Comparative Study between Curved and Straight Pipe Heat Exchanger Using Solid Works

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Abstract

This work focuses on an increase in the effectiveness for straight double pipe heat exchanger through curving the pipe through 180^{o}. The geometry, mesh and boundary conditions are built up using solid works program. The proposed model of the curved pipe heat exchanger is subjected to different boundary conditions, according to inlet tube mass flow rate and inlet shell temperature. The simulated results confirmed that the effectiveness of the curved pipe heat exchanger is higher than straight pipe heat exchanger because the curvature of the pipe gives a longer time to exchange heat between hot and cold fluids. For fixed inlet tube mass flow rate and inlet shell temperature, the increase in the effectiveness of curved pipe is 14.86% compared to straight pipe at 357 K. The maximum effectiveness reached 13.75% at 363 K for curved heat exchanger with 0.22 kg/s inlet tube mass flow rate and fixed inlet shell temperature while it was 12.15% at 363 K for the straight pipe heat exchanger.

Keywords: Curved pipe heat exchanger, Effectiveness, Solid works proram

الخلاصة

هذا البحث يركزعلى زيادة فعالية مبادل حراري مزدوج مستقيم الشكل عن طريق حني الانبوب بزاوية 180^{0}. تم استخدام برنامج Solid works لرسم وبناء الشكل. تعرض نموذج المبادل الحراري المقترح دراسته على ظروف تشغيل مختلفه مشتمله على درجة حرارة الانبوب الداخلي ومعدل جريان المائع بالاضافه الى درجة الحراره الداخلة للقشرة. لقد اظهرت نتائج النمذجة ان كفاءة المبادل الحراري ذو الانبوب المنحني اعلى من كفاءة المبادل الحراري المستقيم وذلك لان الانحناء في الانبوب تعطي وقت اطول للتبادل الحراري بين السائل الحار والبارد. عند ثبوت معدل جريان المائع ودرجه حراره الدخول للقشره لوحظت زياده في كفاءة المبادل الحراري المنحني بنسبة 14.86% بالمقارنه مع المبادل الحراري المستقيم عند درجه حرارة 357 كلفن.لقد وصلت اعظم كفاءة الى 13.75%عند 363 كلفن للمبادل الحراري المنحني عند معدل جريان 0.22 كغم/ثا ودرجه حرارة ثابته للقشره في حين كانت بنسبة 12.15% عند 363 كلفن بالنسبه للمبادل الحراري المزدوج ذو الانبوب المستقيم.

الكلمات المفتاحية:- المبادل الحراري منحني الانبوب،الفعالية، برنامج Solid works,

Nomenclature

Symbol	Definition
G	Gravitational component of acceleration
h	Thermal enthalpy
Q_H	Heat source /sink per volume heat flux
S_i	Distributed external force per unit mass
U	Velocity of fluid
ρ	Density of fluid
ε	Effectiveness

1. Introduction

Heat exchangers are equipments that are usually utilized to exchange heat between two working fluids at various temperatures. Such important components are classified into different grades in engineering applications. The bulky industries, such as chemical, power,and automotive, passing by the highly technique ones such as electronics as well as the production of refrigeration and air conditioning systems, etc. In the recent years, massive research efforts have been investigated to boost the performance of heat exchangers (Nawras *et.al.*, 2012 ; Usman, 2011). The aim of heat transfer improvement catches the aspects of size, cost and enhance the heat duty for a given size heat exchanger.

Several different techniques have been suggested to enhance heat transfer surfaces for the following purposes (Brien *et.al.,* 1982 ; Wang *et.al.,* 1995 ; Chinna *et.al.,* 2014):

(1) Reducing the overall volume by making campact heat exchangers.
(2) Power consumption which must be minimized for a certain heat transfer process.
(3) Boosting the heat transfer coefficient which can be done either by increasing the rate of heat transfer with constant inlet fluid temperature or increasing the efficiency of thermodynamic processes by reducing the mean temperature difference, hence the operating costs is saved.

Some of the available literature works has been mentinoned below;

(Adelaja *et.al.,* 2012) investigated the mechanical and thermal design of shell and tube heat exchanger with the help of computer coding. It includes developing a simple code for the heat transfer calculations and ensures that ensure that time of computational is minimized. The algorithm is designed in such a way that after the satisfaction of the thermal analysis, the program proceeds to the mechanical design automatically. The pressure drop as well as the heat transfer coefficient is well evaluated

(Yusuf *et.al.,* 2004) designed a computer model of shell and tube heat exchangers with the single phase flow. The program calculates the overall dimensions of the shell and optimum surface area required to catch the specified heat transfer work by calculating the pressure drop in the shell side. The study suggests putting the stream with a fewer mass flow rate on the shell side.

