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Research paper

Experimental investigation of distributor configuration on flow maldistribution in plate-fin heat exchangers

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HIGHLIGHTS

- Effect of the inlet angle of distributor on the flow distribution is significant.
- Flow maldistribution in the lateral and gross flow directions is different.
- A new distributor design with a complementary cavity was proposed and tested.
- Non-uniformity of temperature was more pronounced than that of the flow.

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ABSTRACT

Plate-fin heat exchangers are a class of compact heat exchangers that are extensively applied in industry. The distributor configuration used to distribute fluid flow among the channels of a plate-fin heat exchanger can significantly influence the thermal performance of such heat exchangers. In this work, various distributor configurations were used with a plate-fin heat exchanger under different operating conditions to assess the resultant change in its flow distribution and thermal performance. It was found that certain design features of the distributor caused severe flow maldistribution and that the flow Reynolds number based on the average flow velocity in the heat exchanger channels and the channel hydraulic diameter substantially affected the flow distribution, which in turn significantly influenced the heat exchanger's thermal performance. An improved distributor design, with a complementary fluid cavity was built and tested in this work. The experimental results show that improved distributors are very effective in improving the flow distribution in heat exchangers, and consequently, their thermal performance. The most uniform flow distribution and heat transfer were obtained, when the improved distributor configuration parameter, which represents the ratio of the height of the complementary cavity (h) to the total distributor height (H), is 0.2. By incorporating this distributor at the inlet of the plate-fin heat exchanger, the flow and temperature non-uniformity in the same were reduced to 57.4% and 13.7% of the baseline design respectively, at the main test condition. Correlations between the flow distribution uniformity and Reynolds number for the various distributor configurations have also been provided.

1. Introduction

Plate-fin heat exchanger are widely used in air separation, metallurgy, cryogenic and aerospace applications owing to their traditional advantages, such as compactness, lightness, high efficiency, ability to handle multiple fluid streams, and so on [1]. In the thermodynamic design of heat exchangers, it is generally assumed that the inlet fluid is uniformly divided among all the parallel passages in the whole exchanger core. In practice, however, these assumptions are generally not realistic under actual operating conditions due to the imperfect structural design of headers and distributors as well as non-uniform flow passages [2]. Flow maldistribution can result in reduction in thermal performance for single-phase flow heat exchangers. Moreover, flow maldistribution can also result in a significant deterioration of the heat transfer performance for two-phase flow heat exchangers [3]. The problem of improving the fluid flow distribution so as to enhance the efficiency of heat exchangers has attracted the attention of many researchers.

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Flow maldistribution and its effect on the performance of heat exchangers has been investigated extensively. Mueller [4] summarized various types of flow maldistribution in heat exchangers and discussed the reason leading to maldistribution and found that flow maldistribution is more serious for two-phase flow compared to that for single phase flow. Fleming [5] set up a flow maldistribution model in paired-channel heat exchangers and investigated the effect of flow maldistribution on the thermal-hydraulic performance deterioration of the heat exchangers. Ranganayakulu and Seetharamu [6,7] carried out an analysis of the effects of inlet fluid flow non-uniformity on thermal performance and pressure drop in crossflow plate-fin heat exchangers by using a finite element method. Lalot and Florent [8] found that gross flow maldistribution may lead to a loss of effectiveness of about 7% for condensers and counterflow heat exchangers, and up to 25% for crossflow exchangers. Shen and Bell [9] studied the problem of the effect of two-phase flow maldistribution on the performance of a feed-effluent heat exchanger.

Many authors who studied flow maldistribution have found that the inlet configurations of heat exchangers are the main factors affecting the flow maldistribution. Jiao et al. [10–12] and Zhang et al. [13] investigated the effects of inlet angle, and distributor configuration on flow distribution in plate-fin heat exchangers. Jiao et al. [14] also experimentally investigated the effects of the header configuration on flow maldistribution in plate-fin heat exchangers. Zhang et al. [15] proposed a new header configuration, and experimentally studied the effect of the header configuration on the flow distribution. Wen et al. [16–18] researched the flow characteristics in the header of a plate-fin heat exchanger by means of Particle Image Velocimetry (PIV). Wen [19] also employed CFD technique to simulate and analyze the performance of fluid flow distribution and pressure drop in the header of plate-fin heat exchanger. Zhang & Li [20,21] studied the effect of the header and distributor configuration on the flow distribution using CFD simulation and investigated the parameters necessary for achieving optimal performance. Wang et al. [22] investigated the distribution of two-phase flow in a plate-fin exchanger and concluded that the maldistribution of two-phase flow is very serious due to improper inlet configuration. Xuan and Newell [23] visually explored two-phase flow field characteristics in flat plate heat exchangers and have also published photographs of flow distribution in a Chevron-style test section.

