Periodic Simulation for Heat Transfer Applications Using CFD

K Siva Satya Mohan[1], Dr. S. K. Bhatti[2], K P V K Varma[3]

1 Asst Professor, Department of Mechanical Engineering, Gokaraju Rangaraju Institute of Engineering and Technology, Hyderabad.

2 Professor, De Department of Mechanical Engineering, Andhra University, Visakhapatnam

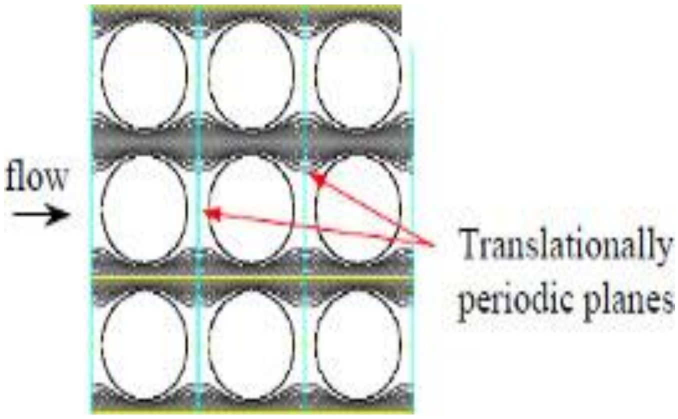
3 Asst Professor, Department of Mechanical Engineering, CMR college of Engineering and Technology, Hyderabad.

Abstract

Many heat transfer applications, such as steam generators in a boiler or air cooling in the coil of an air conditioner, can be modeled in a bank of tubes containing a flowing fluid at one temperature that is immersed in a second fluid in a cross flow at different temperature. Fluids considered in the present study are water and air. Flow is classified as laminar and steady, with Reynolds number between 100-600. In the present paper tubes of different diameters and different mass flow rates are considered to examine the optimal flow distribution. The various static pressures, velocities, and temperatures obtained are reported. Further the problem has been subjected to effect of materials used for tubes manufacturing on heat transfer rate. Materials considered are aluminum, copper and alloys. Results show significant variations between aluminum, copper and alloy as tube materials. Results emphasize the utilization of alloys in place of aluminum and copper as tube material serves better heat transfer with most economic way.

Introduction

The geometry and flow features in industrial applications can be repetitive in nature. In such cases, it is possible to analyze the flow system using only the section of geometry or single building. Doing so helps to reduce the computational effort, without compromising the accuracy. The repetition may be either translational as shown in fig.



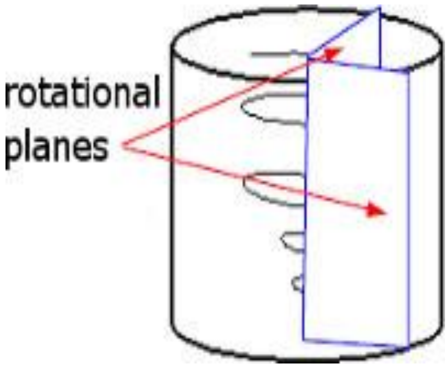


Figure: Schematic representation of periodic planes

It is easy to see from the above fig. if the entire region consists the large numbers of modulus were used as a calculation domain the required computer storage and time would be truly excessive. A practical alternative is provided by recognizing that, beyond a certain development length, the velocity fields and temperature fields will repeat itself module after module. Therefore, it is possible to calculate the flow and heat transfer directly for typical model.

Model description

Many industrial applications, such as steam generation in a boiler, air cooling in the coil of air conditioner and different type of heat exchangers uses tube banks to accomplish a desired total heat transfer.

The system considered for the present problem, consisted bank of tubes containing a flowing fluid at one temperature that is immersed in a second fluid in cross flow at a different temperature. Both fluids are water, and the flow is classified as laminar and steady, with a Reynolds number of approximately 100.The mass flow rate of cross flow is known, and the model is used to predict the flow and temperature fields that result from convective heat transfer due to the fluid flowing over tubes.

