EVAPORATOR DESIGN

BY

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- OBJECTIVE

  To concentrate juice up to desired Bx. with minimum energy consumption

- FUNCTION

  1. To evaporate water present in clear juice in various bodies of MEE system
  2. To bleed vapour to juice heaters , pans for heating of juice & boiling of massecuite

Evaporator Configuration

1. Quadruple effect
2. Double effect + Quad
3. Quintuple effect

Various designs of evaporator

1. Semi- Kestner - Rising film

   a. Tube size - ID – 42 mm , Od 45 mm
      Total length – 4 to 5 meter

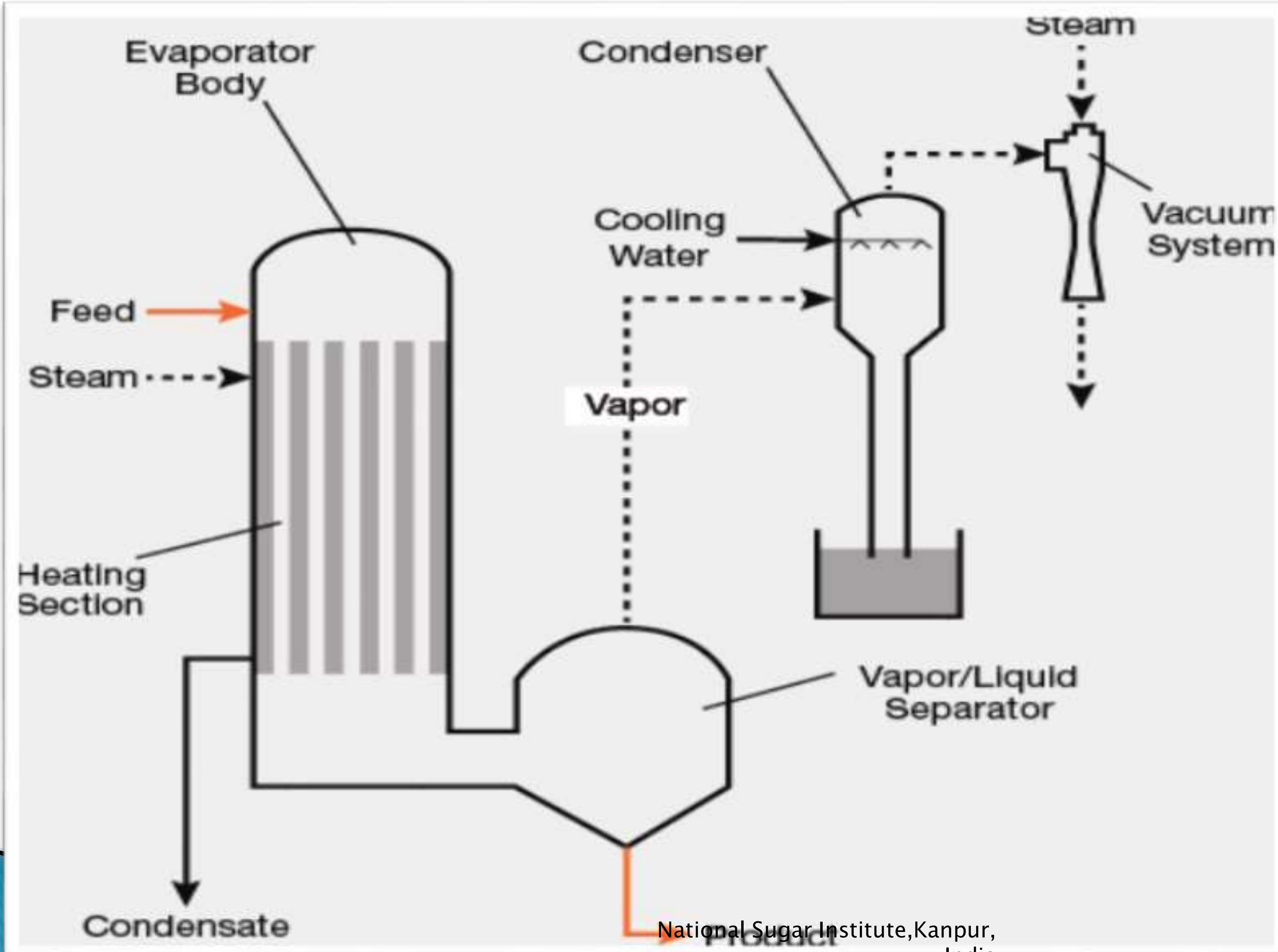
2. Falling Film

   a. Tube size - ID – 35 mm
      Total length - 10 meter

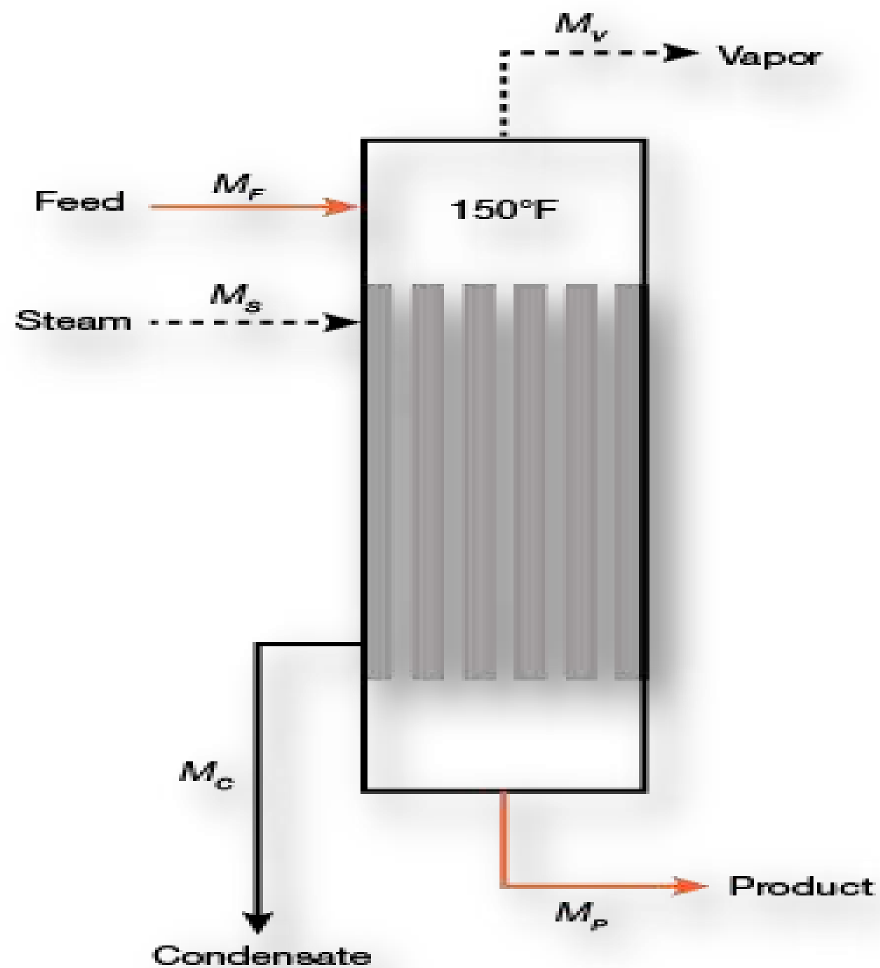
3. Robert evaporator- Conventional design

