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Experiment No. (6)

a. **Name of Experiment:**

Heat Exchanger System

b. **Purposes of Experiment**:

1. To clarify heat exchanger classification.
2. To clarify principles of heat exchanger design and operation.
3. To find (heat transfer effectiveness, capacity ratio CR, number of transfer units NTU of a heat exchanger.

What is a heat exchanger?

A heat exchanger is Equipment in which energy is transferred from one fluid to another across a solid surface or it that facilitate the exchange of heat between two fluids that are at different temperatures.

Heat exchangers are commonly used in practice in a wide range of applications such as power production, refineries, food industries… etc.

Classification of heat exchangers

1. Classification by transfer process
    - Direct contact: heat transfer takes place between two immiscible fluids such as a gas and a liquid for example cooling tower.
    - Indirect contact: the hot and cold fluids are separated by an impervious surface (there is no mixing of the two fluids) such as automobile radiators.
2. Classification by construction type:
    - Shell and tube
    - Plate.
    - Double pipe.
3. Classification by flow arrangement:
    - Counter flow: the hot and cold fluids enter in opposite ends of the heat exchanger.
    - Parallel flow: the hot and cold fluids enter at same end of the heat exchanger.

- Cross flow heat exchanger
- Multi pass flow: multi passing increases the overall effectiveness over individual effectiveness.

Theory of Experiment:

In the double – pipe heat exchanger shown in fig (1-a), (2- a). The fluids may flow in either parallel flow or counter flow, and the temperature profiles for these two cases are indicated in fig (1- b), (2- b).
To calculate the heat transfer in this double- pipe arrangement are use the following equation.

$$q = UA\Delta T_{LMTD} \text{..}(1)$$

U	Overall heat transfer coefficient, W/m^2.˚C
A	Surface area for heat transfer, m^2
ΔT_{LMTD}	Log mean temperature difference, ˚C

An inspection of figs (1-b), (2-b) show that the temperature difference between the hot and cold fluids varies between inlet and outlet, and we must determine the average value for use in eq (1). For the parallel- flow heat exchanger shown in fig (1-b) the heat transferred through an element of area (dA) may be written:

$$dq = -\dot{m}_h c_h dT_h = \dot{m}_c c_c dT_c \text{............................}(2)$$

Where the subscripts h and c designate the hot and cold fluids respectively. The heat transfer could also be expressed:

$$dq = U(T_h - T_c)dA \text{....................................}(3)$$

From eq (2)

$$dT_h = \frac{-dq}{\dot{m}_h c_h}$$

$$dT_c = \frac{dq}{\overset{\bullet}{m}_c c_c}$$

Where in represents the mass flow rate and c is the heat capacity of fluid. Thus:

$$dT_h - dT_c = d\left(T_h - T_c\right) = -dq\left(\frac{1}{\overset{\bullet}{m}_h c_h} + \frac{1}{\overset{\bullet}{m}_c c_c}\right)\text{.........................}(4)$$

Solving for dq from eq (3) and substituting in to eq (4) gives:

$$\frac{d\left(T_h - T_c\right)}{T_h - T_c} = -U\left(\frac{1}{\overset{\bullet}{m}_h c_h} + \frac{1}{\overset{\bullet}{m}_c c_c}\right)dA\text{.......................................}(5)$$

This differential equation may now be integrated between conditions (1) and (2) as indicated in fig (1- b), (2- b). the result:

$$\ell n \frac{T_{h_o} - T_{c_i}}{T_{h_i} - T_{c_o}} = UA\left(\frac{1}{\overset{\bullet}{m}_h c_h} + \frac{1}{\overset{\bullet}{m}_c c_c}\right)\text{......................................}(6)$$

Returning to eq (2) the products $\overset{\bullet}{m}_c c_c$ and $\overset{\bullet}{m}_h c_h$ may be expressed in term of the total heat transfer q and the overall temperature differences of the hot and cold fluids thus:

$$\overset{\bullet}{m}_h c_h = \frac{q}{T_{h_i} - T_{h_o}}$$

$$\overset{\bullet}{m}_c c_c = \frac{q}{T_{c_o} - T_{c_i}}$$

Substituting these relations into eq (6) gives:

$$q = UA\frac{(T_{h_o} - T_{c_i}) - (T_{h_i} - T_{c_o})}{\ln\left[(T_{h_o} - T_{c_i})/(T_{h_i} - T_{c_o})\right]} \ldots\ldots\ldots\ldots\ldots(7)$$

