Design And Analysis Of Heat Resistant Ferrule Used In Heat Exchanger Tube By Using CFD

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Abstract

Many modern Generator or Exchanger operates in high-temperature environments. These exchangers are associated with the chiller system where the where the tube-sheet–tube-ferrule assemblies are exposed to gasses at temperatures approaching 1200ºC. because sulfur compounds are present in the process gas, the carbon steel tube sheet and tubes in the assembly will be deteriorated by sulfidation as the operating metal temperature rises above 800°C.Ferrule systems are used to protect the carbon steel from exposure to excessive temperatures. The temperature distribution in the steel tube-sheet–tube-ferrule system is affected by process gas flow and heat transfer through the assembly. A computational fluid dynamics investigation was conducted to study the flame flow and Temperature distribution on tube inlet and ferrule. It was found that the configuration of the ferrule installation has a large influence on the temperature distribution in the steel materials and, therefore, the possible sulfidation of the carbon steel parts.

Keywords: CFD, non-premixed combustion, ferrule, Standard kepsilon turbulence model, diesel fuel,

1. Introduction

The waste heat exchanger studied is a typical ASME Boiler and Pressure Vessel Code Section VIII Division 1design with a flexible tube sheet. The carbon steel tube sheet is protected by a two-piece solid-head ferrule system. For modern heat exchangers, the tube-sheet design temperature is typically in the range of 650–700°F for ASME Code 1 tube-sheet calculations. The carbon steel component materials are SA 516-70 plate for the tube sheet and SA 106B for the tubes. The ferrules are content ceramic material. The ferrule heads are arranged such that the cold assembly gap closes at operating temperatures due to thermal expansion.

Ferrules are used in direct fired/exhaust fired VAM (vapor absorption machine) tube to tube sheet joints weld protection from direct flame Also used to provide protection to the inlet ends of shell and tube heat exchangers in application where high temperature or corrosive material are processed. as shown in fig:2

Ferrules denote either specialized strengthening rings and caps placed on components, or fittings used in heat exchangers, boiler tubes and condenser tubes as shown in fig: 1.A double-ring ceramic ferrule member insertable into a fire tube of a sulfur plant boiler or cooler, the an article of manufacture capable of reducing damage caused by high temperature gas flow through a fire tube, thereby to protect the fire tube and the tube sheet through which the fire tube extends. The present ferrule member provides improved anchoring capability and increased resistance to fire tube erosion .the sulfur boilers or coolers are typically comprised of a structure containing water which absorbed heat from the hot gas flow directed through the fire tubes disposed in water, heat being thereby exchanged. The water is contained within the structure having a wall which is commonly referred to as a tube sheet, the fire tube extending through the tube sheet. According to this, ceramic ferrule with collar is inserted into each fire tube, approximately half the length of ceramic ferrule being within said fire tube. Hot gas flow is thus directed through the ceramic ferrule extending sufficiently into the fire tube such that the hot gas flow does not directly contact the fire tube along the portion of the fire tube which contacts the tube sheet.

The investigation limited to the tube filled area of the tube sheet assembly. The exchanger has a triangular pitch pattern dictating annular head geometry for the ferrules.

Knowing the temperature profile of the system is critical to the mechanical design of the tube sheet and the prevention of sulfidation of the steel components, as discussed by Martens et al. The thermal profile of a tube-sheet protection system using a ferrule and castable refractory system on the face of the tube sheet is investigated in.

The tubes are welded in the end to the wall of the boiler. Virtually all cracks occur at welded joints or at openings. This is a frequent, costly and dangerous occurrence. The root cause is corrosion fatigue and the fatigue cycling is thermally driven. The thermal fluctuation that occurs is due to the slag and the change of operating conditions also creates alternating stresses. As a result the boiler tubes, welding of tube to tube sheet joint, ceramic ferrule are subjected crack.

The Ferrule used for this investigation having 50mm length, collar thickness =4mm, Diameter of collar= 32mm, OD of ferrule =20.5mm, ID of ferrule =16.6 mm as shown in fig:1 and Material of ferrule material consists of silica60%, magnesia 26%, alumina 12%, calcia/ferric oxide 2%.Therefore because of low alumina the strength of the ferrule will be less. And the chances of collar damaged of ferrule will increased. Because of the hot gas temperature will direct contact with the ferrule. Also from this tube or tube to tube sheet weld joint failure also occur. Using this material, Dimensional accuracy of ferrule is not acceptable: length, ovally etc. Due to dimensional variation fitment in Tube ID is not accurate: falling during transit etc. may lead to joint failure.