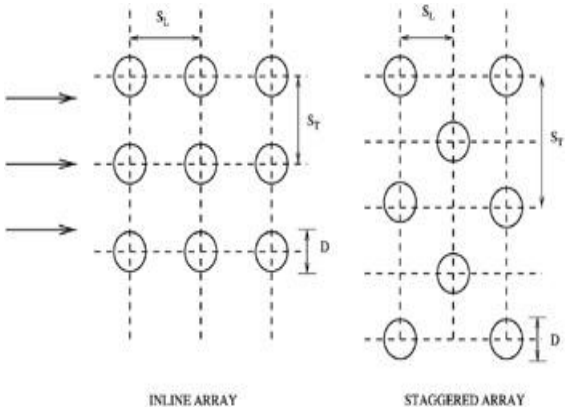


Figure: Configuration of the physical and computational domain

The figure depicts the frequently used tube banks in staggered arrangements. The situation is characterized by repetition of an identical module shown as transverse tubes. Due to symmetry of the tube bank, and the periodicity of the flow inherent in the tube geometry, only a portion of the geometry will be modeled as two dimensional periods heat flows with symmetry applied to the outer boundaries.

CFD modeling of a periodic model

- Creating physical domain and meshing
- Creating periodic zones
- Set the material properties and imposing boundary conditions
- Calculating the solutions using segregated solver.

Modeling details and meshing

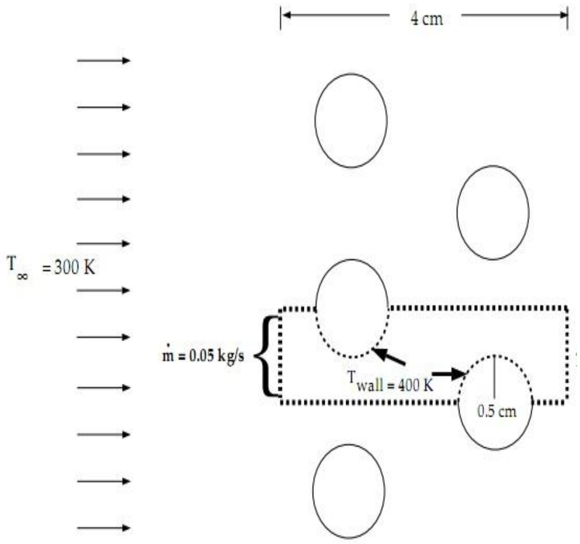


Figure: Schematic of the problem

The modeling and meshing package used is GAMBIT. The geometry consists of uniformly spaced tubes with a diameter D which are staggered in the direction of cross flow. Their centers are separated by a distance of 2cm in x-direction and 1 cm in y-direction.

Material properties and boundary conditions

The material properties of working fluid (water) flowing over tube bank at bulk temperature of 300K, are:

$\rho = 998.2 kg/m^3$

$\mu = 0.001003 kg/m\text{-}s$

$C_p = 4182$ J/kg-k

K= 0.6 W/m-k

The boundary conditions applied on physical domain are as followed

Boundary	Assigned as
Inlet	Periodic
Outlet	Periodic
Tube walls	Wall
Outer walls	Symmetry

Table: Boundary conditions assigned in FLUENT

Fluid flow is one of the important characteristic of a tube bank. It is strongly effects the heat transfer process of a periodic domain and its overall performance. In this paper, different mass flow rates at free stream temperature, 300Kwere used and the wall temperature of the tube which was treated as heated section was set at 400K as periodic boundary conditions for each model which are tabulated as follows:

Tube diameter(D)	Periodic condition
0.8cm	m=0.05kg/s,0.10kg/s
1.0cm	m=0.05kg/s,0.10kg/s
1.2cm	m=0.05kg/s,0.15kg/s
1.4cm	m=0.05kg/s,0.15kg/s

Table: Mass flow rates for different tube diameter

In this present paper three different materials such as aluminum, copper and a alloy are considered for analysis and compared with each other.

Results and Discussions:

The static pressure for different tube diameters and mass flow rate are considered

Fig: static pressure for D=1.0cm and m=0.30 for aluminum as tube material.

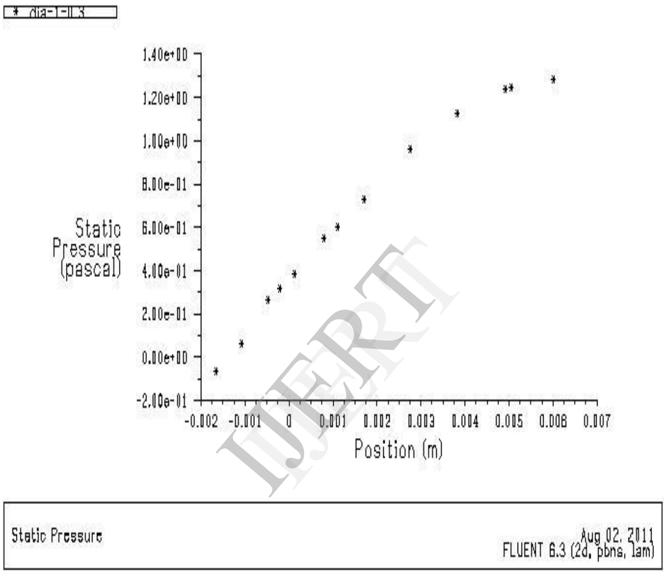


Fig: static pressure for D=0.8cm and m=0.05 for copper as tube material.

