PERFORMANCE ANALYSIS OF CONICAL SHELL-CYLINDRICAL TUBE HEAT EXCHANGER

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Abstract:

In this paper, numerical analysis of conical shell (Continuous decreasing annulus space) heat exchanger has been made considering different Nusselt number correlations for annulus flow. The inner tube is considered cylindrical and the outer shell has three shapes as cylindrical with diameter ratio 1, conical with a diameter ratio of 0.882 and conical with a diameter ratio of 0.765. Water flows through the inner pipe at a constant flow rate of 10 LPM whereas the flow rate of water in outer shell varies from 10 LPM to 20 LPM. Heat transfer coefficients for inner flow and outer flow have been calculated considering different Nusselt number correlations. The calculation has done for overall heat transfer coefficients for all cases and results of conical shapes compared with a cylindrical shape. Results reveal that overall heat transfer coefficient increases up to 11 % in a conical shell having a diameter ratio of 0.882 and 26 % in a conical shell having a diameter ratio of 0.765.

Introduction:

The heat exchanger is an equipment which transfers the energy from a hot fluid to a cold fluid in many domestic and industrial applications like heating and cooling of water, heating and cooling of milk and other products in dairy industries, thermal processes involved in chemical industries and pharmaceutical industries, heating of water in concentrated solar collector etc. Heat transfer enhancement techniques are used to increase the heat transfer rate with minimum investment and running cost.

Heat transfer improvement methods usually reduce thermal resistance either by enhancing the effective heat transfer surface area or by generating turbulence. Rough surfaces/extended surfaces are used to increase effective surface area whereas inserts, winglets, turbulators,etc. are used for generating turbulence.

Many researchers studied the effect of different shapes on the inner and outer side heat transfer of double tube heat exchanger. Agrawal and Sengupta[1] used an inner tube with periodic enhancements instead of a simple cylindrical tube. Heat transfer characteristics obtained for different flow and geometric conditions. They compared results of the unenhanced tube and periodic enhanced tube and found heat transfer in a tube with periodic enhancement was 8 times more than that for the simple tube annulus. Maakoul et al. [2] investigated thermo-hydraulic performance with helical baffles in annulus side. They numerically studied the effect of baffle spacing and Reynolds number on heat transfer characteristics by using FLUENT. They concluded from the results, that helically baffled heat exchanger has a higher heat transfer rate and high-pressure drop compared to the simple heat exchanger. They also developed empirical correlations based on curve fitting. Louw and Meyer [3] studied helically wound tube-tube heat exchanger. Heat exchanger manufactured by placing one tube inside the other. In this case, tubes having no same centerline hence annulus contact occur. They compared the heat transfer coefficient of concentrated and contacted type heat exchanger and observed that the performance was improved where annulus contact occurs. Gonzalez et al. [4] have studied the effect of spiral wires on annulus side heat transfer. They inserted spiral wires on the annulus side of concentric tube heat exchanger. They used spiral wires with different wire diameter and constant pitch. Results concluded that spiral wire increased heat transfer rate at the cost of higher pressure drop. Laohalestdecha and Wongwises [5] investigated the heat transfer coefficient and pressure drop inside a smooth tube and corrugated tube. The corrugation pitches were 5.08, 6.35 and 8.46 mm and depth was fixed at 1.5 mm. They found that corrugation pitches improve heat transfer coefficient and pressure drop simultaneously.

Vaezi et al. [6] have numerically analyzed the effect of aspect ratio in alternating oval double tube heat exchanger. Results revealed that in all aspect ratios, heat transfer rate is higher than the circular pipe. Hashemian et al. [7] employed a conical tube instead of a circular tube as an inner tube of concentric tube heat exchanger. They investigated the effect of the various arrangement of a conical tube with different flow directions. Results revealed that the effectiveness and heat transfer improvement number 55% and 40 % respectively at the optimum condition. Hashemian et al. [8] numerically analyzed conical tube heat exchanger and concluded that modified geometry makes 63 % increment in Nu number and 54 % improvement in heat transfer rate.

In this paper, numerical analysis of conical shell (Continuous decreasing annulus space) heat exchanger has been made considering different Nusselt number correlations [1-10] for annulus flow. These correlations are applicable for the turbulent flow region. All proposed correlations for the Nusselt number are functions of the Reynolds number, the Prandtl number and the annular diameter ratio, a.

Analytical Approach:

In the present paper, following assumptions, parameters and properties were considered for the analysis.

Assumptions

- Steady-state operation
- The properties of the fluids and the heat exchanger wall remains constant
- The heat exchanger is operating adiabatically.
- The heat exchanger to be well insulated
- Fluid is incompressible
- Viscous dissipation is negligible.