   a. Tube size - ID- 42 mm, OD -45 mm
      Total length - 2.0 meter

EVAPORATOR SYSTEM



Mass balance on a single effect



- $M_F = M_p + M_v$
- $M_s = M_c$

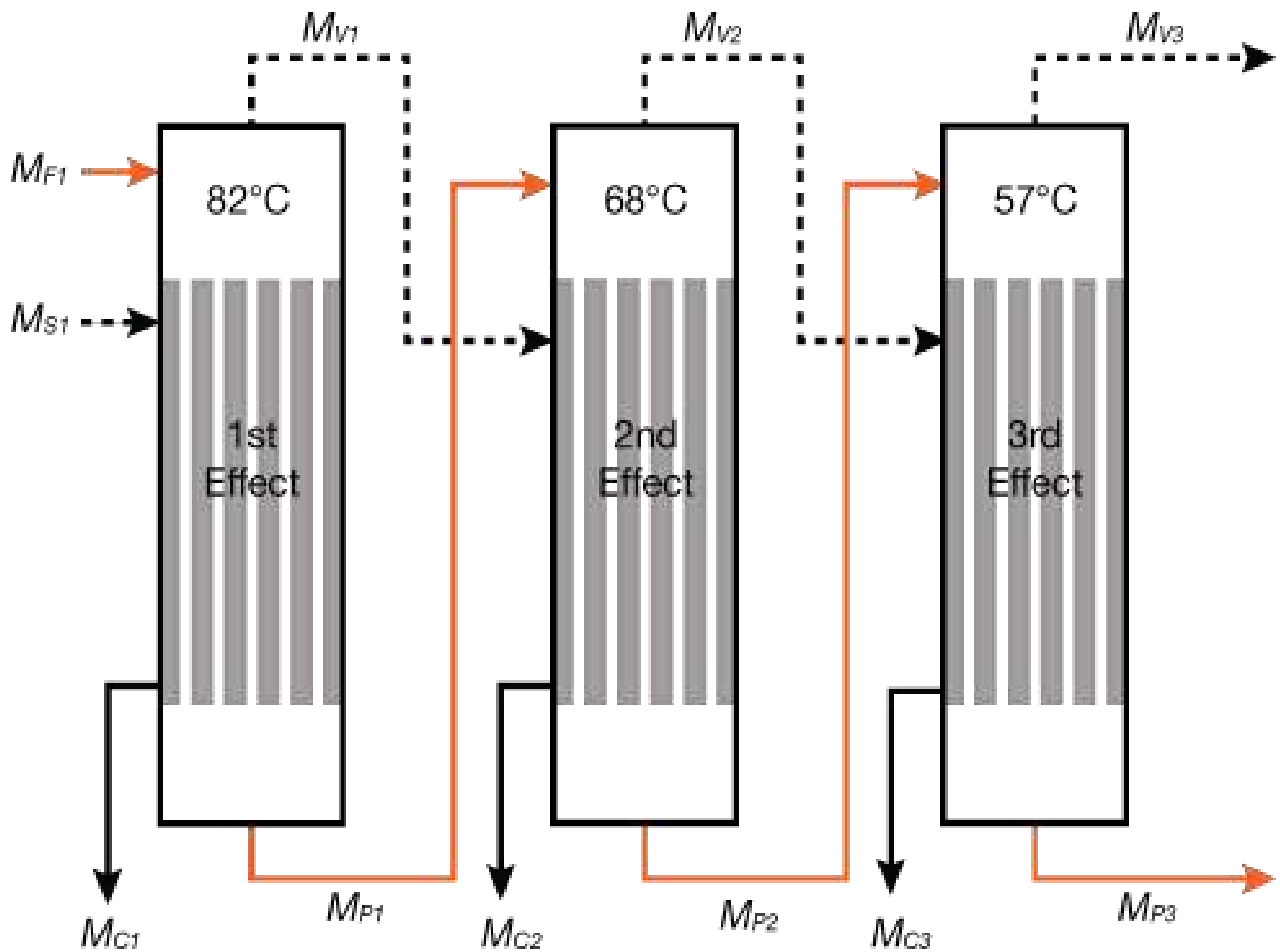
Energy Balance

$$M_F h_F + M_s h_s = M_p h_p + M_v h_v + M_c h_c$$

where M = Mass flow rate of respective streams

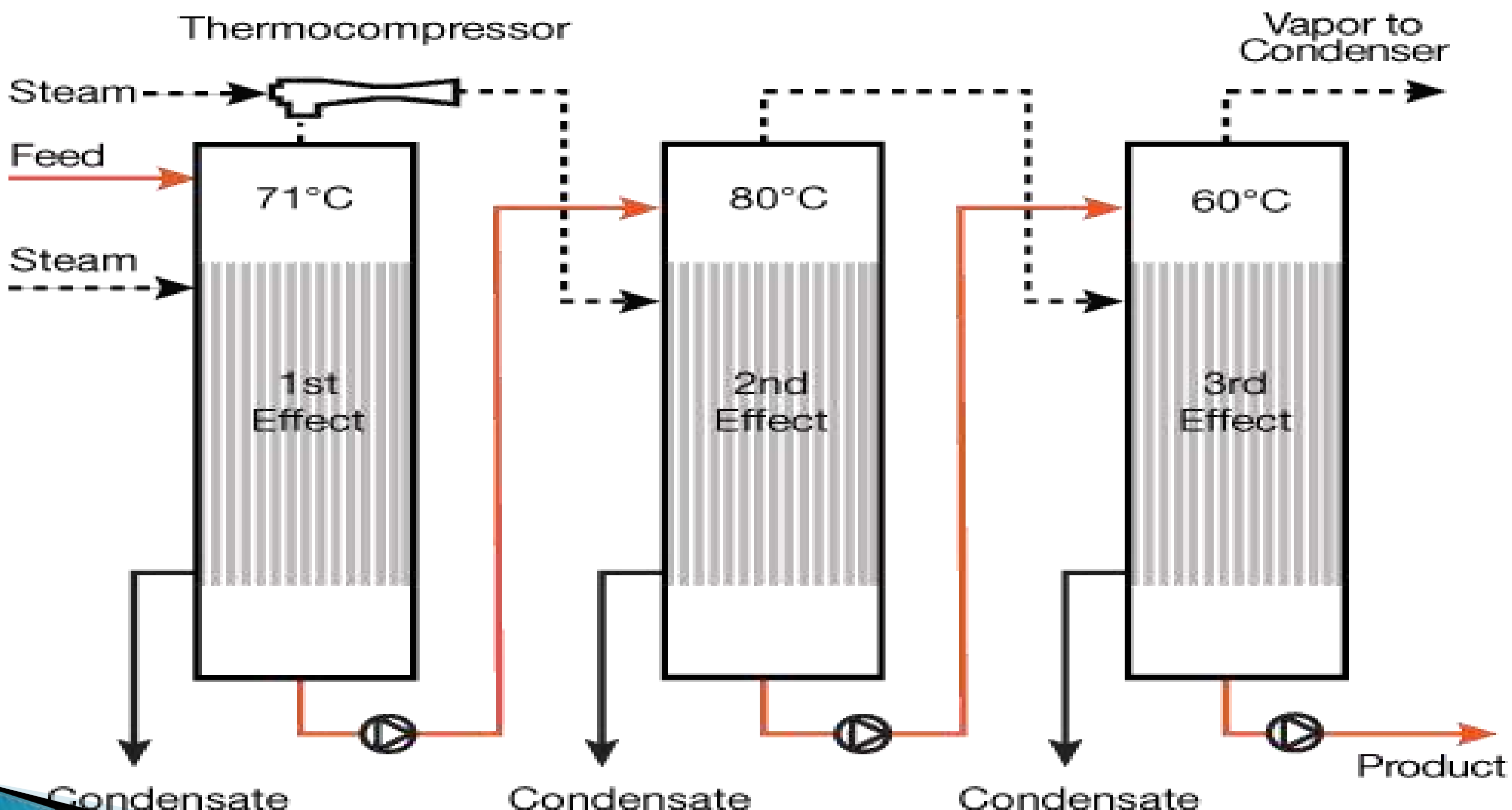
h = Enthalpy of respective streams

Multiple effect evaporators

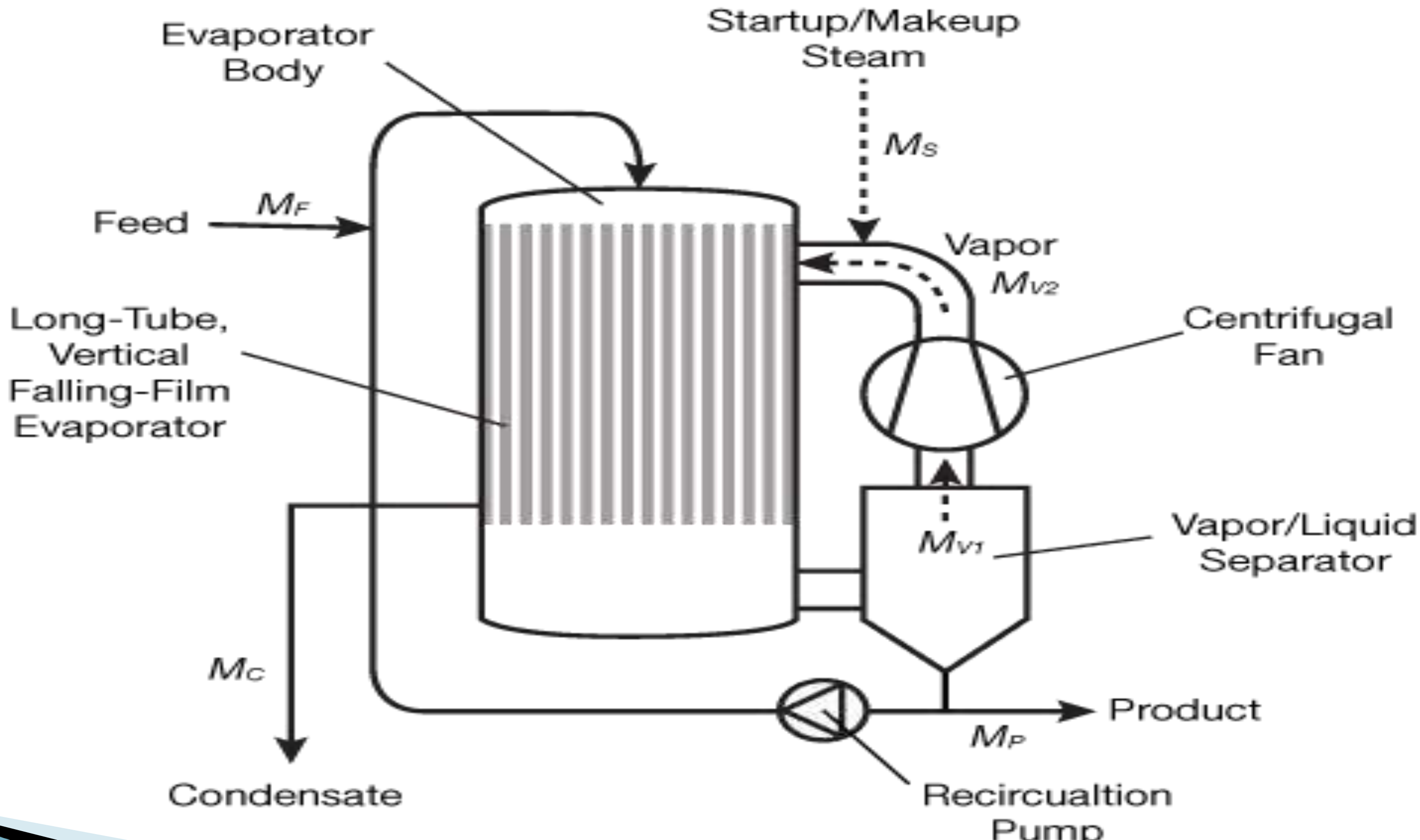


MEE with Recompression

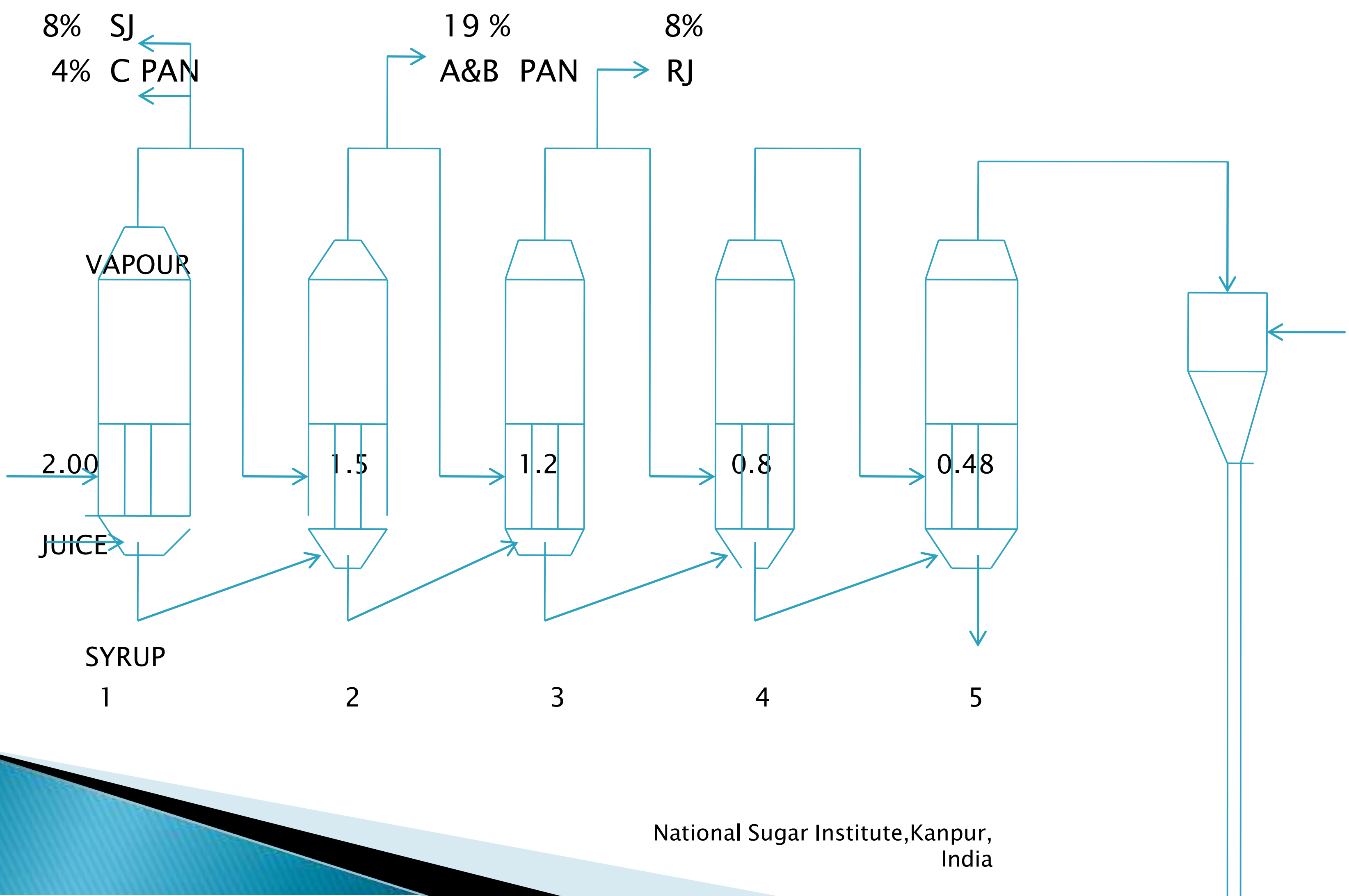
- Thermal Vapour Recompression (TVR)



- Mechanical Vapour recompression (MVR)



Evaporator design(Robert type)



DESIGN PARAMETERS

- Heating surface
- Total number of tubes
- Tube plate diameter
- Down take diameter
- Size of steam inlet
- Size of condensate outlet
- Size of vents
- Catchall design

Heating surface of evaporator

- Depends

1. Crushing rate of the factory (TCH)
2. Clear juice % cane
3. Vapour bleeding from various bodies
4. Standard evaporation rates

Vapour pressure in various bodies