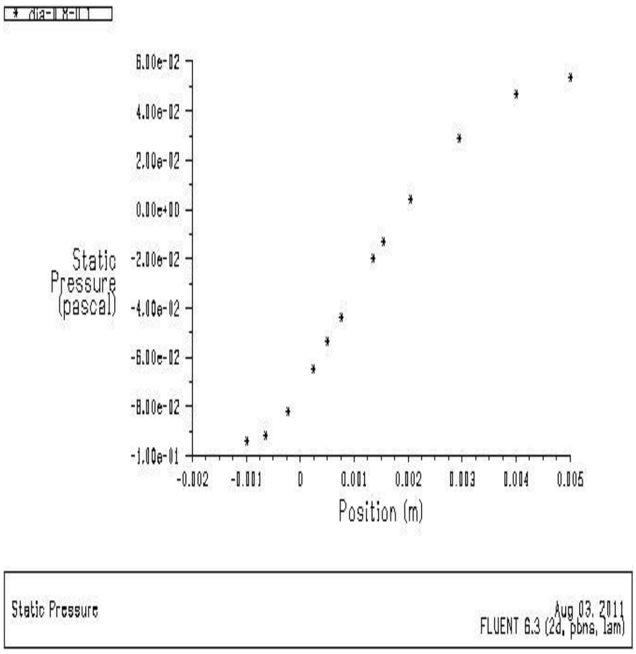
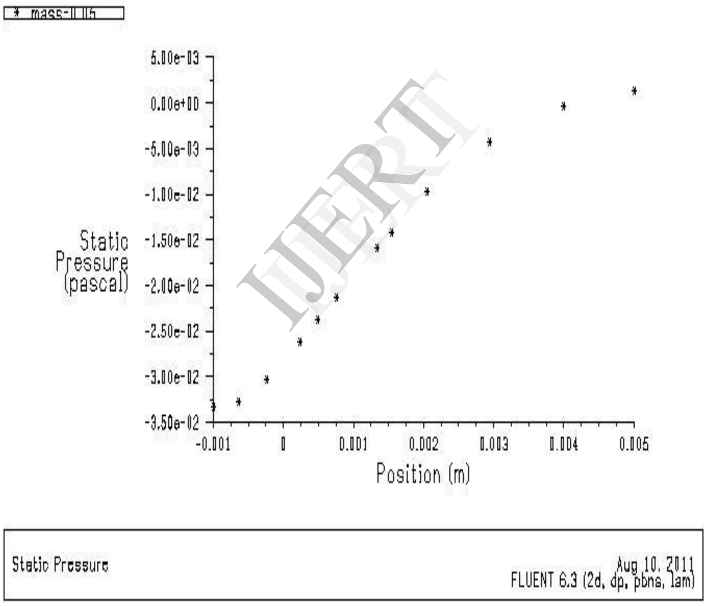


Fig: static pressure for D=0.8cm and m=0.05 for nickel chromium base super alloy as tube material.



The pressure contours for different tube materials are shown figures. The figures reveal that the static pressure exerted at stagnation point for different tube materials and mass flow rates have significant variations. From the figures it can be conclude that alloy as tube material is best selection as we can see that very low pressure drop in case of alloys.

The static temperatures for different tube diameters and mass flow rate are considered

