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Research paper

Interrelation between pin length and heat exchanger performance

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HIGHLIGHTS

- No optimal pin length can be identified based common pin performance parameters.
- Modified pin performance parameters are recommended.
- Optimal pin lengths for different flow conditions and pin arrangement are derived.
- Highest heat exchanger performance corresponds with optimized pin length.

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ABSTRACT

One of parameters influencing pin performance in a heat exchanger is pin length. The optimization of these parameters usually is carried out by considering pin as single heat transfer element operating under some ideal conditions. Optimal pin performance parameters derived in such analysis might not result in optimal heat exchangers. Current paper focuses in such inconsistencies and proposes a novel approach to be followed by optimization of pin length of a practical heat exchanger. The approach proposed in current paper consist in introducing of a corrected pin length in order to consider the influence of channel height carrying fluid on the opposite site to the heat exchanger channels employing pin fins. In the paper is demonstrated that by following the proposed approach one can derive optimal pin length to pin diameter ratios which results in optimal pin performance figures respectively in optimal performance of entire heat exchangers. The approach proposed here, in principle may be used to optimize other fins of other forms commonly used in flat plate and fin heat exchangers.

1. Introduction

Substantial improvement of energy efficiency in many industrial fields can be achieved by employing of more effective heat transfer surfaces. Very often this imply passive enhancement of convective heat transfer. All passive techniques aim for the same, namely to achieve higher values of the product of heat transfer coefficient and heat transfer surface area. Enhancement of heat transfer coefficient is usually achieved by employing of fins of various shape and arrangement. The mechanism, which leads to the high heat transfer coefficient of fins, is the periodic interruption of the boundary layer around the fins that also achieving of a better mixing of the fluid streams at different temperatures. Similar effects also occur in pin fin arrays which may be considered as a special kind of interrupted fins. The competitive ability of pin fins compared with other high performance fins is known since the work of Kays [1]. A similar conclusion was also reached by Kays and Crawford [2], while analyzing the methods for obtaining high-performance heat transfer surfaces. The superiority of pin fins to provide most effective way of enhancing the heat transfer rate within a particular heat exchanger volume was demonstrated also by Sahiti et al. [3] and [4]. In order to analyse the mechanism behind effective heat transfer but also the relatively high pressure drop associated with pin fins, different authors such as Theoclitus [5], Sparrow and Ramsey [6] and Sara et al. [7] carried out basic research work focused on such aspects. There have also been noted some contributions concerning different shapes of pin fin cross-section such as Chen et al. [8] and Li et al. [9]. An extensive numerical investigation of influence of different pin cross section, in thermal and fluid dynamic characteristics of in-inline and staggered pin fin arrays is provided by Sahiti at al [10].

Basic parameters which influence the pin performance are pin cross section, streamwise pin spacing, pin spacing in transversal direction and pin length. The large number of influencing

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parameters make the fin performance optimization an open-ended problem. This implies that it is most unlikely that a fin would exist which would be optimal in all respects. Hence, one needs to select constraints which are more important for a particular application, and then to seek optimal values of the remaining factors.

While the influence of pin cross section and pin spacing on heat transfer and pressure drop is quite extensively examined, there exists no much contribution which describes in details the influence of pin length on the overall performance of a pin fin heat transfer surface. In the literature, the influence of pin length on corresponding heat transfer usually is discussed by considering single pins. However, the optimization of pin length within a particular heat transfer surface respectively heat exchanger may impose considering of other important parameters such as free heat exchanger cross section area within a given heat exchanger volume. This is because in case of flat-tube and pin fin heat exchangers such as those investigated by Kays [1], free cross section area depends on distance between pins but also on pin length respectively on distance between flat tubes. Otherwise the direct relationship between free cross section area of heat exchanger and fluid flow rate imposes free cross section area as one of important aspects to be considered by evaluation of optimal pin length. Current work presents a contribution towards optimization of pin length in practical applications by considering of interrelation between pin length, heat exchanger free cross section and free stream air velocity. Other optimizations relevant parameters such as temperature difference between base wall and inlet air, pin cross section, pin material, distance between pins and heat exchanger flow length were considered constant.

2. Derivation of heat transfer and pressure drop data on pin fins

In order to obtain data on heat transfer coefficient and pressure drop from pin fin heat transfer surfaces with different pin lengths, numerical analysis of staggered and in-line pin fin arrays were performed.