Effect	Quadruple	Quintuple
exhaust	1.75kg/cm²abs	1.75kg/cm²abs
1	1.32	1.40
2	0.91	1.07
3	0.53	0.75
4	0.17	0.45
5	----	0.17

Evaporation Rates

Effect	ER (kg/m² HS/hr)
1 (SK)	45-50
1 (VC)	40-42
2	35-32
3	30-25
4	25-20
5	20-15

Design Parameters

- Total No of tubes (N)

$$N = \frac{\text{HS of evaporator}}{\pi \times Dm \times Leff}$$

Where Dm = (ID + OD)/2

Leff = 2000mm – 2 x 25mm – 2 x 2.5mm

Calculate N

- Diameter of Down take (Dd)
- Circulation Ratio (CR)

CR = CS area of all tubes/CS area of down take

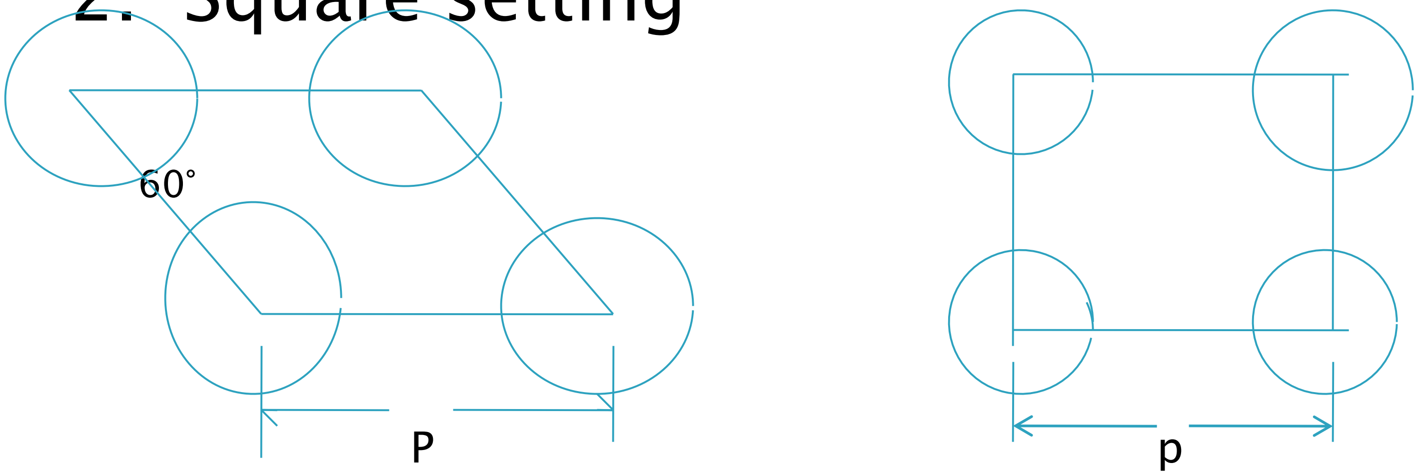
$$= \frac{\pi/4 \, di^2 \times N}{\pi/4 \, Dd^2}$$

Effect	1	2	3	4	5
CR	0.0	13	7.5	6.5	5.5

Diameter of tube plate(Dtp)

Setting of tubes: Two types of setting

1. Triangular setting
2. Square setting



TRIANGULAR SETTING

SQUARE SETTING

L (Ligament) = 12 mm

Area(Triangular) = o.866 P^2

(Square) = P^2

Area of tube plate $= \frac{0.866 P^2 \times N}{o.85}$

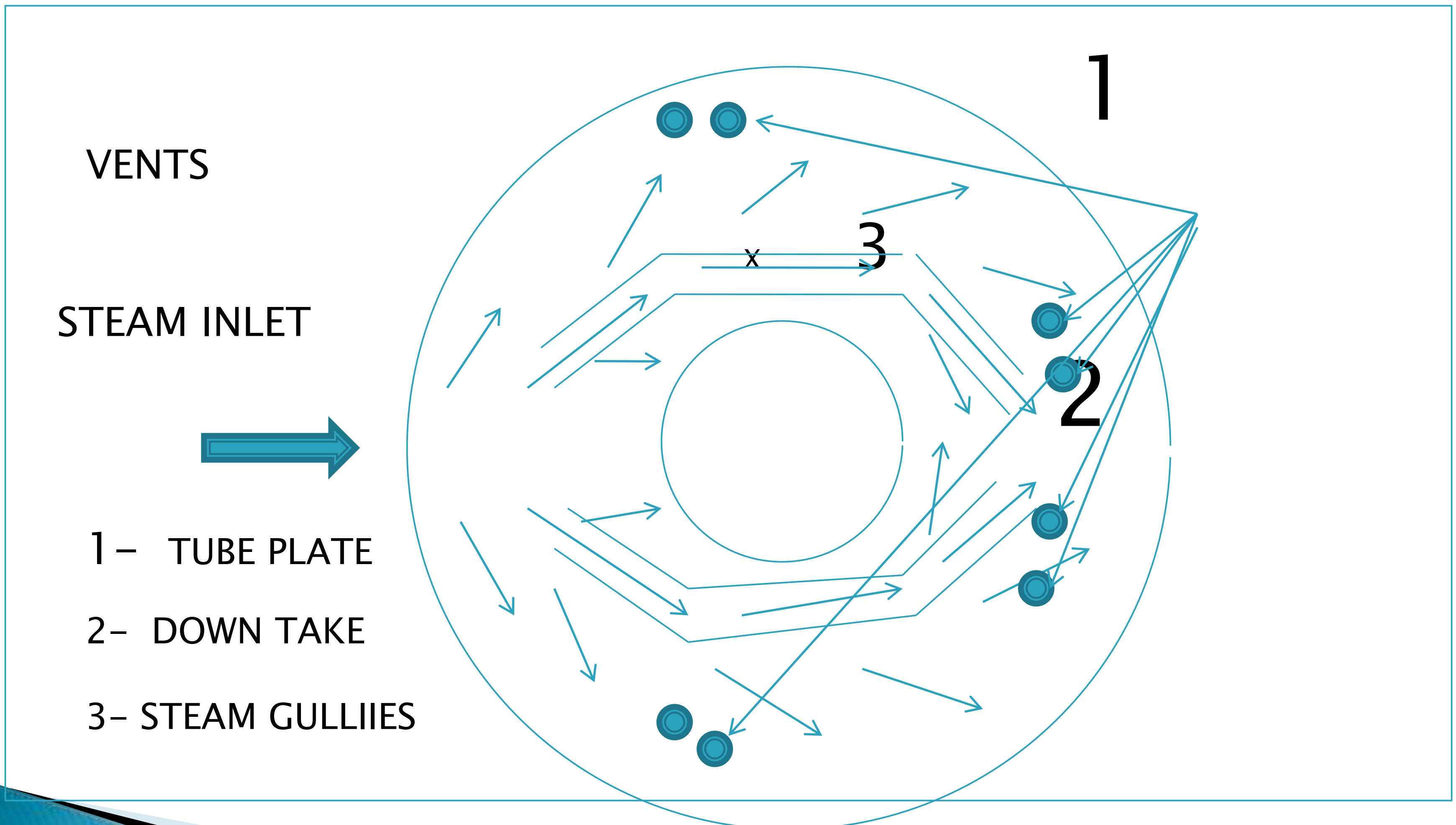
$$\pi/4 \, Dtp^2 = \frac{0.866 P^2 \times N}{0.85}$$

