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Comparative Analysis of Plasma Combustion Model with Alternate Fuel in Thermal Power Plant Boiler using CFD

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***Abstract*: Plasma assisted combustion is a promising technology to improve engine performance, increase lean burn flame stability, reduce emissions, and enhance low temperature fuel oxidation and processing. Over the last decade, significant progresses have been made towards the applications of plasma in engines and the understanding of the fundamental chemistry and dynamic processes in plasma assisted combustion via the synergetic efforts in advanced diagnostics, combustion chemistry, flame theory, and kinetic modeling. New observations of plasma assisted ignition enhancement, ultra-lean combustion, cool flames, flameless combustion, and controllability of plasma discharge have been reported. Advances in understanding of non-thermal and thermal enhancement effects, kinetic pathways of atomic O production, diagnostics of electronically and vibration ally excited species, plasma combustion kinetics of sub-explosion limit ignition, plasma assisted low temperature combustion, flame regime transition of the classical ignition S-curve, dynamics of the minimum ignition energy, and the transport effect by non-equilibrium plasma discharge. In present study comparative analysis is performed for oil-fuel combustion and plasma combustion model using conventional and alternate fuel. Analysis is done by Computational fluid dynamics method using k-epsilon turbulence and static eddy dissipation model. CFD results shows that flow phenomenon of the system is stable in nature. In current study coal is taken as conventional fuel and SRF (polyethylene + polypropylene) is taken as alternate fuel, investigation is done by CFD and results shows that alternate fuel with plasma combustion is More efficient and less emissive as compare to the conventional oil-fuel combustion and plasma combustion(coal).**

***Keywords*: Plasma combustion, Alternate fuel, power plant, Boiler, Furnaces, Burners, CFD, Mathematical modelling, NOx.**

1. Introduction

As a primary objective, researchers in Los Alamos National Laboratory's P-24 Plasma Physics group are aiming to minimize U.S. Energy dependency on foreign resources through experiments incorporating a plasma assisted combustion unit. Under this broad category, researchers seek to increase efficiency and reduce NOX/SOX and unburned hydrocarbon emissions in IC-engines, gas-turbine engines, and burner units. To date, the existing lean burn operations, consisting of higher air to fuel ratio, have successfully operated in a regime where reduced NOX /SOX emissions are expected and have also shown increased combustion efficiency (less unburned hydrocarbon) for propane. By incorporating a lean burn operation assisted by a non-thermal plasma (NTP) reactor, the fracturing of hydrocarbons can occur with increased power (combustion, efficiency, and stability). Non-thermal plasma units produce energetic electrons, but avoid the high gas and ion temperatures involved in thermal plasmas. One non-thermal plasma method, known as silent discharge, allows free radicals to act in propagating combustion reactions, as well as intermediaries in hydrocarbon fracturing. Using non-thermal plasma units, researchers have developed a fuel activation/conversion system capable of decreasing pollutants while increasing fuel efficiency, providing a path toward future U.S. energy independence. Background Combustion processes impact many aspects of modern life; providing propulsion for automobiles, aircraft, and ships; generating electricity; heating homes, water, and commercial buildings. It is vital to maximize the efficiency of these combustion processes to conserve fuel and reduce pollution. Over the past five decades, many attempts have been made to improve combustion using electric fields, which can affect flame stability, flame propagation speed, and combustion chemistry [1], [2]. Electric-field generated thermal plasmas (usually not efficient and selective in directing electrical energy into the promotion of chemical reactions), have been applied to combustion over the past three or more decades with some success [3], particularly in the conversion of fuel air mixtures (into H2 and CO) [4] in efforts to increase internal combustion engine efficiency and to reduce NOX emissions. Non-thermal plasmas (NTPs) are potentially more useful tools for promoting combustion. For NTPs, the electrons are energetic ("hot"), whereas ions and neutral gases are near ambient temperature ("cool"), which results in little waste enthalpy (heat) being deposited in a process gas. Typical electron temperatures in such plasmas are of order a few electron volts, which is sufficient to break down the fuel and to produce free radicals [5]. We consider the silent electrical discharge (also called a dielectric barrier discharge - DBD), as a very promising candidate for combustion enhancement. In 1983, Inomata et al. [6] demonstrated increases in flames speed when applying a DBD upstream of a methane-air flame. More recent work performed by Cha, et al. [7] showed that applying a DBD to the flame region results in a decrease in flame length and reduced soot formation. Our new technology, based on DBDs, pre-treats fuels (not fuel-air mixtures) just prior to combustion [8]. In our technique, fuels are broken down (cracked) into smaller molecular fragments, boosted into reactive excited states, or made into "free-radicals". The `activated' fuel is then mixed with air and combusted. This allows for very "lean-bum" modes of combustion, highly desirable for the reduction of NOX. "Proof of principle" has been demonstrated in experiments using propane as the fuel in a flame-based burner. We investigated the effects of the plasma on combustion by examining combustion stability under lean-bum conditions, observing increases in flame propagation speed by photography, and by sampling and analyzing the gas residues from combustion. Hypothesis for Non-Thermal Plasma Combustion Enhancement Conventional propane-air combustion begins with spark ignition, in which a spark thermally decomposes the propane-air mixture to produce free radicals and other reactive species. Burning then continues by the propagation of the reactive species generated by the heat of combustion. The overall combustion reaction rate is usually determined by the efficiency of new reactive species generation in the propagating flame front. However, the self-generation of reactive species is sometimes insufficient to sustain combustion under certain conditions, for example during lean-burn operation. NTPs can be used to continuously converting atomized-liquid or gaseous fuels into reactive species, so that combustion does not rely on self-generation of reactive species. Two possible mechanisms for fuel-cracking and fuel-activation (creation of more reactive species) exist. One is based on electron impact processes, such as dissociation, dissociative ionization [9], vibrational excitation [10], and electronic excitation of the parent fuel molecule. Under an electron impact, propane is also ionized into multiple species and these species then further fragment into smaller molecular ions [9]. When ionic recombination and/or charge exchange reactions (ion-molecule) follow dissociative ionization, smaller, more easily-combusted molecular fragments result. In analogy with the electric-field enhancement of fuel-air flames mentioned above, the other mechanism to be considered for fragmentation or `active' species formation is an ion-molecular reaction [11].

