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Numerical prediction of erosion in coal burner of 210 MW boiler through computational fluid dynamics modeling

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The splitter plates of coal burners in Indian thermal plants are subjected to severe erosion and erosion-corrosion conditions owing to the combined effect of abrasive nature of coal and elevated service temperature environment. During service, tilting of splitter plates is adopted to achieve the desired final steam outlet temperature which shifts the fireball location and heat release area in the combustion zone. The tilt condition gives rise to a change in the incidence angle of the coal particle as well as the change in flow profile. The erosion life of these plates is predominantly affected by the coal particle velocity, impact angle, particle size and steady state metal temperature during service. The sensitivity of burner tilt angle on the erosion life requires an understanding of primary air with coal particle flow phenomenon within the burners. The effect of burner tilt angle on the erosion of presently used SS310 grade splitter material was studied through computational fluid dynamics. The erosion sensitive velocity exponent was calculated based on the laboratory simulated erosion tests at elevated temperatures upto 700°C. The life of the splitter plates was calculated based on the predicted erosion rate intensity.

Keywords: *Coal burner, high-temperature erosion, Computational Fluid Dynamics (CFD)*

1.0 INTRODUCTION

In a coal based thermal power plant, the pulverized coal from the mill is carried to the boiler by pneumatic conveying using primary air which is maintained at a temperature of 80 to 90 °C. In a tangentially fired PF boiler, coal burner nozzles are provided in the burner zone at seven different elevations which connect the PF pipe from the mill outlet to the boiler. The coal burner nozzles connected at the end of each PF pipe injects the coal particles into the boiler combustion zone. Indian coals contain nearly 45 to 50 % ash. The amount of coal used per MW of generation is nearly double than that of Western and Australian coal based plants. Also, the ash contains a high amount of abrasive minerals such as quartz which are responsible for the erosion of coal handling components. The heat radiated in the combustion zone increases the service temperature of the burner nozzles located at each corner of furnace wall of the boiler. The high erosion propensity of coal combined with elevated service temperatures of burner tip components leads to severe erosion and reduced life. Conventionally, the austenitic stainless steel of 310 grade is widely used as the burner tip material and the service life, in a typical 210 MW is only 4-6 months, depending on the ash content in the coal. The material used for burner nozzle tips should have the characteristics of adequate erosion resistance at elevated temperatures and should perform at least for a continuous period of two years, coinciding with the overhaul of the unit.

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The application of a new material in the actual field condition requires the knowledge of the material behaviour under accelerated test conditions in the laboratory. The erosion intensities in coal burner pipe and nozzle tip is not uniform and depends on the tilt angle as well as the flow profile in the coal pipe. Also, the nozzle tips generally experience severe erosion on the bottom side facing the flow under negative tilt conditions[1–4].

The flow profile in a coal burner is affected by the geometry of the coal burner in terms of its geometry, no. of splitter plates, as well as the burner, tilts angle. It is very much essential to have the characteristics of the flow profile in terms of its velocity, turbulence as it exits the burner tip and enters the fire ball zone. The present study focuses on the evaluation of the high-temperature erosion resistance properties of SS310 material under accelerated test conditions as well as the CFD based flow profile studies for the considered geometry which are considered very important from the view point of field implementation.

In the present study, evaluation of the presently used SS310 grade steel material was assessed for its high-temperature erosion resistance and the CFD modelling was carried out on the actual 210 MW boiler.

2.0 EXPERIMENTAL PROGRAM

2.1 Erosion test

The relative ranking of various metals for their erosion resistance is widely carried out as per the guidelines of ASTM standard G76. The erosion resistance of SS310 was carried out at room temperature and high-temperature conditions of 400 and 700 °C, using an indigenously designed Jet type erosion test rig. The evaluation of erosion resistance of different materials has been carried out using a jet type high-temperature erosion test rig both at room temperature and at temperature conditions of 400°C and 700 °C. Figure 1 shows the schematic view of the test setup used.

