# SOME ASPECTS OF THE PERFORMANCE OF CRYOGENIC HEAT EXCHANGERS

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## Abstract

Gas-to-gas counterflow and cross-counterflow heat exchangers are extensively used in cryogenic refrigeration and liquefaction systems. Such exchangers are normally used to cool the warm high pressure process gas by transferring heat to the cold low pressure stream. The performance of most cryogenic equipment are critically dependent on the effectiveness of the heat exchangers.

Since refrigeration at cryogenic temperatures is expensive due to low COP of even ideal refrigerators, cryogenic heat exchangers are usually designed for much higher effectiveness than those in most chemical process industries. The relation of heat exchanger effectiveness to design and operating parameters has been well established in literature. But practical heat exchangers rarely show the effectiveness predicted by the ideal relations. The deterioration of performance may be attributed to the following sources :

1. Axial heat conduction through the separating wall and fins.
2. Heat leakage from the surroundings.
3. Flow maldistribution.
4. Temperature dependent fluid properties.

In this thesis, the role of the above factors have been analysed theoretically which will help in a more accurate prediction of heat exchanger effectiveness.

The minimum entropy generation principle may be made a basis for the optimum design of heat exchangers and detailed expressions for entropy generation are available in literature. In this thesis simpler expressions have been derived for special cases. For the case of nearly ideal heat exchangers ($\varepsilon \rightarrow 1$) with nearly balance capacity rate ($\nu \rightarrow 1$) an expression for entropy generation has been derived which matches closely with exact calculation.

Axial conduction is a major source of inefficiency in a compact counterflow heat exchanger. Any attempt to reduce axial conduction by using material of low thermal conductivity for the separating wall results in increased resistance to lateral heat flow thereby reducing the overall thermal efficiency. Hence the material of the wall must be chosen to minimise the overall inefficiency considering both these phenomena. This problem has been analysed from the point of minimum irreversibility and the optimum thermal conductivity of the wall has been derived as :

$$\frac{k_{fluid}}{k_{wall}} = \frac{2}{Pe}\left[1 + \frac{C_{tube}}{C_{shell}}\right]$$

where Pe is the Peclet number of fluid in the (inner) tube. The Second Law analysis while predicting the optimum thermal conductivity of the separating wall, provides only an indirect approach to determination of thermal efficiency for a given set of flow parameters. So the governing differential equations have been solved directly including both axial conduction and lateral resistance of the separating wall. An expression for the overall inefficiency of the heat exchanger has been derived in terms of relevant flow parameters.

The performance of cryogenic heat exchangers may be seriously affected by heat inleak from the surroundings. The magnitude of heat leak, controlled by the

thickness and effectiveness of the insulation, is represented by a heat leak parameter $\alpha$. The governing equations have been solved and it is observed that for a given value of $\alpha$, the effective-$N_{tu}$ approaches a limit as the design-$N_{tu}$ is increased indefinitely. It is suggested that heat exchangers should be designed to achieve an effective-$N_{tu}$, which is a given fraction of the limiting value. An expression has been derived for the corresponding design-$N_{tu}$.

Nonuniformity of flow in multichannel heat exchangers causes deterioration of effectiveness. One side nonuniformity and both sides nonuniformity with a continuous distribution have been analysed and compared with discrete distribution models from literature.

The variation of specific heat of working fluid with temperature must be accounted for in designing of heat exchangers. For large intervals between inlet temperatures of hot and cold fluids, the heat exchanger is divided into a number of segments, such that in each of them temperature variation is not excessive. Use of harmonic mean specific heat has been suggested for computing the overall-$N_{tu}$.