2. Literature

1. L. Tarabet et.al With the gradual depletion of petroleum and environmental degradation, intensive research activity has been addressed to the utilization of alternative fuels in internal combustion engines. In the present work, an experimental investigation is carried out to study the effect of eucalyptus biodiesel and natural gas under dual fuel combustion mode on the performance and the exhaust emissions of a single cylinder DI diesel engine. The natural gas (NG) is inducted with the intake air through the inlet manifold. The liquid pilot fuel (eucalyptus biodiesel or diesel fuel) is injected into the combustion chamber to cover approximately 10% of the maximum power output. Then, keeping constant the pilot fuel flow rate, the power output is further increased using only natural gas. The combustion characteristics (cylinder pressure, ignition delay and heat release rate), performance and exhaust emissions of the dual fuel mode (NG–diesel fuel and NG–biodiesel) are compared with those of conventional diesel engine mode at various load conditions. The combustion analysis has shown that biodiesel as pilot fuel exhibits similar pressure–time history, with highest peak, as diesel fuel in conventional and dual fuel modes. The performance and pollutant emission results show that, compared to diesel fuel in dual fuel mode, the use of eucalyptus biodiesel as pilot fuel reduces the high emission levels of unburned hydrocarbon (HC), carbon monoxide (CO) and carbon dioxide (CO_2) particularly at high engine loads. However, this is accompanied by an increase in the brake specific fuel consumption (BSFC) and the nitrogen oxide (NOx) emissions, which can be explained by the lower calorific value and the oxygen presence in the molecule of the eucalyptus biodiesel, respectively.
2. Qiang Zhang et.al The combustion process and emissions of a heavy-duty engine fueled with directly injected natural gas and pilot diesel were experimentally explored. The experiments were carried out under two operating points (A:1275 rpm BMEP 1.05 MPa, B:1550 rpm BMEP 1.05 Mpa) with diesel rail pressure (DRP) varied from 18 Mpa to 30 Mpa and start of natural gas injection (NSOI) in the range of 1˚BTDC to 19˚BTDC. Based on the experimental results, as the injection timing advances, the maximum in cylinder pressure and Nox emissions increase, the flame development duration and brake specific fuel consumption (BSFC) decrease, the maximum heat release rate shows a trend of first decrease and then increase while the changing trend for carbon monoxide (CO) emissions is first increase and then decrease; as the injection pressure raises, the combustion process takes place earlier, causing negative effects on nitrogen oxides (Nox) emissions; with higher engine speed, however, the combustion events are delayed, leading to lower peak value of heat release rate, improved CO and Nox emissions, impaired total hydrocarbon (THC) emissions and higher BSFC.