Calculate Dtp

EVAPORATION RATE

S.No	VESSEL	ER (Kg /hr./m^2heating surface)
1	1^{ST} EFFECT (VESSEL) SK	45 – 50
2	2^{ND} EFFECT (VESSEL) VC	40 – 42
3	3^{RD} EFFECT (VESSEL)	32 –35
4	4^{TH} EFFECT (VESSEL)	25 – 30
5	5^{TH} EFFECT (VESSEL)	15 – 15

TUBE PLATE



VENTS
STEAM INLET
1
2
3
x
1- TUBE PLATE
2- DOWN TAKE
3- STEAM GULLIIES

- Size of steam inlet in calendria

$$\pi/4 D^2 \times v = \frac{HS \times ER \times Sp.\ Volume\ of\ steam}{3600}\ m^3/sec$$

Effect	V (Velocity, m/sec)
1	Exhaust 35
2	30
3	35
4	40
5	45

Calculate D from above equation

Thickness of calendria shell

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

Where Ps = Design pressure

=1.2x working pressure($3.5 kg/cm^2$)

Di = Internal dia. Of calendria shell

f = Safe allowable stress($950 kg/cm^2$)

j = Weld joint efficiency (0.7)

C = Corrosion allowance (1.5mm)

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 = Dia. Of tube plate – Dia of down take
p = Design pressure(3.5kg/cm^2)
f = Allowable shear stress (1575 kg/cm^2)
C = Corrosion allowance (1.5mm)

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

$$\text{where } k = \frac{E_s x t_s (D_0 - t_s)}{E_t x t_t (d_0 - t_i) N}$$

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

THICKNESS OF EVAPORATOR BODY

- Few Bodies of evaporator is subjected to external pressure due to vacuum during operation. Thickness is calculated by following equation :
- $t = D0 / 100[1.15p/f + 0.053(KfL/Do)^{2/3}]$
- Where t = thickness of condenser in mm
- Do = outer diameter of condenser in mm
- L = effective length of condenser in mm
- p = design pressure (0. 13 kgf/cm^2)
- K = Elastic modulus (19.5 $x10^3$ kgf/mm^2)
- f = allowable stress (9.5 kgf/mm^2)

CATCH ALL DESIGN

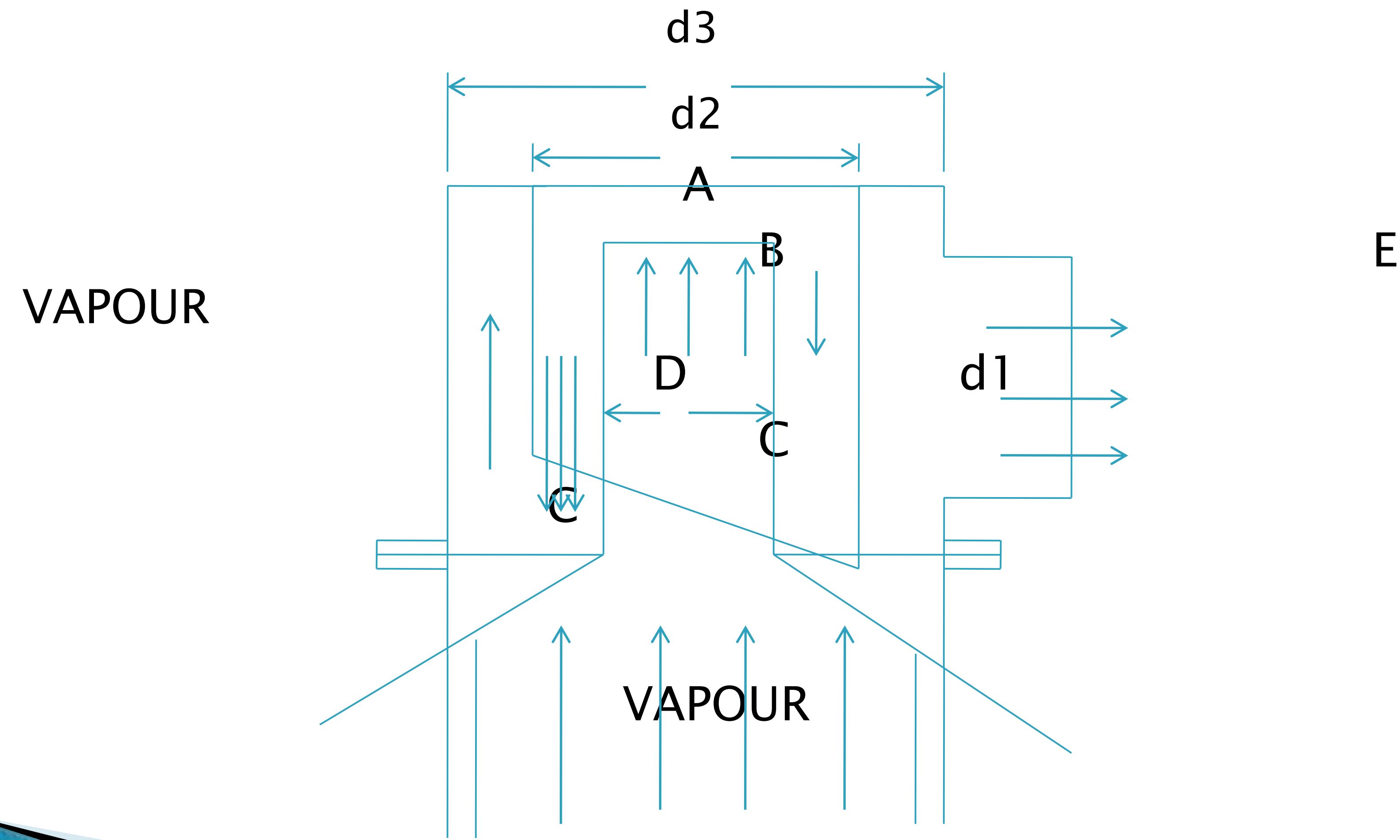
FUNCTION

- To arrest juice particles going along with vapours of various bodies of multiple effect evaporator.

DESIGN PARAMETERS

- Velocity of vapour at various sections of catch all
- Direction of flow of vapours at various section

CATCH ALL DESIGN



CATCHALL DESIGN

VAPOUR VELOCITIES (M/Sec.)

VESSEL	SEC A	SEC B	SEC C	SEC D	SEC E
1ST VESSEL	12	18	12	25	30
2ND VESSEL	18	25	18	30	35
3RD VESSEL	25	30	25	35	40
4TH VESSEL	30	35	30	35	45
5TH VESSEL	35	40	35	45	50

CALCULATIONS

- VAPOUR LOAD = HS X ER X Sp. Volume
  (m^3 /sec.) 3600

$$\text{VAPOUR LOAD} = \frac{HS \times ER \times Sp.\ Volume}{3600} \quad (m^3/sec.)$$

a. Calculation of d1

- $\pi/4\ d1^2 \times V_A$ = VAPOUR LOAD
  where V_A = vapour velocity at sec. A

b. Calculation for h1

- $d1/4 = h1$

c. Calculation for d2

- $\pi (d2^2 - d1^2)/4 \times VB$ =Vapour Load

where VB = vapour vellocity at sec. B

d. Calculation for h2

π d2 x h2 x Vc = VAPOUR LOAD

- $\pi (d_3^2 - d_2^2)/4 \times V_D =$ VAPOUR LOAD
- $\pi/4\ d_4^2 \times V_E =$ VAPOUR LOAD

Condensate extraction

- Centrifugal pump on each effect
- Siphon with equalization leg

- Size of condensate outlet (D)

wt of steam admitted = wt of codensate(kg/sec)

Neglecting NCG

$$\text{Volume of condensate } (m^3/sec) = \frac{\text{wt of condensate}}{1000}$$

$\pi/4D^2 \times v$ = Volume of condensate (m^3/sec)

Take V = 0.6 m/sec.

