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COMPUTER PROGRAM FOR THE PREDICTION OF THERMAL TRANSIENTS IN COMPACT HEAT EXCHANGERS

VOLUME II—TRANSIENT PROGRAM KRONOS (PART I)

by

E.R. Demetri and M. Platt

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VOLUME II - TRANSIENT PROGRAM KRONOS (PART I)

Prepared for
NASA Manned Spacecraft Center
Houston, Texas
(Contract NAS 9-8134)

NORTHERN RESEARCH AND ENGINEERING CORPORATION
219 Vassar Street
Cambridge, Massachusetts 02139

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II

This work was carried out under the direction of D. M. Dix, with E. P. Demetri assuming project responsibility. M. Platt was the other major participant in this program.

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SUMMARY

This is the second volume of a two-volume report on the prediction of thermal transients in compact heat exchangers. The first volume contains a presentation of the analytical procedures derived for performing the transient analysis. This second volume provides a complete description of the computer program (Program KRONOS) developed on the basis of these procedures.

The discussion of the computer program is presented in two parts. The first part provides the information necessary for the effective use of the program. This includes detailed instructions for preparing the necessary input data as well as a description of the various types of output. The manner in which the program is used is illustrated by a discussion of three sample cases.

The second part of the discussion consists of a description of the structure of the program and its component subroutines. This description is sufficiently detailed to allow an experienced programmer to understand completely the logic structure and operation of the program, and to make changes to the program should it become necessary at some future date. The information is given in the form of appendices and consists of a complete Fortran nomenclature and a detailed presentation of the step-by-step calculation procedure for each of the components (subroutines) of the program. The step-by-step procedure for each component includes a presentation of the pertinent equations used along with an accompanying logic-flow diagram and Fortran listing.

INTRODUCTION

Program Function and Capabilities

Program KRONOS is a digital-computer program written in the Fortran-V language for use on the Univac 1108 computing system. The program has been developed for the purpose of facilitating the calculations involved in the transient analysis of compact heat exchangers of the plate-fin variety. For a specified heat-exchanger geometry and pair of fluids, the program can be used to calculate the variations of pressure drop and outlet conditions with time for given initial conditions (corresponding to either a start-up or steady-state situation) and prescribed time variations in inlet temperature (and absolute humidity or vapor quality for a condensing fluid) and flow rate of both streams.

The analytical procedures on which the program is based are those presented in Volume I of this report. Briefly, these involve expressing the time derivatives in the set of governing differential equations in terms of finite differences. The number of equations in the original set is then algebraically reduced to two, one for each fluid. These two equations are solved simultaneously by an iterative procedure to obtain the temperature distributions at each new time, θ, over the desired time interval. The iterative procedure involves numerically integrating the equation for each of the two fluids with respect to distance along its flow length.

The program is capable of computing the transient thermal performance of compact heat exchangers in which one of the fluids is single phase and the other is either single phase or condensing; this latter category includes both single-component fluids or two-component fluids in which the less volatile component condenses (wet gas). The configurations which can be treated are parallel-flow, counterflow, and multipass-crossflow arrangements of plate-fin heat-transfer surfaces (matrices). The crossflow configurations are limited to those in which the fluid turned between passes is single phase. It is felt that the program as developed is sufficiently general to be applied to the wide variety of compact configurations and fluids commonly encountered in the aerospace industry.

Report Arrangement

The main body of the report begins with a section in which the input data necessary for the solution of any case are described in detail; this includes instructions for preparing and supplying this data to the program. The next section contains a discussion of the various types of output data which can be obtained from the program along with guidelines for their interpretation. The last three sections contain miscellaneous information regarding the operation of the program with the computing system, a discussion of three sample cases (single-phase counterflow, wet-gas crossflow, and two-phase crossflow) illustrating the use of the program, and a number of conclusions and recommendations related to the program.

The first appendix consists of a general discussion of the over-all logic structure of the program. The next appendix gives the Fortran nomenclature for the major variables used in the program. The remaining appendices provide detailed descriptions of the various components (main routine and subroutines) which make up the over-all program, one appendix for each component. The appendix for each component contains a presentation of the input and output variables, an internal Fortran nomenclature, a description of the step-by-step calculation procedure, a flow diagram representing the logic structure, and the associated Fortran listing.

INPUT DATA

General Description

The input data used by Program KRONOS falls into two main categories: input data directly specified by the user, and input data obtained from a magnetic tape called the matrix-data tape. Since the matrix-data tape is detailed in References 1 through 4, only a general discussion of its use is presented here. Rather, this section focuses attention upon input data in the first category.

The physical input data directly specified by the user can itself be divided into three categories: general data for the heat exchanger as a unit, fluid or associated matrix data, and time-related data. The general input data consists of:

1. Flow arrangement.
2. Number of passes for a multipass-crossflow arrangement.
3. Core dimensions.
4. Parting-plate thickness, density, and heat capacity.
5. Side-wall thicknesses, density, and heat capacity.

The data specified for each fluid or its associated matrix consists of:

1. Inlet pressure.
2. Heat-transfer matrix.
3. Hydraulic radius of the matrix.
4. Splitter-plate thickness, thermal conductivity, density, and heat capacity for the matrix.
5. Fluid type, i.e., single-phase gas or liquid, and for fluid r, two-phase fluid (that is, single-component condensing fluid) or wet gas.
6. Compressibility factor and gas constant for a vapor or gas.
7. Molecular weight for the gas and vapor components of a wet gas.
8. Saturation temperature and latent heat of vaporization at the pressure level (inlet pressure) for a two-phase fluid.
9. Critical pressure, atmospheric pressure, and acceleration of gravity for a two-phase fluid.