3. Objective of the study

The main objective of present study is to investigate the present plasma model with conventional and alternate fuel and compare the results with the basis of combustion efficiency, emissions, temperature variations, velocity variations, and pressure variations by CFD simulation. We will also find out the validation of reference research and compression between non premixed combustion and plasma combustion with different operating conditions and alternate fuel with cheaper and eco-friendly.

4. 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*

- *Solution Method:* Choose the Solution method to solve the problem i.e. First order, second order
- *Solution Initialization:* Initialized the solution to get the initial solution for the problem.
- *Run Solution:* Run the solution by giving no of iteration for solution to converge.

C. *Post processing*

For viewing and interpretation of Result. The result can be viewed in various formats: graph, value, animation etc.

D. *CFD method applied*

The model was simulated and the required geometry configurations were pre-processed in ANSYS 19.2. This following section illustrates the method used in the CFD simulations in this particular study.

1) *Step I 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:

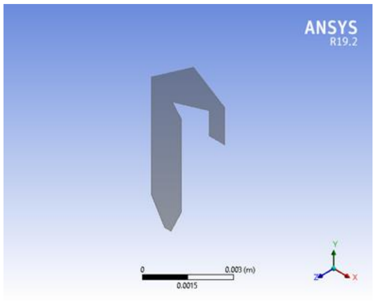


Fig. 1. Cad model

2) *Step 2 Mesh generations*

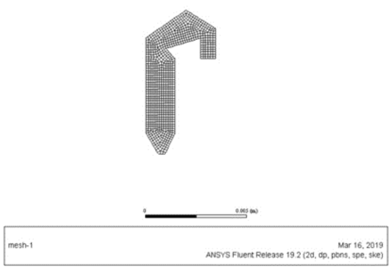


Fig. 2. Mesh model

3) *Step 3 check 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.

E. *Methods*

1. Pressure based
2. 3D Model is used.
3. Gravity is enabling
4. Select Axisymmetric in the 2D Space list.

F. *Model*

1. Energy equation is enabled.
2. K-Epsilon turbulence model used.
3. Non-Premixed condition is used.
4. 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.
5. Finite rate / eddy dissipation in turbulence chemistry. Interactions are used for species model.

G. *Step 4 simulation set up*

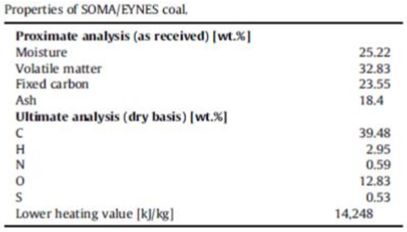
1) *Boundary conditions*

1. Mass Flow Air inlet: - Mass flow rate is 0.5 kg/s,
2. Mass flow Fuel inlet – 0.05 kg/ s of Mixture
3. Outlet – pressure based.

2) *Material*

1. Conventional fuel

Table 1
Properties of SOMA



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

2. Alternate fuel-SRF[Polyethylene+Polypropylene]
1. Mixing law is used.
2. Thermal conductivity: - Define two polynomial coefficients
3. (a) 0.0065234 (b) 8.72369*10-6
4. Polynomial coefficient for viscosity
5. (a) 5.2348e-07 (b) 5.12365e-9
6. For absorption coefficient take stable domain.
7. Scattering coefficient is 1.2e-8.