(Noie B. *et.al.,* 1999) studied theoretical and experimental methods to analysis the thermal behavior of the shell-side flow of a heat exchanger. The effect of various geometric parameters and Reynolds number on the thermal exchange of energy in the flow of shell-side. The results reported alternative variation in the heat profiles between the baffles.

(Vindhya *et.al.,* 2014) achieved a simplified design of shell and tube type heat exchanger using kern's method to cool down the water temperature from 55 C to 45 C. The design is verified with a thermal analysis of steady flow using ANSYS 14.

(Joshi et.al., 1987) developed a model to study the coefficient of heat transfer as well as the friction factor of the fin surface geometry. Visualization experiments are conducted to analyze the transition of flow from laminar to turbulent.

(Saidi *et.al.,* 2001) investigated a computational study of the instantaneous flow and heat transfer in Offset-Strip Fin (OSF) geometries in oscillatory flow. The impact of vortices over the fin surfaces on the heat transfer was analysed at different Reynolds numbers where the flow is laminar, where the vortex shedding and unsteadiness are dominating The results are validated with previous work available in the open literature conducted by (Dejong *et.al.,* 1998).

(Michna *et.al.,* 2005) conducted an experiment to investigate the impact of increasing Reynolds number on the OSFs performance. It is observed that increasing Reynolds number, pressure drop and heat transfer are enhanced, due to the effect of eddy formation as well as vortex shedding and within the turbulent regime. The operation of OSF heat exchangers under higher Reynolds number is useful in systems where minimizing the size of heat exchanger or maximizing the coefficient of heat transfer is important than minimizing the pressure drop.

In this paper a model has been made to enhance the effectiveness of straight, double pipe heat exchanger by using curving technique. The model is built and solved using Soildworks. The pipe is curved with 180 degrees. Water is considered to be the working fluid in the cold and hot pipes with a constant specific heat. The parallel flow is considered to be steady, uniform and phase change doesn't occur.

2. Mathematical Background

The conservation equations of mass, angular momentum, and energy govern the flow of the fluid in the straight and curved pipes. It can be written as follows (Mario , 2015):

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_i}(\rho u_i) = 0 \qquad (1)$$

$$\frac{\partial \rho u_i}{\partial t} + \frac{\partial}{\partial x_j}(\rho u_i u_j) + \frac{\partial p}{\partial x_i} = \frac{\partial}{\partial x_j}(\tau_{ij} + \tau_{ij}^R) + S_i i = 1,2,3 \qquad (2)$$

$$\frac{\partial \rho H}{\partial t} + \frac{\partial \rho u_i H}{\partial x_i} = \frac{\partial}{\partial xi}\left(u_j(\tau_{ij} + \tau_{ij}^R) + q_i\right) + \frac{\partial p}{\partial t} - \tau_{ij}^R \frac{\partial u_i}{\partial x_j} + \rho\varepsilon + S_i u_i + Q_H \qquad (3)$$

$$H = h + \frac{u^2}{2} \qquad (4)$$

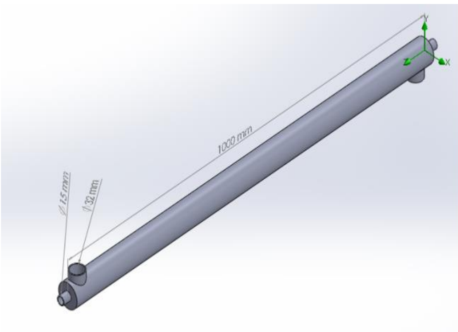
$$\varepsilon = \frac{T_{\max in} - T_{\max out}}{T_{\max in} - T_{m\,in}} \qquad (5)$$

3. CFD Analysis

The CFD Analysis applies various numerical schemes in addition to algorithms to solve and analyze problems that include fluid flow. The surface of interaction with fluid, has to be simulated by applying the initial and boundary conditions which are done using Solid works (Mario , 2015)

3.1 Geometry

The straight and curved pipes are built in the Solidworks workbench design module. Figure 1 and 2 display the geometry and dimensions of straight and proposed (curved) heat exchanger respectively.



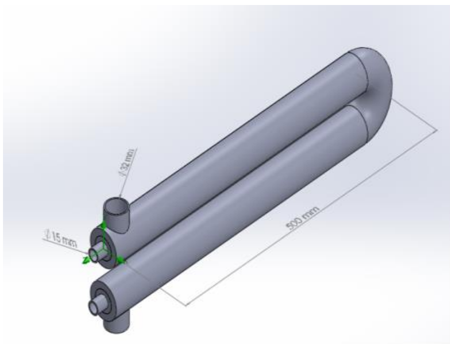


Figure 1 geometry of straight, double pipe **Figure 2 geometry of bend double pipe**

