Design and Optimization of Heat Exchanger with Liquid Helium Chamber for Cooling of Supercritical Helium

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Abstract— The Proposed indigenous helium plant will have mixed mode operation (simultaneous operation as liquefier and as refrigerator) provision having equivalent 2 KW refrigeration at 4.5 K at IPR. there will be a liquid helium chamber will contain a heat exchanger to cool the supercritical helium from about 6 K to 4.8 K. this project will involve the design and optimization of this LHE chamber and internal component of it.this vacuum chamber of cold box will be a horizontal cylinder with tentative diameter of 2.5 m and length 7 m. This vacuum chamber will contain many cold component to produce liquid helium. A part of the flow will be taken to the LHe chamber though J-T valve to produce liquid helium and cool the supercritical helium coming out of the cold circulator using heat exchanger. This cold circulator (CC) will circulate helium in closed loop within the cold box. This CC will provide 300 g/s supercritical helium flow at 4 bar pressure and 6 K temperature. The heat energy going to the supercritical helium due to pumping work and external heat load of the CC need to be removed by heat exchanger contained in liquid helium chamber. The vapour from the chamber will return to the low pressure cold return line passing though the heat exchanger of the main cycle of the helium plant. As this chamber will be within the vacuum vessel, its size has to be minimized considering the size of the heat requirement of operation of helium plant when external helium Dewar is not available, in which this internal LHe chamber will be used to produce liquid helium for performance test of helium plant. This project will involve design and analysis taking into account of manufacturing assembly and maintained aspect and different off-normal condition.

Key words: CC, LHE, Single Wound Tube

I. Introduction

The supercritical helium used in the superconducting elements because of it easy handling. So it gains the heat from the heat reservoir.

So cooling of the supercritical helium is important. This is done by heat exchanger in a liquid helium chamber.

Here the supercritical helium cooled by liquid helium bath and goes to the application when needed. Cold circulator circulates the supercritical helium at 4 bar pressure and 6 k temperature. The liquid helium boils up due to the heating load of supercritical helium

The liquid helium chamber acts as the heat transforming media in which 4.5 k temperature is maintained. The generated helium vapour goes to the main circuit of the system where it is used for further cooling of the incoming helium gas

So heat exchanger design is important for cooling with liquid helium chamber so optimum design is used and maximum utilisation of space is used in liquid helium bath.

II. Design Methodology

1) Step 1-taking standard inner and outer diameter of tube, mass flow rate of the super critical helium passing through tube and given temperature difference, heat transfer through the pipe is calculated from given equation[1].

$$Q = mCp\Delta T \qquad (2.1)$$

2) Step 2- Reynolds's number and Nusselt number inside the tube, are given by [1]

$$R_e = \frac{4m_{He}}{\Pi d_i \mu_{He}} \qquad (2.2)$$

$$\frac{Nu_f}{Nu_o} = \frac{(T_f/T_w)^{\frac{1}{2}}}{06 + 0.4\left[F_1 + F_2 (T_f/T_w)^{\frac{1}{2}}\right]} \qquad (2.3)$$

$$F_1 = \frac{C_f(T_w - T_{sat})}{i_w - i_{sat}}$$

$$F_2 = Ꞩ_f(T_w - T_f){P_r}^{0.6}(1 - T_w/T_{sat})$$

$$Nu_f = 0.0208(Re_f)^{0.8}(Pr_f)^{0.4}[1 + 0.01457(V_w/V_b)] \qquad (2.4)$$

$$h_i = \frac{NuK}{d_i} \qquad (2.5)$$

3) Step 3- Hence, hi can be found out from Nu and ho can be taken from the equation for boiling of LHe .generally pool boiling correlation is that of Kutateladze,which has been verified as follows for cryogenic fluids including N2,O2,H2 and He[1]

$$\frac{Ja}{{Pr_l}^{0.65}} = 0.0007\left[\frac{Q/A_w}{\mu l_i f_g}\sqrt{\frac{g_c\sigma_l}{(\rho_l - \rho_g)}}\right]^{0.3}\left[\frac{\rho_g}{\rho_l}K_p\right]^{0.7} \qquad (2.6)$$

$$K_p = \frac{P_{sat}}{[(g/g_c)\sigma_l(\rho_l - \rho_g)]^{0.5}} \qquad (2.7)$$

$$\text{Jacob no } Ja = \frac{C_l(T_w - T_{sat})}{I_{fg}} = \qquad (2.8)$$

$$h_o = \frac{Q/A_w}{(T_w - T_{sat})} \qquad (2.9)$$

4) Step 4- The overall heat transfer coefficient for clean surface (U) is given by,

$$\frac{1}{U} = \frac{1}{h_o} + \frac{d_o}{h_i} + \frac{r_o}{k}\ln\left(\frac{r_o}{r_i}\right) \qquad (2.10)$$