Properties:

Property	Value	Unit
Viscosity of Water	0.000549	Ns/m^2
Thermal conductivity of Water	0.6	W/mK
Density of Water	1000	Kg/m^3
Prandtl Number	3.56	

Parameters:

Inner side water flow rate (LPM)	10
Annulus side water flow rate (LPM)	10-20
Inner pipe inside diameter (mm)	35
Inner pipe outside diameter (mm)	38
Outer pipe inner diameter (case - 1)	85-85 (Cylindrical) (diameter ratio – 1)
Outer pipe inner diameter (case - 2)	85-75 (Conical with diameter ratio - 0.882)
Outer pipe inner diameter (case - 3)	85-65 (Conical with diameter ratio- 0.765)
Length of pipe (m)	1

Calculations:

Heat transfer coefficient in the inner pipe:

Water is flowing from the inner pipe at a constant flow rate of 10 LPM. The heat transfer coefficient for inner tube calculated by considering Dittus–Boelter correlation of Nusselt Number

$Nu = 0.023\ Re^{0.8} Pr^{0.4}$ [16]

From Dittus-Boelter correlation, properties of water and parameters considered for the inner tube,the value of heat transfer coefficient obtained is

$h_i = 645.94\ W/m^2K$

Heat transfer coefficient in the outer pipe:

The outer shell has three different shapes 1) cylindrical tube having a constant diameter of 85 mm (85-85), 2) conical tube having diameter changes from 85 mm to 75 mm (85-75), 3) conical tube having diameter changes from 85 mm to 65 mm (85-65). The assumption made that water enters from the larger diameter side in a conical tube.

The diameter ratio represents the outlet side diameter of the outer tube to the inlet side diameter of the outer tube. The diameter ratio of above mentioned three cases are 1, 0.882 and 0.765 respectively.

Water flows at the rate of 10, 12, 14, 16, 18 and 20 LPM in the outer annulus for all three cases. Following correlations have been considered for calculation of heat transfer coefficient in annulus side.

Dittus–Boelter correlation: $Nu = 0.023\ Re^{0.8} Pr^{n}$ [16]

Mc Adams correlation: $Nu = 0.023\ Re^{0.8} Pr^{1/3} \left(\frac{\mu}{\mu_w}\right)^{0.14}$ [10]

Davis correlation: $Nu = 0.038\ a^{0.15}(a-1)^{0.2} Re^{0.8} Pr^{1/3} \left(\frac{\mu}{\mu_w}\right)^{0.14}$ [9]

McAdams correlation: $Nu = 0.03105\ a^{0.15}(a-1)^{0.2} Re^{0.8} Pr^{1/3} \left(\frac{\mu}{\mu_w}\right)^{0.14}$ [10]

Foust & Christian correlation: $Nu = \frac{0.04a}{(a+1)^{0.2}} Re^{0.8} Pr^{0.4}$ [11]

Monrad & Pelton correlation: $Nu = 0.023\left(\frac{2\ln a - a^2 + 1}{a - \frac{1}{a} - 2a\ln a}\right) Re^{0.8} Pr^{n}$ [12]

Wiegand et al. correlation: $Nu = 0.023\, a^{0.45} Re^{0.8} Pr^{n} \left(\frac{\mu}{\mu_w}\right)^{0.14}$ [13]

Potukhov & Roizen correlation: $Nu = \frac{0.06759\, a^{0.16}}{(a+1)^{0.2}} Re^{0.8} \xi$ [15]

$$\xi = 1 \; for \; a \leq 5$$

Stain & Begell correlation: $Nu = 0.02\, a^{0.5} Re^{0.8} Pr^{1/3}$ [17]

Crookston et al. correlation: $Nu = 0.023\, a^{1/4} Re^{3/4} Pr^{1/3}$ [18]

Heat transfer coefficient remains constant in a cylindrical annulus whereas in conical shape annulus varies with the diameter as mentioned in equation [20] of heat transfer coefficient of the annulus

$$h_o = \frac{Nu}{(d_o - d_i)}\; k$$

In the conical tube, diameter decrease along the length which leads to increase in velocity and ultimately Reynolds number. So in the conical annulus, Reynolds number varies along the length which varies local heat transfer coefficient as shown in figure 1.

