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Design Of Tangentially Fired Pulverized Coal Burner Nozzle For Enhanced Erosion Resistance

Kewal Singh[1]; Navdeep Singh Grewal[2]*; Sukhdeep Singh[3]
[1,2,3]Department of Mechanical Engineering, Guru Kashi University, Talwandi Sabo, Punjab, India

Corresponding Author: Navdeep Singh Grewal[2]

Abstract:- Erosion-induced failure of pulverized coal burner nozzles (PCBN) presents a significant challenge in pulverized coal-based thermal power plants. Investigations have identified multiple causative factors leading to the accelerated degradation and consequent reduced lifespan of PCBN. These factors include the erosive impact of solid fuel particles carried at high velocities and angles, as well as the high-temperature conditions within the combustion zone. To mitigate erosion, strategies often revolve around enhancing material resistance or optimizing aerodynamic profiles to minimize drag forces. This study employs Computational Fluid Dynamics (CFD) via the CFX code to model and analyze the erosion dynamics within PCBN. By adjusting the geometry of the inner plates within the PCBN, simulations indicated a notable improvement in erosion resistance. The optimized design achieved this by expanding the flow area between the innermost bifurcated plates without altering their angle, leading to a more uniform flow distribution and favorable velocity and pressure gradients. These modifications have the potential not only to prolong nozzle life but also to contribute to more efficient combustion in tangentially fired furnaces.

Keywords:- *Erosion Behavior, Pulverized Coal Burner Nozzles (PCBN), Aerodynamics Effects, Computational Fluid Dynamics (CFD), Impact Angle.*

I. INTRODUCTION

Tangentially coal-fired boilers, prominently utilized in modern thermal power plants, are known for their comprehensive flame coverage within the furnace volume, granting good flame stability and adaptability for various coal ranks and loads [1,2]. The coal, pulverized to fine grains and mixed with air, is conveyed pneumatically to burners, forming the heart of the combustion process. The efficiency of the boiler and, by extension, the power plant, depends on the complete combustion of this coal dust, which is achieved by controlling the feeding rate and air availability through sophisticated computer systems [3,4]

The pulverized coal burner nozzle (PCBN) is a crucial component in this process, facilitating the injection of coal-air mixtures into the combustion zone [5].Designed from high-quality steel bifurcated plates, these nozzles direct the flow of pulverized coal, with the geometry of the burner and the velocity ratio of the fuel and air jets being pivotal for stable combustion and efficient fuel burnout [6].Tangential firing systems, wherein the pulverized coal is fed into the furnace from four corners at various heights, create a cylindrical combustion zone with a strong swirl that promotes turbulence and combustion in a central flame zone, differing from horizontal firing systems [7].

However, the PCBNs are subjected to severe erosive conditions due to the high-speed coal particles and extreme temperatures within the combustion zone. The tips of the nozzles, especially the baffle or splitter plates, experience rapid erosion, which is further exacerbated by the heat of the flame, leading to warping and cracking, even in regular operations [8,9]. In India, the coal's large ash content, including abrasive minerals like quartz and feldspars, intensifies the erosion suffered by these components [10].This solid particle erosion (SPE) is a progressive loss of material, quantified by the volume or mass removed by impacting particles, resulting from several mechanisms like cutting wear, plastic deformation, and thermal fatigue [11,12]

The costs associated with SPE in thermal power plants are significant, with erosion leading to frequent replacements of nozzles and pipes, which account for a substantial portion of production costs and plant downtime [13]. While new high-grade materials can reduce the erosion rate of PCBN, their cost is prohibitive [14]. Consequently, there's a shift towards computational methods, like Computational Fluid Dynamics (CFD), to predict erosion rates and simulate flow to improve the aerodynamics of particles, thus reducing drag forces and changing the erosion dynamics without incurring high costs [15,16] These simulations aid in improving the life of PCBN by enhancing material properties and reducing aerodynamic effects [17].

This research is focused on addressing the challenges posed by solid particle erosion in PCBNs within tangentially fired coal-based power plants. By employing a multifaceted approach that combines the use of advanced high-grade materials and Computational Fluid Dynamics (CFD) simulations, the study aims to significantly reduce the erosion rates and thereby enhance the operational life of these critical components. Through detailed analysis and simulation, design modifications are proposed that promise not only to increase the erosion resistance of PCBNs but also to optimize the combustion process within the furnace. Ultimately, this work endeavors to present a comprehensive solution that mitigates erosion while improving the overall efficiency and reliability of coal-fired power generation.

II. EXPERIMENTATION

The experimental work involved selecting three software tools: Catia V5.0 R19.0 for 3D modeling, HyperMesh 10.0 for meshing, and Ansys CFX-12.0 for CFD analysis, which were integral in developing the final results. The current design of PCBN was first assessed using CFD to determine erosion behavior. Subsequently, the CFD model incorporated changes in the positioning of the internal plates of PCBN, leading to an improved design through a one-time investment [18]. Optimal coal-air mixture velocities and erosion-resistant materials were key considerations in the design process to minimize erosion [19].

A 2D drawing was generated from an actual model of a fresh nozzle at GNDTP, Bathinda as shown in Fig. 1.