3) Step 5 solutions

Method

- Coupled

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.

NOTE: - Higher time scale size is used for the energy and species equation to converge the solution in less number of iterations.

- *Solution initialization:* The solution is initialized
- *Run calculation*: Start the calculation for 5000 iterations.

5. Results

Fig. 3. Velocity contour in conventional oil-fuel method

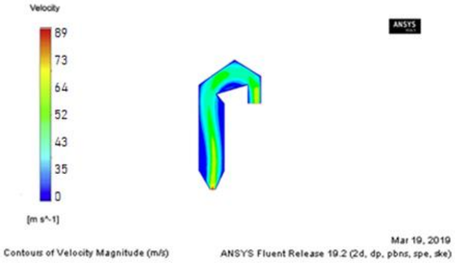


Fig. 4. Velocity contour in plasma method (Conventional fuel)

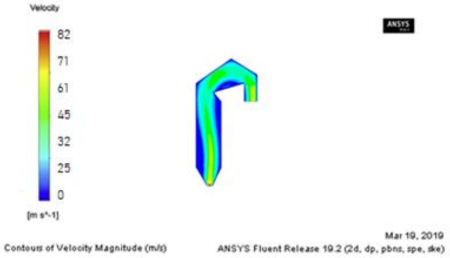


Fig. 5. Velocity contour in plasma method (Alternate fuel)

Fig. 6. Pressure contour in conventional oil-fuel method

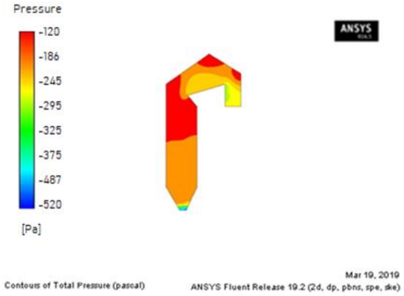


Fig. 7. Pressure contour in plasma method (Conventional fuel)

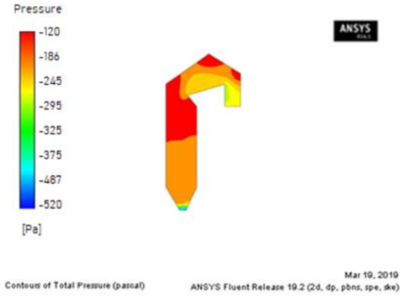


Fig. 8. Pressure contour in plasma method (Alternate fuel)

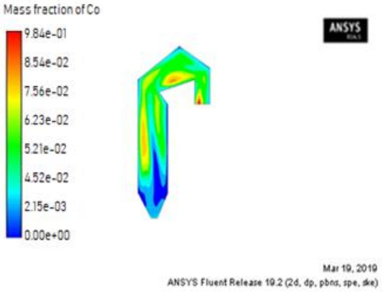


Fig. 9. Mass fraction of CO in conventional oil-fuel method

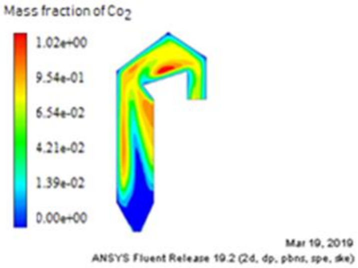


Fig. 10. Mass fraction of CO_2 in conventional oil-fuel method

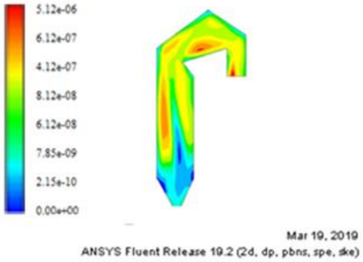


Fig. 11. Mass fraction of NO in conventional oil-fuel method

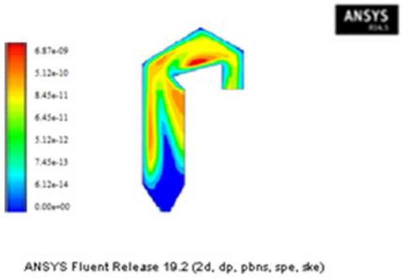


Fig. 12. Mass fraction of NO_2 in conventional oil-fuel method

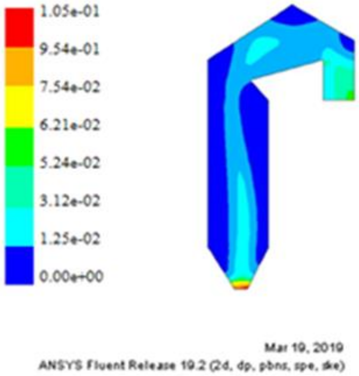


Fig. 13. Mass fraction of CO in plasma combustion method (Conventional fuel)