Calculate D from above equation

Steam saving devices

- Vapour line juice heater
- Direct Contact Heater
- Cigar
- Condensate heater

THANKS

PAN DESIGN

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PAN DESIGN

FUNCTION

Final stage of boiling of sugar solution is done under vacuum to develop sugar crystals with desired purity drop with minimum energy energy consumption

TYPES

1. Batch pan
2. Continuous pan

VACUUM PAN

1 CALENDRIA

2 DOWNTAKE

3 CATCHALL

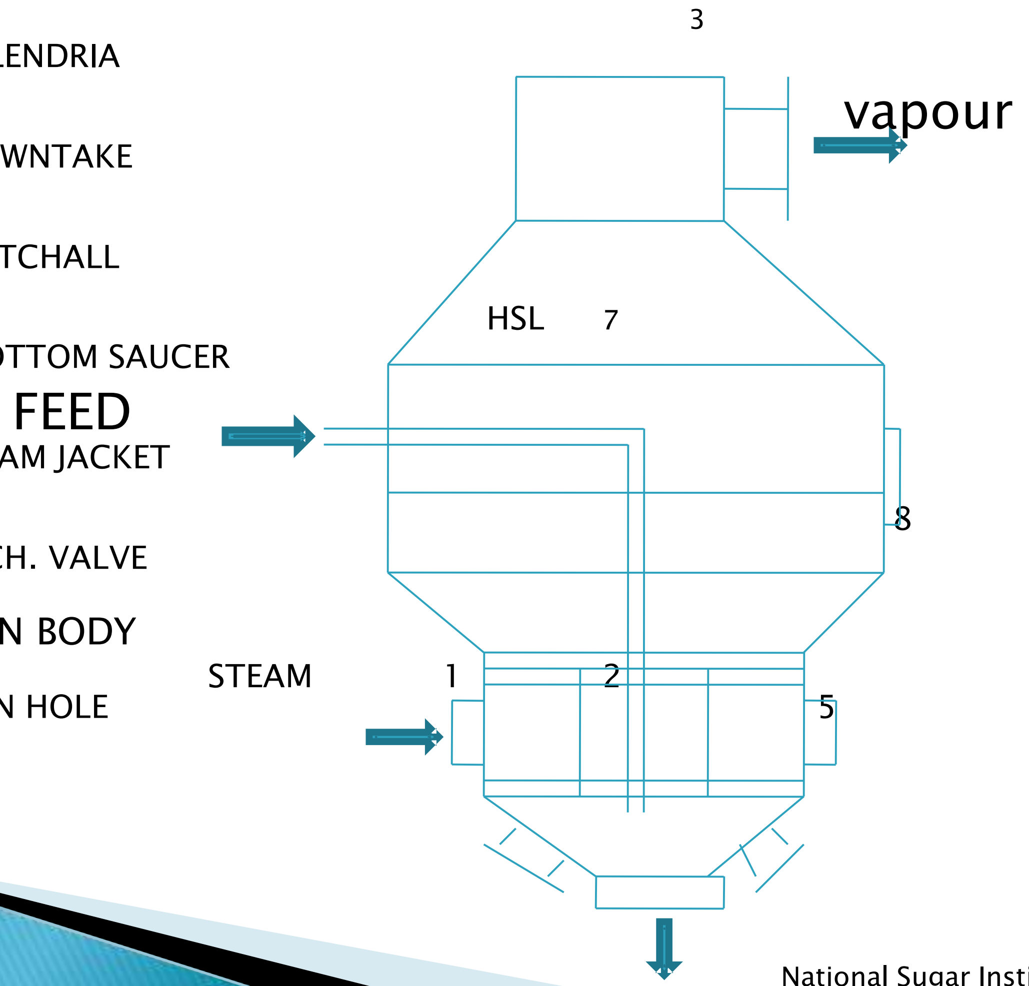
4 BOTTOM SAUCER

5 STEAM JACKET

6 DISCH. VALVE

7 PAN BODY

8 MAN HOLE



DESIGN CONSIDERATIONS

- Hydrostatic head should be as low as possible
- Circulation of massecuite should be as rapid as possible in order to give rapid working and good exhaustion
- The graining volume should be as small as possible in order to permit the maximum exhaustion with the minimum volume of massecuite
- Higher S/V ratio for high grade massecuite and lower S/V for low grade massecuite

DESIGN PARAMETERS

- Heating surface
- Total number of tubes
- Diameter of down take
- Diameter of tube plate
- Hydrostatic head
- Height of vapour space
- Catch all design (centrifugal type)
- Thickness of calendria shell
- Thickness of tube plate

Given parameters

- Capacity of pan in tonnes
- Size of tube – 101.6 mm OD, 16 gauge thick
- Total length of tube- 900-1000 mm
- Graining volume- 37% of working volume
- Circulation ratio (CR) – 2.5
- Angle of bottom saucer – 17 to 22°

Material of construction & code of practice

- Low carbon steel (mild steel)as per BIS code IS: 226 and IS: 2062 for fabrication of calendria, pan body, bottom saucer, vapour pipe etc.
- Solid drawn brass tube with Cu & Zn of 70 : 30 ratio as per IS 407 OR stainless steel as per IS 304 grade steel for pan tubes

CALCULATIONS

- Cap of pan(m^3) = 0.7 x cap of pan in tonnes
- **Heating Surface(S)** = Cap. Of pan in m^3 x 6.6 m^{-1}
  since S/V = 6.6 m^{-1}

- **Total number of tubes(N)** = $\frac{\text{HS of pan } (m^2)}{\text{HS of one tube } (m^2)}$

- **Dia. Of down take**

C R = 2.5 = Internal CS area of all tubes /Internal CS of downtake

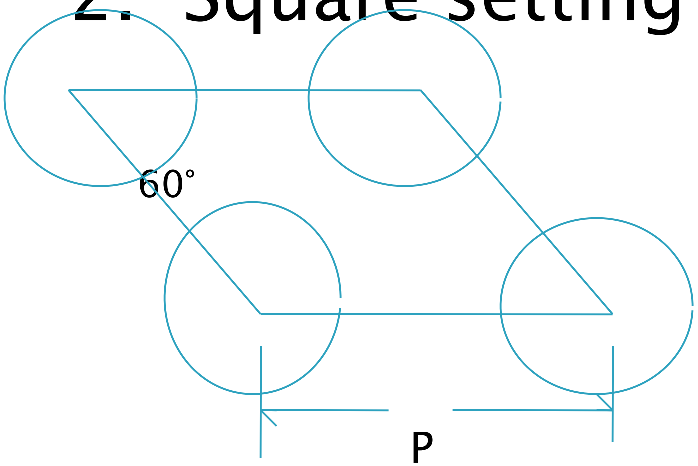
$$= \frac{\pi \times di^2 \times N/4}{\pi \times D_d^2 /4}$$

Calculate Dd from above equation

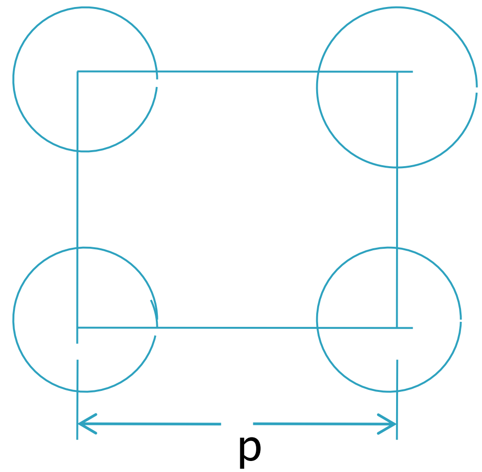
Diameter of tube plate(Dtp)

Setting of tubes: Two types of setting

1. Triangular setting
2. Square setting



TRIANGULAR SETTING



SQUARE SETTING

- Diameter of tube plate (Dtp)

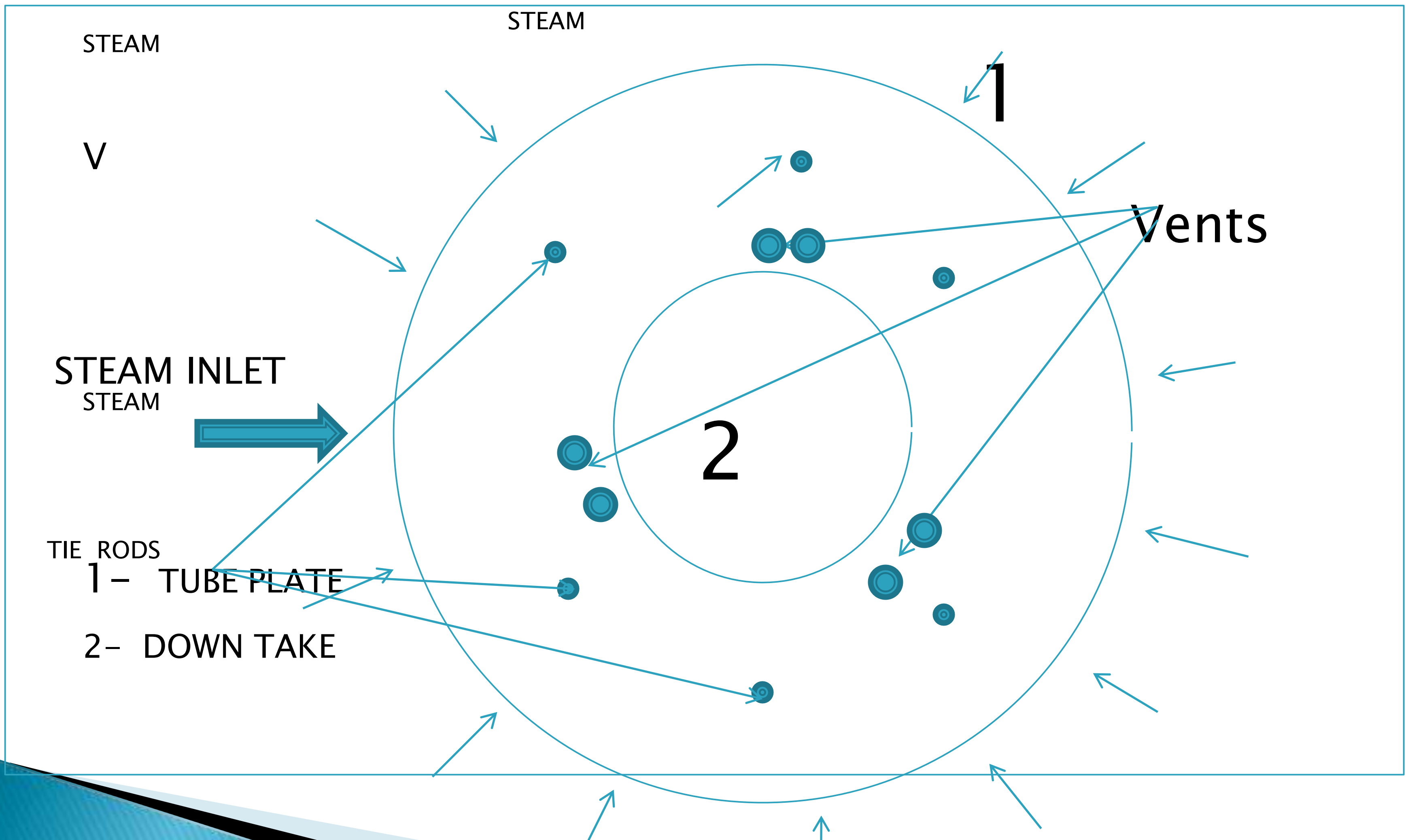
$$\pi \times Dtp^2/4 = \frac{(0.866p^2 \times N)+\pi/4 \times D_d^2}{0.85}$$

