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# A review on triple tube heat exchangers

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ABSTRACT

In the past decades have faced the challenges in meeting out the cooling demand due to the technological developments. More works are being carried out for optimum heat transfer in concentric heat exchangers, one among the double tube heat exchangers investigation is the triple tube heat exchangers (TTHE). Reported that the triple tube heat exchangers are more effective than double tube heat exchangers. In this paper, investigations carried out on triple tube heat exchangers are reviewed and the reports published by different researchers are critically analyzed in order to carry out the advanced research work on triple tube heat exchangers.
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## 1. Introduction

The basic type of heat exchanger used in a wide range of applications is a double tube heat exchanger. Its working phenomenon is based on heat transfer between two pipes with cold and hot fluids. It has its significance in freezing, boiling drying, dairy, and pharmaceutical, food, pasteurization and chemical industries. In order to manage high-temperature differences, the heat exchange area should be increased, which could be possible only by increasing the heat exchanger's length. TTHE solves this problem, by increasing the heat transfer area for the same length of the double tube heat exchanger.

It has three concentric tubes specifically three compartments which are mentioned to be inner tube, inner annulus and outer annulus. It is needed to flow the target fluid whose temperature variations are of main concern for application fulfillment within the inner annulus for taking better advantage of the heat exchanger. The inner annulus has 2 heat exchange surfaces (inner tube outer surface and outer tube inner surface) that will increase the heat exchange area of heat exchanger marginally compared to double tube device (has just one heat exchange surface) which will increase the speed of heat exchange. It conjointly in terms will increase the potency of heat exchanger. Therefore, it conjointly decreases the length of desired heat changer for constant temperature distinction compared to double tube devices.

In the case of the double tube heat exchanger, the possible flow configurations are parallel flow and counter flow. In regards with the triple tube heat exchanger (TTHE), there are three fluids flowing resulting four possible configurations. Further, in terms of the type of fluid following configurations in Table 1 can be attained. Comparison of the above configuration results in eight possible flow configurations.

## 2. Triple tube exchanger advancements

The transition from the Double tube heat exchanger to the triple tube heat exchanger is mainly due to the heat transfer area increase and reduction in heat exchanger length. As, an energy conservation concern the triple tube heat exchangers has more efficiency compared to the double tube heat exchangers.

In considerations with the double tube heat exchangers there are lot of research and experimental frameworks in place. Despite the advantages of triple tube heat exchanger (TTHE), the research and experimental work in this arena is limited. This review links the brief research findings in the past years in terms of design, mathematical modelling, and experimental analysis in consideration with different parameters. The timeline proceeds as below.

Unal [1] developed the first mathematical modeling with derivation and probable solutions of the governing differential equations for parallel flow and counter flow configurations with

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**Table 1**
Possible tube flow configurations.

| *Flow Arrangement* | *Outer Annulus* | *Inner Annulus* | *Inner tube* |
|---|---|---|---|
| C–H–N | Cold Flow | Hot Flow | Normal Flow |
| N–H–C | Normal Flow | Hot Flow | Cold Flow |

respect to triple tube concentric heat exchanger. The formulation was for a well-insulated triple tube heat exchanger under fully developed flow condition and using some properly defined parameter such as heat capacity flow rates, NTU and some other non-directional parameters.

Unal [2] solved the first order differential through Laplace transformations for distinct roots only. The terminal equations expressed bulk temperature variation of three fluids with respect to heat exchanger length and determined that the performance of the triple tube concentric heat exchanger was influenced by the relative size of the tubes. The effect of tube radius ratio on performance and length of heat exchanger were presented in graphical format based on the experimentation results. Ahmet Unal [3] plotted effectiveness versus NTU graph for individual tubes and concluded that a counter flow arrangement was comparatively more effective than parallel flow arrangements.

García-Valladares [4] used the governing equations and resolved it iteratively in a very segregated manner and evaluated the flow variables at each point of the grid on the device surface. At the end, the heat transfer effectiveness increase in the counter flow arrangement.

