Numerical study on heat transfer and fluid flow characteristic of tube bank with integral wake splitters (Effect of wake splitter length)

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ABSTRACT

The purpose of this research is to study pressure drop and heat transfer characteristics in a tube bank heat exchanger with triangular arrangements by using Computational Fluid Dynamics (CFD). Given the importance of wide practical applications in our lives for heat exchanger. We can improve the thermal and hydraulic performance for heat exchangers by several ways same like adding integral wake splitters (fins) on tubes to reduce pressure drop and increase heat transfer across tube bank. When the flow of fluid through the tube banks in the heat exchanger, there is a rise in pressure drop and decrease in heat transfer, to reduce pressure drop and increase heat transfer through the tube banks must consider how to improve and develop the arrangement of tubes (diameter, length, S_t and $S_{l)}$ for tube bank in heat exchanger, To improving the thermal and hydraulic performance of these heat exchangers have been reached several ways to improve performance like adding a new set of integral wake splitter (0.5D, 1D with different direction) on tube bank. For this study we used the 395 x 395 x 1230 mm test section size. The geometric layout of the tube bank is staggered with seven rows of five tubes in each row. The tube diameter, transverse pitch and horizontal pitch are 48.5 mm, 79 mm and 65.8 mm respectively. The analysis was at different values of Reynolds number between ($5000 < Re > 27800$). The temperature of air was (290 K), and heat flux for each tube was (5250 W/m^2).

ABSTRACT

Tujuan kajian ini bertujuan untuk mengkaji kejatuhan nilai tekanan dan cirri-ciri pemindahan haba di dalam tiub penukar haba dengan susunan segitiga dengan menggunakan Penkomputeran Dinamik Bendalir (CFD). Memandangkan pentingnya aplikasi praktikal yang luas dalam hidup kita untuk penukar panas, kita dapat meningkatkan prestasi terma dan hidrolik untuk penukar panas dengan beberapa cara yang sama seperti menambah pemisah (sirip) pada tabung untuk mengurangkan penurunan tekanan dan meningkatkan pemindahan haba merentasi tabung tiub . Bila aliran cecair melalui tabung tiub dalam penukar haba, ada peningkatan dalam penurunan tekanan dan dalam penukar haba, untuk mengurangkan penurunan tekanan dan peningkatan pemindahan haba melalui tabung tiub harus mempertimbangkan bagaimana untuk meningkatkan dan membina susunan tabung (diameter, panjang, St dan Sl) untuk tabung tiub di dalam penukar haba, Untuk meningkatkan prestasi terma dan hidrolik penukar haba ini telah dicapai beberapa cara untuk meningkatkan prestasi seperti menambah satu set baru pemisah integral, (0.5D 1D dengan berbeza arah) pada tabung tiub. Untuk kajian ini, kami telah menggunakan saiz 395 x 395 x 1230 mm untuk bahagian ujian. Susunan geometri tabung tiub bersilih ganti dengan tujuh deretan lima tabung dalam setiap baris. Diameter tabung, pitch melintang dan pitch mendatar masing-masingn adalah 48,5 mm, 79 mm dan 65,8 mm. Analisis ini dibuat pada nilai nombor Reynolds yang berbeza antara (5000 <Re> 27800). Suhu udara (290 K), dan panas fluks untuk setiap balang (5250 W/m2).

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LIST OF SYMBOLS AND ABBREVIATION

P_∞	Pressure upstream
P_o	Pressure at the stagnation point
U	Flow velocity
v_θ	Velocity at any point on the cylinder surface
Q	Heat transfer flux
$\bar{h}$	Average heat transfer coefficient
Re	Reynolds number.
U_{app}	Approach velocity of the fluid.
T_{tube}	Temperature of the tube
T_{wall}	Temperature of the wall
2D	Two dimensions
3D	Three dimensions
S_t	Transverse pitch
S_l	Horizontal pitch
D	Diameter of tube
L	Length of tube
F	Outside forces effect on the body
μ	Air dynamic viscosity

ρ	Density of the fluid
$V_{upstream}$	Upstream velocity
$V_{downstream}$	Downstream velocity
ΔP	Pressure drop
EGM	Entropy generation minimization
β	Coefficient of thermal expansion
ΔT	Average difference temperature
P_{pump}	Power of pump

Numerical study on heat transfer and fluid flow characteristic of tube bank with integral wake splitters

1.1- Introduction.

A heat exchanger is a device designed for efficient heat transfer from one medium to other. Where, a flow can be separate into a heat exchanger by a solid wall, as can be mixed or unmixed.

The selecting a heat exchanger to a particular use is depending on some characteristics "temperature, fluid phases (liquid or gas), the amount of energy required to transfer, and a pressure drop ...etc". As, a pressure drop linked directly with the pumping capacity and indirectly associated with the rate of heat transfer. Whereas, a pressure drop controls the flow speed, hence on the rate flow cluster. Therefore, these factors will affect on the performance of heat exchanger. (J. R. Culham and M. M. Yovanovich, 2007).

The following Figure 1 shows the details of the heat exchanger of the type tube banks. When, the Fluid (I) move across the tubes while fluid (II) at a different temperature passes through the tubes as the figure: -

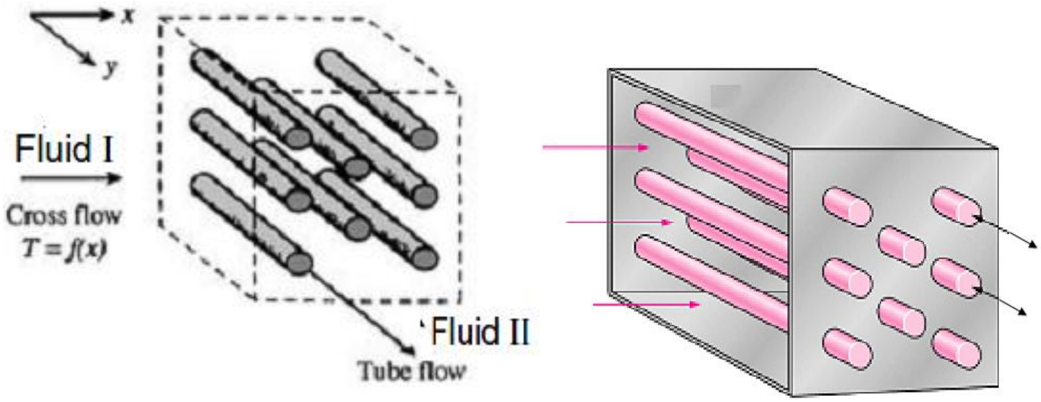

Figure 1.1 tube bank (Tao Xing 2000)

The fluid flow is ideally normal to the tubes. The most usual tube arrays are staggered and inline, although other arrangements are possible. The flow converges in the inter-tube spaces inside a bank and forms a highly turbulent flow over the inner tubes. The recirculation region in the rear of an inner tube is smaller than in a single tube. The situation is governed by the relative pitches and the bank geometry. The more compact a bank is, the larger is the difference from the single-tube situation. (M. A. Mehrabian Iran 2008)

Generally speaking, flow around a body placed in a uniform flow develops a thin layer along the body surface with largely changing a velocity and a pressure, i.e. the boundary layer, due to the viscosity of the fluid. Furthermore, the flow separates behind the body, discharging a wake with eddies. Figure 2-a and 2-b shows the flows around a cylinder. The flow from an upstream point (a) is stopped at point (b) on the body surface with its velocity decreasing to zero; (b) is called a stagnation point. The flow divides into the upper and lower flows at point (b). For a cylinder, the flow separates at point(c) producing a wake with eddies.