10. Pressure and latent heat of vaporization as a function of saturation temperature for the vapor component of a wet gas.
11. Specific heat, viscosity, thermal conductivity, and, for a liquid, density as a function of temperature for a single-phase gas or liquid, both vapor and liquid phases of a two-phase fluid, or both gas and vapor components of a wet gas.

The time-related data consists of:

1. Initial condition, i.e., start-up or steady-state.
2. Heat exchanger metal temperature for the start-up initial condition.
3. Number of time periods into which the transient investigation is divided.
4. Length and nominal number of time increments for each time period of the transient investigation.
5. Mass flow rate as a function of time, either in analytical or tabular form, for both fluids.
6. Inlet temperature as a function of time, either in analytical or tabular form, for both fluids except possibly fluid r when it is always two-phase at inlet.
7. Absolute humidity at inlet as a function of time, either in analytical or tabular form, for fluid r when it is a wet gas.
8. Vapor quality at inlet as a function of time, either in analytical or tabular form, for fluid r when it is a two-phase fluid except possibly when it is always single-phase at inlet.

Finally, in addition to the physical input data, the user must specify various other data which are necessary to obtain a solution.

The matrix-data tape is the one generated by Program OPTIMA, a computer program previously supplied to NASA by NREC and described in References 1 through 4. This tape contains the geometric data and flow and heat-transfer performance data for the various plate-fin heat-transfer surfaces available for use as the passages in the exchanger. For each surface (or matrix), the data on the tape are in three groups. The first group consists of an index number (N_{core}) and title identifying the surface. The identification number can have any value between 1 and 10,000. The

numbering system used in referencing the matrices is given in Table X of Reference 2. The second group of data consists of the hydraulic radius (r_h) and the nondimensional geometric quantities, S_f^o, ℓ_f^o, δ^o, b^o, A_f/A, σ_{int}, A_H, $(V_f/N)_{int}$, ℓ_{rat}, and N_L (see Appendix I of Ref 2 for a more detailed description of these quantities and the relations used to compute them). In addition, it includes the value of an index, N_{type}, specifying the type of surface. The last group of data consists of a table of experimental values of friction factor (f) and Colburn modulus (j) versus Reynolds number (Re). The matrix to be used for each fluid is specified in the input data by giving the appropriate identification number previously assigned to the matrix in generating the tape. The required data for the matrix are then read from the tape when needed by the program.

Detailed Description of Input Data

The information required to prepare the input data for a case is furnished in the table given below. This information contains a description of each input item as well as a description of the form in which these items are written on input data sheets. The descriptions of the input items refer frequently to several points, relevant to the selection of input values, which are discussed in the subsequent subsection. The discussions of these numbered points provide additional detailed information useful in preparing the input data for any case. It should be noted that any consistent set of units may be used for the input items; however, the English system of units is included in the description of each item.

The first input item read by Program KRONOS consists of a description of the case. This item, as specified by a FORMAT statement, consists of 1-72 alphanumeric characters; any combination of numbers, capital letters, punctuations, or blanks may be used.

Line	Location	Fortran Symbol	Description
1	1-72	COMENT	A statement describing the case to be considered; this may be left blank but may not be omitted

The remaining input items are read into Program KRONOS using a NAMELIST statement. Input data referring to a NAMELIST statement begins with a $ in the second location on a new line, immediately followed by the NAMELIST name, immediately followed by one or more blank characters. Any combination of three types of data items may then follow. The data items must be separated by commas. If more than one line is needed for the input data, the last item on each line, except the last line, must be a number followed by a comma. The first location on each line should always be left blank since it is ignored. The end of a group of data is signaled by $END in the second through fifth locations of a line. The form that data items may take is:

1. Variable name = constant, where the variable name may be an array element or a simple variable name. Subscripts must be integer constants.
2. Array name = set of constants separated by commas where k* constant may be used to represent k consecutive values of a constant. The number of constants must be equal to the number of elements in the array.
3. Subscripted variable = set of constants separated by commas where, again, k* constant may be used to represent k consecutive values of a constant. This results in the set of constants being placed in consecutive array elements, starting with the element designated by the subscripted variable.

The items in the namelist NAM3 are as follows:

Fortran Symbol	Input Item	Description
NFLO		Indicator: NFLO=1 if the flow arrangement is multipass-crossflow NFLO=2 if the flow arrangement is parallel flow NFLO=3 if the flow arrangement is counterflow (see point 1)
NPC	N_P	Number of passes in a multipass-crossflow arrangement; this item may be omitted if NFLO≠1

Fortran Symbol	Input Item	Description
NXIN	N_x	Number of increments into which the parallel or counterflow heat exchanger is divided for the calculations; this item may be omitted if NFLO=1 (see point 2)
NXPPIN	$N_{x,p}$	Number of increments in the x direction into which each pass of the crossflow heat exchanger is divided for the calculations (see point 2); this item may be omitted if NFLO≠1
NYPIN	$N_{y,p}$	Number of increments in the y direction into which each pass of the crossflow heat exchanger is divided for the calculations (see point 2); this item may be omitted if NFLO≠1

The user of the program may specify that the value set in the program of either N_x, $N_{x,p}$, or $N_{y,p}$ should be used in the calculations by setting either N_x, $N_{x,p}$, or $N_{y,p}$, respectively, equal to zero in the input data. (The values set in the program are $N_x = 10$, $N_{x,p} = 5$, and $N_{y,p} = 10$.)

