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On the adverse influence of higher statistical moments of flow maldistribution on the performance of a heat exchanger

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ABSTRACT

The work presented in this paper investigates the degradation effect of flow maldistribution on the thermal and hydraulic performance of a heat exchanger. A new mathematical model is derived based on Taylor series expansion to describe the contribution of each of the four statistical moments of distribution on the degradation problem. It is found that the first two moments, i.e. mean and standard deviation, have the highest effect on the performance degradation. Subsequent higher moments will give declining degradation effects until the fourth moment, kurtosis, which has no significant effect. Maldistribution with low standard deviation and high positive skew will give low thermal deteriorations, though a distribution with negative skew is preferred for low hydraulic performance losses. The design of the heat exchanger could be modified to give these favourable moments which would minimize the degradation effects of the maldistribution. Consequently, any effort to modify the flow distribution profile should be focused on optimizing the first three moments.

1. Introduction

The degradation effects of flow maldistribution on the performance of a heat exchanger are well-known. Not only does the thermal performance decrease but the fluid pressure drop across the exchanger core also increases simultaneously. A review of the previous research in this area shows that the thermal performance of a heat exchanger can degrade by up to 25% as a result of flow maldistribution [1,2]. Hydraulic performance deterioration due to the increase of pressure drop can be up to 6 to 9 times of the thermal performance deterioration in a heat pump unit [3]. As a result of this, the energy efficiency of the exchanger reduces. For optimal performance of the exchanger, the adverse effects of maldistribution should be minimized.

Flow maldistribution occurs in all types of heat exchangers. This phenomenon has been investigated in a shell-and-tube kettle reboiler by Grant et al. [4] where the degradation effect due to combined shell-side vapour blanketing and tube-side air blanketing was investigated. The maximum heat flux was improved from 40 kWm^{-2} to 250 kWm^{-2} by plugging the upper tubes which were ineffective for heat transfer. Chiou [5] and Ranganayakulu et al. [6] have done extensive work to quantify this thermal degradation in both streams of a cross-flow heat exchanger. In both these papers, the heat exchanger was discretized into elements for analysis where 2-dimensional non-uniform flow distributions were applied on both fluid streams in the exchanger. Chiou has also correlated graphically the magnitude of thermal degradation with a Non-uniformity Factor and the exchanger NTU [5]. Berryman and Russell [7] have studied flow maldistribution across tube bundles in air-cooled heat exchangers. Their experimental results have detected thermal degradation up to 4% at flow distribution standard deviation of 0.30. In the work by Rao et al. [8], flow maldistribution in the channels of a plate heat exchanger was examined. A flow maldistribution parameter, m^2, was used to characterize the exchanger effectiveness. The effects of maldistribution in fin-tube heat exchangers, which takes place on the air-side through the fin passages as well as on the liquid side in the tube circuits, have been investigated by several researchers, for example Fagan [9], Chwalowski et al. [10], Lee and Domanski [11], and Aganda et al. [12]. The findings of these works have indicated dependence of the degradation on the mean and standard deviation of the flow maldistribution profile.

The reasons for such maldistribution occurring in an exchanger include the layout of the exchanger with respect to other components in the system, effects of manufacturing tolerances, the design of the flow circuits in the exchanger and the design of the inlet and outlet headers. In some instances, the maldistribution could also be induced due to temperature effects. These factors become even more critical when the exchangers are applied in compact designs which involve a tortuous flow path for both the fluid streams.

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