Let the pressure upstream at (a), which is not affected by the body, be (P_∞). The flow velocity is (U) and the pressure at the stagnation point is (P_o) Hence.

$$\mathrm{P_o} = P_\infty + \frac{\rho U^2}{2} \tag{1. 1}$$

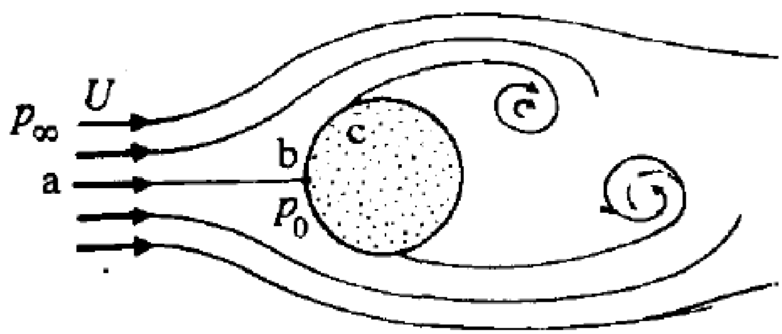

Figure 1.2-a Flow past a cylinder. (Johan H.lienhard . 2004)

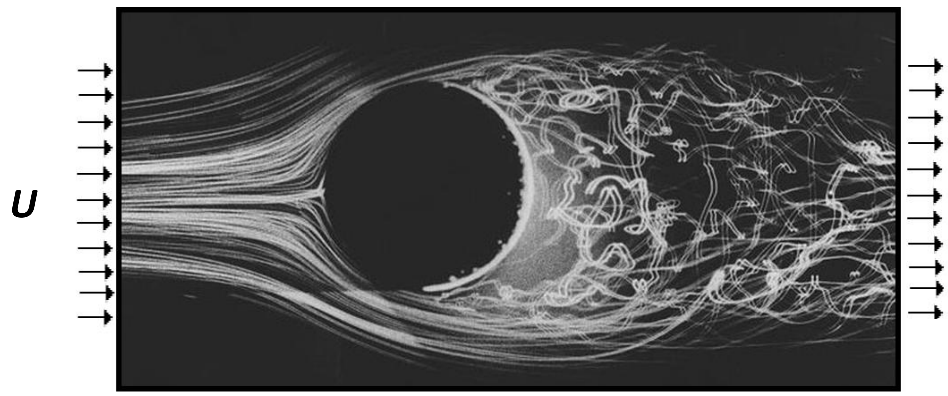

Figure 1.2.b Flow past a cylinder . (Johan H.lienhard . 2004)

Let us theoretically study (neglecting the viscosity of fluid) a cylinder placed in a flow. The flow around a cylinder placed at right angles to the flow (U) of an ideal fluid is as shown in Fig 3-a and 3-b the velocity (v_θ) at any point on the cylinder surface is as follows:

$$v_\theta = 2U\sin\theta \tag{1. 2}$$

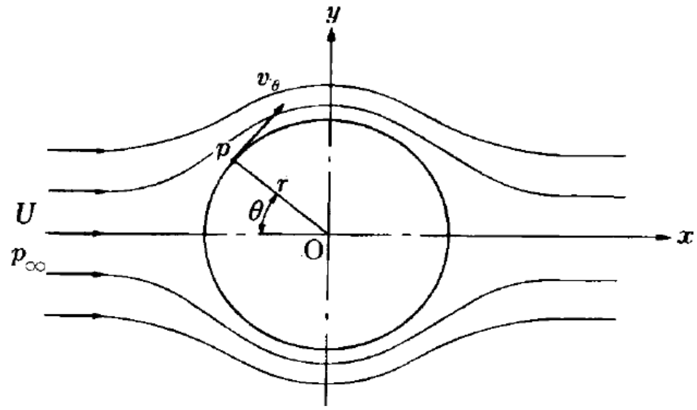

Figure 1.3.a velocity (v_θ) at any point on the cylinder surface (Johan H.lienhard . 2004)

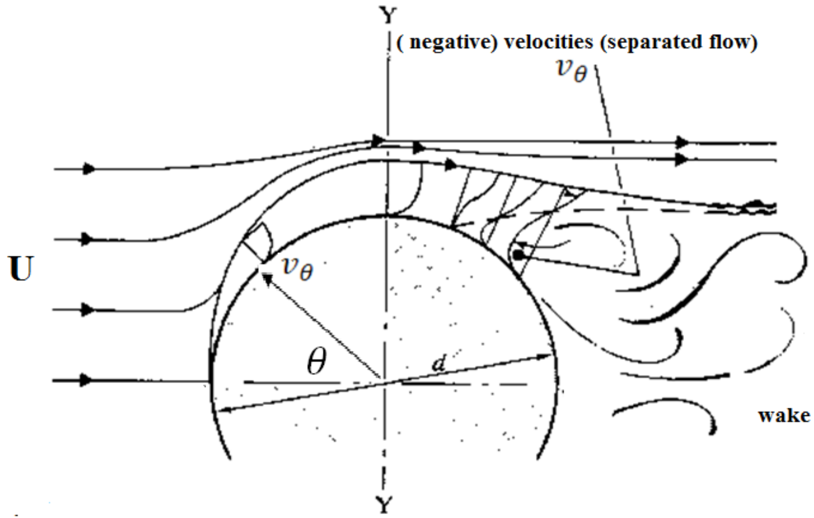

Figure 1.3.b velocity (v_θ) at any point on the cylinder surface (Johan H.lienhard. 2004)

