7 Heat Exchangers for Food Processing

Lecture Note
Principles of Food Engineering (ITP 330)

Prof. Dr. Purwiyatno SHariyadi, MSc

Dept of Food Science & Technology
Faculty of Agricultural Technology
Bogor Agricultural University
BOGOR

Heat Exchangers
Learning Objectives

- **Understand basic principles of the design and operation of heat exchangers**
- **Be able to list and discuss various applications of heat exchangers**
- **Be able to describe applications of various types of heat exchanges**

Purwiyatno Hariyadi/ITP/Fateta/IPB

HEAT EXCHANGERS

- Heating and cooling systems
  - o use a flowing fluid to provide the heating or cooling effect
  - o Examples:
    - > refrigeration systems
    - > steam jacketed kettles
    - > plate heat exchangers
- Need to know how much heat can be transferred to (or from) a fluid flowing in a system
- Other important factors include:
  - o fluid flow rate
  - o fluid properties
  - o fluid thickness (or pipe diameter)

Purwiyatno Hariyadi/ITP/Fateta/IPB

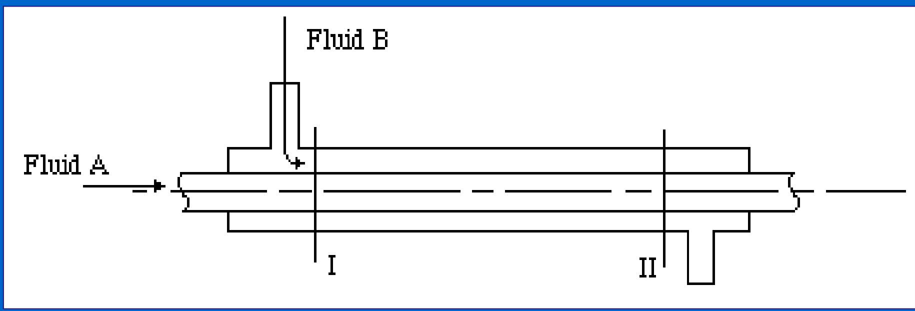
HEAT EXCHANGERS

- Heat exchangers are used extensively in many food operations
- Used where many heating and cooling operations are involved
- Basis function is to transfer heat from one fluid to another
- Some cases fluids are mixed - when steam is added to water
- In most cases, the fluids must be physically separated by a plate, pipe wall, or other good conductor

Purwiyatno Hariyadi/ITP/Fateta/IPB

HEAT EXCHANGERS

- **Simple heat exchanger - one pipe mounted inside another**



- **Double-type heat exchanger is excellent for analyzing heat exchanger characteristics**

Purwiyatno Hariyadi/ITP/Fateta/IPB

HEAT EXCHANGERS : Multi Tube Tubular HX

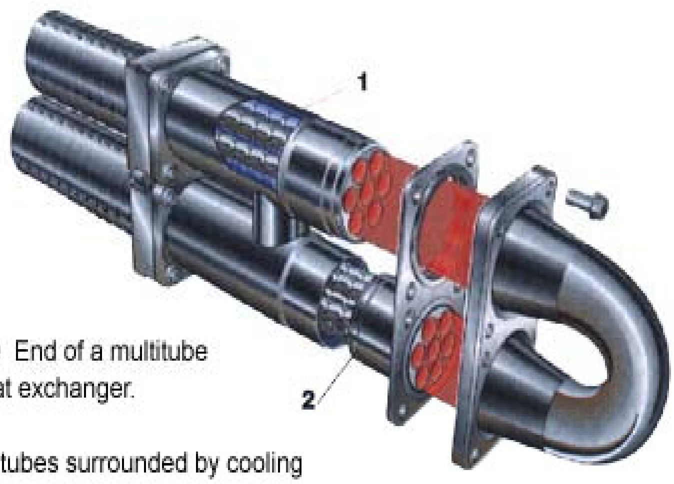


Fig. 6.1.19 End of a multitube tubular heat exchanger.