Where P = pitch of the tube = od of tube + ligament

i.e. 102+16 mm = 118 mm

Calculate Dtp from above equation

TUBE PLATE



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GRAINING VOLUME

- It is the volume of high purity syrup or melt fed to the pan before turning on the steam valve which should be as low as possible.
- Normally, It is the volume of pan up to top of the top tube plate i.e.
- Volume of all tubes (V1) + Volume of downtake (V2) + Volume of bottom saucer(V3)

- Volume of all tubes (V1) $= \pi/4 d_i^2 \times L \times N$
- Volume of downtake (V2) $= \pi/4 D_d^2 \times L$
- Volume of bottom saucer (V3)

  $= 1/3\ h\ (A1 + A2 + \sqrt{A1A2})$

  where h = height of bottom saucer

  $= \tan\alpha\ (D_{tp} - D_{dis})/2$

  A1 = CS area corresponding to D_{tp}

  A2 = Cs area corresponding to D_{dis}

- Dia. Of Discharge valve (D_{dis})

$$= \sqrt{\frac{4 \times U}{\pi\, v\, t}}$$

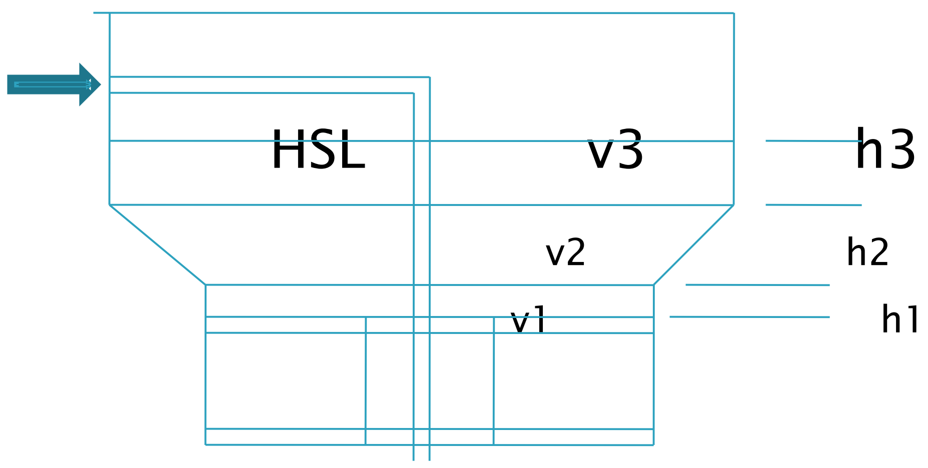
where U = volume of massecuite(m^3)

v = velocity of m/s discharge i.e. 1 meter/ min.

t = time taken for discharge i.e. 10 – 15 min.

Hydrostatic Head

Hydrostatic Head



- **HSL = h1 + h2 + h3 ----------------- 1**

  h1 = 100 mm

  h2 = $\tan\theta$ (Dc – Dtp)/2

  where θ =60°

  Dc = 1.15 Dtp

- Working volume = GV + V1 + V2 + V3 ------------- 2

  V1 = $\pi/4$ Dtp^2 x 100

  V2 = 1/3 h2 (A1 + A2 + $\sqrt{A1\ A2}$)

  where A1 corresp. to Dtp & A2 corresp. to Dc

  V3 = $\pi/4$ Dc^2 x h3

Calculate h3 from equation 2

Now calculate HSL from equation 1

Height of Vapour space

- Height of vapour space above HSL is approximately kept 1.5 meter which is the height of cylindrical portion of pan body.
- It is one of the important parameter to control entrainment .
- Lower value of vapour space or exceeding the level of massecuite beyond HSL may result into entrainment.

- Size of steam inlet in calendria

$$\pi/4 D^2 \times v = \frac{HS \times ER_{max} \times Sp.\ Volume}{3600} \ m^3/s$$

ER_{max} =	A m/c	60kg/m²/hr
	B m/c	50kg/m²/hr
	C m/c	40kg/m²/hr
	v =	30- 35m/sec.

Calculate D from above equation

- Size of condensate outlet (D)

wt of steam admitted = wt of condensate(kg/sec)
Neglecting NCG

$$\text{Volume of condensate } (m^3/sec) = \frac{\text{wt of condensate}}{1000}$$

$$\pi/4D^2 \times v = \text{Volume of condensate } (m^3/sec)$$

where $v = 0.5$ to 0.6 m/s

Calculate D from above equation

Removal of non condensable gases

- Continuous removal of NCGs from calendria is essential to ensure proper and continuous entry of steam in calendria
- Vent connections are suitably provided at proper location keeping in view steam entry arrangement
- 1cm² cross sectional area to be provided for each 10 m² heating surface of pan

- Thickness of calendria shell

$$t = P\,Di / (2fJ - P) + c$$

Where t = thickness of calendria shell

P = Internal press.or test press (3.5 kg/cm^2)

Di = Inside dia. of shell

f = allowable stress (950kg/cm^2)

J = weld joint efficiency (0.7)

c = Corrosion allowance (1.5mm)

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 = Dia. Of tube plate – Dia of down take

p = Design pressure(3.5kg/cm^2)

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

C = Corrosion allowance (1.5mm)

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

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

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

THICKNESS OF PAN BODY

- Body of pan is subjected to external pressure due to vacuum during operation. Thickness is calculated by following equation :

$$t = D0 / 100[1.15p/f + 0.053(KfL/Do)^{2/3}]$$

Where t = thickness of pan body in mm

D_o = outer diameter of pan in mm

L = effective length of pan in mm

p = design pressure (0. 13 kgf/cm^2)

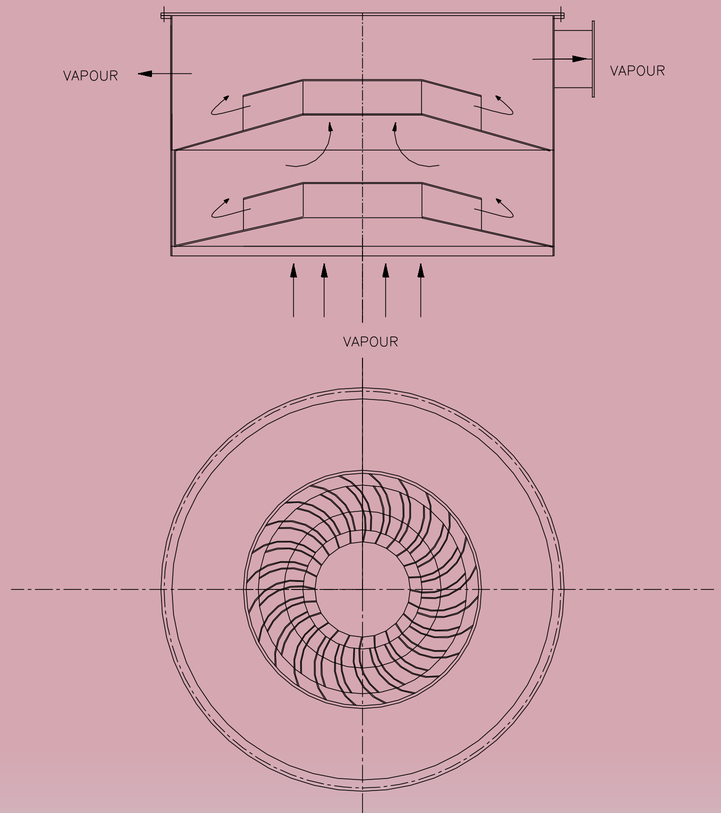
K = Elastic modulus (19.5×10^3 kgf/mm^2)

f = allowable stress (9.5 kgf/mm^2)

Centrifugal catch all design

- Working principle

1. Tangential ejection of vapour from vanes of centrifugal impeller caused spiral current with efficient abrasion against outer wall results into better separation of sugar particles from vapour.
2. Centrifugal action assists to seperate heavier sugar particles from vapour
3. Involute profile of vanes offer less resistance to vapour result into increased velocity at exit of centrifugal impeller.