Fig: static temperature for D=1.0cm and m=0.30 for aluminum as tube material

ISSN: 2278-0181
Vol. 2 Issue 12, December - 2013

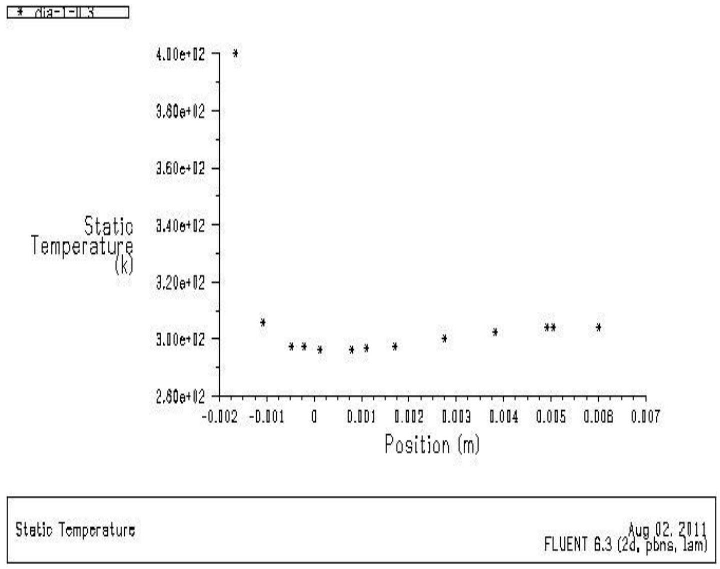


Fig: static temperature for D=0.8cm and m=0.05 for copper as tube material.

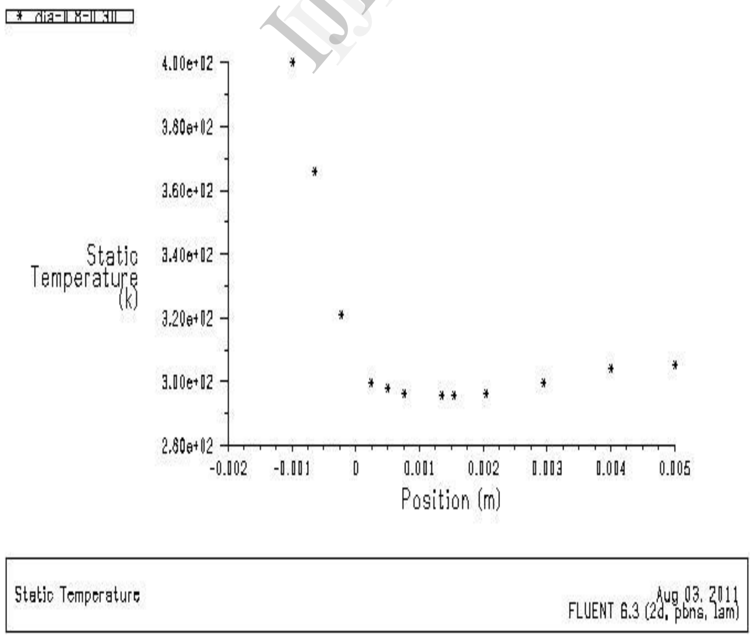
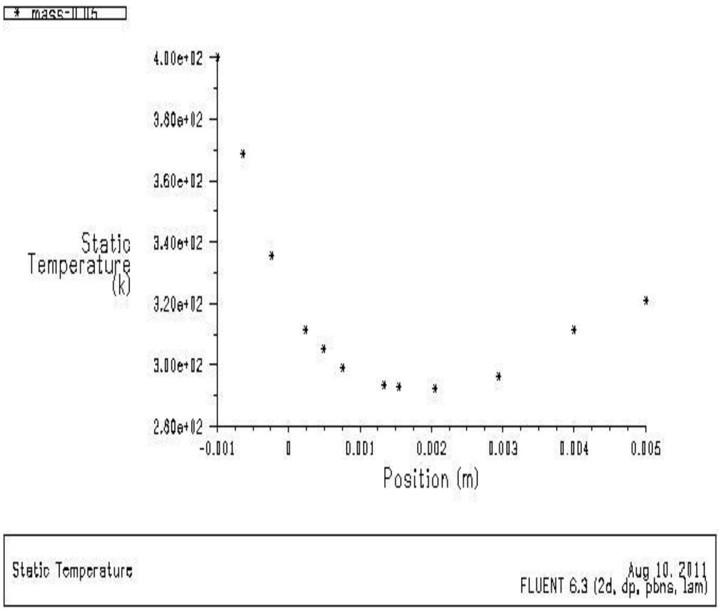


Fig: static temperature for D=0.8cm and m=0.05 for nickel chromium base super alloy as tube material.



The temperature contours for different tube materials are shown figures. It can be seen that higher heat flow rate was obtained from alloy as tube material.

The velocity for different tube diameters and mass flow rate are considered.