1 Product tubes surrounded by cooling medium

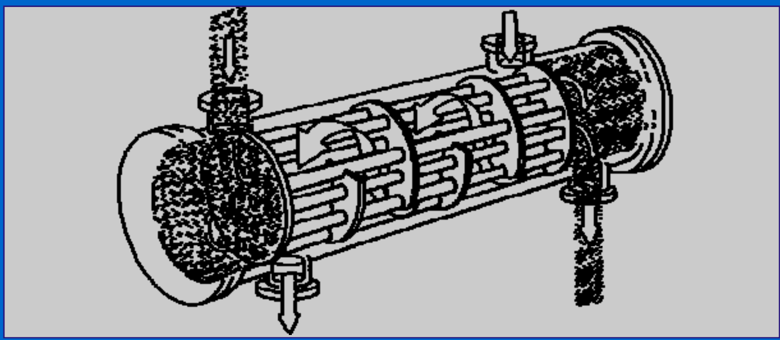
2 Double O-ring seal

Purwiyatno Hariyadi/ITP/Fateta/IPB

HEAT EXCHANGERS

Shell-and-tube heat exchanger

- o has tubes mounted inside an outer shell



- o One fluid flows through the tube while the other is in the shell surrounding the tubes

Purwiyatno Hariyadi/ITP/Fateta/IPB

HEAT EXCHANGERS

Shell-and-tube HX

- bundle of parallel tubes contained within a shell
- tube-side: food product
- shell-side: heating or cooling medium
- shell side not sanitary
- NO regeneration
- very inexpensive

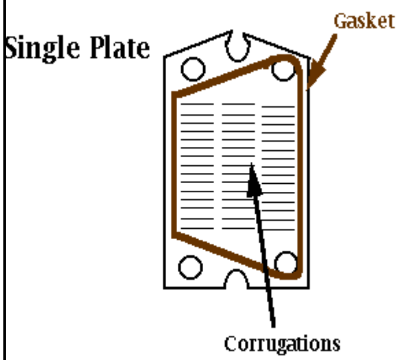
Purwiyatno Hariyadi/ITP/Fateta/IPB

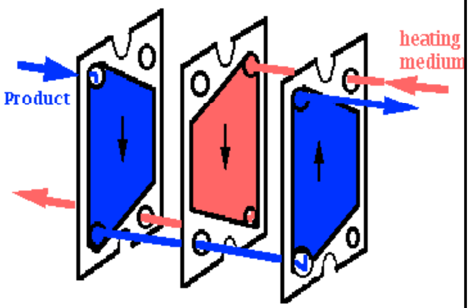
Example : Tube HX

These two feedwater heater tube bundles have passed quality control inspection and await installation into their shells.

Purwiyatno Hariyadi/ITP/Fateta/IPB

plate heat exchanger.





HEAT EXCHANGERS

Swept-surface HX

- viscous fluids
  - –cheese sauce
  - –pudding
- <u>NO</u> regeneration
- expensive

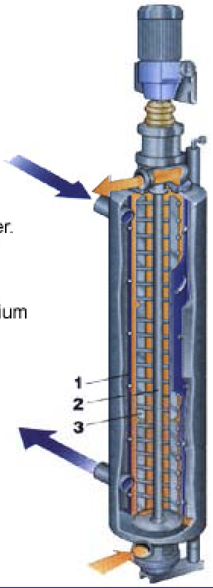
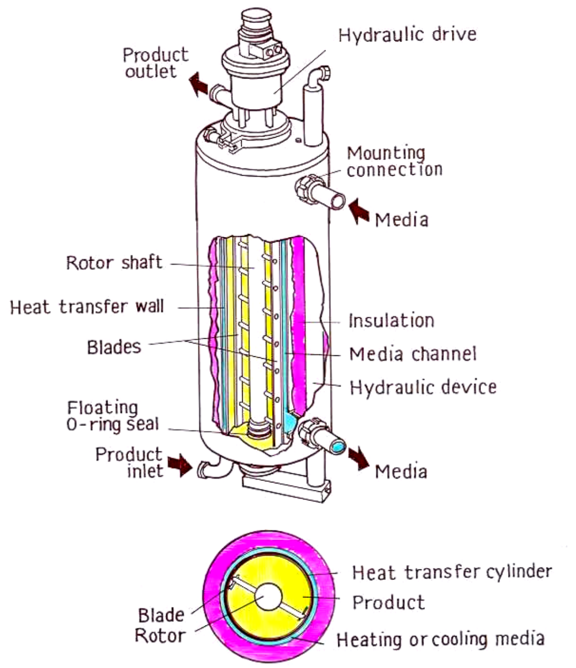


Fig. 6.1.20 Vertical type of scraped-surface heat exchanger.

