HEAT EXCHANGER FOR SOLAR COLLECTOR

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ABSTRACT

The objective of this study is to design and simulate an optimum heat exchanger for evacuated tube solar collector. The simulation was carried out in ANSYS FLUENT 14.0 with two different tube designs, spring and S-Shape. Four materials was analysed in this study, copper, aluminium, steel and brass. Both tube designs are varied by three different sizes and four shapes, circular, ellipse, square and hexagon. There are four flow rates are considered in the study, 1kg/s, 0.5kg/s, 0.25kg/s and 0.01kg/s. Based on the study, copper 61.25% effective compare to aluminium and followed by steel and brass. In the overall, spring design performs better than S-Shape design and ellipse shape tube in leading. At the flow rate of 1kg/s, large size ellipse-spring tube design provide higher performance with rate of heat transfer 109192.02W. At flow rate of 0.5kg/s and 0.25kg/s medium size ellipse-spring tube design performs better than the others. While at the flow rate of 0.01kg/s, small size ellipse-S-Shape design is chosen.

ABSTRAK

Tujuan utama kajian ini adalah untuk merangka dan membuat simulasi bagi perubahan haba dalam tiub penyimpan solar. Simulasi tersebut dijanlankan megunakkan ANSYS 14.0 dengan megunakan dua reka bentuk iaitu spring dan tiub berbentuk-S. Empat bahan yang berbeza iaitu kuprum, aluminium, besi dan juga tembaga. Reka bentuk tersebut juga dikaji dengan tiga jenis saiz yang berbeza dan juga empat jenis reka bentuk yang berlainan iaitu bujur, elips, segi empat tepat dan juga segi enam. Empat jenis halaju yang dicuba bagi penyelidikan ini iaitu 1kg/s, 0.5kg/s, 0.25kg/s and 0.01kg/s. Mengikut kajian yang telah dibuat, kuprum menujukkan keputusan yang paling tinggi iaitu sabanyak 61.25% diikuti dengan aluminium, besi dan tembaga. Secara keseluruhanya, reka bentuk spring menjukkan keputusan yang lebih baik daripada reka bentuk S. Pada halaju 1 kg/s, saiz besar elips reka bentuk spring menjukkan keputusan yang baik dengan kadar pemindahan haba 109192.02W dan bagi halaju 0.5 kg/s dan 0.25 kg/s, tiub bersaiz medium menjukkan keputusan yang lebih baik. Manakal, pada halaju 0.01 kg/s, tiub berbentuk kecil menjukkan reka bentuk yang terbaik.

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LIST OF SYMBOLS

°C	Degree Celsius
K	Kelvin
p	Density
Cp	Specific Heat
Re	Reynolds number
Nu	Nusselt number
A_{cs}	Cross section area
ε	Emissivity
°	Degree
%	percentage
v	Velocity
μ	Viscosity
D	Diameter
l_e	Length-entrance
$\dot{m}$	Mass flow rate
T	Temperature
U	Total heat transfer coefficient
h	Heat transfer coefficient
k	Thermal conductivity

LIST OF ABBREVATIONS

FPC	Flat Plate Collector
ETSC	The Evacuated tube solar collector
CFD	Computational Fluid Dynamics
CAD	Computer Aided Design
3D	3-Dimensional
EXTEK	Twisted multi head annulus tube
CuO	Copper (II) Oxide
Al_2O_3	Aluminium Oxide
SiO_2	Silicon Dioxide
Re	Reynolds Number
Nu	Nusselt Number
T_{out}	Temperature out of cold fluid

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

Heat exchanger is a device used to transfer heat from one medium to another. The heat transfer equipment's are used since the dawn of civilization. The first heat exchanger were introduces by Alfa-Laval on 1938 and Pontus Hytte develop and do the first production to Lund. On 1962, AB Rosenblad's patents come up with a spiral and the series of plate design heat exchanger and the designs become highly demand on 1976. As the time flows, a lot of researcher have conducted vary researchers to increase the efficiency of the heat exchanger.

Basically heat exchanger is a device which has both hot and cold fluid in a closed volume and being separated by solid wall. Nowadays, heat exchanger widely used in vary areas such as solar collector system, refrigeration, power plants, sewage treatment, chemical plants, petroleum refineries, air conditioning, petrochemical plants, space heating and natural gas processing. In solar collecting system, the heat exchanger working as a medium to transfer the thermal energy gathered by the fluid inside the solar collector to the cold or room temperature fluid and return back to the collector. The hot and cold fluid will constantly flow in their circuits to continuing heat transfer.

