Experimental Performance of Coil Finned Tube Type Heat Exchanger

Smit S. Patel\(^1\) Prof. Dr. S.M.Mehta\(^2\)
\(^1\)Department of Cryogenics Engineering \(^2\)Department of Mechanical Engineering
\(^1\)\(^2\)L.D.College of Engineering, Ahmedabad-15

Abstract— It is known that the gas liquefaction system is very crucial part of cryogenics engineering because it is used to produce different cryogens. Heat Exchanger is the most crucial component in cryogenic processes, for improving efficiency and decreasing cost of the whole plant. Coiled finned-tube heat exchangers have been used in small and medium helium refrigerators/liquefiers, miniature J-T refrigeration systems for many years. The efficiency of these cryogenic systems strongly depends on the thermal and pressure drop performance of these heat exchangers. A considerable improvement in the performance of heat exchanger is possible by choosing an appropriate geometrical configuration for a given process requirement. In this work fabrication and experimentation has been carried out. Geometry of heat exchanger has been derived taking into consideration the clearance provided for manufacturing of the heat exchangers. The predictions of four end temperatures from design method have been compared with the actual experimental results of one of the prototypes fabricated in our lab.

Key words: Coil, Heat Exchanger, Cryogenic

I. INTRODUCTION

A series of coiled finned-tube heat exchanger is used in a cryogenic refrigerator/liquefer. These heat exchangers were first used by Collins in his helium liquefer [1]. The main requirements of these heat exchangers are high effectiveness and low pressure drops in both of fluid streams to stipulated limits. These parameters govern the performance of the whole system. In fact, a cryogenic liquefer will produce no liquid if the heat exchanger effectiveness is less than approximately 85% in contrast to a conventional heat exchanger, used in other process plants, with lesser effectiveness [3]. Atrey [2] has shown in his analysis that decrease in heat exchanger effectiveness from 97% to 95% reduces the liquefaction yield in helium liquefer by 12%. This necessitates thorough understanding of different loss contributing mechanisms that affect the performance of heat exchanger to arrive at an optimum geometrical configuration.

Design and optimize different geometrical and operating parameters for coiled finned tube exchangers was carried out by s.j.patel & s.m.mehta [8]. To improve the effectiveness of heat exchanger the theoretical analysis has been carried out by theoretical modeling. The efforts have been made to study the effect of different geometrical parameters like coil diameter, tube diameter by in depth study of DIN number, fin height and fin spacing etc. and operating parameters like pressure drop.

The design and optimization of geometrical and operating parameters are done to achieve the desired temperature drop of cold fluid. This optimized parameters were taken for manufacturing.

Design and Optimization of Coil-finned tube type heat exchanger for Cryogenics application was carried out by p.k.gupta [5]. Thermal And Pressure Drop characteristics were applied to this type of heat exchanger. Same procedure is carried out for calculating axial length of coil finned tube type heat exchanger.

Another Major issue of developing these heat exchangers is to ensure uniform flow distribution over the finned tubes of heat exchanger by controlling the manufacturing clearance to achieve the higher order of magnitude of effectiveness.

II. EXPERIMENTAL SET-UP

![Heat exchanger test facility](image)

Fig. 1: Heat exchanger test facility

A. Procedure:

The main heat exchanger will be kept in the vacuum chamber except the compressor.
1) First, compress the Nitrogen gas, which is at atmospheric temperature and it's pressure will increase up to 12-14 bar from the compressor.
2) Now, this high pressure hot fluid will pass through the coil-finned tube of the Heat exchanger where it will exchange the heat with returned cold stream.
3) Then the outlet stream of the Heat Exchanger will pass through pressure regulator valve to make exhaust to atmospheric Pressure.
4) The outlet of pressure regulator valve will then passed through LN2 Bath which is at about 77.36 k Temperature for Cooling purpose.
5) The outlet Stream of LN2 bath is at low temperature and pressure, and this low temperature and low pressure fluid will again passed through the Shell side of Heat Exchanger as a return stream(cold stream).This cold fluid will cool down the temperature of incoming hot fluid.
Nomenclature

