Assignment

- Topic-

Basic considerations in process equipment design

Introduction

- Setup of new plant or modification/ expansion of existing plant involves both technical and economic evaluation
- Knowledge various technical aspects such as unit operation, process design, equipment design, thermodynamics, reaction kinetics etc. is a prerequisite to the establishment and development of any plant

Design consideration

- Two aspects:

1. Structural design

   It includes selection of material, chemical and mechanical properties, stress analysis, thickness calculation etc. to withstand load, pressure and operating conditions

2. Functional design

   It includes specification and selection of equipments , power requirement, matching with other process equipments, ease of operation , process automation & controls, safety measures etc.

General considerations

- Plant location
- Site and plant layout
- Plant operation and control
- Utilities
- Storage
- Waste disposal
- Health and safety
- Material handling

JUICE HEATER DESIGN

BY
J.P.SRIVASTAVA
Ex Chief Design Engineer
National Sugar Institute, Kanpur ,India

- **OBJECTIVE**

  To get desired temperature of juice required during sugar processing with minimum energy requirement

- **FUNCTION**

  To heat juice by indirect/direct contact with steam by utilizing latent heat of vaporization

TYPE OF JUICE HEATER

Design consideration

1. tubular calendria type juice heater
2. Plate type juice heater
3. Direct contact juice heater
4. Condensate juice heater

Functional consideration

1. Vapour Line Juice Heater
2. Dynamic juice heater
3. Raw juice heater
4. Sulphited juice heater
5. Clear juice heater

Operating parameter (Temp.)

J.H. TYPE	TEMP.(IN) Juice	TEMP. (OUT) juice	TEMP. (STEAM)	CALENDRIA/ PHE
Vapour line juice heater	35ºC to 38ºC	45ºC to 48ºC	55ºC	CALENDRIA
Dynamic juice heater	45ºC to 48ºC	70ºC	94ºC	CALENDRIA
Raw juice heater	45ºC to 48ºC	70ºC	94ºC	CALENDRIA
Sulphited juice heater	68ºC	102ºC	110ºC	CALENDRIA
Clear juice heater	95ºC	110ºC	120ºC	PHE

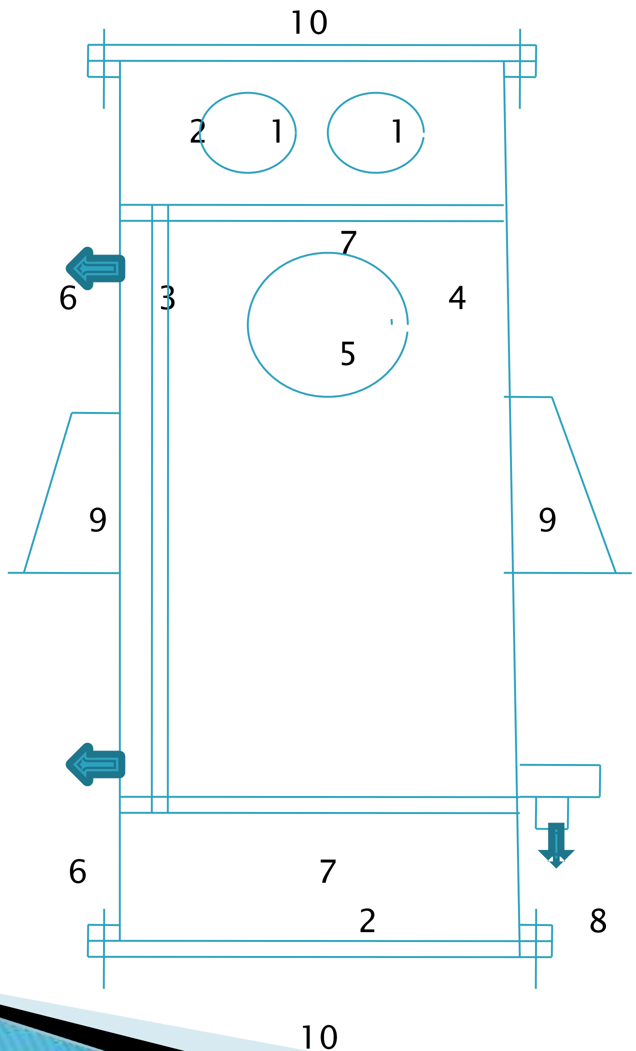
GIVEN PARAMETERS

1. Crushing rate of sugar plant(TCH)
2. Mixed juice % cane
3. Initial temperature of juice
4. Final temperature of juice
5. Temperature of heating medium(Steam)
6. Size of tube- diameter(inside/outside), length of tube
7. Velocity of juice- 1.8m/sec. to 2.0m/sec.

