Design &Testing of Vacuum Pan in Sugar Industry

Prof. Dr. A.D. Desai, Prof. A.B. Verma, Prof. A.B. Bhane, G.H.Kulkarni.

Principal, Mechanical Engineering Dept., SRCOE, Maharashtra, India
HOD, Mechanical Engineering Dept., SRCOE, Maharashtra, India
P.G Coordinator, Mechanical Engineering Dept., SRCOE, Maharashtra, India
Student, Mechanical Engineering Dept., SRCOE, Maharashtra, India

ABSTRACT

In this paper we are going to study the most important equipment in the sugar industry which plays very vital role in the boiling house. Steam is the important parameter in sugar industry which is used for heating the cane juice coming from mill house. After juice heating and sulphitation its allowed to pass in the evaporator station and then it is converted in to the muddy Syrup whose concentration is more than the syrup in the evaporator station. In sugar Vacuum pan concentration of syrup is increased and then its converted in to mud called massecuite.Design of Vacuum pan is the important task in the sugar industry in which design were carried on trial and error basis by considering the more thickness of all the accessories in the sugar pan. But in this paper we are going to optimize the various thickness, diameters of inlet and outlet pipes for juice and steam inlet.

Keyword : - *Vaccum Pan, Shell thickness calculation ,Pan Model 3D*, *Types of pan.*

---

1. INTRODUCTION

The pan station of a sugar factory is located on separate floor either in line with the evaporator station at a height of 7-8 m. from ground floor or at a height of 15-16 m. from ground floor so as to facilitate gravity flow of Massecuitte from pans up to centrifugal station. Pan station is equipped with 4 to 8 pans of capacities varying from 50 to 60 t. together with 15-20 syrup and molasses tanks and seed crystallizers for storing seed for high grade boiling. Besides these, vacuum crystallizers are also installed now days for storing 'cutting' from pans. The entire boiling is conducted under vacuum and therefore the pans are connected to condensers by large vapor pipes. The various important pipe connections of a Pan include:-

(i) Steam or Vapour,
(ii) Syrup and Molasses,
(iii) Seed Intake or Cut over Pipe,
(iv) Condensate Outlet,
(v) Vapour Outlet,
(vi) Hot Water,
(vii) Gauges and Meters

1.1 Types of Pans in Sugar Industry

Pan boiling has so far been a batch operation but in the last two decades Continuous pans have been introduced. In Indian industry gradually continuous pans will take the place of batch pans in the near future particularly for intermediate grade boiling. The batch pans can be broadly classified into two types

(i) Coil pans,

(ii) Calendria pans.

Whatever the design or type of pan it is necessarily fitted with following accessories

(a) a condenser connected to vapor pipe, either barometric type or a multi-jet one.
(b) Catchall at the top before the vapor pipe to prevent entrainment or carryover.
(c) A vacuum breaking valve to be used before dropping a strike.
(d) Sight glasses on the front as well as at the back.
(e) Manhole door.
(f) Large discharge valve.
(g) Pan washing arrangement.

Besides above the various pipe connections are provided with appropriate valves

i) Coil Pan

The sugar plants established in the thirties or even prior to 1930 were provided with coil pans. In the old design, coils were of copper tubes bent into spirals with the upper end connected to the wall of the pan while the other one i.e. the lower one is joined to the condensate-drain. The coil is wound in such a way as to facilitate easy drainage of condensate. A set of coils is installed, each one being connected to steam line through valve and steam trap to enable independent start or cutout of any one coil. The successive coils are so laid as to aid circulation of massecuite in the pan. The pan body can be of MS. or cast iron. The coils are made of 10-15 cm. dia copper tubes with wall thickness of about 2.5 - 4 mm. The ratio of length to diameter of coil is 200-250 for live steam, but for using exhaust steam it has to be 75-100. The pan is equipped with usual fittings like sight glasses for observing levels of Massecuitte, catch all etc. Pan with flattened coils—In a new design of coil pan introduced in Queensland the flattened coils form the heating surface. The coil constructed of 12.5 cm. dia. copper tube is flattened so as to give nearly 1½ times or double the height over the width. The coil consists of concentric flattened tubes with two ends connected to steam manifold and condensate outlet respectively. The only advantage of the coil pans is that the heating surface is gradually cut in or brought into operation as the strike level rises but the main

Disadvantages are-

(a) High maintenance costs,
(b) Use of vapors or low pressure exhaust is not possible as mostly live steam is required for boiling.
(c) Mechanical circulator cannot be installed.

