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Experimental Investigation and Computational Validation of Bared Inline Un-Finned Tube Configuration forHeat Exchanger

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ABSTRACT :*In the recent last two years, work was done on the prediction of the economizer tube failure. It include study of boiler tube leakages tube failure mechanism, development of equation to calculate wear rate of economizer tube material, experimental validation of wear rate equation, placing the specimen tube in the economizer area. Literature study suggested that with the increasing use of low quality high ash coals over the past few decades, the very factor that had been an advantage of the CFS (Continuous Fin Surface) economizer design became disadvantages, as the design's spacing proved more susceptible to plugging and fly ash erosion[1]. The plant under study uses a very high ash content Indian coal as fuel and is thus prone to cause heavy fly ash erosion in economizer. Literature study and root cause analysis suggested that CFS staggered arrangement of economizer could be one of the prominent reason of failure of economizer tube bundle due to fly ash erosion[2]. This paper focuses primarily to find out variation in air velocity moving over the inline un-finned tube configuration and finned staggered tube configuration used in economizer. Simulation results are validated with experimental results. Experiments were conducted on different specimens placing them in wind tunnel.*

Keywords*: Boiler tube failure, velocity of ash particle, size of ash particle, fins, direction of flow, heat exchanger.*

I. INTRODUCTION

Study of recent boiler tube failure and relevant literature survey suggested that the erosive tendency of ash particle is highest in economizer zone where the gas temperature is lowest compared to other boiler zones and velocity of flue gases is highest. This may be one of the reasonsof tube failure in economizer area of the plant under study. The boiler tube can fail due to creep, fatigue, corrosion, erosion etc.The erosion rate(E) is generally depends on particle in impingement velocity(Vp) that is $E \alpha Vp^a$ where a=2.3-2.7 for ductile material and 2-4 for brittle material. The allowable velocity for economizer design is specified as 9-10 m/s with maximum localized velocity not exceeding12m/s. Paper furthermentions that the most common and reliable economizer design is the bare tube, in-line, cross flow type. When coal is fired, the fly ash creates a high fouling and erosive environment. The bare tube, inline arrangement minimizes the likelihood of erosion and trapping of ash as compared to a staggered arrangement. It is also the easiest geometry to be kept clean by soot blowers. To reduce capital costs, most boiler manufacturers have built economizers with a variety of fin types to enhance the controlling gas side heat transfer rate. Fins are inexpensive which can reduce the overall size and cost of an economizer. However, successful application is very sensitive to the flue gas environment. Surface clean ability is key concern. Turbulence can be controlled by providing lesser changes in the direction of flow along tube bundle.[3] Therefore this paper focuses on primarily to find out variation in air velocity moving over the inline un-finned tube configuration and finned staggered tube configuration used in economizer and Simulation results are validated with experimental results. Experiments were conducted on different specimens placing them in wind tunnel.

II. EXPERIMENTAL SET UP

There are two methods which are experimentally validated. One is onsite method; In this method actual size of economizer is installed on the plant size and perform the experiment and find the required results and other is model testing method; In this method model is tested in wind tunnel by reducing actual size of economizer as per windtunnel test section which gives same result as that of prototype performance. As compared to on site method it is easier, cheaper and safer method so that this method is preferred for experimentation. The Fig.1 shows the experimental set up of wind tunnel test section which is one of the most important facilities for experimental work in aerodynamics and fluid flow.

Fig.1 Experimental set up

The Apparatus consists of a wind tunnel with maximum air velocity range 0-30 m/s provided with a transparent test section dimensions 1000 × 300 × 300 mm.

III. SAMPLE CALCULATION

The test section is provided with a pressure tapping to measure wall static pressure h1The pressure tapping provided on cylinder measure pressure head h_2. Difference of these two pressures gives pressure acting on cylinder (ΔP).