Quadir et al. [5] fabricated a triple concentric pipe heat exchanger and experiments carried out using it to investigate the heat exchange behavior between three fluids under different operating conditions. The result identified for insulated and non- insulated conditions of triple tube heat exchanger and found that temperature profiles along the length of heat exchanger under parallel flow concurrent configurations. The rate of heat transfer between three fluids in N–H–C arrangement more effective than C–H–N arrangement. Further, normal water heated more in N–H–C arrangement than in C–H–N arrangement. It is observed that the crossover point occurs between hot and normal water for insulated as well as non-insulated conditions under N–H–C arrangement. The crossover point is seen when the flow rate of hot water is same or slightly less than that of other two fluid flow rates. The crossover point appears earlier along the length of heat exchanger when the outer annulus is exposed to ambient having higher temperature than that of the fluid in outer annulus. The heat transferred from hot water to fluid in outer annulus is higher in N–H–C arrangement whereas it is almost same for both the fluids in C–H–N arrangement.

Gomaa et al. [6] used a finite volume discretization method developed numerical CFD model for triple tube concentric heat exchanger. The experiment conducted on four flow patterns such as co-current, counter current, co-current to counter current flow and counter current with co-current. Correlations of friction factor, Nusselt number and heat exchanger effectiveness with the dimensionless design parameters are presented.

Nora Boultif and Cherif Bougriou [7] performed numerical analysis for triple tube heat exchanger with the aid of FDM. Temperature variations of three fluids along the length of the heat exchanger with respect to time is presented. Interpretation of the three fluids have a time lag for parallel flow, which was not visualized in the case for the counter flow because the only fluid that has a time lag was the hot fluid and heat exchanges were comparatively lower in the unsteady state than the steady state case.

Quadir et al. [8] experimentally studied that, C–H–N and N–H–C arrangements in insulated and non-insulated conditions in triple tube device. Heat transfer was comparatively more effective in N–H–C and heat transfer from hot to outer annulus fluid was excessive in N–H–C whereas it's same for both in C–H–N. After the execution of the experiment, proceeded numerically to determine the performance of a triple concentric tube device with the aid of FEM for the pre-mentioned flow arrangements. The comparison of both experimental and numerical results were near enough.

Batmaz and Sandeep [9] determined the overall heat transfer coefficients and temperature distribution of fluids axially in a TTHE with the help of energy balance equations on control volume. The computed overall heat transfer coefficients and temperature profiles were useful for designing a heat exchanger.

Zuritz [10] derived a mathematical model to identify the fluid temperature at any location axially along the length of a TTHE. The results obtained with the different equations were in excellent agreement and proved useful for heat exchanger design and evaluation purposes.

Batmaz and Sandeep [11] predicted that all three-overall heat transfer coefficient values were higher in the countercurrent arrangement than in the co-current arrangement in addition to that, the effectiveness in the countercurrent arrangement was higher than that in the co-current arrangement.

Gomaa et al. [12] developed correlations for Nusselt number, effectiveness and friction factor and concluded the work that, the Nusselt number of triple tube heat exchanger increases with Reynolds number for both configurations. Average heat transfer is high in counter flow configuration compared to other flow configuration for the same specific heat. Higher values of Performance index is obtained for lower values of Reynolds number. Capacity rate of hot water is higher than other two fluids. At constant Reynolds number, effectiveness is higher for high hot water inlet temperature in TTHE.

Mohapatra et al. [13] verified the coil side Nusselt number found by Wilson technique was compared with literature available and assessed that, increasing volume flow rate of hot water, normal water and air increases overall heat transfer coefficient in parallel and counter flow configuration. Effectiveness of TTHE increase in parallel flow configuration but decrease in counter flow configuration with volume flow rate of air and effectiveness depends on capacity ratio, NTU and residence time.

Mohapatra et al. [14] performed an experimental investigation on triple fluid heat exchanger by maintaining Reynolds number value from 9000 to 54,000 and used a coil tube heat exchanger inserted between two concentric straight tube in which hot water supplied, and assessed that coil side Nusselt number increase with increase in volume flow rate or Reynolds number of hot water inside the helical tube. When hot water flow rate increases, overall heat transfer coefficient increases but effectiveness of heat exchanger decreases.