In recent past for the above reasons coil pans have completely been replaced by Calendria pans.

ii) Calendria Pans

Like an evaporator body a Calendria pan has tubular Calendria with the difference that the tubes are of larger diameter and shorter length as also larger down take to facilitate circulation of high brix material. Circulation of thick Massecuitte is of utmost importance in the design of Calendria and this is brought about by providing large down-take for the ascending stream of mass through the tubes. As a result of heat transfer from the steam or vapor to the Massecuitte it raises in the tubes and on reaching the top of upper tube plate descends through the down take. This efficiency and speed of circulation of mass is an important characteristic of any Calendria pan design. In a conventional design of 30m3 capacity pan, the Calendria is fitted with 100 mm. O.D. and 96 mm I.D. brass tubes of 1.1 m. length, with end portions expanded and fixed in two plates of 25 mm. thickness with a ligament of 16 mm. In the Calendria of M.S. construction the down take is provided with deflector of fanned shape at an angle of 45° at the upper end of the downtake opening to prevent short circuiting of Massecuitte flow. Usually one steam connection is provided and the condensates drained from the opposite side into a tank located on ground floor. The shell of pan body is of 12 mm. M.S. construction and has an internal catchall in the top dome which is connected to vapor Pipe going to condenser. The conical bottom is bolted to the Calendria or even welded in some case and the pan discharge valve is located in the centre. The feed is connected to the bottom cone away from the discharge valve but in some designs the feed enters the pan in the downtake. A cut over line is connected to the bottoms of all pans and seed or vacuum crystallizer. The conical bottom of each pan is joined to the cutover line through an opening and valve. The diameter of central cylindrical down take is 40-50% of that of the Calendria. The heating surface to volume ratio has to be 6-6.5 m^2 per m^3 of working volume but for good circulation the height of boiling Massecuitte should not exceed 1.5 m. and to achieve these twin objectives the size of the pan belt above the upper tube plate of Calendria is increased in diameter. Thus the diameter of Massecuitte belt is made larger than that of Calendria by 0.6

- 1.6 m. the two being joined to each other by a sloping cone. The advantages of low head pans are

(a) Low graining or footing volume, about 25-30% the strike volume,

(b) Good natural circulation of Massecuitte even when the strike level reaches the maximum limit, resulting in reduced time of boiling,

(c) Higher H.S. to volume ratio can be maintained which adds to the speed of boiling

2.0 MAJOR DESIGN CONSIDERATIONS

In pan boiling along with speed of boiling a strike, it is important that no pockets of stagnant mass remain inside the pan which will not only affect the quality of sugar but will bring about destruction of sugar also. In vacuum pan operation maximum exhaustion of mother liquor is aimed at along with proper development of crystal size and shape. The factors which come into play in achieving the desired results in respect of pan design are as under—

(a) Even distribution of steam in the steam belt and effective removal of incondensable gases are inter-linked in the sense that the steam path is so arranged as to drive the incondensable gases to the points of their removal. In pans of large capacities two steam entry points are provided in the Calendria. Needless to state that the condensate extraction from the bottom of the calandria should leave no accumulation. The steam must reach all pockets of the Calendria, in a uniform manner for efficient heat transmission to the Massecuitte in the tubes.

(b) Low graining volume or footing volume is useful when a footing is to be cut into a vacuum crystallizer or another pan and similarly it reduces the amount of footing the pan is to be filled up with. Low volume is very helpful for grain development in high grade boiling and purity control in low grade boiling.

(c) The height of the strike when full above the top tube plate of Calendria has to be low for two reasons—

(i) The high hydrostatic head raises the boiling point of mass in contact with heating surface particularly in the lower portions of the Calendria,

(ii) Circulation rate is lowered at top portion as height of strike increases, which in other words means that the velocity of movement of Massecuitte through the tubes upwards and its return to the bottom is reduced.

(d) Introduction of feed of syrup or molasses in the system has to be such that the feed is quickly dispersed uniformly in the upward moving mass.

(e) With the recent trend of employing vapor from pre-evaporator for vapor boiling, it is essential that the pan design in respect of heating surface to strike volume ratio and distribution of vapor should be suitable for boiling pan at about 0.2 kg/cm^2.

(f) Entrainment separation has to be efficient as during early stages of the strike boiling, when the brix is comparatively low chances of carryover of liquid with vapor make it necessary to effect efficient separation of liquid from the rising vapor.

