CFD Analysis of Triple Concentric Tube Heat Exchanger

Dharmikkumar A. Patel[1] Dr. V. D. Dhiman[2] Jignesh Patel[3]
[1]P.G Student [2]Associate professor [3]Assistant professor
[1,2,3]Department of Mechanical Engineering
[1]Gujarat Technological University, India [2]G.E.C. Surat, India [3]M.G.I.T.E.R, Navsari, India

Abstract— Triple concentric tube heat exchanger performs better than double concentric tube heat exchanger. Triple concentric tube heat exchanger consists of three tube of different diameter as connected concentrically. Most of previous study used two fluids for different arrangement. Cold fluids flow from inner tube and outer annulus and hot fluid from inner annulus. Objective of present work is give review on performance analysis of triple concentric tube heat exchanger. Different parameters which affect the performance analysis of triple concentric tube heat exchanger were determined.

Key words: Triple concentric tube heat exchanger

I. INTRODUCTION

Heat exchanger is a device which transfers thermal energy from hot fluid to cold fluid with maximum rate and minimum investment and running cost. Concentric tube plays an important role in food industry. The most common concentric tube type is double pipe heat exchanger. In double pipe heat exchanger one tube fitted in other concentrically. Introducing an intermediate pipe to double pipe heat exchanger which performs better than double pipe heat exchanger and it called triple concentric pipe heat exchanger. In triple pipe heat exchanger there are three section inner tube, inner annulus space and outer annulus space. In triple pipe heat exchanger thermal fluid pass in inner annulus and heat transfer fluid passed in other two tubes. The chief function of third pipe is to improve the heat transfer rate through an additional flow passage and larger transfer per unit exchanger length. In triple concentric tube heat exchanger three pipe of different diameter are used and three fluid exchange heat among each other. In triple concentric tube heat exchanger thermal fluid (hot fluid) contact with heat transfer fluid (hot fluid) from both sides, so provide larger heat transfer area and increase heat transfer rate. The performance of non-insulated triple concentric tube heat exchanger is different from insulated heat exchanger mainly due to effect of surrounding ambient present in case of non-insulated heat exchanger. In case of non-insulated heat exchanger there are three thermal communication surfaces. According to fluid passes from tube there are two arrangements N-H-C and C-H-N. In N-H-C arrangement normal fluid passes in inner tube, hot

Fluid in inner annulus and cold fluid from outer annulus. Cold and normal water are interchanged in the C–H–N arrangement keeping hot water flow unchanged.Generally there are two fluid are used which are cold and hot. In this arrangement cold fluid are flow from inner tube and outer annulus and hot fluid from inner annulus. The technical and economic advantages that are ensured by the use of triple concentric tube heat exchanger in comparison to the double pipe heat exchanger are represent by the higher heat transfer area per unit length and higher velocity due to presence of annular space. Replacing the double pipe heat exchanger with triple pipe heat exchanger application of triple concentric pipe heat exchanger is mainly in food industries such as pasteurization, sterilization, drying, cooling, freezing, evaporation, refrigeration etc. By using triple pipe heat exchanger in place of double pipe heat exchanger increase the efficiency of heat exchanger, reduce the length and saving the space and material of heat exchanger by increasing the heat transfer rate.

The need to understand the transfer of heat between various systems in industrial as well as residential application is an important process which motivates the researcher to improve design and performance of heat exchanger.The performance of the heat exchanger generally depends on the various physical characteristics of the fluid and the material.There are many researches done for double concentric tube heat exchanger but for triple concentric tube heat exchanger less research done. Study of mathematical model, numerical and experimental analysis for triple concentric tube heat exchanger is done by the researcher. But the available information about triple concentric tube heat exchanger is less. From available literature, major contributions of researchers are as follows.

Ahmet unal: Part 1 [1] carried out theoretical study in two parts. First part deals with the mathematical modeling. Derivation and possible solution of governing differential equation was found for both parallel and counter flow. Equation was derived for well insulated triple pipe heat exchanger under fully developed flow condition and using some properly defined parameter such as heat capacity flow rates, NTU and some other nondimentional parameters. Mathematical formulation was carried out for both parallel and counter flow. Governing equation used in study was two second order differential equation for inner tube and outer annulus and first order differential equation for inner annulus. Resultant equations express bulk temperature variation of three fluids with exchanger length. Design and performance calculation of triple pipe heat exchanger and effect of various parameters on heat exchanger performance was carried out.