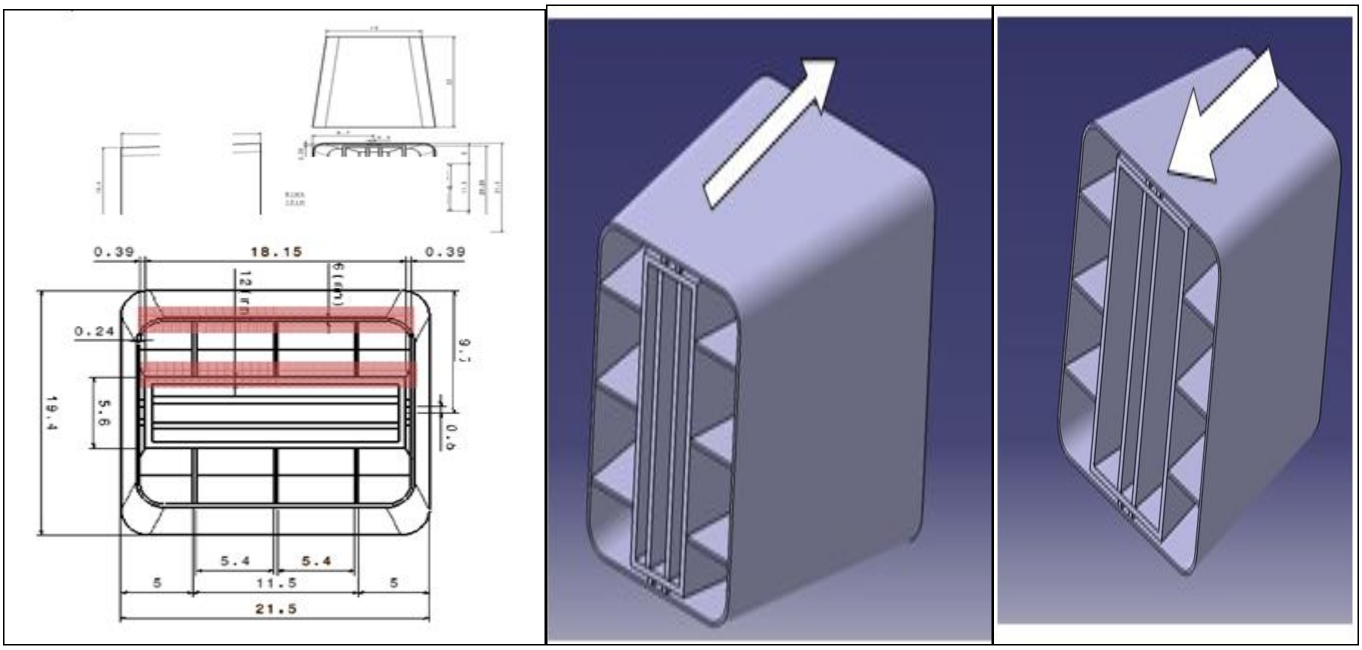

Fig 1: Design of Nozzle Burner (All Dimensions in Inches)

This drawing was based on the geometric figures studied, followed by the creation of a 3D CFD mesh. The meshing process included defining regions and attributes, generating volume mesh, and ensuring the quality of meshes for accurate CFD simulations. Special attention was given to resolving boundary layer phenomena, with the boundary layers selected for the outer wall of PCBN having a thickness of 0.02mm for each layer. The inner surface layers, where interaction with the PC mixture occurs, were smoothed to 0.1mm, and the outer surface layers were smoothed to 0.2mm . An additional flow region was added at the inlet and outlet of PCBN to accommodate the pulverized coal mixture flow. The final meshed file of PCBN shows the section meshing results and the meshing at inlet and outlet.

Properties of the pulverized coal used in GNDTP, Bathinda plants—mainly Lignite and Bituminous—were documented. These coals are characterized by their high carbon content, hardness, and calorific value, with a significant ash content containing abrasive minerals like quartz. Flow parameters were meticulously selected to reflect the mean operational conditions of the boilers. Variations in flow velocity and mass flow rate were accounted for, based on the coal consumption data from the furnace's sixteen burners over a 24-hour period. The selected parameters are summarized in Table 1, with flow velocities ranging from 6.0 to 15.0 m/sec and mass flow rates from 0.5 to 1.1 kg/sec, aiming for a mean designed flow velocity of 10.0 m/sec and mass flow rate of 0.75 kg/sec.

Table 1: Design of Nozzle Burner (All Dimensions in Inches)

Particulars	Units	Highest	Lowest	Mean (Designed)
Flow Velocity	m/sec	15.0	6.0	10.0
Mass FlowRate	Kg/sec	1.1	0.5	0.75

The steady-state analysis utilizing ANSYS CFX12.0 proceeded through three modules: CFX-Pre, CFX Solver, and CFX-Post. The meshed file of PCBN was imported into CFX-Pre, where flow physics, boundary conditions, initial values, and solver parameters were defined. This step ensured control over the execution order and solution dependencies, crucial for initializing transient analysis based on the results from the steady-state analysis.

III. RESULTS AND DISCUSSION

This study utilized a simulation model within the Ansys CFX12.0 computational fluid dynamics software to predict the erosion patterns and rates in pulverized coal burner nozzles (PCBN). The model assessed the effects of erosion on the inner plates and evaluated the impact of design modifications validated by simulation results, as depicted in Figure 2.