Fortran Symbol	Input Item	Description
RHUNIT	$r_{h,unit}$	Proportionality factor by which the values of hydraulic radius obtained from the matrix-data tape are multiplied to convert them to the appropriate units. This quantity is required only if the user of the program does not wish to specify the hydraulic radius for each fluid, but instead wishes to use the values obtained from the matrix-data tape (see point 3)
GC	g_c	Proportionality constant in Newton's Law (4.169×10^8), ft lbm per lbf hr^2
ELX	L_x	Core dimension in the x direction, ft (see sketch included with Nomenclature)
ELY	L_y	Core dimension in the y direction, ft (see sketch included with Nomenclature)
ELNF	L_{NF}	Core dimension in the nonflow direction, ft (see sketch included with Nomenclature)
PP	a	Parting-plate thickness, ft
DENSMP	$\rho_{met,f}$	Density of the parting-plate metal, lbm per cu ft

Fortran Symbol	Input Item	Description
CPMP	$c_{p,met,p}$	Heat capacity of the parting-plate metal, Btu per lbm deg R
SWL	$a_{sw,\ell}$	Thickness of the side wall parallel to the parting plates, ft
SWT	$a_{sw,t}$	Thickness of the side wall normal to the parting plates, ft
DENSMW	$\rho_{met,sw}$	Density of the side wall metal, lbm per cu ft
CPMW	$c_{p,met,sw}$	Heat capacity of the side-wall metal, Btu per lbm deg R
PINS	$p_{in,s}$	Inlet pressure for fluid s, psf
NCORES	$N_{core,s}$	Identification number of the matrix associated with fluid s (see point 3)
RHINS	$r_{h,s}$	Hydraulic radius of the matrix associated with fluid s, ft. The user of the program may specify that the value of $r_{h,s}$ obtained from the matrix-data tape be used in the calculations by setting $r_{h,s}$ equal to zero and entering the correct value of RHUNIT (see point 3)
SPLS	$a_{sp,s}$	Splitter-plate thickness for the matrix associated with fluid s, ft
CONDMS	$k_{met,s}$	Conductivity of the metal for the matrix associated with fluid s, Btu per hr ft deg R
DENSMS	$\rho_{met,s}$	Density of the metal for the matrix associated with fluid s, lbm per cu ft
CPMS	$c_{p,met,s}$	Heat capacity of the metal for the matrix associated with fluid s, Btu per lbm deg R
ICOMPS	$i_{comp,s}$	Indicator for fluid s: ICOMPS=1 if fluid s is a gas ICOMPS=2 if fluid s is a liquid
ZS	z_s	Compressibility factor for fluid s; this item may be omitted if ICOMPS=2
GASKS	R_s	Gas constant for fluid s, ft lbf per lbm deg R; this item may be omitted if ICOMPS=2
NTFPS		Number of temperatures at which values of the fluid properties are specified for fluid s (a maximum of 10 is allowed)
(TFPS(N), N=1,NTFPS)	$\hat{T}_{n,s}$	Table of values of temperature at which fluid properties are entered for fluid s, deg R (see point 4)

Fortran Symbol	Input Item	Description
(CPXS(N), N=1,NTFPS)	$\hat{c}_{p,n,s}$	Table of values of specific heat corresponding to the temperatures TFPS for fluid s, Btu per lbm deg R
(VISXS(N), N=1,NTFPS)	$\hat{\mu}_{n,s}$	Table of values of viscosity corresponding to the temperatures TFPS for fluid s, lbm per hr ft
(THKXS(N), N=1,NTFPS)	$\hat{k}_{n,s}$	Table of values of thermal conductivity corresponding to the temperatures TFPS for fluid s, Btu per hr ft deg R
(ROXS(N), N=1,NTFPS)	$\hat{\rho}_{n,s}$	Table of values of density corresponding to the temperatures TFPS for fluid s, lbm per cu ft; this item may be left blank if ICOMPS=1
PINR	$p_{in,r}$	Inlet pressure for fluid r, psf
NCORER	$N_{core,r}$	Identification number of the matrix associated with fluid r (see point 3)
RHINR	$r_{h,r}$	Hydraulic radius of the matrix associated with fluid r, ft. The user of the program may specify that the value of $r_{n,r}$ obtained from the matrix-data tape be used in the calculations by setting $r_{n,r}$ equal to zero and entering the correct value of RHUNIT (see point 3)
SPLR	$a_{sp,r}$	Splitter-plate thickness for the matrix associated with fluid r, ft
CONDMR	$k_{met,r}$	Conductivity of the metal for the matrix associated with fluid r, Btu per hr ft deg R
DENSMR	$\rho_{met,r}$	Density of the metal for the matrix associated with fluid r, lbm per cu ft
CPMR	$c_{p,met,r}$	Heat capacity of the metal for the matrix associated with fluid r, Btu per lbm deg R
KPHR		Indicator for fluid r: KPHR=1 if fluid r is single phase KPHR=2 if fluid r is single component, two phase KPHR=3 if fluid r is a two component wet gas

If KPHR=2 the input data for fluid r resumes on page 11 with the item TSAT, whereas if KPHR=3, the input data for fluid r resumes on page 13 with the item ZG.