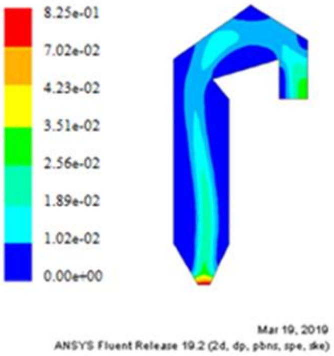


Fig. 14. Mass fraction of CO_2 in plasma combustion method (Conventional fuel)

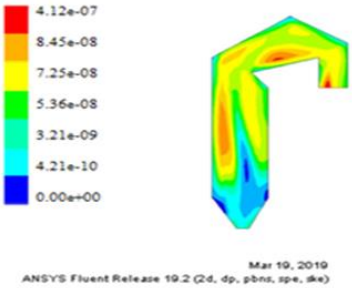


Fig. 15. Mass fraction of NO in plasma combustion method (Conventional fuel)

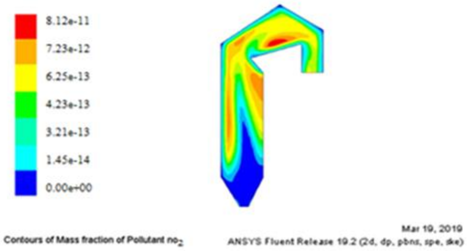


Fig. 16. Mass fraction of NO_2 in plasma combustion method (Conventional fuel)

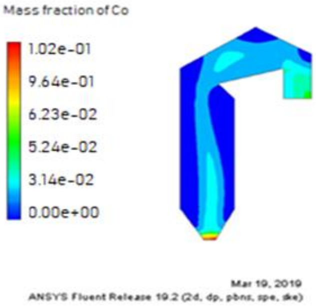


Fig. 17. Mass fraction of CO in plasma combustion method (Alternate fuel)

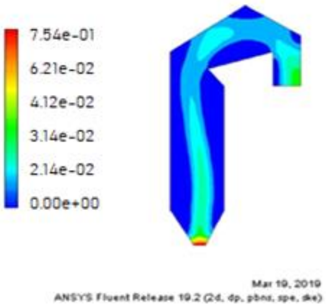


Fig. 18. Mass fraction of CO_2 in plasma combustion method (Alternate fuel)

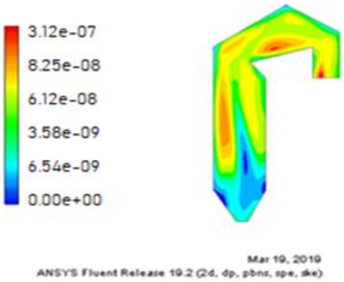


Fig. 19. Mass fraction of NO in plasma combustion method (Alternate fuel)

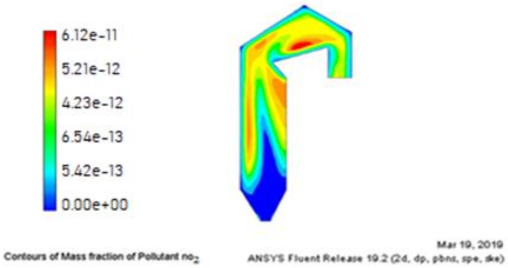


Fig. 20. Mass fraction of NO_2 in plasma combustion method (Alternate fuel)