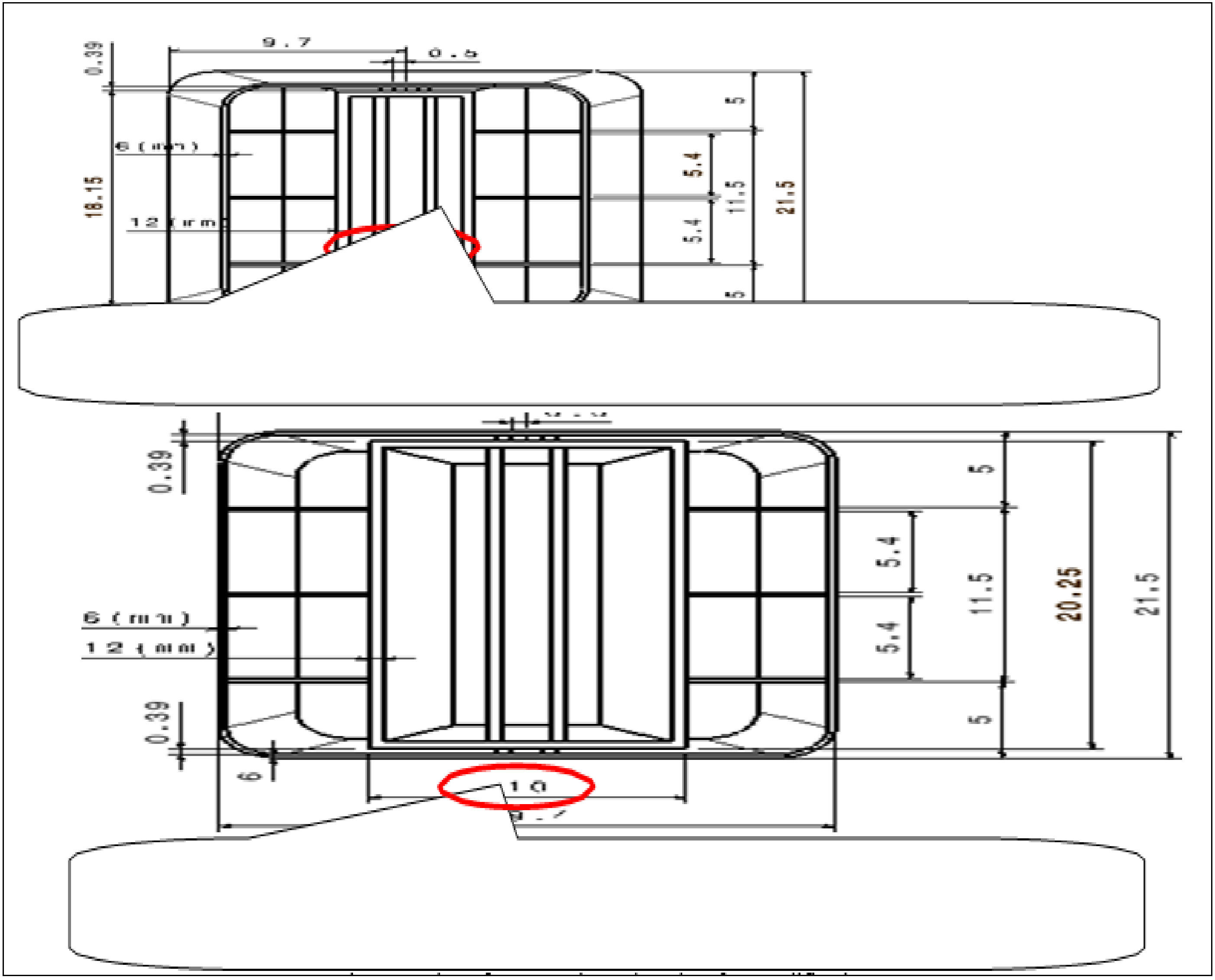

Fig. 2: Design of PCBN Inlet and Outlet after Modifications

A. *Influence of Geometric Changes on Erosion Behavior*

The study explored the relationship between geometric modifications of the PCBN and their effects on erosion. Changes in the flow area between the bifurcated inner plates were found to affect erosion patterns, flow velocity gradients, pressure gradients, and mass flow rate distribution within the nozzle. Figures 3 and 4 illustrate how an increased flow area leads to a reduction in the erosive impact on the top surfaces due to decreased flow velocity near the duct and PCBN walls, attributed to wall friction [20,21]. Consequently, a significant improvement in erosion patterns was observed.

The bottom and downward-inclined inner plates, on the other hand, did not exhibit a significant change in erosion patterns due to the lack of direct impact from the pulverized coal mixture, as shown in Figure 5 and 6. These findings indicate that the flow area alterations have negligible effects on surfaces that do not directly encounter the coal-air stream [22].