3.2 Mesh Generation

The mesh in the simulation of flow has a rectangular section any wherein the domain. The sides of mesh cells have met the system of Cartesian coordinate orthogonally. Nevertheless, because of special measures, the heat flux as well as mass is treated in a proper way in such cells and called partial. The right view mesh for the straight and bend heat exchangers are shown in figures 3 and 4 respectively. The detailed computational mesh for both pipes are described in Table (1)

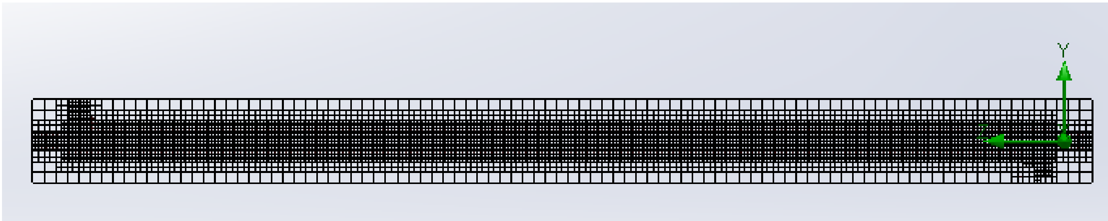


Figure 3 Right view of straight pipe mesh

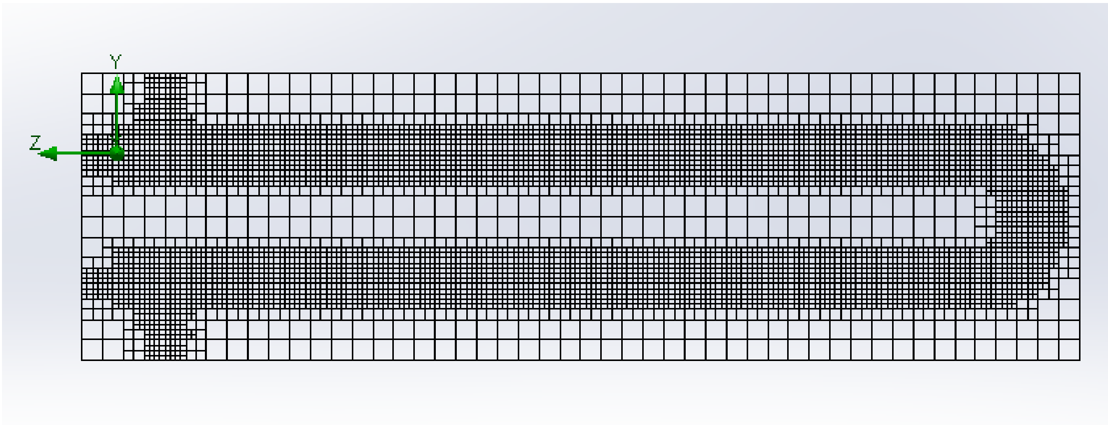


Figure 4 Right view of curved pipe mesh

Table (1) Number of cells in the computational mesh

Type of heat exchanger	No of Fluid cells	No. of solid cells	No. of partial cells
Straight pipe	14525	13418	33833
Curved pipe	11330	13459	31960

3.3Boundary Conditions

The boundary conditions depend on the model requirements. Table (2) presents the boundary conditions used in this work

Table (2) Model Boundary Conditions

Boundary condition **Case1**	Straight pipe (tube)	Straight pipe (shell)	Curved pipe (tube)	Curved pipe (shell)
Inlet mass flow rate	0.2 kg/s	0.8 kg/s	0.2 kg/s	0.8 kg/s
Inlet temperature	343 K-361 K	283 K	343-361 K	283 K
Inlet Pressure	101325 pa	101325 pa	101325 pa	101325 pa
Exit Pressure	101325 pa	101325 pa	101325 pa	101325 pa
Boundary condition **Case2**				
Inlet mass flow rate	0.22 kg/s	0.8 kg/s	0.2 kg/s	0.8 kg/s

Inlet temperature	343 K-365 K	283 K	343-361 K	283 K
Inlet Pressure	101325 pa	101325 pa	101325 pa	101325 pa
Exit Pressure	101325 pa	101325 pa	101325 pa	101325 pa
Boundary condition Case3				
Inlet mass flow rate	0.2 kg/s	0.8 kg/s	0.2 kg/s	0.8 kg/s
Inlet temperature	343 K-361 K	293 K	343-361 K	293 K
Inlet Pressure	101325 pa	101325 pa	101325 pa	101325 pa
Exit Pressure	101325 pa	101325 pa	101325 pa	101325 pa

4. Results and Discussion

After checking the mesh quality and applying the boundary conditions, then the solution is started with a nice convergence after (4212) iteration. Some of the various contours, vectors and x-y plot of the straight and curved pipe are presented in this section. Many cases are tested in the software, but only three cases are chosen and discussed over here as in theses cases a dramatic change is observed in the effectiveness of the heat exchanger pipes.

