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Strategy for selection of elements for heat transfer enhancement

N. Sahiti, F. Durst *, A. Dewan [1]

LSTM—Erlangen Institute of Fluid Mechanics, Friedrich-Alexander-Universität Erlangen-Nürnberg Cauerstr. 4, D-91058 Erlangen, Germany

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Abstract

The present paper points out that the selection of elements for heat transfer enhancement in heat exchangers requires a methodology to make a direct comparison of the performances of heat exchanger surfaces with different elements. Methods of comparison used in the past are, in many respects, approximate and hence fail to predict accurately the relative performance of conventional heat exchanger surfaces operated with different heat exchanger elements. Owing to the direct use of the Colburn factor for performance assessment, these methods over-predict the relative performance of heat exchangers. In the present paper, a more consistent comparison method is presented and is demonstrated to work by comparison of the performance of an experimentally investigated pin fin heat exchanger with that of a smooth pipe heat exchanger. The method yields results that belong to the volume goodness factors group. It represents a practical approach, as it is applicable to all kinds of heat exchanger surfaces and does not require the conversion of the experimental data in terms of Nusselt number and friction factor for comparison purposes. The present work demonstrates that the suggested method can also be used for performance comparison of existing heat exchanger surfaces with available heat transfer and pressure loss data.
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Keywords: Comparison method; Heat exchanger performance; Heat exchanger selection; Heat transfer enhancement

1. Introduction and aim of the work

Continuous efforts to improve the performance of heat exchangers in all fields of applications have resulted in the accumulation of a large amount of data containing the thermal and flow characteristics of many investigated heat exchangers. Among the available data are also those that were obtained for elements of heat transfer enhancements, and engineers usually apply these data for a preliminary selection of elements for heat transfer enhancements. However, the availability of the data for a large variety of elements for different heat exchanger surfaces is of little benefit unless proper methods to compare the final performances of such surfaces are provided. Moreover, during the development of new heat exchangers, one needs to plot the data in an appropriate way in order to assess directly the performance of the proposed heat exchanger compared with an earlier developed one. The development of such comparative methods should result in the selection of a surface or enhancement element which would lead to the most effective heat exchanger within given constraints. The comparison should be as simple as possible but with some confidence that the surface selected by such a comparison will meet the requirements of the heat exchanger under operating conditions.

A common way to present the thermal and fluid dynamic characteristics of heat exchangers is in the form of Nusselt number Nu or Colburn factor j and friction factor f. However, a direct comparison of the dimensionless parameters for different heat exchanger surfaces would not provide the answer as to which surface will perform best under given operating conditions. For example, compact heat exchangers built up with surfaces containing enhancement elements are characterized by higher pressure drop than less compact heat exchangers. Hence, an undesirable consequence of the utilization of elements for heat transfer enhancements is a larger increase in f, often larger in percentage, than the corresponding increase in Nu for a

* Corresponding author. Tel.: +49 9131 8529501; fax: +49 9131 8529503.
E-mail address: durst@lstm.uni-erlangen.de (F. Durst).
[1] On leave from the Department of Mechanical Engineering, Indian Institute of Technology Guwahati, Guwahati 781039, India.

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Nomenclature

A	heat transfer surface area, m^2
c_p	isobaric specific heat capacity, J/(kg K)
C	heat capacity rate, J/(s K)
d_h	hydraulic diameter, m
e	volume or area reduced power input, W/m^3 or W/m^2
E	power input, W
f	friction factor
h	convective heat transfer coefficient, W/(m^2 K)
j	Colburn factor
l	flow length between boundary-layer disturbance, m
L	flow length of heat exchanger, m
$\dot{m}$	mass flow rate, kg/s
Nu	Nusselt number
NTU	number of heat transfer units
Pr	Prandtl number
$\dot{q}$	volume or area reduced heat transfer rate, W/m^3 or W/m^2
$\dot{Q}$	heat transfer rate, W
Re	Reynolds number
St	Stanton number
T	temperature, K
u_∞	free fluid stream velocity, m/s
U	overall heat transfer coefficient, W/(m^2 K)
V	heat exchanger volume, m^3

Greek symbols

β	heat exchanger compactness, m^2/m^3
ε	heat exchanger efficiency
η	fin efficiency
η_t	total extended surface efficiency
μ	dynamic viscosity, Pa s
ν	kinematic viscosity, m^2/s
ρ	density, kg/m^3
σ	ratio of free flow area to the frontal area

Subscripts

b	bare surface area reduced parameter
c	minimum cross-section, cold
in	inflow
h	hydraulic, hot
min	minimum
n	used by Soland et al. [7]
t	total
v	volume reduced parameter

given frontal area and flow rate. Therefore, by comparing the ratio f/Nu of a heat exchanger of interest, one may incorrectly conclude that less compact heat exchangers are more effective heat transfer devices. Obviously, although the dimensionless factors are suitable for scaling purposes among one class of heat exchangers, they do not offer the answer as to which of exchanger surface or enhancement element will meet the performance objectives within the design constraints. Therefore, in a practical application, this form of presentation is not useful, since for such applications one primarily needs to know, among heat exchangers with different heat transfer elements, which one will provide higher heat transfer rates for a given pressure drop or vice versa.

Depending on a specific application, one may identify various performance objectives and constraints that would determine the final heat exchanger configuration. The objectives and constraints for heat exchanger comparisons are the major heat exchanger operating and design variables such as the heat transfer rate, power input, flow rates and heat exchanger volume. Heat exchanger comparison can be performed by selecting one of the operating variables as a performance objective and the rest as constraints, e.g., if the reduction of heat exchanger volume is selected as the objective, the constraint might be the fixed heat transfer rate, fixed power input or both fixed heat transfer rate and fixed power input. Usually, performance objectives in the selection procedure are either the reduction of heat exchanger volume or increase in the overall heat transfer coefficient or reduction of power input for a given heat transfer rate [1]. The last objective could also be reformulated as an increased heat transfer rate for a fixed power input. The importance of reduced heat exchanger volume lies in the reduced material cost, weight and space requirements. The improvement of the overall heat transfer coefficient results in an increased heat transfer rate or in the reduction of heat transfer driving potential (temperature difference). Further, the reduced temperature difference is associated with lower thermodynamic irreversibilities, resulting in lower thermodynamic costs.

Various comparison methods, known as the performance evaluation criteria (PEC) or goodness factor, have been developed in the past while seeking appropriate heat exchanger selection procedures. In order to simplify the analysis, the PEC usually consider only the heat exchanger surface controlling the heat transfer resistance, e.g., air or gas side, and neglect the thermal resistance of the separating walls and fluid flow arrangement. Further, the PEC account only for the core pressure drop, which do not include pressure changes due to the entrance and exit effects and the acceleration effect.

Sahiti et al. [2] have already emphasized the importance of an appropriate comparison method. They presented one of the comparison methods for the performance assessment of different heat exchanger surfaces, without giving much detail of the method. The review of the known PEC,

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