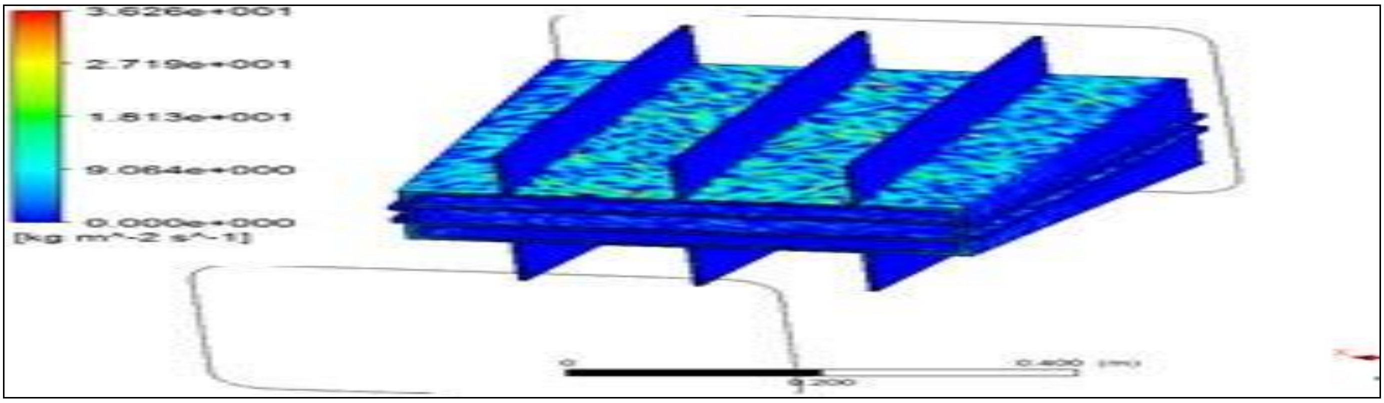

Fig 3: Erosion Behavior on the TopSurface of Inner Plates of Old PCBN

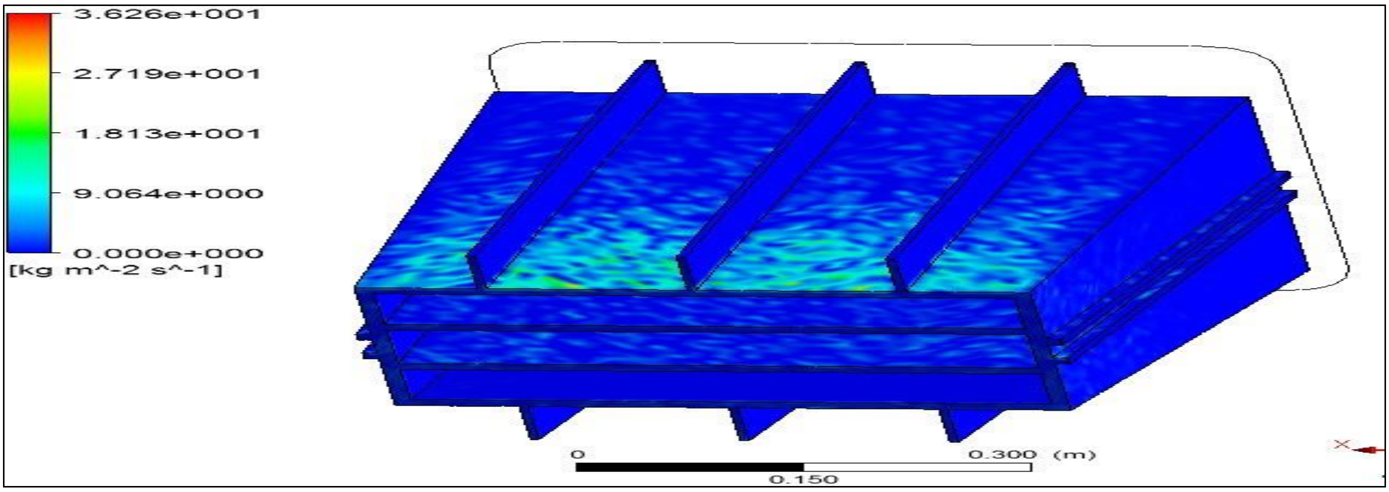

Fig 4: Erosion Behavior on the Top Surface of Inner Plates of modified PCBN

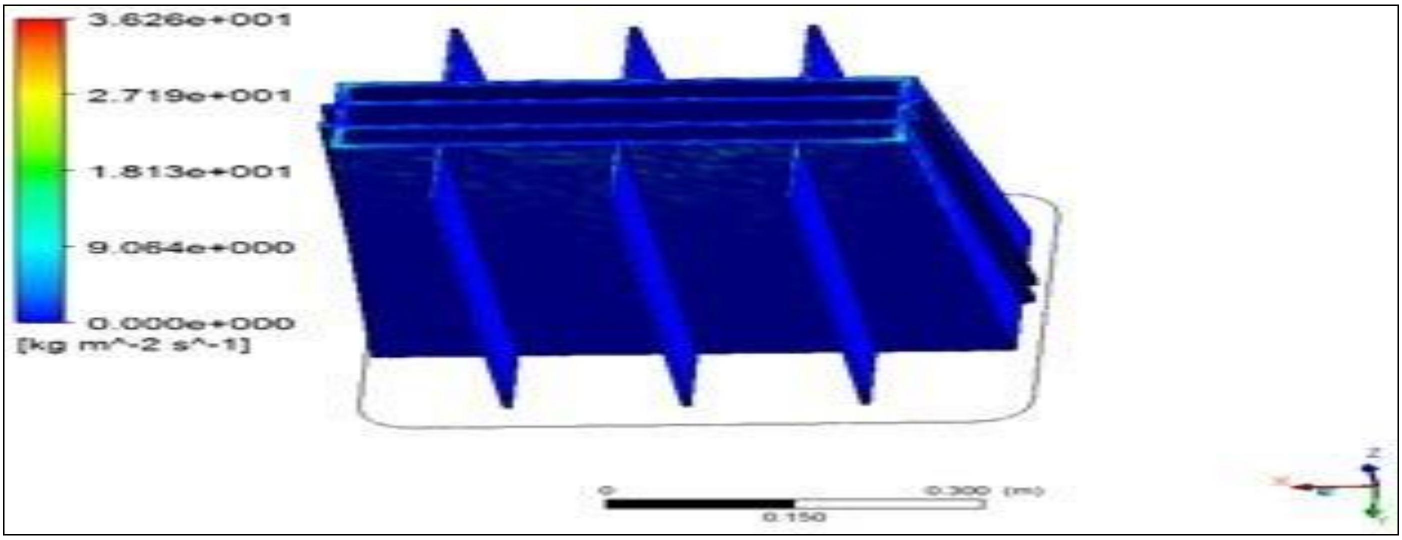

Fig 5: Erosion Behavior on the bottom Face of Inner Plates of old PCBN

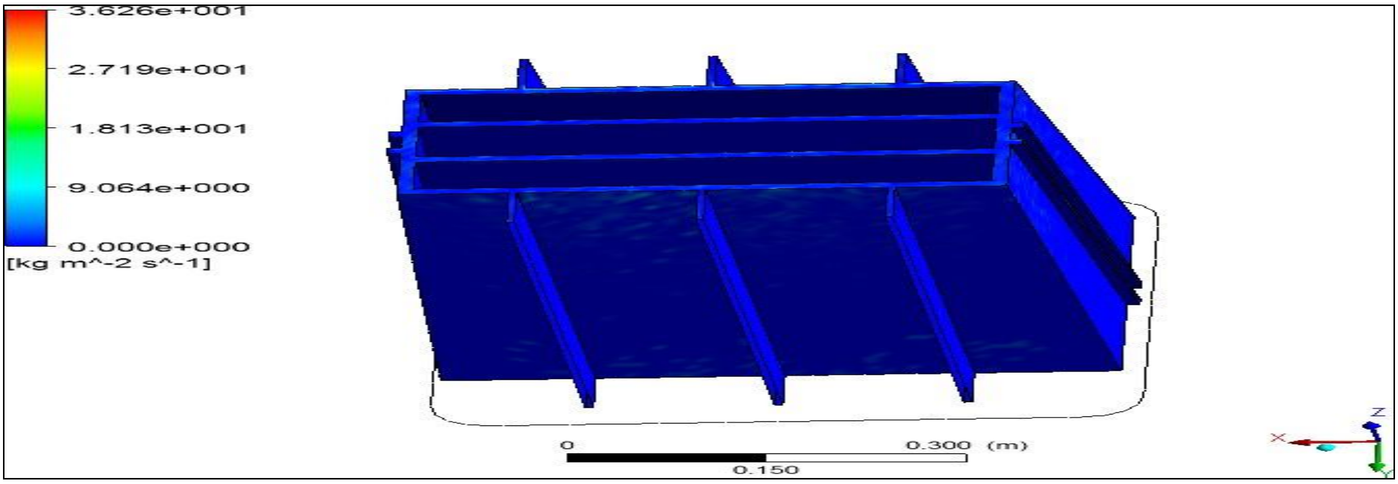

Fig 6: Erosion Behavior on the Bottom Face of Inner Plates of Modified PCBN

B. *Erosion Pattern and Velocity Gradient Improvements*

The simulation results further revealed that erosion patterns and velocity gradients within the PCBN can be significantly improved by modifying the flow area [23,24]. The alteration led to a more uniform velocity distribution, especially at the center of the PCBN [25], where the highest velocity components are typically found. This uniformity in velocity gradients contributes to a more efficient erosion behavior and is exemplified in Fig. 7 and 8, with the latter showing an "I" type structure indicating non-uniformity in the old design.

C. *Dynamic Pressure Gradient Distribution*

The distribution of dynamic pressure gradients also displayed improvement. An increase of up to 15% in pressure uniformity was observed in the modified PCBN design [26], which is crucial for reducing erosion [27]. The higher-pressure gradients were positioned further away from the inner surfaces of the PCBN walls, as demonstrated in Fig. 9 and 10.. This redistribution is instrumental in enhancing the erosion resistance of the nozzle [28].