As the demand for energy rapidly increasing, there are a lot of studies are being conducted to enhance the performance of the heat exchanger. The effectiveness of a heat exchanger depend on vary characteristic fluid, type of flow, material used as wall among them, mass flow rate of the fluids, shape and design of the tubes, wall and the additional fins.

1.2 PROBLEM STATEMENT

It is true that, in term on heat transfer and for heat exchanger model, there are many improvements that had been made compare to the early days.

H. Y. Zhang, M. A. (1992). Convective heat transfer in the thermal entrance region of parallel-flow noncircular duct heat exchanger arrays.

LUNSFORD, K. M. (1998). Increasing Heat Exchanger Performance.

Even though the heat transfer term has been used for centuries; there are no fully efficient heat exchangers in market. However there are not much study has been conducted on enhancing effectiveness of heat exchanger inside the storage tank. With the continuous study and research there are a lot more ways to be found to enhance the performance. The purpose of this study is to simulate an optimum heat exchanger for evacuated tube solar collector. Vary materials, flow rate, size, shape and design of tubes will be analyse using ANSYS FLUENT 14.0.

Rao, S. K. (2007). Analysis of flow maldistribution in tubular heat exchangers by fluent.

1.3 THE OBJECTIVE OF THE STUDY

To design and simulate a heat exchanger inside the storage tank for evacuated tube solar collector.

1.4 SCOPE OF PROJECT

The scope of the project:

I. Limited to 3-dimensional modelling, meshing and simulation using ANSYS WORKBENCH & FLUENT 14.0 under academy license.
II. The value of flow rate based on current system at Solar House UMP.
III. The temperature of hot fluid considers being maximum, 373K.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter provides the review from previous research efforts related to heat transfer, heat exchanger and the enhancement methods. This chapter also involves a review of some research studies like the statistical method , numerical methods and experimental methods which are related to the mathematical modelling the present study. Substantial literature has been studied on ability of material on thermal conductance, flow rate of fluid, type of flow, shape and design of tubes and the vary designs of heat exchanger. This study has been made in order to help identify proper parameters involved for this modelling and simulation. The review is fairly detailed so that the present research effort can be properly tailored to add to the current body of the literature as well as to justify the scope and direction of present.

2.2 SOLAR COLLECTORS

Solar collector is a main component of this solar collecting system. It works as a special kind of heat exchanger that modifies solar radiation energy to the internal energy of the transport medium. The main purpose of the solar collector it to absorb the incoming solar radiation and convert into heat and transfers the heat to the working fluid. The collected solar energy will be carried by circulating fluids. The fluid could be either directly in use or to storage tank, from where the energy can be saves for use in the absence of sun.

There are two types of solar collectors in market. The stationary or non-concentrating solar collector and concentrating solar collector are widely in use. The stationary collectors are permanently fix in position and has same area for intercepting and for absorbing the solar radiation. However the concentrating collector usually has concave reflecting surface to intercept and focus the solar radiation beam to a specific area, which increases the radiation flux (Soteris A. Kalogirou, 2004).

The solar energy collectors are distinguished by their motion, stationary, single axis tracking and two axis tracking and the operating temperature.

2.2.1 Flat Plate Collector (FPC)

Flat Plate Collector (FPC) is typically fixed in a permanent position. The purpose of FPC is to collect as much as possible solar thermal energy at the lowest possible cost. When the solar radiation passes through the transparent cover on top of it and it impinges on the blackened absorber surface, which has high absorptivity. A large portion of this solar energy will be absorbed by the plate and then transferred to the transport medium in the fluid tubes to be carried away for use or storage. The side casing and the underside of the absorber plates are well insulated to reduce heat loss through conduction. The transparent cover is added to reduce the convection losses from the absorber plate by the restraint of the stagnant air layer between the glass and the absorber plate and also to reduces the radiation losses from the collector as the glass is transparent to the short wave thermal radiation received by the sun but it is nearly opaque to long wave radiation emitted by the absorber plate.

The flat plate solar collectors has to be oriented directly towards the equator, which facing south in the northern hemisphere and north in the southern. The optimum tilt angle of the collector is equal to the latitude of the location with angle variations of 10° -15°, depending on the applications.

