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Research Article

CFD Analysis of Waste Heat Boiler Duct for Maximum and Even Flow Distribution of Hot Gases

O.P. Jakhar and Madan Singh Kavia

Mechanical Engineering Department, Government Engineering College, Bikaner, Rajasthan, India

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Abstract

Waste heat boiler power plants are widely used throughout the world for recovering waste heat from sources like exhausts gases of gas turbines, heat generated during some process in a plant or heat absorbed by cooling fluid from high temperature equipment etc. The duct which is the object of study was a part of waste heat boiler of a working power plant. Cracks, pits and overheating of duct casing was observed after some time of service of this duct. The theoretical studies as well as simulation with the help of available CFD software have been carried out in this work for finding the root cause and its solution. Commercially available computational fluid dynamics (CFD) software ANSYS-FLUENT15.0 is used for numerical simulation of duct. Results of simulation revealed that duct design was creating swirl inside the duct and flow of gases was unevenly distributed inside it. Un even distribution of flow of hot gases was the main reason of uneven distribution of heat which caused overheating and failure of duct. The solution is to get maximum and even flow distribution of hot gases inside the duct .Duct model was modified by modeling guide plate sin side its two inlets i.e. GT(gas turbine) inlet and RA (regenerative air) inlet in different numbers, configurations and angles to get distributed flow of hot gases inside the duct.

Keywords: *Waste heat boiler (WHB), Gas turbine (GT), Steam turbine (ST), Computational fluid dynamics (CFD), Swirl, Flow distribution.*

1. Introduction

The duct which is the object of study of this thesis was a part of a captive power plant of working refinery. The waste heat boiler duct has two inlets i.e. Gas Turbine (GT) inlet and Regenerative Air (RA) inlet. The purpose of duct is to act as inlet for hot gases to boiler. Exhaust of gas turbine and regenerative air enter sin to the duct through GT inlet and RA inlet respectively.

As per the data received the boiler uses waste heat from two sources. First is gas turbine exhaust which is coming from gas turbine cycle which has temperature of the order of 901K and second is regenerative air which is coming from regenerator of fluid catalytic cracking (FCC) unit of refinery and has a temperature of 857K. Regenerative air is also flue gases produced during FCC process of heavy gas oil (Reza Sadeghbeigi, 2000)

1.1 Data Received for WHB

Waste heat boiler duct working parameters which were collected from plants for numerical study to find the root cause of duct failure and its solution are given in Table 1.1.

Table 1.1 Data Received for Waste Heat Boiler and Working Fluids

Fluid	Flue Gases
Temperature at RA inlet	857 K
Temperature at GT inlet	901 K
Mass flow rate at RA inlet	337 kg/s
Mass flow rate at GT inlet	147 kg/s
Density (ρ)	0.6215 kg/m3
Viscosity (μ)	0.0284 kg/m-s
Conductivity(k)	0.042749 W/m-K
Specific heat (CP)	1099.87 J/kg-K
Total pressure at RA inlet	4722 Pa
Total pressure at GT inlet	1131 Pa
Total pressure at Outlet	325 Pa
Temperature at Outlet	502 K
Internal Diameter of RA inlet	2251 mm
Internal Diameterof GT inlet	1946 mm

Mohammad Ameri, Farnaz Jazini Dorcheh (2013), analyzed Heat recovery steam generator (HRSG) inlet duct using CFD for maximum uniform flow distribution using correction devices like perforated plates and guide plates. This study also revealed that numerical

*Corresponding author **Madan Singh Kavia** is a M.Tech Scholar (Thermal Engineering Student); **Dr. O.P. Jakhar** is working as Associate Professor

simulation with k-ε model can give desired reliable results as compared to experimental study. It was observed that if the flow distribution is more even, variation of temperature at the outlet section is less abrupt.