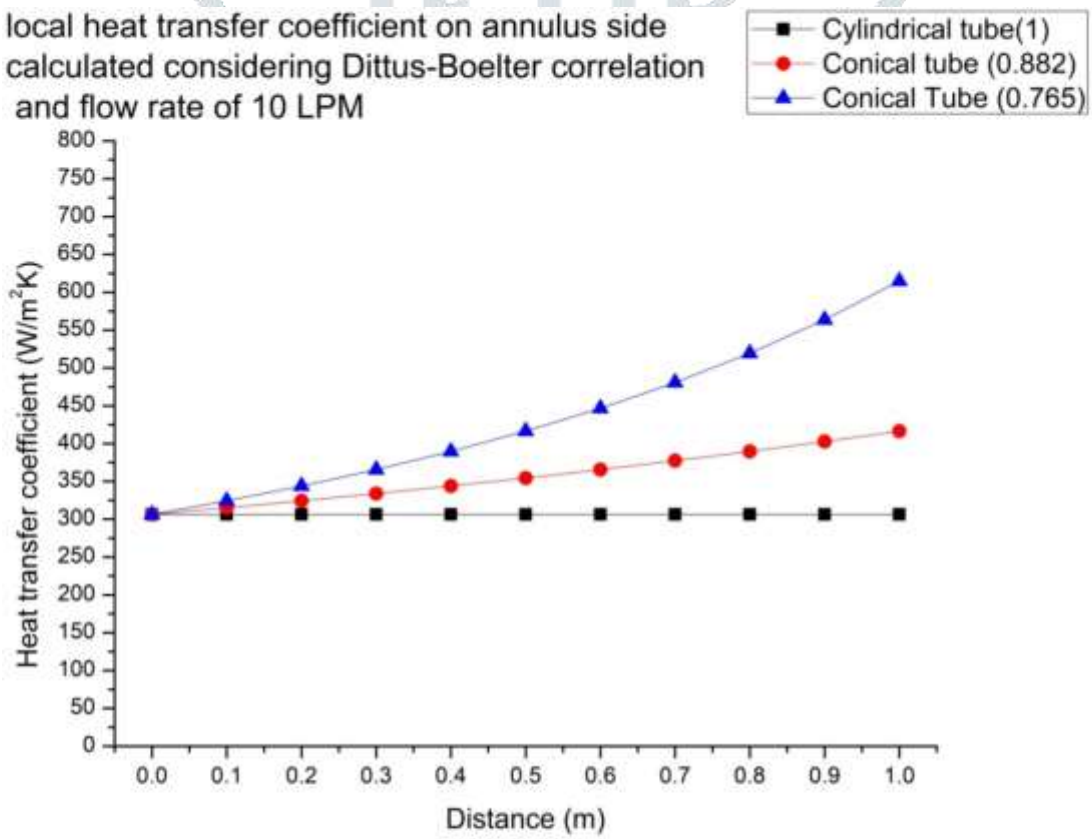
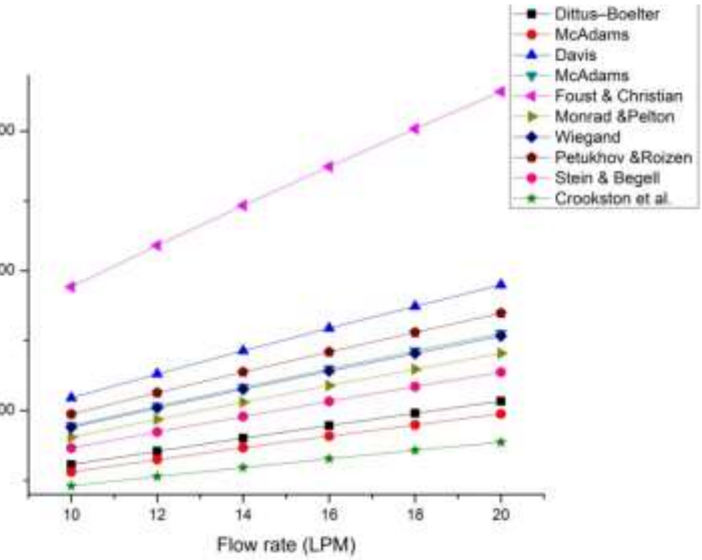


Figure 1 variation of the local heat transfer coefficient along the length

Heat transfer coefficient on annulus side calculated by using Nusselt number correlations [9-18]. Average heat transfer coefficients for cylindrical annulus (diameter ratio 1), conical annulus with a diameter ratio of 0.882 and conical annulus with a diameter ratio of 0.765 are as shown in Fig 2, 3 and 4 respectively.



e 2 Average heat transfer coefficient on annulus side for drical annulus

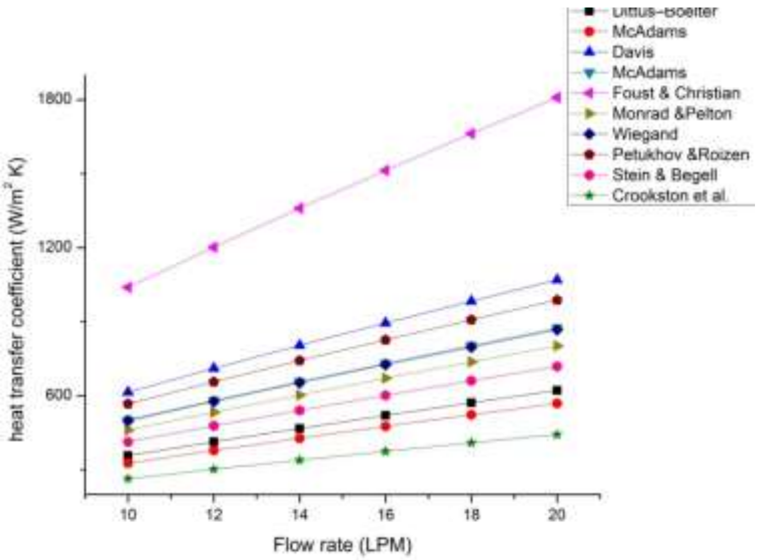


Figure 3 Average heat transfer coefficient on annulus side for conical annulus (diameter ratio 0.882)