The test rig consisted of three stage heater assemblies for heating the air used for accelerating the particle through a ceramic nozzle. The outlet temperature of the air coming out of the ceramic nozzle was measured initially using a “K” type thermocouple placed closed to the exit of the hot air stream, for different combinations of set temperatures in the heater stages. The erodent particles are fed at a controlled rate into a ventury type mixing chamber. The hot air with the particles flow out of a ceramic nozzle and impinge on the sample target material kept at a distance of 10 mm from the exit of the nozzle.

The flow rate of the air is controlled by the digital mass flow controller, provided at the discharge pipe of the compressed air line. The actual velocity of particles impacting the target test material was measured at room temperature air conditions by well-known time–of-flight principle, using a Double disk apparatus, the details of which was reported elsewhere [5]. The impact angle was varied by changing the inclination of the sample with respect to the axis of the hot air-particle stream.

The dry air from the compressor, upon heating through the three stages is allowed to impinge on the sample for a period off iveminutes, prior to the star to feeding of the erodent so as to ensure that the local temperature at the point of impact was same as that of the hotair. The sample was exposed to erosion conditions till the known quantity of erodent is used to impact the target test surface. The tested sample was cleaned by the high-pressure air stream tore move all the loose particles and weighed using the analytical balance.

The erosion test conditions used are:

Erodent type	:	Silica sand (AFS 70)
Nozzle diameter	:	5 mm
Erodent flux rate	:	140 g/min
Sample size	:	75 x 25 x 8 mm
Impact angles	:	15,30,45,60 and 90°
Test Temperature	:	Room temp, 400 °C and 700 °C

There sults in terms of weight loss of the sample perk go fabrasive used are cal culated and the average of three results is reported. As the burner splitter plates under go the maximum tilt angle of 30° down ward from the horizontal (-30°), the velocity exponent at 30° impact angle was considered for all CFD analysis.

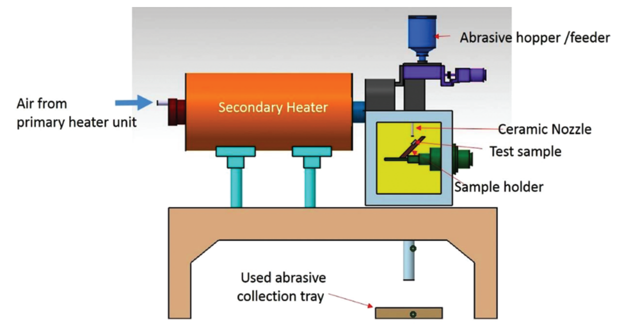


FIG. 1 SCHEMATIC VIEW OF HIGH-TEMPERATURE EROSION TEST RIG

3.0 RESULTS AND DISCUSSION

3.1 Erosion resistance of SS310 material at room temperature

The erosion resistance of (SS-310) material increases with particle impact velocity for all impact angles. Since the air velocity at the burner tip reaches close to 30 m/s, analysis of erosion resistance at 32 m/s velocity at all temperatures has been carried out. Also, the burner is tilted to a maximum angle of -30°. (downward direction with respect to the burner axis) to control the degree of attemperation. In general, the operating tilt angle is -20° to -30° in most of the 210 MW Indian thermal plants. Hence, the material of splitter plates should have adequate erosion resistance under 20 to 30° impact angle.

In the present study, the erosion loss of SS310 material is maximum at 30° impact angle and decreases as the angle is increased. The maximum erosion loss of SS 310 at 32 m/s velocity is calculated to be 18.8 mg/kg of abrasive used at room temperature conditions.

3.2 Erosion loss of SS 310 materials at elevated temperatures

In general, as the temperature of the target material increases, the erosion rate increases. In general, as the temperature increases, the erosion loss increases upto a maximum of 30° impact angle and subsequently decreases as the incidence angle approaches to 90°, for all three particle velocity conditions (Figure 2). While the change in erosion loss at 400 °C is observed to be two times that of room temperature erosion, the metal erosion loss decreases at 700 °C. The relative change in weight loss is minimal up to 30° impact angle and decreases for angles in excess of 45° compared to 400 °C. This is mainly attributed to the decrease in hardness properties at that temperature. The reported erosion resistance data on different stainless steel material corroborate these findings[6,7]. The steady state service temperature of the burner tip and splitter plates is considered to be more than 700 °C. Thus, the increase in erosion loss factor with test temperature was calculated based on the ratio of weight loss of SS310 at 700 °C compared to room temperature (RT) erosion results. The increase in erosion loss factor of SS 310 at 400 and 700 °C is observed to be 3.46 to 4.40 times more than that of RT conditions, especially at 30° and the results are given in Table 1.