Ahmet unal: Part 2: [2] carried out theoretical study on counter flow triple concentric pipe heat exchanger in second part. Several case study were conducted on the basis of solution obtain in first part. Case study include both design and performance calculation. The conclusion was the relative size of the three tubes with respect to each other was the most important parameter that influences the performance of triple pipe heat exchanger. Result present in the graphical form for better understanding the effect of tube radius ratio on performance and length of heat exchanger.

Ahmet unal: Part: 3 [3] developed fully analytical expression for the effectiveness of triple pipe concentric tube heat exchanger with both counter and parallel flow based on previously obtain data in third part. The effect of number of transfer unit on effectiveness represented graphically.

Sinziana Radulescu et al [4] explained calculation algorithm used in heat transfer studies when triple pipe heat exchanger was used. Correlation for determining partial co-efficient of heat transfer for three fluid heat exchanger based on experimental data was developed. Correlation developed for design purpose on heat transfer device were Nu=2.718$Re^{0.597}8Pr^{1/3}(\frac{d_{h2}}{L})^{2/3}$ used for Reynolds number of 2264 to 7893 and velocity between0.11 to0.36 m/s.

C. A. Zuritz [5] developed a set of analytical equations for fluid temperatures at any axial location along the heat exchanger for parallel and counter flow configurations and conducted simulation of triple concentric pipe heat exchanger. Three first order differential equations were derived through laplas transformation for three fluid flows in triple concentric tube heat exchanger. The equations account for heat losses to the surroundings and are useful for design purposes Simulations show that the creation of an annular region within the inner pipe increases the overall heat transfer efficiency and reduces the heat exchanger length requirement by almost 25%.

D. P. Sekulic et al [6] offered in detail a review on thermal design theory of three fluid heat exchanger, where they have allowed for third fluid temperature to vary according to main thermal communication while neglecting interaction with ambient. Effectiveness- NTU (number of heat transfer units) approach was used for corresponding rating and sizing problems for the determination of the effectiveness or NTU for a three-fluid heat exchanger.

Ediz Batmiz et al [7] [8] developed more generic way of calculating overall heat transfer coefficients in a triple tube heat exchanger. Temperature profiles of all streams in a triple tube heat exchanger in the axial direction were determined. An effective overall heat transfer coefficient that is related to the total resistance to heat transfer in the triple tube heat exchanger, was also determined to facilitate comparison of a triple tube heat exchanger to an equivalent double tube heat exchanger. When the fluids were flowing in a co-current manner, the temperature of the cooling medium with lower heat capacity exceeded the temperature of the product before the fluids exit the TTHE which caused a loss in effectiveness of the TTHE.

Min Zho et al [9] developed mean temperature difference method called IMTD for parallel three fluids heat exchanger with two communication surfaces. Design and simulation procedure of IMTD model as well as its validation with previous exact model was conducted. IMTD formula for three fluids heat exchanger was similar to LMTD method for double pipe heat exchanger. Derived IMTD formula and accelerated method improved the design processes. Fast convergence which is usually within 10 steps for all parallel stream arrangement was achieved. IMTD model have same accuracy as past exact analytical model with simplicity.

G.A.Quadir et al [10] conducted the performance of triple pipe heat exchanger carried out numerically by using FEM method under steady state condition for different flow arrangement and for insulated and non –insulated condition. The results were present in the form of non-dimensional temperature variation of fluid along the length of heat exchanger for different flow rate. The conclusion was that numerical methodology is accurate enough to predict the temperature variation along length if correct value of overall heat transfer is used. Parametric study was also carried out to find the effect of individual parameter on performance of the heat exchanger.