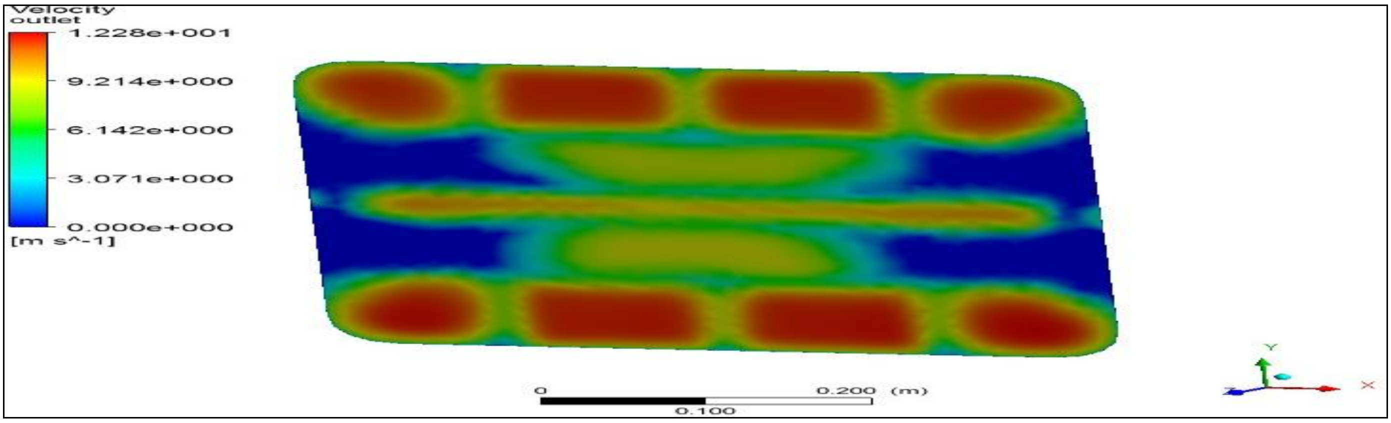

Fig 7: Velocity Gradient Distribution Outline atthe Outlet of Old PCBN

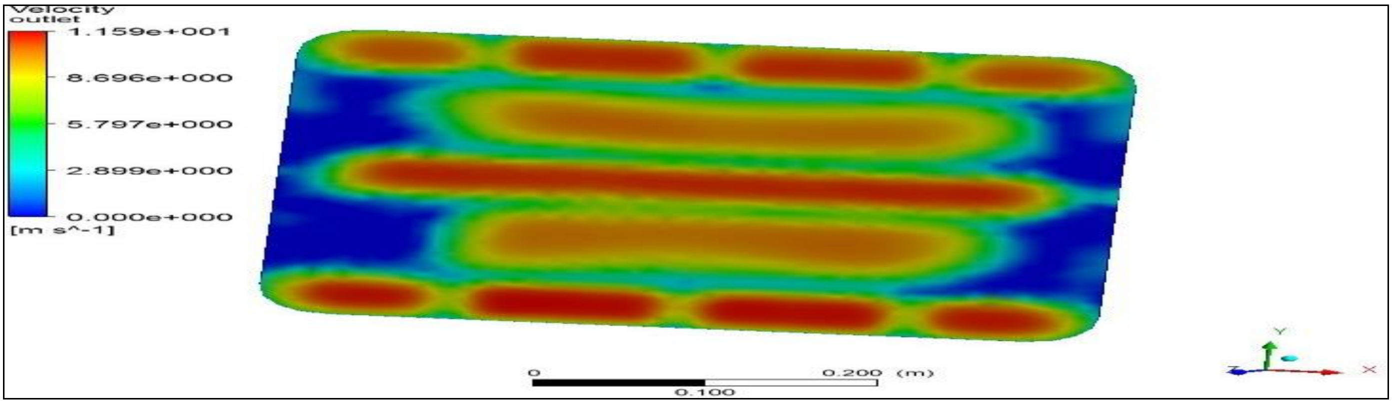

Fig. 8 Velocity Gradient Distribution Outline at the Outlet of Modified PCBN

D. Mass Flow Rate Distribution

The mass flow rate distribution pattern plays a critical role in the erosion behavior of the PCBN. The simulations suggested that increasing the flow area between the inner plates leads to a mass flow rate distribution that is maximized at the center of the outlet [29], as evidenced in Fig. 11 and 12.