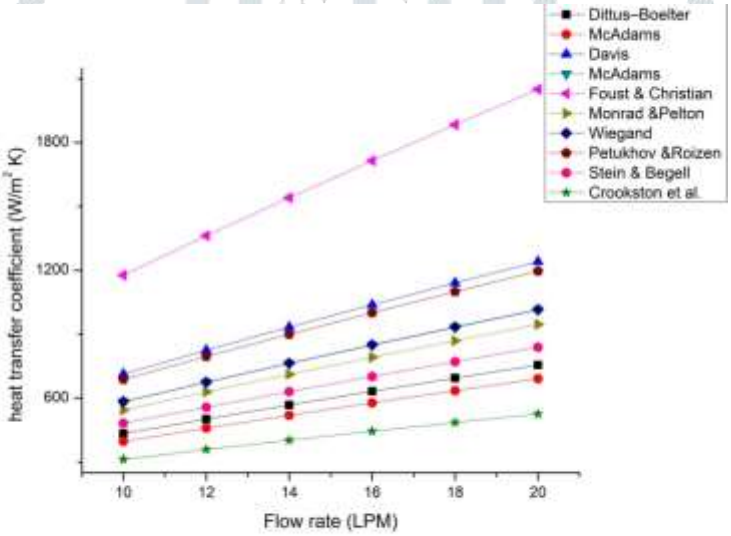


Figure 4 Average heat transfer coefficient on annulus side for conical annulus (diameter ratio of 0.765)

Overall heat transfer coefficient:

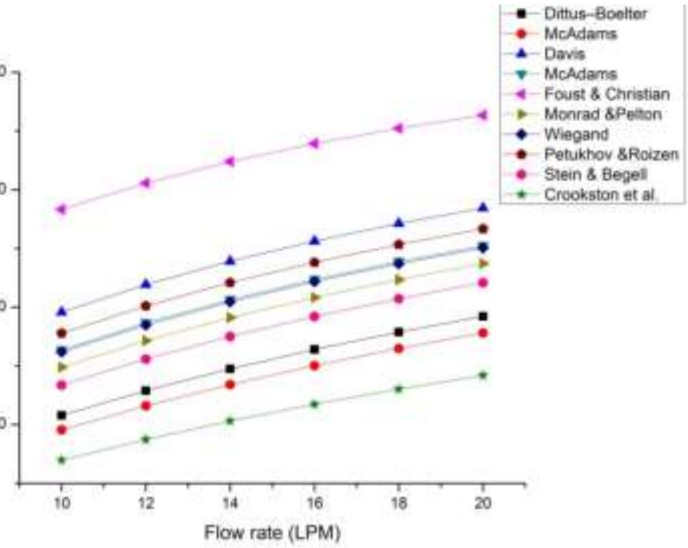
Overall heat transfer coefficient calculated by using the following equation [11] assuming negligible thermal resistance due to conduction.

$$\frac{1}{U} = \frac{1}{h_i} + \frac{1}{h_o}$$

Result and Discussion:

Overall heat transfer coefficients have been calculated considering different correlations with a flow rate ranging from 10 LPM to 20 LPM for cylindrical and two conical annulus.

Overall heat transfer coefficients for cylindrical annulus (diameter ratio 1), conical annulus with a diameter ratio of 0.882 and conical annulus with a diameter ratio of 0.765 are as shown in Figure 5, 6 and 7 respectively.



e 5 Overall heat transfer coefficient on the annulus side for drical annulus

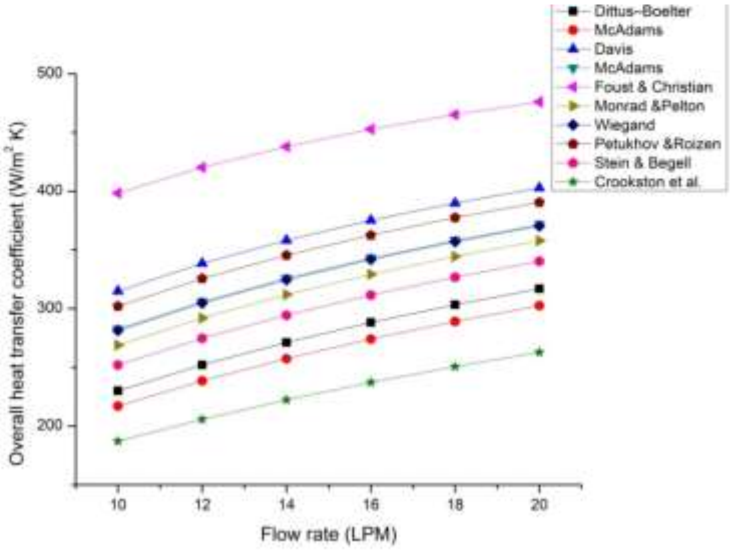


Figure 6 Overall heat transfer coefficient on annulus side for conical annulus (diameter ratio 0.882)