CENTRIFUGAL CATCH ALL

NATIONAL SUGAR INSTITUTE, KANPUR		
DATE		CENRTIFUGAL CATCH ALL
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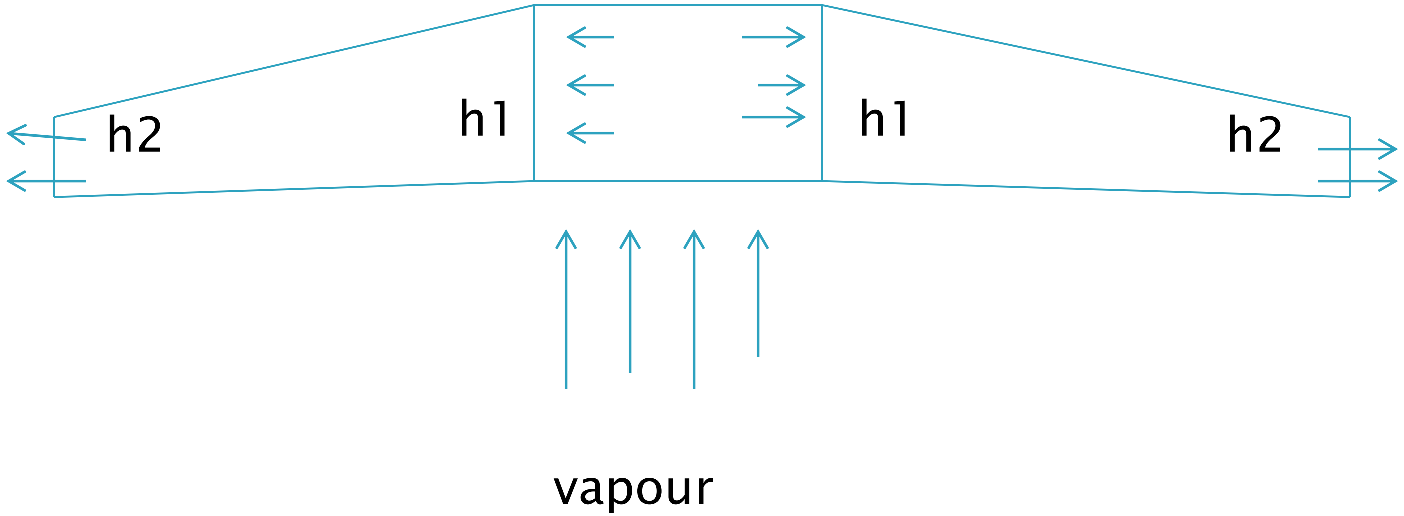

h2
h1
h1
h2
vapour

- Calculate vapour load V (m^3/s) considering ER corresponding to type of massecuite & HS
- Calculate D1 , take velocity of vapour 35m/sec
- $\pi D1 = n(b + s)$ ------------ 1

  Where D1 = dia of vapour inlet in catchall

  n = no of vanes

  b = Space between two vanes

  s = thickness of vane (1.5 mm)

Calculate 'b' from Eq. 1

- $V = n \times b \times h \times v$ ---------------- 2 where V = vapour load (m^3/s)

n = no of vanes

b = space between two vanes

h = height of vanes

v2 = vapour velocity in vanes at h2 (50 m/ sec)

v1 = vapour velocity in vanes at h1 (35 m/sec)

Calculate ‘h1 & h2’ from Eq. 2 taking v1 & v2 respectively

- D = D1 / sin θ

  where D = outer dia of catchall

  D1 = dia of vapour inlet in catchall

  θ = 25^o

- No of vanes (n) = 360 /7.5

CONTINUOUS PAN

- CLASSIFICATION

  1. Multi- compartment horizontal tube configuration, FCB design
- 2. Multi-compartment vertical tube configuration

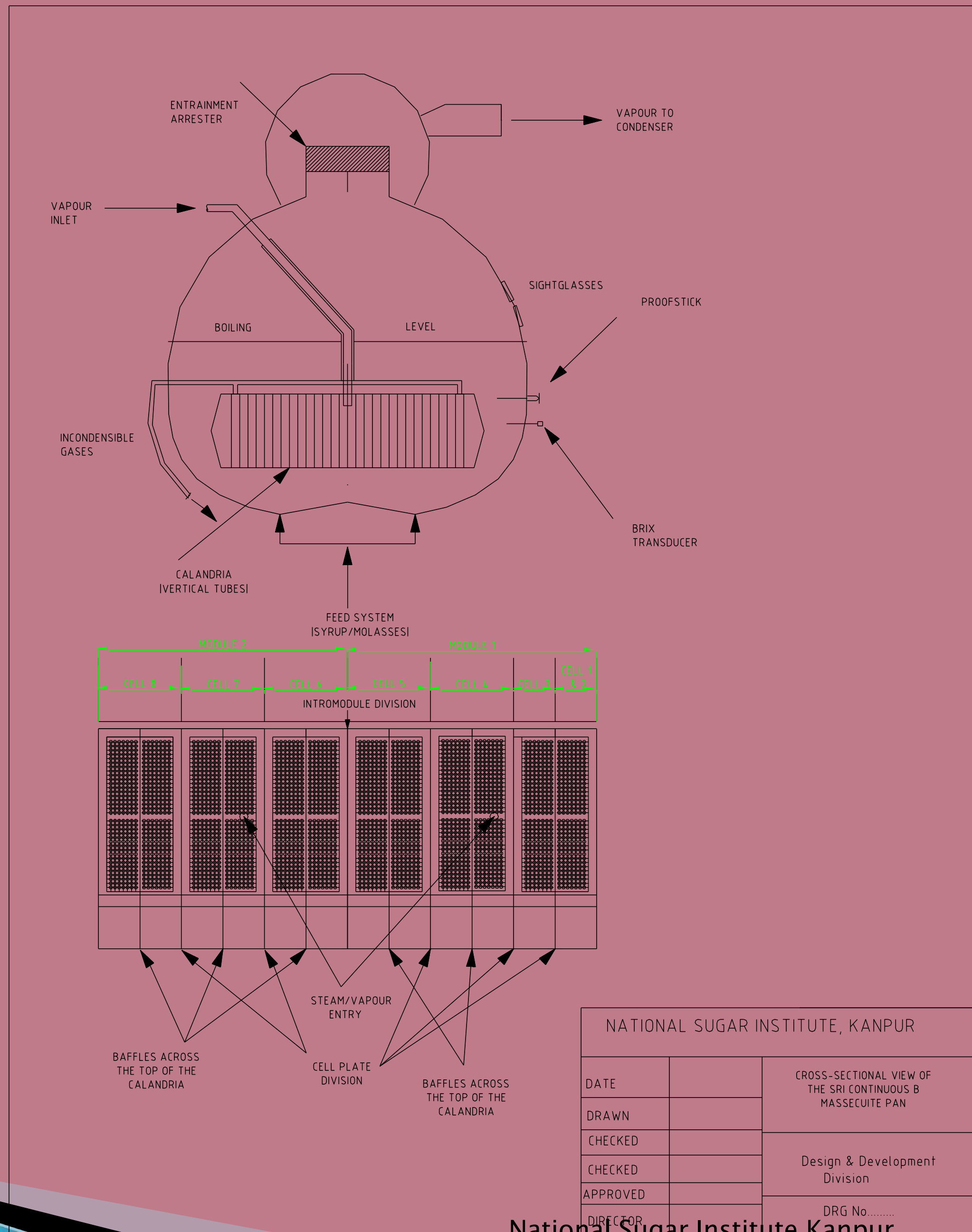
It is further classified as :

a. Long vertical tube (1200 mm)

b. Short vertical tube (900 mm)

c. Central downtake with side calendria

d. Central calendria with side downtake



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CONTINUOUS PAN

- Design Parameters

1. S/V ratio = Heating Surface/working Volume
   = 10 m^{-1}
2. Circulation Ratio (CR) = 1
3. Retention time = 60% – 75% of batch process

4 Size of tube

a. Horizontal design = 35mm X 38 mm
b. Vertical design = 101.6 mm OD
c. Thickness 16 gauge

	A m/s	B m/s	C m/s
Retention time (R) (Hrs)	2-2.5	3.5-4	5.5-6
Massecuite % cane	25	12	8

- flow rate of massecuite (M^3/hr) = TCH x M/S % Cane x 0.7/100
- Volume of massecuite in pan (V) = R x flowrate of massecuite
- This is varies from 57 to 60 % of total volume of pan
- Therefore, total volume of pan = V x 100 /57 m^3

- Diameter of pan normally to betaken as :
- 3.0, 3.5, 4.0, 4.5 meter
- Length of normally taken as 11 to 12 meter
- Number of compartments 11 to 13
- Layout of tube in horizontal tube

  Square setting of tube with 85 mm pitch for tube size of 35 mm ID/ 38 mm OD

Layout of tube for vertical tube

Triangular setting of tube with 118 mm pitch

CONTINUOUS PAN

5. NCG used (Jigger steam) to agitate massecuite in pan to avoid formation of stagnant pockets
6. Pan is designed for 70-80 % of total volume for feeding of molasses/ syrup and rest volume for hardening purposes
7. Massecuite height above tube plate
   = 420 mm for A m/s
   = 320 mm for B & C m/s
8. Vapour space height 1.5 meter
9. Complete automation of pan operation

CONTINUOUS PAN

- EVAPORATION RATE

1 A m/s 30-35 $kg/m^2/hr$

2 B m/s 25 $kg/m^2/hr$

3 C m/s 15 kg/m^2

- ASPECT RATIO

  1. Ratio between longitudinal path length and circulation path length.

  2. The normal value is 1.5 to 1.6 to give uniform size of crystal and better exhaustion

CONTINUOUS PAN

- ADVANTAGE

1. It is energy efficient operation
2. It operates at low calendria pressure to promote steam economy
3. Improved circulation and faster evaporation
4. Better exhaustion of sugar from mother liquor
5. Manpower saving and better working control
6. Reduced maintenance cost
7. Longer operating cycle(water boiling after 35 to 40 days)

THANKS

CONDENSER DESIGN

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

CONDENSER DESIGN

- **Objective:**

  To create desired vacuum in a closed vessel

- **Functions:**

1. To condense vapour by spraying cold water
2. To remove air /non condensable gases from the system

TYPE OF CONDENSER

- Surface Condenser:
  No direct contact of vapour with cold water.
  It is used where condensate is re-circulated

