M C B Ü Soma Meslek Yüksekokulu Teknik Bilimler Dergisi Yıl: 2017 Sayı:24 Cilt: II

BASICS OF HEAT EXCHANGER THERMAL DESIGN METHODOLOGY

Anıl Başaran[1] , Ali Yurddaş[2]

ABSTRACT

The present study illustrates certain practical aspect of thermal design of heat exchangers for industrial applications. In general heat exchanger design is made for a special industrial application with its own features. These features of the industrial applications introduce some limitations and problems in the design procedure of heat exchanger. Main purpose of heat exchanger design is to provide solutions to these limitations and problems. Determination of thermal performance of new or existing heat exchanger is the problem commonly encountered in industry. Determination of the heat transfer performance of heat exchangers can be basically defined thermal design of the heat exchanger and is the computational process. Recognizing of basics of thermal design methodology in detail is of great importance in heat exchanger design with regard to making versatile and cost-effective industrial applications. In this respect, the basics of thermal design heat exchangers has been accentuated in this study. With the detailed calculation procedure, the paper provide information about various design approach to define thermal performance of heat exchangers.

Keywords: Thermal design,   LMTD method, ε-NTU method, P-NTU method

ISI EŞANJÖRÜ ISIL TASARIM METODOLOJİSİNİN TEMELLERİ

ÖZET

Bu çalışma, endüstriyel uygulamalar için ısı değiştirici ısıl tasarımlarının pratik yönünü ele almaktadır. Genel olarak bir ısı değiştirici tasarımı, kendine has özelliklere sahip özel bir endüstriyel uygulama için yapılmaktadır. Endüstriyel uygulamaların kendine has bu özellikleri, ısı değiştirici tasarım aşamasında bazı sınırlamaları ve problemleri ortaya çıkartmaktadır. Isı değiştirici tasarımının başlıca amacı, bu sınırlamaları ve problemleri ortadan kaldırmaktır. Yeni veya var olan bir ısı değiştiricinin ısıl performansının belirlenmesi, endüstride sıklıkla karşılaşılan bir durumdur. Isı değiştiricilerin ısı aktarım performansının belirlenmesi temelde ısı değiştiricilerin ısıl tasarımı olarak tanımlanabilmektedir ve bu süreç hesaplamaya dayanan bir süreçtir. Isıl tasarım metodolojisinin temellerini ayrıntılı olarak bilmek, verimli ve maliyet etkin bir endüstriyel sistem ortaya koymak açısından önem arz etmektedir. Bu kapsamda, bu çalışmada ısı değiştiricilerin ısıl tasarımları üzerinde durulmuştur. Ayrıntılı hesaplama yöntemleri ile bu çalışma, ısı değiştiricilerin ısıl performanslarının belirlenmesi için çeşitli tasarım yaklaşımları hakkında bilgi sunmaktadır.

Anahtar kelimeler: Isı tasarım, LMTD yöntemi, ε-NTU yöntemi, P-NTU yöntemi

---

[1] Manisa Celal Bayar Üniversitesi Mühendislik Fakültesi Makine Mühendisliği Bölümü Şehit Prof.Dr. İlhan Varank Kampüsü- Yunusemre-Manisa- Tel: 0(236) 201 23 82-e-mail: anil.basaran@cbu.edu.tr *iletişimden sorumlu yazar.

[2] Manisa Celal Bayar Üniversitesi Mühendislik Fakültesi Makine Mühendisliği Bölümü Şehit Prof.Dr. İlhan Varank Kampüsü- Yunusemre-Manisa- Tel: 0(236) 201 23 79-e-mail: ali.yurddas@cbu.edu.tr

1. INTRODUCTION

Environment includes many heat transfer process such as weather cycles and energy exchange between ecosystems. Heat exchange is a natural phenomenon occurring throughout our environment. Controlling over dynamics of heat transfer between two or more fluids has been main focus of industry. Heat exchangers allow operate the dynamics of heat transfer process and are used in widespread applications, such as energy (geothermal, solar, nuclear, co-generation, heat machine/pump, waste heat recovery, power plants, waste water cooling), food processing (oil heating/cooling, juice heating/cooling, sugar processing, protein processing, prepared food, dairy and pasteurization, food additives, beverage), electronic (cooling of electronic devices, computer manufacturing, semiconductor manufacturing, chip manufacturing), chemical process (petrochemical, inorganics, chemical process, dissolution, gasification and liquefaction, chemical reactors), healthy and pharmaceutical (conservation of blood, in morgue, operating theatre, drug and cosmetic production), aerospace (spacecraft, aircraft, helicopters, scientific studies), residential applications (HVAC-R, refrigerators, district heating).