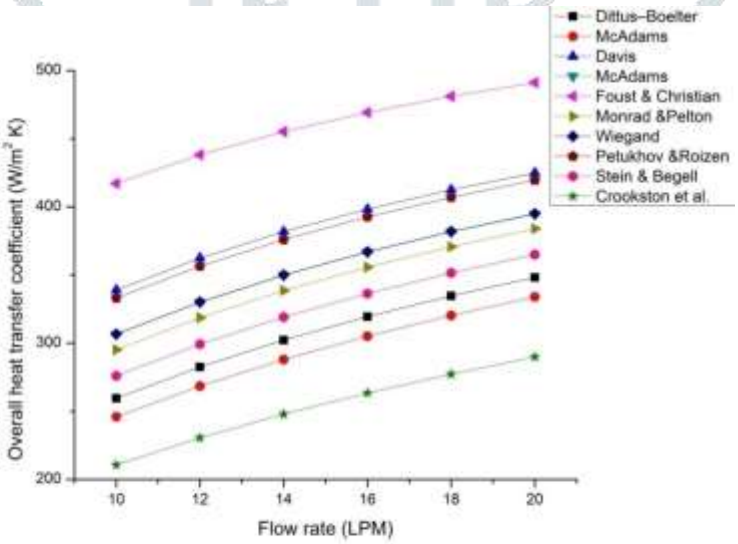


Figure 7Overall heat transfer coefficient on annulus side for conical annulus (diameter ratio 0.765)

Rise in overall heat transfer coefficient with diameter ratio for different flow rate 10-20 LPM are represented by Figure 8-13.

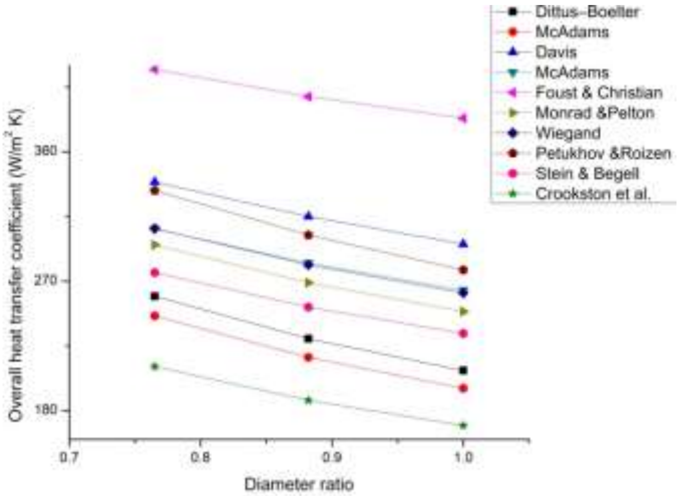


Figure 8 Overall heat transfer coefficient Vs. diameter ratio (10 LPM)

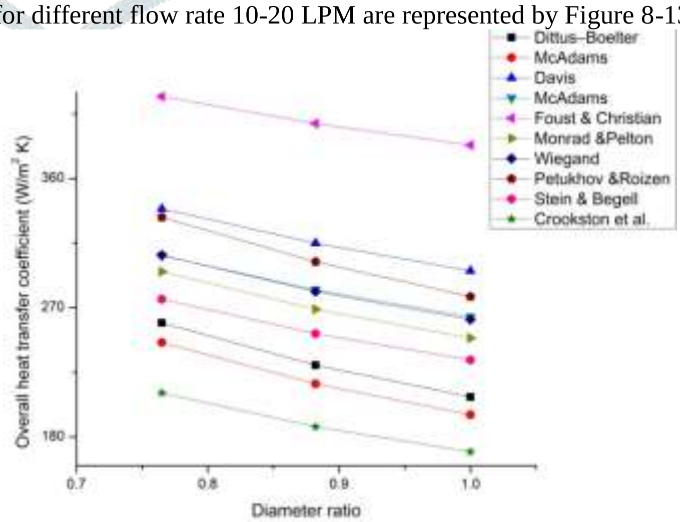


Figure 9 Overall heat transfer coefficient Vs. diameter ratio (12 LPM)