Case 1 represents fixed inlet shell temperature (283 K) and fixed mass flow rate of tube (0.22 kg/s). The inlet shell mass flow rate is kept constant through all cases under investigation (0.8 kg/s). Figure 5 and 6 display the contours of tube temperatures for straight and curved pipe heat exchanger respectively. The hot tube temperature enters with 343K and exits with 336 K in case of straight pipe while it exists with 331 K in case of curved pipe. It can be observed that through curving the pipe the hot water tube gets a better cooling than straight pipe, as the hot tube fluid takes a longer time because of curvature to cool compared to the straight pipe heat exchanger.

Case 2 can be noted in figures 7 and 8, which represents a 10% increase in the flow rate of hot tube (0.22 kg/s) and constant shell tube temperature (283 K). Even the flow rate of the inner tube is increased, but the results reported an enhancement in the effectiveness of the curved pipe heat exchanger comparatively with ordinary straight pipe heat exchanger. Both figures show a gradual decrease in the hot tube temperature. For the original straight heat exchanger the hot tube temperature was around 340 K in the mid section of the pipe and 335 K at the outlet while it was 337 K in the mid section and 334 K at the outlet of the curved heat exchanger.

Case 3 represents the increase in the inlet shell tube temperature by 10 % (293 K). Figures 9 and 10 show the cut plot temperature contours for straight and curved heat exchanger pipes. As compared to the standard double heat exchanger pipe (straight), the curved pipe had a better reduction in the hot tub temperature due the enhanced heat transfer characteristics cause by curved the pipe which directly responsible for the boosted effectiveness, as the hot fluid will have enough time to exchange heat with the cooled fluid (shell).

The effectiveness verse inlet tube temperature for straight and curved double pipe heat exchangers are graphed and discussed in the three cases under study. Case 1 is displaced in figure 11. As the inlet tube temperature increased, the effectiveness increased for both types of heat exchangers. The curved pipe has higher effectiveness as compared to ordinary straight pipe heat exchanger. The results reported maximum effectiveness at 357 K inlet tube temperature is 14.58% for the curved pipe heat exchanger, while It was 12.68% in the case of the straight pipe heat exchanger, hence an increase in the effectiveness by 14.67% is gained while using the suggested curved pipe heat exchanger. Beyond 375 K, the effectiveness started to decrease in both types of heat exchangers. The message from this point says " the heat exchangers can work effectively up to 375K".

Figure 12 shows case 2 where additional flow rate is inducted to the inlet hot tube. The effectiveness follows the same scenario as observed in figure 11. The percentage of increase in the effectiveness of the curved pipe heat exchanger is 11.36% compared with standard double pipe heat exchanger pipe. The range of operation starts with 343 K and allowed up

to 365 K as beyond that a reduction in the effectiveness is recorded in the two types of heat exchanger under study.

The last case is presented in figure 13 where the inlet shell temperature increased from 283 K to 293 K. The maximum increase in the effectiveness was noticed at 373 K where it was 15.15% in curved heat exchanger while it was 13.75% for the original straight pipe heat exchanger.

5. Conclusions

The main conclusions from the present work are shown below:

1. Using Soildworks is an interesting tool to simulate the flow in the heat exchanger efficiently.
2. Curving the pipe of the heat exchanger by 180 degrees is a promising technique to boost the effectiveness of the heat exchanger.
3. For fixed inlet tube mass flow rate and inlet shell temperature, the increase in the effectiveness of curved pipe is 14.86% compared to straight pipe at 357 K.
4. The maximum effectiveness reached 13.75% at 363 K for curved heat exchanger with 0.22 kg/s inlet tube mass flow rate and fixed inlet shell temperature while it was 12.15% at 363 K for the straight pipe heat exchanger.
5. The maximum effectiveness reached 15.15% at 373 K for curved heat exchanger with a 10 % increase in the inlet shell temperature while it was 13.95% at 373 K for the straight pipe heat exchanger.
6. Case 3 is the best compromise case which gives better heat exchanger performance as well as larger temperature operation ranged from 343K to 373K