G.A. Quadir et al [11] fabricated the triple pipe heat exchanger and experiment was carried out to investigate the performance of heat exchanger under two different flow arrangements. There are two arrangement N-H-C and C-H-N were investigated. Results were present in term of temperature variation along the length of heat exchanger under co-current flow for N-H-C and C-H-N for insulated as well as non-insulated. Results show that heat transfer rate from hot fluid to cold fluid is more in N-H-C arrangement than C-H-N. For N-H-C arrangement the temperature of cold water is increased too much higher degree in comparison to that of the normal water. Reason was that the higher amount of heat was transferred to cold water due to larger temperature difference between the cold and hot water.

Rajshekher K. et al [12] investigated the heat transfer rating and performance analysis of triple pipe heat exchanger with fin. Fin arranged vertically on outer tube only. Hot and cold fluid in opposite direction and cold fluid flow in central tube only. This arrangement increases effectiveness of heat transfer rating with compact size. Experimental setup used to calculating convective and conductive heat transfer coefficient of tube and fins. Heat transfer coefficient and effectiveness for overall and individual tube was finding. The conclusion was triple pipe heat exchanger increases the heat transfer area, reduce the cooling time and increase effectiveness with compact size.

Ch.V.V. satyanarayan et al [13] conducted design and performance testing of a small scale ultra-high temperature (UHT) sterilizer suitable for rural tropical cooperative. Triple tube heat exchanger was design for heating milk from 95^{o} to145^{o} in the annulus of the triple tube heat exchanger using steam in the innermost and outermost tubes. An iterative procedure was followed to developed software to handle design calculation. Set up was tested with milk for determination of heat transfer coefficient. Three milk floe rate of 4.1, 4.7, 5.4 litter/min was selected. Chromel-alumel+ thermocouples with a digital indicator were used for temperature measurement. The inlet milk temperature was 95°C in all cases. Sterilized samples with zero count indicate the effectiveness of the process. The conclusion was as the flow rate increases both outlet temperature and fluid back pressure decreases and overall heat transfer increased.

P. K. Sahoo et al [14] design and tested a laboratory model indirect type helical tube ultra-high temperature milk sterilizer. The helical triple tube modelling and simulation was carried out for heating milk from 90^{0}C to 150^{0}C in the annulus of triple tube using steam in the innermost and outermost tubes. Effectiveness during process and storage of UHT processed milk for two month were found. The quality attribute of the UHT processed milk were also tested during the processing and storage period. Whiteness index of sterilized milk was decreased slowly during the early period of storage and decreased sharply after one month of storage. Yellowness index of sterilized milk was increased very slowly for first one month of storage and increased sharply between 30 and 45 days of storage. After one and half month of storage, the change was significant. The change may be due to a browning action, which was preventing during the storage period.

K. Sopian et al [15] investigated the application of a triplex tube heat exchanger with a phase-change material (PCM) (paraffin wax RT 82) in the middle tube to power a liquid-desiccant air-conditioning system. The experiment examined the effects of mass flow rates and heating methods selected on PCM melting. Three techniques were investigated: heating the inside tube, heating the outside tube, and heating both sides tube. The PCM temperature gradients in the radial, angular, and axial directions were analyzed. Results indicated that the third case (i.e., heating both sides) achieved complete PCM melting within a short time and used a lower inlet heat transfer fluid temperature compared with the other cases. No significant temperature variation in the axial direction was indicated. The heat transfer phenomena in the radial and angular directions can be predicted in melted PCM.

Sohif et al [16] numerically investigated the effect of internal and external fin for phase changing material (PCM) in triple pipe heat exchanger. Effect of number of fin, fin length, fin thickness, material and PCM geometry on melting time of PCM was numerically investigated. Melting time decreases with increase of fin length and fin thickness. Melting rate decrease with increase the number of fin and temperature differences. Higher temperature differences in Stefan number rapid increase of melting function and short time for melting. The conclusion was melting rate is significantly increase by adding internal and external fin in Triple tube heat exchanger because the fin extend the heat transfer area and conduct it directly to PCM surface.

O. Garcia [17] developed numerical model for analyzing behavior of triple pipe heat exchanger. Model present was consider realistic situation such as transient effect, heat conduction within the tube wall and insulation, temperature dependent fluid property and the possibility of two phase flow condition so it different from simplified model. The result show the effectiveness of counter flow was 12% more than parallel flow and outlet temperature of hot fluid was 7^0C lower in counter flow arrangement.