3.0 DIFFERENT DESIGNS OF VACUUM PAN IN SUGAR INDUSTRY

In view of the above requirements of the pan boiling, and for improving circulation characteristics, different designs of pans have been introduced, some of which are as follows—

(a) **Floating Calendria**

In a floating type Calendria, in place of central down take the downward movement of the descending Massecuitte is provided in the annular space. The heated Massecuitte rises towards the top and flows radically towards shell and downwards through the annular space. In one design the Calendria is conical shaped at the bottom and flat at the top, which has added to the heating surface. In the conical bottom type floating Calendria designed by Hugot10 the steam connection is provided at the centre through pipe passing through the save all at the top. One great isadvantage with floating Calendria pans is that mechanical circulator cannot be installed in such pan.

Segura pan—

This pan has a floating type Calendria with some special features with respect to steam entry and peripheral down take. The top tube plate is in horizontal plane but the bottom tube plate possesses the shape of inverted cone with tubes becoming shorter from centre to periphery. In the down take are fitted 20 inclined baffle plates to guide the Massecuitte. The steam entry is provided at the centre of Calendria, the steam pipe entering in the steam chest, at the bottom. The steam pipe is shielded by larger pipe inside the pan and vacuum is maintained in the gap between the steam pipe and outer pipe to avoid overheating of Massecuitte above the upper tube plate. The pan feed of syrup or molasses is arranged through an outside pipe forming a ring from which feed enters the peripheral down take at different points. This pan design permits fast boiling and use of low pressure vapor or steam. Moreover the footing volume is also low. In view of the good circulation characteristics the pan needs no mechanical circulation.

(b) Conical Calendria-

This type of Calendria has a central down take but the tube plates of the Calendria are inclined towards the centre, the lower tube plate being at 25° and the upper one at 10°-25°. The idea behind the top tube plate sloping towards centre is to render washing and cleaning of top of Calendria easy after the pan is dropped. The inclined conical shape provides higher heating surface, less idle space in the bottom cone and lower graining volume as compared to conventional central down take straight type Calendria.

(C)Ring Type Calendria

The Grantzdorffer design of calandria11 is characterized by concentric rings which are on the same level at the top but are extended downwards so as to form a conical bottom conforming to the shape of bottom cone of the p a n . The Massecuitte circulates through the rings and the central down take. In t he improved version of this type of Calendria designed by Tate & Lyle the rings a r e

Made of ribbons.12a The steam inlet for the rings is at the top while the condensate drains out from bottom of the elements. The annular ring design is good for efficient circulation and these are widely adopted in refineries. The refinery strikes can be concentrated to 95° Bx due to ease of discharge and very high yields of sugar a r e obtained.

(d) Horizontal Design

In a recent design of horizontal pan of Fives Lille-Cail the heating surface is provided by hollow plate type elements vertically placed. The shape of t h e pan permits of low footing volume (up to 26%). The heights of elements increase towards the centre from the periphery. The Massecuitte is dropped through t h r ee openings at the bottom. The ratio of heating surface to strike volume can be v a r i ed from 6 to 7.5 m2/m3.

(e) Rotary Horizontal Pan-

Lafeuille design13 has the merit of low hydrostatic head a n d rapid boiling on account of low resistance to circulation and good heat transmission. Nests of tubes constitute the heating surface and the space between these n e s ts provides passage for Massecuitte circulation. Fixed connections for steam, vacuum, incondensable gases are attached to the plain ends of the rotary cylinder. T h e

discharge of strike is effected through 2-3 openings. One such pan was installed at Ravalgaon for producing extra white sugar of large size from melt.14 this pan c a n boil strikes to a very high brix. However this rotary type construction of pans has n o t found much favor with manufacturers of sugar machinery or technologists.

(f) Other Designs

In one pan designed in India the steam feed is provided at the c e n t re as in Segura design, the steam pipe being extended to the bottom of Calendria and t h e pipe inside the Calendria has openings for radial distribution of steam. The pan h a s peripheral down take for circulation of massecuite.16 The saucer bottom p a n developed in Hawaii has a shallow bottom shaped to assist circulation of Massecuitte. The Calendria is of conventional central down take type but because of the special shape of the bottom the footing volume is low and the discharge valve is on one s i d e at the lowest level. In the Fletcher design the down take of Calendria is almost half in diameter of the Calendria and the syrup and molasses feed is arranged in the central portion of the down take so as to get mixed with the descending Massecuitte before it