TABLE 1

INCREASE IN EROSION LOSS FACTOR AT 700° C WITH IMPACT ANGLES

Particle velocity (m/s)	Impact angle (degrees)				
	15	30	45	60	90
20	4.41	3.35	1.52	1.02	0.83
26	3.23	2.41	1.48	1.42	0.78
32	2.49	1.86	2.18	1.28	0.80

4.0 PREDICTION OF EROSION INTENSITY THROUGH CFD APPROACH

The numerical modeling of pneumatically conveyed coal particle has been carried out considering the actual coal burner geometry. The dimensions of the coal burner of typical 210 MW with standard three splitter plate configuration with rib support configuration has been considered (Figure 3). The erosion intensity analysis, for identification of critical erosion prone regions in the air flow path, has been carried out using

Ansys CFX -14. The model inputs such as velocity exponent and reference velocity are taken from the

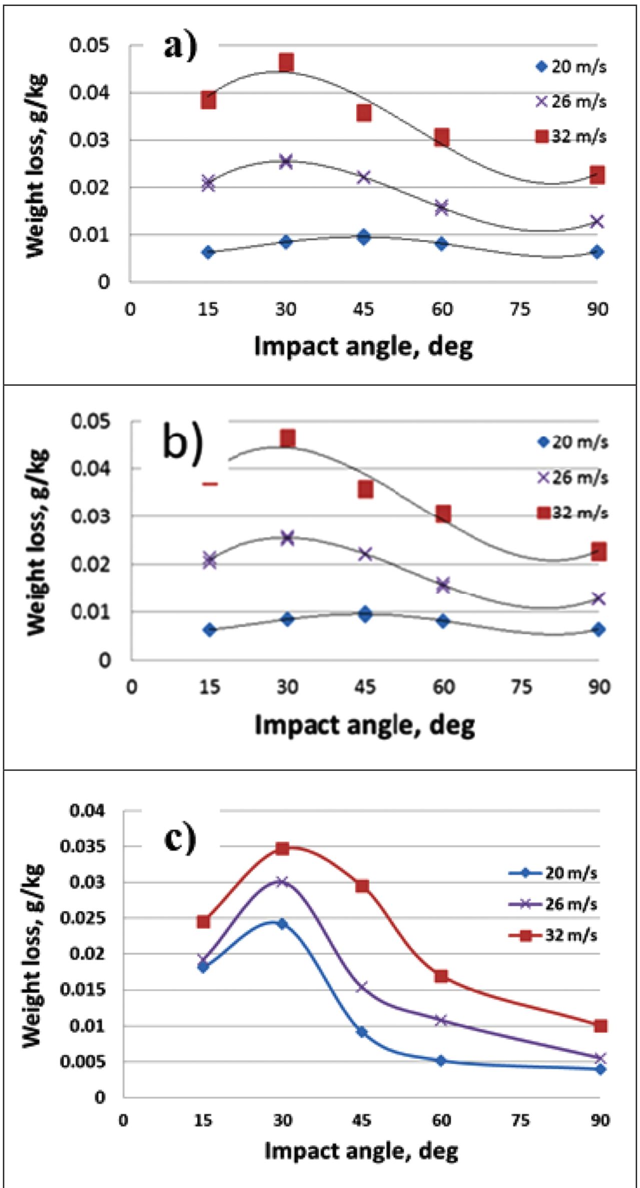


FIG. 2 EROSION LOSS OF SS310 WITH DIFFERENT IMPACT ANGLES A) ROOM TEMPERATURE B) 400 °C C) 700 °C

actual high-temperature erosion experiments conducted on the SS310 material. CFD approach is used to identify specific erosion regions in the coal burners with different tilt configurations of splitter plates. The particle erosion analysis process consists of a two-phase simulation of the transport of sand particles in the turbulent flow field where the impact of the particles on the components surface can be interactively monitored.