Fig: velocity for D=1.0cm and m=0.30 for aluminum as tube material

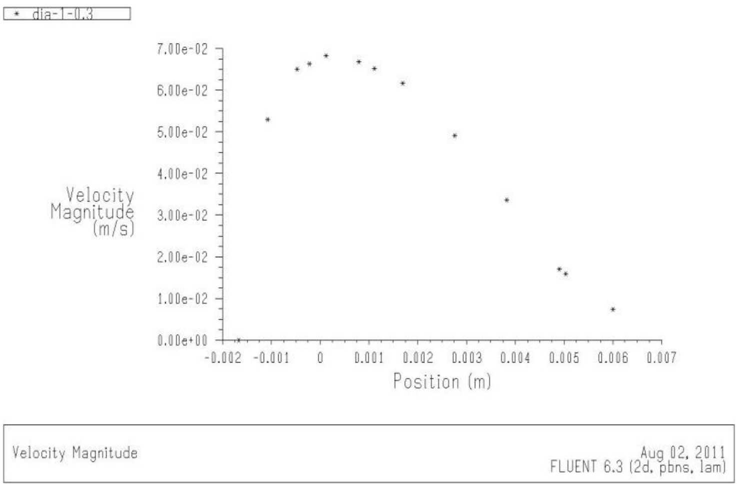


Fig: velocity for D=0.8cm and m=0.05 for copper as tube material.

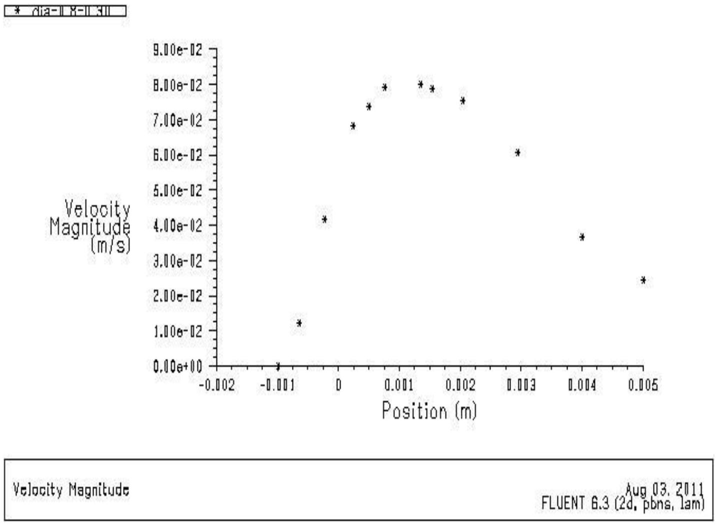
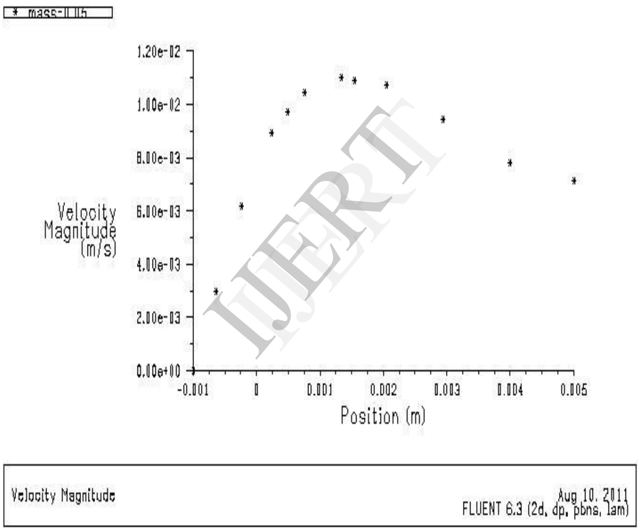


Fig: velocity for D=0.8cm and m=0.05 for nickel chromium base super alloy as tube material



The velocity contours for different tube materials are shown figures. If the mass flow rate increases the velocity also increases and narrow stream of maximum velocity fluid is flow through tube bank.

Verification of Results

The maximum velocity magnitude obtained from the simulation is used to calculate the Reynolds number from the following expression,

$$\mathbf{Re_{D,max} = \rho\, u_{max} D/\mu}$$

With the above $Re_{D,max}$ the nusselt number was calculated using correlation

$$\mathbf{Nu=C1(C\, Re^{n}\, Pr^{0.33)}}$$

The total surface heat flux values obtained from simulation was used to calculate the Nu values at x=0.01 at middle of the first tube which was used to compare with correlation valves. The table presents results generated using different mass flow rates for different tube materials. The results obtained from the simulation were compared to correlation results.