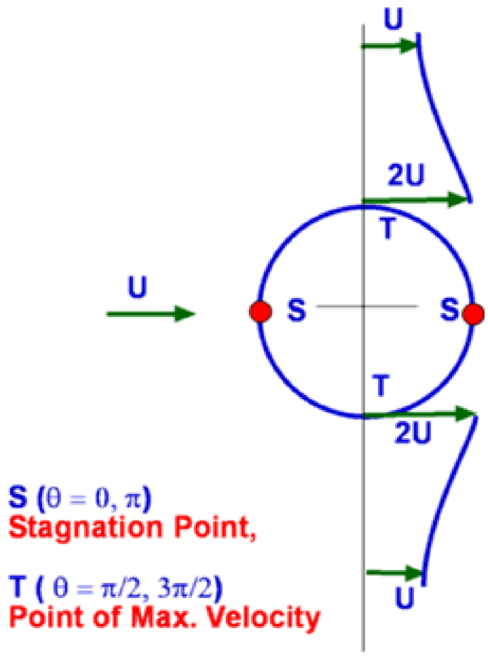

Figure 1.3.c Stagnation Points for Flow about a Circular Cylinder (Johan H.lienhard . 2004)

Putting the pressure of the parallel flow as (P_∞) and the pressure at (a) given point on the cylinder surface as (p); Bernoulli's equation produces the following result. (Johan H.lienhard .U.S.A. 2004)

$$P_\infty + \frac{\rho U^2}{2} = P + \frac{\rho v_\theta^2}{2} \tag{1. 3}$$

$$\mathrm{P} - \mathrm{P}_\infty = \frac{\rho\left(U^2 - v_\theta^2\right)}{2} = \frac{\rho U^2}{2}\left(1 - 4\sin^2\theta\right)$$

$$\frac{P-P_{\infty}}{\frac{\rho U^2}{2}} = \left(1 - 4\sin^2\theta\right) \quad (1.4)$$

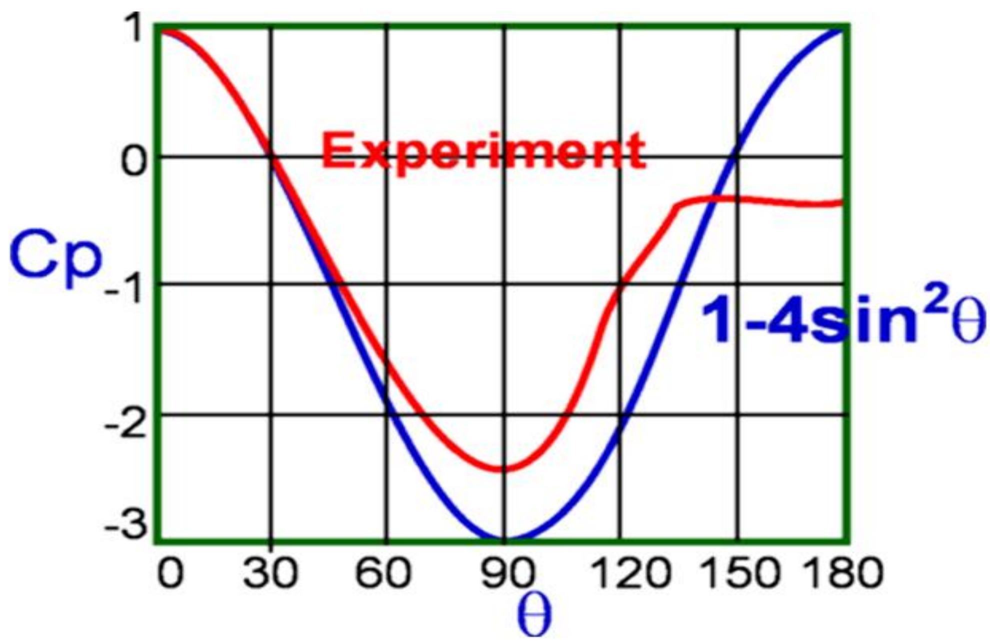

Figure 1.4 Cp distributions for flow past a circular cylinder (Johan H.lienhard . 2004)

Convection heat transfer is described by Newton's law of cooling, which states that the rate of heat loss of a body is proportional to the difference in temperatures between the body and its surroundings. The law is given as the equation (Y.Nakayama. Japan.2000).

$$Q = A * h * (T_{surface} - T_{flow}) \quad (1.5)$$

Flow inside inline banks approaches that in straight channels, and the mean velocity distribution in the minimum inter-tube space of a transverse row is highly influenced by the relative pitches. The leading tubes induce vertical flow and a variable velocity distribution around the inner tubes. The fluid flow inside a staggered bank may by compared to periodically narrowing and widening channels such as those formed between corrugated plates in plate heat exchangers. At low Reynolds number, the inside flow is predominantly laminar with large vortices in the recirculation regions. Their effect on the front parts of inner tubes is eliminated by viscous forces and negative pressure gradients. Laminar boundary layers are still formed on the inner tubes which separate and form recirculation regions in the rear. This pattern may be called a predominantly laminar flow and is observed at Reynolds number <1000. Significant changes are introduced at higher values of Reynolds number. The Inter-tube flow becomes vertical and highly turbulent. On inner tubes, in spite of high turbulence, laminar boundary layers are still observed (A.Zukauskas and J.Ziugzda, 1985). A negative pressure gradient on the front part of an inner tube causes an acceleration of the flow. The boundary layer is thin and changes but little with the distance from the stagnation point. Both the intensity of turbulence and its generation in the inter-tube spaces are governed by the bank geometry and Reynolds number. With shorter transverse pitches, the velocity fluctuations become more intensive. The turbulence level of the main flow can influence fluid dynamics only over the first and second rows (E. S. Gaddis, and V. Gnielinsky, 1985).

But there is a way; it can change the properties of the wake downstream. Through the development of plate separation in the middle of a circular tube usually, does not prevent the formation of eddies, but can reduce them. Plate separation greatly reduces the pressure loss and reduced heat transfer from the surface of the tube. However, the existence of separate panel increases the total heat transfer to a large extent through a supplement to the extended surface heat transfer. Thus, the team's results in the promotion of the General Division of the heat transfer. (S.Tiwari,D. Chakraborty.G.BiswasP.K.PanigrahiInstitute. Indian. 2004).

1.2- The methods used to improve performance of heat exchangers

Given the importance of heat exchangers and the frequent use started to go towards improving the thermal and hydraulic performance of these heat exchangers have been reached several ways to improve performance (Kakac Setal. 1981).

1. Add surface roughness.
2. Extended surfaces or fins.
3. Methods to move fluid.
4. Rotation of flow fluid.
5. Methods of surface tension.
6. An addition improved materials to thermal properties of liquids.
7. An addition improved materials to thermal properties of gases.
8. The surface vibration.
9. The use of electrostatic fields.
10. Injection fluids with good thermal properties.
11. The withdrawal or removal of membrane fumes.