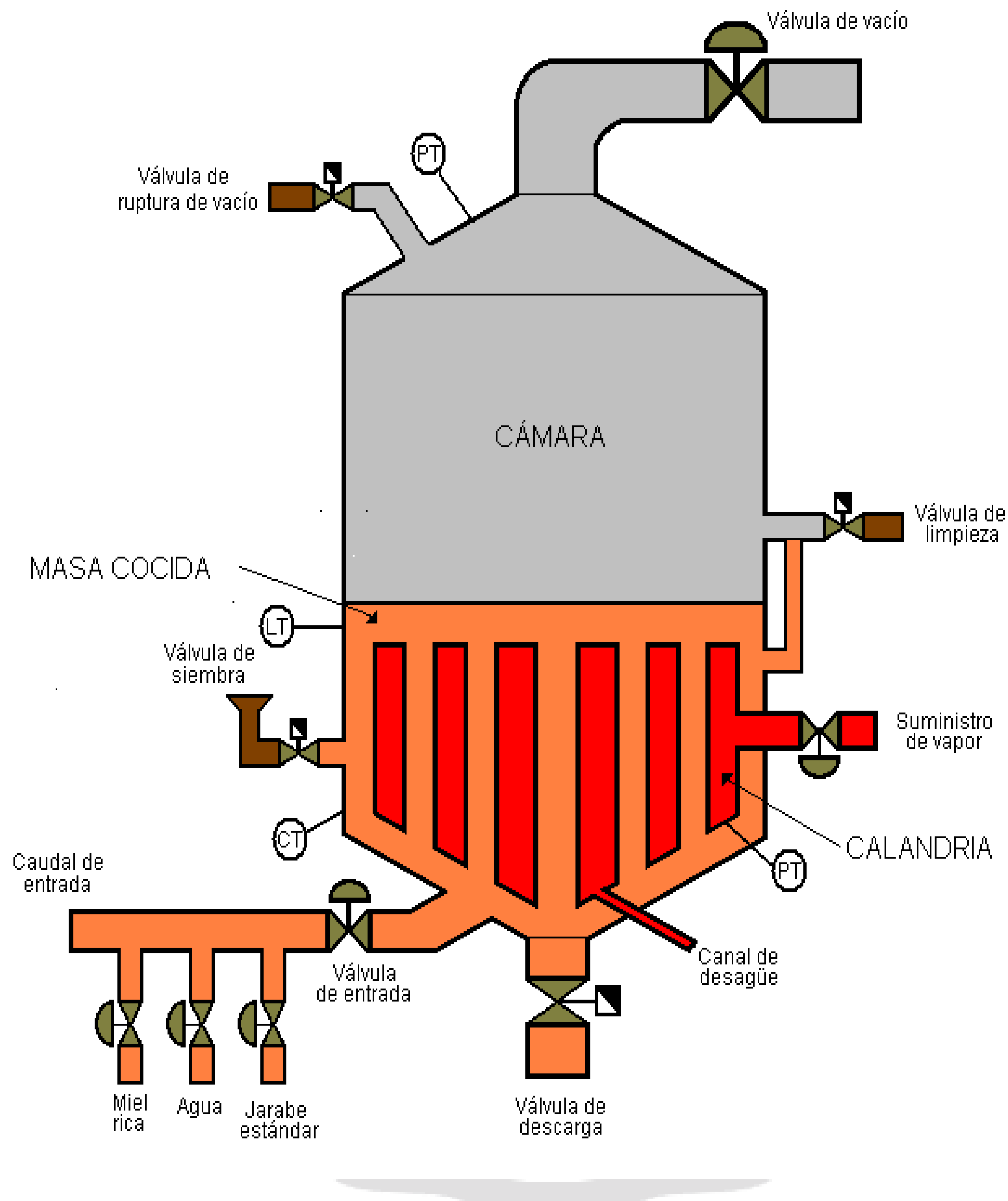

Fig No-01(G.A OF VACCUM PAN)

4.0 DESIGNS OF VACUUM PAN IN SUGAR INDUSTRY

a) To Find the Number of Tubes in the Vacuum Pan-

Inputs-

Massecuitte Density-1.428 T/m^3
S/V Ratio-6.6
Internal Diameter of Tube (D)-102mm

