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Influence of wire fin on performance of coiled tube heat exchanger in a small J-T refrigerator

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ABSTRACT

Heat exchangers are the most critical components that dictates the performance of the small J-T refrigerators. Using mixture of refrigerants as a working fluid in these type of heat exchangers will takes place boiling and condensation simultaneously. Designing and evaluating the temperature distributions of these wire finned heat exchanger is not available. With this aim in the present study a coiled wire finned heat exchanger is used to cool the mixed refrigerant down to cryogenic temperatures. The modified Granryd [12] model was used to estimate the heat transfer coefficients on tube side and shell side respectively. A computational technique is also developed to estimate the length of the heat exchanger by giving mass flow rate, diameter of tube and shell as input parameters. It was predicted that the size of the heat exchanger required reduces by 43% when a wire fin was wound over the inner tube.

Keywords: J-T refrigerator, wire fin, coiled tube heat exchanger, cryogenic temperature.

1. INTRODUCTION

Heat exchangers are one of the most critical components of any cryogenic refrigerator. A small ineffectiveness of the heat exchanger results significant percentage of decrease in the performance of the refrigerator. Coiled tube heat exchangers are widely used in small J-T refrigerators (heat capacities are typically less than 10 W) due to simplicity in its construction, less space occupancy and low longitudinal heat conduction [1]. Ardhapurkar et al.[2] conducted series of experiments on multiple tubes- in tube heat exchanger. Based on the mixture composition he stated the performance of heat exchanger in terms of overall heat transfer coefficient along the length of heat exchanger. Few researchers [3-8] have investigated experimental and numerical studies related to usage of mixed refrigerants in J-T refrigerators but they kept their attention mainly on how to optimize the mixture composition moreover very limited literature is available about the performance analysis of such type of heat exchangers. Apart from its above advantages coiled tube heat exchangers may also suffer from the touching of tube walls with shall wall which leads to flow mal distribution on the shell side of the heat exchanger which in turn decreases the effectiveness of the heat exchanger. One way to overcome the above problem is to wound a wire over the inner tube which separates the tubes with other tubes and the shell wall. Winding wire will also improve the turbulence on the shell side and helps in improvement of rate of heat transfer. One of the objective of present paper is to theoretically design a coiled wire finned tube heat exchanger using existing single phase and two phase heat transfer models. The second objective is to compare the size of the heat exchanger with wire fin and without wire fin over the inner tube.

2. MODEL DISCRIPTION

Table 1 gives the details of the coiled tube heat exchanger used in the study of atrey [9]. The total length of the heat exchanger was about 15 m with a coil diameter of 0.2 m. Similarly, Table 2 gives the details of the composition of the mixture used to obtain temperatures of the order of 100 K [9]. In this study a wire fin of dia 0.8 mm was assumed to be wound over the inner tube.

Table 1: Specifications of the Heat Exchanger [9]

Tube	ID (mm)	OD (mm)
Inner	4.83	6.35
outer	7.89	9.52

Table 2: Mixture Specifications [9]

Mixture composition, N2/CH4/C2H6/C3H8/iC4H10(%mol)		Temperature range (k)
Charged	**Circulation**	
36/15/13/19/17	39.86/16.86/12.84/17.38/13.0	<100

3. METHODOLOGY

Krasnikova et al. [10] developed correlations for estimating the single phase heat transfer coefficient in wire finned heat exchanger and the same has been used in this study. The correlation is given as follows [10]

$$J = 178.2 * 10-2 * (\partial w/\partial es)1.36\,(tf/\partial w) - 0.057\,(\partial z/des)0.414\,(Res)n)/40000 \quad (1)$$

A number of studies exist in the literature on predicting the heat transfer coefficients of pure fluids. Further there are studies in which the same pure fluid two phase heat transfer models were used to estimate the heat transfer coefficients of the mixtures [11]. In the present study modified Granryd [12] two phase heat transfer model has been used to predict the heat transfer coefficient on the tube side and the shell side. The reason for the selection of the modified Granryd [12] model is due to its consistency with pure fluids and reasonable predictions with mixtures. Lots of literature is available to design a heat exchanger for J-T refrigerator but no data available regarding the design of wire finned heat exchanger. In the present work a numerical model is developed to design a wire finned heat exchanger for better performance and to reduce the size of the heat exchanger.