Fortran Symbol	Input Item	Description
ICOMPR	$i_{comp,r}$	Incicator for fluid r: ICOMPR=1 if fluid r is a gas ICOMPR=2 if fluid r is a liquid
ZR	z_r	Compressibility factor for fluid r; this item may be omitted if ICOMPR=2
GASKR	R_r	Gas constant for fluid r, ft lbf per lbm deg R; this item may be omitted if ICOMPR=2
NTFPR		Number of temperatures at which values of the fluid properties are specified for fluid r (a maximum of 10 is allowed)
(TFPR(N), N=1,NTFPR)	$\hat{T}_{n,r}$	Table of values of temperature at which fluid properties are entered for fluid r, deg R (see point 4)
(CPXR(N), N=1,NTFPR)	$\hat{c}_{p,n,r}$	Table of values of specific heat corresponding to the temperatures TFPR for fluid r, Btu per lbm deg R
(VISXR(N), N=1,NTFPR)	$\hat{\mu}_{n,r}$	Table of values of viscosity corresponding to the temperatures TFPR for fluid r, lbm per hr ft
(THKXR(N), N=1,NTFPR)	$\hat{k}_{n,r}$	Table of values of thermal conductivity corresponding to the temperatures TFPR for fluid r, Btu per hr ft deg R
(ROXR(N), N=1,NTFPR)	$\hat{\rho}_{n,r}$	Table of values of density corresponding to the temperatures TFPR for fluid r, lbm per cu ft; this item may be left blank if ICOMPR=1

The input data in the case where KPHR=1 resumes on page 14 with the item INC.

TSAT	T_{sat}	Saturation temperature of fluid r corresponding to the inlet pressure $p_{in,r}$, deg R
HFGSAT	$h_{fg,sat}$	Latent heat of vaporization of fluid r corresponding to the saturation temperature T_{sat}, Btu per lbm
PCRIT	p_{crit}	Critical pressure of fluid r, psf
PATM	p_{atm}	Atmospheric pressure (2116.2 at standard conditions), psf
GACC	g	Acceleration of gravity (4.169×10^8 for a standard station on earth), ft per hr^2

Fortran Symbol	Input Item	Description
ZV	Z_v	Compressibility factor for the vapor phase of fluid r
GASV	R_v	Gas constant for the vapor phase of fluid r, ft lbf per lbm deg R
NTFPV		Number of temperatures at which values of the fluid properties are specified for the vapor phase of fluid r (a maximum of 10 is allowed)
(TFPV(N), N=1,NTFPV)	$\hat{T}_{n,v}$	Table of values of temperature at which fluid properties are entered for the vapor phase of fluid r, deg R (see point 4)
(CPXV(N), N=1,NTFPV)	$\hat{c}_{p,n,v}$	Table of values of specific heat corresponding to the temperatures TFPV for the vapor phase of fluid r, Btu per lbm deg R
(VISXV(N), N=1,NTFPV)	$\hat{\mu}_{n,v}$	Table of values of viscosity corresponding to the temperatures TFPV for the vapor phase of fluid r, lbm per hr ft
(THKXV(N), N=1,NTFPV)	$\hat{k}_{n,v}$	Table of values of thermal conductivity corresponding to the temperatures TFPV for the vapor phase of fluid r, Btu per hr ft deg R
NTFPL		Number of temperatures at which values of the fluid properties are specified for the liquid phase of fluid r (a maximum of 10 is allowed)
(TFPL(N), N=1,NTFPL)	$\hat{T}_{n,\ell}$	Table of values of temperature at which fluid properties are entered for the liquid phase of fluid r, deg R (see point 4)
(CPXL(N), N=1,NTFPL)	$\hat{c}_{p,n,\ell}$	Table of values of specific heat corresponding to the temperatures TFPL for the liquid phase of fluid r, Btu per lbm deg R
(VISXL(N), N=1,NTFPL)	$\hat{\mu}_{n,\ell}$	Table of values of viscosity corresponding to the temperatures TFPL for the liquid phase of fluid r, lbm per hr ft
(THKXL(N), N=1,NTFPL)	$\hat{k}_{n,\ell}$	Table of values of thermal conductivity corresponding to the temperatures TFPL for the liquid phase of fluid r, Btu per hr ft deg R
(ROXL(N), N=1,NTFPL)	$\hat{\rho}_{n,\ell}$	Table of values of density corresponding to the temperatures TFPL for the liquid phase of fluid r, lbm per cu ft.

The data for fluid r in the case where KPHR=2 resumes on page 14 with the item INC.

Fortran Symbol	Input Item	Description
ZG	z_g	Compressibility factor for the gas component of fluid r
GASKG	R_g	Gas constant for the gas component of fluid r, ft lbf per lbm deg R
EMWG	M_g	Molecular weight of the gas component of fluid r, lbm per lbm-mole
NTFPG		Number of temperatures at which values of the fluid properties are specified for the gas component of fluid r (a maximum of 10 is allowed)
(TFPG(N), N=1,NTFPG)	$\hat{T}_{n,g}$	Table of values of temperature at which fluid properties are entered for the gas component of fluid r, deg R (see point 4)
(CPXG(N), N=1,NTFPG)	$\hat{c}_{p,n,g}$	Table of values of specific heat correponding to the temperatures TFPG for the gas component of fluid r, Btu per lbm deg R
(VISXG(N), N=1,NTFPG)	$\hat{\mu}_{n,g}$	Table of values of viscosity corresponding to the temperatures TFPG for the gas component of fluid r, lbm per hr ft
(THKXG(N), N=1,NTFPG)	$\hat{k}_{n,g}$	Table of values of thermal conductivity corresponding to the temperatures TFPG for the gas component of fluid r, Btu per hr ft deg R
ZV	z_v	Compressibility factor for the vapor component of fluid r
GASKV	R_v	Gas constant for the vapor component of fluid r, ft lbf per lbm deg R
EMWV	M_v	Molecular weight of the vapor component of fluid r, lbm per lbm-mole
NTSAT		Number of saturation temperatures at which values of pressure and latent heat of vaporization are specified for the vapor component of fluid r (a maximum of 10 is allowed)
(TSATX(N), N=1,NTSAT)	$\hat{T}_{sat,n}$	Table of values of saturation temperature at which values of pressure and latent heat of vaporization are entered for the vapor component of fluid r, deg R