Output-

First we have to find the volume of pan by using above input parameters
A) Volume of Pan= Total Capacity of Pan/Density of Massecuitte
V=42/1.428
V=29.41 m^3

b) **Heating Surface Area of Pan (S)= Volume of Pan X (S/V) Ratio**
S=29.41 X 6.6
S=194.1176 m^2

c) Effective Length of Tube(L_{et})= Total Length of Tube-Thickness of top tube plate-Thickness of bottom tube plate-5-5
L_{et}= 740-25-25-10
L_{et}=690 mm= 0.690 m

d) Number of Tubes(N)= Total Heating Surface Area/ (3.14 X D X L_{et})
N=194.1176/(3.14 X 0.694 X 0.102)
N=819 Nos

e) To Calculate Vapour Inlet Pipe Diameter for Pan Calculation

Inputs-

Massecuite Density-1.428 T/m^3
S/V Ratio-6.6
The Heating Surface Area (S) is-194.1176m^2
The Vapour Outlet Velocity- 30 m/s.
The Vapour inlet Temprature-100 deg
The Evaporation Rate of Pan-65 kg/cm^2/hr

Output-

The Vapour Produced in Pan per hour= Heating Surface Area X The Evaporation Rate
=194.1176 X 65
=12617.65 Kg/hr

We have to Consider the Extra Margin of Vapour Produced , we can take it 10% Extra

Vapour calculated by considering margin=(10/100) X 12617.65=13879.41 kg/hr

Vapour Produced per Second=13879.41/3600=3.855 kg/s

We have to take help of steam table and we have to find out the Specific Volume of vapor at given temperature i.e 100 deg and from steam table it is 9.584 m^3/kg

The Volume of Vapour Entered per Second = Volume of Vapour produced per second X Specific Volume at given temperature.

=3.855 X 9.584

=**36.95 m^3/sec**

We Know,

Q=A X V

36.95= 0.7854 X D^2 X 30

D=1253 mm

f) To Calculate Vapour Outlet Pipe Diameter for Pan Calculation

Inputs-

Massecuitte Density-1.428 T/m^3
S/V Ratio-6.6
The Heating Surface Area (S) is-194.1176 m^2
The Vapour Outlet Velocity- 48 m/s.
The Vapour inlet Temprature-100 deg
The Vapour outlet Temprature-55 deg
The Evaporation Rate of Pan-65 kg/cm^2/hr

Outputs-

Specific Volume of Vapour for given temperature is 9.3 from steam table
Final Amount of Vapour Generated by considering margin is 3.85 X 9.3 equals 35.85 m3
We Know,
Q= A X V
35.85=0.7854 X D^2 X 48
D=975mm

g) Various Diameters and Height Calculations of Sugar Vacuum Pan:-

To Find the Diameter of Calendria Shell for Vacuum Pan

Pitch of Tubes (P)= OD of Tube + Ligament
P=102 +16=118 mm

Total Number of Tubes(N_t)= Calculated Number of Tubes(N) + Number of Stay Rods/Bolts to support the Top Tube plate + Number of Tubes to eject the noxious gases generated in the Pan

N_t=819 + 8 + 10
N_t= 837 Nos
D_{cal}= 1.24 X P X N^0.5
D_{cal}=1.24 X 118 X 837^ 0.5
D_{cal}= 4233.3 mm

Now we have to consider the 5 % margin because material can vary its quantity , so by keeping safer side we have considered this amount , after considering the margin we have to calculate the Calendria shell diameter and we have to round figure it appropriately for manufacturing point of view.

D_{cal}= (5/100) X 4233.3 +4233.3
D_{cal}=4445 mm
By Round Figure,
D_{cal}= 4450 m……This will be final Calendria Diameter.

h) To Find Thickness of Calendria Shell of Vacuum Pan-

Inputs-

Working Pressure (P) - 3 Kg/cm^2
Allowable Pressure (F)-9 kg/cm^2
Joint Efficiency (J)-0.7
Calendria Diameter (D_{cal}) - 4450 mm
Constant(C) - 1.5

Outputs-

T_{cal}= ((P X D_{cal})/200 X F X J- P)+C)
T_{cal}=((3 X 4450)/200 X 9 X 0.7-9)+ 1.5)
T_{cal}=12.1 mm

Considering Weight of mass, Nox gas connection, stay rods/bots for supporting the top tube plate of vacuum pan , we have to consider appropriate margin,
By considering above margin,
T_{cal}=18 mm

i) To find the down take diameter of Vacuum Pan-

We have to always take diameter of down take diameter equals to 45 % of Calculated Calendria shell diameter, as per Hugot.
D_{dt}= (45/100) X 4450
D_{dt}=2002.5 mm………. we have to round Figure it
D_{dt}=2000mm……………Final Down take diameter

j) To Find the Height of Vapour Space-

Inputs-

Pan Volume-29.412 m^3
Total Volume of Pan(V_t)- 100 %
Graining Volume (V_g)-42 %
Height of Strike Level-2000mm…This height is required to avoid the entrainment of Vapour
Calendria Diameter- 4450 mm