Purwiyatno Hariyadi/ITP/Fateta/IPB

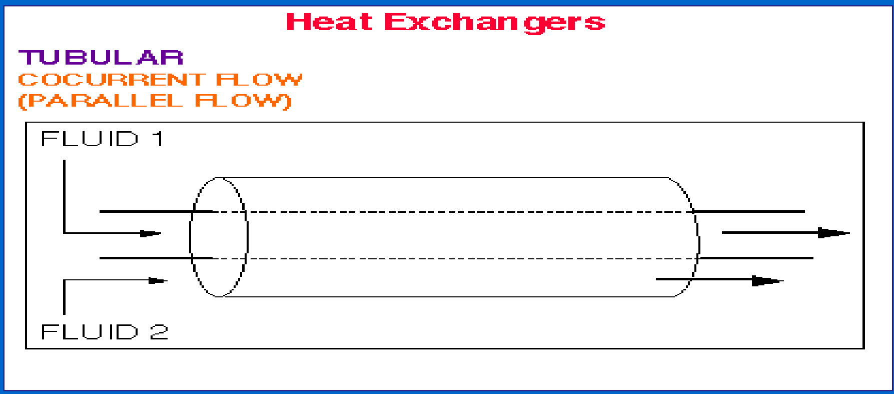
Vertical type of scraped-surface heat exchanger



Purwiyatno Hariyadi/ITP/Fateta/IPB

HEAT EXCHANGERS

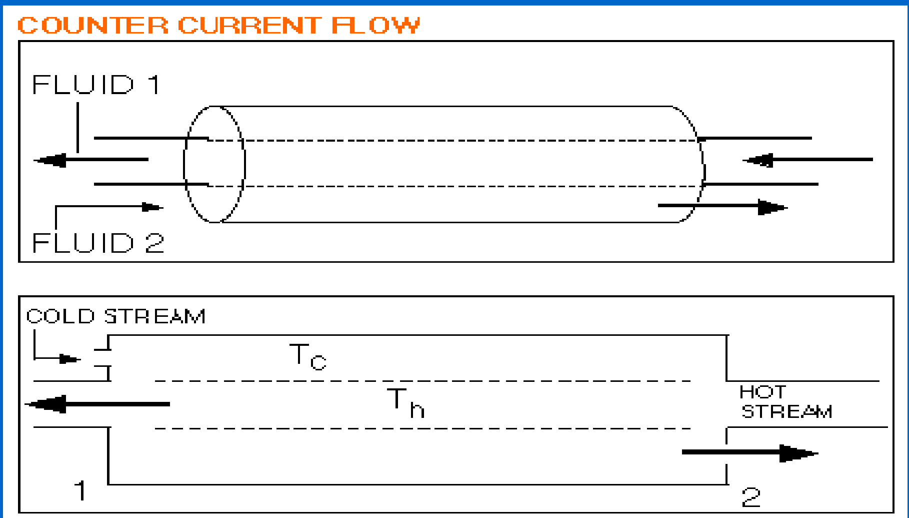
- Heat exchangers also identified by the flow pattern of the fluids in the exchanger
- Double-pipe heat exchanger - a parallel flow unit since the fluids flow in parallel.



Purwiyatno Hariyadi/ITP/Fateta/IPB

HEAT EXCHANGERS

Reversing either fluid would produce a counter flow system



Purwiyatno Hariyadi/ITP/Fateta/IPB

HEAT EXCHANGERS

- Heat exchangers vary greatly in the design to obtain desired heat transfer characteristics
- Cross-flow system - fluids flow perpendicular to each other
- Combinations of several designs are sometimes used in special situations