Fig: Nusselt number for D=1.0cm and m=0.30 for aluminum as tube material.

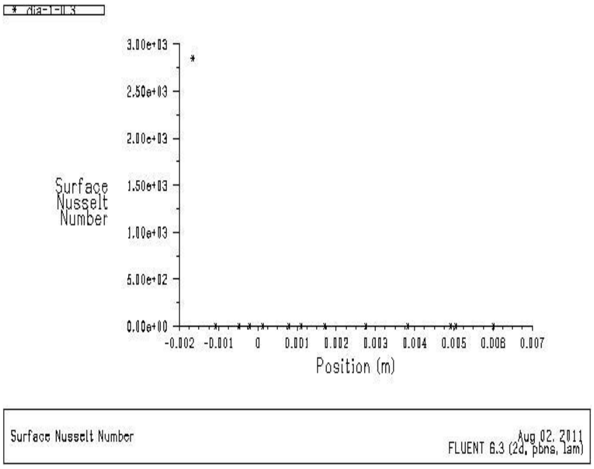


Fig: Nusselt number for D=0.8cm and m=0.05 for copper as tube material

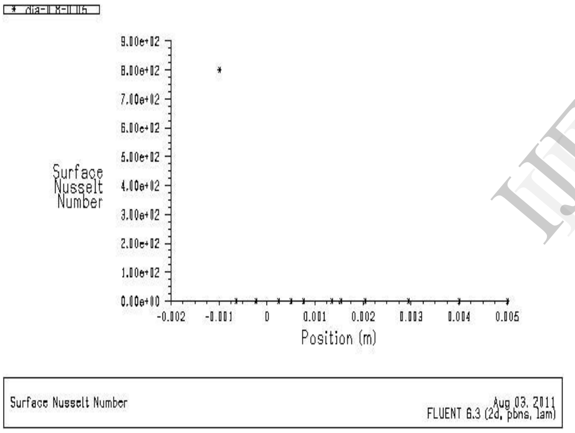
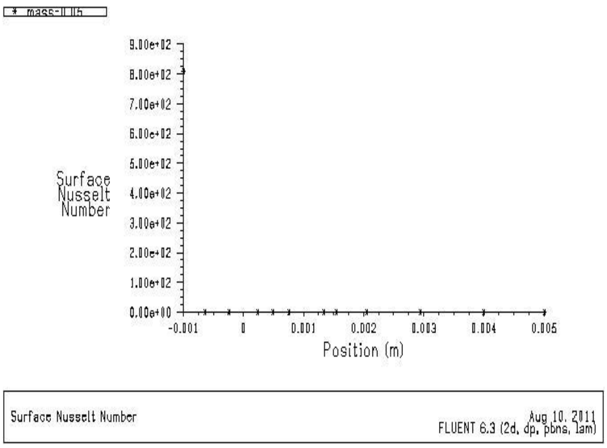


Fig: Nusselt number for D=0.8cm and m=0.05 for nickel chromium base super alloy as tube material



Results comparison

Table. Comparison values of Fluent Vs Correlation of Aluminum tubes

Diameter(cm)	Mass Flow Rate(kg/s)	Max Velocity(m/s)	ReD	Pr	NuD(corr)	$NuD_{x=0.01}$	% Error
D=0.8	M=0.05	0.0115	91.559	6.99091	9.296	8.278	0.1095
	M=0.10	0.0238	189.488	6.99091	13.97	8.975	0.3575
	M=0.15	0.0382	304.137	6.99091	18.20	8.125	0.55405
	M=0.20	0.0512	407.639	6.99091	21.45	5.675	0.7356
	M=0.25	0.0654	520.690	6.99091	24.606	2.650	0.8923
	M=0.30	0.0795	632.95	6.99091	27.449	4.740	0.827
D=1.0	M=0.05	0.0095	94.545	6.99091	34.30	13.336	0.6114
	M=0.10	0.0201	200.03	6.99091	14.40	18.465	0.2198
	M=0.15	0.0324	322.44	6.99091	18.81	23.785	0.2208
	M=0.20	0.0425	422.96	6.99091	21.90	27.082	0.191
	M=0.25	0.0593	590.16	6.99091	24.89	27.750	0.1027
	M=0.30	**0.0689**	**685.70**	**6.99091**	**28.707**	**28.590**	**0.00409**
D=1.2	M=0.05	0.00752	89.808	6.99091	9.19	16.150	0.4305
	M=0.10	0.01625	194.066	6.99091	14.158	22.230	0.36309
	M=0.15	0.02534	302.62	6.99091	18.15	24.820	0.2684
	M=0.20	0.03675	438.889	6.99091	22.36	27.120	0.1755
	M=0.25	0.04635	553.53	6.99091	25.463	27.345	0.0688
	M=0.30	**0.05780**	**690.28**	**6.99091**	**28.814**	**27.565**	**0.0433**
D=1.4	M=0.05	0.006103	85.033	6.99091	8.919	6.830	0.234
	M=0.10	0.0131	182.522	6.99091	13.680	7.450	0.455
	M=0.15	0.0210	292.593	6.99091	17.818	7.825	0.560
	M=0.20	0.0295	411.023	6.99091	21.55	7.935	0.631
	M=0.25	0.0382	532.240	6.99091	24.91	7.995	0.679
	M=0.30	0.0475	661.817	6.99091	28.143	8.001	0.750