In general, the erosion resistance of the wall material predominantly depends on the velocity of the particle and the particle impact angle. A wide variety of erosion equations or models has been developed considering these two parameters as the variable [8–11]. In particle laden flow through coal burners, the path of erodent particles may deviate to a large extent from the fluid stream path. The impact angle at the splitter plates is predominantly affected by the angle of burner tilt. Quite often, a tilt angle of -30° with respect to the axis of the burner is used during normal operation of the burners in a thermal power station. This coincides with the peak erosion of all ductile metals such as stainless steels leading to a lower life of steel splitter plates in burners.

The CFD based erosion modeling involves three basic steps: flow modeling, particle tracking and applying erosion equations. To determine the particle impact velocity at the target splitter surface, the particle trajectory is determined by integrating the force balance on the particle. This force balance equates the particle inertia with the forces acting on the particle. During the particle trajectory calculations, the particle-wall interaction information such as impact velocity, impact location, and impact intensity etc. are stored. These parameters are applied in appropriate erosion equations for prediction of the erosion rate at the specific location. The Lagrangian Particle Tracking Method is used to predict particle trajectories. The tracked paths represent the average behavior of the dispersed phase of an actual number of particles. A total 2000 particles are tracked during modeling.

4.1 Calculation of velocity exponent for CFD modelling

The velocity exponent to be considered for the prediction of erosion intensities during modelling has been taken from the experimental results on erosion loss at different particle velocities and the test temperature and results are given in Table 2. As maximum erosion loss is observed at 30°impact angle, the velocity exponent corresponding to 30° impact angle is considered

TABLE 2		
CONSTANTS USED FOR THE EROSION MODEING		
Temperature	**Constant K**	**Velocitye xponent**
Room temperature	1.502e-8	2.058
400 °C	1.672e-10	3.633
700 °C	2.426e-6	0.769

4.2 Geometrical modeling of burner

The geometry of the coal burner modelled included an extended length of rectangular volume up to a maximum length of three meters from the nozzle tip. This is particularly done to visualize the velocity and flow profiles of air and particles, as it exits the nozzle tip and enters into the boiler combustion zone. The discretization of the geometry of coal pipe and burner assembly was carried out using tetrahedral elements and the meshed geometry is shown in Figure 4. The details of the discretized geometry elements include;

Number of Nodes : 65216

Number of Tetrahedra elements : 320177

The air carrying the coal particle enters the coal burner domain at the inlet and passes through the divider plate to the nozzle tip. The stream gets split into three curtains and get a discharge into the extended domain, representing the boiler combustion zone. Fine meshing is provided at the surfaces of the splitter plates where the erosion intensity calculations are made.

4.3 Boundary conditions used during modeling

The total mass flow rate of air entering single coal pipe is calculated, considering the total coal flow occurring in a 210 MW generation plant. The typical boiler flow conditions considered are:

Total air flow : 300 t/h through 5 mills in operation (5x4 corners=20 burners)

Air flow per coal pipe = 15 t/h or 4.17 kg/s
Total coal flow : 130 t/h

Average quartz content in coal = 10%. The calculated quartz flow per coal pipe nozzle is 13/20 =0.65 t/h or 0.18 kg/s. The set boundary conditions are ;