1.3- Project background

When flow of fluid through the tube banks into the heat exchanger. There is, a rise in pressure drop and increase in heat transfer through the tube banks, because there

Vortices behind the tubes. Where, the properties of the fluid in that region are changing rapidly. Meanwhile, Vortices are causing pressure drop and Increase of heat transfer. Therefore, must considering by studying the pipes, through adding a new set of wake splitters to tubes .They will be a different forms, lengths and directions,. To improve heat exchanger (reduce pressure drop and Increase the area of heat transfer).

1.4- Problem Statement.

A Heat exchanger design is a complex problem which involves both quantitative calculations and qualitative judgments. The amounts of pressure drop and heat transfer are highly dependent on the geometry of the tube bank. The flow of fluid will create Vortices behind the tubes, they will be a reason on change the properties of the fluid at those regions a rapidly. Meanwhile, they are causing to increase (pressure drop and heat transfer) (Osama Abd Elhamid 2008).

1.5- Research objectives.

The purpose of this project is using Computational Fluid Dynamics (CFD) to study on heat transfer and fluid flow characteristic of tube bank with several types and different location of wake splitters. Where, heat transfer and pressure drop represent coefficients those imposed on the flow by each successive row of tubes.

1.6- Research of scopes.

1. Design of model using the (Gambit).
2. Analysis the model using the (Fluent).
3. Study will be conducting at Reynolds number $Re = \frac{\rho D V}{\mu}$ based on tube bank diameter.

$$5000 < Re < 280000$$

4. Studying a Pressure drop and a heat transfer between an entrance and an outlet of tube bank.

1.7- Significance of the study.

There are many studies on the effects of fin is only done on a single tube. There has been no farther study was conducted by CFD on the effect of weak splitters to heat transfer and fluid flow characteristic to a tube bank. This project aims to improve the heat exchanger performance. Through decreasing the pressure drop and Increase the heat exchange.

1.8- Expected results.

The results will be expected for this project. When adding different types of several wake splitter on the tube bank. It is expected decrease on pressure drop and an increase to heat transfer, Compared to tube bank without several wake splitter.

1.9- Research Organization.

1.9.1- Thesis Planning

This study divided into five chapters as follows:

1- Chapter one will Show the introduction, this chapter covers some aspects of the general information about the Project, background of the problems, statement of the problems, thesis objectives, and scope of thesis are also presented in this chapter.

2- Chapter two will be discussing the literature review.

3- Chapter three will be talking about the research methodology.

4- Chapter four will draft the results.

5- Chapter five will Shows the summary of entire work, conclusions and recommendations for future research.

1.9.2- Thesis Outline

Below is the proposal the steps of this study. ‘Title, research problem, research objectives, research scope, research methodology’ Expected result and thesis planning are correlates to each other.

Project background

When, flow of fluid through the tube banks into the heat exchanger. There, a rise in pressure drop and increase in heat transfer through the tube banks, because there Vortices behind the tubes. Where, the properties of the fluid in that region are changing rapidly. During that moment, they are causing pressure drop and increase of heat transfer.

Research Title

Numerical study on heat transfer and fluid flow characteristic of tube bank with integral wake splitters

Problem Statement

Heat exchanger design is a complex problem which involves both quantitative calculations and qualitative judgments. The amount of pressure drop and heat transfer is highly dependent on the geometry of the tube bank. Where, vortices behind the tubes are causing to change the properties of the fluid on those regions a rapidly. Meanwhile they are causing (pressure drop and heat transfer).

Research Objectives

The purpose of this project is using Computational Fluid Dynamics (CFD) to study on heat transfer and fluid flow characteristic of tube bank with integral wake splitters. Where, heat transfer and pressure drop represent coefficients those imposed on the flow by each successive row of tubes.

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Scope of Research Study

Scopes of study are:

1. Design of model using the (Gambit).
2. Analysis the model using the (Fluent).
3. Study will be conducting when the Reynolds number based on tube bank diameter.

$$10000 < Re < 50000$$

4. Studying a Pressure drop and a heat transfer between an entrance and an outlet of tube bank.

Significance of the study

There are many studies on the effects of fin is only done on a single tube. There has been no farther study was conducted on the effect of weak splitters to heat transfer and fluid flow characteristic to tube bank. This project aims to improve the heat exchanger performance. Through decreasing the pressure drop and Increase the heat exchange.

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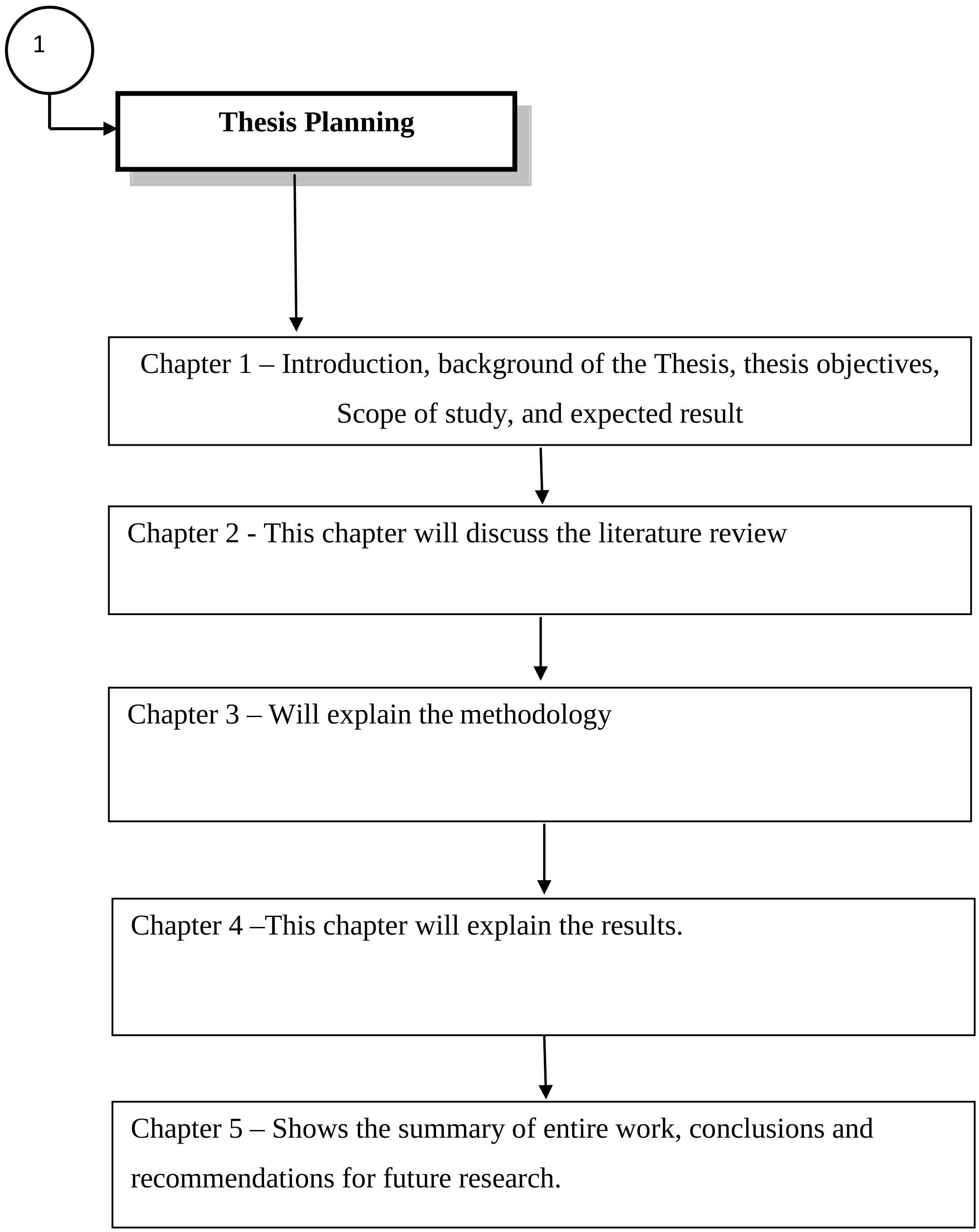
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Thesis Planning
Chapter 1 – Introduction, background of the Thesis, thesis objectives, Scope of study, and expected result
Chapter 2 - This chapter will discuss the literature review
Chapter 3 – Will explain the methodology
Chapter 4 –This chapter will explain the results.
Chapter 5 – Shows the summary of entire work, conclusions and recommendations for future research.