Nowadays, need of energy has increased in the direct proportion to World population. A great majority of needed energy has been met fossil fuels currently. Fossil fuels usage around the world leads to some environmental problems such as global warming, pollution, ozone depletion. Therefore, productive, correct and wise use of energy resources gain importance in both modern life activities and industrial activities. One of the reasons to usage of heat exchanges is desire of productive and wise use of energy in industry. Therefore, making a correct and versatile heat exchanger design become more of an issue in terms of ascertainment energy efficient industrial applications.

There are innumerable heat exchanger designs in use to meet the numerous heat transfer requirements. Such design can be classified in great number of different ways. Heat exchangers in industrial applications have generally classified according to construction, compactness, transfer process, flow configurations, pass arrangements, heat transfer mechanism and phase of fluids. However, industrial heat exchangers have commonly classified according to geometry of construction. A broad classification of heat exchangers based on their construction is given in Fig. 1. Heat exchangers are generally characterized four major construction type according to the construction geometry: tubular, plate, extended surface and regenerative exchangers (Gupta, 1986). A large variety of heat exchanger designs are available as described in Fig. 1. Meanwhile, there are numerous variable linked with heat exchanger design such as geometrical variables, construction materials properties, operating conditions, size and cost of the heat exchanger. The heat transfer enhancement techniques can be added in these variables (Gupta, 1986). The question involving the selection of the appropriate heat exchanger design for given application appear at this point. It needs to be emphasized that the selection of the heat exchanger design for a given application are of importance in industry in terms of making fertile and cost-effective systems.

It is known that, in industries, heat exchangers are generally characterized and selected as a suitable heat transfer device for applications according to their designs. Therefore, in this study, thermal design of heat exchangers is handled and reviewed. It is aimed to present detailed information about thermal design methodology of heat exchangers in order to make productive and cost effective heat exchanger designs.

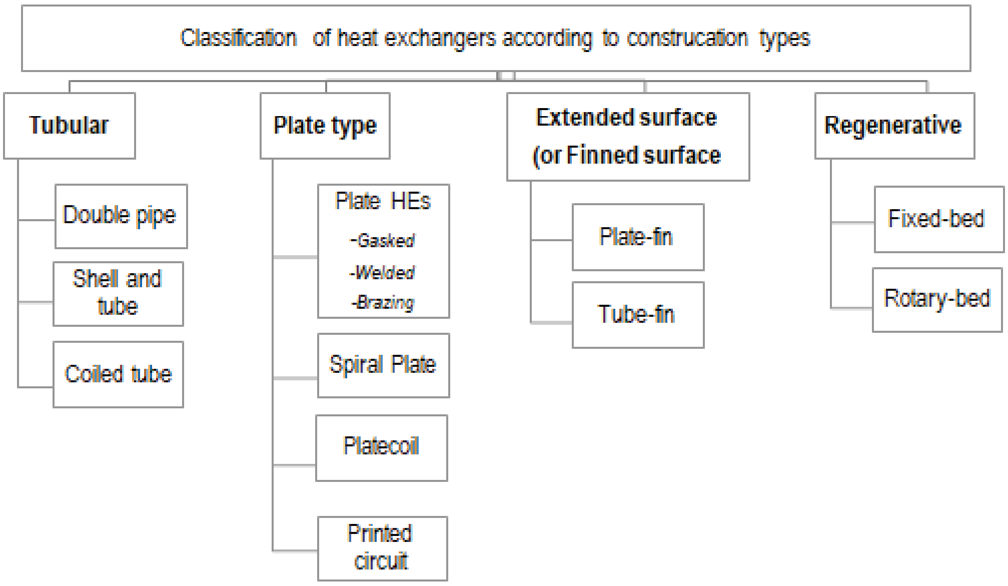

Figure 1- Classification of heat exchangers according to construction type

1.1. Historical background of heat exchanger designs

Efforts to understand what is heat dates back to ancient times. The ancients had the opinion that heat was relevant to fire. After the centuries, in 1761, Scottish chemist Joseph Black (1728-1799) who was the first modern chemist suggest that heat flow like a fluid. In 1789, French chemist Antoine Lavoisier (1743-1794) firstly explained the transfer of heat and formulized the heat-fluid concept into called caloric theory. The caloric theory suggests that caloric was a colorless, massless, tasteless and odorless substance which can be moved from one body to another. Also, the caloric theory asserts that the motion of caloric to a body increased the temperature, and the loss of calorics decreased the temperature correspondingly. American Benjamin Thompson (1753–1814) presented in his papers in 1798, that heat can be generated continuously through friction. But, in 1843, the attentive experiments made by Englishman James P. Joule (1818–1889) eventually convinced the skeptics that heat was not a substance after all, and so lay the caloric theory to rest. In the 19th century the kinetic theory which states that energy or heat is created by the random motion of atoms and molecules put all other theories to rest (Theodore, 2011)(Nagensgast, 2011).