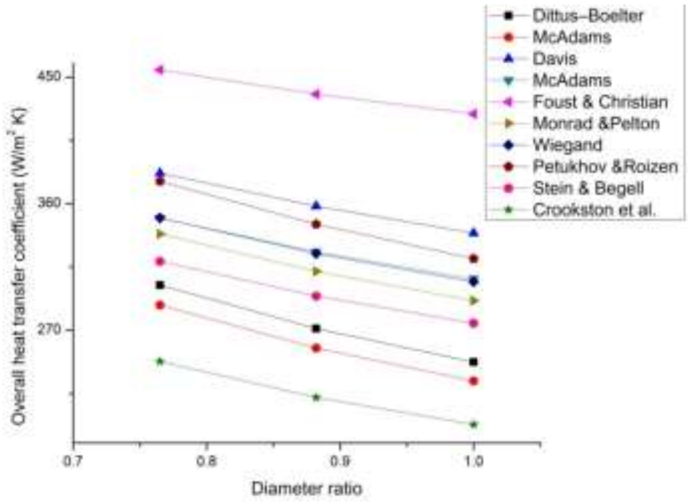


Figure 10 Overall heat transfer coefficient Vs diameter ratio (14 LPM)

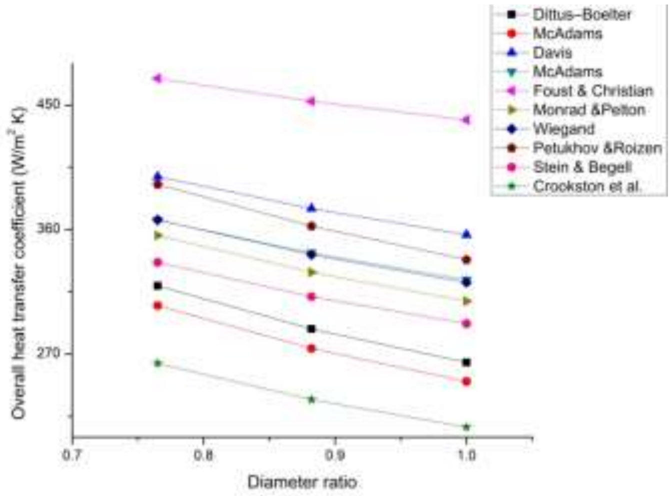


Figure 11 Overall heat transfer coefficient Vs diameter ratio (16 LPM)

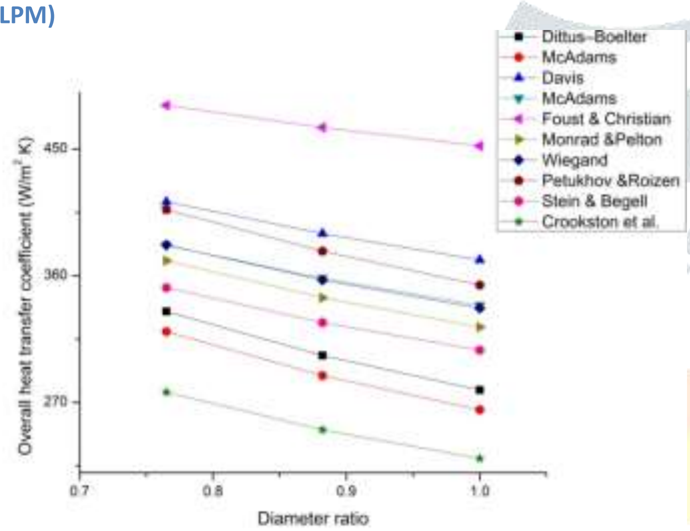


Figure 12 Overall heat transfer coefficient Vs. diameter ratio (18 LPM)

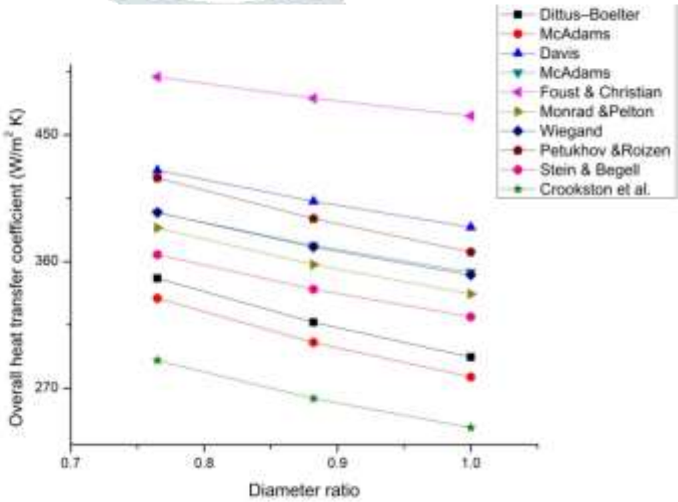
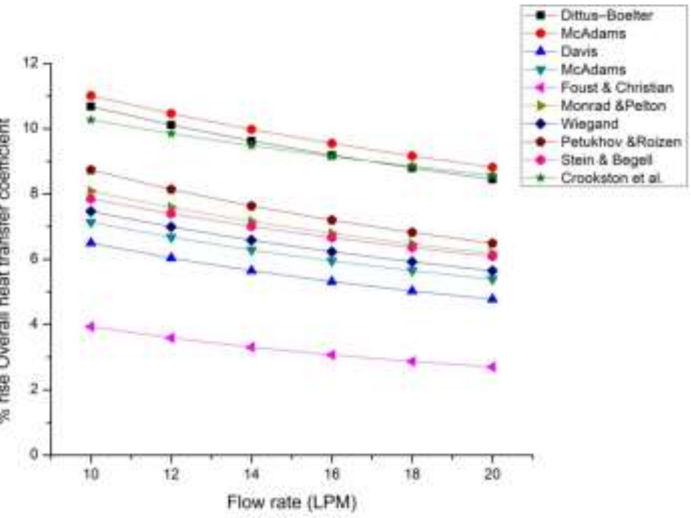