Some useful conclusions have been obtained in previous studies of flow maldistribution in plate-fin heat exchangers. However, it should be noticed that most of these works only studied the performance of heat exchangers at non-uniform inlet temperatures with numerical methods. The present authors only studied the conventional distributor currently used in industry. Few authors have studied the effect of different distributor configurations on flow distribution. Moreover, they employed mostly liquid, and not gas, as the experimental fluid. In this paper, an experimental investigation has been conducted to understand the effect of various distributor configurations on flow maldistribution and its effects on the thermal-hydraulic performance of plate-fin heat exchangers.

2. Experiment

2.1. Experimental system and test procedure

The test facility (Fig. 1) consists of the air loop and the data acquisition system. The air loop includes an air compressor, a filter, an electric heater, the plate-fin heat exchanger test section, and a passage-switching device. The data acquisition system comprises an acquisition board, an acquisition program and a personal computer. The instrumentation used mainly consists of gas turbine flow meters, thermocouples, pressure and differential pressure transducers.

Two types of tests, air flow distribution and heat transfer experiments are performed using the test facility shown in Fig. 1. In the flow distribution experiments, air is supplied to the distributor by the air compressor and adjusted to the required flow rate by a system of valves. The flow rate in the gross (i.e., header) and channel passages is measured by gas-turbine flow meters. The air at the outlet of the heat exchanger flows into the passage-switching device and the air from each channel can be switched one at a time to the channel gas-turbine flow meter, so that the air flow rate in each channel can be accurately measured.

In the heat transfer experiments, the air is forced by an air compressor and is divided into two branches. One of the air streams

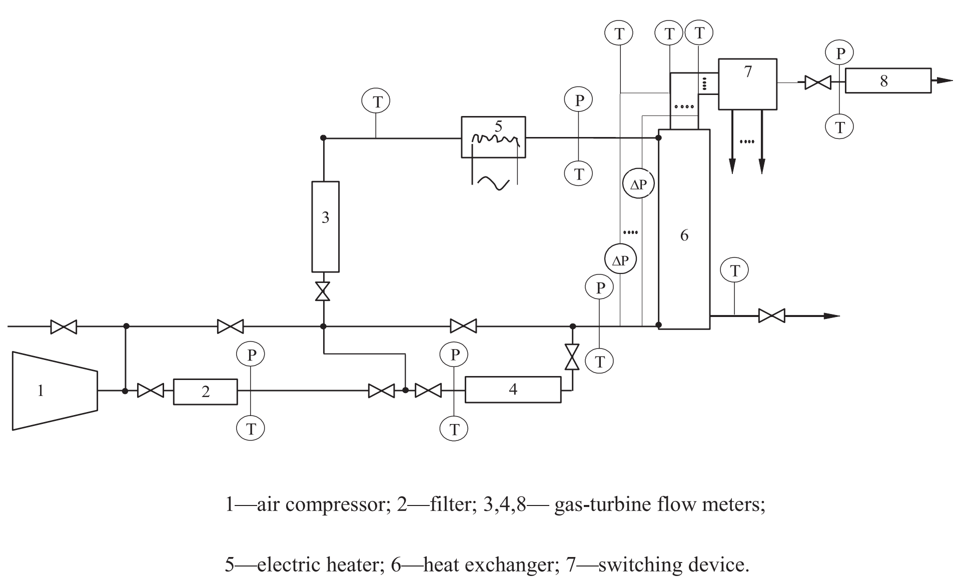

Fig. 1. Schematic flow diagram of experimental system.