2.2.2 Evacuated Tube Solar Collector

The Evacuated tube solar collector (ETSC), working as reheating system in circulating water. The ETSC working system is opposite to FPSC. The flat plate solar collector is climate sensitive. Therefore it can only be used under Tropical country or at the time when the intensity of the solar radiation is substantially high. Their efficiency reduces when it exposed to cold, cloudy and windy day. However Evacuated Tube Solar collector works as the same principle as leaving a jar under the sun and let it content to heat up. Evacuated tube solar collector is not sensitive of climate change. There are many researchers has concluded that Evacuated Tube Solar Collector (ETSC) have higher efficiency compare to Flat Plate Collector (FPC) (Gordon and Society, 2001; Morrison et al., 2005).

ETSC consists of two glass tube which made of extremely strong glass. The outer tube has very high transitivity and low reflectivity. It enables the radiation to passes through and high emissivity which blocks the radiation from loss back through the glass. The inner tube has a selective coating layer which can maximizes absorption of solar energy while minimizes the refection, thereby it locking the heat. The tubes which are sealed with copper pipe continuously bonded to a selectively coated copper fin or absorber plate which collects the solar energy and convert it to heat. The energy is conducted to the working fluid in heat pipe and vaporise it. The vapour rises to the condenser bulb at a higher elevation, where the heat transfer happens and the condensate returns to the collector heat zone by gravity. At this evacuation process the air is pumped out from the cavity. The main purpose of the vacuum created is to recreate the thermos flask and let vacuum act as insulator which block the infrared radiation from escape through glass tube. The absorber plate on the internal surface of the inner glass tube collects all the solar radiations passes through the glass layer. This effect tends to give advantages to ETSC over FPC in day long performance and be efficient at season climate area.

The most effective absorbers are aluminium and copper which has high heat reflectivity and transitivity quotient. The surface of the absorber tube has been blackened to make it act as black body and ideally has $a = \varepsilon \sim 1$. The area of absorber has to be maximizing to make sure the absorber plate is placed in direct contact with the inner glass tube (Siddharth Arora, 2011). The absorbed energy can be transfer directly or indirectly based on the design. In the indirect method, the secondary fluids, which can be water, liquid refrigerant or a nanofluid, transfer the heat to the working fluid with the aid of the heat exchanger (Gordon and Society, 2001).

2.3 HEAT EXCHANGER

Ramesh.k and et.all, 2003, pp1 states that heat exchanger can be classified according to the geometry construction, flow arrangement, heat transfer mechanisms and the type of transfer process. According to Kelvin M. Lunsford, 1998, the performance of heat exchanger can be enhancement by either passive or active method. In passive method, the extended inserts, surface, coiled or twisted tubes, surface treatment and additives will be used to enhance the efficiency. While in active methods electrostatic fields, surface vibration, injection and suction will be considered to increase the performance.

2.3.1 Geometry Construction of Heat Exchanger

Typically the heat exchanger characterized by its conduction feature. There are four major conduction features in count, which are tubular, plate, extended surface and regenerative exchanger. The tubular heat exchangers are made of tubes. There will be a fluid flow inside and the outside of the tube. The tube designs need to be considered about the diameter, shape, number, pitch and the arrangement of the tube. The tubular heat exchanger commonly used for liquid to liquid and liquid to phase change heat transfer applications. The tubular heat exchanger can be classified as shell and tube, double pipe and spiral heat exchanger.

Kelvin M. Lunsford, 1998, stated that shell and tube heat exchanger is among the most commonly used exchanger in the industry process and it can easily be modified based on needs and provides large ratio of heat transfer area to volume and weight. There are various shape of tubes are being manufactured in shell and tube heat exchanger. The straight or U-tube bundles are widely used because they provide least expensive construction and easy for cleaning. U-tube has advantage over straight tube bundle in rate of heat transfer and also least expensive. However it cannot be clean mechanically and it only works in even number of tubes.

According to Sadik Kakac and Hongtan Liu, 2002, pp8-11, stated that there are various type of shell and tube heat exchanger as in table 2.1 in market. The rate of heat transfer can be enhancing by using baffles in the shell as in Figure 2.1. The number of shell side and the tube side flow arrangement depend on the pressure drop, heat duty, fouling factor, manufacturing techniques, cost, corrosion control and the cleaning purpose. B.T Lebele-Alawa and Victor Egwanwo, 2012, have conducted a numerical analysis on heat transfer in shell and tube heat exchanger using governing equation based on the three parameters including outlet temperature, heat transfer coefficient and the heat exchanger effectiveness. They used discrete system to simplify the model into subdivided component for formulation of heat transfer and fluid flow. They found that the heat transfer enhance by adding helical baffle into the shell because it force the shell side flow to approach the plug flow condition.