The earliest heat exchanger was stones. Ancient people used stones for the heat transport from hot springs to indoor air. The large part of early equipments from the point of view heat transfer equipments involved the transfer of heat across pipes. The history of utilization of pipes for various purposes dates back to the Roman Empire at first, pipe systems was made of the materials like stone and wood, and gravity was the driving force of fluid. Various developments have been made to the piping system over time. The pipes have progress in many aspects such as shape, size, material, etc. and nowadays they are made from different materials such as metals and plastic, and even glass for some applications, with different diameters and wall thicknesses. Over the past several hundred years' copper pipes and copper alloys used in heat exchangers design have evolved associated with heat transfer technologies.

In 1769, copper tubes were first used as condenser for steam engines. The first regenerator was invented by Robert Stirling in 1816, and is commonly found as a component of his Stirling engine. In 1863 Robert Briggs and Joseph Nason patented a new design which is vertical wrought iron tubes screwed into a cast iron base, thus they firstly introduced radiators. In 1874, the first popular cast iron radiator was invented by Nelson. The cast iron segmental radiators have become very common by the 1880s (Gulben, 2011). Plate heat exchanger was first patented by Albrecht Darche in Germany, in 1878. In 1890s, plate heat exchangers were improved by Langen and Hundhausen as device which transfers heat between two fluids have different temperature throughout plane and square plates (Saari, 2001). Because of that steam power plants, steam generators, and locomotives and ships powered by steam became common at the beginning of 20th century, heat exchangers which were important components of these systems developed rapidly. Afterwards, the rapid growth of petrochemical and petroleum industries began to require durable and large-scale heat exchangers for various processes. The main forms of the numerous heat exchangers used today were improved and bettered between 1920 and 1950. These heat exchangers still remain the choice for most process applications (Nagengast, 2011). Increasing energy cost due to the energy crisis of 1970s and being competitions between firms obligate to design more efficient heat exchangers. Especially after 1980s, efforts of designing of new efficient heat exchanger increased with research funds in the matter of heat exchanger design. These efforts have already continued in these days when energy is precious.

2. MAIN OBJECTIVES OF HEAT EXCHANGER DESIGN

Every heat transfer application requires different type equipments and different configurations of heat transfer device. The essaying to meet the heat transfer requirements within the specified restriction with the heat transfer equipments has led to numerous types of heat exchanger designs (Theodore, 2011). Proliferation of heat exchangers utilization in widespread applications and industries put forward requirement of new heat exchanger designs or of enhancing available heat exchanger designs. Designing of heat exchanger primarily include all the necessary information to feature on demand of heat exchanger, objectives of heat exchanger usage, operating conditions and working fluids. In the heat exchanger design, there are worthy of notice parameters such as types, flow rates, thermo-physical properties, inlet and outlet temperatures, fouling characteristics of working fluids, types, heat load, number of passes, allowable pressure drop, maximum operating pressure of heat exchanger and temperature, pressure, moisture context of operating environment. These parameters can be classified as limiting parameters which restrict selection of heat exchanger, unalterable parameters necessary to achieve objectives of heat exchanger usage and alterable parameters preferred for applications (Puttewar and Andhare, 2015). Among the parameters heat transfer, pressure losses, efficiency and cost of heat exchanger are vital parameters in terms of heat exchanger design. In many industries, the designing and thermal rating of heat exchanger are carried out in order to reduce cost, material and energy consumption and to obtain maximum heat transfer. The main challenge in heat exchanger design is to make it compact, to get maximum heat transfer in minimum space and to get minimum pressure drop (Shah and Sekulic, 2003). In terms of energy saving with increasing heat exchanger effectiveness, the most effective methods are to enhance heat transfer that is primary objective of heat exchanger usage and to reduce pressure losses that is basically conducive energy consumption.

3. HEAT EXCHANGER THERMAL DESIGN METHODOLOGY

The design methodology of heat exchanger is quite complex because of that heat transfer applications have specifically design constraints and requirements. Heat exchanger design concept consist of various design considerations. One of the major design considerations is design and process specifications involve type of exchanger, flow arrangement, construction materials, operating conditions, and design/manufacturing considerations. Another major design consideration is thermal and hydraulic design which include rating which mean quantitative heat transfer and pressure drop computation and/or heat exchanger sizing. Beside this major considerations, in heat exchanger design, various considerations can be taken account according to the need of the industry: Mechanical design consideration is important to provide the mechanical unity of the exchanger during exchanger design life under steady-state or transient, startup or shutdown, part-load, and upset operating conditions. Manufacturing considerations that include manufacturing equipment considerations, processing considerations, etc. and cost estimates are made in consideration of optimized solutions acquired from thermal and mechanical design considerations data. The total cost of a heat exchanger can be categorized into three main groups: the capital, installation, operating, and sometimes also disposal costs. In heat exchanger design, trade-off analysis which developed to costs heat transfer performance, pressure drop, envelope size, weight, leakage, initial cost versus life of the exchanger for corrosion, fouling, and fatigue failures, and the cost of a one-of-a-kind design versus a design with a large production run is an important design consideration (ASHRAE, 2008).