Figure 13 Overall heat transfer coefficient Vs. diameter ratio (20 LPM)

The observation made from the results presented in Fig 8-13 that overall heat transfer coefficient increases with a decrease in diameter ratio. For the cases with conical annulus, the overall heat transfer coefficient was found to increase compare to the values obtained for the cylindrical annulus. Overall heat transfer coefficient increases up to 11 % in a conical tube with diameter ratio 0.882 compared to cylindrical tube and up to 26 % in a conical tube with diameter ratio 0.765 compared to the cylindrical tube (Fig. 14 & 15). The increase in overall heat transfer coefficient in conical annulus compared to cylindrical annulus for same flow rate was due to higher turbulence in conical annulus. Higher turbulence is a result of higher velocity due to reduction in annulus space in conical shape.

Foust & Christian's correlation represents fewer rises in overall heat transfer coefficient in conical shape whereas McAdams' correlation shows a high rise in the overall heat transfer coefficient. Results represent that Weigand and McAdams's results are coinciding.

Results revealed that the % rise in overall heat transfer coefficient decreases with flow rate (Fig. 14 & 15). The overall heat transfer coefficient increased by 4-11 % for 10 LPM flow rate in conical heat exchanger with diameter ratio 0.882 and reduced to 3-9 % for 20 LPM flow rate. Same as it is increased by 9-26 % for 10 LPM flow rate in conical heat exchanger with diameter ratio 0.765 and reduced to 6-22 % for 20 LPM flow rate. It represents effect of conical shape is higher for lower flow rate.



gure 14 % rise in overall heat transfer coefficient Vs flow rate
iameter ratio 0.882)

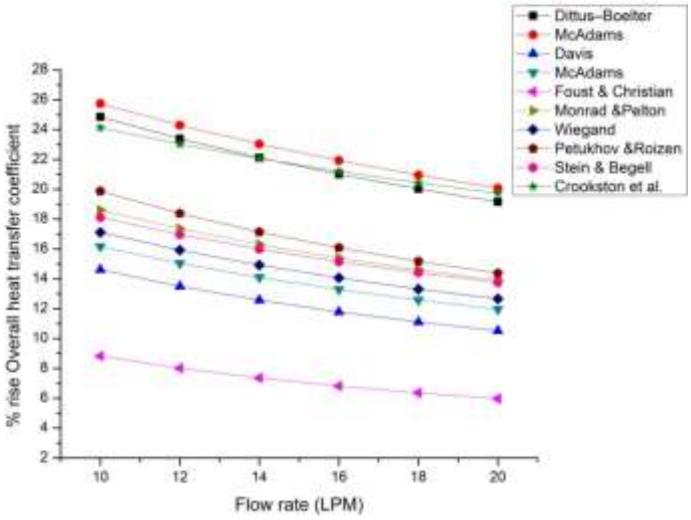


Figure 15 % rise in overall heat transfer coefficient Vs flow rate (diameter ratio 0.765)

Conclusion:

From the present study following conclusions have been made:

- The overall heat transfer coefficient increases with the increase in flow rate
- The overall heat transfer coefficient increase with a decrease in diameter ratio
- Overall heat transfer coefficient increases up to 11 % in a conical tube with a diameter ratio of 0.882 compared to cylindrical tube
- Overall heat transfer coefficient increases up to 26 % in a conical tube with a diameter ratio of 0.765 compared to cylindrical tube
- % rise in overall heat transfer coefficient inversely proportional to flow rate which represents effect of conical shape is higher on heat transfer coefficient for lower flow rate
- Foust & Christian's correlation represents fewer rises in overall heat transfer coefficient in a conical shape and McAdams' correlation shows a high rise in the overall heat transfer coefficient. Weigand and McAdams's results are coincide

Nomenclature:

a = Ratio of the inner diameter of the outer tube to the outer diameter of the inner tube
Nu = Nusselt number
Re = Reynold number
Pr = Prandtl number
h_i= Heat transfer coefficient for the inner tube
μ = Dynamic viscosity
μ_w= Dynamic viscosity at the wall surface
h_o= Heat transfer coefficient for an outer rube
d_o= Inner diameter of the outer tube
d_i= Outer diameter of the inner tube
k = Thermal conductivity of the fluid
U = Overall heat transfer coefficient

References:

[1] A. K. & S. S. Agrawal, "Laminar fluid flow and heat transfer in an annulus with an externally enhanced inner tube," *Int. J. Heat Fluid Flow*, vol. 14, no. 1, pp. 54–63, 1993.

