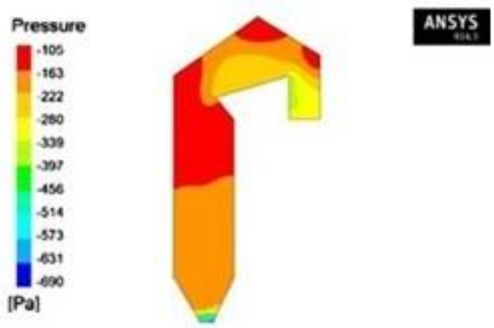


Figure 5.4: Plasma technique pressure contour

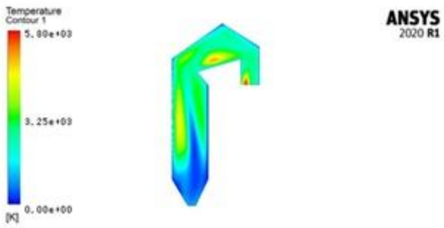


Figure 5.5: Temperature curve in the traditional oil-fuel approach.

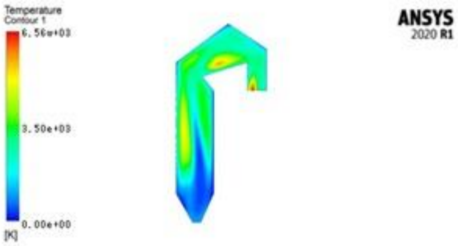


Figure 5.6: Temperature contour in the plasma process.

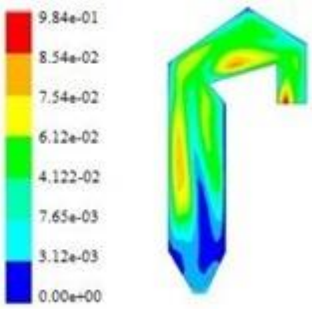


Figure 5.7: CO mass fraction in the traditional oil-fuel technique.

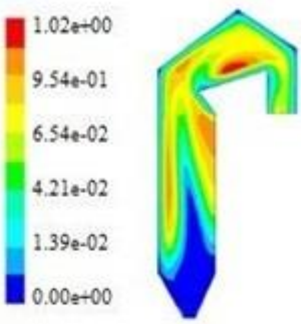


Figure 5.8: CO2 mass fraction in a traditional oil-fuel technique.

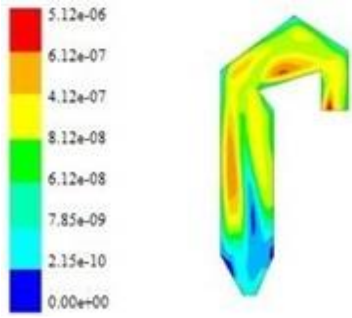


Figure 5.9: NO mass fraction in the traditional oil-fuel technique.

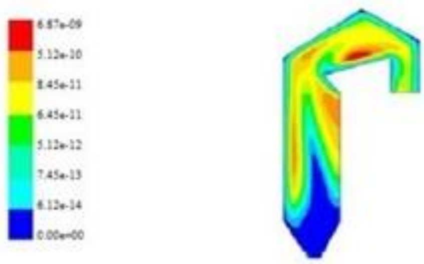


Figure 5.10: NO2 mass fraction in the traditional oil-fuel technique.

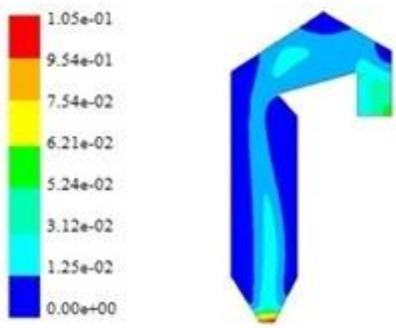


Figure 5.11: In the plasma combustion process, shows the CO mass fraction.

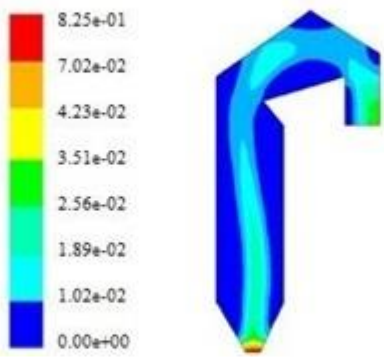


Figure 5.12: Mass fraction of CO_2 in plasma combustion method.

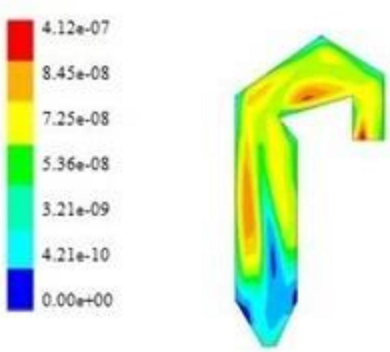


Figure 5.13: NO mass fraction in plasma combustion.

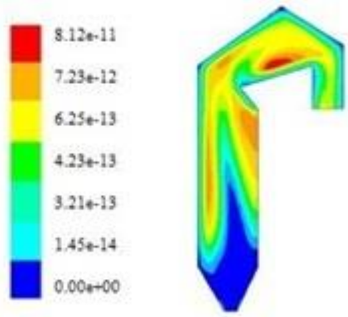


Figure 5.14: NO2 mass fraction in plasma combustion.

RESULT TABLE

Fluid Variables And Emissions	Conventional Oil –fuel combustion	Plasma combustion
Velocity (m/s)	92	84
Pressure Drop (Pa)	85	100
Temperature (K)	5.80E+03	6.86 e+03
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

6. CONCLUSION

In the present study comparison of plasma and oil fuel combustion is shown in result table, parameters like temperature, velocity, pressure and emissions are discussed and found plasma combustion being an excellent system for boiler furnace producing increased temperature and reducing the emissions.

7. REFERENCES

[1] Beyca n Ibrahimoglu , M. Zeki Yilmazoglu , Ahmet Cucen 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] Arkadiusz Dyjakon[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, Raffaele Tuccillo, " 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] Abdulaziz Alsairafi, Abbas Khoshhal, Masoud Rahimi, 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.