PARAMETERS TO BE CALCULATED

- Heating Surface
- Total number of tubes
- Number of tubes per pass
- Number of passes
- Number of compartments on top header
- Number of compartments on bottom header
- Diameter of tube plate
- Height of header
- Size of steam inlet
- Size of condensate outlet
- Size of vents
- Thickness of tube plate
- Thickness of calendria shell

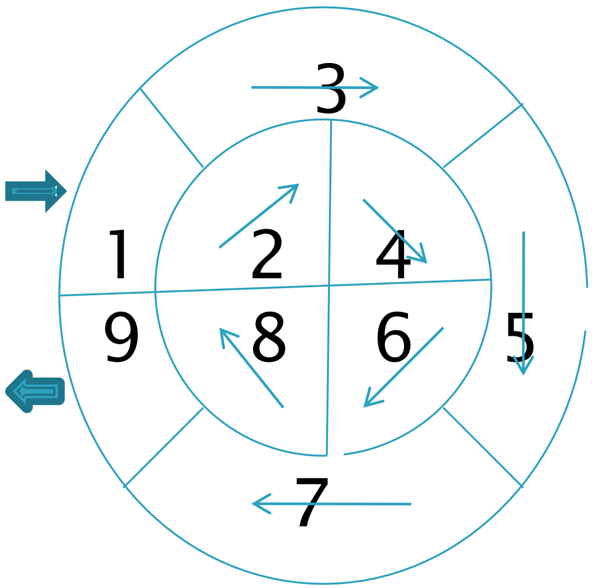
JUICE HEATER DESIGN



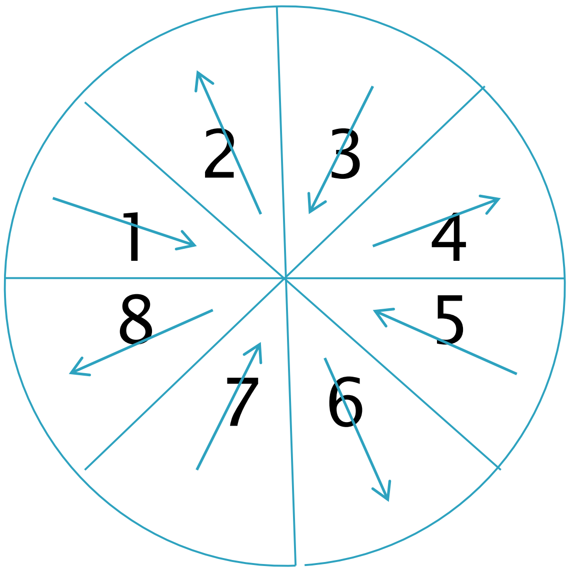
1. JUICE INLET/OUTLET
2. TOP/BOTTOM HEADER
3. TUBE
4. CALENDRIA
5. STEAM INLET
6. VENTS
7. TOP/BOTTOM TUBE PLATE
8. CONDENSATE OUTLET
9. SUPPORTS
10. COVER

GENERAL ARRANGEMENT

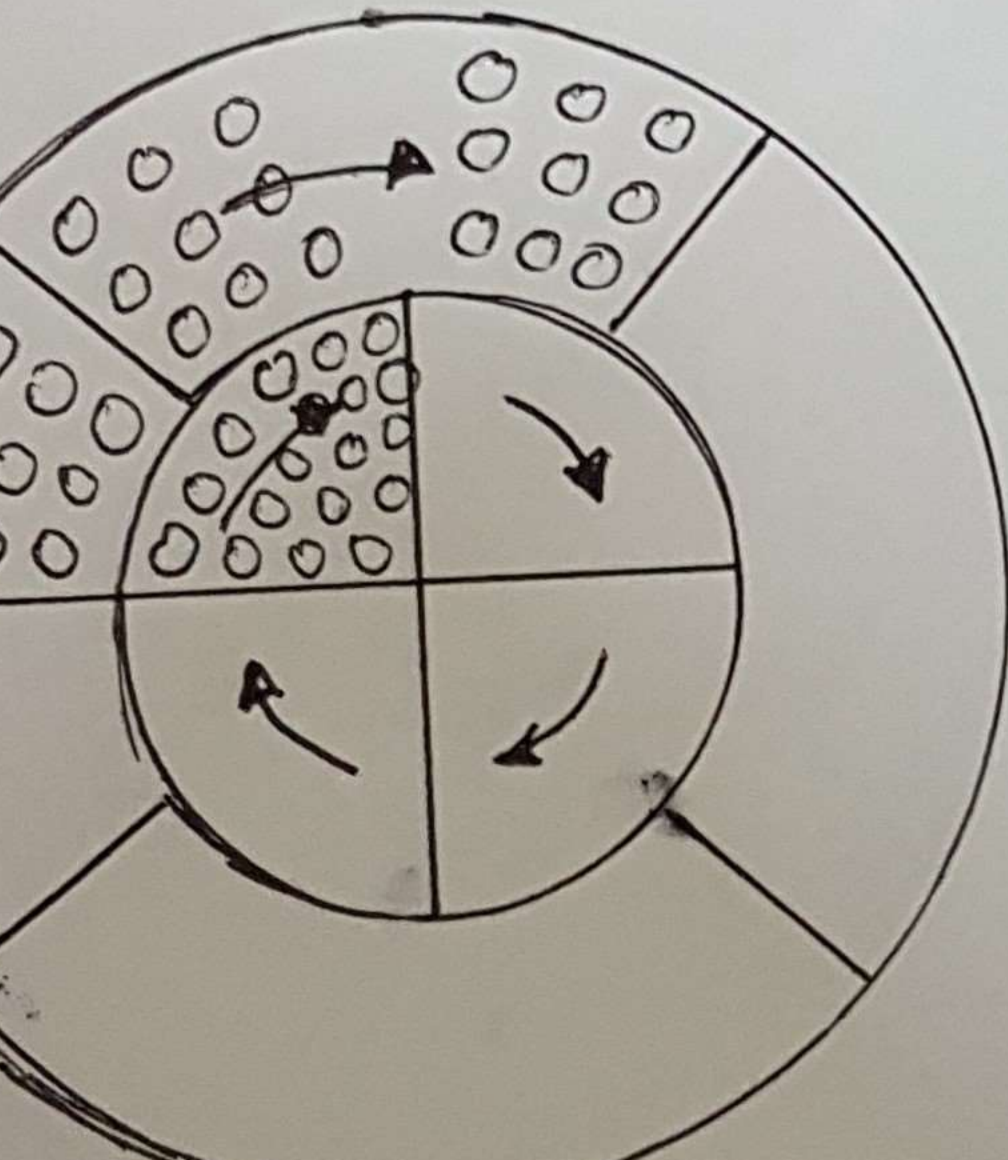
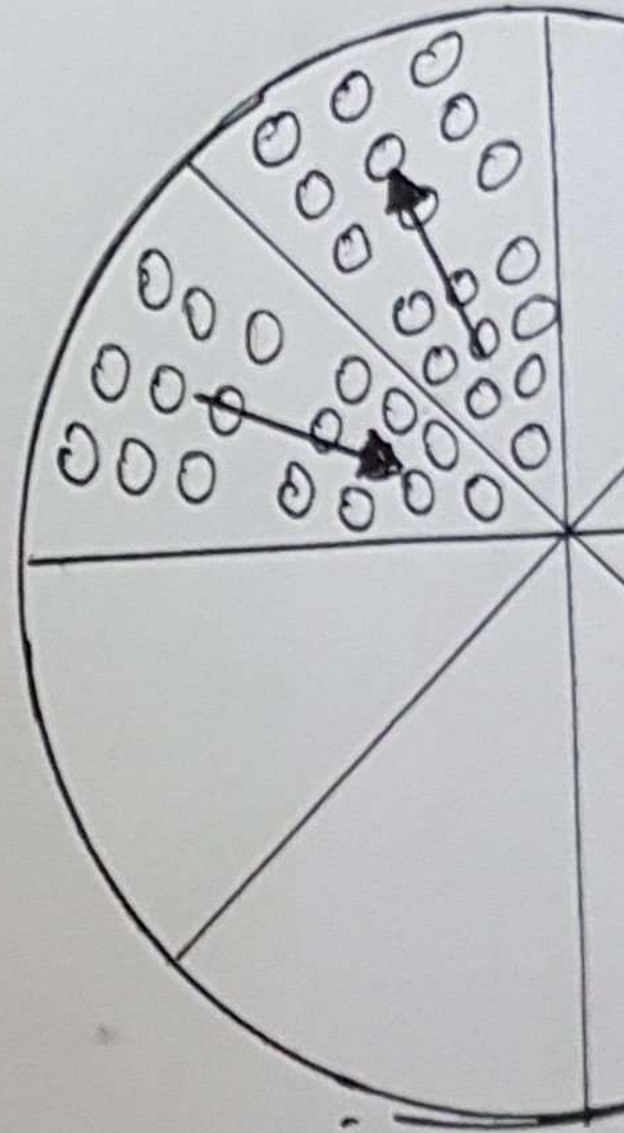
HEADER DESIGN