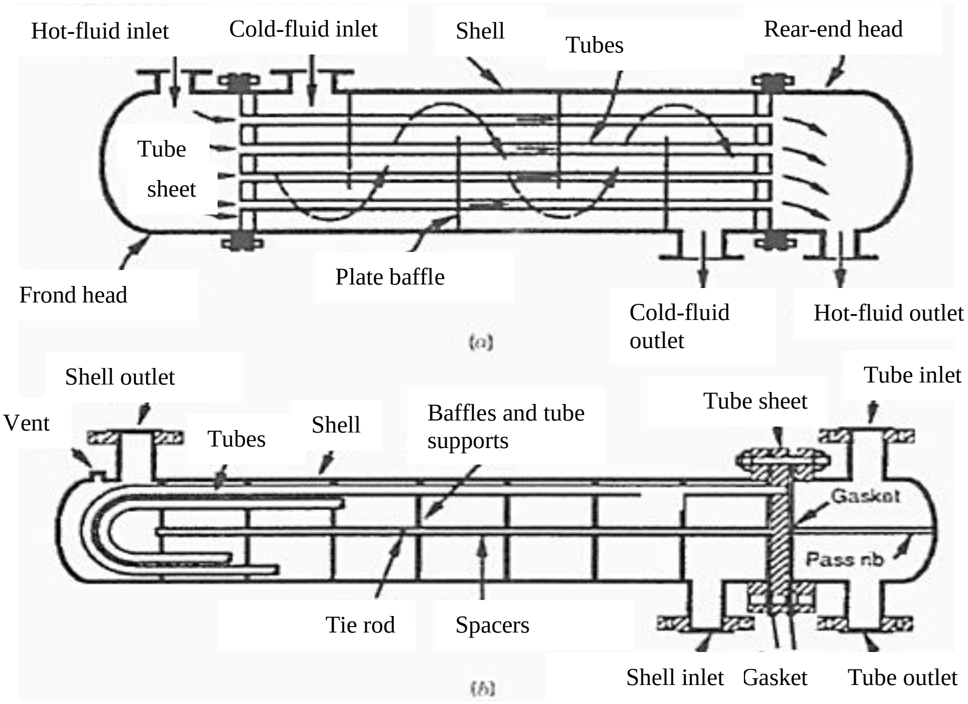


Figure 2.1: a) Shell and tube heat exchanger with one shell and tube; b) Shell and tube heat exchanger with one shell and two tubes.

Source: Sadik Kakac and Hongtan Liu, (2002)

Table 2.1: Types of shell-and-tube heat exchangers

Characteristic	**Segmental Baffle**	**Rod Baffle**	**Twisted Tube**	**Helical Baffle**
Good heat transfer per unit pressure drop	No	Yes	Yes	Yes
High shell-side heat transfer coefficient	Yes	No	No	Yes
Tube-side enhancement	With inserts	With inserts	included	With inserts
Suitable for very high exchanger effectiveness	No	Yes	Yes	Yes
Tends to have Low fouling	No	Yes	Yes	Yes
Can be cleaned mechanically	Yes, with square pitch	Yes	Yes	Yes, with square pitch
Low flow-induced tube vibration	With special designs	Yes	Yes	With double helix
Can have low finned tubes	Yes	Yes	Yes	Yes

Source**:** Sadik Kakac and Hongtan Lira (2002)

Based on Young Seok Son and Jee Young Shin, 2001, spiral baffle plates provide better enhancement then vertical plates. The rotational flow caused by the spiral baffle removes the stagnation area in the shell side flow in shell and tube heat exchanger. Polley, G. and J. Gibbard, 1997, state that adding inserts are not a brilliant choice because as it increases the heat transfer, it also increases the pressure drop. As a solution modification of the number of passes can lower the pressure drop.