Comparing eq (7) with eq (6) we find that the Log mean temperature difference is the grouping of terms in the brackets. Thus

$$\Delta T_{LMTD} = \frac{(T_{h_o} - T_{c_i}) - (T_{h_i} - T_{c_o})}{\ell n\left[(T_{h_o} - T_{c_i})/(T_{h_i} - T_{c_o})\right]}$$

Which may be written as:

$$\Delta T_{LMTD} = \frac{\Delta T_{LHS} - \Delta T_{RHS}}{\ell n\left(\frac{\Delta T_{LHS}}{\Delta T_{RHS}}\right)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(8)$$

This temperature difference is called the log mean temperature difference (LMTD). If a heat exchanger other than the double pipe type is used the heat transfer is calculated by using a correction factor applied to the LMTD as follows:

$$q = UAF\Delta T_{LMTD}$$

Where F is a correction factor (from fig (3))

$$U_o = \frac{1}{\frac{A_o}{A_i}\frac{1}{h_i} + \frac{A_o \ell n(r_o/r_i)}{2\pi kL} + \frac{1}{h_o}}$$

$$U_i = \frac{1}{\frac{1}{h_i} + \frac{A_i \ell n(r_o/r_i)}{2\pi kL} + \frac{A_i}{A_o}\frac{1}{h_o}}$$

Where the subscripts (o. i) refers to the outer and inner surface of the smaller tube.

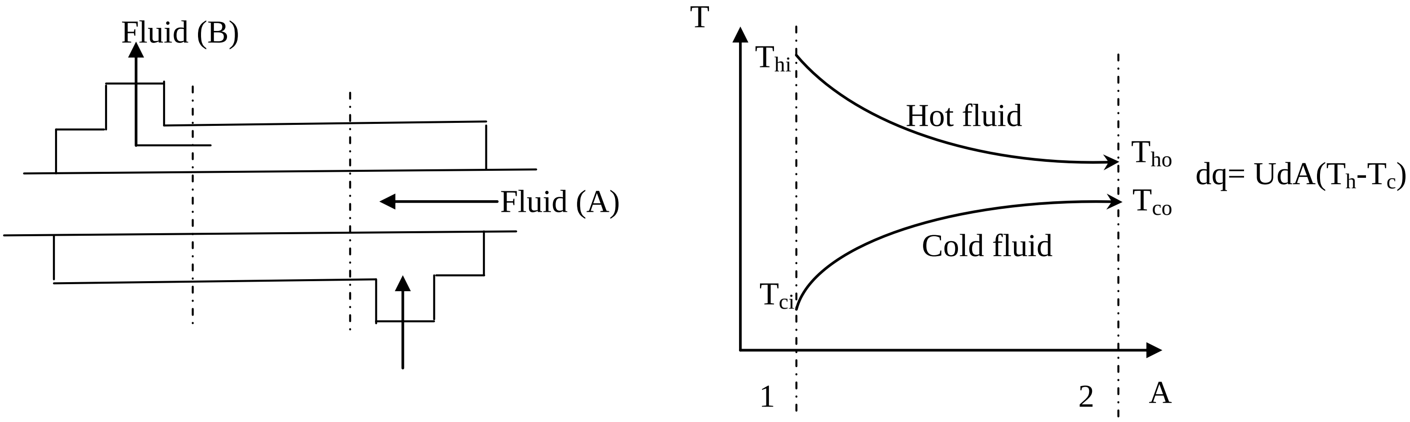
For tubes made of thin walled and high conductive material the above eq. reduces to:

$$\boxed{U = \frac{1}{\frac{1}{h_o} + \frac{1}{h_i}}}$$

The above derivation for LMTD involves two important assumptions:

1. The fluid heat capacities don't vary with temperature.
2. The convection heat transfer coefficient is constant through the heat exchanger.

