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CFD Analysis of Condensation Heat Transfer in Helical Coil Heat Exchanger

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Abstract: **-** In the present study effect of steam temperature on heat transfer coefficient is studied using ANSYS Fluent (2015). In this study CFD analysis is performed to validate experimental data of condensation heat transfer coefficient. Steam temperature is varied from103^{0}C -115^{0}C and its effect on heat transfer coefficient is done. Three helical coils having different coil diameter is used. It is observed that as saturation temperature of steam increases heat transfer coefficient increases and as coil diameter increases heat transfer coefficient decreases and the percentage of error is within 9-15%.
Keywords: *- Helical coil; condensation; CFD; Saturation temperature; heat transfer coefficient.*

I. Introduction

Heat exchanger is a device that transfers heat from one medium to another. A heat exchanger is a device which is used to transfers thermal energy between two or more fluids which may be in direct contact or flowing separately at different temperature and in thermal contact. It is found from literature that heat transfer rate in helical coil is higher as compared to straight tube. Helical coil is more advantageous than straight tube due to their compact structure and enhanced heat transfer coefficient. The increase in heat transfer coefficient of helical coil is result of coil curvature, curvature of coil produces centrifugal force on moving fluid and secondary flow. The secondary flow produces additional transport of the fluid over the cross – section of the pipe. Due to this additional convective transport both heat transfer and pressure drop increases as compared to straight tube. In many industrial application helical coil heat exchanger are one of the most common equipment. Helical coils are widely used as heat exchanger and reactor because of higher narrow residence time distribution, compact structure, mass transfer coefficient and higher heat transfer coefficient. Due to centrifugal force the flow in helical coiled tubes is modified. In helical coiled tube fluid particles move toward the core region of the tube due to development of secondary flow field. The heat transfer rate in helical coil increases due to secondary flow as it reduces the temperature gradient across the cross-section of the tube. In conventional heat exchanger, there does not exist an additional convective heat transfer mechanism perpendicular to main flow. From various studies it is found that helical coiled tubes are more superior to straight tubes when applied in heat transfer application. The development of secondary flow is the result of centrifugal force due to curvature of coil which help in mixing the fluid and increases heat transfer. Due to more heat transfer coefficient and mass transfer coefficient it is widely used in various industrial application such as in thermal processing plants, food and dairy processing, HVAC'S , steam generators, refrigerators, chemical plants and domestic hot water system. As residence time distribution is less in helical coiled tube thus it is more advantageous as compared to straight tube.

II. Literature Review

Jose Fernandez-seara et.al (2014)[1] carried work on the performance of a vertical coil heat exchanger. Numerical model and experimental validation. In this study a numerical model was developed to see the effect of coil tube diameter, pitch, tube length and coil diameter on the heat transfer coefficient and pressure drop. Natural convection was considered as boundary condition. The result obtained shows that nusselt number increases with increase in outer tube diameter. It was also observed that as number of turn's increases for the same $D_{c,}$ p and d_o, nusselt number decreases and it also shows larger influence of the increasing diameter on the reduction of pressure drop.

R.Thundil karuppa Raj et.al (2014)[2] had investigated numerical analysis of helically coiled heat exchanger using CFD technique. The geometry was created in Unigraphics software and meshing was performed in ICEM CFD tool. 3D numerical analysis was performed to see the effect of different pitch size on heat transfer characteristic. In this analysis flow inlet velocity was changed from 1 to 3m/s and SST k-ω turbulence model was used with standard wall function. It was found that 60 mm coil pitch gives better heat transfer coefficient as compared to 30 mm coil pitch.

Mir Hatef Seyyedvalilu and S.F. Ranjbar (2015)[3] had studied the effect of geometrical parameter on heat transfer and hydro dynamical characteristic of helical exchanger. In this research work CFD investigation was done to see the influence of various parameters such as coil radius, coil pitch and inner diameter of tube on heat transfer characteristic of double tube helical heat exchanger. It was concluded that maximum velocity is obtained in central region of the inner tube. By increasing inner tube diameter, overall heat transfer coefficient of heat exchanger increases. It was also observed that as pitch size increases heat transfer coefficient reduces and as number of coil increases, nusselt number decreases.

G.B.Mhaske and D.D.Palande (2015)[4] studied enhancement of heat transfer rate of tube in tube helical coil heat exchanger. In this study LMTD, heat transfer rate, overall heat transfer coefficient, efficiency, Reynolds number, nusselt number and friction factor were calculated using experimentation. CFD analysis was carried out for helical coil tube in tube heat exchanger and analysis results were used to predict the flow and thermal development in tube in tube helical coil heat exchanger. It was found that inner tube nusselt number increases by 4.92% compared to conventional heat exchanger. It was also observed that log mean temperature difference (LMTD) of helical coil heat exchanger was 1.4^{o}c more as compared to conventional heat exchanger.

