Optimization of Circuitry Arrangements for Heat Exchangers

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Abstract Text:

Heat exchanger performance is important in various heating and air-conditioning systems that are widely used in residential and commercial applications. Although these systems are manufactured in various shapes and configurations [1], a common configuration is that of the crossflow fin-and-tube type, in which a refrigerant flows through a set of pipes and moist air flows across a possibly enhanced surface on the other side of the pipe, where thermal energy is transferred between the air and the refrigerant.

Heat exchanger performance optimization can be achieved by optimizing a number of different metrics including maximization of heating or cooling capacity, size reduction, component material reduction, manufacturing cost reduction, reduction of pumping power, or a combination of these metrics. Systematic optimization of heat exchanger design has been a long-standing research topic [2–4]. It is a particularly challenging problem mainly for the following reasons: (i) there is a highly discontinuous and nonlinear relationship between the circuitry design and the heat exchangers performances, and (ii) the decision space is extremely large making exhaustive search algorithms insufficient for searching the entirety of the solution space.

In this paper, we propose a new formulation for the refrigerant circuitry design problem. We model this problem as a constrained binary optimization problem. We incorporate only realistic manufacturing constraints to the optimization problem without requiring extensive domain knowledge. As a result, the proposed approach can be applied to different types of heat exchangers. In order to evaluate the heat exchanger performance using different refrigerant circuitry designs, we use CoilDesigner [5], a steady-state simulation and design tool for air to refrigerant heat exchangers, which acts as a black-box since the exact relationship of the objective functions with the decision variables is not explicit. We apply derivative-free optimization algorithms [6] to optimize heat exchanger performance. Although the derivative-free optimization literature has recently been attracting significant attention, it currently lacks systematic comparisons between mixed-integer constrained derivative-free optimization algorithms on industrially-relevant problems. Another contribution of this work is the systematic comparison of four different mixed-integer constrained derivative-free optimization algorithms (MIDACO [7], NOMAD [8], TOMLAB/glcDirect [9], and TOMLAB/glcSolve [9]) and a box-bounded derivative-free optimization algorithm (CMAES [10]) that are applied to optimize heat exchanger circuitry using two different thermal efficiency criteria.

Computational results on 17 different circuitry architectures show that TOMLAB/glcDirect and TOMLAB/glcSolve have the best performance among all derivative-free optimization solvers. Timewise, TOMLAB/glcSolve is faster than TOMLAB/glcDirect on smaller, but TOMLAB/glcDirect is much faster on larger instances and on average. We also formulated the circuitry optimization problem as a constraint satisfaction problem using Choco solver in order to automate the procedure of finding all possible feasible circuitry designs and verify the results of the derivative-free methods for small heat exchangers. The results show that the proposed method provides optimal refrigerant circuitries satisfying realistic manufacturing constraints.

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