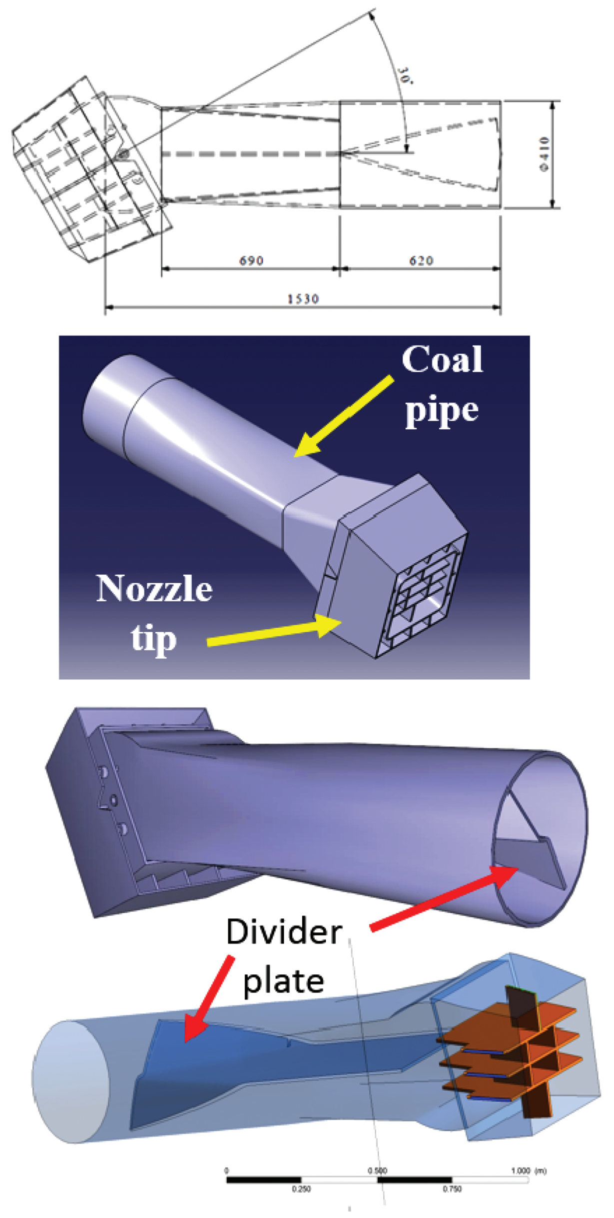


FIG. 3 GEOMETRY OF COAL PIPE WITH BURNER AND 3D GEOMETRICAL MODEL USED FOR CFD

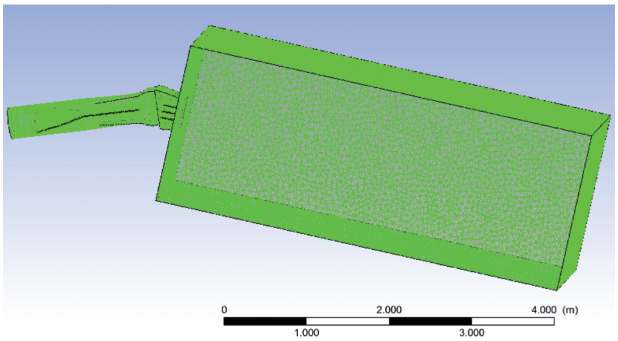


FIG. 4 MESHED MODEL OF COAL PIPE WITH BURNER TIP

Inlet to coal pipe	Mass flow of air at 80 °C and quartz flow rate
Outlet	The static pressure of 10 mm of water column at the burne relevation
Mass flow of air	4.17 kg/s
Mass flow of quartz	0.18 kg/s
Particle size	200 µm
Particle shape factor	0.75

4.4 Erosion modeling

The wear of a wall due to the erosive effect of particle impacts is a complex function of particle impact, particle and wall properties. For nearly all metals, erosion is found to vary with impact angle and velocity according to the relationship

$$E = K \, x \, Vp^{n} \, x \, f(\gamma) \qquad ....(1)$$

where

$$f(\gamma) = 0.33 \, x \, Cos^{2}\gamma, \;\; if \tan\gamma > 0.33$$

$$f(\gamma) = \mathrm{Sin}(2\gamma) - 3\,\mathrm{Sin}(2\gamma), \text{if} \tan\gamma < 0.33$$

The variable E is a dimensionless mass, Vp is the particle impact velocity and f(γ) is a dimensionless function of the impact angle. The variable 'γ' is the impact angle in radians between the approaching particle track and the wall. The value of the exponent n and K were calculated from the plot of results of mass loss versus particle velocity.

The Reynolds number at the inlet of the coal pipe is calculated to be $4.89 x 10^{5}$, hence the k-ε turbulence model was for turbulent flow. Particle size is assumed to have a shape factor of 0.75. As the coal particle hit a pipe and splitter plate, they assumed to bounce in elastically with a perpendicular and parallel coefficient of restitution as 1.0.