According to J. Chen et al., 2001, adding dimples on tubes can increase the heat transfer coefficient compare to the smooth tube. For the constant Reynolds number fluid flow the heat transfer increases 1.25 - 2.3 7 times while for the constant pumping power heat transfer increases 1.15 - 1.84 times. Thundil Karuppa Raj R, Srikanth Ganne, 2011, conducted numerical analysis on shell and tube heat exchanger considering the effect of the baffle inclination angle on fluid flow using CFD. The mass flow rate must b less the 2kg/s because when it increases beyond 2kg/s the pressure drop will increases rapidly with little variation in outlet temperature. As the baffle inclination angle of the heat exchanger be 10°, the pressure drop decreases by 4% and 16% for the heat exchanger with the incline angle of 20°. The incline angle cannot be more than 20° because the centre row of the tubes will not be supported. Hence the baffle cannot be used effectively.

Ramesh.k and et.all, 2003, pp. 22 states that double pipe heat exchanger suitable for the pressured flow and it commonly used for small capacity applications where the total heat transfer surface area required about 50m2. R. Tiruselvam et.all, 2012 has conducted an investigation on heat transfer enhancement for double pipe heat exchanger with laminar and turbulent flow. The EXTEK twisted multi head annulus tube, EXTEK tube, Turbo-C annulus tube and plain tube are used to study the comparison based on the heat transfer, flow friction and the pressure drop. Even though Turbo-C increases the flow turbulence, EXTEK twisted multi head annulus tube and plain tube achieves higher efficiency as shown in Figure 2.2 because EXTEK twisted multi head annulus tube has higher shear stress along the wall which gives longer effective path for heat transfer then the others.

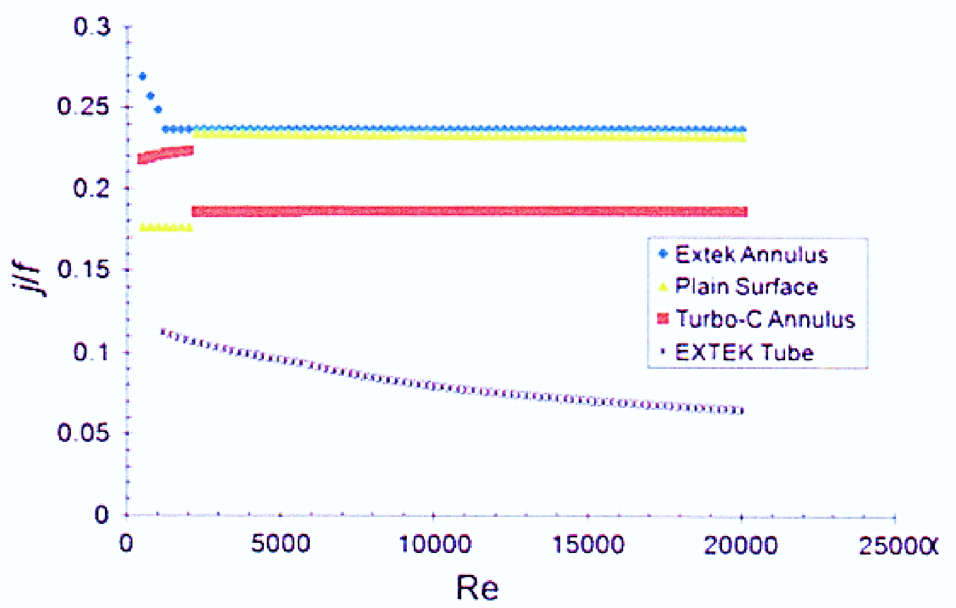
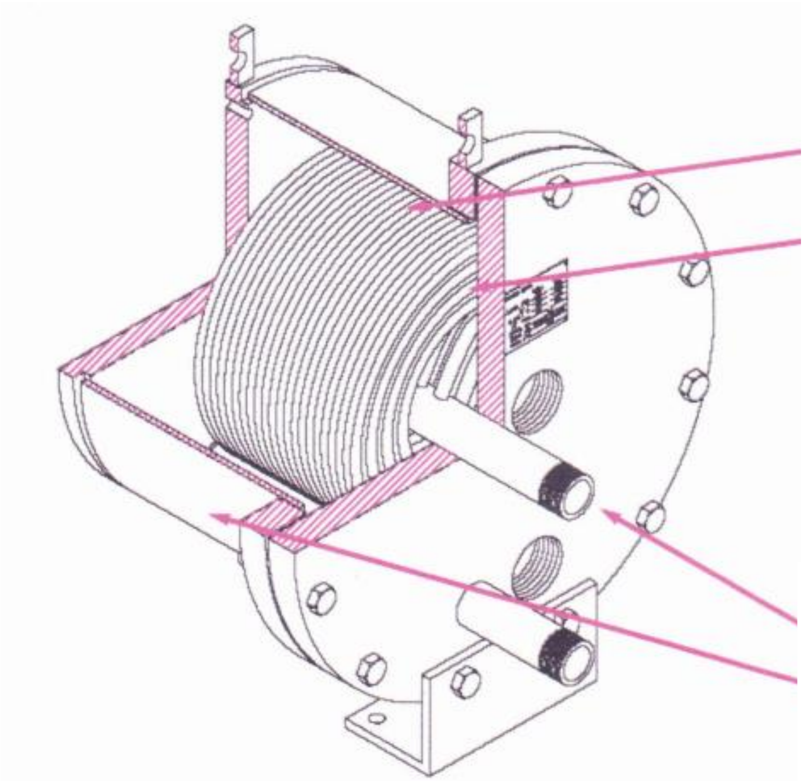