Here, clean condition is considered since, LHe and He used will be 99.999% pure, so,

There will be no fouling over or inside the tube.

5) Step 5- Hence, outer surface area is given by,

$$A_o = \frac{Q}{U \times LMTD} \qquad (2.11)$$

LMTD used is for counter-flow pool boiling condition

6) Step 6- Overall Length of the coil, L, is given by,

$$L = \frac{A}{\Pi d_o} \qquad (2.12)$$

7) Step 7- Pitch of the coil, Pc and Number of turns of coil Nc are given as,[10]

$$P_c = 1.5 \times d_o \qquad (2.13)$$

$$N_c = \frac{L}{\{(\Pi D_c)^2 + P_c^2\}} \qquad (2.14)$$

8) Step 8- Height of coil, Hc,

$$H_c = N_c \times P_c \qquad (2.15)$$

The pressure drop encountered by the fluid making Np passes through the heat
Exchanger is a multiple of the kinetic energy of the flow. Therefore, the tube-side

– Pressure drop is calculated by,[1]

$$f_c = f_s + 0.01\left(\frac{d}{D}\right)^{0.5}$$

$$\nabla p = \frac{fLG^2}{d_i 2\rho}$$

Friction factor for the straight tube $f_s = 0.0014 + \frac{0.125}{R_e^{0.36}}$

III. Optimization

A. *For Single Wound Tube:*

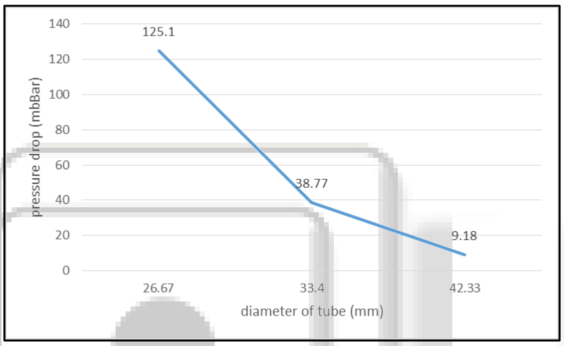

Fig. 1: The Diameter of the Tube Increased the Pressure Drop Is Also Increased.

In shown in fig when the diameter of the tube increased the pressure drop is also increased.

But the selected pressure drop in the system is <50 mbar so the acceptable range is in that region.

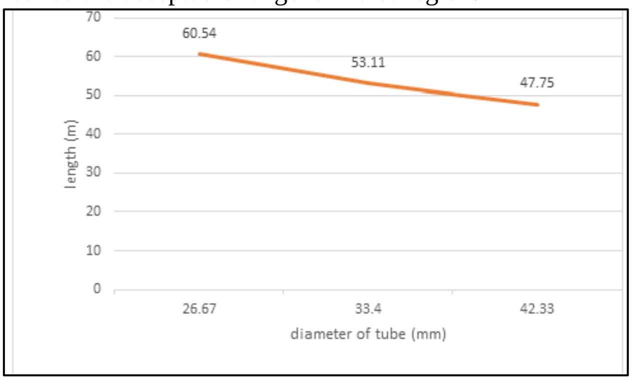

Fig. 2:

From this graph it is shown that the length of the tube is decreased as the diameter of the tube increased. So it is overall beneficially for any system when the heat exchanger design at the higher diameter of tube