1.10- Conclusion

Chapter one covers some characteristic when the fluid flows around cylinder. Methods used to improve performance of heat exchangers, thesis problems, Project background, thesis objectives, Problem Statement, Scope of Research Study, Significance of the study, Research organization.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Heat exchangers with a tube array are commonly used in air-conditioning industry and in air-cooled condensers of power plants. One of the challenging tasks for researchers is to optimize the arrangement of tube bundles. The flow fluid inside heat exchangers is associated with maximum heat transfer and minimum pressures drop/pumping power.

The information accumulated from earlier work serves as a basis to bring into perspective the later work on tubes and tube bundles. In a bank of tubes, each tube has a neighbor in the longitudinal or lateral direction. The influence of the neighbors is considerable for Close-pitched tubes, in the direction of flow. Also, a number of reports have been published in recent years describing attempts to modify the boundary layer on the circular cylinder in transverse air flow, and these studies are explaining that:

(McClintock, 1951) was the first one who employed the concept of irreversibility for estimating and minimizing the usable energy wasted in heat exchangers design. Bejan (1977, 1982) presented an optimum design method for balanced and imbalanced counterflow heat exchangers. He proposed the use of a “number of entropy production units” Ns as a basic parameter in describing heat exchanger performance. This method was applied to a shell and tube regenerative heat exchanger to obtain the minimum heat transfer area when the amount of units was fixed. Later on, Aceves-Saborio et al. (1989) extended that approach to include a term to account for the energy of the heat exchanger material. Grazzini and Gori (1988) Sekulic (1990), Zhang et al. (1997), Ordonez and Bejan (2000) and Bejan (2001, 2002) demonstrated that the optimal geometry of a counterflow heat exchanger can be determined based on a thermodynamic optimization subject to volume constraint. Yilmaz et al. [2001] first recalled and discussed the need for the systematic design of heat exchangers using a second-law-based procedure and then presented second-law-based performance evaluation criteria for heat exchangers. Entropy generation rate is generally used in a dimensionless form. Unuvarn and Kargici [2004] and Peters and Timmerhaus (1991) presented an approach for the optimum design of heat exchangers.

They used the method of steepest descent for the minimization of annual total cost. They observed that this approach is more efficient and effective to solve the design problem of heat exchangers. Optimization of plate-fin and tube-fin crossflow heat exchangers was presented by Shah et al. (1978) and Van den Bulck (1991). They employed optimal distribution of the UA value across the volume of crossflow heat exchangers and optimized different design variables like fin thickness, fin height, and fin pitch. Cylinder geometry was optimized in a paper by Poulikakos and Bejan (1982) and Khan et al. (2003). After the general formula was derived using the entropy generation minimization (EGM) method analytical methods and graphical results were developed that resulted in the optimum selection of the dimensions of several different fin configurations. Bejan et al. (1996) showed that EGM may be used by itself in the preliminary stages of design, to identify trends and the existence of optimization opportunities. In two different studies, Stanescu et al. (1996), and Matos et al. (2001) demonstrated that the geometric arrangement of tubes/cylinders in crossflow forced convection can be optimized for maximum heat transfer subject to overall volume constraint. They used FEM to show the optimal spacings between rows of tubes. Vargas et al. (2001) documented the process of determining the internal geometric configuration of a tube bank by optimizing the global performance of the installation that uses the cross flow heat exchanger.

2.2 Tube and Tube Banks

In a bank of tubes, each tube has a neighbour in the longitudinal or lateral direction. The influence of the neighbours is considerable for close-pitched tubes. In the direction of flow, a tube is immersed in the wake of another tube, Examined the two dimensional, non-homogeneous flow over a circular cylinder immersed in the wake of another identical cylinder. He found that the aerodynamic parameters are determined by the oncoming wake flow which is characterized by variations of velocity, static pressure and turbulence quantities in both the lateral and longitudinal directions. The mean lift on the rear cylinder, when the two cylinders are not aligned with the free stream flow direction, is directed towards the centerline of the oncoming wake, which is opposite to the direction predicted by in viscid flow theory. The main factors contributing to the generation of this lift force are identified as (i) the static pressure gradient in the approaching flow and (ii) the gradient of turbulence intensities between the two sides of the rear cylinder which affects the boundary layer development on both sides, resulting in asymmetrical separation points and pressure distribution.

Study Endres, L. et al, This study was entitle (some characteristics of the fluctuating wall pressure field in tube bank), This study was focused on analysis of pressure and velocity fluctuations of the cross flow in tube banks, with triangular and square arrangements, and four different aspect ratios.

Study J. R. Culham and M. M. Yovanovich 2007, this study was entitle (Optimal Design of Tube Banks in Crossflow Using Entropy Generation Minimization Method). This study was designed to reduce losses geothermal heat transfer and pressure drop for fluid flow in the banks of tubes, through the evaluation of the combined effect of heat transfer and pressure drop at a time through interaction with the banks of tubes, the results of this study that there is a range of different variables affect the heat transfer and low pressure in the banks of tubes at one time and also there are other variables such as engineering standards and conditions of fluid flow in pipes.