TOP HEADER



BOTTOM HEADER

Heating Surface (S)

$$S = \frac{Qj \times c \times T}{K \times \Delta m}$$

Where Qj= Juice flow rate

c = Sp. Heat of juice (.89)

T = Rise in temp. (°C)

k = heat transfer coefficient

Δm = Log Mean Temp. Diff.

$$= \frac{\Delta i - \Delta_0}{\log \frac{\Delta i}{\Delta_0}}$$

where ΔI = Temp. diff between incoming steam& juice

Δ_0 = Temp. diff between outgoing steam /cond.& juice k = Heat transfer coefficient(kcal/m^2/hr/°C)

= $6T(V/1.8)^{0.8}$

where T= Temp. of steam,C

V= velocity of juice (meter/sec)

1.8- 2.2 meter/sec

Total number of tubes(N) (tentative)

$$N = \frac{\text{Heating surface of juice heater(S)}}{\text{Heating surface of one tube(s)}}$$

$s = \pi D_{mean} \times L_{effective}$

$D_{mean} = (ID + OD)/2$ 42mm ID, 45 mm OD

$L_{effective}$ = Total length – 2x TP thickness – 2x expansion allowance

Take TP thickness = 25mm
Expansion allowance = 2.5 mm

Number of tubes per pass(n)

$\pi/4\ d_i^2 \times n \times v$ = Flow rate of juice(m^3/sec) -1

where di = ID of tube

and v = velocity of juice (2m/sec.)

Calculate 'n' from Eq-1 above which should be in whole number

Number of passes(P)

$$P = \frac{\text{Total number of tubes}}{\text{Number of tubes per pass}}$$

P should be always in even number

Actual No of tubes = n x P

Number of compartments:

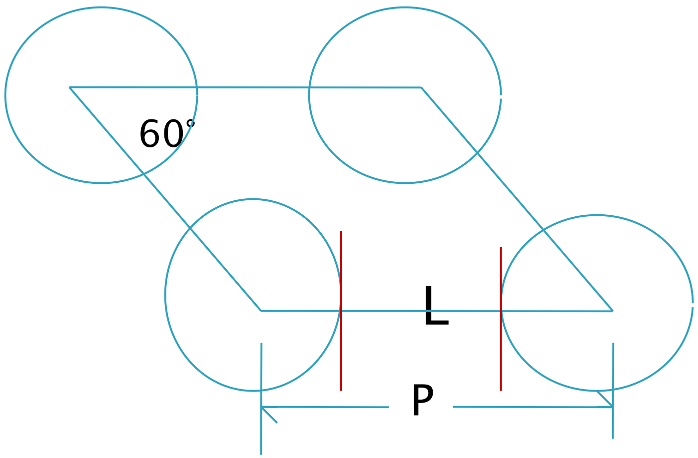
Top Header – P/2+1

Bottom Header – P/2

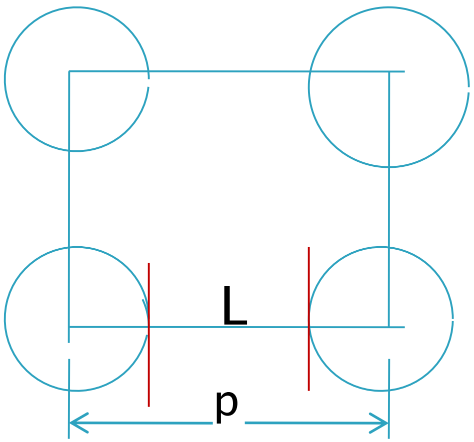
Diameter of tube plate (Dtp)

Setting of tubes: Two types of setting

1. Triangular setting
2. Square setting



TRIANGULAR SETTING



SQUARE SETTING

- Ligament (L) = 12 mm
- Area requires to set one tube = $0.866\ P^2$ (Triangular setting)
- Area requires to set one tube = P^2 (Square)
- Area of tube plate ($\pi/4\ Dtp^2$) $= \dfrac{0.866 P^2 \times N}{\beta}$

Where β is Factor of proportionality, taken = 0.56

$$\pi/4\ Dtp^2 = \frac{0.866 P^2 \times N}{0.56}$$

Calculate Dtp

Juice inlet/Outlet

- **Juice Inlet(dj) :**

$\pi/4 dj^2 x\ v$ = Flow rate of juice (m^3/sec)

= TCH x MJ% cane/3600 x100xds

Where

v = Velocity of juice(2m/sec.)

dj = Dia. Of juice inlet/outlet

ds = Density of juice ($1050 kg/m^3$)

Calculate dj

Size of juice inlet & juice outlet will be same. Both valves (Double beet valve) are operated simultaneously to close/open . This arrangement is provided to facilitate to take any juice heater in line and off line when required .

Steam inlet in calendria

- <u>Steam Inlet (Ds)</u>

$Q x L = Q_j x \ c x \ T$

$$Q = \frac{Q_j \times c \times T \times \text{sp. Volume of steam}}{L}$$

Where Q= Steam flow rate(kg/sec.)

Qj =Juice flow rate(kg./sec.)

c = Sp. Heat of juice(kcal/kg/°C)

L = Latent heat of vaporization(kcal/kg)

T = Rise in temp of juice(°C)

Calculate Q from above Equation

Now,

$\pi/4 \ Ds^2 x \ v$ = Volumetric steam flow rate (m^3/sec.)

Take velocity of steam (v) = 35m/sec

Calculate Ds

Non condensable gas outlet

- One cm^2 cross sectional area for each $10m^2$ heating surface of juice heater should be provided for removal of non condensable gases from calendria.
- It is provided at two places in shell of calendria i.e. at upper portion and at lower portion above the level of codensate.
- It is essential to remove from calendria to ensure continuous entry of fresh steam

Condensate outlet

- Wt. of condensate = Wt. of steam admitted
- Calculate corresponding volume of condensate (m^3/sec)
- $\pi/4 x dc^2 x v$ = Volume of condensate($m^3/sec.$)

Where v= velocity of condensate

= 0.6m/sec.

dc = dia. of condensate outlet

Continuous removal of condensate is essential

Thickness of calendria shell

- $$t_{cs} = \frac{P_s \times D_i}{2fj - P_s} + C$$

Where Ps = Design pressure

=1.2x working pressure($5 kg/cm^2$)

Di = Internal dia. Of calendria shell

f = Safe allowable stress($1000 kg/cm^2$)

j = Weld joint efficiency (0.7)

C = Corrosion allowance (1.5 mm)

Thickness of tube plate

- $$t_p = FG\sqrt{\frac{0.25\,p}{f}} + C$$

where tp = Tube plate thickness

F = Const. = $\sqrt{k/2+3k}$

G = Internal dia. Of shell

p = Design pressure($5 kg/cm^2$

f Allowable shear stress($1575 kg/cm^2$)