Outputs-

Working Volume-100-42=58 %
Volume above top tube plate of working volume = (58/100) X 29.412=17.059 m^3
We have to find out the height of vapor space so we have to apply general equation of volume,
V_{pan}=0.7854 X D_{cal} 2 X H_s
17.059=0.7854 X 4450 X 4450 X H_s
H_s= 911.72 mm
Final Height of Vapour Space= Strike Level Height + Calculated height of Vapour Space
Final Height of Vapour Space=2000 + 911=2911 …Round Figure it

Final Height of Vapour Space=3000 mm

k) Various Heights and Diameters of Vacuum Pan

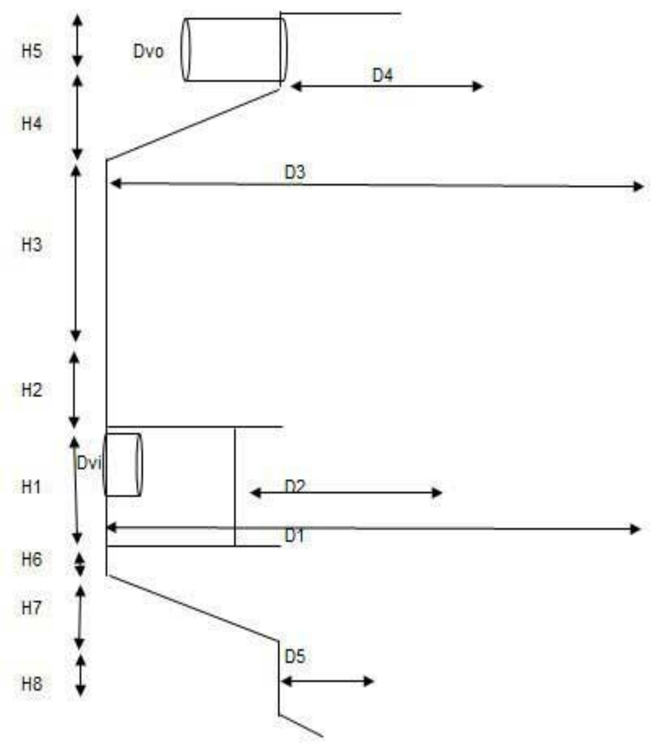

Fig No-02 (VARIOUS HEIGHTS OF PAN)

Various Diameters of Pans

D1 =Calendria Shell diameter ….Already Calculated
D2-=Down take diameter ……..…Already Calculated
D3 =Vapour Body diameter …Equals to D1..
D4 =Vapour Dome diameter =2 X d_{vi}=2 X 1250= 2500 mm=2600 mm by considering FOS
D5 =Discharge diameter (for 40 Ton it is 700 mm to be considered)….Standard Assumptions
D_{vo} = Vapour Outlet diameter… Already Calculated
D_{vi} =Vapour Inlet diameter……. Already Calculated

Various Heights of Pans

H1 =Calendria shell height (Depends on tube height)… ….Already Calculated
H2 =Strike level height from the top tube plate (Depends on graining volume of pan).. ….Already Calculated
H3 =Vapour space above the strike level (1500mm to 2000 mm)
H4 =(D3-D4) x Tan α (α = 20 to 30)=4450-2500 X x Tan 30 =1125mm=1150mm
H5= Height of the Vapour dome =1.75 X Dvo= 1.75 X 1250 =2187.5=2200 mm
H6 =Bottom ring (150mm to 400 mm)..Standard Assumption
H7 = (D1-D5) x Tan α (α= 17 to 25)=4450-700 X tan 17=1146=1150 mm
H8 =150mm to 200mm…. Standard Assumption

5.0 VACUUM PAN MODELLING

Vacuum Pan Environment

Operating in semi batch mode, it is in the vacuum pans where the sugar is separated from the juice which is extracted from the sugar beets by means of a crystallization method controlled by evaporation in a vacuum environment.

