Heat Transfer and Flow Friction Characteristics of Plate Fin Heat Exchanger Surfaces – A Numerical Study

Abstract

Plate fin heat exchangers, because of their compactness, low weight and high effectiveness are widely used in aerospace and cryogenic applications. This device is made of a stack of corrugated fins alternating with nearly equal number of flat separators known as parting sheets, bonded together to form a monolithic block. Appropriate headers are welded to provide the necessary interface with the inlet and the exit streams. While aluminium is the most commonly used material, stainless steel construction is employed in high pressure and high temperature applications.

The performance of a plate fin heat exchanger is determined, among other things, by the geometry of the fins. The most common fin configurations are - (1) plain (straight and uninterrupted) rectangular or trapezoidal fins (2) uninterrupted wavy fins and (3) interrupted fins such as offset strip, louver and perforated fins. The interrupted surfaces provide greater heat transfer at the cost of higher flow impedance.

The heat transfer and flow friction characteristics of plate fin surfaces are presented in terms of the Colburn factor j and the Fanning friction factor f vs. Reynolds number Re, the relationships being different for different surfaces. One of the earliest and the most authoritative sources for j and f data on plate fin surfaces is the monograph *Compact Heat Exchangers* by Kays and London [1984]. Although nearly two decades have passed after the latest edition, there has not been any significant addition to this database in open literature.

Attempts have been made at numerical prediction of j and f factors by solving the continuity, momentum and energy equations. But they have not been successful because of the complexity of the problem and the limitations on computing resources. In recent years, with significant increase of computing power, fresh attempts are being made in that direction, but with limited success. In the absence of theoretical relations for

j and f factors, many authors have worked out empirical relations by fitting experimental data, supplemented with approximate analytical models. Correlations of Wieting [1975], Webb and Joshi [1987], Manglik and Bergles [1995] and Muzychka and Yovanovich [2001] on offset strip fin surfaces have been particularly successful in industrial design. But unlike analytical and numerical formulations, empirical relations do not provide any insight into the physics of heat transfer enhancement and pressure drop.

Unlike simpler geometries, the thermal performance of plate fin surfaces is not uniquely determined by the hydraulic diameter; other geometric variables such as fin spacing (s), fin height (h), fin thickness (t), offset strip length (l), wave length (Λ), and wave amplitude (a) have significant effect. It will be prohibitively expensive and time consuming to fabricate heat exchanger cores and carry out experiments over reasonable ranges of so many geometric variables. In contrast, it is reasonably easy and cost effective to conduct a parametric study in numerical simulation and derive correlations for use by the heat exchanger designer. But, because numerical solution is based on certain simplifying assumptions, the computed results are, in general, different from experimentally observed values. To alleviate this problem, we have evolved a procedure where some of the constants in the correlations are estimated from numerical simulation, the rest being determined by fitting experimental data

We have used the finite volume based CFD software, PHOENICS as the numerical tool. Three-dimensional, steady, Navier-Stokes equations and the Energy equation have been solved with appropriate boundary conditions for plain, offset strip and wavy fin surfaces. We have observed that the laminar flow model underpredicts j and f values at high Reynolds number, while the 2-Layer k-e turbulence model overpredicts the data throughout the range of interest. Because most industrial heat exchangers operate with Re less than 3000, and because the j and f data predicted by the laminar and the 2-layer k-e turbulence model differ little from each other at low Reynolds numbers, we have used the laminar flow model up to Reynolds number of 10,000, which is considered to be the limit for plate fin heat exchangers operating with gases. Velocity, pressure and temperature fields have been computed and **j** and **f** factors determined over appropriate range of Reynolds number and geometric dimensions. The **j** and **f** data have been expressed in the form:

$$j \text{ or } f = F(\text{Re, geometry})$$
$$= A\text{Re}^b \, \mathcal{F}(\text{dimensionless geometric parameters})$$

The function $\mathcal{F}$ is also a power law expression in the geometric parameters such as h/s, t/s, ℓ/s etc. We have determined the indices of $\mathcal{F}$ by multiple regression from numerically computed results, and the constants A and b by fitting experimental data of Kays and

London. Because the **j** or **f** vs. Re curves show significant non-linearity, we have expressed the correlations in terms of two separate equations over the low and the high Re regimes. The transition Reynolds number has also been correlated with dimensionless geometric parameters.

We have thus carried out an exhaustive numerical study on the heat transfer and flow friction phenomena in plate fin heat exchanger surfaces with plain, wavy and offset strip fins. While the data for plain and offset-strip fins have been correlated successfully by pure power law expressions, those for wavy fins have demanded more complex relations. The indices of the dimensionless geometrical factors in wavy fin geometry have been expressed as simple polynomials of Reynolds number. A practical approach has evolved for determining the dependence of j and f factors on Re and dimensionless geometrical features. A set of correlations has been generated for use in heat exchanger design. These correlations are expected to extend the range and accuracy of available correlations, particularly for offset strip fin and wavy fin surfaces.

Key words: Plate Fin Heat Exchanger, Heat Transfer Correlations, Plain Fin, Offset Strip Fin, Wavy Fin.