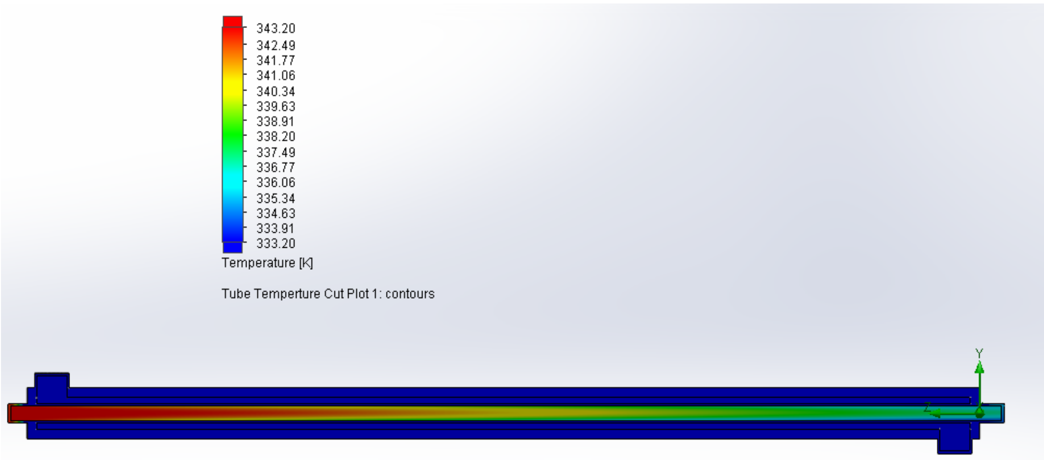


Figure 5 Straight pipe tube temperature cut plot case1

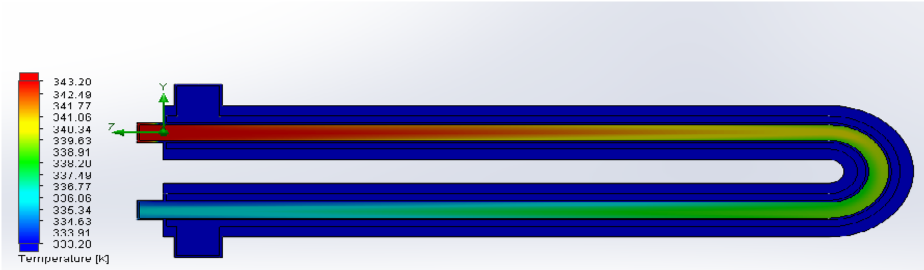


Figure 6 Curved pipe tube temperatures cut plot case1

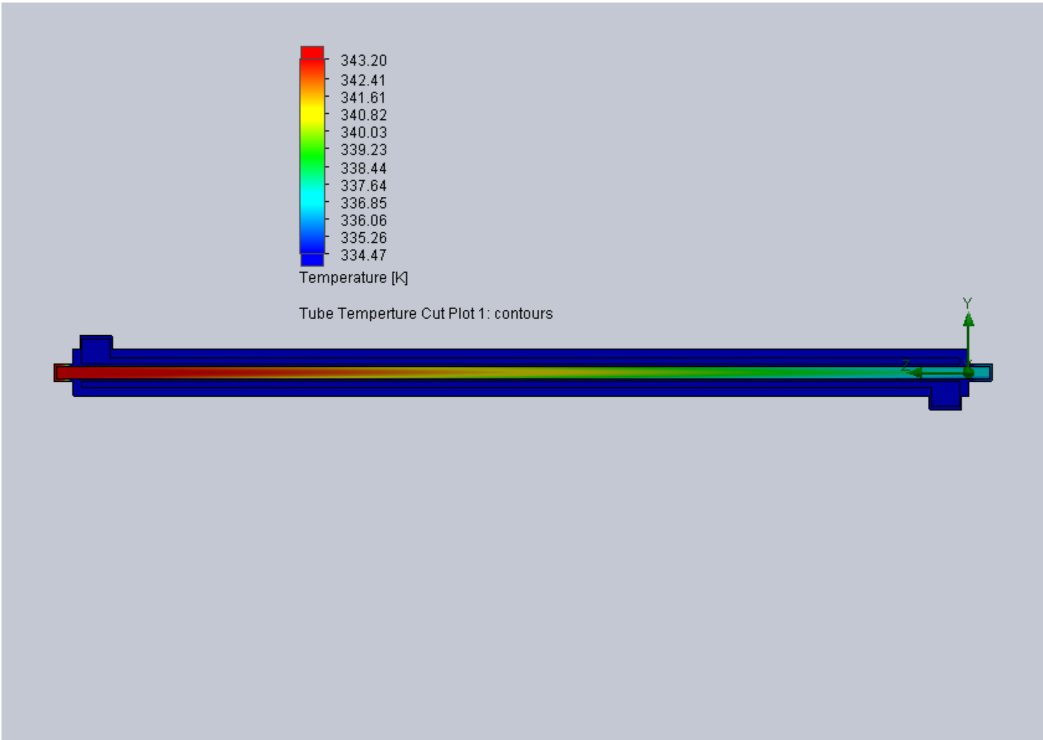


Figure 7 Straight pipe tube temperatures cut plot case 2

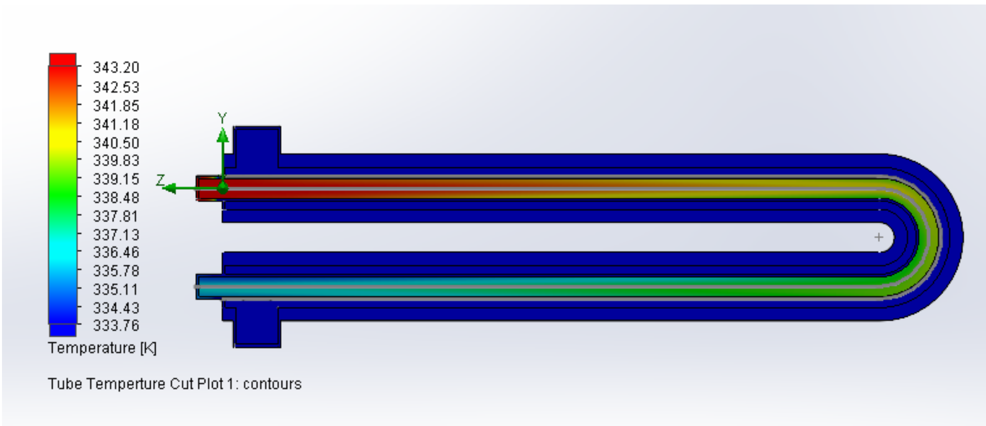


Figure 8 Curved pipe tube temperatures cut plot case2

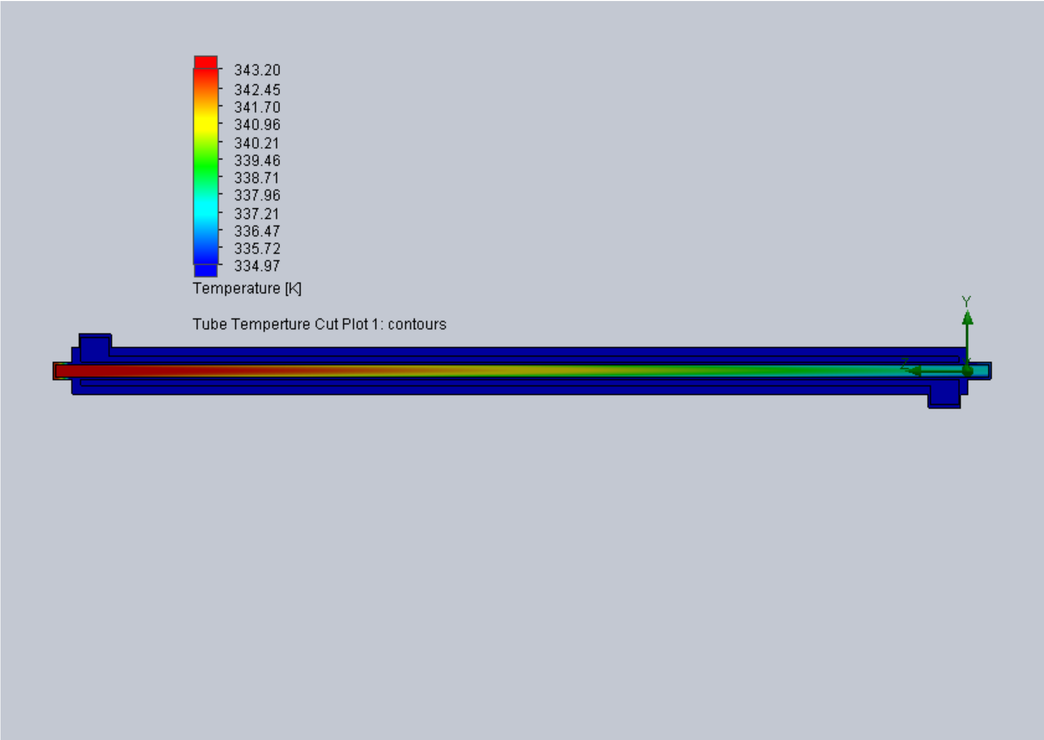


Figure 9 Straight pipe tube temperatures cut plot case 3

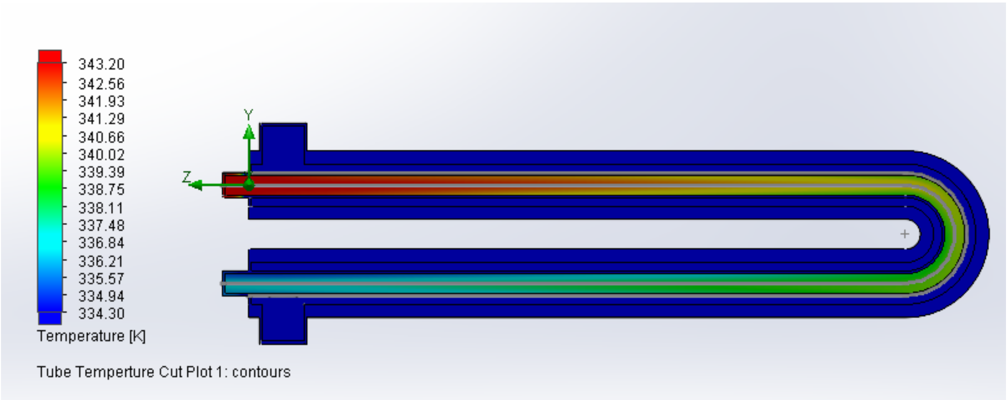


Figure 10 curved pipe tube temperatures cut plot case 3

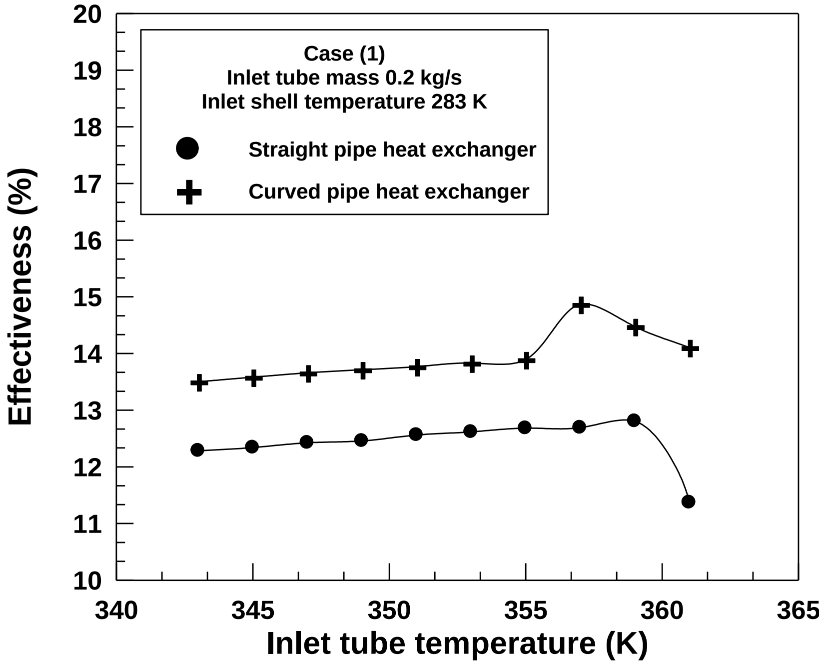


Figure 11 Effectiveness v/s inlet tube temperature –case1

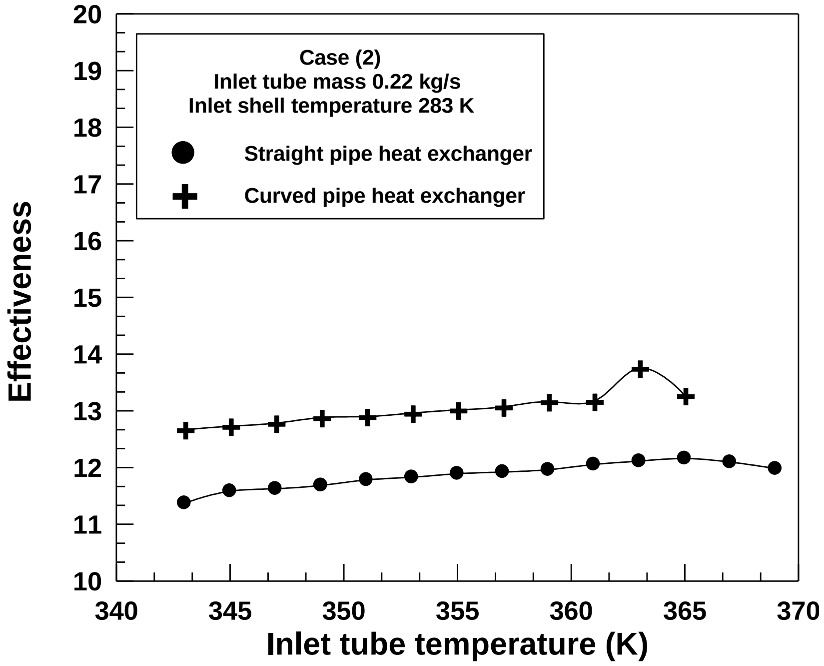


Figure 12 Effectiveness v/s inlet tube temperature-case2

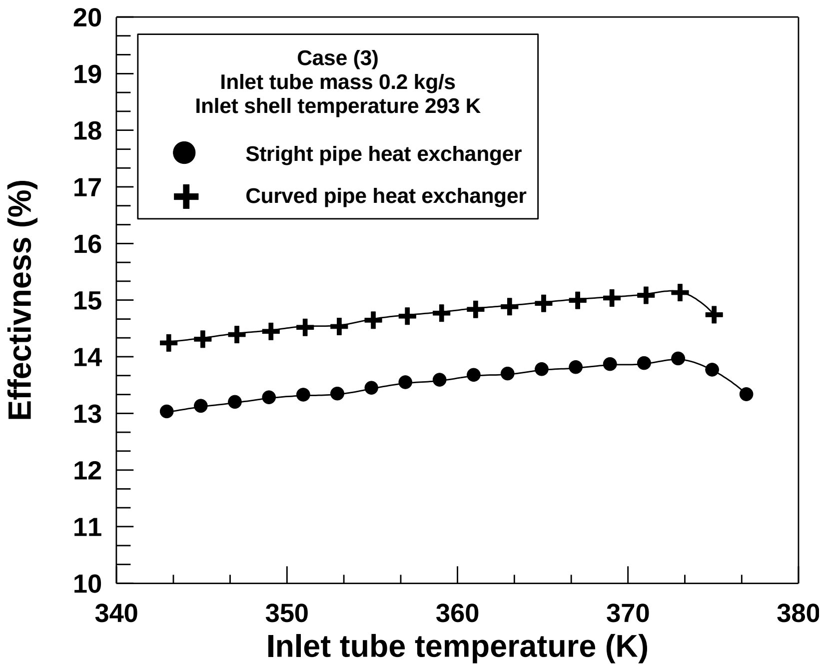


Figure 13 Effectiveness v/s inlet tube temperature-case 3

References