Radulescu et al. [15] performed an analysis of heat transfer achieved at cooling a petroleum product with water in a DTHE and a TTHE. Based on experimental data obtained in the laboratory, the values of main parameters were compared to assess the differences in heat being transferred in the two heat exchangers. The results showed that, for the identical length of the heat exchanger, the heat transfer area and the overall heat transfer coefficients for TTHE are higher than for DTHE. These results are in accordance with the theoretical advantages of a TTHE versus a DTHE.

Sahoo et al. [16] found that the temperature increases along the length of the heat exchanger towards the outlet. As time progresses, the temperature drops gradually at the respective nodes along the length of the heat exchanger due to the occurrence of fouling. At the beginning, the occurrence of fouling deposit is uniform along the length of the heat exchanger. With progress of time, as the fouling deposit increases, the flow area available for the process fluid decreases.

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Nema and Datta [17] conducted an experiment on triple tube heat exchanger for sterilizing milk at 93 °C and supplied to the inlet. They developed an improved simulation model is used to predict fouling thickness and the milk outlet temperature very close to the experimental value.

Patraşcioiu and Radulescu [18] developed a mathematical model of TTHE by considering several assumptions for predicting fluid outlet temperature. Both of them used correlations for determining overall heat transfer coefficient with different Reynold number values. They also predicted that outlet temperature having some deviation with experimented values. The calculated values for the heat transfer coefficients have been similar with the literature data. The calculated values for the effective overall heat transfer coefficient have been close to those of tubular heat exchangers, presented in literature.

Sekulic [19] developed a mathematical model by considering different assumption for four flow configurations and obtained a compact solution for temperature distribution and temperature cross of triple fluid heat exchanger with two thermal communications among three unbalanced fluid streams.

Aulds and Barron [20] formulated a mathematical model by considering some assumptions and used different value of Reynolds number ranging from 900 to 28,000 for all three tubes. The effectiveness of heat exchanger found satisfactory between theoretical and experimental values. It was found that thermal resistances plays a major role for difference in values of experimental and analytical values and also difference in circumferential conduction results in difference in thermal resistance.

Basal and Unal [21] developed a triple tube heat exchanger type heat storage system by keeping phase change material in the inner annulus tube and fluids flowing through the inner most and outer annulus tube is having same mass flow rate and same amount. The comparison showed that the melting time of PCM is reduced to certain level compared to double tubes. The radial position and thickness of the PCM play significant parameters affecting the time of charging and capacity of storage.

Esapour et al. [22] investigated the melting characteristics of PCM by placing one or more tubes in the double tube heat exchanger by keeping PCM in the inner annulus, and in other tubes, heat transfer fluid circulated. Based on the study, mass flow rate and heat transfer fluid inlet temperature increases melting time of PCM reduces and better than double tube heat exchangers.

Zhao and Li [23] derived an integral-mean difference (IMTD) formulae for three fluid parallel flow heat exchanger with two thermal communications. These formulae were used to design and simulate three-fluid heat exchanger with faster convergence compared to other LMTD models.

Eiamsa-ard et al. [24] examined the triple spirally twisted tubes with triple channel twisted tubes using RNG k-ε turbulence model. They considered two types of tube/tape arrangement belly to belly, belly to neck. They summarized that this setup improves fluid mixing, heat transfer enhancement and with the increase in pressure drop. Nusselt number increases in a twisted tube with triple channel twisted tape compared to the arrangement without tapes. Due to synergetic swirling effect, there is higher pressure drop in the combined device as Reynolds number decreases. In this twisted tube combination with twisted tape, arrangement possesses the highest thermal performance factor.

Shrivastava and Ameel [25,26] developed a general analytical model for the TTHE with three thermal communications for all flow arrangements and discussed the effects of six dimensionless design parameters on the solutions of three fluid streams temperature distribution. In addition to that six effectiveness parameters were included in order to complain with the five engineering goals, a standardized set of metrics to assess the overall performance of three fluid heat exchanger.

Krishna et al. [27] investigated the effect of atmospheric heat-leak-in to the cold fluid using analytical and FEM in a TTHE of non-concentric type heat exchangers and carried out the investigation to study the effect of seven dimensionless number on hot fluid behavior in terms of effectiveness, degradation factor and temperature profile. The results showed that any variation in seven dimensionless numbers either increase or decrease the effectiveness, temperature profile and degradation factor. Krishna et al. compared the result with already available data and showed versatility.

