A numerical modeling of cryogenic heat exchanger: Review

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ABSTRACT

The heat exchanger is crucial component of any cryogenic process. The cryogenic heat exchanger governs the performance of cryogenic system. High effectiveness of heat exchanger must be required in cryogenic application. The present work reports the introduction of numerical modelling of heat exchanger which is used in cryogenic application. There is several type of heat exchangers used in cryogenic application. Out of them we focused on coiled finned tube type heat exchanger. The aim of present study is to introduce importance of numerical modelling and methods of numerical modelling of heat exchanger. To study effect of position or time on heat transfer rate of cryogenic heat exchanger a numerical analysis has been carried out by numerical modelling. The efforts have been made to study different methods of analysis and effect of position and time in transient analysis by numerical modelling.

KEYWORD : *Cryogenic heat exchanger, Numerical modelling*

I INTRODUCTION

Cryogenic consists of two words that are cryo and genics which means cold produced. Cryogenic includes all those processes which has temperature interaction below 123 K. Cryogenic system always needs highly effective heat exchanger, it may be regenerative type or recuperative type heat exchanger. Effectiveness of heat exchanger widely affects the efficiency and yield of cryogenic system such as liquefier and cryogenic refrigeration. Heat exchanger used both for heating and cooling purposes. The cryogenic system like liquefiers, heat exchanger is one of the most important components, and play significant role. In fact, a cryogenic liquefier will produce no liquid if the heat exchanger effectiveness is less than approximately 85% [2]. If the effectiveness of a heat exchanger is reduced from 97% to 95% the liquid yield is reduced by 12% [3]. These facts suggest the need of high-effectiveness heat exchangers, of the order of more than 90%. So a heat exchanger should be designed in a manner to have optimum effectiveness with lower pressure drop. Due to the increased focus of environmental sustainability, it has also become important to look at possibilities of utilizing the energy in ”waste heat” or background heat.

As heat exchanger is the most critical component of liquefier system, this recuperative heat exchanger has been studied extensively by many researchers.

There are many demands on the heat exchanging systems such as weight and size. Maximizing profits are also usually desirable. Therefore, it is important to be able to design heat exchangers efficiently. This requires a good understanding of the mechanisms of heat transfer [1].

Due to the complexity of the heat transfer mechanisms, it has been important to investigate the field of numerical modelling of heat transfer. There are many types of heat exchangers which can be characterized by a number of factors due to geometries (plate exchangers, tubular exchangers, fins), flow natures (cross flows, co- and counter-flows) and thermodynamic working conditions (multi-phase, multi mediums).

II LITERATURE ON ANALYSIS OF HEAT EXCHANGER

Ardhapukar and Atrey [4] presented a steady state analysis for the performance optimization of a miniature J–T cryocooler in which they have used coiled finned tube type heat exchanger. In their analysis they prepared numerical model of heat exchanger using governing equations of heat transfer which is discussed later.

R.M.Damle and M.D.Atrey [5] presented a work of transient simulation of miniature Joule Thomson (J-T) cryocooler with and without the distributed J-T effect. In their work they prepared numerical model in which two variables such as position and time are considered.

Alex Hansen, IFY [1] did his master degree dissertation work on Numerical methods for solving complex heat exchanger models in transient operation. In his project work an analysis and comparison using different numerical methods for solving a thermally complex heat exchanger under steady state condition was conducted. An extension to this work is to implement a numerical solver for transient operation. The solver should be used both as an alternative to the steady-state solver for reaching steady conditions and to study the effects of process disturbances relevant for a selected industrial case.

Bidarmaghz A., Narsilio G., Johnston I. [6] presented work Numerical Modelling of Ground Heat Exchangers with Different Ground Loop Configurations for Direct Geothermal Applications. The design of ground heat exchangers (GHEs) involves the selection of detailed configuration options. However, there is limited understanding of the relative importance of different design choices on performance. This study investigates the effects of different design parameters such as pipe configuration and fluid flow rate on the heat extraction rate, and will be helpful to design a system which is energy efficient and cost effective. Different pipe configurations in vertical grouted boreholes including single Upipe, double U-pipe, and double cross U-pipes for small diameter boreholes, and spiral and multiple U-pipes for larger diameter boreholes, are modelled in detail using state-of-the-art finite element methods. The effects of GHE configurations and fluid flow rate on system efficiency is determined and contrasted. Numerical results indicate that the thermal performance of the system is enhanced by transitioning from laminar to turbulent regime, and by increasing the volume of carrier fluid inside the pipes for a given GHE length (i.e., single versus double pipes). However, in larger diameter boreholes, GHE's thermal performance does not change significantly for different pipe configurations with similar pipe lengths inside the borehole (i.e., spiral versus multiple U-pipes).