C = Corrosion allowance 1.5mm

$$F = \text{Const.} = \sqrt{k/2+3k}$$

where $k = \dfrac{E_s \times t_s (D_0 - t_s)}{E_t \times t_t (d_0 - t_i) N}$

E_s = Modulus of elasticity of shell

E_t = Modulus of elasticity of tube

D_0 = Outer dia. Of shell

d_0 = Outer dia. Of tube

t_s = Thickness of shell

t_i = Thickness of tube

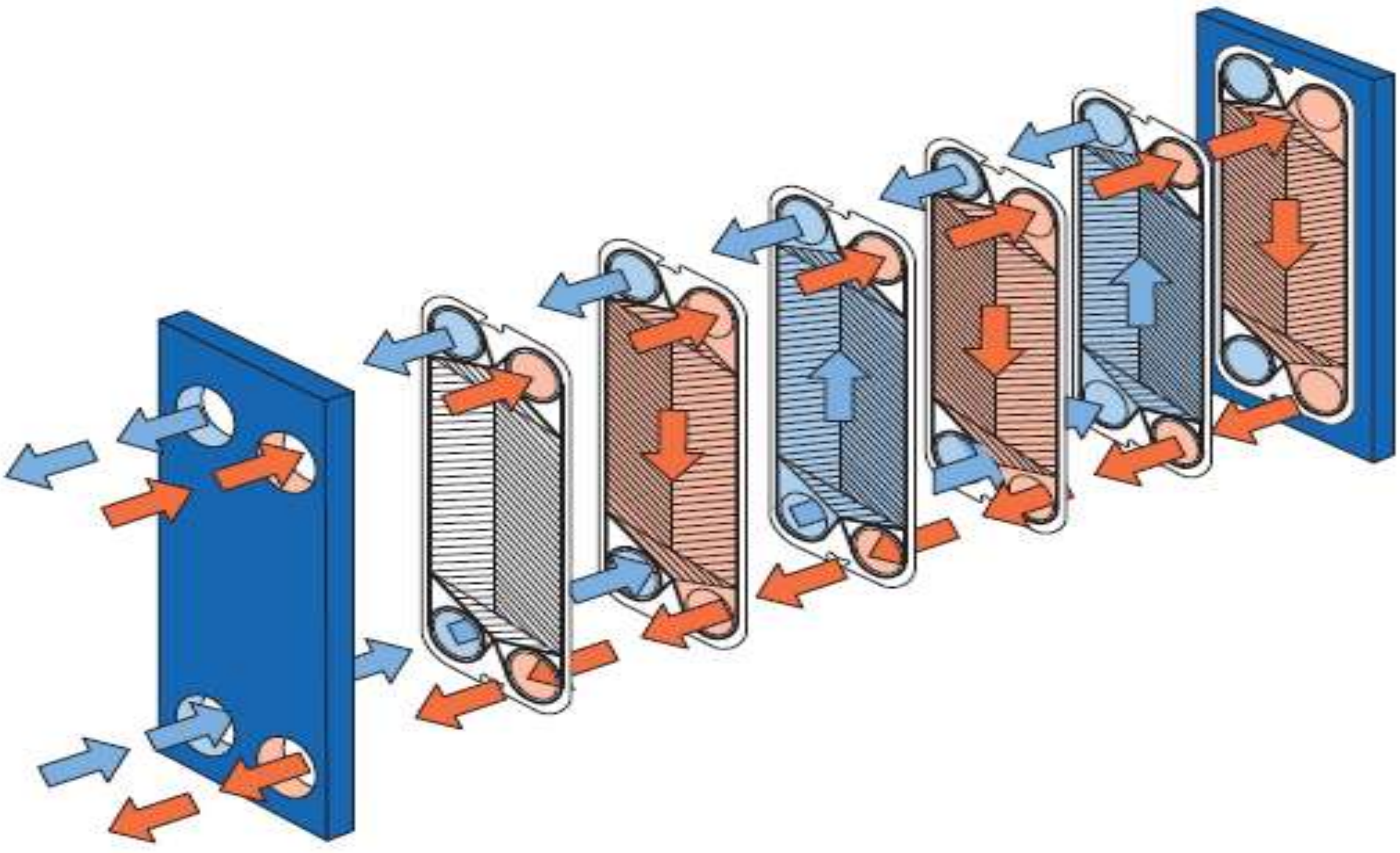
N = total number of tubes

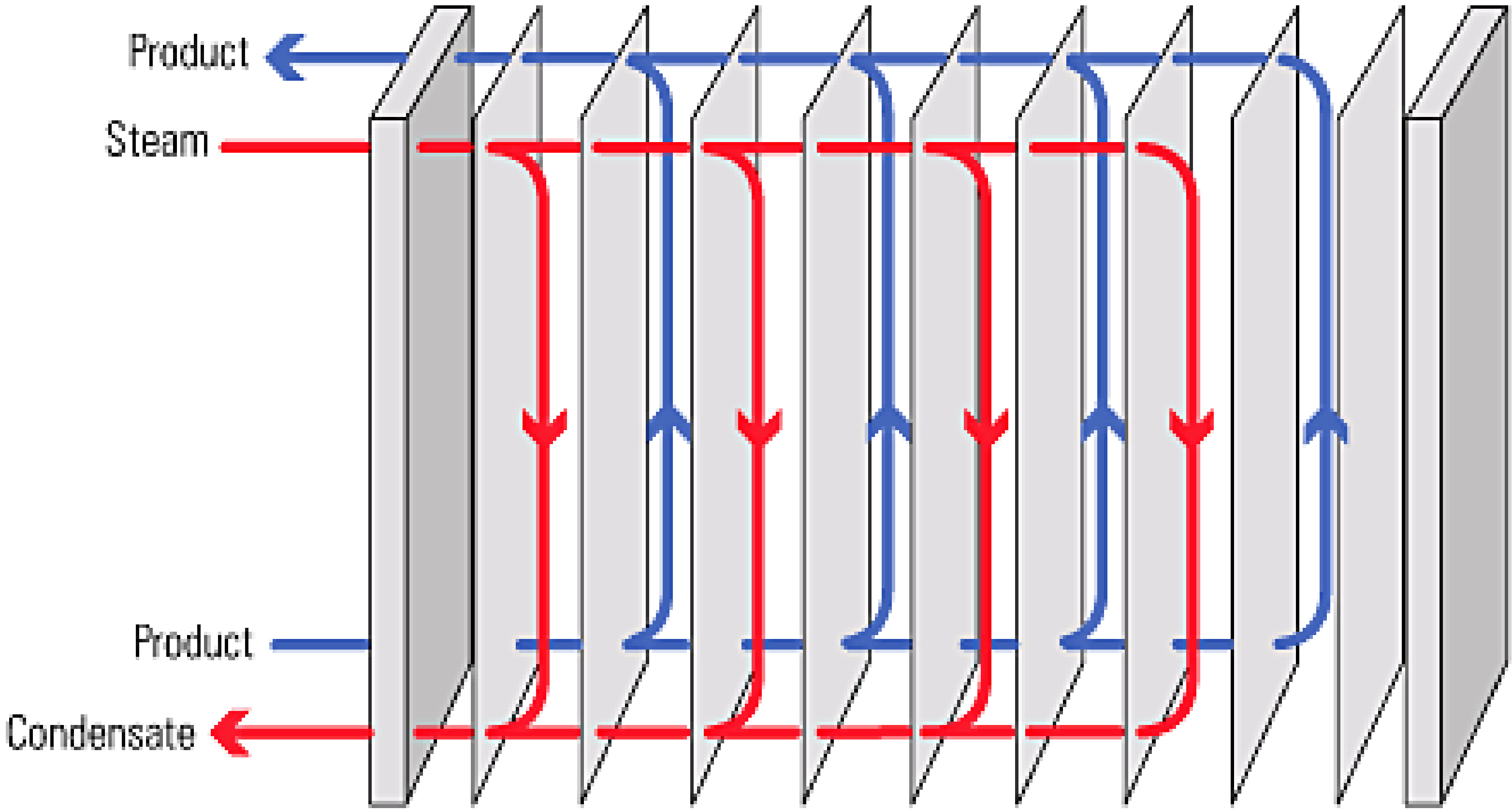
PLATE HEAT EXCHANGER

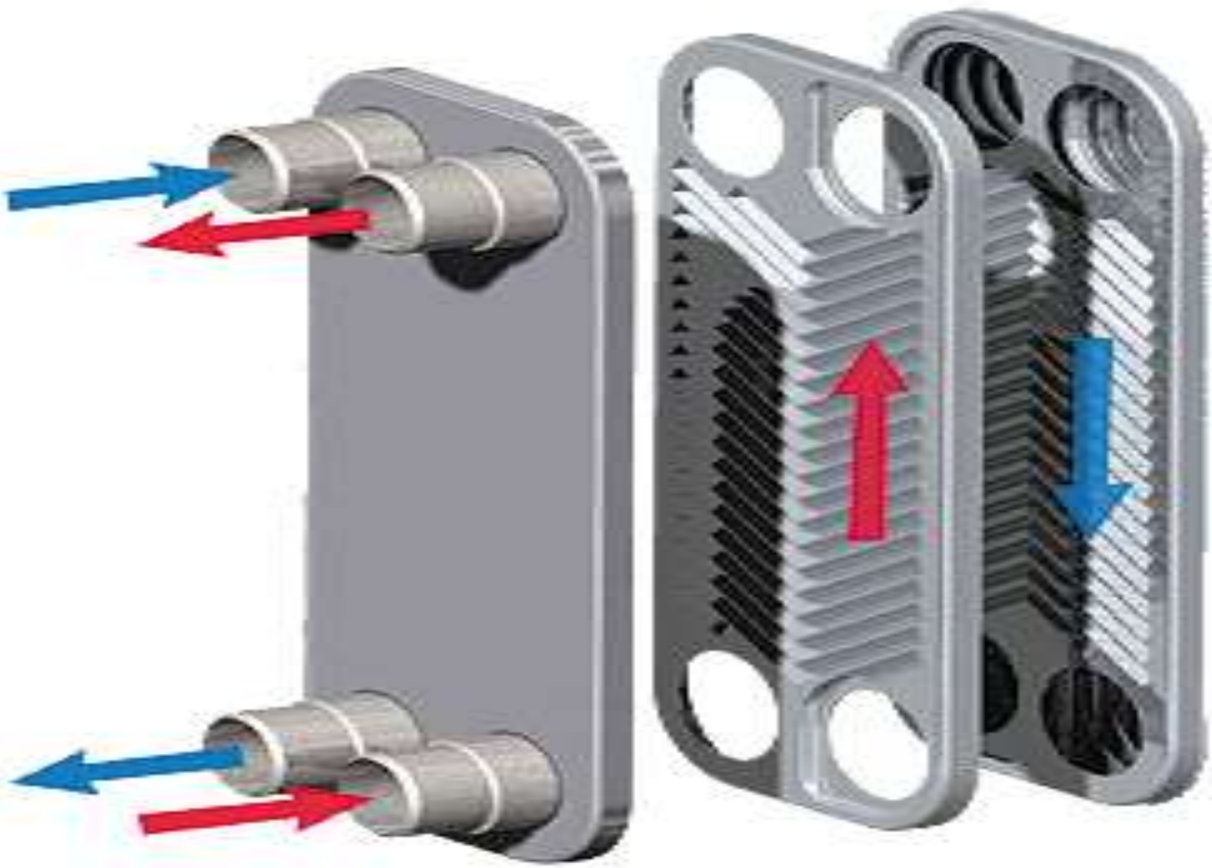
- The heat transfer surface consists of a number of thin corrugated plates pressed out of a high grade metal.
- The pressed pattern on each plate surface induces turbulence and minimises stagnant areas and fouling.
- Unlike shell and tube heat exchangers, which can be custom-built to meet almost any capacity and operating conditions, the plates for plate and frame heat exchangers are mass-produced using expensive dies and presses.
- All plate and frame heat exchangers are made with what may appear to be a limited range of plate designs.