3.1. Thermal design of heat exchangers

Basically, heat exchangers can be defined as the devices that enable the heat transfer between two or more fluids that are at different temperature with mixing or without mixing each other. The heat transfer in heat exchangers is caused by temperature difference of fluids. During the heat transfer, phase change like fluid changing from liquid to vapor, vapor to liquid can be occurred or phase change do not occur. In practice, heat exchangers are designed or selected to transfer either sensible heat or latent heat. In sensible heat applications, heat is transferred from one liquid to another without phase change. Latent heat application involves phase change of one of the liquids. Heat exchangers can be considered as steady-flow device due to the fact that they generally operate without any change in operating conditions for long time periods. For many requirements of applications, heat exchangers are design various flow configurations; parallel, counter and cross flow configurations are common examples. Fig. 2 indicates schematically these flow configurations. In parallel flow configuration, fluid streams parallel to each other and in the same direction. In counter flow configuration, shown schematically in Fig. 2 (b), fluid streams are parallel to each other, but the direction of the streams is opposite. In cross flow configuration, the two fluid streams flow at right angles to each other (Kacar and Erbay, 2013).

In heat exchangers encountered in many applications, fluids are generally separated by a heat transfer surface to exchange the heat between fluids through this separating wall with no mixing of fluids each other. Such heat exchanger devices are named as direct transfer type, or recuperators (Thulukkanam, 2013). This type exchangers usually involve convection in each fluid and conduction through the separating wall. In contrary to recuperators, in heat exchangers referred to as indirect transfer type or regenerators, heat is intermittently transferred between hot and cold fluids by the way of thermal energy storage during hot fluid passing and release during cold fluid passing through the exchanger surface or matrix. A regenerator usually composed of a heat transfer surface named as matrix and hot fluid and cold fluid periodically and alternatively flow through this matrix. Initially the hot stream surrender its heat to the regenerative matrix. Then the cold stream flows through the same passage to gather the store heat given up by hot fluid (Schltinder, 1983).

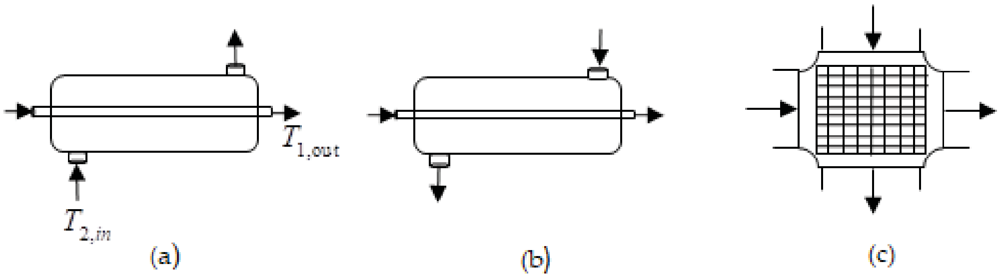

Figure 2- Schematic representation of (a) parallel flow, (b) counter flow, (c) cross flow heat exchangers

During heat exchange, local temperature difference of fluid differs along the flow path due to heat exchange between two fluids flowing through heat exchanger (Roetzel et al.). The local heat transfer rate between the two streams is expressed as

$$dQ = U(T_h - T_c)dA \tag{1}$$

where and are the local temperatures of hot and cold streams, respectively. U is the overall heat transfer coefficient, A is the heat transfer area related to the coefficient . The usual design problem is to determine the total area in a heat exchanger required to transfer the specified total amount of heat. The classical expression for determining the area of a heat exchanger - the thermal design problem - is defined by the fundamental equation (Thulukkanam, 2013):

$$A = \int_0^Q \frac{dQ}{U(T_h - T_c)} = \Sigma \frac{\Delta Q}{U(T_h - T_c)} \tag{2}$$