Purwiyatno Hariyadi/ITP/Fateta/IPB

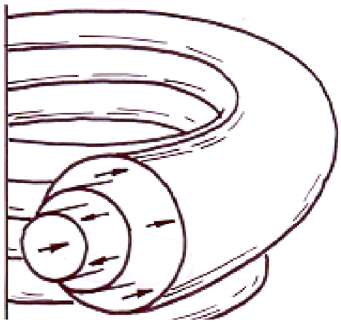
SPIRAL-TUBE HX

- helical tube within shell
- used on some aseptic systems

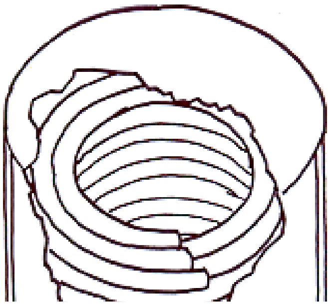
STEAM-INFUSION HX

- thin layer of food cascades through steam chamber
- direct contact with steam=dilution
- viscous foods
- possibly foods with particulates

Purwiyatno Hariyadi/ITP/Fateta/IPB



The concentric tubes
in a triple tube heat exchanger

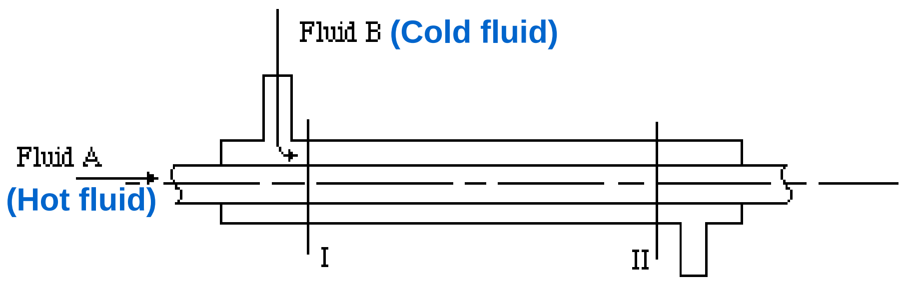


Consentric tubes wound cylindrically
to form coils.
The unit is placed in
a stainless steel jacket

Purwiyatno Hariyadi/ITP/Fateta/IPB

HEAT EXCHANGERS : Analysis

- **Assume the following:**
  - o **double-pipe heat exchanger**

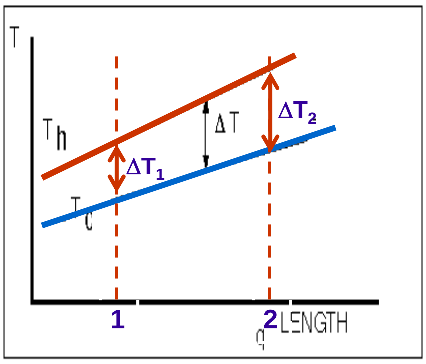


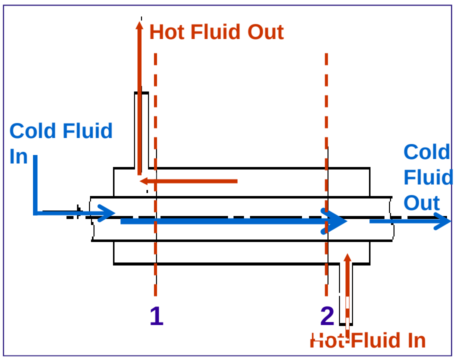
- o **hot fluid flowing in the inner pipe**
- o **cooler fluid flows in outer pipe**
- o **flow is parallel**

Purwiyatno Hariyadi/ITP/Fateta/IPB

HEAT EXCHANGERS : Analysis

Temperature distribution along length of heat exchanger



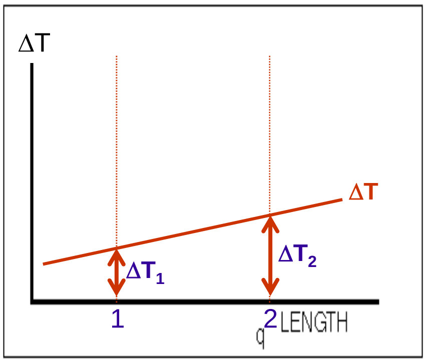


ASSUMPTIONS
-- Steady state flow
-- No heat conduction parallel to direction of fluid flow
-- Overall heat transfer 'U' is constant throughout the length