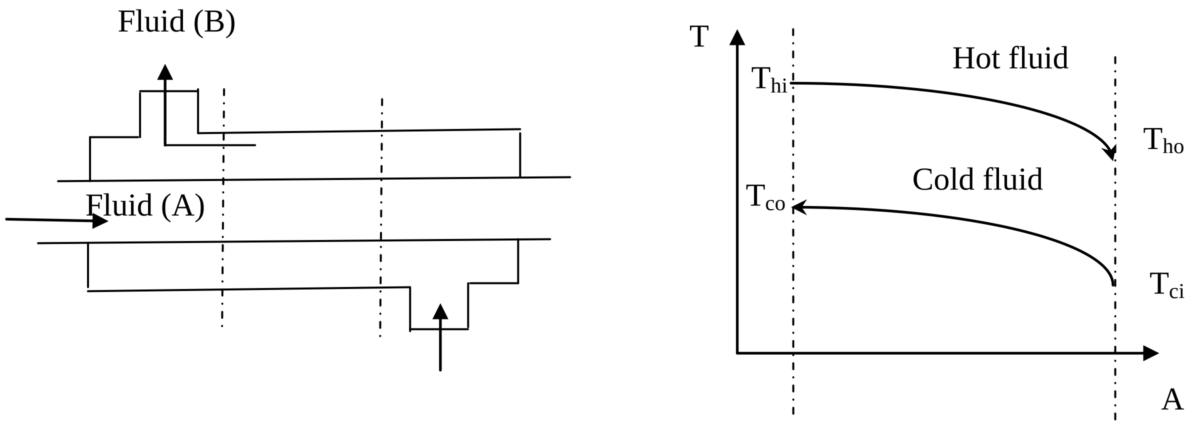
c. Description of Instrument:



Double- pipe parallel flow heat exchanger
(a)

Temperature profile for parallel flow in double pipe heat exchanger
(b)

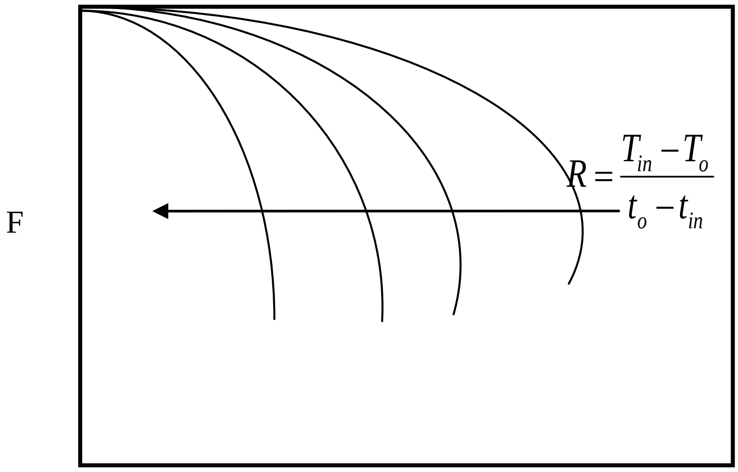
Fig. (1)



Double- pipe counter flow heat exchanger
(a)

Temperature profile for counter flow in double pipe heat exchanger
(b)

Fig. (2)



$$p = \frac{t_o - t_{in}}{T_{in} - t_{in}}$$

Correction Factor of LMTD

Fig .(3)

T	Temp. of fluid at shell side.
t	Temp. of fluid at tube side.

d. **Reading**

No.	T_{hi}	$T_{h\ out}$	T_{cin}	T_{cout}
1.		?		?
2.		?		?
3.		?		?

ε NTU method

The effectiveness offers many advantages for analysis if a comparison between various types of heat exchangers must be made for purposes of selecting the type best suited to accomplish a particular heat transfer objective. We define the heat exchanger effectiveness as

$$Effectiveness = \varepsilon = \frac{actual\ heat\ transfer}{\max imum\ possible\ heat\ transfer}$$

The actual heat transfer may be computed by calculating either the energy lost by the hot fluid or the energy gained by the cold fluid.
For counter flow exchanger

$$\boxed{q = m_h^{\bullet} c_h \left(T_{h_i} - T_{h_o}\right) = m_c^{\bullet} c_c \left(T_{c_o} - T_{c_i}\right)}$$

Maximum possible heat transfer is expressed as:

$$\boxed{q_{\max} = \left(m^{\bullet} c\right)_{\min} \left(T_{h_{inlet}} - T_{c_{inlet}}\right)}$$

The minimum fluid may be either the hot or cold fluid depending on the mass flow rate and heat capacity.
For counter flow heat exchanger

$$\boxed{\varepsilon = \frac{\dot{m}_h c_h \left(T_{h_i} - T_{h_o}\right)}{C_{min}\left(T_{h_i} - T_{c_i}\right)}}$$

Or

$$\boxed{\varepsilon = \frac{\dot{m}_c c_c \left(T_{c_o} - T_{c_i}\right)}{C_{\min}\left(T_{h_i} - T_{c_i}\right)}}$$

The subscripts on the effectiveness symbols designate the fluid which has minimum value of m·c.