\[ A_s \] surface area
\[ A_{fc} \] free-flow area of fins
\[ A_{cc} \] clearance cross-section area
\[ A \] total shell side free-flow area
\[ A_o \] surface area of finless tube of same diameter and length
\[ C \] heat capacity rate of fluids
\[ c \] diametrical clearance
\[ d_i \] inner diameter of tube
\[ d_f \] fin diameter
\[ d_o \] fin root diameter
\[ D_e \] mean diameter of shell
\[ D_h \] hydraulic diameter
\[ f_s \] fin spacing
\[ h \] heat transfer coefficient
\[ h_f \] fin height
\[ k \] thermal conductivity of gas
\[ L \] axial length of shell
\[ l \] length of finned tube
\[ m \] mass flow rate
\[ m_f \] actual mass flow rate passes through fins
\[ n \] number of fins per unit length
\[ p \] pitch of tube
\[ Pr \] Prandtl number
\[ Q \] heat transfer
\[ Re \] Reynolds number
\[ Re_f \] Reynolds number (actual flow)
\[ s \] perimeter of tube
\[ t \] mean thickness of fin
\[ T \] temperature
\[ T_m \] fluid mean temperature
\[ T_1 \] log mean temperature difference
\[ U \] overall heat transfer coefficient
\[ \Delta T \] temperature difference
\[ \Delta T_{LMTD} \] log mean temperature difference

Subscripts

\[ c \] cold fluid
\[ h \] hot fluid
\[ in \] inner
\[ i \] inner
\[ in \] inlet
\[ out \] outlet
\[ t \] tube
\[ s \] shell

Several equations are presented for the calculation of various parameters involved in the performance of the heat exchanger, including:

6) Finally, the output cold stream of the Heat exchanger will again compress through compressor and again the whole process will repeated.
7) We measure the temperature at three point inlet of hot stream of main heat exchanger, outlet of hot stream of heat exchanger and cold stream inlet. We use PTR-100 temperature sensors to measure the temperature.

III. DESIGN EQUATION

1) Shell side free flow area
\[ A_{sc} = \pi D_c (d_i + c) - \pi D_c [(d_i - d_o)nt + d_o] \]

2) Free flow area offered by fins section
\[ A_{fc} = \pi D_c [(d_i - d_o)(1 - nt)] \]

3) Free flow area offered by clearance section
\[ A_{cc} = \pi D_c c \]

4) The surface area offered by the outer finned surface in one coil
\[ A_s = \pi n^2 [n/2 (\int df / f + do)^2 + do(1 - tn) + dtn]d_e \]

5) Perimeter of outer finned surface
\[ S_o = (\pi n^2 [n/2 (df^2 + do^2) + do(1 - tn) + dtn]d_e) / df \]

6) Perimeter of inner tube surface
\[ Si = \pi n^2 D_e / df \]

7) Bypass factor
\[ K = A_{cc} / A_{fc} \]

8) Mass flow rate of cold stream
\[ mf = mc / (K + 1) \]

9) Reynolds No.
\[ Re_f = Re_{woc} / (K + 1) \]

10) Reynolds no without clearance
\[ Re_{woc} = mc * \mu / D_f \]

11) Hydraulic diameter
\[ D_h = 4 * A_{sc} / (As / L) \]

12) Mass flow rate per unit free flow area
\[ G = m_c / A_{sc} \]

13) Actual mass flowing through fins
\[ G_r = G / (K + 1) \]

14) Total heat removed
\[ Q = C_o (T_{in} - T_{out}) = UL \Delta T_{LMTD} \]

15) Logarithmic mean temperature difference
\[ \Delta T_{LMTD} = (\Delta T_1 - \Delta T_2) / \ln(\Delta T_1 / \Delta T_2) \]

16) Inner stream heat transfer coefficient
\[ h_i = 0.033 * C_h * m_h^{0.8} * \mu_h^{0.2} * d_i^{-1.8} \]

17) Outer stream heat transfer coefficient
\[ h_o = 0.021 * C_h * G_f * Re_f^{-0.2} \]

18) Overall heat transfer coefficient
\[ U = 1 / ((1 / \mu_i) + (1 / \mu_o)) \]

19) Length of tube required is calculated
\[ L = Q / (U \times \Delta T_{LMTD}) \]

From this calculation we get length of heat exchanger.
IV. OPTIMIZED PARAMETERS

Optimization of parameters is carried out by literature available, some of that geometrical parameters and their graphs are shown here.

