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The influence of the moments of probability density function for flow maldistribution on the thermal performance of a fin-tube heat exchanger

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ABSTRACT

The work presented in this paper reports the quantitative study on the influence of the statistical moments of probability density function, i.e., mean, standard deviation, skew and kurtosis, for an air flow maldistribution profile on the thermal performance of a fin-tube heat exchanger. The effects of the geometrical parameters of the heat exchanger, i.e., tube diameter, fin pitch, row pitch, tube pitch, number of rows and fin surface pattern, are also investigated. The thermal performance is found to be noticeably affected by mean, standard deviation and skew but not the kurtosis. In addition, the interaction between the external and internal thermal resistances has a significant effect. All the geometrical parameters examined, except for the number of rows and fin pattern, have either a weak or an insignificant effect on the thermal performance degradation factor. Physical reasoning has been provided to explain the trends of the degradation with respect to the moments and geometrical parameters. From these trends, a new set of correlation equations is proposed to predict the degradation effect of the flow maldistribution on wavy fins. The correlation agrees well with experimental data within ±10%.

1. Introduction

This paper documents the continuation of the work presented in an earlier paper by the authors [1] which has demonstrated the mathematical model used to describe the contribution of each of the statistical moments of the probability density function for flow maldistribution on the performance degradation of an arbitrary heat exchanger. From that work, the general relationship between the thermal degradation factor, *D*, which is defined in the following equation (1), and the moments have been established. Only the first three moments, i.e., mean, standard deviation and skew, have significant effect, while the fourth moment, kurtosis does not have any effect.

$$D = \frac{Q_u - Q_m}{Q_u} \times 100\% \quad (1)$$

In the present work, focus has been given to study the air flow maldistribution problem on fin-tube heat exchangers, or more commonly called *coils*, which are widely used in the Heating, Ventilation and Air-Conditioning and Refrigeration (HVAC&R) and automotive industries. Examples of such application include radiators, oil coolers, evaporator and condenser coils in air-conditioning systems, and water coils in Air Handling Units (AHU). The air flow rate through the fin passages of these exchangers becomes maldistributed as a result of the mechanical disposition of the exchanger with respect to other components in the system. The fluid flowing in the tubes could either be in single-phase (e.g., water) or two-phase (e.g., refrigerant).

By systematically changing the flow maldistribution moments of air on the fin-tube coil, the magnitude of the degradation factor, *D*, is quantified. Since the external and internal heat transfer coefficients determine the heat transfer capacity of the exchanger, their effect on the magnitude of *D* is also determined. This is taken into consideration with two non-dimensional quantities, i.e., *R*, the ratio between the external and internal heat transfer coefficients and NTU.

The heat transfer capacity of the fin-tube coil is also very much dependent on its geometry. As such, the geometrical parameters of the exchanger are expected to have an effect on the performance degradation. Therefore, the study in this work has included quantifying the magnitude of *D* while the geometrical parameters are systematically varied.

With all these effects identified and quantified, a complete physical understanding of the maldistribution phenomenon on the fin-tube heat exchanger is obtained. This enables the development of correlation equations to be used as a design tool to predict the exchanger thermal performance degradation.

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