J.S.Jayakumar et.al (2008) [5] had carried out experimental and CFD estimation of heat transfer in helically coiled heat exchanger. In this study geometry and the mesh were created in GAMBIT 2.2 of the CFD (fluent package). In this study heat transfer coefficient were compared for various boundary conditions. It was found that for actual heat exchanger boundary condition like constant wall temperature or constant heat flux not reaches to proper modeling hence it should be modeled by considering conjugate heat transfer. After comparing experimental result with CFD calculation result using CFD package 6.2 a new correlation was developed to calculate inner heat transfer coefficient.

Kishor Kumar sahu et.al (2016)[7] carried out computational fluid dynamic analysis for optimization of helical coil heat exchanger. In this study effect of pitch length of helical coil and mass flow rate of fluid on heat transfer rate in helical coil heat exchanger was observed. Nitrogen was used as working fluid and hydrogen as a coolant. Analysis was carried out in CFD software package Ansys CFX (15.0).Simulation was conducted on two phase in first phase coil pitch with 30 mm was used at different mass flow rate and in second phase coil pitch of 20 mm was used at different mass flow rate .It was found that with decrease in coil pitch length and relative velocity in helical coil heat exchanger heat transfer rate increases.

Umang k Patel et.al (2017)[6] has carried out CFD analysis helical coil heat exchanger. The study was done to improve effectiveness, D/d geometrical parameter for different boundary condition and to see the impact of this modification on cold water temperature, hot water temperature, cold water velocity, hot water velocity and Reynolds number. The geometry was created in creo software and then it was imported in Ansys 14.5 and analysis was performed in Ansys 14.5. Hot water and cold water was used as fluid. Hot water was flowing at inside and cold water at outside so there was two inlet and outlet. From CFD analysis it was observed that LMTD increases with inner tube flow rate for constant cold water flow rate. Also nusselt number and Reynolds number increases with increasing inner tube flow rate at constant cold water flow rate.

Jiawen Yu et.al (2018) [8] has carried out numerical investigation on flow condensation of zeotropic hydrocarbon mixtures in a helically coiled tube. In this study a numerical analysis was carried out to see the effect of mass flux, saturation pressure and vapour quality on heat transfer coefficient of methane/propane and ethane/propane mixture in a helically coiled tube. It was found that heat transfer coefficient increases with increase in mass flux and vapour quality whereas it decreases with increase in saturation pressure. Results obtained from CFD simulation were compared with existing condensation heat transfer coefficient correlation and improved heat transfer correlation was developed.

III. Objectives

- To validate experimental data with CFD simulation for condensation heat transfer in helical coil heat exchanger.
- To study effect of steam temperature and coil diameter on heat transfer coefficient.

IV. CFD Methodologies

For simulation of condensation heat transfer in helical coil heat exchanger first geometry of helical coil is created in SOLIDWORKS 2016. After creating geometry it is imported in ANSYS 2015. After importing geometry and meshing problem is analyzed in ANSYS 15. Inner fluid is taken as steam and outer fluid as water. Modeling starts with defining initial boundary condition. Finally, it is followed by result, discussion and conclusion.

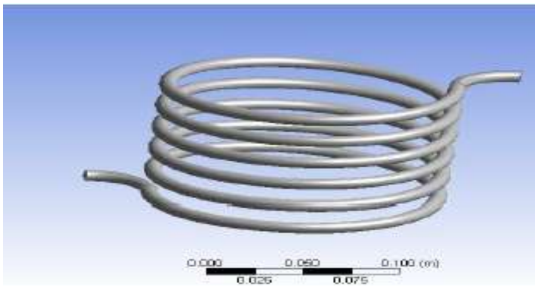

Fig 1 Model of heat exchanger helical coil

Solution:
It is achieved in following steps:
General: Type-Density based, Time- steady, Velocity formulation- Absolute
Model: Energy equation-ON, Viscous model- K-Ɛ model, Multiphase- Implicit
Material: Phase1-water vapour, phase 2- water liquid, solid- steel
Cell zone condition: Fluid
Boundary condition: inlet- mass flow, outlet- pressure, wall- constant temperature.
Solution Methods: Scheme – Simple, Pressure- standard, Gradient- least square cell based, Momentum- second order upwind, Turbulent dissipation rate – Second order upwind, Turbulent kinetic energy- Second order upwind
Solution initialization: Hybrid initialization
Run calculation: Number of iteration-500, reporting interval -1, profile update interval -1
Results: graphics and animation- contours of wall fluxes and heat transfer coefficient

V. Results And Discussions

- **Validation of experimental data with CFD simulation for impact of steam temperature on condensation heat transfer coefficient**

Effect of steam inlet temperature on heat transfer coefficient is studied at various steam temperature and having different coil diameter at 3 lpm.