Adelaja, S. J. Ojolo and M. G. Sobamowo, 2012,"Computer Aided Analysis of Thermal and Mechanical Design of Shell and Tube Heat Exchangers", Advanced aterials Vol. 367 (2012) pp 731-737 © Trans Tech Publications, Switzerland.

Brien J.O. and E. M. Sparrow , 1982, Corrugated-Duct Heat Transfer, Pressure Drop, and Flow Visualization, Transactions of the ASME, Journal of Heat Transfer, Vol. 104, pp.410-416.

Chinna Ankanna, B. Sidda Reddy, 2014. Performance Analysis of Fabricated Helical Coil Heat Exchanger. International Journal of Engineering Research, Volume No.3 Issue No: Special 1, pp: 33-39.

Dejong N. C., Zhang L. W., Jacobi A. M., Balchandar S. and Tafti D. K. 1998. A Complementary Experimental and Numerical Study of Flow and Heat Transfer in Offset Strip Fin Heat Exchangers. Journal of Heat Transfer 12:690:702

Joshi H. M. and Webb R. L. 1987. Heat Transfer and Friction in Offset Strip Fin Heat Exchanger, International Journal of Heat and Mass Transfer. 30(1): 69-80

Mario H. Castro-Cedeño, June, 2015. Introduction to SolidWorks second edition text book. http://creativecommons.org/licenses/by-nc/3.0/.

Michna J. G., Jacobi A. M. and Burton L. R. 2005. Air Side Thermal- Hydraulic Performance of an Offset Strip Fin Array at Reynolds Number up to 12, 0000. Fifth International Conference on Enhanced Compact and Ultra Compact Heat Exchangers. Science, Engineering and Technology 8-14.

Nawras H. Mostafa Qusay R. Al-Hagag , 2012. Structural and Thermal Analysis of Heat Exchanger with Tubes of Elliptical Shape, IASJ,Vol-8 Issue-3.

Noie S. Baghban, M. Moghiman and E. Salehi , 1998, " Thermal analysis of shell-side flow of shell-and tube heat exchanger using experimental and theoretical methods" (Received: October 1- Accepted in Revised Form: June 3, 1999).

Saidi A. and Sudden B. 2001. A Numerical Investigation of Heat Transfer Enhancement in Offset Strip Fin Heat Exchangers in Self Sustained Oscillatory

Flow. International Journal of Numerical Methods for Heat and Fluid Flow. 11(7): 699-716

Usman Ur Rehman, 2011. Heat Transfer Optimization of Shell-and-Tube Heat Exchanger through CFD Studies, Master thesis, Chalmers University of Technology.

Vindhya Vasiny Prasad Dubey, Raj Rajat Verma, Piyush Shanker Verma A.K.Srivastava) "Performance Analysis of Shell & Tube Type Heat Exchanger under the Effect of Varied Operating Conditions" IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 11, Issue 3 Ver. VI (May- Jun. 2014), PP 08-17,www.iosrjournals.org

Wang and S. P. Vanka , , 1995, Convective Heat Transfer in Periodic Wavy Passages, International Journal of Heat and Mass Transfer, Vol. 38, pp. 3219-3230.

Yusuf Ali Kara, Ozbilen Guraras, 2004, “A computer program for designing of Shell and tube heat exchanger”, Applied Thermal Engineering 24(2004) 1797–1805.