Fortran Symbol	Input Item	Description
(PSATX(N), N=1,NTSAT)	$\hat{p}_{sat,n}$	Table of values of pressure corresponding to the saturation temperatures TSATX for the vapor component of fluid r, psf
(HFGSTX(N), N=1,NTSAT)	$\hat{h}_{fg,sat,n}$	Table of values of latent heat of vaporization corresponding to the saturation temperatures TSATX for the vapor component of fluid r, Btu per lbm
NTFPV		Number of temperatures at which values of the fluid properties are specified for the vapor component of fluid r (a maximum of 10 is allowed)
(TFPV(N), N=1,NTFPV)	$\hat{T}_{n,v}$	Table of values of temperature at which fluid properties are entered for the vapor component of fluid r, deg R (see point 4)
(CPXV(N), N=1,NTFPV)	$\hat{c}_{p,n,v}$	Table of values of specific heat correponding to the temperatures TFPV for the vapor component of fluid r, Btu per lbm deg R
(VISXV(N), N=1,NTFPV)	$\hat{\mu}_{n,v}$	Table of values of viscosity corresponding to the temperatures TFPV for the vapor component of fluid r, Btu per lbm deg R
(THKXV(N), N=1,NTFPV)	$\hat{k}_{n,v}$	Table of values of thermal conductivity corresponding to the temperatures TFPV for the vapor component of fluid r, Btu per hr ft deg R
INC		Indicator: INC=1 if the initial conditions correspond to start-up INC=2 if the initial conditions correspond to steady-state (see point 5)
TEX	T_{exch}	Temperature of the heat exchanger metal at start-up, deg R; this item may be omitted if INC=2 (see point 5)
NPER	N_{per}	Number of time periods of constant time increment into which the transient investigation is divided; a maximum of 10 is allowed (see point 6)
(THPER(N), N=1,NPER)	$\theta_{per,n}$	Length of each successive time period in the transient investigation, hr

Fortran Symbol	Input Item	Description
(NDTH(N), N=1,NPER)	$N_{\Delta\theta,n}$	Nominal number of time increments for each time period of the transient investigation (see point 6)
(ITHC(N), N=1,NPER)		Indicator for each time period of the transient investigation: ITHC(N)=0 if the size of the time increment in time period n corresponds to the nominal number of time increments ITHC(N)=1 if the size of the time increment in time period n corresponds to the nominal number of time increments, but is bounded by calculated maximum and minimum values ITHC(N)=2 if the size of the time increment in time period n corresponds to the average of the calculated maximum and minimum values (see point 6)
IMS		Indicator for fluid s: IMS=1 if the variation of mass flow rate with time is expressed analytically IMS=2 if the variation of mass flow rate with time is expressed tabularly

If IMS=2 the input data for fluid s resumes below with item NMS.

(CMS(N), N=1,9)	$c_{ws,n}$	Array of nine coefficients in the analytical expression for mass flow rate as a function of time for fluid s (see point 7)

The data for fluid s in the case where IMS=1 resumes on page 16 with item ITS.

NMS		Number of entries in the tabular specification of mass flow rate as a function of time for fluid s (a maximum of 20 is allowed)
(THWS(N), N=1,NWS)	$\hat{\theta}_{ws,n}$	Table of values of time at which values of mass flow rate are entered for fluid s, hr
(WSX(N), N=1,NTS)	$\hat{w}_{s,n}$	Table of values of mass flow rate corresponding to the times THWS for fluid s, lbm per hr

Fortran Symbol	Input Item	Description
ITS		Indicator for fluid s: ITS=1 if the variation of inlet temperature with time is expressed analytically ITS=2 if the variation of inlet temperature with time is expressed tabularly

If ITS=2 the input data for fluid s resumes below with item NTS.

(CTS(N), N=1,9)	$C_{TS,n}$	Array of nine coefficients in the analytical expression for inlet temperature as a function of time for fluid s (see point 7)

The fluid input data in the case where ITS=1 resumes below with item NMR.

NTS		Number of entries in the tabular specification of inlet temperature as a function of time for fluid s (a maximum of 20 is allowed)
(THTS(N) N=1,NTS)	$\hat{\theta}_{TS,n}$	Table of values of time at which values of inlet temperature are entered for fluid s, hr.
(TINSX(N), N=1,NTS)	$\hat{T}_{in,s,n}$	Table of values of inlet temperature corresponding to times THTS for fluid s, deg R
IMR		Indicator for fluid r: IMR=1 if the variation of mass flow rate with time is expressed analytically IMR=2 if the variation of mass flow rate with time is expressed tabularly

If IMR=2 the input data for fluid r resumes below with item NMR.

(CMR(N), N=1,9)	$C_{wr,n}$	Array of nine coefficients in the analytical expression of mass flow rate as a function of time for fluid r (see point 7)

The data for fluid r in the case where IMR=1 resumes on page 17 following item WRX.