Hilton and Generous, (1933) suggested the general correlations of the friction factor in a turbulent flow. This correlation is slightly conservative for staggered banks but gives low pressure losses for in-line banks. Gunter and Shaw (1945) also suggested the correlation equation of the friction factor using an equivalent. Volumetric hydraulic diameter in a turbulent flow. This correlation gives a rather good representation of data from both in-line and staggered banks for a turbulent flow. Grimison (1937) attempted graphical correlation of the extensive data for heat transfer and pressure drop of Huge (1937) and Pierson (1937). His correlation is the best method for representing available data for various configurations in the Reynolds number range of 2.000 to 40.000. As an alternative. Jakob (1938) proposed an expression for representing the friction factor in terms of tube spacing. An excellent critical comparison of pressure data and the proposed correlation was given by Boucher and Lapple (1948).

Pierson (1937) this study was about a large number of tube arrangements in the bank at Reynolds numbers between 2,000 and 40,000. Huge (1937) tested different tube diameters at Reynolds numbers ranging from 2,000 to 70,000. He confirmed the validity of the principle of similarity applied to the tube banks in spite of some departure from the true geometric similarity in the ratio of length to diameter or to the intertube space. Brevoort and Tifford (1942) detailed the flow conditions in a bank of staggered circular tubes, especially to clarify the physical picture of the phenomena occurring in tube banks with Reynolds numbers over 2 x 104.

Kays and London tried to extend the available data to lower Reynolds numbers. From 1,000 to 10,000, for a flow of gases normal to banks of circular tubes of small diameter in various staggered arrangements (1952) and in-line arrangements (1954) Mc Adams (1942) discussed the effect of the Prandtl number and large differences in temperature dependent properties in a wide range Reynolds numbers from laminar to turbulent flow. Laminar flow and pressure drop across tube banks has been investigated by Bergelin et al. (1949, 1950, and 1952). They tested different variables. Such as tube arrangement and tube diameter, for Reynolds numbers less than 1.000 and suggested correlation equations for the flow and pressure drop. The nondimensional viscosity term was added into the general pressure drop correlation equations to predict the large differences in temperature dependent properties.

Jones, Monroe (1958) and Gram: Mackey and Monroe (1958) in two companion papers. Reported and correlated overall pressure drop and heat transfer coefficients in a cross-air flow with different temperature ranges. Fairchild and Welch reported new heat transfer and pressure drop data after correcting some deficiencies in the above two papers. They examined a cross-air flow over ten row deep tube bundles within a range of Reynolds numbers between 1.000 and 20.000.Also. In another paper by Welch and Fairchild (1964) obtained heat transfer coefficients on the individual rows of the tube banks under various pitch ratio arrangements across ten rows in in-line tube banks.

The most recent series of investigations has been carried out by Zukauskas and his coworkers to study rates of pressure drop in the cross flow over bundles of smooth tubes. One of these investigations By Samoshka et al. (1968).Was of a closely-spaced staggered tube bundle of large diameter smooth tubes in water streams within a turbulent region. They found that the efficiencies of the bundles from an energetic point of view increases as the tube spacing of the bundles decreases. Zukauskas (1972) reported the pressure and hydrodynamic resistance of single tubes and banks of tubes of various arrangements in flows of gases and v-viscous liquids at higher Reynolds numbers and various Prandtl numbers from 0.7 to 500. Pressure drops for each row in the tube bundle were compared. And the influence of the properties of fluids, Different ranges of Prandtl numbers from 3 to 7 were considered by Zukauskas and Ulinskas (1978) for in-line and staggered tube bundles in a cross flow of water at Reynolds numbers ranging from 5 x 104 to 2 x 106. They considered the patterns of the pressure drop in a critical flow past the bundles and determined the optimal configurations and geometries of the tube bundles, in a cross flow of oil at Reynolds numbers from 1 to 2 X 104.

Two papers of the Engineering Science Data Item covered a wide range of regular arrays of in-line and staggered tubes for the heat transfer coefficient and pressure drop (1973) over tube banks, in these data, based on existing experimental data, the various variables, such as the number of tube rows, Different pitch ratios, Inlet turbulence, And tube inclination to the cross flow. Were considered in order to correlate various variables of the cross flow.

A. Page and J.H.Warsap, British Aero. Res. 1930, "Effect of Roughness and Stream Turbulence on the Drag of Circular Cylinders", This study was showed that free stream turbulence surface roughness and surface roughness elements all had a systematic effect on the relationship of drag coefficient to Reynolds number, investigations of the boundary layer on a cylinder where the influence of Reynolds number and turbulence was demonstrated, particularly near the separation point. A most extensive and precise measurement of the local variation of the heat transfer coefficient around a cylinder was made by Schmidt and Werner

Study. Jayavel and Shaligram Tiwari 2008, This study was entitle (Numerical study of heat transfer and pressure drop for flow past inline and staggered tube bundles), this study was developed an indigenous three-dimensional computational code and apply it to compare flow and heat transfer characteristics for inline and staggered arrangement of circular tubes in a tube bundle. A finite volume-based numerical investigation is carried out to study the flow and heat transfer for flow past inline and staggered arrangement of tube bundles confined in a rectangular channel. The investigations are performed after thorough grid independence study and the computed results are validated against those available in literature. The present investigation identify the range of Reynolds number in which staggered arrangement of tubes in a tube bundle provide more heat transfer causing less pressure drop compared with inline arrangement of tubes. However, at lower Reynolds numbers inline arrangement of tubes are found to be preferable due to heat transfer and smaller pressure drop.

Recently Zukauskas (1980) reviewed the various schemes and types of air-cooled heat exchangers. He examined pressure drop of different configurations of smooth and rough, or finned, tube banks in a cross flow of air at Reynolds numbers ranging from 1 to 107, which gives an opportunity to characterize in detail the process of pressure drop in sub critical, critical and supercritical flow ranges.

Mueller (1983) has reviewed some alternate correlation between Delaware's data by Bergelin et at. Anddata by Zukauskas et al, at low Reynolds numbers. It was pointed out that the Delaware and Russian data have good agreement (within 10%) for the in-line arrangement of 1.5 pitch ratio. but the two curves have slightly different slopes for the staggered arrangement.

2.3 Tubes with wake splitters

The conventional augmentation techniques aim to increase heat transfer without a proportionate increase in pressure drop. Another approach to augmentation of heat exchanger performance is to reduce the pressure drop without a proportionate reduction or even no reduction in heat transfer. This approach is of particular value for gases such as air, since the cost. This was attributed to the fact that the splitter plate altered the downstream flow to a separated and reattached boundary layer enclosing a region of reverse flow between it and the surfaces of the plate and the cylinder.