Initially, a sub saturated sugary juice known as standard liquor which is stored in standard liquor tanks is pumped into the vacuum pan. This standard liquor is then heated in vacuum conditions in order to reduce the boiling point and prevent thermal decomposition of the sucrose (a process known as caramelisation). When this juice becomes Supersaturated, it is seeded into small crystals and grown by adding more liquor and maintaining the supersaturated conditions. When the maximum level is reached in the vacuum pan, the contents are discharged and the pan is cleaned, ready for a new cycle. To heat the juice and evaporate part of the water, the vacuum pans are equipped with a heating Element known as the Calendria. Steam flows through the Calendria at a pressure above that of atmospheric pressure and as it condenses, it releases heat to the Massecuitte in the vacuum pan. The steam is supplied to the vacuum pans through steam supply pipes which form a closed circuit that runs around the complete industrial plant. To maintain a partial vacuum (0.2-0.3 bar) in the vacuum pan in order to evaporate the water at low temperature (65-70°C), the vacuum pan must be connected to a barometric condenser. This condenser maintains a determined vacuum as it Absorbs the steam coming from the vacuum pans and condenses it by means of cooling. The cooling effect is obtained by the entry of water which is carried via pipes from the outside. The vacuum produced in the condenser depends on the outside temperature, which means it works better in winter. Once the crystallization process of the sucrose in the vacuum pan is completed, the resulting Massecuitte is discharged into horizontal tanks. In the tanks it is kept moving at a determined temperature so as to maintain its consistency until it can proceed to one of the centrifugals. In the centrifugals the crystallized sugar is separated from the mother liquor as the batch is centrifuged at high speed, leaving the crystals retained by a screen. The process takes just a few minutes. The mother liquor is separated into syrup for seed magna and syrup for Massecuitte which is distributed according to the needs of the plant. Above Figure shows what a vacuum pan looks like in overall aspect in sugar industry boiling house.

As per the calculations done , the model has been prepared in Solid Edge ST9 Software for better clarity of manufacturing

6.0 MODEL OF VACCUM PAN PREPARED IN SOLID EDGE ST9

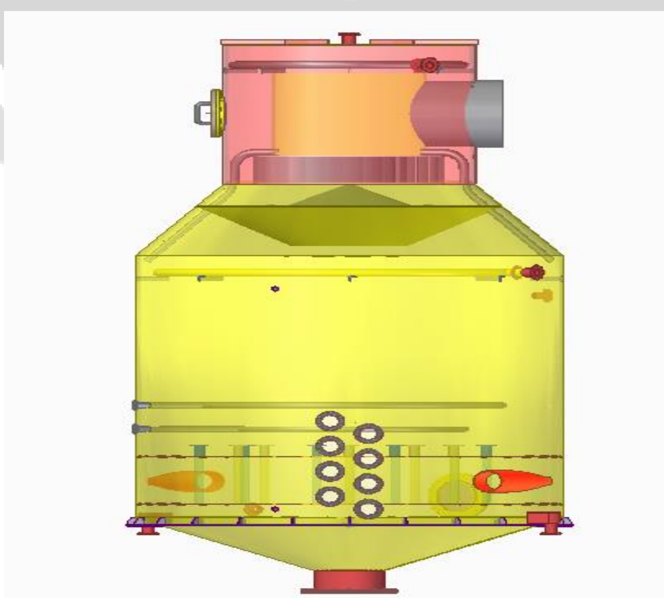

Fig no-03(front view)

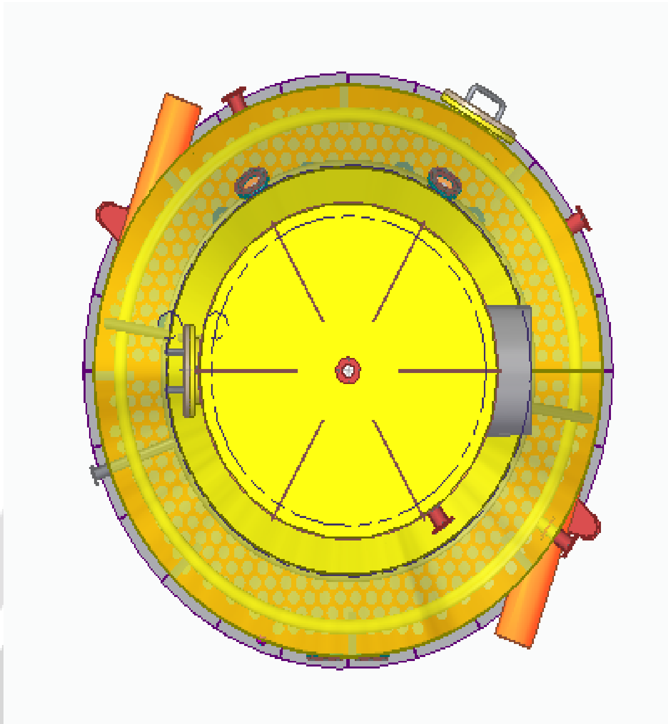

FIG NO-04(TOP VIEW)