NMR		Number of entries in the tabular specification of mass flow rate as a function of time for fluid r (a maximum of 20 is allowed)
(THWR(N), N=1,NWR)	$\hat{\theta}_{wr,n}$	Table of values of time at which values of mass flow rate are entered for fluid r, hr.
WRX(N), N=1,NWR)	$\hat{w}_{r,n}$	Table of values of mass flow rate corresponding to the times THWR for fluid r, lbm per hr

If KPHR=2 the input data for fluid r resumes on page 18 with the item ITXV.

Fortran Symbol	Input Item	Description
ITR		Indicator for fluid r: ITR=1 if the variation of inlet temperature with time is expressed analytically ITR=2 if the variation of inlet temperature with time is expressed tabularly

If ITR=2 the input data for fluid r resumes below with item NTR.

(CTR(N), N=1,9)	$C_{Tr,n}$	Array of nine coefficients in the analytical expression for inlet temperature as a function of time for fluid r (see point 7)

The input data in the case where ITR=1 and KPHR=1 is now complete. Data for additional cases may be entered by returning to line 1 and repeating the above procedure. The input data in the case where ITR=1 and KPHR=3 resumes below with item IOM.

NTR		Number of entries in the tabular specification of inlet temperature as a function of time for fluid r (a maximum of 20 is allowed)
(THTR(N), N=1,NTR)	$\hat{\theta}_{Tr,n}$	Table of values of time at which values of inlet temperature are entered for fluid r, hr
(TINRX(N), N=1,NTR)	$\hat{T}_{in,r,n}$	Table of values of inlet temperature corresponding to the times THTR for fluid r, deg R

The input data in the case where ITR=2 and KPHR=1 is now complete. Data for additional cases may be entered by returning to line 1 and repeating the above procedure. The input data in the case where ITR=2 and KPHR=3 continues with item IOM.

IOM	Indicator for fluid r: IOM=1 if the variation of absolute humidity at inlet with time is expressed analytically IOM=2 if the variation of absolute humidity at inlet with time is expressed tabularly

If IOM=2 the input data for fluid r in the case when KPHR=3 resumes on page 17 with item NOM.

Fortran Symbol	Input Item	Description
(COM(N), N=1,9)	$C_{\omega,n}$	Array of nine coefficients in the analytical expression for absolute humidity at inlet as a function of time for fluid r (see point 7)

The input data in the case where IOM=1 and KPHR=3 is now complete. Data for additional cases may be entered by returning to line 1 and repeating the above procedure.

NOM		Number of entries in the tabular specification of absolute humidity at inlet as a function of time for fluid r (a maximum of 20 is allowed)
(THOM(N), N=1,NOM)	$\hat{\theta}_{\omega,n}$	Table of values of time at which values of absolute humidity at inlet are entered for fluid r, hr
(OMX(N), N=1,NOM)	$\hat{\omega}_{in,r,n}$	Table of values of absolute humidity at inlet corresponding to the times THOM for fluid r

The input data in the case where IOM=2 and KPHR=3 is now complete. Data for additional cases may be entered by returning to line 1 and repeating the above procedure.

ITXV

Indicator for fluid r:

ITXV=1 if fluid r is always a single-phase vapor at inlet and the variation of inlet temperature with time is expressed analytically

ITXV=2 if fluid r is always two phase at inlet and the variation of inlet vapor quality with time is expressed analytically

ITXV=3 if fluid r may be single or two-phase at inlet and the variation of both inlet temperature and inlet vapor quality with time are expressed tabularly

If ITXV=2 the input data for fluid r resumes on page 19 with item CXV, whereas if ITXV=3 the input data for fluid r resumes on page 19 with item NTXV.

(CTR(N), N=1,9)	$C_{T,r,n}$	Array of nine coefficients in the analytical expression for inlet temperature as a function of time for fluid r (see point 7)

The input data in the case where ITXV=1 and KPHR=2 is now complete. Data for additional cases may be entered by returning to line 1 and repeating the above procedure.

Fortran Symbol	Input Item	Description
(CXV(N), N=1,9)	$C_{xv,n}$	Array of nine coefficients in the analytical expression for inlet vapor quality as a function of time for fluid r (see point 7)

The input data in the case where ITXV=2 and KPHR=2 is now complete. Data for additional cases may be entered by returning to line 1 and repeating the above procedure.

NTXV		Number of entries in the tabular specification of inlet temperature and vapor quality as a function of time for fluid r (a maximum of 20 is allowed)
(THTXV(N), N=1,NTXV)	$\hat{\theta}_{Txv,n}$	Table of values of time at which values of inlet temperature and vapor quality are entered for fluid r, hr
(TINRX(N), N=1,NTXV)	$\hat{T}_{in,r,n}$	Table of values of inlet temperature corresponding to the times THTXV for fluid r, deg R
(XVINX(N), N=1,NTXV)	$\hat{X}_{v,in,n}$	Table of values of vapor quality at inlet corresponding to the times THTXV for fluid r

The input data is now complete. Data for additional cases may be entered by returning to line 1 and repeating the above procedure. With the exception of the descriptive statement which is entered on line 1, only those items whose values are to be changed for the new case need be entered.