Table. Comparison values of Fluent Vs Correlation of Copper tubes

Diameter(cm)	Mass Flow Rate(kg/s)	Max Velocity(m/s)	ReD	Pr	NuD(corr)	$NuD_{x=0.01}$	% Error
D=0.8	**M=0.05**	**0.0103**	**82.005**	**6.99091**	**8.740**	**8.12**	**0.0709**
	M=0.10	0.0227	180.730	6.99091	13.60	8.48	0.3760
	M=0.15	0.0363	289.010	6.99091	17.69	7.61	0.5701
	M=0.20	0.0512	417.990	6.99091	21.75	5.02	0.769
	M=0.25	0.0682	542.988	6.99091	25.19	2.532	0.8995
	M=0.30	0.0826	657.637	6.99091	28.04	4.940	0.823
D=1.0	M=0.05	0.00913	90.863	6.99091	9.256	13.000	0.6114
	M=0.10	0.0199	198.04	6.99091	14.32	18.245	0.2151
	M=0.15	0.0327	325.43	6.99091	17.45	23.567	0.2592
	M=0.20	0.0432	429.93	6.99091	22.10	27.254	0.1889
	M=0.25	0.0515	512.53	6.99091	24.36	27.895	0.1256
	M=0.30	**0.0599**	**596.133**	**6.99091**	**26.543**	**28.674**	**0.0743**
D=1.2	M=0.05	0.00783	93.510	6.99091	9.406	14.150	0.335
	M=0.10	0.01656	197.768	6.99091	14.309	19.532	0.267
	M=0.15	0.02534	302.62	6.99091	18.15	24.820	0.2684
	M=0.20	0.0383	457.4005	6.99091	22.883	27.120	0.156
	M=0.25	0.0498	594.74	6.99091	26.508	28.645	0.0746
	M=0.30	0.05245	626.38	6.99091	27.289	29.565	0.0769
D=1.4	M=0.05	0.006546	91.205	6.99091	9.276	6.430	0.306
	M=0.10	0.0165	229.894	6.99091	15.567	7.875	0.494
	M=0.15	0.0210	292.593	6.99091	17.818	7.925	0.555
	M=0.20	0.0299	416.596	6.99091	21.717	7.978	0.6326
	M=0.25	0.0395	550.3535	6.99091	25.38	8.05	0.682
	M=0.30	0.0475	661.817	6.99091	28.143	8.12	0.711

Table. Comparison values of Fluent Vs Correlation of Nickel-Chromium base super alloy based tube