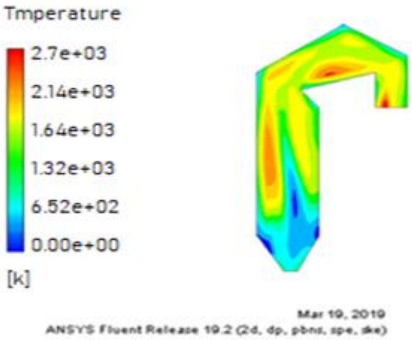


Fig. 21. Temperature contour in conventional oil-fuel method

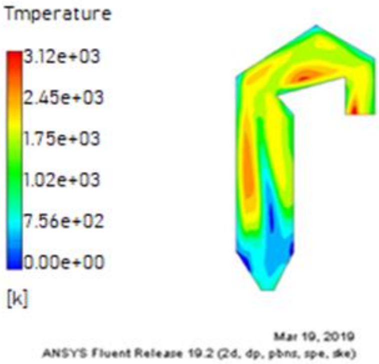


Fig. 22. Temperature contour in conventional Plasma method (Conventional fuel)

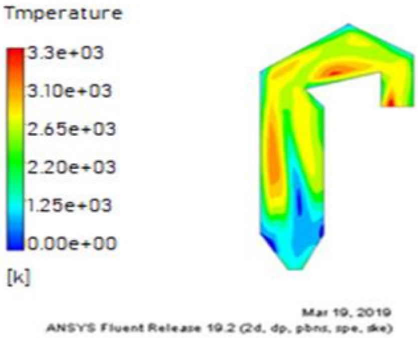


Fig. 23. Temperature contour in conventional Plasma method (Alternate fuel)

Table 2
Results

Fluid Variables And Emissions	**Conventional Oil –fuel combustion**	**Plasma Combustion (Conventional fuel)**	**Plasma Combustion (Alternate fuel)**
Velocity (m/s)	98	89	82
Pressure Drop (Pa)	120	110	95
Mass fraction of CO	9.84e-01	1.05e-01	1.02e-01
Mass fraction of CO2	1.02e+00	8.25e-01	7.54e-01
Mass fraction of NO	5.12e-06	4.12e-07	3.12e-07
Mass fraction of NO2	6.87e-09	8.12e-11	6.12e-11
Temperature (k)	2700	3120	3300
Total energy (j/kg)	4785	5500	5812

6. Conclusion

Fuel-oil burners are generally in use in thermal power plants for the startup operation and flame stabilization. Plasma activation of coal particles instead of using fuel-oil burners promotes more effective and environmentally friendly combustion. Plasma systems are also used for combustion stabilization in utility boiler furnaces. Plasma combustion systems can be used to promote early ignition and enhanced stabilization of a pulverized coal flame. In addition, plasma combustion systems reduce the harmful emissions originated from coal combustion. Ignition of coal by plasma requires less energy compared to the case of using fuel oil or natural gas in thermal power plants for startup and flame stabilization. In Present research work comparative investigation is done by Computational fluid dynamics method with the basic of different parameters like Temperature, total energy, pressure, velocity and emissions. 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. CFD results shows that velocity is increasing in plasma combustion (conventional and alternate fuel) and pressure drop is also decreasing continuously which is desirable for rapid mixing of fuel and stability of the system. Due to higher rate of mixing approximate complete combustion has been done in case of alternate fuel as compare to other one and emission percentages is also decreasing in an efficient manner.

References

[1] Tarabet et.al, "Experimental investigation of DI diesel engine operating with eucalyptus biodiesel/natural gas under dual fuel mode", Fuel 133 (2014).

[2] Qiang Zhang, "Combustion process and emissions of a heavy-duty engine fueled with directly injected natural gas and pilot diesel", Applied Energy 157 (2015).

[3] Miqdam Tariq Chaichan, " Combustion of Dual Fuel Type Natural Gas/Liquid Diesel Fuel in Compression Ignition Engine", IOSR Journal of Mechanical and Civil EngineeringVolume 11, Issue 6 Ver. IV (Nov-Dec. 2014).

[4] Pali Rosha et.al, "Performance and emission characteristics of Diesel+LPG dual fuel engine with exhaust gas recirculation", International Journal of Science, Engineering and Technology Research (IJSETR), Volume 3, Issue 10, October 2014.