Figure 2.2: Comparison of j/f for Turbo-C and EXTEK test sections

Source**:** R. Tiruselvam et.all, (2012) The plate type heat exchanger consists of thin plates which will be a separator between the hot and cold fluid. Shive Dayal Pandey, V. K. Nema, 2011, has done an analysis on heat transfer, friction factor and exergy loss in plate heat exchanger using fluent. The analysis was carried out with single pass under parallel and counter flow. It is found that rate of heat transfer and friction factor increase as the pressure drop decreases with the increase in Reynolds number. Besides the pressure drop greatly increases the capital cost for heat transfer.

The spiral tube heat exchanger consists of spirally wound coils fitted in the shell. According to Ramesh.k and et.all, 2003, pp. 22 and K.Sudhakara Rao, 2007, the spiral tube provides higher rate of heat transfer the straight tube because the larger amount of surface area can be achieved in smaller space as can see in Figure 2.3. The compact assembly of coil with no dead sport promotes the efficiency of heat transfer.



Optimized performance
Multiple tube side parameters (Diameter, length, number and material)
Variable shell side flow path gap and length

Easy to install
Simple piping and access.
Easy to remove the shell for inspection and cleaning.
Virtually no tube bundle pull requirement.

Figure 2.3: Spiral tube heat exchanger

Source**:** K.Sudhakara Rao, (2007)

M. Kanan et.all, 2012 has conducted an experiment to analyse the performance of the heat exchanger using parallel flow by varying flow rate and addition of fins. A comparison has been presented as in Figure 2.4, based on the efficiency of the normal tube with modified tubes and it is concluded that annular tube provides higher enhancement compare to rectangular fin, spiral rod and the normal tube. The fin works as a trigger who converts the laminar flow to turbulent flow, which rapid the heat transfer. The spiral rod trigs and promotes the turbulent flow and reduces the hydraulic diameter.

