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Analysis of entransy dissipation in heat exchangers

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ABSTRACT

The optimization of heat exchangers is an important topic. Entropy generation is used to describe the irreversibility of heat transfer processes and the principle of minimum entropy generation is sometimes used to optimize heat exchanger designs. This paper defines the heat exchanger thermal resistance based on its entransy dissipation and analyses various heat exchangers. Entropy generation analyses are also presented for comparison. The results indicate that the minimum entransy-dissipation-based thermal resistance always corresponds to the highest heat transfer rate, while the design with the minimum entropy generation is not always related to the design with the highest heat transfer rate.

1. Introduction

Energy consumption is continuously increasing and energy issues are becoming increasingly prominent. We need to improve the efficiency of energy utilization to reduce energy consumption and emissions of greenhouse gases from the fossil fuels. Heat exchangers are used to transfer thermal energy from one fluid to another, they are widely used in industry and daily life, and about 80% energy utilization are involved in heat transfer processes. Therefore, there is great interest in improving heat exchangers performance by optimizing the heat transfer processes in heat exchangers for high-efficiency energy utilization.

The heat transfer in heat exchangers is an irreversible process from the point of view of non-equilibrium thermodynamics. Onsager [1,2] set up the fundamental equations for non-equilibrium thermodynamic processes and derived the principle of least energy dissipation using the variational principle. Prigogine [3] developed the principle of minimum entropy generation based on the idea that the entropy generation in a thermal system at steady-state should be minimum. However, both of these principles do not deal with heat transfer optimization. Many researchers have tried to establish a link between heat exchanger performance and its heat transfer irreversibility. McClintock [4] carried out a pioneering work in this area by applying the irreversibility concept to heat exchanger design. Bejan [5–7] explained two contributions to the exergy loss as heat transfer across a finite temperature difference and through the fluid friction in channels. He introduced an entropy generation number, N_S, to quantitatively estimate the entropy generation. The analysis of a counterflow heat exchanger showed that the entropy generation number, N_S, approaches zero in two limits: when the number of transfer unit approaches infinity, $NTU \to \infty$, or the effectiveness approaches unity, $\varepsilon \to 1$, which represents the ideal limit of zero driving temperature difference, and when the number of transfer unit approaches zero, $NTU \to 0$, or the effectiveness approaches zero, $\varepsilon \to 0$, which represents the heat transfer surface approaching zero. As shown in Fig. 1, the entropy generation number reaches maximum at $\varepsilon = 0.5$ and the heat exchanger effectiveness increases with the increasing entropy generation number for $\varepsilon \in (0,0.5)$. On the right side, smaller entropy generation numbers result in larger effectiveness. Bejan referred to this symmetry behavior as the entropy generation paradox. The entropy generation paradox is not consistent with the principle of minimum entropy generation. Some scholars have tried to explain the entropy generation paradox in terms of the entropy generation in heat exchangers. Sekulic [8,9] explained that temperature cross between hot stream and cold stream caused this paradox and examined the influence of parameters like the inlet temperature ratio, fluid flow heat capacity rate ratio and the effectiveness on the quality of the energy transformation for different types of heat exchangers. Hesselgreaves [10] and Ogiso

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