**Graph 1:** Effect of DIN No.

**Graph 2:** Effect of fin density

**Graph 3:** Effect of fin diameter

This parameters are used for manufacturing the coil finned tube type heat exchanger.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass flow rate</td>
<td>9 g/s</td>
</tr>
<tr>
<td>Tube side pressure</td>
<td>14 bar</td>
</tr>
<tr>
<td>Shell side pressure</td>
<td>1.013 bar</td>
</tr>
<tr>
<td>Mean dia. of shell De</td>
<td>145 mm</td>
</tr>
</tbody>
</table>

**Table 1:** Parameters for mfg.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fin dia. d₁</td>
<td>13.5 mm</td>
</tr>
<tr>
<td>Diametrical clearance c</td>
<td>1.2 mm</td>
</tr>
<tr>
<td>Fin root dia. Do</td>
<td>11.5 mm</td>
</tr>
<tr>
<td>Fin density n</td>
<td>670 fins/m</td>
</tr>
<tr>
<td>Mean thickness of fin t</td>
<td>0.3 mm</td>
</tr>
<tr>
<td>Inner dia. of tube di</td>
<td>11.1 mm</td>
</tr>
<tr>
<td>Axial length L</td>
<td>1000 mm</td>
</tr>
<tr>
<td>Pitch of tube</td>
<td>20 mm</td>
</tr>
<tr>
<td>Pitch of fins</td>
<td>1.47 mm</td>
</tr>
</tbody>
</table>

Fig. 2: Fins over Tube on Mandrel & Sectional view of coil finned tube heat exchanger

Tube length required:
- From above fig. mean coil dia. =145 mm
- Pitch = 20 mm
- Axial length = 1000 mm
- So, num. of turns = 1000/20 =50 turns
- Length of tube = 50 * length required in one turn
  = 50 * \( \text{nD}_{\text{mean}} \)
  = 50 * n * 145
  = 22765 mm
  = 22.765 m ≈ 23 m

Fig. 3: Hot & cold fluid in heat exchanger
V. OTHER COMPONENTS REQUIRED

1) Pressure Regulator Valve.
Two Stage S.S 316 METAL Diaphragms with Teflon seat.
   - Maximum Inlet Pressure = 280 (Kg/cm2).
   - Maximum Outlet Pressure = 0 to 16 Kg/cm2.

2) LN2 bath & Coil.
By taking inlet and outlet parameters of helium and properties of LN2, diameter and length required are as under
   
   \[
   \begin{align*}
   D_i &= 11.5 \text{ mm} \\
   D_o &= 13.5 \text{ mm}
   \end{align*}
   \]

   From these parameters: Required length of immersed pipe is \(1.98 \text{ m}\) from MATLAB programming.

3) Mass flow regulator.
   Range = 0-4 gm/s
   Output signal = 0-5 VDC/ 4-20 mA
   Supply = 24 VDC
   Inlet pressure = 15 kg/cm²
   Operating Range = 0° – 50°C

4) Temperature Sensor with Digital Controller
5) Compressor
6) Tubing & Coupling
7) Diffusion Pump for vacuum insulation

VI. RESULTS

Temperature Reading by PTR-100 :-

<table>
<thead>
<tr>
<th>Temperature at different point</th>
<th>value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temp. @ inlet of heat exchanger</td>
<td>312 K</td>
</tr>
<tr>
<td>Temp. @ outlet of heat exchanger</td>
<td>225 K</td>
</tr>
<tr>
<td>Temp. @ outlet of pressure regulator</td>
<td>236 K</td>
</tr>
<tr>
<td>Temp. @ inlet of LN2 bath</td>
<td>250 K</td>
</tr>
<tr>
<td>Temp. @ outlet of LN2 bath</td>
<td>198 K</td>
</tr>
<tr>
<td>Temp. @ inlet to shell side of heat exchanger</td>
<td>212 K</td>
</tr>
<tr>
<td>Temp. @ outlet to shell side heat exchanger</td>
<td>315 K</td>
</tr>
</tbody>
</table>

Table 2:

So, Effectiveness of heat Exchanger \(\mathcal{E}\) = \[
\frac{Ch (Th1−Th2)}{Cmin (Th1−Tc1)} = \frac{(312−225)}{(312−212)}
\]

= 0.87 = 87%

VII. CONCLUSION

The heat exchanger is tested for nitrogen gas cooled by liquid nitrogen (LN2) bath at 78 K. The four main temperatures at inlet and outlet of coil finned tube type heat exchanger was measured by PTR-100. Due to minor leakage and heat in leak the effectiveness achieved by experiment is 87% while analytically effectiveness of nitrogen based heat exchanger is somehow close to this value. So, from this paper we can conclude that thermal design of heat exchanger is satisfactory.

VIII. FUTURE SCOPE

There is a still scope of geometrical modification like at LN2 bath we can improve the coil design by using steel tube of smaller diameter and directly we can put it inside the standard cryocan available in market. Also we can test the coil finned tube type heat exchanger by helium gas at 3 g/s mass flow rate.

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REFERENCES