Krishna et al. [28] examined the effect of linear heat conduction in the separating walls on the performance of a three fluid cryogenic heat exchanger involving thermal interaction between all three fluids using the analytical method and FEM. The paper concluded with the observations over four flow arrangements with the objective of determining the deviation in the temperature profiles of all three fluids, due to the effect of longitudinal conduction in the three walls even in the absence of ambient heat in leak.

Saeid and Seetharamu [29] evaluated the thermal performance of TTHE for co-current and counter-current flow configurations using finite element method but restricted to insulated conditions. In the work, the increase in Reynolds number decrease the effectiveness for all flow configurations and found that for the same heat capacity rate in counter flow arrangements the average heat transfer rate was higher than other flow configurations.

Veerabhadrappa et al. [30] numerically investigated the transient temperature response of a counter flow three fluid heat exchanger using FEM with three thermal communications and compared the result with steady state response. The investigation showed that, any step-change in inlet temperature of one fluid, the other two fluids reach steady state faster in outlet compared with inlet temperature changed fluid. The effectiveness of hot fluid increase or decrease based on outlet fluid temperatures. Transient behavior of any real time systems could be predicted effectively using the mathematical model developed.

## 3. Conclusions

It is studied from the published papers on triple tube heat exchangers that most of the research works have been carried out by using water as a heat transfer medium. Moreover, it is observed that the flow rate and heat transfer rate are directly proportional in all research papers and none of the paper is taken alternate heat transfer fluid rather than water. The works on triple tube heat exchanger (TTHE) are very limited while comparing double tube heat exchanger (DTHE) due to its practical applications. Further study can be carried out by using alternate heat transfer fluid among the three fluids.

## References

[1] A. Unal, Theoretical analysis of triple concentric-tube heat exchangers part-1: mathematical modeling, Int. Commun. Heat Mass Transf. 25 (1998) 949–958.
[2] A. Unal, Theoretical analysis of triple concentric-tube heat exchangers part-2: case studies, Int. Commun. Heat Mass Transf. 28 (2001) 243–256.
[3] A. Unal, Effectiveness-NTU relations for triple concentric-tube heat exchanger, Int. Commun. Heat Mass Transf. 30 (2003) 261–272.
[4] O. Garcia-Valladares, Numerical simulation of triple concentric-tube heat exchangers, Int. J. Therm. Sci. 43 (2004) 979–991.
[5] G.A. Quadir, I.A. Badruddin, N.J.S. Ahmed, Numerical investigation of the performance of a triple concentric pipe heat exchanger, Int. J. Heat Mass Transf. 75 (2014) 165–172.
[6] A. Gomaa, M. Mohamed, A.M. Elsaid, Experimental and Numerical investigation of a triple concentric-tube heat exchanger, Appl. Therm. Eng. 99 (2016) 1303–1315.
[7] N. Boultif, C. Bougriou, Steady and Unsteady State Thermal Behavior of Triple Concentric Tube Heat Exchanger, Heat Mass Transfer, Springer, 2016.
[8] G.A. Quadir, S.S. Jarallah, N.J.S. Ahmed, I.A. Badruddin, Experimental investigation of the performance of a triple concentric pipe heat exchanger, Int. J. Heat Mass Transf. 62 (2013) 562–566.