Tiwari, D. Chakraborty, G. Biswas P.K. Panigrahi 2004 (Numerical prediction of flow and heat transfer in a channel in the presence of a built-in circular tube with and without an integral wake splitter) This study was focused on the coefficient of pressure, coefficient of drag, vortex structure, limiting streamlines and heat transfer with the chord length of the splitter plate. This study has shown that the characteristics of the wake downstream of a circular tube can be altered by placing a splitter plate on the wake centerline downstream of the circular tube. Flow visualization indicated that a splitter plate produced a stabilizing effect via reduction of transverse flapping of the shear layers. The splitter plate streamlines the flow. The vortices are pushed downstream, followed by narrowing of the wake. Usually, the plate does not inhibit the formation of vortices, but the vertical motion does not extend far downstream. The heat transfer is decreased from the tube surface. However, the presence of the splitter plate increases the total heat transfer substantially by complementing for extended surface heat transfer. Hence, the splitter plate results in an overall enhancement of heat transfer. The splitter plate being a slender body reduces the pressure loss penalty significantly.

Study W.A. Khan and others 2006, This study was entitle (Convection heat transfer from tube banks in crossflow: Analytical approach), in this study Heat transfer from tube banks in crossflow was investigated analytically and simplified models of heat transfer for both arrangements (in-line and staggered). The results obtained from this study are as follows: Both models can be applied over a wide range of parameters and are suitable for use in the design of tube banks. The average heat transfer coefficients for tube banks in crossflow depend on the longitudinal and transverse pitches, Reynolds and Prandtl numbers. Compact banks (in-line or staggered) indicate higher heat transfer rates than widely spaced ones. The staggered arrangement gives higher heat transfer rates than the in-line arrangement.

Study   Bengt Sunden, Lund University, Lund, Sweden, 2010 Was entitle (Simulation of compact heat exchanger performance) The purpose of this study was presenting some methods to analyses and determine the performance of compact heat exchangers; show the applicability of various computational approaches and their limitations, provide examples to demonstrate the methods, and present results to highlight the opportunities and limitations of the considered methods. A description of computational procedures for compact heat exchangers was provided. Rating and sizing methods as well as CFD procedures for analysis of heat transfer and fluid flow for surfaces in heat exchanger applications were presented.

Examples to demonstrate the methods were provided.

Problems and difficulties were outlined.

It is found that computational heat transfer methods of various kinds, complexities etc. are useful tools if carefully handled. However, there are several constraints, difficulties and limitations to be aware of Simulation of compact heat exchanger performance.

REFERENCES:

Aceves-Saborio, S., Ranasinghe, J., and Reistad, G. M. (*An Extension to the Irreversibility Minimization Analysis Applied to Heat Exchangers*) Journal of Heat Transfer, Vol. 111, No. 1, 1989, pp. 29–36.

A.Page and J.H.Warsap, Aero. Res. Council, "*Effect of Roughness and Stream Turbulence on the Drag of Circular Cylinders*". UK, 1930.

A.Zukauskas and J. Ziugzda, (*Heat Transfer of a Cylinder in Cross Flow*). Washington D. C: Hemisphere, 1985.

Bejan, A., "*Fundamentals of Energy Analysis, Entropy Generation Minimization, and the Generation of Flow Architecture*," International Journal of Energy Research, Vol. 26, No. 7, 2002, pp. 545–565.

Bejan, A., *Entropy Generation through Heat and Fluid Flow,* John Wiley & Sons, New York, 1982.

Bejan, A., (*The Concept of Irreversibility in Heat Exchanger Design: Counterflow Heat Exchangers for Gas-to- Gas Applications*) Journal of Heat Transfer, Vol. 99, Aug. 1977, pp. 375–380.

Bergelin, O. P., Hull, G. A., and Sullivan, F. W., *Heat Transfer and Fluid Friction during Viscous Flow* .4.cross Banks of Tubes III, Trans. ASME, Vol. 72, pp, 881-888, 1950. Bergelin, O. P., Brown, G. A., and Doberstien, S. C., *Heat Transfer and Fluid*

Friction during Flow across Banks of Tubes IV, Trans. ASME, Vol. 74, pp. 953-960, 1952.

Bengt Sunden, Lund University, Lund, (*Simulation of compact heat exchanger performance*). Sweden, 2010.

Boucher, D. F., and Lapple, C. E., *Pressure Drop across Tube Banks: Critical Comparison of Available Data and of Proposed* J'lethods of Correlation; Chemical Engineering Progress, Vol 44, No.2 pp. 117-134, Feb., 1948.

Chilton, T. H. And Genereaux, R. P., *Pressure Drop across Tube Banks.* Trans. Aiche, Vol. 29, pp. 161-173, 1933.

E. S. Gaddis, and V. Gnielinsky, (*Pressure Drop in Cross Flow across Tube Bundles*), International Journal of Chemical Engineering, 1985).

Fluent Inc. October 12, 2006.

Grimison, E. D., *Correlation and Utilization of New Data on Flow Resistance and Heat Transfer for Cross Flow of Gases Ot'er Tube Banks.* Trans. ASME. Vol. 59, pp... 583-594, Oct., 1937.

Grazzini, G., and Gori, F. (*Entropy Parameters for Heat Exchanger Design*) International Journal of Heat and Mass Transfer, Vol. 31, No. 12, 1988, pp. 2547–2554.

Gunter, A. Y., and Shaw, W. A., .4 *General Correlation of Friction Factors for various Types of Surfaces in Crossflow*, Trans. ASME, Vol. 67. 1945.

Huge, E. C., *Experimental Investigation of Effects of Equipment Size on Connection Heat Transfer and Flow Resistance in Cross Flow of Gases over Tube Banks*, Trans. ASME, Vol. 59, pp. 573-.581, 1937.

.

J.R.Culham and M.M.Yovanovich University of Waterloo, Waterloo N2L 3G1, (*Optimal Design of Tube Banks in Crossflow Using Entropy Generation Minimization Method*). Canada 2007.

Johan H.lienhard (*A heat transfer text book Third Edition*) Cambridge Massachusetts .U.S.A. 2004.

Jones, C.E.Monroe, E.S., *Convection heat transfer and pressure drop of air flowing across in –line tube banks*. Part I, trans. ASME vol.80.pp.18-24, 1958.

Kakac Setal.(*Heat exchangers thermal and hydraulic fundamentals and design*)Hemisphere Publishing Corp., New York, 1981.

Kays, W.M., and London, A. 1., *Basic Heat Transfer and Flow Friction Design Data for Gas Flow Normal to Banks of Staggered Tubes - Use of Transient Technique*, Tech. Rpt. 15, Stanford Univ., Aug., 1952.