Purwiyatno Hariyadi/ITP/Fateta/IPB

HEAT EXCHANGERS : Analysis

Temperature distribution along length of heat exchanger

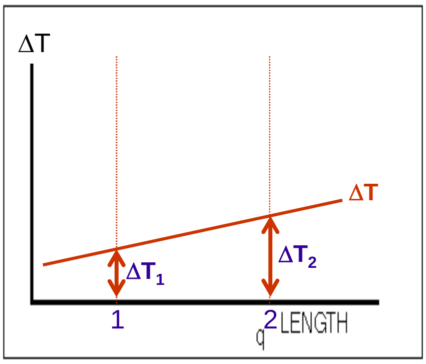


ASSUMPTIONS
-- Steady state flow
-- No heat conduction parallel to direction of fluid flow
-- Overall heat transfer 'U' is constant throughout the length

Purwiyatno Hariyadi/ITP/Fateta/IPB

HEAT EXCHANGERS : Analysis

Temperature distribution along length of heat exchanger



ASSUMPTIONS

- -- Steady state flow
- -- No heat conduction parallel to direction of fluid flow
- -- Overall heat transfer 'U' is constant throughout the length

$$\frac{d\Delta T}{dq} = \frac{\Delta T_2 - \Delta T_1}{q}$$

$$dq = U_i \Delta T dA_i$$

$$\frac{d\Delta T}{U_i \Delta T dA_i} = \frac{\Delta T_2 - \Delta T_1}{q}$$

$$\frac{1}{U_i}\left(\frac{d\Delta T}{\Delta T}\right) = \frac{\Delta T_2 - \Delta T_1}{q} dA_i$$

$$\frac{1}{U_i}\int_{DT1}^{DT2}\left(\frac{d\Delta T}{\Delta T}\right) = \frac{\Delta T_2 - \Delta T_1}{q}\int_0^{Ai} dA_i$$

$$q = U_i A_i \frac{\Delta T_2 - \Delta T_1}{\ln \frac{\Delta T_2}{\Delta T_1}}$$

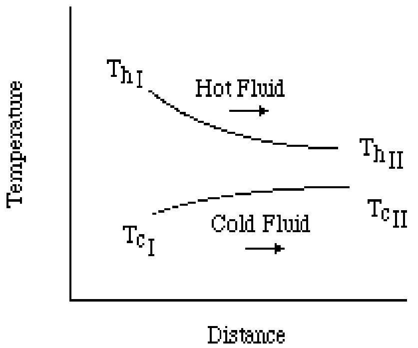
dimana

$$LMTD = \frac{\Delta T_2 - \Delta T_1}{\ln \frac{\Delta T_2}{\Delta T_1}}$$

Purwiyatno Hariyadi/ITP/Fateta/IPB

HEAT EXCHANGERS : Analysis

Energy balance :
Total energy lost (by hot fluid) : $q_h = \dot{m}_h c_h (T_{hI} - T_{hII})$



Where:

$\dot{m}_h$ = mass flow rate of hot fluid (kg / s)

c_h = specific heat of hot fluid (kJ / kg ^{0}C)

T_{hI} = temperature of hot fluid at position I (^{0}C)

T_{hII} = temperature of hot fluid at position II (^{0}C)

q_h = rate of heat transferred from hot to cold fluid (kJ / s or kW)

Total energy lost (by cold fluid) : $q_c = \dot{m}_c c_c (T_{cII} - T_{cI})$

Purwiyatno Hariyadi/ITP/Fateta/IPB

HEAT EXCHANGERS : Analysis

$$q = U\,A\,\Delta T_m$$

where:

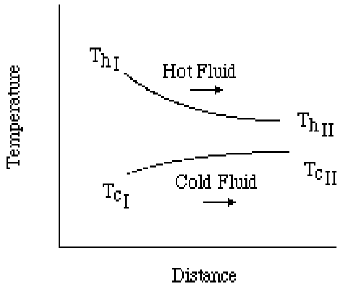
$U =$ overall heat transfer coefficient $(kW/m^2\text{-}^0C)$

$A =$ surface area for heat transfer consistent with definition of U (m^2)

$\Delta T_m =$ log mean temperature difference (LMTD)

$$\Delta T_m = \frac{\Delta T_{II} - \Delta T_I}{\ln\left(\frac{\Delta T_{II}}{\Delta T_I}\right)}$$

$$\Delta T_m = \frac{(T_{hII} - T_{cII}) - (T_{hI} - T_{cI})}{\ln\left(\frac{(T_{hII} - T_{cII})}{(T_{hI} - T_{cI})}\right)}$$