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[9] E. Batmaz, K.P. Sandeep, Calculation of overall heat transfer coefficients in a triple tube heat exchanger, Heat Mass Transfer 41 (2005) 271–279.
[10] C.A. Zuritz, On the design of triple concentric-tube heat exchanger, J. Food Process Eng. 21 (1990) 113–130.
[11] E. Batmaz, K.P. Sandeep, Overall heat transfer coefficients and axial temperature distribution in a triple tube heat exchanger, J. Food Process Eng. 31 (2008) 260–279.
[12] M.A. Halim, Abdalla Gomaa, Ashraf Mimi Elsaid, Enhancement of cooling characteristics and optimization of a triple concentric-tube heat exchanger with inserted ribs, Int. J. Therm. Sci. 120 (2017) 106–120.
[13] Taraprasad Mohapatra, Biranchi N. Padhi, Sudhansu S. Sahoo, Experimental investigation of convective heat transfer in an inserted coiled tube type three fluid heat exchanger, Appl. Therm. Eng. 117 (2017) 297–307.
[14] Taraprasad Mohapatra, Biranchi N. Padhi, Sudhansu S. Sahoo, Rudra N. Pramanik, Performance analysis of three fluid heat exchanger used in solar flat plate collector system, Energy Procedia 109 (2017) 322–330.
[15] S. Rădulescu, L.I. Negoiţă, I. Onuţu, Analysis of the heat transfer in double and triple concentric tube heat exchangers, IOP Conf. Series: Mater. Sci. Eng. 147 (2016), 012148.
[16] P.K. Sahoo, I.A. Ansari, A.K. Datta, Milk fouling simulation in helical triple tube heat exchanger, J. Food Eng. 69 (2005) 235–244.
[17] P.K. Nema, A.K. Datta, Improved milk fouling simulation in a helical triple tube heat exchanger, Int. J. Heat Mass Transf. 49 (2006) 3360–3370.
[18] C. Patrascioiu, S. Radulescu, Prediction of the outlet temperatures in triple concentric-tube heat exchangers in laminar flow regime: case study, J. Heat Mass Transf. 1385 (2014) 01–14.
[19] Dusan P. Sekulic, A compact solution of the parallel flow three-fluid heat exchanger problem, Int. J. Heat Mass Transfer 37 (14) (1994) 2183–2187.
[20] Darrell D. Aulds, Randall F. Barron, Three-fluid heat exchanger effectiveness, Int. J. Heat Mass Transfer 10 (1967) 1457–1462.
[21] B. Basal, A. Unal, Numerical evaluation of a triple concentric-tube latent heat thermal energy storage, Sol. Energy 92 (2013) 196–205.
[22] M. Esapour, M.J. Hosseini, A.A. Ranjbar, Y. Pahamli, R. Bahrampoury, Phase change in multi-tube heat exchangers, Renew. Energy 85 (2016) 1017–1025.
[23] Min Zhao, Yanzhong Li, New integral-mean temperature difference model for thermal design and simulation of parallel three-fluid heat exchanger, Int. J. Therm. Sci. 59 (2012) 203–213.
[24] S. Eiamsa-ard, P. Promthaisong, C. Thianpong, M. Pimsarn, V. Chuwattanakul, Influence of three-start spirally twisted tube combined with triple-channel twisted tape insert on heat transfer enhancement, Chem. Eng. Process. 102 (2016) 117–129.
[25] D. Shrivastava, T.A. Ameel, Three-fluid heat exchangers with three thermal communications Part A: general mathematical model, Int. J. Heat Mass Transf. 47 (2004) 3855–3865.
[26] D. Shrivastava, T.A. Ameel, Three-fluid heat exchangers with three thermal communications Part B: effectiveness evaluation, Int. J. Heat Mass Transf. 47 (2004) 3867–3875.
[27] V. Krishna, P.G. Hegde, N. Subramanian, K.N. Seetharamu, Effect of ambient heat-in-leak on the performance of a three fluid heat exchanger, for cryogenic applications, using finite element method, Int. J. Heat Mass Transfer 55 (2012) 5459–5470.
[28] V. Krishna, S. Spoorthi, P.G. Hegde, K.N. Seetharamu, Effect of longitudinal wall conduction on the performance of a three-fluid cryogenic heat exchanger with three thermal communications, Int. J. Heat Mass Transfer 62 (2013) 567–577.
[29] N. Saeid, K. Seetharamu, Finite element analysis for co-current and countercurrent parallel flow three-fluid heat exchanger, Int. J. Numer. Methods Heat Fluid Flow 16 (2006) 324–337.
[30] Kavadiki Veerabhadrappa, K.N. Gulabal Vinayakaraddy, Pradeep G. Seetharamu, V. Krishna Hegde, Transient behavior of three-fluid heat exchanger with three thermal communications under step change in inlet temperature of fluids using finite element method, Appl. Therm. Eng. 108 (2016) 1390–1400.

Please cite this article as: P. C. Mukesh Kumar and V. Hariprasath, A review on triple tube heat exchangers, Materials Today: Proceedings, https://doi.org/10.1016/j.matpr.2019.06.719