In this investigation, the failed tube specimen of HTG(high temperature generator)and failed ceramic ferrule specimen were collected from the direct fired vapor absorption machine and dimensional accuracy of the ceramic ferrule corrected using the change of material and compare existing and new ferrule using experimently.CFD study was conducted to establish the temperature profiles at tube inlet and ferrule
The flame temperature, gas properties and material properties used were specific for the unit under study.

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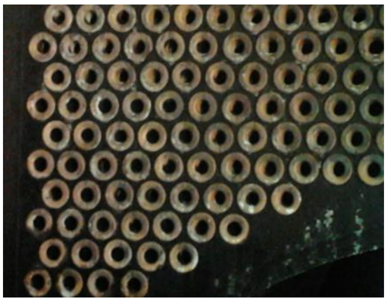

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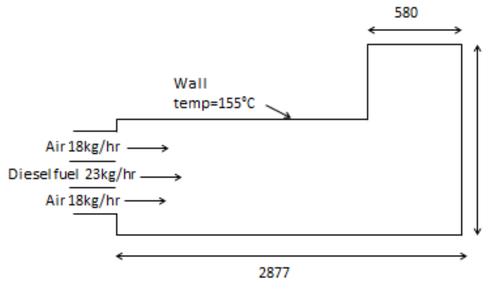
2. Methodology

Computational fluid dynamics is part of fluid mechanics that uses numerical method and algorithm to solve and analyse problem that related to fluid flow. CFD – FLUENT 6 is used for the modelling and simulation in this project. CFD – FLUENT 6 is computer software that allows modelling and simulation of flow of fluid and heat and mass transfer in complex geometries. It is capable to complete meshing flexibility, solving flow problems with unstructured meshes that can be generated through the complex geometries

2.1 Geometry Design/Meshing Geometry ICEM:

ICEM which is a geometric modelling and grid generation tool is provided along with the FLUENT technology. ICEM allows the user to import geometry from other designing software or computer-aided design (CAD) software or create own geometry entirely based on ICEM itself. Figure 3 shows a sketch of the computational domain used in this study. The temperature of the fuel and ambient air was considered to be 37˚C. And the ambient pressure was 101325 Pa.



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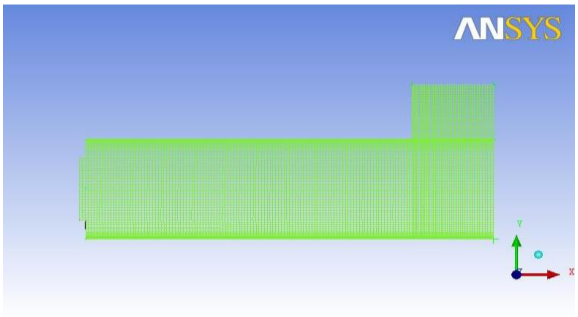
2.2 Geometry and mesh generation:

Mesh generation was performed in a Fluent pre-processing program called ICEM. The current model is cavity-based fuel injector with non-premixed combustion as shown in figure 4. The geometry of the 2D combustor was created in ICEM meshing software only where 19050 nodes, 18582 quadrilateral cells, 36698 2D interior faces, 48 2D velocity-inlet faces,42 2D pressure-outlet faces, 842 2D wall faces, mesh was created. The mesh was then refined at boundaries of the combustor a two million cell hex-dominant of high temperature and velocity gradients to give a grid independent 3.6 million cell mesh. In this particular model the walls of the combustor duct do not have thicknesses. The domain is completely contained by the combustor itself; therefore there is actually no heat transfer through the walls of the combustor.



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2.3 Fuel Model:

When fuel is injected into the combustion chamber as a spray, heat transfer, phase change, chemical transformation and occur. These processes convert fuel liquid into volatile vapor and gases, which later on burn in the oxidizing environment surrounding the spray. In CFD modeling these processes are critical because they control the overall performance of the combustion process. As the liquid droplet enters the hot combustion chamber, heat transfer between the droplet and the hot surroundings occurs, and vaporization starts. CFD Analysis was carried out using FLUENT for the combustion analysis of diesel fuel. Diesel was injected with a nozzle of 0.001 dia. At a pressure of bar, air was inducted at atmospheric temperature & pressure and diesel fuel was injected through the injector at a pressure of 20bar directly into the combustion chamber.

2.4 Boundary condition:

The boundary conditions are such that, the air inlet and fuel inlet surfaces are defined as mass flow inlets and pressure outlet. In this particular model the walls of the combustor duct do not have thicknesses. The domain is completely contained by the combustor itself; therefore there is actually no heat transfer through the walls of the combustor. During analysis we have taken same pressure for both fuel and air for all the models. Temp inlet and temp outlet conditions were taken on the left and right boundaries respectively. Pressure inlet condition was taken for fuel injector. The walls, obstacles and other materials were set to standard wall conditions. The computations were initially carried out with various levels of refinement of mesh.