E. Jesulin Immanuel, Azhagiri Pon (2015), performed numerical analysis of HRS G inlet duct to achieve uniform gas flow distribution. Computational fluid dynamics simulation was carried out to see flow patterns in the transition zone of HRSG. A perforated plate is placed at the junction of two divergent angles. Simulation results show that surface area at outlet of duct with ±25% of average axial velocity for composite inlet duct with perforated plate was 75%.

Jeff Daiber (2006), performed numerical analysis of Vogt power international heat recovery steam generator's duct which had a turning path at the starting of duct. Turning or curved vanes offered desired distribution of flow and less velocity drop within design parameters. It offered more than80% of area at outlet within ±25% of average velocity.

Drew Robb, Keith C. Kaufman (2013), analyzed Heat recovery steam generator duct flow and found non-uniform flow profile without any flow guide measure. To improve flow distribution and velocity profile at outlet of duct two layer distribution grid is placed in the duct. As a result the flow is distributed to 90% of the cross-section of the duct. Velocity distribution was also improved by 20%.

2. Modeling

2.1 First Duct Model (Actual Duct Model)

This model is the Actual duct model as the duct was installed at site location before failure. This model has two plates 20mm thick in RA duct. Angle of tilt of plates is 6°.

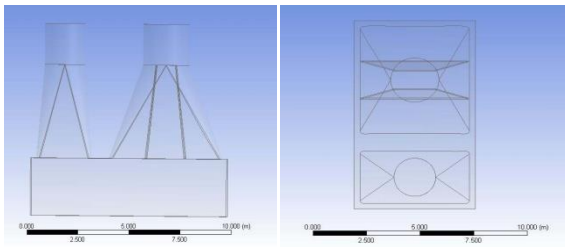

Fig. 2.1 3D model of WHB inlet duct first (Actual) model (a) Elevation (b) Plan view

Table 2.1 3D Model Details of First Duct Model

RA DUCT	GT DUCT
Number of plates - 2	Number of plates - 0
Direction of plates - Transverse direction of mixing chamber	Direction of plates - N-A
Distance from duct center - 450mm (Each plate's top edge)	Distance from duct center - N-A (Each plate's top edge)

All other duct models are modeled by adding different numbers and angles of plates in first duct model.

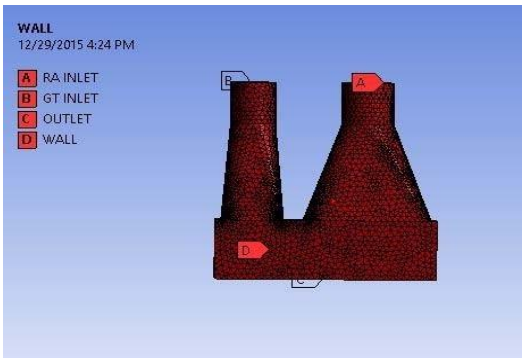

Fig. 2.2 Name Selection of All Duct Models

Table 2.2 Model Constant for RNG k-ε Turbulence Model

Cμ	C1ε	C2ε	Swirl Factor	Wall Prandtl Number
0.084	1.42	1.68	0.09	0.85

2.2 Boundary Conditions

Boundary conditions are taken as per the data received for WHB duct.

RA Inlet

It is a mass flow inlet
Mass flow rate: 337 kg/s
Temperature of gases entering: 857K

GT Inlet

It is also a mass flow inlet
Mass flow rate: 147 kg/s
Temperature of gases entering: 901K

Outlet

This is taken as pressure outlet.
Initial pressure on outlet is taken 101325 N/m2.
Initial pressure at outlet of duct is taken as atmospheric pressure because initially the pressure at out let will be equal to atmospheric.

3. Results and discussion

3.1 Results of First Model (Actual Duct Model)

This model has two plates in RA duct. Details of plates are given in Table-2.1. Velocity streamlines as results of simulation are shown below:

Results show that flow of hot gases in both inlets i.e. GT inlet and RA inlet is not properly distributed so flow distribution or guiding measures should be employed within duct volume in the path of gas flow which can make flow of gases evenly distributed.