Abebe Kebede Endalew [7] has worked in **Master of Science Thesis entitled** Numerical Modelling and Experimental Validation of Heat Pipe Solar Collector for Water Heating. In his work, he studies the performance of heat pipe solar collector for water heating. Experimental results are validated using numerical modeling. Homemade heat pipes with distilled water as a working fluid were used for experimental tests. Both natural and forced convective heat pipe condensing mechanisms are studied and their results are compared with conventional natural circulation solar water heating system. Cross flow and parallel flow heat exchanger were tested in forced type heat pipe condensing mechanism. Experimental and numerical results showed good agreement. Heat pipe solar collectors outperformed conventional solar collector because of their efficient heat transport method. Forced convective heat exchanger was found to give higher efficiency compared to natural convective heat pipe condensing system. However, natural convective heat pipe condensing is free from parasitic power and low system weight. It also showed appreciable system efficiency and can be further developed to be used in rural areas where grid electricity is scarce. Cross flow and parallel flow heat exchanger have been tested for forced convective heat pipe condensing mechanism and no appreciable difference was found due to higher fluid velocity in heat exchangers.

III NEED OF NUMERICAL MODELLING

1. Correct dimensioning and design is essential for the plant to operate as wanted.
2. Tools that correctly predict the performance of heat exchangers are therefore very important.
3. The descriptions of heat transfer and pressure drop are often highly nonlinear.
4. Due to complex geometry of heat exchanger it is not easy for designer engineer to predict its performance with sufficient reliability.
5. Numerical modelling provides reliable data which can be used to validate experimental results.

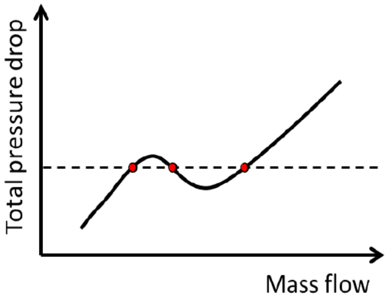

Figure 1. total pressure drop as function of mass flow rate

IV Numerical Modeling

Numerical modeling involves the formulation of different thermal heat transfer and fluid dynamic process in terms of partial differential eq., or ode, or any other co relation.

Numerical modeling uses following basic law used for determining numerical model of any system. Let us assume heat exchanger is coiled finned tube type heat exchanger.

The conservation of mass, momentum and energy equation for fluid and energy equation for solid can be written as

Conservation of mass over a fluid CV

$$A\frac{\partial\bar{\rho}}{\partial t}+\frac{\partial\dot{m}}{\partial x}=0 \qquad (1)$$

Conservation of momentum

$$A\frac{\partial(\bar{\rho}\bar{V})}{\partial t}+\frac{\partial(\dot{m}V)}{\partial x}=-\frac{\partial P}{\partial x}A-\tau_w l_p \qquad (2)$$

Conservation of energy

Hot fluid:

$$m_h C_{ph}\frac{dT_h}{dx}= h_h P_{ci}(T_w-T_h) \qquad (3)$$

Cold fluid:

$$m_c C_{pc}\frac{dT_c}{dx}= h_c[P_{co}(T_c-T_w)+P_{si}(T_c-T_s)+P_{mo}(T_c-T_m)] \qquad (4)$$

The energy equations for the solid elements

1. Finned tube

$$K_w A_w \frac{d^2T_w}{dx^2} = h_h P_{ci}(T_w - T_h) + h_h P_{ci}(T_w - T_c) \tag{5}$$

2. Mandrel

$$K_m A_m \frac{d^2T_m}{dx^2} = h_c P_{mo}(T_m - T_c) \tag{6}$$

3. Shield

$$K_s A_s \frac{d^2T_s}{dx^2} = h_c P_{si}(T_s - T_c) + h_r P_{so}({T_s}^4 - {T_a}^4) \tag{7}$$

Now by providing boundary conditions to numerically formulated equation can be solved satisfactorily by using any techniques such as finite elemental method, MOL, control volume technique etc..

V Results and discussion

Results generated by solving governing equations by any suitable methods lead to produce plots showing variation of one parameter along length of tube or shell side and also considered time dependency to achieve steady state.

It provides reliable data which can be used to validate experimental results. It also make problem feasible so that geometric and operating parameter can be optimized as per requirement. Numerical modeling considered the coefficient as function of position and time. So, it reveals more accurate and stable results.

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