The range of the parameter variations was selected according to the pin distances and pin length of a hypothetical flat-tube and pin fin heat exchangers which might be used in air conditioning industry, automobile motor cooling etc (Fig. 1). Analysis have shown that for successful application of pin fins instead other fin forms, they should have comparable cross section areas, Kays [1]. Having in mind common fin thickness in heat exchangers applied in the automobile industry (usually <0.2 mm) but also higher cost for eventually construction of prototype flat-tube and pin fin heat exchanger with smaller pin fin diameter, a reasonable compromise has been found to be a pin diameter of 0.35 mm for all simulated cases within the current paper According to the heat exchanger model, the conduction heat transfer takes place from the base plate (representing the channel wall) and transfers heat to the middle section of the pin, which coincides with the central section of the air channel.

In an ideal case, the same amount of heat is also transferred from the opposite base wall towards the central axis of the channel section. Consequently, the symmetry plane of the air channel separates the pins into two parts, each of which has an adiabatic tip that coincides with the symmetry plane, with the root of the fin attached to the base wall.

In order to apply the theory of one-dimensional heat transfer through fins, the pin length l_P is considered to be equal the half of the channel height.

For both pin arrangements, the following range of parameter variations was selected:

$$\frac{S_T}{d} = \{1.5;\ 2.0;\ 2.5;\ 3.0;\ 3.5;\ 4.0;\ 4.5\},\ \frac{S_L}{d} = 3.5,\ \frac{l_P}{d} = 5 \quad (1)$$

$$\frac{S_T}{d} = \{1.5;\ 2.5;\ 3.5;\ 4.5\},\ \frac{S_T}{d} = 3.5,\ \frac{l_P}{d} = 5 \quad (2)$$

$$\frac{l_P}{d} = \{2.5;\ 5.0;\ 7.5;\ 10.0;\ 12.5;\ 15.0\},\ \frac{S_T}{d} = 3.5,\ \frac{S_T}{d} = 3.5 \quad (3)$$

where S_T and S_L denotes the pin spacing in transversal and streamwise direction and d the pin diameter.

In total, 15 different simulation cases were generated based on variation of geometrical parameters in the range given by equations (1)–(3). For each of these cases, the inlet air velocity was varied from 2 to 12 m/s in steps of 2 m/s. The thermal conditions for all simulated models were taken to be the same. These were specified with inlet air temperature $t_{in} = 20\ °C$ and base wall temperature

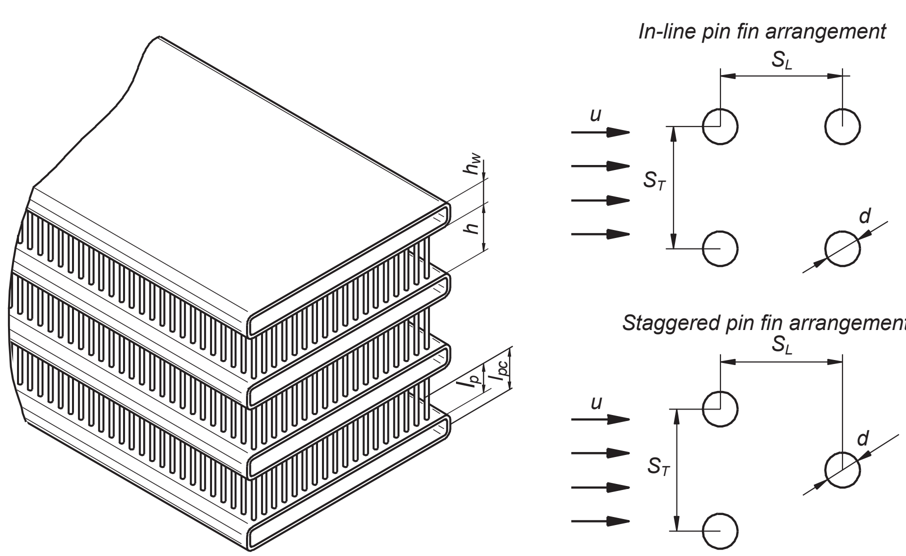

Fig. 1. Some geometric parameters of the flat-tube and pin fin heat exchanger model.