4.5 Results of Erosion Modeling

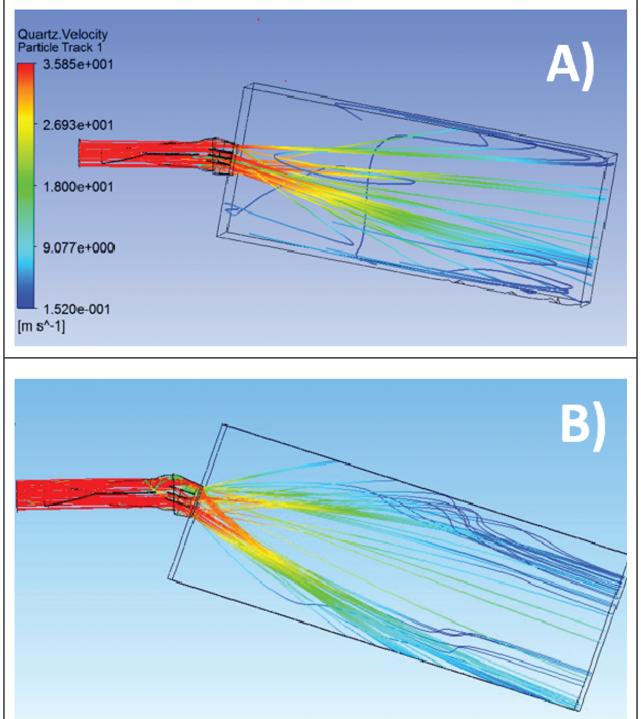
4.5.1 Particle Velocity distribution

As the primary air + particles enter the coal pipe, the likely roping effect of the particle is eliminated by the divider plate in the coal pipe and the uniformly distributed discrete particles enter the nozzle tip and flow over the splitter plates and enters the boiler. To account for the boiler internal volume, rectangular volume at the exit of the nozzle tip is considered as a part of the geometry and the boundary conditions of -10 mm of the water column is considered as in the actual boiler.

The flow profile of air + particle streamlines is getting affected by the operating tilt angle of the burner. The particle streams generally move along straight lines and gets deflected by the divider plate provided in the coal pipe before the nozzle tip. In addition, the flow streamlines get affected by the orientation of the splitter plates in the nozzle tip. As the tilt angle is increased from 10 to 30°, the observed particle tracks are quite different at the exit of the burner tip. At 10° angle, it has been observed that the small percent of particles deviate after hitting the splitter plates and the movement of the particle both in the upward and downward direction could be seen in through the particle tracking. Figure 5 shows the variation of erosion intensity observed in splitter plates and nozzle tip at different tilt angles. The quantum of particles deflecting from the flow direction is further increased when the angle is increased to -30°. This situation eventually would lead to increased carbon in the bottom ash, as all the coal particles are not carried to the fireball zone during combustion. This is indicative of the fact that the design of the splitter plates needs to be designed to have a profile so as to achieve streamlined flow of particles, after the exit of the nozzle tip.

The particle streamlines in the coal burner indicate that the particle impact at the splitter plate almost at the same angle of the tilt condition of the splitter plates. Thus the value velocity exponents such as K and n were taken corresponding to impact angle (γ) of 30°and used as the input parameters during erosion modeling. It is generally observed that top side of the tip material undergoes more erosion compared to the bottom side. In steel based burners, the tip experience almost same erosion intensity both at top and bottom sides of the internal surfaces.

In general, the bottom side of the splitter plates is observed to experience considerably higher erosion than that of the top sides of the splitter plates. for both the conditions of 20 and 30° (Figure 6 & 7). In addition, the internal walls of the nozzle tip region undergo erosion due to the deflected particles from the leading edge of the splitter plate as well as the due to the rebounding particles. The intensity of erosion on the tip of the wall is relatively higher at 30° tilt compared to 20° tilt conditions (Figure 8).