The main problems encountered in heat exchanger design are sizing of heat exchanger (sizing problem) and specifying of heat exchanger performance (rating problem). The sizing problem include the design of a new or existing type heat exchangers. In the applications in which mass flow rates of fluid streams and inlet and outlet temperatures of fluid streams are specified, the logarithmic mean temperature difference (LMTD) method is very appropriate for determining the size of a heat exchanger to perform specified outlet temperatures of fluids. The heat transfer surface area, A, is designated by the means of the LMTD method and the heat exchanger with this surface area is selected. Another problem defined as performance problem covers the determination of the heat transfer rate and the outlet temperatures of the hot and cold streams for prescribed mass flow rates and inlet temperatures. In such problems, the size and type of the heat exchanger are determined. In other words, the performance problem takes into consideration heat transfer performance of either an existing or an already sizing heat exchangers. Here the task is to determine the heat transfer performance of a specified heat exchanger or to determine if a heat exchanger available in storage will do the job (Theodore, 2011). The effectiveness-NTU ($\varepsilon - \mathrm{NTU}$)) or $\mathrm{P} - \mathrm{NTU}$ method are suitable for the performance problems.

3.1.1. Mean temperature difference concept

With the logarithmic mean temperature difference method, the task is to select heat exchanger which will meet the defined heat transfer requirements. The heat transfer rate between the fluid streams can be calculated using

$$Q = UA\Delta T_{lm} \tag{3}$$

where U is the overall heat transfer coefficient, A is the heat transfer area related to the coefficient U, and ΔT_{lm} is the convenient mean temperature difference. The logarithmic mean temperature, for a heat exchanger with the specific heat of liquids and the constant overall uniform heat transfer coefficient, U is calculated as follows;

$$\Delta T_{lm} = \frac{\Delta T_1 - \Delta T_2}{\ln(\frac{\Delta T_1}{\Delta T_2})} \tag{4}$$

where the subscripts 1 and 2 stand for each end of heat exchanger. Therefore, ΔT_1 and ΔT_2 represent the temperature differences between the fluids at each end of heat exchanger. ΔT_{lm} is the logarithmic mean temperature difference (LMTD) (Kacar and Erbay, 2013). Temperature distribution along the heat exchanger for parallel and counter flow configuration can be seen in Fig. 3. The logarithmic mean temperature difference defined in Eqn (4) can be only used for counter and parallel flow heat exchangers. For other flow configuration, the logarithmic mean temperature difference is also developed as Eqn (5).

$$\Delta T_{lm} = F.\Delta T_{lm,CF} = F\frac{(T_{h,i} - T_{c,o}) - (T_{h,o} - T_{c,i})}{\ln[\frac{(T_{h,i} - T_{c,o})}{(T_{h,i} - T_{c,o})}]} \tag{5}$$

where F is correction factor (less than 1.0) that is applied to heat exchanger configurations that do not follow a true counter flow design. Correction factor, F, depends on heat exchanger geometry and the inlet and outlet temperatures of the hot and cold fluids. Working with an overall heat transfer coefficient, is convenient because of that it take into account conduction along the separating wall and convection in each fluid. That is why overall heat transfer coefficient is affected by the physical arrangement of the heat transfer surface area.

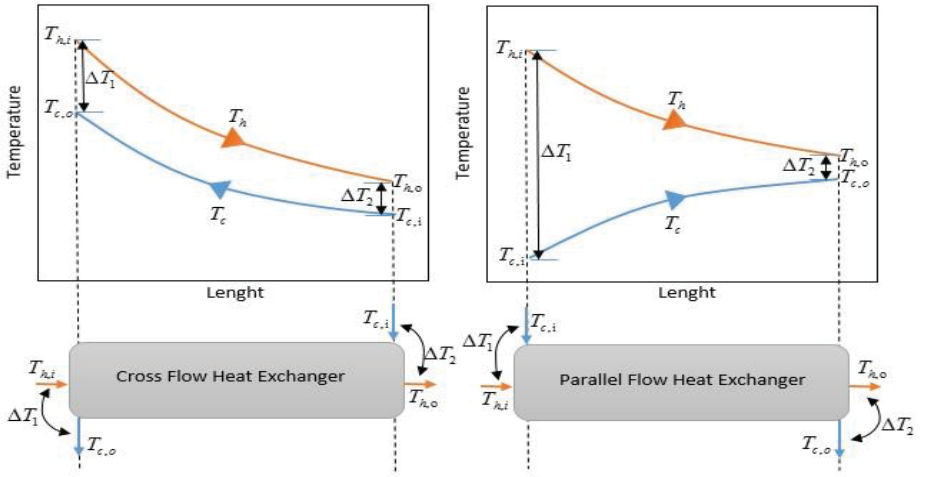

Figure 3- Temperature distribution in parallel and counter flow heat exchangers

3.1.2. Effectiveness: NTU concept

When the temperature of the working fluids leaving the heat exchanger are unknown, using LMTD method leads to trial and error calculation. In this case, ε − NTU method which uses certain dimension parameters that are Heat Exchanger Effectiveness (ε), Number of Exchanger Heat Transfer Units (NTU) and Capacity Rate Ratio (C_r) is alternatively used to avoid these trials and error calculations. In ε − NTU method, heat exchanger effectiveness ε is defined for a specified heat exchanger of any flow arrangement as a ratio of actual heat rate from the hot fluid to the cold fluid to maximum possible heat transfer rate q_{max} thermodynamically permitted (ASHRAE 2008). Effectiveness ε is a measure of thermal performance and non-dimensional.