$$h_{cv} = h_{lo}\left(\frac{F_p}{1+A}\right) \qquad (2)$$

Here h_{lo} is liquid heat transfer coefficient determined from Dittus-Boelter equation as given below

$$h_{lo} = 0.023\left(\frac{k_l}{d_{hs}}\right)(1-x)\left(\frac{G\,d_{hs}}{\beta}\right)Pr_l^{0.4} \quad (3)$$

Flow boiling for pure refrigerants can be calculated by equation 4.

$$F_p = 2.37\left(0.29+\left(\frac{1}{X_{tt}}\right)\right)^{0.85} \qquad (4)$$

where

$$X_{tt} = \left(\frac{1-x}{x}\right)^{0.9}\left(\frac{\rho_v}{\rho_l}\right)^{0.5}\left(\frac{\beta_l}{\beta_v}\right)^{0.1} \quad (5)$$

$A =$

$$\left(\frac{F_p}{c_{lg}}\right)x^2\left(\left(\frac{1-x}{x}\right)\left(\frac{\beta_v}{\beta_l}\right)\right)^{0.8}\left(\frac{Pr_l}{Pr_v}\right)^{0.4}\left(\frac{k_l}{k_v}\right)\left(\frac{Cp_v}{Cp_w}\right) \quad (6)$$

$$Cp_w = \left(\frac{\partial H}{\partial T}\right)_p \qquad (7)$$

$$Cl_g = 1.4 \text{ if } G > 500 \quad \frac{Kg}{m^2 s} \qquad (8)$$

$$Cl_g = 2 \text{ if } G < 300 \quad \frac{Kg}{m^2 s} \qquad (9)$$

4 RESULTS AND DISCUSSIION

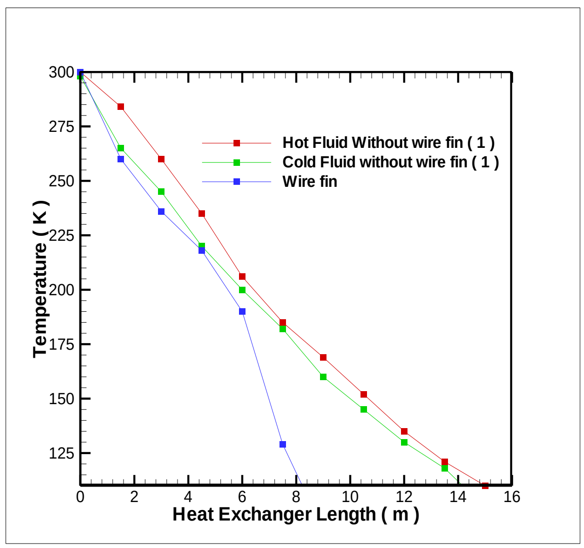

Figure 1: Variation of temperature with and without wire fin along the length of heat exchanger.

Figure 1 shows the temperature profiles with and without wire fin wound over the inner tube along the length of the heat exchanger. it is clearly observed from the above figure if there is no fin wound over the inner tube, the pinch point occurs at 15m length of heat exchanger whereas when the complete length of the tube is wounded by a wire, the formation of pinch point shifted to 4.5m and the length of the heat exchanger is reduced from 15m to 8.5m. This shows that there is almost 43% reduction in size of heat exchanger. This is due to creation of turbulence between shell and tube of the heat exchanger and increase in heat transfer coefficient.

5. CONCLUSION

In the present work, temperature distributions are determined for a helical coiled heat exchanger when its inner tube is wound over with wire fin and without wire fin. This study reveals that

1. Temperature distribution will depends on the composition of the mixture and their thermodynamic properties.

2. Formation of pinch point plays a predominant role on the performance of heat exchanger.

3. Occurrence of pinch point at 4.5m length and the length of the heat exchanger reduced to 8.5m when wire fin wound over the tube which leads to 43% reduction in size of the heat exchanger

Nomenclature

Specifications

ID Inner diameter (m)

OD Outer diameter (m)

Greek Symbols

β Dynamic viscosity, Pa.s

ρ Mass density, kg/m^3

Subscripts

g Gas

lo Liiquid only

l Liquid

v Vapour

Notations

A Cross sectional area (m^2)

C Enhancement factor

Cp_w Apparent local specific heat (j/kg-k)

Cv Control volume

Fp Parameter for flow boiling

G Mass velocity (kg/m^2 s)

h Heat transfer coefficient(w/m^2-k)

K Thermal conductivity (w/m-k)

Xtt Martinelli parameter

j Heat emission

dw/des Relative fin spacing

tf/dw Relative tube diameter

nt Function of relative surface roughness

Non-dimensional Numbers

Pr Prandtl number

Re Reynolds number

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