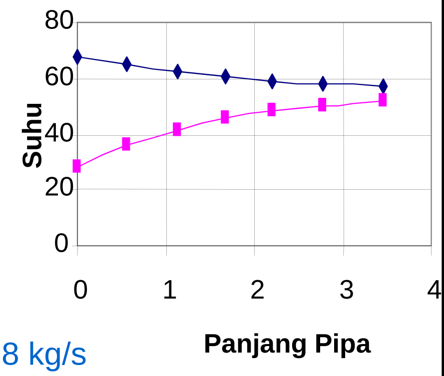


Purwiyatno Hariyadi/ITP/Fateta/IPB

HEAT EXCHANGERS : Analysis

Contoh Soal

PARALLEL FLOW		
Length of pipe (m)	Temp of hot water (°C)	Temp of cold water(°C)
0.000	67.7	28.1
0.560	64.8	35.9
1.130	62.8	41.3
1.680	60.4	45.5
2.195	58.8	48.1
2.770	57.7	50.1
3.340	56.8	51.8



Diketahui :

- Laju aliran air pendingin = 0.028 kg/s
- Luas area HX = 0.1226 m^2
- Kapasitas panas air = 4.1868 kJ/kg.^oK

Ditanya :

- Berapa nilai U *(overall Heat Transfer Coef)*?

Purwiyatno Hariyadi/ITP/Fateta/IPB

HEAT EXCHANGERS : Analysis

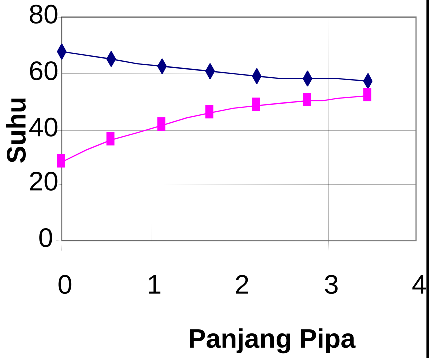
Contoh Soal

Dari data yang ada :

→ $q = m\ c_p\ \Delta T$;

Diketahui : $m_c = 0.028$ kg/s

$C_p = 4.1868$ kJ/kg.°C



Jadi,

→ $q = (0.028\ \text{kg/s})(4.1868\ \text{kJ/kg.}^{o}\text{C})(51.8-28.1)^{o}\text{C}$

$= 2.778$ kW

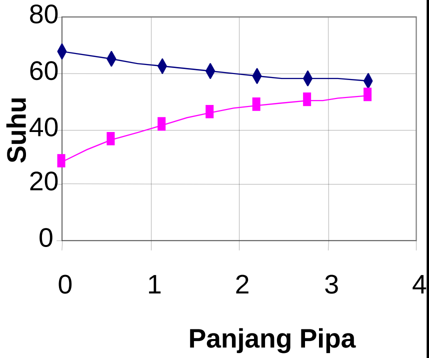
Purwiyatno Hariyadi/ITP/Fateta/IPB

HEAT EXCHANGERS : Analysis

Menggunakan data yang ada (lihat grafik), cari LMTD

$$\text{LMTD} = \frac{[(56.8 - 51.8) - (67.7 - 28.1)]}{\ln\left(\frac{56.8 - 51.8}{67.7 - 28.1}\right)}$$

$$= 16.72\ ^{\circ}\text{C}$$



Diketahui $A = 0.1226\ m^2$

Maka, sesuai dengan teori Pindah panas

→ $q = U\ A\ \Delta T_m = U\ A\ (\text{LMTD})$

$U = q/[A(\text{LMTD})]$

$U = (2.778\ \text{kW})/(0.1226*16.72)\text{m}^2.^{o}\text{c} = 1.355\ \text{kW/m}^2.^{o}\text{c}$

Purwiyatno Hariyadi/ITP/Fateta/IPB

HEAT EXCHANGERS

Plate HX

- regenerative heat/cool
- compact
- THE standard for milk pasteurization
- low-viscosity fluids
  - juice
  - UHT milk

Selesai ....

Sekarang ke…….

Proses Termal