$$\varepsilon = \frac{q}{q_{max}} \tag{6}$$

For any flow arrangement, heat transfer between two fluid stream have different temperature can be written as:

$$q = C_h\left(T_{h,i} - T_{h,o}\right) = C_c\left(T_{c,o} - T_{c,i}\right) \tag{7}$$

where $C_h = \dot{m}_h Cp_h$ and $C_c = \dot{m}_c Cp_c$ are heat capacity rates. To determine the maximum possible heat transfer rate, the maximum temperature difference in a heat exchanger that is the difference between the inlet temperatures of the hot and cold fluids is taked into account. The maximum possible heat transfer rate can be obtained in a counter flow heat exchanger with very large surface area and zero longitudinal wall heat conduction and the actual operating conditions (Akkoca, 2004). Therefore, the maximum possible heat transfer rate can be expressed as:

$$q_{max} = C_{min}\left(T_{h,i} - T_{c,i}\right) \tag{8}$$

In ε -NTU method, heat transfer rate of heat exchanger became is as follow:

$$q = \varepsilon C_{min}\left(T_{h,i} - T_{c,i}\right) = \varepsilon C_{min} \Delta T_{max} \tag{9}$$

when C_h is minimum, effectiveness is written as:

$$\varepsilon = \frac{q}{q_{max}} = \frac{C_h\left(T_{h,i} - T_{h,o}\right)}{C_{min}\left(T_{h,i} - T_{c,i}\right)} = \frac{\left(T_{h,i} - T_{h,o}\right)}{\left(T_{h,i} - T_{c,i}\right)} \tag{10}$$

when C_c is minimum, effectiveness is written as:

$$\varepsilon = \frac{q}{q_{max}} = \frac{C_c\left(T_{c,o} - T_{c,i}\right)}{C_{min}\left(T_{h,i} - T_{c,i}\right)} = \frac{\left(T_{c,o} - T_{c,i}\right)}{\left(T_{h,i} - T_{c,i}\right)} \tag{11}$$

One point worth mentioning here is that the value of effectiveness ε ranges between 0 and 1. It generally is dependent on the number of heat transfer units (NTU), the heat capacity ratio (C_r) and the flow arrangement.

$$\varepsilon = \phi(NTU, C_r, flow\ arrangement) \tag{12}$$

Number of heat transfer units (NTU) designates the non-dimensional heat transfer size or thermal size of heat exchanger. NTU is defined as a ratio of overall thermal conductance to the smaller heat capacity (Akkoca, 2004).

$$NTU = \frac{U.A}{C_{min}} = \frac{1}{C_{min}} \int_A U.dA \tag{13}$$

where A is the area used to define overall coefficient U.

Basically, heat capacity ratio C_r is a ratio of the smaller to larger heat capacity rate for the two fluid streams, so that $C_r \leq 1$. If C_r is equal to 1, heat exchanger is considered balanced

$$C_r = \frac{C_{min}}{C_{max}} = \frac{(\dot{m}Cp)_{min}}{(\dot{m}Cp)_{max}} \tag{14}$$

C_r is a heat exchanger operating parameter since it is dependent on mass flow rates and/or temperature of fluids in the heat exchanger.

3.1.3. Temperature effectiveness: NTU concept

$P-NTU$ method represents a variant of the $\varepsilon-NTU$ method. The origin of this method is related to shell and tube exchangers. In order to avoid possible errors and to avoid keeping track of the C_{min} fluid side, the temperature effectiveness P is taken as a function of NTU and heat capacity rate of that side to that of the other side, R. General *P-NTU* functional relationship can be written as bellow (Akkoca, 2004).

$$P = \phi(NTU_t, R, flow\ arrangement) \quad (15)$$

In the *P-NTU* method, the heat transfer rate from the hot fluid to the cold fluid in the exchanger is expressed as

$$q = PC_t\Delta T_{max} = PC_t\left(T_{h,i} - T_{c,i}\right) \quad (16)$$

where P is the temperature effectiveness for fluid streams in heat exchangers, $C = \dot{m}Cp$ is the heat capacity rate for fluids. In this equation, subscript t denotes fluids pass through in heat exchanger.