Discussion of Input Data

Some important aspects to be considered in appropriately specifying the input data are discussed below. Numerical reference to these discussions has been made in the preceding subsection in which the input format was described. The points referred to are as follows:

1. Fluid Designation - In all cases, fluid s must be single-phase throughout the exchanger. Fluid r may be single-phase throughout, a single-component condensing fluid (two-phase),

or a two-component fluid in which the less volatile component is condensing (wet gas). For multipass-crossflow configurations, fluid s must be the one which is turned between passes and its over-all flow direction must be the negative x direction. In all cases, the positive x direction is defined as the flow direction of fluid r. The value of the indicator NFLO then completely specifies the flow direction of fluid s. A parallel-flow arrangement (NFLO=2) indicates fluid s flows in the positive x direction, a counterflow arrangement (NFLO=3) indicates fluid s flows in the negative x direction, and a multipass-crossflow arrangement (NFLO=1) indicates fluid s is turned between passes and it flows over-all in the negative x direction.

2. Number of Increments - For purposes of analysis, the exchanger is considered to be divided into a number of finite-difference elements. The per cent error of heat balance for the steady-state case gives an indication of the truncation error associated with distance in the solution procedure. The values of N_x, or $N_{x,p}$ and $N_{y,p}$ set in the computer program ($N_x = 10, N_{x,p} = 5$, and $N_{y,p} = 10$) are thought to provide sufficiently accurate results in most cases-- less than 1 per cent error in the heat balance for counterflow or parallel-flow arrangements, and approximately 3 or 4 per cent for crossflow arrrangements. However, if the per cent error of the heat balance is not satisfactory, the user of the program can alter the value through the specification of N_x, or $N_{x,p}$ and $N_{y,p}$. The error varies inversely with the number of finite-difference elements.

3. Geometry and Performance of Core - The heat-exchanger core consists of plate-fin heat-transfer matrices whose internal geometry and flow and heat-transfer performance characteristics must be specified by the program user. This is done by specifying the matrix identification number (N_{core}) associated with each of the two fluids. The required geometric

and performance data for each matrix are read from the matrix-data tape described previously. The internal dimensions of the matrix are computed from the nondimensional data given on the tape and a value of the hydraulic radius. The option is available of using either the value of r_h obtained from the tape or a value specified by the user. The latter option is equivalent to scaling the dimensions of the actual matrix used in measuring the experimental f and j data given on the tape. A reasonable amount of scaling (a factor of about 2 or 3) should be possible for uninterrupted-fin matrices without significantly affecting the measured flow and heat-transfer performance. However, a lesser amount of scaling (say a maximum of about a 10 or 20 per cent change in hydraulic radius) should be used with the interrupted-fin variety of matrix.

4. Fluid Properties - The temperatures at which fluid properties are specified should cover the range of temperatures the fluid could possibly assume in the case, so that interpolation will always be performed. In any case, extrapolation of properties, with the exception of f and j data, is not allowed; rather bounding values of the property will be used. Further, if the interpolation procedure is to function properly, the temperatures at which fluid properties are specified must be in monotonically increasing order.

5. Start-up Conditions - It is felt that the start-up initial condition can best be simulated by the computer program by setting (a) the fluid temperatures at $\theta=0$ equal to the temperature of the heat-exchanger metal specified in the input data (T_{exch}), and (b) the fluid mass flow at $\theta=0$ equal to zero. Both fluid temperatures and mass flows should then be allowed to reach their intended values in a manner modeled after the actual variation.

6. Time increment - The specification of time increment in the transient investigation is influenced by (a) the truncation

error associated with time in the solution procedure, and (b) the hyperbolic nature of the governing differential equations. The former influence leads to greater accuracy as the size of the time increment decreases, while the latter influence (see Appendix IV of Volume I) causes a decrease in accuracy at small values of θ if the size of the time increment decreases beyond a certain value. In most cases, these influences combine to produce a relatively wide range of acceptable values of time increment at each point in time which is bounded by both minimum and maximum values. In the input data, the transient investigation is first divided into a number of time periods. The total time interval to be investigated ($\theta_{interval}$) is determined by the number of periods and length of each period,

$$\theta_{interval} = \sum_{n=1}^{N_{per}} \theta_{per,n}$$

For each time period, the user of the program has the option of either (a) specifying a constant time increment (ITHC=0) given by dividing the length of the time period by the number of time increments, (b) the time increment of (a) above but bounded by internally calculated maximum and minimum values at each point in time (ITHC=1), or (c) the time increment obtained by averaging the internally calculated maximum and minimum values at each point in time (ITHC=2). The first option (a) should be used when results are desired at definite values of θ (for example, values below the minimum $\Delta\theta$ calculated by the program) over the total time interval. The second option (b) provides a semi-automatic procedure for selecting the time increment, allowing the program user some control over the values of θ at which calculations are performed; it is suggested that this option be used in most cases. The third option (c) provides a completely automatic procedure which can be used in cases where the program user has no preference as to the values of θ at which calculations are performed and results printed.

7. Analytical Variation of Input Data with Time - The analytical variation of time-dependent input data is specified in the form of nine coefficients for each input item. In the computer program, the nine coefficients are applied to the following general expression:

$$f(\theta)=C_1+C_2\,e^{C_3\theta}+C_4\,e^{C_5\theta}(C_6\sin C_7\theta+C_8\cos C_9\theta)$$

Hence a wide variety of analytical variations of input data may be specified.

OUTPUT DATA

The output of Program KRONOS consists entirely of printed data. The printed data falls into two main categories: normal output, and error messages with additional output. The normal output, which is illustrated by the sample cases included in the report, will be described first. Although the units of the output are determined by the input data, the English system of units is included in the description of each item.