Pressure head (h) $= h_1 – h_2 = 3 – (-7) = 10$ mm = 0.01 m
Pressure (P) = $\rho \times g \times h = 1000 \times 9.81 \times 0.01 = 98.1$ Pa
$P_{total} - P_{static} = \frac{1}{2} \times \rho \times v^2 = P$ i.e. V = 12.655 m/s

IV. EXPERIMENTAL RESULT AND DISCUSSION

From the experimentation it is observed that pressure and velocity distribution will be same on the front side as well as back side of tube. The flow accelerates from θ = 0˚-90˚ beyond theθ = 90˚ the flow is subjected to an adverse pressure gradient and hence it decelerates. Under this condition pressure is acting against fluid flow.The Bare inline Tube configuration consists of 4 tubes and 4 tapping position provided for each tube at angle θ = 90˚. When angle of attack of striking the air on the tube at α = 0˚, the flow over the tube is separated at θ = 90˚ and at that point velocity of air striking on the tube is maximum at that point. But when α = 30˚ the flow is separated before θ = 90˚ and velocity is maximum at that point. The angle of attack of air changed from α =10˚ to 30˚ there is no any effect because of its same orientation of tube. The staggered finned tube configuration consists of 5 tubes with fin and 4 tapping position are provided for each tube at an angle θ = 90˚. When angle of attack of striking the finned tube, the flow is separated at θ = 90˚ and the velocity of striking the air is maximum at that point. But when angle of attack changes from α = 10˚ to 30˚, the flow is separated before θ = 90˚ and at that point velocity of striking the finned tube is maximum. Because of high angle of attack of striking the air, the velocity is maximum which causes increase in rate of erosion (i.e. velocity of striking the air is directly proportional to erosion rate tube) and fails the tube. It shows that the bare inline tube configuration is preferred to stagger finned tube configuration.

V. SIMULATION

This simulation is focused on CFD analysis of economizer to understand the capabilities of CFD as a validation tool. The intention was to check and validate the results of manual calculations performed for the economizer. In CFD calculations, there are three main steps Pre-Processing, Solver Execution and Post-Processing. Pre-Processing is the step where the modeling goals are determined with selection of computational domain and computational grid is created. In the second step of numerical models and boundary conditions are set to start up the solver. Solver runs until the convergence is reached. When solver is terminated, the results are examined which is post processing part.

Model: 1- Bare Inline Tube Configuration

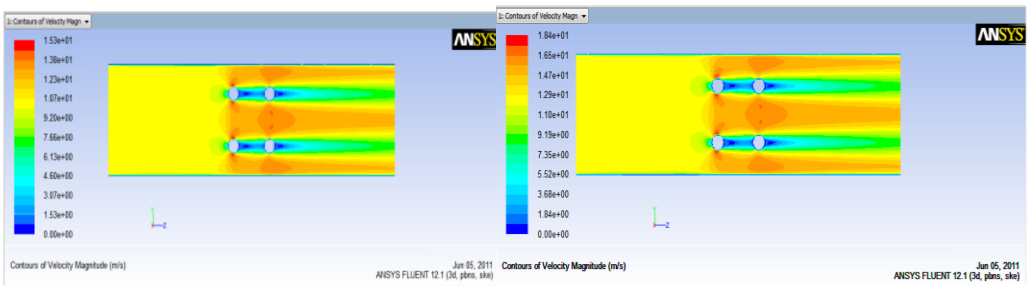

Fig.2 Flooded Contour for distribution of velocity (inlet velocity 10m/s and 12 m/s)

Model: 2- Staggered Finned Tube Configuration

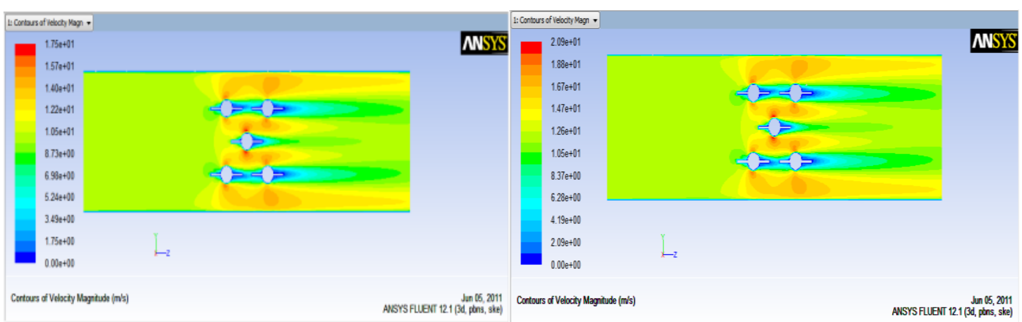

Fig.3 Flooded Contour for distribution of velocity (inlet velocity 10m/s and 12m/s)