The temperature effectiveness of the tube-side fluid P is referred to as thermal effectiveness in the shell-and- tube heat exchanger literature and non-dimensional, similar to ε. It is defined as the ratio of the temperature rise (drop) of the tubeside fluid (regardless of whether it is hot or cold fluid) to the difference of inlet temperature of the two fluid [9,15]. According to this definition, P is given by

$$P = \frac{t_2 - t_1}{T_1 - t_1} \quad (17)$$

where t_1 and t_2 refer to tube-side inlet and outlet temperatures, respectively and T_1 and T_2 refer to shell-side inlet and outlet temperatures, respectively. It can be shown that

$$P_1 = P_2R_2 \ and \ P_2 = P_1R_1 \quad (18)$$

In this method, heat capacity ratio, R is the ratio of the capacity rate of tube-side fluid to shell-side fluid. The heat capacity ratio is defined as

$$R = \frac{C_{tube-side}}{C_{shell-side}} = \frac{T_1 - T_2}{t_2 - t_1} \quad (19)$$

Number of transfer units NTU_t is defined as a ratios of the overall conductance to the tube side fluid heat capacity rate for a shell and tube heat exchanger. NTU_t is defined as:

$$NTU_t = \frac{U.A}{C_{tube-side}} \quad (20)$$

3.2. Basics heat transfer enhancement techniques

Investigation of the ways to improve heat exchanger efficiency is an effort to create productive systems. The design procedure of a heat exchanger include consideration of both the heat transfer rates between the hot and cold fluids and the mechanical pumping power which is consumed in order to overcome pressure drop arising from fluid friction. The main design objective to create efficient heat exchanger is to obtain the highest heat transfer surface area with the least friction power expenditure. The friction power expenditure corresponds to mechanical energy in overcoming friction power generated in the heat exchanger as s result of fluid power (Koca, 2007). The most important objective in heat exchanger applications is to be get closer to each other hot fluids temperature at outlet and cold fluids temperature at inlet. Meanwhile, the augmentation of convection coefficient between hot and cold fluid is the most effective methods to ensure energy savings and to improve heat exchanger efficiency. It should be noted that the augmentation of convection coefficient with using enhancement technique can lead to increase of pressure losses. Increment of pressure losses can cause increase of construction and operation cost (Yakar, 2007)(Khaled et al.). The improvement of heat exchanger efficiency and thus energy savings can be achieved with applying enhancement technique to heat exchanger design. It is desirable with applying enhancement technique that heat exchangers are made smaller and the mechanical pumping power consumed to defeat fluid friction is reduced (Khaled et al.). As increase cost of energy and heat exchanger size, heat transfer enhancement techniques gain importance to a great extent.

The improvement of the heat transfer effectiveness of internal and external fluid flow can be achieved with heat transfer enhancement techniques. These enhancement techniques typically lead to fluid mixing by the way of increasing flow vorticity, turbulence, unsteadiness or by the way of limiting the growth of thermal boundary layer close to the heat transfer surface Heat transfer enhancement techniques may be categorized into two main methods, i.e., passive and active methods (Baysal, 2009). Passive methods are the heat transfer enhancement techniques that are given no additional external energy with the exception pumping power to heat transfer fluid. On the other hand, heat transfer enhancement in the active methods is achieved by the way of providing external energy. Principles of active and passive methods are given in Fig. 4.

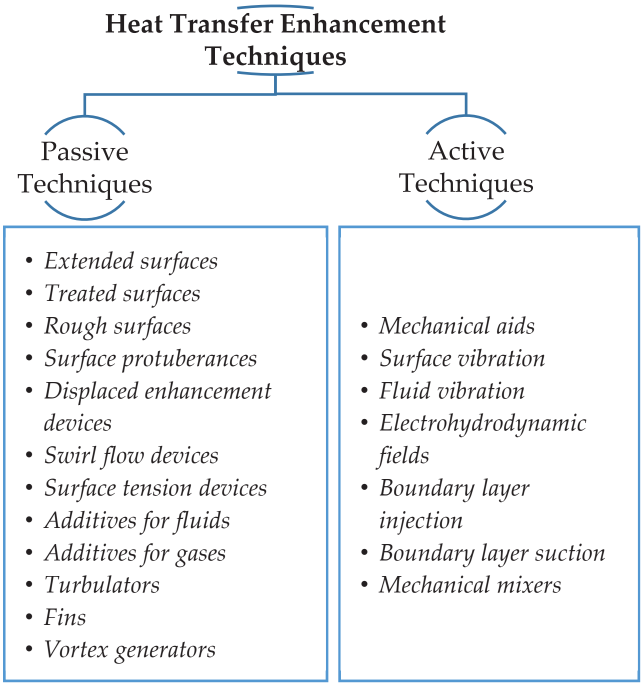

Figure 4- Heat transfer enhancement techniques (Thulukkanam, 2013)(Koca, 2007)(Baysal, 2009)

4. CONCLUSION

In this study, calculation procedure has been handled and reviewed to make thermal design of heat exchangers. One of the key factors in heat exchanger design for industrial applications is the selection of a suitable heat exchanger type. After selection, determination of the thermal performance of the selected heat exchanger play a key role in heat exchanger design.