We define C (the capacity rate) as:

$$\boxed{C = \dot{m} c} \quad (\mathrm{W/^\circ C})$$

We define the number of transfer units (NTU) as :

$$\boxed{NTU = \frac{UA}{C_{\min}}}$$

e. Procedure:

1. Setting the thermostat on the required temp.
2. Turn on the heater in the tank to warm.
3. Opening the cold and hot water to make the exchange of heat them.
4. Read the first calculation for the $T_{h\ out}$.
5. Read the first calculation for the $T_{c\ out}$
6. Repeat the above for another runs.

f. Calculation:

1. Find the value of q.

$$q = UA_s \Delta T_{LMTD}$$

ΔT_{LMTD}: calculated as shown previously.

A: Total surface area of the tubes= nπdL (n= numbers of tubes).

$$U = \frac{1}{\frac{1}{h_o} + \frac{1}{h_i}}$$

To find h_i

$$Nu = \frac{h_i d_i}{k}$$

di	inlet diameter of tube (m)
k	From table for water W/m.˚C
P_r	Prandtle. No

$Nu = o.o23(\mathrm{Re})^{0.8}(\mathrm{Pr})^{\frac{1}{3}}$, where the flow is turbulent

$$\mathrm{Re} = \frac{\rho u d_i}{\mu}$$

$m_c^{\bullet} = \rho A_x u$, to find the value of u.

Note: A_x must multiply by n (Ax×n), or $m_c^{\bullet}$ divided by numbers of tubes (n).
You can find the values of (ρ,μ, k, Pr) from properties of water in table at T_f .

u	= velocity
A_x	Cross sectional area for the tube, $\frac{\pi}{4} d_i^{\,2}$
A_s	nπdL
T_f	$\frac{T_{c_1} + T_{c_2}}{2}$, for cold water
ΔT_{LMTD}	$\frac{(T_{h_o} - T_{c_i}) - (T_{h_i} - T_{c_o})}{\ell n\left[(T_{h_o} - T_{c_i}) / (T_{h_i} - T_{c_o})\right]}$

2. Find the number of transfer units (NTU)

$$\boxed{NTU = \frac{UA}{C_{\min}}}$$

We must find the minimum capacity rate by compare $m_c^{\bullet}$, with $m_h^{\bullet}$ to choose the minimum between them.

By using the energy balance between hot water and cold water we may find the value of $m_h^{\bullet}$

$$\boxed{q = m_h^{\bullet} c_h \left(T_{h_i} - T_{h_o}\right) = m_c^{\bullet} c_c \left(T_{c_o} - T_{c_i}\right)}$$

C_c finds it from water properties at T_f

$$T_f = \frac{T_{c_i} + T_{c_o}}{2}$$

C_f finds it from water properties at T_f

$$T_f = \frac{T_{h_i} + T_{h_o}}{2}$$

We can find the value of $m_h^{\bullet}$

We define C (the capacity rate) as:

$$\boxed{C_{\min} = m^{\bullet} c} \quad (\mathrm{W/^{\circ}C})$$

Where $C_{\min}$ is equal to $m_c^{\bullet} c_c$ or $m_h^{\bullet} c_h$ whichever is smaller.

3. effectiveness may be defined as:

$$Effectiven\,ess = \varepsilon = \frac{actual\ \ heat\ \ transfer}{\max imum\ \ possible\ \ heat\ \ transfer}$$

$$\boxed{\varepsilon = \frac{m_h^{\bullet} c_h \left(T_{h_i} - T_{h_o}\right)}{C_{min}\left(T_{h_i} - T_{c_i}\right)}}$$

Or

$$\boxed{\varepsilon = \frac{m_c^{\bullet} c_c \left(T_{c_o} - T_{c_i}\right)}{C_{\min}\left(T_{h_i} - T_{c_i}\right)}}$$