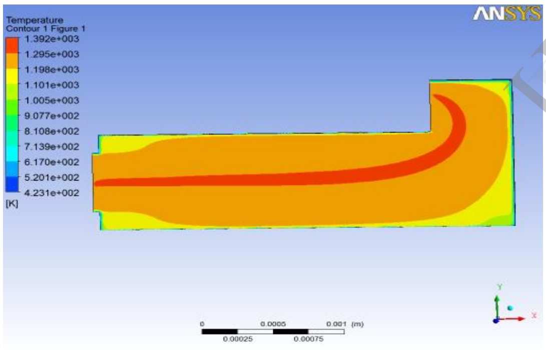
Temperature of fuel injection 40°C
Fuel consumption is 135kg/hr
Flow rate of air is 1 kg/s
Temperature of air injection: 40°C
Atmospheric pressure: 101325 Pa
Flame temperature: 1200ºC

2.5 Modeling Details:

In the CFD model, the Standard k-εturbulent model is selected which is one of the most common turbulence models. It is a two equation model that means it includes two extra transport equations to represent the turbulent properties of the flow. This two equation model accounts for history effects like convection and diffusion of turbulent energy. Non-Premixed Combustion enables the calculation of turbulent reacting flow using the non-premixed combustion model. This option is available only for turbulent flows using the pressure-based solver. Non-premixed modeling involves the solution of transport equations for one or two conserved scalars (the mixture fractions). Equations for individual species are not solved. Instead, species concentrations are derived from the predicted mixture fraction fields. The thermo chemistry calculations are pre-processed and then tabulated for look-up in ANSYS FLUENT. Interaction of turbulence and chemistry is accounted for with an assumed-shape Probability Density Function (PDF).Energy equations were considered and the solution was initialized from the air inlet for simplicity. Discrete phase model were considered to calculating the particle trajectories for each discrete phase injection. The convergence criterion requirement is set to be 10-3 for energy and about 10-3 for the other terms of the transport equations.

2.6 CFD Result:

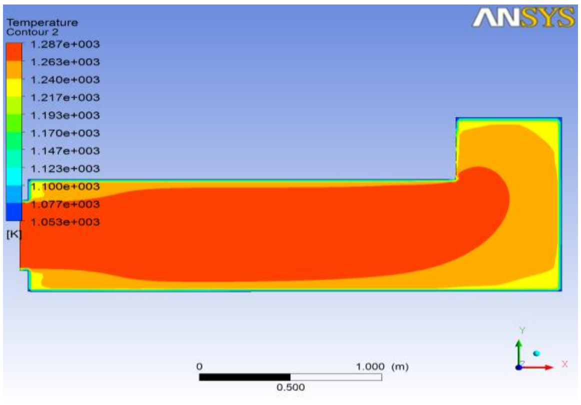
The reactive simulations presented in this section are carried in the geometry (Figure-3)
In this section results of flame flow and temperature at tube inlet observed .The red colour regions are the regions where the properties attain their maximum values. The blue coloured regions indicate the regions where the properties are at their minimum. The properties that were analyzed were static temperature,



2.6.1 Static Temperature:

From Fig 5 it is evident that static temperature increases from inlet to the outlet. This is due to combustion of the air and injected diesel fuel. The heat released due to combustion heats up the combustion products (water) and hence, an increase in the static temperature from 423 to 1392 K is observed. Temperature at inlet of tube 1296K and flame temperature 1392K at inlet is observed.

2.6.2 Static temperature with low alumina ferrule wall and at tube inlet (outlet):



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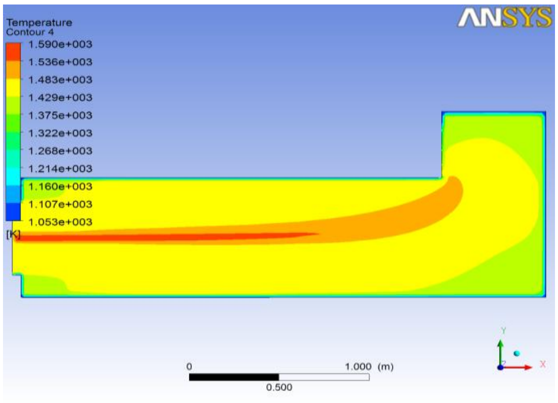
From Fig 6 it is evident that static temperature increases from inlet to the outlet using CFD result. This is due to combustion of the air and injected diesel fuel it was found that the temperature on ferrule becomes high. Average temperature on ferrule wall is 1290.76K and average temperature at outlet is 1276.24 K is observed.