PERFORMANCE OF PHE

- Superior thermal performance is the hallmark of plate heat exchangers.
- Compared to shell-and-tube units, plate heat exchangers offer overall heat transfer coefficients 3 to 4 times higher.
- These values, typically 4000 to 7000 W/m^2 °C (clean), result in very compact equipment.
- This high performance also allows the specification of very small approach temperature (as low as 2 to 3°C) which is sometimes useful in geothermal applications.
- This high thermal performance does come at the expense of a somewhat higher pressure drop.
- Selection of a plate heat exchanger is a trade-off between U-value (which influences surface area and hence, capital cost) and pressure drop (which influences pump head and hence, operating cost).
- Increasing U-value comes at the expense of increasing pressure drop.




Product
Steam
Product
Condensate

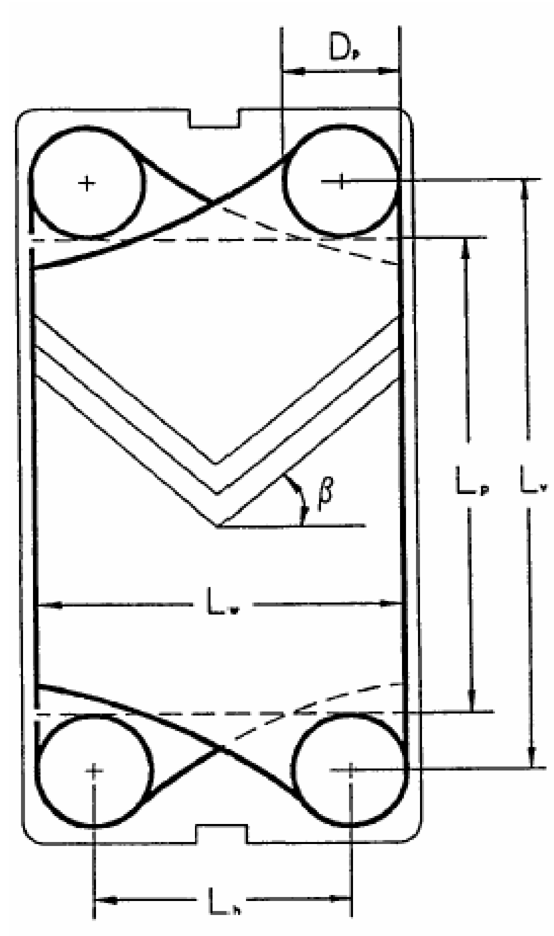


PERFORMANCE OF PHE

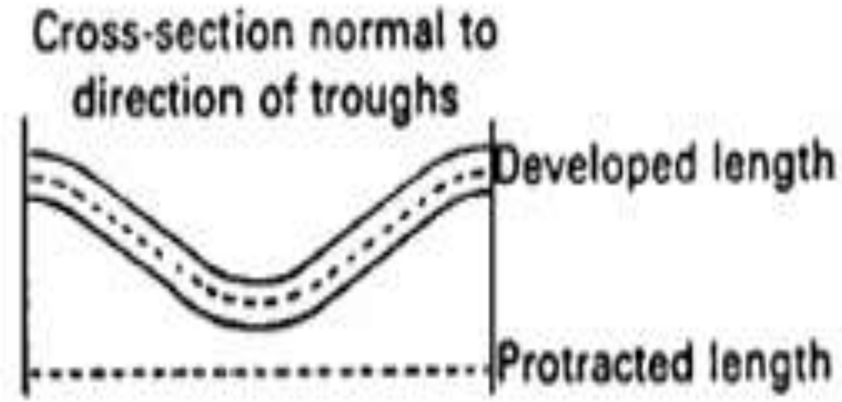
- Superior thermal performance is the hallmark of plate heat exchangers.
- Compared to shell-and-tube units, plate heat exchangers offer overall heat transfer coefficients 3 to 4 times higher.
- These values, typically 4000 to 7000 W/m^2 °C (clean), result in very compact equipment.
- This high performance also allows the specification of very small approach temperature (as low as 2 to 3°C) which is sometimes useful in geothermal applications.
- This high thermal performance does come at the expense of a somewhat higher pressure drop.
- Selection of a plate heat exchanger is a trade-off between U-value (which influences surface area and hence, capital cost) and pressure drop (which influences pump head and hence, operating cost).
- Increasing U-value comes at the expense of increasing pressure dr

SINGLE PLATE WITH GASKET

- **Chevron Angle**: This important factor, usually termed β, is shown in Figure, the usual range of β being 25°–65°.
- **Effective Plate Length** : The corrugations increase the flat or projected plate area, the extent depending on the corrugation pitch and depth.
- To express the increase of the developed length, in relation to the projected length, an enlargement factor ϕ is used.
- The enlargement factor varies between 1.1 and 1.25, with 1.17 being a typical average.