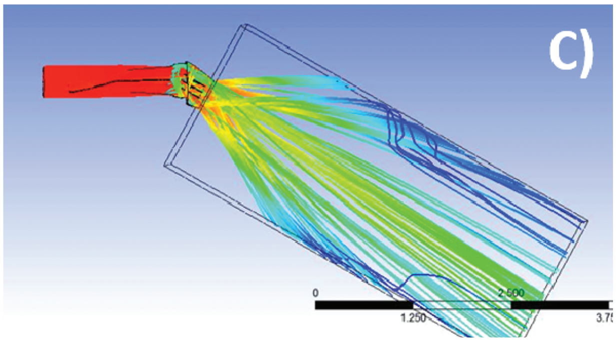


FIG. 5 PARTICLE TRACKING IN BURNER FOR DIFFERENT TILT CONDITION A) 10° B) 20° C) 30°

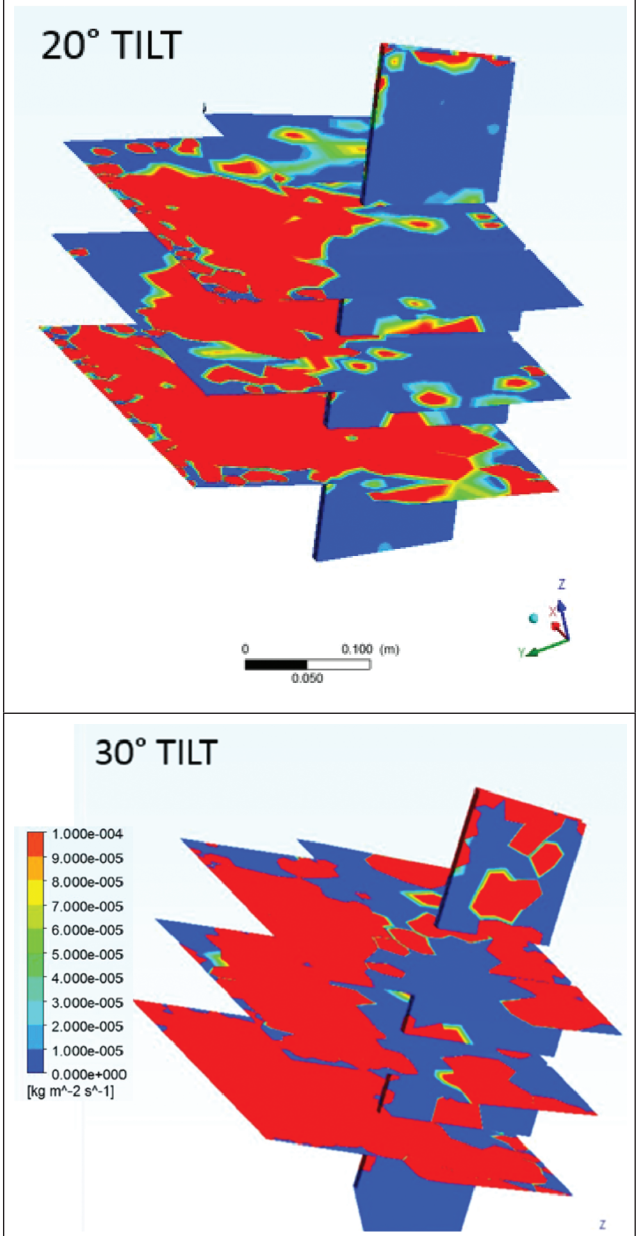


FIG. 6 EROSION RATE INTENSITY AT 700 °C ON THE BOTTOM SIDE OF SPLITTER PLATES FOR 20° AND 30° TILT CONDITIONS

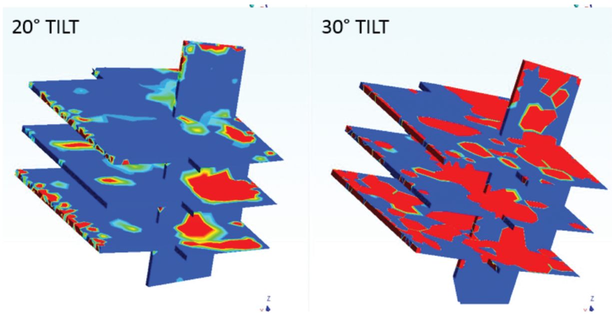


FIG. 7 EROSION RATE INTENSITY AT 700 °C ON THE TOP SIDE OF SPLITTER PLATES FOR 20° AND 30° TILT CONDITIONS

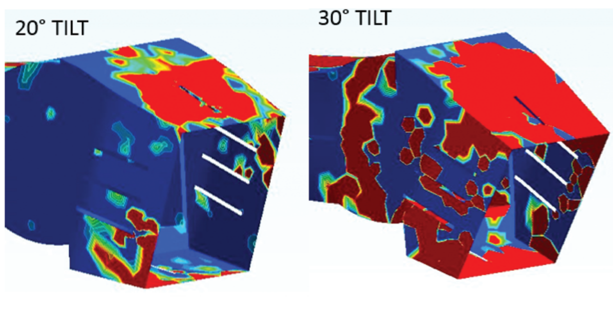


FIG. 8 EROSION RATE INTENSITY AT 700 °C ON THE NOZZLE TIP INNER SURFACES FOR A) 20° B) 30° TILT CONDITIONS

5.0 CONCLUSIONS

Erosion resistance performance data of conventional SS310 grade coal burner tip material was studied both at room temperature and high-temperature conditions upto 700°C, under three different velocities and five impact angles, using silica sand as the erodent material. The identification of critical erosion intensity zones for three different burner tilt conditions have been analysed through CFD. The systematic investigation indicated the following.

The SS material shows peak erosion at 30° impact coinciding with the maximum burner tilt conditions. Above 30° impact angle, the erosion loss decreases.

The SS material shows more sensitivity to test temperatures. An increase in erosion loss over room temperature erosion results is observed to be 3.5 to 4.5 times in case of SS 310 steel

The decrease in erosion loss at 700° C in SS310 material may be attributed to the softening of the erodent material at elevated temperature. Based on the laboratory results on erosion loss at high temperatures, the SS310 steel material has shown increased erosion rates, especially at 700° C.

The bottom surfaces of the splitter plates are observed to experience relatively higher erosion compared to the top surface. Also, the top surface of the nozzle tip is subjected to erosion due to rebounding particles from the splitter plate.