2.6.3 Static temperature with high alumina ferrule wall and at tube inlet (outlet):



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From Fig 7 it is evident that static temperature increases from inlet to the outlet using CFD result. This is due to combustion of the air and injected diesel fuel it was found that the temperature on ferrule becomes high. Average temperature on ferrule wall is 1470K and average temperature at outlet is 1296.24 K is observed.

2.7 Experimental methodology

2.7.1 Materials and Specimens:

The experiments were performed using a carbon steel tube and ceramic ferrule, as shown in Fig. The dimensions of the tube and ferrule are listed in Table 1 and the chemical and mechanical properties shown in table 2

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	Tube	Ceramic ferrule
Outer diameter	25.4	20.5$^{+0.4/-0.8}$
Thickness	2.05	2
Inner diameter		16.6$^{+0.5}$
Length		50$^{+/-3.0}$
Collar thickness		4$^{+/-1.0}$
Collar OD		32$^{+/-1.0}$

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	Moulded ferrule(existing)	**Machined ferrule(new)**
Results observed	Out of five samples 3 found with collar damaged/broken	No damaged observed

	Existing ferrule (molded)	New ferrule (machined)
Material	ceramic	ceramic
Composition	Alumina12%	Alumina 94%
	Silica60%	Silica 1%`
	calcia/ferric oxide 2%	calcia 1%
	Magnesia26%,	Magnesia1%
Tensile strength, kpsi	15	25

2.7.2 Test procedure:

The loading the specimen (Ferrule) were inserted in carbon steel pipe (to create VAM condition) with Sodium silicate on plate & put a plate with 10 ferrule samples in furnace for 6 heat treatment cycles at 600 degree +/-10 degree cycle. Use 5 samples each from existing & new type, (Ferrule kept in the Furnace. (In Ferotherm industry – Bhosari) This test procedure is used for high temperature testing of existing and new type ferrule sample under operating condition. The maximum temperature value of the alternation action in the test is defined by the results of 2D computational analysis. This high temperature testing are with 600 degree +/-10 degree cycle for 10 days.

2.7.3 Test Results:

Results observed after furnace as shown in following photograph fig no: 7

Table 3: experimental result table

3. Results and discussion:

Detailed temperature profiles for the system were developed. For comparison reasons, the temperatures indicated by CFD analyses were queried at the same locations used for the experimental study .the CFD study indicates temperature of 1296K at the tip of the tube. This temperature is well above the 600°F maximum design temperature typically used for carbon steel components to assure acceptable service life. The rate of sulfidation that would be expected to occur at 835°F would not be considered an acceptable service life.

From this paper it is concluded that temperature difference is due to the effects of heat transfer by radiation were addressed in the CFD analysis. Inspection of and CFD analysis results makes it apparent that the temperature at the tip of the tube–to–tube-sheet junction, noted as in Fig 5 and Fig 6, is highly dependent on the amount of process gas.

It is also apparent that the tube to tube sheet weld joint during operation and condition of high alumina ceramic ferrule in this joint and throughout the system are very important to controlling the process gas bypassing and for the successful protection of the carbon steel components.

The temperature profile in the tube end, as indicated in the analysis, has a considerable gradient. The gradient results in the highest temperature occurring at the tip of the tube at the area of the tube–to–tube-sheet attachment weld. This is the area that is usually observed to have sulfidation corrosion when the tubesheet–tube protection system is not adequate. From a practical engineering viewpoint, the possible elevated temperature at the tip of the tube–to–tube-sheet joint is a greater concern for sulfidation corrosion failure than for exceeding the tube-sheet design temperature.

4. Conclusion:

The use of CFD provides the design engineer considerable in-sight into the critical temperature profile at the tip of the tube–to–tube-sheet junction. The CFD analysis provides qualification and quantification of this critical temperature profile and assures the design engineer that a suitable design temperature is utilized for ASME Code calculations. The development of ferrule for weld protection from direct flame can be achieved to assess change the material composition and manufacturing method.

The mode of failure for a boiler, heat exchanger tube end crack was investigated and suggested solution for a ceramic ferrule. The ferrule is to be fitted on to the inlet end of the tube to prevent thermal shock when hot flue gas enters the tube. Ceramic materials are chemically inert to almost all materials.

The paper shows that all ferrule systems used to protect the carbon steel tube sheets and tubes of heat exchangers are critical Therefore, the used of high alumina machined ferrule in place of moulded ferrule will get the Get better quality and accurate dimensioned ferrule. Also Fitment problem shall get eliminated.

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