Dp
β
Lp
Lv
Lw
Lh



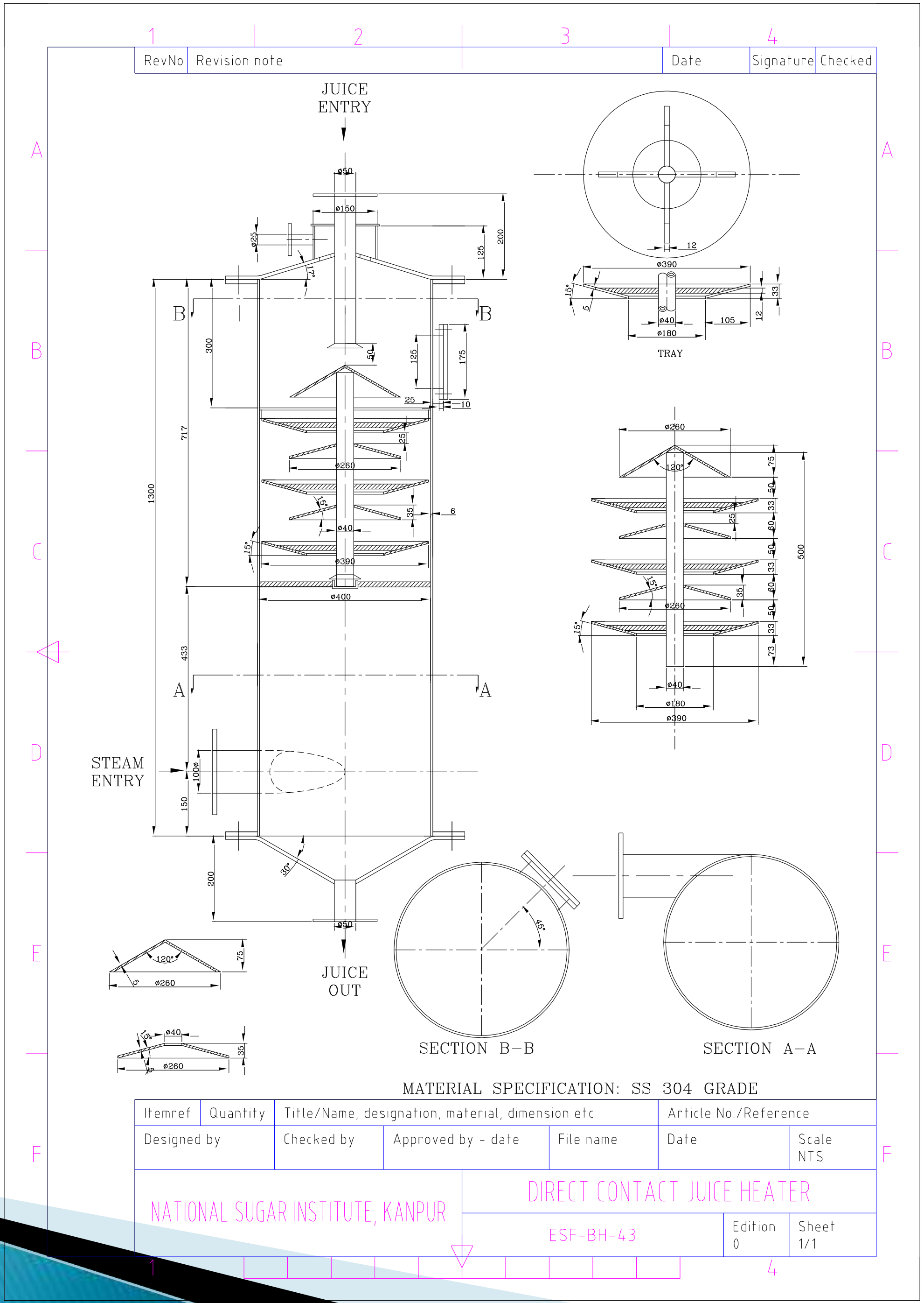
$$\phi = \frac{\text{developed length}}{\text{projected length}}$$

DESIGNING OF PHE

- Unlike tubular heat exchangers for which design data and methods are easily available, a plate heat exchanger design continues to be proprietary in nature.
- Manufacturers have developed their own computerized design procedures applicable to the exchangers marketed by them.
- Manufacturers of plate heat exchangers have, until recently, been criticised for not publishing their heat transfer and pressure loss correlations.
- Information which was published usually related to only one plate model or was of a generalized nature.
- The plates are mass-produced but the design of each plate pattern requires considerable research and investment, plus sound technical and commercial judgment, to achieve market success.

- As the market is highly competitive the manufacturer's attitude is not unreasonable.
- The Chevron plate is the most common type in use today.
- The correlation enables a thermal design engineer to calculate heat transfer and pressure drop for a variety of Chevron plates.

DIRECT CONTACT HEATER


RevNo
Revision note
Date
Signature
Checked
JUICE ENTRY
STEAM ENTRY
JUICE OUT
TRAY
SECTION B–B
SECTION A–A
MATERIAL SPECIFICATION: SS 304 GRADE
Itemref
Quantity
Title/Name, designation, material, dimension etc
Article No./Reference
Designed by
Checked by
Approved by - date
File name
Date
Scale NTS
NATIONAL SUGAR INSTITUTE, KANPUR
DIRECT CONTACT JUICE HEATER
ESF-BH-43
Edition 0
Sheet 1/1

THANKS