If it is possible to determine the inlet and outlet temperatures and mass flow rates of the fluid streams in the industrial applications, the problem in design of heat exchanger is the determination of heat exchanger size that can meet to heat duty. In this type sizing problems, the logarithmic mean temperature difference (LMTD) method is very appropriate for determining the size of a heat exchanger. Heat transfer area to perform specified outlet temperatures of fluids can be calculated via LMTD method.

If it is not possible to determine the temperature of the fluid streams leaving the heat exchanger, $\varepsilon - \mathrm{NTU}$ method is more suitable than LMTD method to calculate thermal performance of heat exchanger. The heat transfer rate and the outlet temperatures of the fluid streams for prescribed fluid mass flow rates and inlet temperatures can be determined with $\varepsilon - \mathrm{NTU}$ method.

P-NTU is alternative method to $\varepsilon - \mathrm{NTU}$ method. The main difference of *P-NTU* from $\varepsilon - \mathrm{NTU}$ method is that the temperature effectiveness P is taken as a function of NTU and heat capacity rate of that side to that of the other side, R. *P-NTU* method can be used to determination of the thermal performance of heat exchangers when fluid mass flow rates and inlet temperatures of fluid streams are known.

In the thermal design of heat exchangers, the heat transfer enhancement techniques can be taken consideration to make versatile heat exchanger design. Active and passive enhancement techniques gain importance to a great extent with respect to thermal design. With the enhancement methods, heat transfer between the fluid streams can be increased while pressure drop decrease. In this way, the improvement of heat exchanger efficiency and thus energy savings can be achieved in the thermal design.

5. REFERENCES

[1] Gupta JP. *Working With Heat Exchangers: Questions and Answers.* USA: Hemisphere Pub. Corp; 1986.

[2] Theodore L. *Heat Transfer Applications for the Practicing Engineer.* Canada: John Wiley & Sons, Inc; 2011.

[3] Nagengast. “An Early History of Comfort Heating 2001”. http://www.achrnews.com/articles/87035-an-early-history-of-comfort-heating#comments (6.11.2011).

[4] Gulben G. Development of a computer program for desıgnıng-Gasketed plate heat exchangers for varıous workıng condıtıons and verıfıcatıon of the computer program wıth experımental data (in Turkish). MSc thesis TOBB Economics and Technology University, Ankara, Turkey. 2011.

[5] Saari J. Heat *Exchanger Dimensioning. Lappeeranta University of Technology*, LUT Energy.2001

[6] Puttewar AS, Andhare AM. Design and thermal evaluation of shell and helical coil heat exchanger. *International Journal of Research in Engineering and Technology,* 416–23, 2015

[7] Shah RK, Sekulic DP. *Fundamentals of Heat Exchanger Design.* New York: John Wiley and Sons; 2003.

[8] ASHRAE. *ASHRAE Handbook—HVAC Systems and Equipment*. 2008.

[9] Kaçar EN, Erbay LB. A design review for heat exchangers. *Engineer and Machinery*, 54:14–43, 2013.

[10] Thulukkanam K. *Heat Exchanger Design Handbook*. 2. ed. Boca Raton, USA: CRC Press LLC; 2013.

[11] Schltinder EU. *Heat Exchanger Design Handbook*. USA: Hemisphere Publishing Corporation; 1983.

[12] Roetzel W, Heggs PJ, Butterworth D. *Design and Operation of Heat Exchangers*. EUROTHERM, Springer; 1991.

[13] Akkoca A. Computational modeling of turbulent heat transfer in plate fin and tube heat exchangers. PhD thesis. Çukuroava University, Adana, Turkey. 2004.

[14] Koca T. Analysis of heat transfer and pressure loss in heat exchangers with both helical and rotational inner pipe (in Turkish). PhD thesis. Fırat University, Elaziğ, Turkey. 2007.

[15] Yakar G. The effect of turbulence created in fin-tube type heat exchangers with perforated fin on heat transfer and pressure drop (in Turkish). PhD thesis, Pamukkale University, Denizli, Turkey. 2007.

[16] Khaled ARA, Siddique M, Abdulhafiz NI, Boukhary AY. Recent advances in heat transfer enhancements: A review report. *International Journal of Chemical Engineering*. 28p, 2010.

[17] Baysal E. Experimental and numerical investigation of effects of helical turbulators in concentric tube heat exchangers (in Turkish). PhD thesis. Gazi University, Ankara, Turkey. 2009.