[5] Chunhua Zhang et.al, "Effects of combustion duration characteristic on the brake thermal efficiency and NOx emission of a turbocharged diesel engine fueled with diesel-LNG dual-fuel", Applied Thermal Engineering 127 (2017).

[6] Jeongwoo Lee et.al, "Classification of diesel and gasoline dual-fuel combustion modes by the analysis of heat release rate shapes in a compression ignition engine", Fuel 209 (2017).

[7] Carmelina Abagnale et.al, "Combined numerical-experimental study of dual fuel diesel engine", Energy Procedia 45 (2014).

[8] Peng Geng et.al, "Effects of alternative fuels on the combustion characteristics and emission products from diesel engines: A review", Renewable and Sustainable Energy Reviews (2016).

[9] Abdelrahman Hegab, "Towards keeping diesel fuel supply and demand in balance: Dual-fuelling of diesel engines with natural gas", Renewable and Sustainable Energy Reviews 11 (2016).

[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

[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] Jafar Ghafouri, Amin Maghbouli, Rahim Khoshbakhti Saray, Sina Shafee, "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] Anand Odedra, 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, November 2013, 68-83.

[15] Ingwald Obernberger, 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, pp. 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, pp. 646-665

[18] A. Askarova, E. Karpenko, Yu. Karpenko, E. Messerle, A. Ustimenko Mathematical modelling of the processes of solid fuel ignition and combustion at combustors of the power boilers 7th International Fall Seminar on Propellants, Explosives and Pyrotechnics. Xian, Vol. 7, 672, (2007).

[19] A. Askarova, V Messerle, A Ustimenko, S Bolegenova, V Maximov, Z Gabitova Numerical simulation of pulverized coal combustion in a power boiler furnace, High temperature, Vol. 53, issue 3, 445, (2015).

[20] V. Maximov, S. Bolegenova, M. Beketayeva, P. Safarik et al. Numerical Modeling of Pulverized Coal Combustion at Thermal Power Plant Boilers, Journal of thermal science, Vol. 24, issue 3, 275 (2015).

[21] V. Messerle, A. Ustimenko, A. Askarova A. Nagibin Pulverized coal torch combustion in a furnace with plasma-coal system, Thermophysics and aeromechanics, Vol. 17, issue 3, 435, (2010).

[22] E. Karpenko, V. Messerle et al. Plasma enhancement of combustion of solid fuels, Journal of High Energy Chemistry, Vol. 40, Issue: 2, 111, (2006).

[23] V. Messerle, Ye. Lavrishcheva, E. Karpenko, A. Ustimenko et al. Plasma-supported coal combustion in boiler furnace, IEEE Transactions on Plasma Science, Vol. 35, Issue 6, 1607, (2007).

[24] A. Askarova, V Messerle, A. Ustimenko, S. Bolegenova, V. Maksimov Numerical simulation of the coal combustion process initiated by a plasma source, Thermophysics and aeromechanics, Vol. 21, issue 6, 747, (2014).

[25] S. Bolegenova, V. Maximov, A. Bekmukhamet, M. Beketayeva, Z. Gabitova etc. Computational method for investigation of solid fuel combustion in combustion chambers of a heat power plant, High temperature, Vol. 5, issue 5, 751, (2015).

[26] A. Askarowa, M. Buchmann Structure of the flame of fluidized-bed burners and combustion processes of high-ash coal, Gesell Energietech, Combustion and incineration - eighteenth dutch-german conference on flames, VDI Berichte, v. 1313, 241, (1997).

[27] S. Vockrodt, R. Leithner, A. Schiller et al. Firing technique measures for increased efficiency and minimization of toxic emissions in Kasakh coal firing, VDI, 19th German Conference on Flames, Germany, VDI Gesell Energietechn; Verein Deutsch Ingn., Combustion and Incineration, VDI Berichte, v. 1492, 93, (1999).

[28] M. Gorokhovski, A. Chtab-Desportes, I. Voloshina, A. Askarova Stochastic simulation of the spray formation assisted by a high pressure, AIP Conference Proceedings, Xian, Vol. 1207, 66, (2010).