- Jet Condenser :
  Direct mixing of vapour with cold water.
  Condensate mixes with cold water

SURFACE CONDENSER

- It is further classified into:

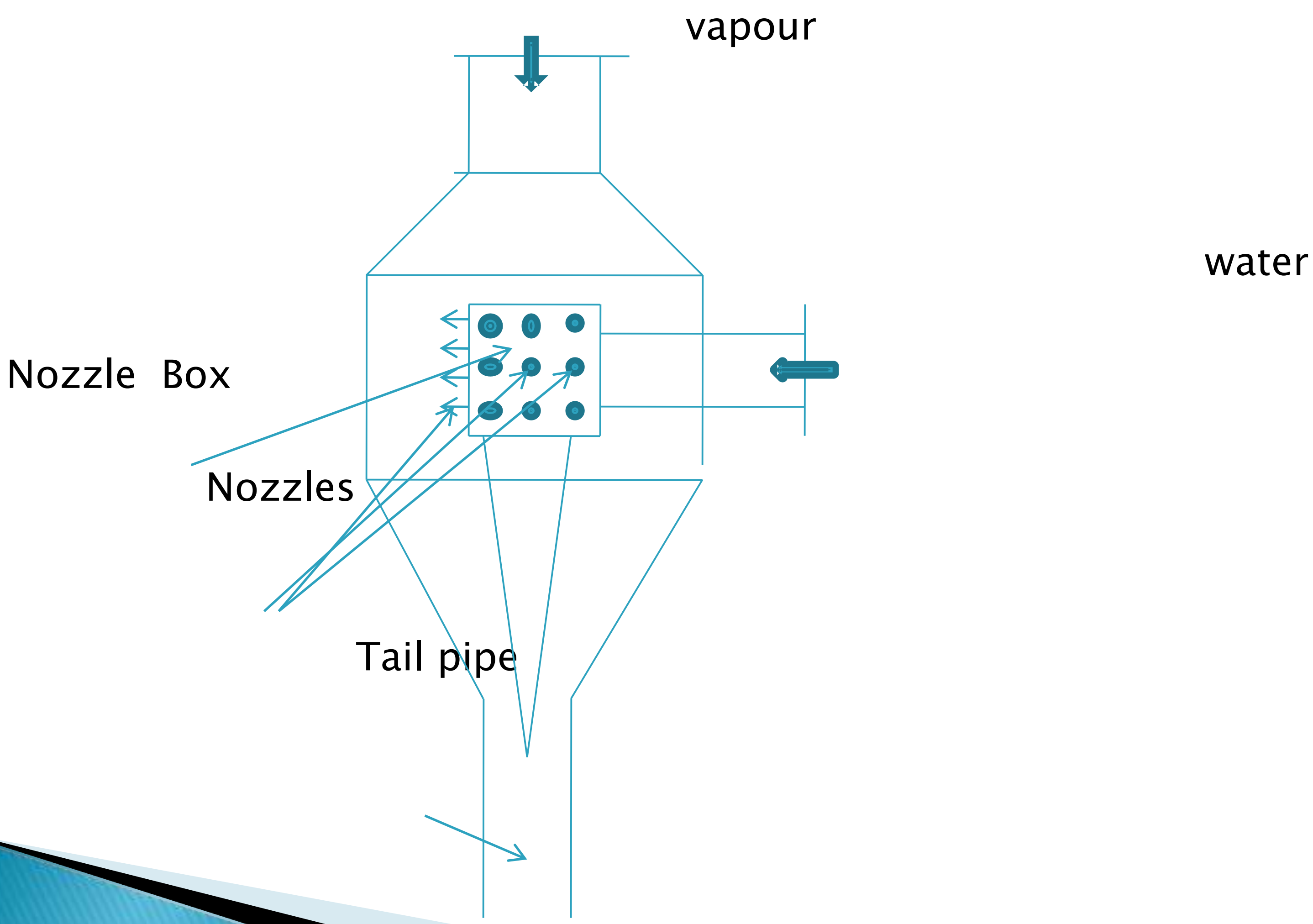
1. WATER COOLED

- Condensation of vapour is done by cold water.
- Vapour comes in contact with tubes from out side surface
- Inside the tubes cold water circulate

2. AIR COOLED

- Condensation of vapour is done by air circulation
- Vapour circulates inside the finned tubes .
- Air circulation is done on outside surface of tubes.
- Big fans are used in each shell to circulate air
- Steam ejectors are used to remove air from system

MULTIJET CONDENSER



APPROACH TEMPERATURE

- It is the difference in temperature of vapour and tail pipe water (waste water)

$$= \quad t_v \; - \; t_2$$

- This should be as low as possible and ranging
  between 5 to 7 deg. C

WATER REQUIREMENT

$$W = \frac{H - t2}{t2 - t1}$$

where H = Enthalpy of vapour

t2 = Temp. of waste water

t1 = temp. of cold water

w = Water in kg/kg of vapour

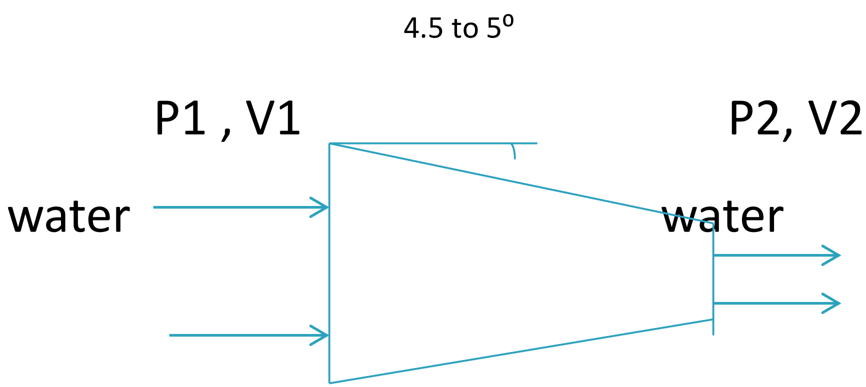
TYPES OF NOZZLE

- Spray Nozzle – variable opening through pneumatically operated plunger responsible for condesation of vapour

- Jet nozzle – at the bottom of jet box responsible for extraction of air from system as well as partly condense vapour

JET NOZZLE DESIGN

- Shape of nozzle – Convergent
- Slope of nozzle – 9 to 10 º
-



Discharge through single Nozzle:

$$Cd\ A \sqrt{2gh} \quad m^3/sec.$$

- Cd = Coefficient of discharge
  = 0.94 – 0.96
- A = Area of cross section at outlet
- g = Gravitational Acceleration
  = 9.8 meter/ $sec.^2$
- h = (P1 - P2) x equivalent head
  = (P1 – 0.135) x 10.36 meter

MAIN DESIGN PARAMETERS

1. Diameter of Vapour pipe inlet (D1)

vapour load (m^3/ sec) = HS x ER x sp vol of vapour/3600

HS – heating surface (m^2)

ER - evaporation rate (kg/m^2/hr)

45 -50 Kg/hr/m^2 for pan

$$D1 = \sqrt{\frac{4 \times \text{vapour load}}{\pi \times V_{vap}}}$$

V_{vap} = 50 m/sec

2. Diameter of condenser (D)

CS area of condenser = 0.1 to 0.12 m^2/1000 Kgs of vapour/hr

3. Height of condenser (straight height)

= 0.8D to 0.9D

4. Diameter of water inlet (d)

$$\frac{(H - t2)/(t2 - t1) \times \text{kg vap.}/\text{sec}}{1000} = (\pi/4)\, d^2 \times V_W$$

H = Total heat of vapour (kcal)

t2 = Temperature of tail pipe water (°C)

t1 = Temperature of Cold water (° C)

V_W = Velocity of water (3 meter/sec)

d = Dia of vapor pipe (m)

5. Diameter of tail pipe (d1)

$$(\pi/4)\, d1^2 \times V_{ww} = \frac{Q\,(W + 1)}{1000 \times 3600} \text{ cubic meter/sec}$$

Q = Wt. of vapour generated /hr

W = Wt of water/unit wt of vapour

V_{ww} = Velocity of water in tail pipe

= 3 meter/sec

6. Length of tail pipe (H)

$H = H0 + h + s$

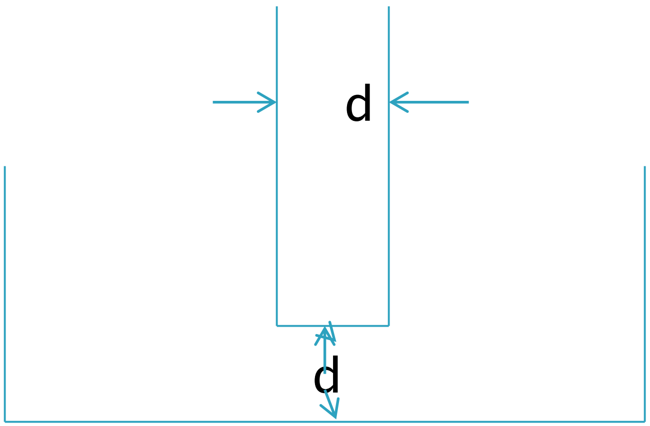
$H0$ = Equivalent barometric head (m)

h = velocity head ($V^2/2g$)

s = Safaty margin = 0.5 meter

- Size of sealing pit

Volume = 1.5 x volume of tail pipe



THICKNESS OF CONDENSER

- Body of condenser is subjected to external pressure due to vacuum. It is calculated by following equation :

$$t = D_0 / 100 \left[1.15p/f + 0.053(KfL/D_o)^{2/3} \right]$$

Where t = thickness of condenser in mm

D_o = outer diameter of condenser in mm

L = effective length of condenser in mm

p = design pressure (0. 13 kgf/cm^2)

K = Elastic modulus (19.5 $x10^3$ kgf/mm^2)

f = allowable stress (9.8 kgf/mm^2)

THANKS