Protection of the splitter plates, as well as the nozzle tip, requires hard coating processed through hard facing or thermal spraying, to extend the service life.

REFERENCES

[1] D Moumakwa, K Marcus, Tribology in coal-fired power plants, Tribol. Int. Vol. 38, pp. 805–811, 2005

[2] K Szyma, A Hernas, G Moskal, H Myalska, Thermally sprayed coatings resistant to erosion and corrosion for power plant boilers - A review, Surface & Coatings Technology, Vol. 268, pp. 153-164, 2015

[3] C Katsich, E Badisch, M Roy, G R Heath, F Franek, Erosive wear of hardfaced Fe-Cr-C alloys at elevated temperature, Wear, Vol. 267, pp. 1856–1864, 2009.

[4] E Citirik, Root-cause analysis of burner tip failures in coal-fired power plants, Appl. Therm. Eng. Vol. 73, pp.831–841, 2014.

[5] L K I A W Ruff, Measurement of solid particle velocity in erosive wear, Wear, Vol. 35, pp.195–199, 2003.

[6] G Sundararajan, M Roy, Solid particle erosion behaviour of metallic materials at room and elevated temperatures, Tribol. Int. Vol. 30, pp. 339–359, 1997.

[7] S K Das, K M Godiwalla, S P Mehrotra, K K M Sastry, P K Dey, Analytical model for erosion behaviour of impacted fly-ash

particles on coal-fired boiler components, Vol. 31 pp. 583–595, 2006.

[8] G Sundararajan, P G Shewmon, A new model for the erosion incidence of metals at normal, Vol. 84, pp. 237–258, 1983.

[9] B Bozzini, M E Ricotti, M Boniardi, C Mele, Evaluation of erosion-corrosion in multiphase flow via CFD and experimental analysis, Wear, Vol. 255, pp. 237–245, 2003.

[10] F Jianren, Z Dadong, Z Keli, C Kefa, Numerical and experimental study of finned tube erosion protection methods, Wear, Vol. 152, pp.1–19, 1992.

[11] D Dodds, J Naser, Numerical study of the erosion within the pulverised-fuel mill-duct system of the Loy Yang B lignite fuelled power station, Powder Technol. Vol. 217, pp. 207–215, 2012.