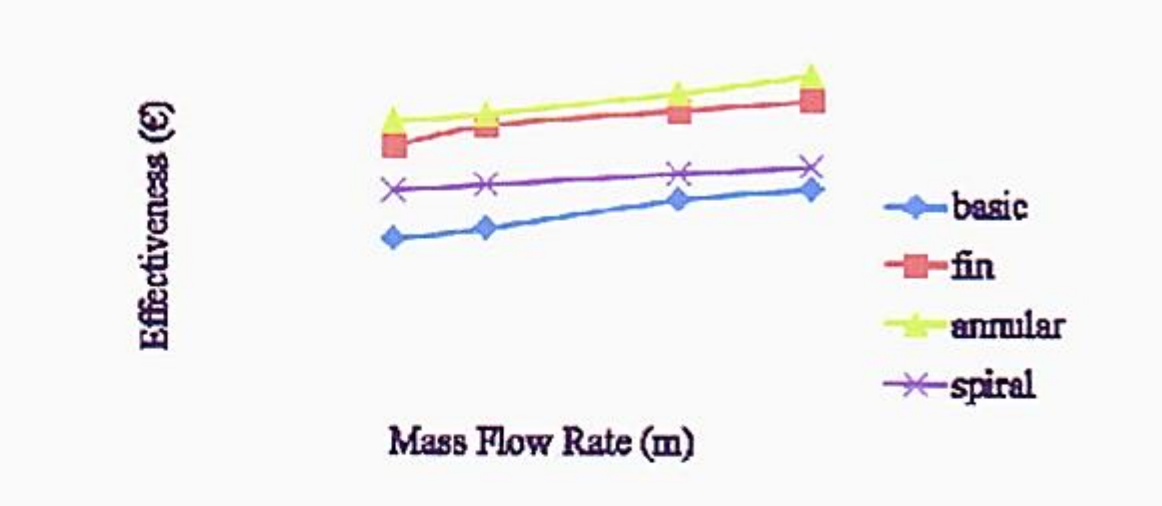


Figure 2.4: Effectiveness vs. mass flow rate of hot water

Source**:** M. Kanan et.all, (2012)

Shilling, 1997, stated that heat transfer can be enhancing by adding fins on both interior and exterior of the tube. Additions of surface area enhance the heat transfer by creating turbulence. Inserts, tabulators are the most effective add-ons in promoting turbulences flow with high viscosity fluids in laminar regime and increases the heat transfer film coefficient five times higher.

Isak Kotcioglu et.all.2011, conducted an analysis on heat exchanger with cross flow based on the pressure drop. The empirical derivative equation correlates the mean Nusselt number and the friction coefficients as a function of the Reynolds number are used to analyse the data. The hexagonal, square and circular pin fins are investigated in the line and staggered array. The result shows that the hexagonal pin fin is more effective the square and circular pin fins and the line array better than staggered array. The spaces between the fins are in study and it`s concluded as the most closely arranged pin fin provide better enhancement. The pressure drop of circular pin fin is smaller compared to the hexagonal and square pin fin. The pressure drop decreases as the Relative longitudinal pitch of the pin fin increases. The hexagonal pin fin has higher heat transfer then the square and circular pin fin as shown in Figure 2.5.

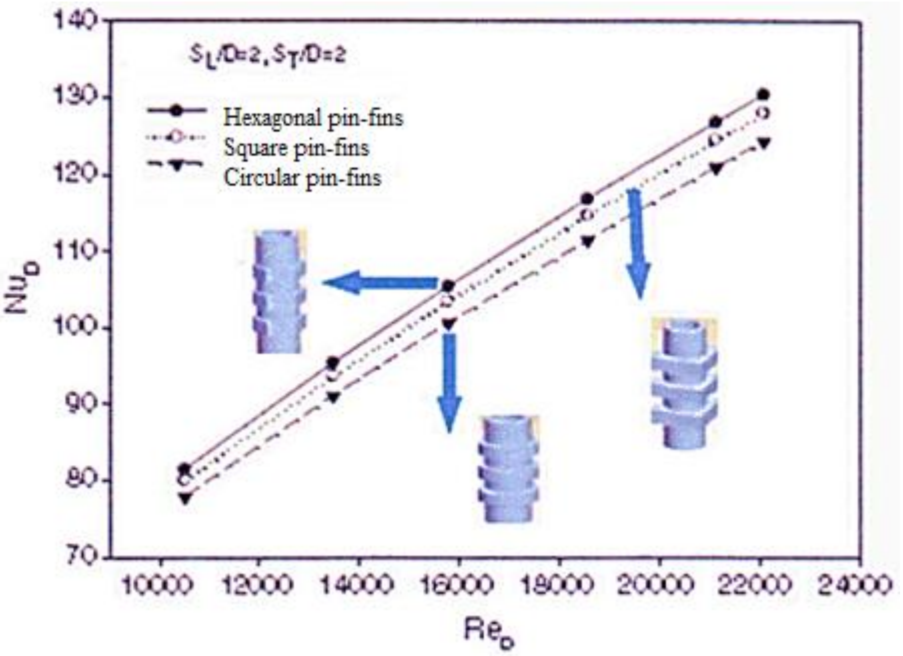


Figure 2.5: Nusselt number as a function of Reynolds number for the various pin fin

Source**:** Isak Kotcioglu et.all, (2011)

Zong Yanbing et.all, 2009, conducted a simulation on heat transfer performance for integral steel fin-tube through Ansys. The purpose of the study is to find the effect of the fin tube parameters and the fluid temperature on heat transfer performance. It is found that the rate of heat transfer increases with the height decreases as in Figure 2.6 (a). The thickness of the fin effective to certain level and the rate of heat transfer drop. While the fin spacing is important as it will influent the heat transfer as in Figure 2.6(b).