Khan, W. A., Culham, J. R., and Yovanovich, M. M., "*The Role of Fin Geometry in Heat Sink Performance*," presented at International Electronic Packaging Technical Conference and Exhibition, American Society of Mechanical Engineers, New York, 2003; also Journal of Electronic Packaging (to be published).

M.A.Mehrabian University of Kerman (*Heat transfer and pressure drop characteristics of cross flow of air over a circular tube in isolation and/or in a tube bank*). Iran 2008.

Matos, R. S., Vargas, J. V. C., Laursen, T. A., and Saboya, F. E. M., "*Optimization Study and Heat Transfer Comparison of Staggered Circular and Elliptic Tubes in Forced Convection,"* International Journal of Heat and Mass Transfer, Vol. 44, 2001, pp. 3953–3961

McClintock, F. A., (*The Design of Heat Exchangers for Minimum Irreversibility*) ASME Paper 51-A-108, 1951.

McAdams, W. H., Heat Transmission, McGraw-Hill' Company. Inc., New York, N. Y., 1942.

Moneno, A. A. Y., *Heat Transfer and Pressure Drop in Tube Bank Inclined with Respect to the Flow*, Ph.D. Thesis, University of Minnesota, 1985.

Mueller A. C., *Experimental Data and Correlations for Tube Banks. Low Reynolds number heat exchanger design*, hemisphere pub., 1983.

Ordonez, J. C., and Bejan, A., "*Entropy Generation Minimization in Parallel-Plates Counterflow Heat Exchangers,"* International Journal of Energy Research, Vol. 24, No. 10, 2000, pp. 843–864.

Osama Abd Elhamid (*An Experimental and Numerical Investigation of Tube Bank Heat Exchanger Thermo fluids*). Abu Dhabi, United Arab Emirates 2008.

Omohundro. G. A., Bergelin, O. P., and Colburn, A. P., *Heat Transfer and Fluid Friction during Viscous Flow Across Banks of Tubes*, Trans. ASME, Vol. 71, pp. 27-34, 1949.

Peters, M., and Timmerhaus, K., Plant *Design and Economics for Chemical Engineers*, 4th ed., McGraw–Hill, Singapore, 1991.

Pierson, O. L., *Experimental Investigation of the Influence of Tube Arrangement on Convection Heat Transfer and Flow Resistance in cross Flow of Gases over Tube Banks*, Trans. ASME, Vol. .59, pp. 563-572, 1937.

Samoshka, P. S., Makaryavichyus, V. I, Shlanchyauskas, A.A., Zhyughda, II, Zukauskas, A. A., *Heat Transfer and Pressure Drop for Closely Spaced Tube Banks in Water Flow*, International Chemical Engineering, Vol. 18.No.3, pp.388-392, 1968.

Sekulic, D. P.(*The Second Law Quality of Energy Transformation in a Heat Exchanger*) Journal of Heat Transfer, Vol. 112, May 1990, pp. 295–300.

S Jayavel and Shaligram Tiwari, Institute of Technology Madras, Chennai, India. This study was entitle (*Numerical study of heat transfer and pressure drop for flow past inline and staggered tube bundles*), Indian.2008.

Shah, R. K., Afimiwala, K. A., and Mayne, R. W., "*Heat Exchanger Optimization,"* Proceedings of the Sixth International Heat Transfer Conference, Vol. 4, Hemisphere Publishing Corporation, Washington, DC, 1978, pp. 185–191.

S. Tiwari, D. Chakraborty, G. Biswas P.K. PanigrahiInstitute of Technology Kanpur (*Numerical prediction of flow and heat transfer in a channel in the presence of a built-in circular tube with and without an integral wake splitter*). Indian. 2004

Stanescu, G., Fowler, A. J., and Bejan, A., "*The Optimal Spacing of Cylinders in Free- Stream Crossflow Forced Convection,"* International Journal of Heat and Mass Transfer, Vol. 39, No. 2, 1996, pp. 311–317.

S. Tiwari, D. Chakraborty, G. Biswas P.K. Panigrahi Indian Institute of Technology Kanpur (*Numerical prediction of flow and heat transfer in a channel in the presence of a built-in circular tube with and without an integral wake splitter*). Indian .2004.

Tao Xing and Fred Stern IIHR-Hydro science (*Mechanics of Fluids*) & Engineering the University of Iowa. 2000

Unuvarn, A., and Kargici, S., "*An Approach for the Optimum Design of Heat Exchangers*," International Journal of Energy Research, Vol. 28, No. 15, pp. 1379–1392.2004

Vargas, Jose, V. C., Bejan, A., and Siems, D. L., "*Integrative Thermodynamic Optimization of the Crossflow Heat Exchanger for an Aircraft Environmental Control System*," Journal of Heat Transfer, Vol. 123, Aug. 2001, pp. 760–769.

Van Den Bulck, E., "*Optimal Design of Crossflow Heat Exchangers*," Journal of Heat Transfer, Vol. 113, No. 2, 1991, pp. 341–347.

W.A. Khan and others, University of Waterloo, Waterloo, Ont. (*Convection heat transfer from tube banks in crossflow Analytical approach*). Canada .2006.

Welch, C. P., and Fairchild, H. N., *Individual Row Heat Transfer in A Crossflow: In- line Tube Banks*, Trans. ASME, Vol. • pp. 143-148. 1964.

Yilmaz, M., Sara, O. N., and Karsli, S., "*Performance Evaluation Criteria for Heat Exchangers Based on Second Law Analysis*," Energy, Vol. 1, No. 4, pp. 278–294.2001.

Y.Nakayama. Former Professor, (*Introduction to Fluid Mechanics*).Tokai University, Japan and UK Editor R. F. BOUCHER Principal and Vice Chancellor, UMIST, 2000.

Zhihua Li, Jane Davidson and Susan Mantell(*Numerical simulation of fluid field and heat transfer of streamlined cylinder in crossflow*).U.S.A. 2005

Zhang, L. W., Balachandar, S., Tafti, D. K., and Najjar, F. M.(*Heat Transfer Enhancement Mechanisms in In-line and Staggered Parallel- Plate Fin Heat Exchangers*) International Journal of Heat and Mass Transfer, Vol. 40, No. 10, 1997, pp. 2307–2325.

Zukauskas, A. A .*Heat Transfer from Tubes in Crossflow. Advanced heat transfer*, Vol. 8, PP.93-160, Academic press, New York, 1972.

Zukauskas, A. A.,Ulinskas, R. V., *Heat Transfer Efficiency of Tube Bundles in Crossflow at Critical Reynolds Numbers*, Heat Transfer-Soviet Research, Vol. 10, No.5, pp. 9-15, 1978.

Zukauskas, A. A., *Air Cooled Heat Exchangers, Heat Exchanger*. : McGraw Hill Company, New York, 1980.