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Review

Thermal and hydraulic performance of finned-tube heat exchangers under different flow ranges: A review on modeling and experiment

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ABSTRACT

Now-a-days fin-and-tube heat exchangers are employed in a wide variety of engineering applications such as modern heat exchangers, automotive radiators, automotive air conditioning evaporators and condensers. In order to improve the performance, further innovative designs, additional applications, and advanced geometries are expected. Researchers and academicians had been working on this topic for last few decades. A number of experimental and numerical studies have been conducted and various correlations were developed. The optimum design parameters with the maximum overall heat conductance and minimum pressure drop needs more focus and research. In this paper, different experimental/numerical studies performed are reviewed, grouped and summarized based on the types of heat exchangers, heat transfer and pressure drop performance, effects of geometrical parameters under different flow conditions. Overall, this paper will highlight on the existing technologies and emerging trends in designing of finned-tube heat exchangers considering different arrangements and geometric parameters under variable flow conditions which will be helpful for selecting appropriate design depending on the requirement.

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1. Introduction

Plate fin-and-tube heat exchangers are employed in a wide variety of engineering applications for instance, in air-conditioning equipment, process gas heaters, and coolers. They are quite compact, lightweight, and characterized by a relatively low cost fabrication. The heat exchanger consists of mechanically or hydraulically expanded plurality of equally spaced parallel tubes through which a heat transfer medium such as water, oil, or refrigerant is forced to flow while a second heat transfer medium such as air is directed across the tubes in a block of parallel fins. In such type of heat exchangers, continuous and plain or specially configured fins are used on the outside of the array of the round tubes of staggered or in-lined arrangement passing perpendicularly through the plates to improve the heat transfer coefficient on the gas side. The heat transfer between the gas, fins and the tube surfaces is determined by the flow structure which is in most case three-dimensional. In realistic applications the governing thermal resistance for an air-cooled heat exchanger is usually on the air side which may account for 85% or more of the total resistance [1]. As a result to effectively improve the thermal performance and to significantly reduce the size and weight of air cooled heat exchangers that is to improve the overall heat transfer performance, the use of enhanced surfaces is very popular in air cooled heat exchangers, although a continuous plain fin is still a commonly used configuration where low pressure drop characteristics are desired. Common types of specially configured fin types used in these heat exchangers are plain fin, wavy or corrugated fin, Louvered fin, offset strip fin and perforated fin. Wavy or corrugated fin are very popular fin patterns that are developed to improve the heat transfer performance .The wavy surface can lengthen the flow path of the airflow and cause better air flow mixing. Therefore, higher heat transfer performance is expected compared to the plain plate fin surface. However the higher heat transfer performance of the wavy fin surface is accompanied by the higher pressure drop as compared to the plain fin type.

Gas is one of the major fluids used in the plate and fin heat exchangers. According to Ref. [2], in forced convection heat transfer between a gas and a liquid, the heat transfer coefficient of the gas is typically 5–20% that of the liquid. The extended surfaces are responsible to reduce the gas side thermal resistance. It is advantageous to use specially configured extended surfaces which provide increased heat transfer coefficients. Such special surface geometries may provide heat transfer coefficients 50–150% higher than those given by plain extended surfaces. Enhanced surfaces provide a substantial heat exchanger size reduction in the heat transfer between gases. Two very basic concepts are extensively used for the heat transfer enhancement for such extended surfaces. These are: (i) Special channel shapes, such as wavy channel, which provide mixing due to the boundary layer separation within the channel. (ii) Repeated growth and wake destruction of boundary layers. This concept is employed in the offset strip fin, in louvered fin and, to some extent, in the perforated fin. Early variants of the extended plate-and-fin heat exchangers were applied to gas-to-gas applications. It is now used for gases, liquids, or two-phase fluids on either side. Designs using extruded aluminum tubes with internal membranes allow quite high tube-side design pressure (e.g. 150 atmospheres). Further innovative designs, additional applications, and advanced fin geometries are expected. The plate-and-fin heat exchangers are currently made using aluminum, steel and even the ceramic.

This review paper will discuss the heat transfer and pressure drop performance of different plate finned-tube heat exchangers under different thermal and operating conditions. The outcomes of recent studies, fundamental characteristics of different types of heat exchanger, effects of various performance parameters under different flow conditions will be discussed. Optimum conditions for efficient performance of the heat exchanger, correlation developed for different cases will be highlighted from technical point of view. This paper will also present a brief overview of the existing types of heat exchangers and their characteristics in different experimental works. Overall, this paper provides an extensive review of the fundamental aspects of plate heat exchangers of various types and emerging trends in designing considering different types of geometric parameters and flow conditions. A number of attempts in experiment/numerical analysis published so far are reviewed, grouped and summarized which will guide the researchers to further investigations. Also, based on the author's previous numerical work, a complete data set considering different geometric parameters such as longitudinal pitch, transverse pitch, fin pitch and wavy angle under various flow ranges are presented which will be helpful for designing such type of heat exchangers depending on the heat transfer and pressure drop requirements.

1.1. Types of heat exchangers

The fin geometry has become as increasingly important factor in the design of a plate-and-fin heat exchanger. The high

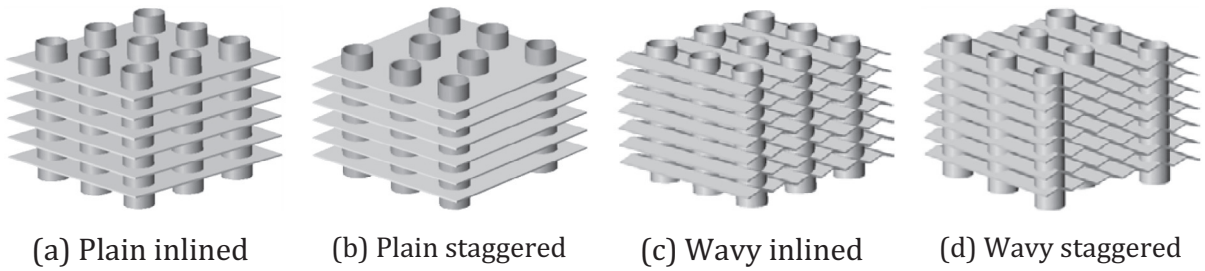

Fig. 1. Different fin and tube arrangement in plain and wavy finned-tube heat exchanger [3–6].