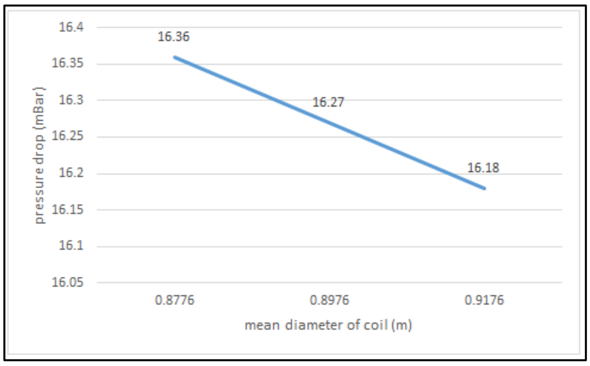

Fig. 3:

If we draw the graph of the mean diameter of coil and the pressure drop then the pressure drop is also very according to the mean diameter.as the clearance in the system decreased the mean diameter is increased and it also reduced the pressure drop inside the heat exchanger.

But it reduced the pressure drop in very less amount

B. *For Double Wound Tube*

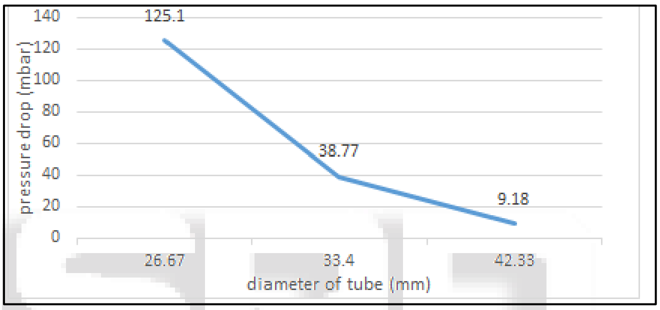

Fig. 4:

Here if we draw the double wound tube then the pressure drop is reduced for the particular system at different diameter. Because the friction drop is also less generated in the system so pressure drop is the system. So optimum result is taken out from the different graph section

IV. Optimized Result and Discussion

A. *For Single Wound Tube:*

– Diameter of container space= 1m
– Height of container space= 1m
– Clearance provided at side = 0.03m
– Pitch of coil p= 0.050796m
– Pitch circle diameter of coil= 0.89767 m
– Number of turns of coil= 16.94183m ~ 16.9
– Height of coil= 0.858452m
– Inlet temperature of hot fluid Th1 5K
– Outlet temperature of hot fluid Th2 4.7K
– Pressure inside tube Ph 4bar
– Mass flow rate of hot fluid mh 0.3kg/s
– Flow temperature Tf=(Tb+Tw)/2 4.7625K
– Wall temperature Tw 4.675K
– Average temperature Tavg(b) 4.85K
– Specific heat of hot fluid Cph 5.0097kJ/kgK

- Density at Temperature Pf 129.06 kg/m^3
- Viscosity µ¬f 3.51E-06 Pa*s
- Thermal conductivity Kf 2.11E-05kw/mK
- Outer diameter 0.04233 m
- T 0.002769 m
- Inside diameter dI 0.036792 m
- Specific heat Cph(f) 4.7754 kJ/kgK
- Kinematic viscosity v(w) 2.7114E-08m^2/s
- Kinematic viscosity v(f) 2.72191E-08m^2/s

B. *For Double Wound Tube:*

- Internal tube
- Diameter of container space= 1m
- Height of container space= 1m
- Clearance provided at side = 0.05m
- Pitch of coil p= 0.04008m
- Pitch circle diameter of coil= 0.8666m
- Length of tube(L1) 40m
- Number of turns of coil= 14.69980787~ 15
- Height of coil= 0.5891683 m
- Friction in straight tube 1.93E-03
- Friction in helical tube(fc) 0.002138345
- Diameter of container space= 1m
- Height of container space= 1m
- clearance provided at side = 0.05 m
- Pitch of coil p= 0.04008 m
- Pitch circle diameter of coil= 0.8666 m
- Length of tube(L2) 13.11321m
- Number of turns of coil= 4.81904
- Height of coil= 0.193147 m
- Friction in straight tube 1.93E-03
- Friction in helical tube(fc) 0.00372

V. CONCLUSION

1) From this result it is shown that in double wound heat exchanger have lower pressures drop comparison to the single wound pressure drop.
2) As the mean diameter of the coil increased pressure drop is decreased
3) Friction factor is decreased when the number of wound coil is used for any heat exchanger

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