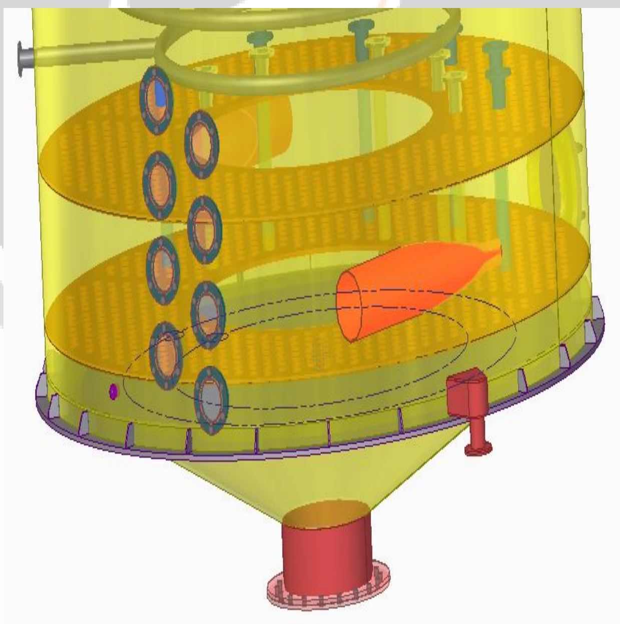

Fig no-05(PAN bottom view (isometric))

FIG NO-06(ISOMETRIC VIEW

7.0 CONCLUSION

From Above design calculations it has been found that For following are the calculated parameters

Volume of Pan (V) is 29.41 m^3
Heating Surface Area of Pan (S) is 194.1176m^2
Effective Length of Tube (L_{et}) is 0.690 m
Numbers of Tubes (N) are 819 Nos
Vapour Inlet Pipe Diameter is 1250 mm
Vapour Outlet Pipe Diameter =975mm
Diameter of Calendria Shell (D_{cal})=4450 mm
Thickness of Calendria Shell **(**T_{cal})=18 mm
Down take diameter of Vacuum Pan**(** D_{dt})=2000mm
Height of Vapour Space (H_s) 911.72 mm
Final Height of Vapour Space=3000 mm
Vapour Dome diameter = 2500 mm
Height of the Vapour dome =2200 mm

8.0 REFERENCES

[1] Austmeyer E 2013 Analysis of sugar boiling and its technical consequences; Part II , Heat transfer during sugar boiling . Int Sugar J.88(1046);23-29

[2] Stephens, D.W. 2008. Studies on modeling circulation in sugar vacuum pans. PhD. Thesis, Univ. James Cook.

[3]. Stobie, R.M. 2015 Pneumatic agitation of high grade massecuite. Int. Sugar J. 101(1206):302-306.

[4] Van der Poel, 2004 P.W., H. Schiweck, and T. Schwartz. 1998. Sugar Technology. Verlag, Bartens, Berlin.

[5] Webre, A.L. 2006 Natural and mechanical circulation in vacuum pans. Pages: 394-452. In: Principles of Sugar Technology, Vol. 2, Crystallization. P. Honig, ed. Elsevier, Netherlands.

[6]Wright, P.G. 2000 Circulation movements in sugar vacuum pans. Proc. Queensland Soc. Sugar Cane Technol. 33:179-184.

[7] Bergeron, S., and G. Carline. 2003. Changing the heating surface to volume ratio on a low grade batch pan. J. Amer. Soc. Sugar Cane Technol. (abstract) 24: In press.

[8] Bosworth, R. 2008. Luis Fernando Echeverri Measurements and computations of the flow in
full-scale sugar evaporative-crystallizers and in labscale models

[9] Brown, D.J., K. Alexander, and F. Boysan. 2008 Crystal growth measurement and modeling of fluid flow in a crystallizer. Zuckerind 117(1):35-39.

[10] E.E.A. ROUILLARD 1985 a study of boiling parameters under conditions of laminar and non Newtonian flow with massecuite boiling reference

[11] Chen, J., and C. Chou. 2015. Cane Sugar Handbook. John Wiley & Sons, 12th Ed.

[12]Chetty, S., S.B. Davis, A. Raghunandan, and S. Maharaj. 2002. A successful modification to the Dorr 444 clarifier. Proc. S. Afr. Sugar Technol. Assoc. 76:433-434.