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Thermal Performance Modeling of Cross-Flow Heat Exchangers

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Contents

Notations

A	Exchanger outer total heat transfer area, m^2
C	Heat capacity rate, W/K
C^*	Heat capacity rate ratio, C_{min}/C_{max}, dimensionless
F	LMTD correction factor, dimensionless
G	Designation of flow arrangement configuration
i	Number of elements in each tube
j	Number of tubes per row
k	Number of tube rows
N	Number of data points
N_c	Number of tube fluid circuits
N_e	Number of elements per tube
N_r	Number of rows in the heat exchanger
N_t	Number of tubes per row
NTU	Number of transfer units, UA/C_{min}, dimensionless
P	Temperature effectiveness, $(T_{c,o} - T_{c,i})/(T_{h,i} - T_{c,i})$, dimensionless
q	Heat transfer rate, W
R	Temperature ratio, $(T_{h,i} - T_{h,o})/(T_{c,o} - T_{c,i})$, dimensionless
T	Temperature, K
U	Overall heat transfer coefficient, $W/(m^2K)$

Greek Symbols

δ	Relative differential
δp	Established relative tolerance
ε	Conventional heat exchanger effectiveness, q/qmax, dimensionless
λ	Relative error
Γ	Dimensionless parameter defined by Eq. (2.30) (local effectiveness)
Λ	Constant, ${C_c}^e {\Gamma}^e / {C_h}^e$, dimensionless

Subscripts

∞	Infinite
A	Mixed fluid side
air	Air side (external fluid)
av	Average value
B	Unmixed fluid side
c	Cold fluid side of heat exchanger (external fluid, air side)
d	Total differential or derivative
e	Element
fr	Frontal face
h	Hot fluid side of heat exchanger (in-tube fluid)
i	Inlet conditions, or cold fluid entrance, $i = 0$, and exit, $i = 1$ (EES program)
j	Number of elements in each tube (EES program)
l	Number of in-tube fluid passes
m	Mean value or number of tube rows per pass of the in-tube fluid
max	Maximum value
min	Minimum value
n	Number of in-tube fluid rows
new	New value
o	Outlet conditions
r	Row
t	In-tube fluid side of heat exchanger
th	Theoretical

Superscripts

cc	Overall counter cross-flow configuration
cf	Cross-flow configuration
e	Element
k	Designates either cf or cc or pc superscripts
pc	Overall parallel cross-flow configuration

Abbreviations

DAES	Differential algebraic equation systems
LMTD	Logarithm mean temperature difference
HETE	Heat exchanger thermal effectiveness

Abstract

This monograph introduces a numerical computational methodology for thermal performance modeling and evaluation of cross-flow heat exchangers, which may find application in contemporary chemical, refrigeration, and automobile industries. According to this methodology, the heat exchanger is discretized into small elements following the tube side fluid circuits. Each element constitutes itself in a one pass mixed-unmixed cross-flow heat exchanger. The algebraic governing equations obtained for each element are solved iteratively for the whole heat exchanger using local values of the element's temperature, assuming constant physical properties, and heat transfer coefficients. This computational methodology has been used by the authors for simulating several flow arrangement configurations of cross-flow heat exchangers. The methodology allows obtaining effectiveness-number of transfer units (ε-NTU) data for several standard and complex flow arrangements. Simulated results have been validated through comparisons with results from analytical solutions for one pass cross-flow heat exchangers with one and more rows, and for 1–4 passes, parallel and counter cross-flow arrangements. In addition, comparisons have been performed with complex flow arrangements approximate solutions. Very accurate results have been obtained over wide ranges of NTU and C* values in all cases. New effectiveness data for some of the aforementioned configurations have been found, along with data for a complex flow configuration proposed elsewhere. The proposed procedure constitutes a useful research tool both for theoretical and experimental studies of cross-flow heat exchangers thermal performance. A computational program based on the proposed algorithm was implemented and named HETE, which is an acronym for *Heat Exchanger Thermal Effectiveness*. A version of this code will be presented in the appendix A of the monograph and will be available for downloading. Solved examples are also presented showing in details how the HETE code works for classical flow arrangements. Tables and plots for (ε, NTU) data are provided in appendix C for several flow arrangements configurations. In addition to the aforementioned capabilities, the proposed procedure can be used extensively for computing the classical log-mean temperature difference correction factor (F), the so-called "heat exchanger reversibility norm" ($HERN$), and the newly introduced concepts of heat exchanger efficiency, and dimensionless entransy dissipation number. Other heat exchanger effectiveness definitions could also be computed.

Keywords Cross-flow heat exchangers · Heat exchanger effectiveness · HETE code · Iterative computational algorithm · Number of transfer units · Numerical simulation