VI. RESULT AND DISCUSSION

In case of bare inline un-finned tube configuration at inlet velocities 10, 12 m/s as shown in fig.3, the velocity of air striking the front side of the first two tubes is almost same but velocity is reduced in second two tubes as well as back side of the tubes (i.e. wake region) is same but at the top and bottom sides of all tubes the velocity of air is maximum. In case of staggered finned tube configuration at inlet velocity 10, 12 and 14 m/s, air passes over the staggered finned tubes and creates high turbulence due to frequent change in the flow direction of air. Because of higher turbulence results higher velocity near the tube wall and the velocity of air strikes on the front as well as back side of tube is 10 to 15 % maximum as compare to bare inline un-finned tube configuration. The velocity at the top side and bottom side of tube is 20 % maximum. Because of higher velocity higher turbulence in staggered finned tube configuration. Hence Bare In-line un-finned tube configuration is more suitable than staggered finned tube configuration.

Comparison Between Experimental and CFD Result

The graph shown in Fig. 4 shows comparison between experimental and CFD result. It consist position of pressure tapping on X-axis and velocity of air over the tubes is on Y-axis.

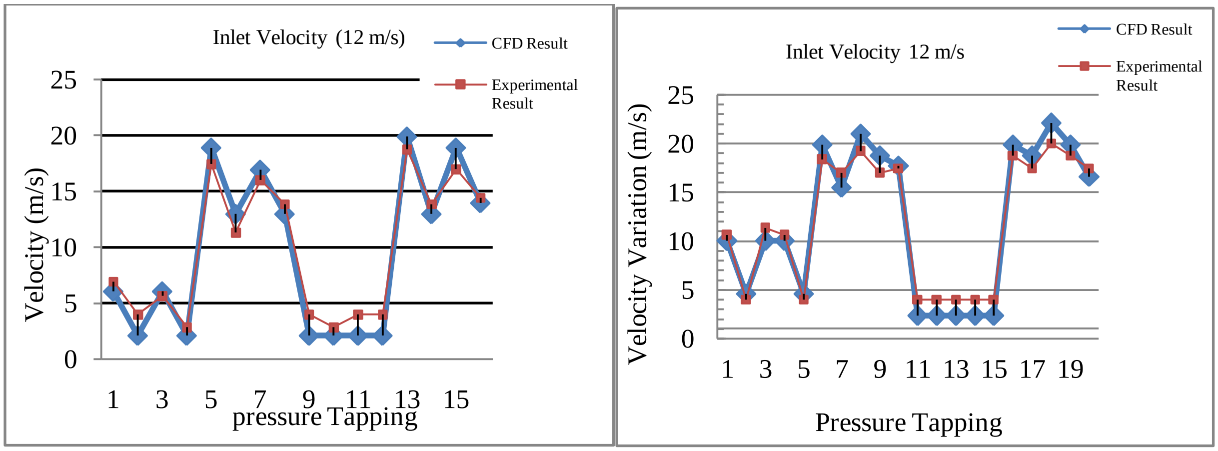

Fig.4 Bare Inline Un-finned Tube and Staggered Finned Tube Configuration

Comparing the experimental and CFD results as shown in Fig.4 between staggered finned tube arrangement and bared in-lined unfinned tube arrangement it is observed that in staggered finned tube arrangement velocity of air is higher in each tapping position due to tortuous path as compared to bared in-lined un-finned tube arrangement. As velocity of air increases erosion rate also increases and tube fails. Hence it is concluded that bared in-lined un-finned tube arrangement is most preferred as compared to staggered finned tube arrangement used in economizer.

VII. CONCLUSION

- The Staggered tube bundle creates more turbulence due to frequent change in the flow direction of air. So higher turbulence is localized near the tube wall.
- The strike efficiency is also much higher in staggered finned arrangement as can be visualized from figure
- Staggered finned arrangement causes higher resistance to air flow resulting in higher pressure drop than bare inline arrangement.
- Total weight of bare inline tube type economizer is less compared to staggered finned tube economizer.
- Due to entrapment of air in the torturous path of staggered arrangement, there was reduced flow area available for air resulting in increased peak flow velocities around the tube passages. The rate of erosion is proportional to the exponential power of particle impingement velocity. This result in increased erosion rate. Therefore bare tube inline arrangement can replace the staggered finned tube economizer.

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