Diameter(cm)	Mass Flow Rate(kg/s)	Max Velocity(m/s)	ReD	Pr	NuD(corr)	$NuD_{x=0.01}$	% Error
D=0.8	**M=0.05**	**0.0103**	**82.005**	**6.99091**	**8.740**	**8.12**	**0.0709**
	M=0.10	0.0227	180.730	6.99091	13.60	8.48	0.3760
	M=0.15	0.0363	289.010	6.99091	17.69	7.61	0.5701
	M=0.20	0.0512	417.990	6.99091	21.75	5.02	0.769
	M=0.25	0.0682	542.988	6.99091	25.19	2.532	0.8995
	M=0.30	0.0826	657.637	6.99091	28.04	4.940	0.823
D=1.0	M=0.05	0.00913	90.863	6.99091	9.256	13.000	0.6114
	M=0.10	0.0199	198.04	6.99091	14.32	18.245	0.2151
	M=0.15	0.0327	325.43	6.99091	17.45	23.567	0.2592
	M=0.20	0.0432	429.93	6.99091	22.10	27.254	0.1889
	M=0.25	0.0515	512.53	6.99091	24.36	27.895	0.1256
	M=0.30	**0.0599**	**596.133**	**6.99091**	**26.543**	**28.674**	**0.0743**
D=1.2	M=0.05	0.00783	93.510	6.99091	9.406	14.150	0.335
	M=0.10	0.01656	197.768	6.99091	14.309	19.532	0.267
	M=0.15	0.02534	302.62	6.99091	18.15	24.820	0.2684
	M=0.20	0.0383	457.4005	6.99091	22.883	27.120	0.156
	M=0.25	0.0498	594.74	6.99091	26.508	28.645	0.0746
	M=0.30	0.05245	626.38	6.99091	27.289	29.565	0.0769
D=1.4	M=0.05	0.006546	91.205	6.99091	9.276	6.430	0.306
	M=0.10	0.0165	229.894	6.99091	15.567	7.875	0.494
	M=0.15	0.0210	292.593	6.99091	17.818	7.925	0.555
	M=0.20	0.0299	416.596	6.99091	21.717	7.978	0.6326
	M=0.25	0.0395	550.3535	6.99091	25.38	8.05	0.682
	M=0.30	0.0475	661.817	6.99091	28.143	8.12	0.711

Conclusion

A Two-Dimensional numerical solution of flow and heat transfer in a bank of tubes which is used in industrial applications was carried out. Laminar flow past a bank is numerically simulated in the low Reynolds number regime. Nusselt number variations are obtained and they are correlated with the theoretical values. The effect of mass flow rates on both flow and heat transfer is significant. This is due to the variation of space of the surrounding tubes. It was concluded that 1.0 cm diameter of tubes and 0.30 kg/sec mass flow rate yields optimum results for aluminum as tube material, where as it was 0.8 cm and 0.05 kg/sec mass flow rate in case of copper as tube material. From the above result we can conclude that alloys serves as a better material for tube when compared with copper and aluminum. Flow process has an important effect on heat transfer. An optimal flow distribution can result in high temperature and low pressure drop. From the simulation the optimal flow distribution was found for 0.8 cm diameter and 0.05 kg/sec mass flow rate in case of alloy as tube material. Alloy (Nickel-Chromium based) serves as a better material for heat transfer applications with low cost.

Further improvements of heat transfer and fluid flow modeling can be possible by modeling three dimensional model and changing the working fluid.

References:

[1]Patanker,S.V.andSpalding.D.B.(1974),"A calculation for the transient and Steady State behavior of Shell-and –Tube Heat Exchanger", Heat transfer design and theory Sourcebook,Afgan A.A.and Schluner E.U., Washington.pp.155-176.

[2] Kelkar,K.Mand Patankar,S.V.,1987 "Numerical prediction of flow and Heat transfer in a Parallel plate channel with staggered fins",Jouranal of Heat Transfer,Vol.109,pp 25-30.

[3]Berner,C.,Durst,F.and McEligot,D.M., "Flow around Baffles", Journal of Heat Transfer,vol.106pp743-749.

[4] Popiel,C.O.&Vander Merwe,D.F., "Friction factor on Sine-pipe flow,Journal of fluids Engineering",118,1996,341-345.

[5] Popiel,C.O.&Wojkowiak,J.,"Friction factor in U-type undulated pipe flow,Journal of fluids Engineering",122,2000,260-263.

[6] Dean, W.R., Note on the motion of fluids in a curved Pipe,The London,Edinburgh and Dublin philosophical Magazine,
7(14), 1927, 208-223.

[7] Patankar, S.V.,Liu,C.H.&Sparrow,E.M., "Fully developed flow and Heat Transfer in Ducts having stream wise periodic variations in cross-sectional area", Journal of Heat Transfer, 99, 1977, 180-186.

[8] Webb,B.W&Ramdhyani,S.,"Conjugate Heat Transfer in an channel with staggered Ribs"lnt.Journal of Heat Transfer and Mass Transfer 28(9),1985,1679-1687.

[9] Park,K., Choi,D-H & Lee, K-S.,"Design optimization of plate a Heat exchanger with staggered pins",14th lnt.symp.on Transport phenomena,Bali,Indonesia,6-9 July 2003.

[10]N.R.Rosaguti,D.F.Fletcher&B.S.Haynes "Laminar flow in a periodic serpentine channel", 15th Australasian fluid mechanics conference. The University of Sydney, Australia 13-17 December 2004.