[2] A. El Maakoul, A. Laknizi, S. Saadeddine, A. Ben Abdellah, M. Meziane, and M. El Metoui, "Numerical design and investigation of heat transfer enhancement and performance for an annulus with continuous helical baffles in a double-pipe heat exchanger," *Energy Convers. Manag.*, vol. 133, pp. 76–86, 2017.

[3] W. I. Louw and J. P. Meyer, "Heat transfer during annular tube contact in a helically coiled tube-in-tube heat exchanger," *Heat Transf. Eng.*, vol. 26, no. 6, pp. 16–21, 2005.

[4] J. I. Gonzalez, O. G. Valladares, and R. G. Gordin, "Experimental Study of Heat Transfer Enhancement for Fluid Flow Inside Annulus with Spiral Wires," *Heat Transf. Eng.*, vol. 39, no. 1, pp. 15–26, Jan. 2018.

[5] S. Laohalertdecha and S. Wongwises, "The effects of corrugation pitch on the condensation heat transfer coefficient and pressure drop of R-134a inside horizontal corrugated tube," *Int. J. Heat Mass Transf.*, vol. 53, no. 13–14, pp. 2924–2931, 2010.

[6] S. Vaezi, S. Karbalaee M., and P. Hanafizadeh, “Effect of aspect ratio on heat transfer enhancement in alternating oval double pipe heat exchangers,” *Appl. Therm. Eng.*, vol. 125, pp. 1164–1172, 2017.
[7] M. Hashemian, S. Jafarmadar, and H. Sadighi Dizaji, “A comprehensive numerical study on multi-criteria design analyses in a novel form (conical) of double pipe heat exchanger,” *Appl. Therm. Eng.*, vol. 102, pp. 1228–1237, 2016.
[8] M. Hashemian, S. Jafarmadar, J. Nasiri, and H. Sadighi Dizaji, “Enhancement of heat transfer rate with structural modification of double pipe heat exchanger by changing cylindrical form of tubes into conical form,” *Appl. Therm. Eng.*, vol. 118, pp. 408–417, 2017.
[9] Davis, E. S., Heat Transfer and Pressure Drop in Annuli, *Transactions of ASME*, pp. 755–760, October, 1943.
[10] McAdams, W. H., *Heat Transmissions*, 3rd ed., New York, pp. 241–244, 1954.
[11] Foust, A. S., and Christian, G. A., Non-Boiling Heat Transfer Co-Efficients in Annuli, *American Institute of Chemical Engineers*, vol. 36, pp. 541–554, 1940.
[12] Monrad, C. C., and Pelton, J. F., Heat Transfer by Convection in Annular Spaces, *American Institute of Chemical Engineers*, vol. 38, pp. 593–611, 1942.
[13] Wiegand, J. H., McMillen, E. L., and Larson R. E., Annular Heat Transfer Coefficients for Turbulent Flow., *American Institute of Chemical Engineers*, vol. 41, pp. 147–153, 1945.
[14] Kays, W. M., and Leung, E. Y., Heat Transfer in Annular Passages—Hydrodynamically Developed Turbulent Flow with Arbitrarily Prescribed Heat Flux.,*International. Journal of Heat and Mass Transfer*, vol. 6, pp. 537–557, 1963.
[15] Petukhov, B. S., and Roizen, L. I., Generalized Relationships for Heat Transfer in Turbulent Flow of Gas in Tubes of Annular Section, *High Temp.*, vol. 2, pp. 65–68, 1964.
[16] Dittus, F.W., and Boelter, L.M. K., *Publications on Engineering*, vol. 2, pp. 443, 1930.
[17] Stein, R. P., and Begell, W., Heat Transfer to Water in Turbulent Flow in Internally Heated Annuli. *American Institute of Chemical Engineers Journal*, vol. 4, no. 2, pp. 127–131, June 1958.
[18] Crookston, R. B., Rothfus, R. R., and Kermode R. I., Turbulent Heat Transfer with Annuli with Small Cores, *International Journal of Heat and Mass Transfer*, vol. 11, pp. 415–426, 1968.
[19] Sadik Kaka, *Heat Exchangers*, 3rd ed., Boca Raton, pp. 37–39, 2012.
[20] Dirker,J. and Meyer J.P., Convective Heat Transfer Coefficients in Concentric Annuli, *Heat Transfer Engineering*, vol. 26, no. 2, pp. 38–44, 2005.