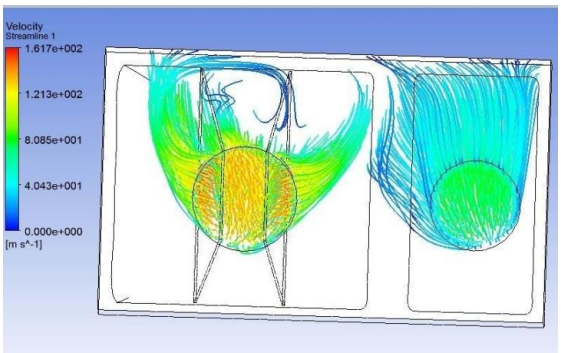

Fig. 3.1 Velocity streamlines of first duct model

3.2 Results of Second model

In this model direction of plate sin RA inlet is changed from transverse to longitudinal direction of mixing chamber. From simulation results of second model it was observed that changing direction of plates improves flow distribution in RA inlet but flow in GT inlet remain sun changed. To improve flow distribution in GT duct, guide plates should be used. Velocity stream lines are taken the indication of flow distribution of gases in duct. Result of simulation of second duct model is given below:

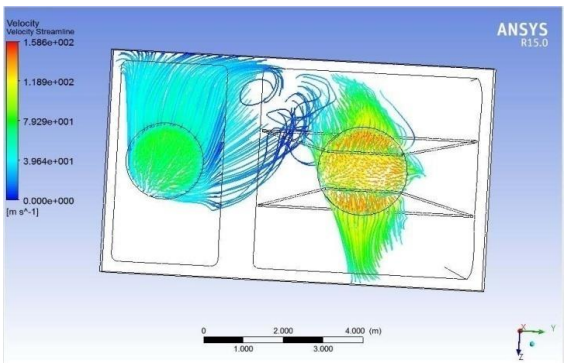

Fig. 3.2 Velocity streamlines of second duct model

3.3 Results of Third model

In this model two plates are added in GT duct also.

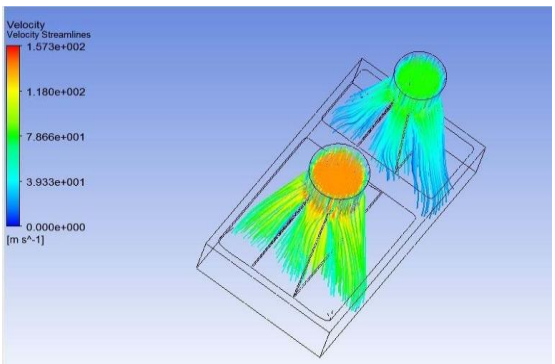

Fig. 3.3 Velocity streamlines of third duct model

3.4 Results of Fourth model

This model has four plates in RA duct and 2 plates in GT duct. Angle of tilt is kept same as 6°.

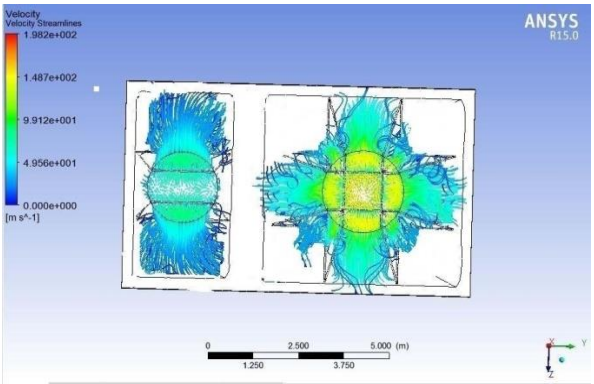

Fig. 3.4 Velocity stream lines of fourth duct model

3.5 Results of Fifth Model

This model also has total 6 plates, 4 plate sin RA duct and 2 plates sin GT duct all 20mm thick. In this model angle of plates is also changed from 6o to 10o.Details are given below:

Table 3.1 3D Model Details of Fifth Duct Model

RA DUCT	GT DUCT
Number of plates - 4	Number of plates - 2
Direction of plates - 2- Transverse, 2- Longitudinal	Direction of plates - Longitudinal
Distance from duct center (Each plate's top edge) Transverse plates - 450mm Longitudinal plates - 400mm	Distance from duct center - 350mm (Each plate's top edge)
Angle of tilt - 10o (From top edge)	Angle of tilt - 10o (From top edge)

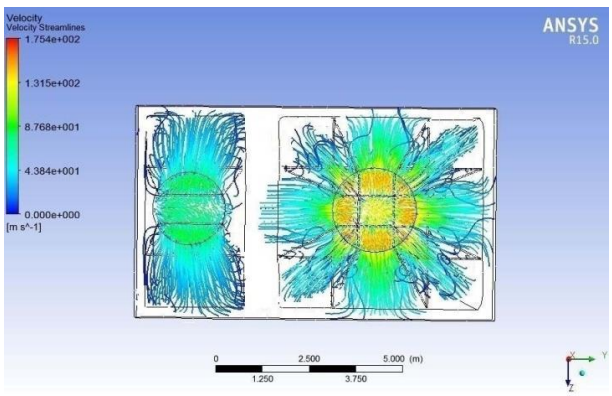

Fig. 3.5 Velocity streamlines off if the duct model (View1)

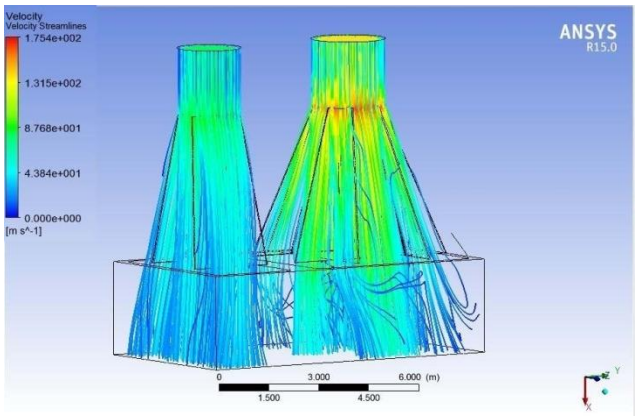

Fig. 3.6 Velocity stream lines of the duct model (Rotated view)

3.6 Results of Sixth Duct Model

In this duct model angle of guide plates is increased from10^{o} to 12°.

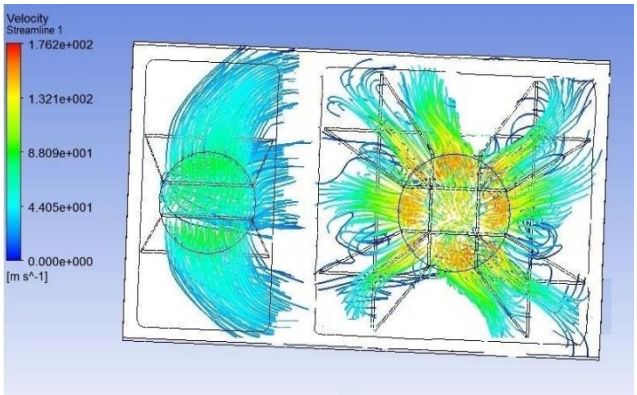

Fig. 3.7 Velocity streamlines of sixth duct model

Conclusions

Based on results it was found that as the number of plates along flow direction are increased velocity streamlines and flow of gases becomes more evenly distributed within the duct and less swirl and turbulence is seen. The results show that when angle of tilt of plates is increased above 10o, flow profile is disturbed. The fifth duct model was accepted as final solution with 4 plate sin RA duct and 2 plate sin GT duct having 10otilt angle from to pedge. This model gives whole flow distributed in even manner within duct volume and at the outlet of mixing chamber. Negligible swirl was observed which will avoid noise and vibrations. This model was accepted by majority of waste heat boiler manufacturers. New duct was manufactured as per this design.

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