Birol basal et al [18] numerical investigated the triple concentric tube heat exchanger for latent heat thermal energy storage by using enthalpy method. The latent thermal energy storage system was studied which use PCM for heat storage. An annulus shaped PCM layer that was contact with heat transfer fluid from both side provide better performance due to larger heat transfer area. Based on numerical calculation the effect of system parameter such as mass flow rate, inlet temperature and variation of tube radius on system performance were investigated. Numerical calculation was carried out by considering RT52 as the PCM and water as the heat transfer fluid. The effect of the inlet temperature of the heat transfer fluid, on the other hand, is very significant. Melting time of PCM can be reduced considerably by using the proposed storage configuration instead of the classical double-tubes.

Long Jian you[19] developed a simple numerical method, called temperature & thermal resistance iteration method for the analysis of PCM solidification and melting in the triplex concentric tube with PCM filling in the middle channel, with hot heat transfer fluid flowing outer channel during charging process and cold heat transfer fluid flowing inner channel during discharging process. Inlet temperature of HTF evidently affects the time for complete both solidification and melting. Lower inlet temperature for solidification and higher inlet temperature for melting result in shorter time for complete solidification and melting. Time for complete solidification and melting strongly depends on mass flow rate of HTF. Larger mass flow rate results in shorter time for complete solidification and melting.

P.K. Nema et al [20] developed an improved simulation model for the accurate estimation of fouling thickness and milk outlet temperature in triple pipe heat exchanger. The temperature increases along the length of the heat exchanger towards the outlet. With the progress of time, the temperature drops gradually at the respective nodes along the length of the heat exchanger. This is due to the occurrence of fouling. Fouling deposited on the outer surfaces of inner tube increase with time. Right from the beginning, the occurrence of fouling deposit is found to be more at the outlet than at the inlet of the heat exchanger. The conclusion was that from beginning fouling occur to greater extend toward the outlet and with progress of time rate of increase of fouling is decrease and milk outlet temperature decrease with time as fouling increased.

II. CONCLUSION

Concentric tube heat exchangers are mainly use in food industries. For increase heat transfer rate, effectiveness and refused size of heat exchanger triple concentric tube was used instead of double pipe heat exchanger due to higher heat transfer area. There are three thermal communication surface was consider for performance analysis of triple concentric tube heat exchanger In order to achieve maximum efficiency of heat exchanger many researcher have put their effort to maximize the performance along with reduced cost.

(1) Triple concentric tube heat exchanger performs better than double pipe heat exchanger. For triple concentric tube heat exchanger mathematical model, numerical analysis and experiment was carried out by different researcher.
(2) For triple concentric tube heat exchanger parameter which affected the performance were relative sizes or radius of inner tube, inner annulus and outer annulus, mass flow rate, thermo physical property of fluid.
(3) Among them radius of inner tube, inner annulus and outer annulus was important parameters. In triple concentric tube heat exchanger heat transfer rate was increased due to increase of heat transfer area.
(4) Triple concentric tube heat exchanger increased effectiveness and considerable amount of saving space and material compare to double pipe heat exchanger.
(5) Effectiveness of counter flow arrangement was higher than parallel flow arrangement.
(6) Heat transfer rate was affected by number of fin, fin length, and fin thickness if internal and external fin was used in triple concentric tube heat exchanger.
(7) Heat transfer between three fluids was more effective in N-H-C arrangement of fluid as compare to the C-H-N arrangement.

(8) For solidification and melting of PCM in triple tube heat exchanger Inlet temperature of HTF evidently affects the time for complete both solidification and melting. Lower inlet temperature for solidification and higher inlet temperature for melting result in shorter time for complete solidification and melting. Time for complete solidification and melting strongly depends on mass flow rate of HTF. Larger mass flow rate results in shorter time for complete solidification and melting.

(9) In triple concentric tube heat exchanger fouling occurred greater extend toward the outlet and with the progress of time rate of increase of fouling thickness decreased. Outlet temperature of fluid decreased with the time as fouling increased. Copper and aluminum were used as material for tube in triple concentric tube heat exchanger because of high thermal conductivity. Steel was used as alternative because of low cost and easy fabrication.

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