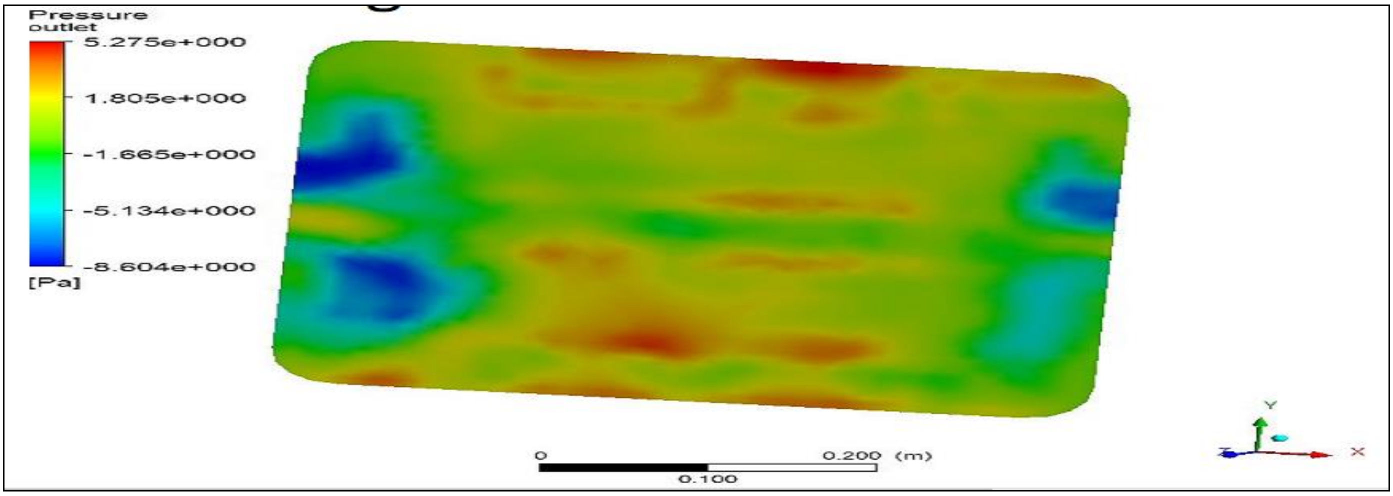

Fig 9: Dynamic Pressure Gradient Distribution at the Outlet of Old PCBN

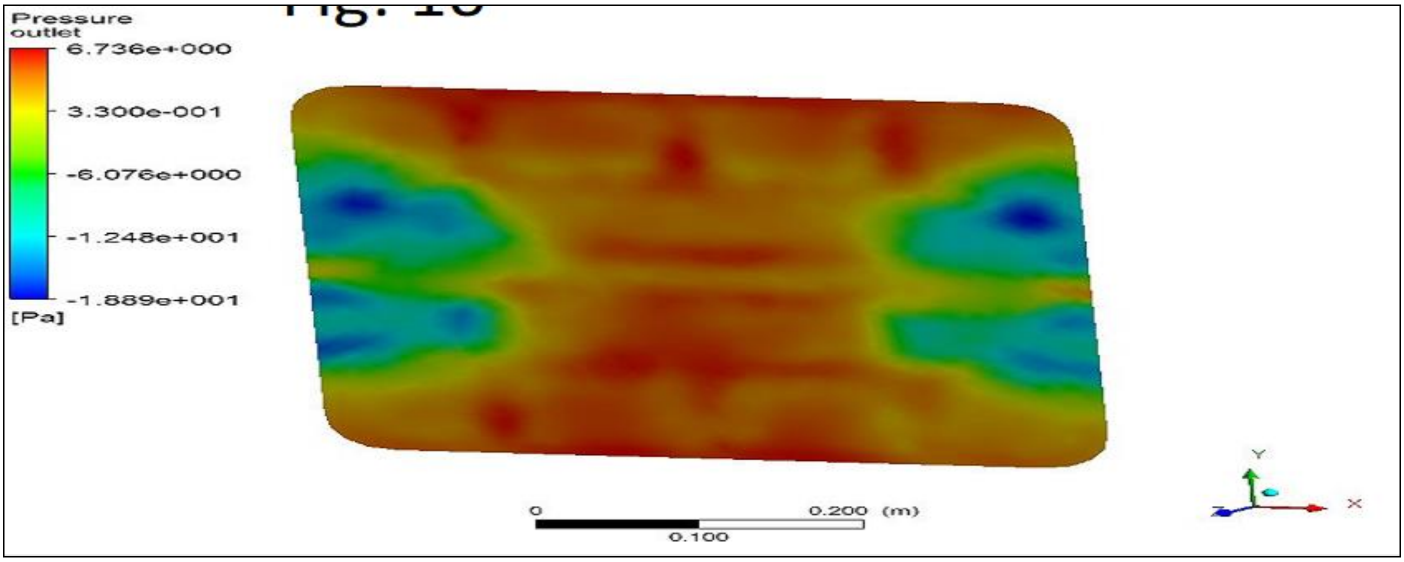

Fig. 10: Dynamic Pressure Gradient Distributionat the Outlet of Old PCBN

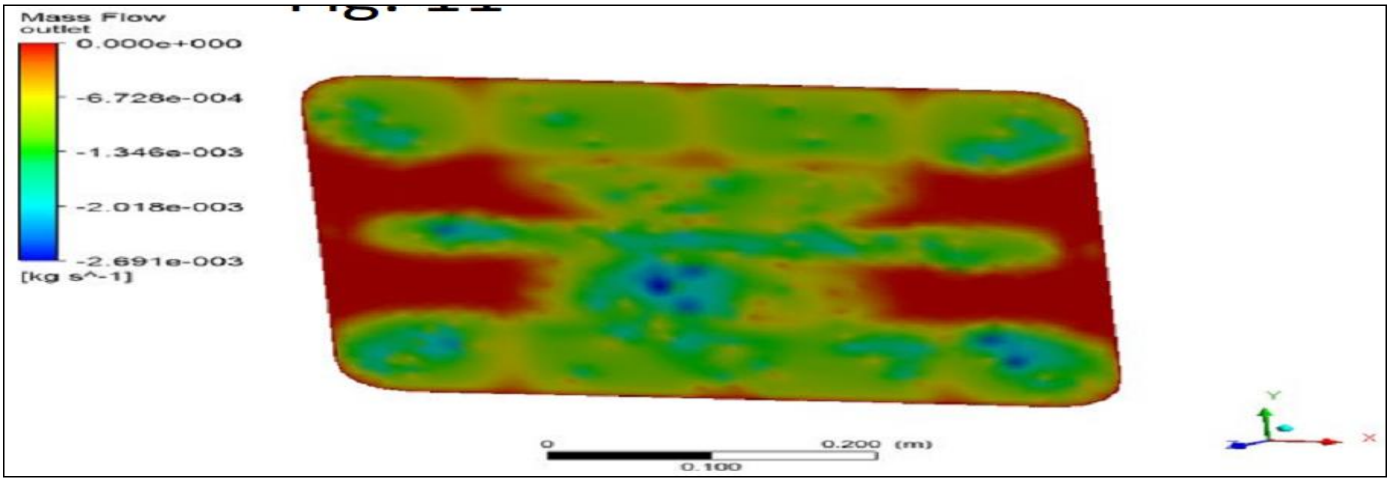

Fig. 11 Mass flow Rate Distribution at the Outlet of Old PCBN

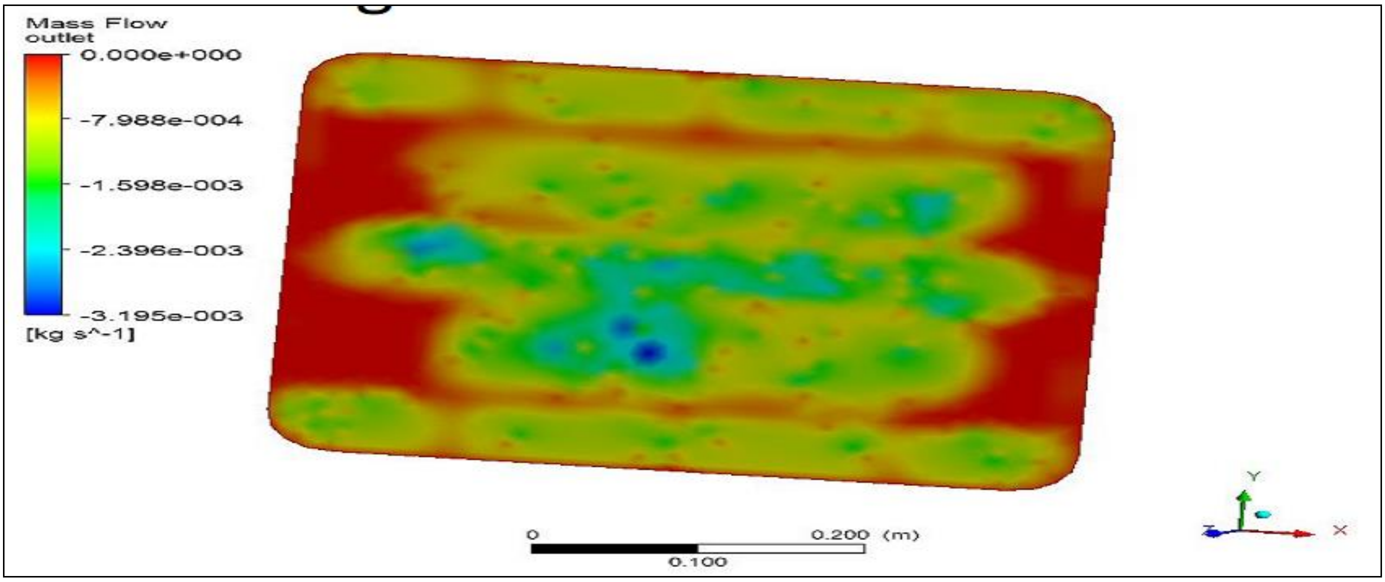

Fig. 12 Mass Flow Rate Distribution at the Outlet of Modified PCBN

These results affirm the importance of mass flow rate distribution patterns in achieving significant improvements in the erosion behavior of PCBNs.

IV. CONCLUSION

The erosion of pulverized coal burner nozzles (PCBN) poses a significant challenge, leading to their rapid degradation. The application of Computational Fluid Dynamics (CFD) has proven to be an effective approach for examining and forecasting the erosion patterns and rates affected by various flow parameters. Particularly for complex geometries, CFD erosion modelling emerges as a robust predictive tool for solid particle erosion scenarios.

Through strategic design modifications of the PCBN, notable improvements in erosion behavior have been achieved. The study found that an increase in the flow area through the inclined outermost inner plates of the PCBN leads to a substantial improvement in the erosion pattern. Furthermore, this enlargement of the flow area has been shown to reduce the erosion rate. It also facilitated a more uniform distribution of velocity gradients and, to a certain extent, pressure gradients within the nozzle. The distribution pattern of the mass flow rate is directly influenced by the size of the flow area, confirming the pivotal role of aerodynamic behavior on the erosion dynamics within the nozzle or tubes.

FUTURE SCOPE

The use of Computational Fluid Dynamics (CFD) has established itself as an influential investigative tool for analysing erosion behavior, particularly in complex geometries, enabling precise prediction of erosion patterns.

Future advancements in this area could include combining CFD techniques with hard facing methods to further enhance the erosion resistance of pulverized coal burner nozzles (PCBN).Exploring the aerodynamic effects within the ducts following the PCBN represents another avenue for research. Developing detailed erosion models for these areas could yield insights into how erosion behavior can be mitigated beyond the nozzle itself. Additionally, the adoption of hexahedral meshing for the flow region within the PCBN may refine the simulation results, offering a more nuanced understanding of erosion dynamics compared to tetrahedral meshing.

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