ABSTRACT

Perforated plate matrix heat exchangers (PPHEs) are constructed of a stack of high thermal conductivity perforated plates interspaced with low thermal conductivity spacers. They offer high surface area density, uniform flow distribution, reduced longitudinal heat conduction loss and manufacturing advantage over other types of compact heat exchangers. The PPHEs are increasingly used in cryogenic refrigeration and liquefaction systems, cryosurgery, air separation plants and helium plants etc.

Standard equations for heat exchangers do not serve the purpose of designing cryogenic PPHEs because of the complex mechanism of heat transfer and longitudinal heat conduction losses through the walls. The design is obtained either numerically or by using approximated analytical equations. Analytical or closed form expressions offer many advantages such as straight forward solution, less computational time etc. and they can be used in design optimization and studying transient behavior of the heat exchanger.

The existing closed form expressions for PPHEs, however, are available only for balanced flow conditions. In many applications e.g. gas liquefiers or process plants involving multiple fluids, the heat exchangers often operate in unbalanced flow conditions. Therefore, the first work done in this thesis is to derive (or modify the existing ones) expressions for unbalanced flows. Initially, unbalanced flow with longitudinal heat conduction only through the separating wall is considered. It is proved that an analytical expression for a balanced flow can be used for an unbalanced flow by using a modified axial conduction parameter.

In order to study the effect of the outer wall, performances of PPHEs having various flow channel geometries are computed numerically. The studies indicate severe performance degradation for very low mass flow rate or for high NTU heat exchangers. The available closed form expressions with longitudinal heat conduction only through the outer wall and for balanced flow are modified for using them in unbalanced flows.

Analysis of PPHEs requires convection heat transfer coefficient at the outer wall. The complex geometry of a PPHE, however, makes it difficult to obtain heat transfer coefficient at the outer wall. Considering this uncertainty, investigations on the influence of heat convection or heat transfer coefficient (at the outer wall) on the heat exchanger's performance are carried out and approximate way of solution is brought out.

Having obtained the closed form expressions, with axial conduction losses separately for fluid separating and outer walls, the next step considers the combined effect of both the walls. In such a case, the governing equations are strongly coupled and closed form analytical expression is not possible to obtain even for balanced flow heat exchangers. In the present work, a procedure for obtaining analytical solution considering both the wall effects and with balanced as well as unbalanced flows is presented.

Another issue which strongly influences the design of PPHEs is the heat transfer and flow friction correlations. A number of correlations for perforated plates are available in literature. However, they do not include all the geometrical variables. In this thesis, heat transfer and flow friction correlations as functions of all the variables are developed by using an efficient numerical model. From the computed data and the correlations, effects of geometrical parameters on thermo-hydraulic characteristics of perforated plates are discussed.

The closed form expressions obtained in the thesis can be used for carrying out design optimization of a PPHE. Using Teaching Learning Based Optimization (TLBO) method, optimized design solutions for PPHEs of two problems are presented. Maintaining the desired heat duty, optimized designs of the PPHEs are obtained by minimizing the volume of the heat exchanger while observing the given constraints in pressure drop. Some results are compared with the solutions from Genetic Algorithm (GA).

The closed form analytical expressions are limited to some selected flow channel geometries such as rectangular two-channel, rectangular multi-channels (spread in one dimension) and circular annular geometries. For other types of complex flow channel geometries e.g. rectangular multi-channels (spread in two dimensions), circular inter wound spiral or circular multi-channel etc., such closed form expressions are difficult to obtain. For these geometries, we need to design the heat exchanger numerically. However, the major issues in numerical modelling are the large computational time and memory requirements especially when the number of plates is large (>200). In this work, a new method of numerical modeling is proposed where the heat exchanger is split longitudinally into two parts, the hot fluid side and the cold fluid side. Two sides are separately drawn, meshed and modelled numerically in parallel mode with common interface wall temperatures. Detailed computational procedure is presented and validated.