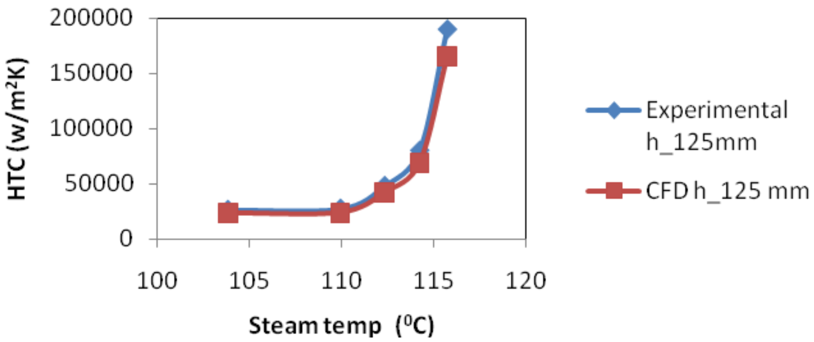

Fig.2 Steam temp Vs HTC at 3lpm

Above graph shows variation in heat transfer coefficient with steam temperature for 125 millimeter coil diameter.

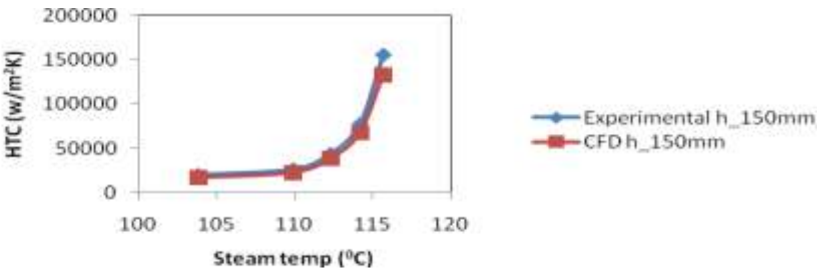

Fig 3 Steam temp Vs HTC at 3lpm

Above graph shows variation in heat transfer coefficient with steam temperature for 150millimeter coil diameter.

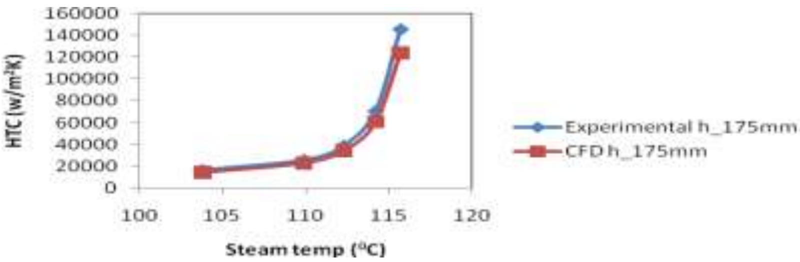

Fig 4 Steam temp Vs HTC at 3 lpm

Above graph shows variation in heat transfer coefficient with steam temperature for 175 millimeter coil diameter

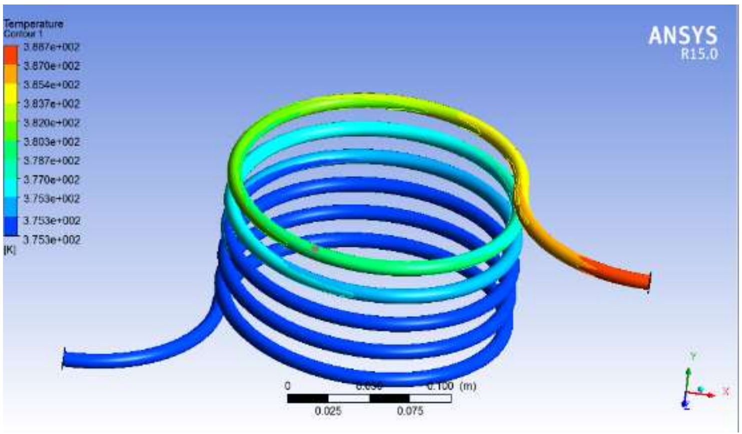

Fig. 5 Temperature contour

Figure depict temperature contour across helical coiled tube.

VI. Conclusion

CFD package (ANSYS FLUENT 15.0) is used to validate experimental data of condensation heat transfer coefficient. The effect of steam temperature on heat transfer coefficient is studied and it is observed that as steam temperature increases heat transfer coefficient increases and also observed that heat transfer coefficient is maximum for smaller coil diameter and lower for bigger coil diameter.

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