Normal Output

The information included in the normal output can be divided into the following categories:

1. General input data.
2. Fluid or associated matrix input data.
3. Time-related input data.
4. General results of the calculations.
5. Time-dependent results of the calculations.

A description of the items in each category is given below.

The normal output of a typical case begins with the statement describing the case, immediately followed by the items in category 1--general input data. The general input data consists of:

1. Flow arrangement.
2. Number of passes for a multipass-crossflow arrangement.
3. Number of calculation increments to be used.
4. Proportionality factor by which values of hydraulic radius obtained from the matrix-data tape are multiplied to obtain the desired units.
5. Proportionality constant in Newton's Law, ft lbm per lbf hr^2 .
6. Core dimensions, ft .
7. Parting-plate thickness, ft, density, lbm per cu ft, and heat capacity, Btu per lbm deg R .
8. Side wall thicknesses parallel and normal to the parting plates, ft, density, lbm per cu ft, and heat capacity, Btu per lbm deg R .

The normal output of a typical case continues with the items in category 2-- fluid or associated matrix input data. The items, which appear for fluid s and fluid r consist of:

1. Inlet pressure, psf.
2. Flow direction.
3. Matrix identification number.
4. Hydraulic radius, ft, of the matrix or a statement that the hydraulic radius has been obtained from the matrix-data tape.
5. Splitter-plate thickness, ft, thermal conductivity, Btu per hr ft deg R, density, lbm per cu ft, and heat capacity, Btu per lbm deg R, for the matrix material.
6. Fluid type, i.e., gas or liquid and, for fluid r, two-phase fluid or wet gas.
7. Compressibility factor and gas constant, ft lbf per lbm deg R, for a gas or vapor.
8. Molecular weight, lbm per lbm-mole, for the gas and vapor components of a wet gas.
9. Saturation temperature, deg R, and latent heat of vaporization, Btu per lbm, corresponding to the inlet pressure for a two-phase fluid.
10. Critical pressure, psf, atmospheric pressure, psf, and acceleration of gravity, ft per hr^2, for a two-phase fluid.
11. Tabulated values of pressure, psf, and latent heat of vaporization, Btu per lbm, as a function of saturation temperature, deg R, for the vapor component of a wet gas.
12. Tabulated values of specific heat, Btu per lbm deg R, viscosity, lbm per hr ft, thermal conductivity, Btu per hr ft deg R, and, for a liquid, density, lbm per cu ft, as a function of temperature, deg R, for a single-phase gas or liquid, both vapor and liquid phases of a two-phase fluid, or both gas and vapor components of a wet gas.

The normal output of a typical case concludes printing the input data with the items in category 3-- time-related input data. The items consist of:

1. Initial conditions, i.e., start-up or steady-state.
2. Heat exchanger metal temperature for the start-up initial condition, deg R.
3. Number of time periods into which the transient investigation is divided.
4. Length, hr, nominal number of time increments, and indicator of the option used to determine the size of the time increment for each time period. The meaning of the indicators appears below their specification.
5. Mass flow rate, lbm per hr, as a function of time, hr, either as an analytical expression or as tabulated values, for both fluids.
6. Inlet temperature, deg R, as a function of time, hr, either as an analytical expression or as tabulated values, for both fluids except possibly fluid r when it is always two-phase at inlet.
7. Absolute humidity at inlet as a function of time, hr, either as an analytical expression or as tabulated values, for fluid r when it is a wet gas.
8. Vapor quality at inlet as a function of time, hr, either as an analytical expression or as tabulated values, for fluid r when it is a two-phase fluid except possibly when it is always single-phase at inlet.

The results of the calculations appear next in the normal output for a typical case, beginning with the items in category 4-- general results of the calculations. The general results consist of:

1. Identification number and name (in parentheses) of the matrix associated with each side of the heat exchanger.
2. Hydraulic radius, ft, plate spacing, ft, fin spacing, ft, and fin thickness, ft, of the associated matrix for each side of the heat exchanger.

3. Void volume, cu ft, and total heat-transfer area, sq ft, of the associated matrix for each side of the heat exchanger.
4. Core volume, cu ft, and core weight (dry), lbm, of the over-all heat exchanger.
5. Heat capacity of the core structure, Btu per deg R, and heat capacity of the sidewall in contact with each fluid, Btu per deg R.

The normal output of a typical case concludes with the items in category 5-- time dependent results of the calculations. These items, which appear for each value of θ at which calculations are performed, consist of:

1. Mass flow rate, lbm per hr, inlet temperature, deg R, and outlet temperature, deg R; for fluids s and r of the heat exchanger.
2. Vapor quality at inlet and outlet for fluid r if it is a two-phase fluid.
3. Absolute humidity at inlet and outlet for fluid r if it is a wet gas.
4. Pressure drop, psf, inlet pressure, psf, and outlet pressure, psf, for each side of the heat exchanger.
5. Average value of Reynolds number (except for fluid r if it is two phase), heat-transfer coefficient, Btu per hr sq ft deg R, and heat-transfer surface efficiency.
6. Effectiveness ($\mathcal{E}$) and average total conductance (UA), Btu per hr deg R, of the heat exchanger where,

$$\mathcal{E} \equiv \frac{|T_{out} - T_{in}|_{max}}{|T_{in,r} - T_{in,s}|}$$

$$\frac{1}{UA} \equiv \frac{1}{(\eta_o hA)_{ave,r}} + \frac{1}{(\eta_o hA)_{ave,s}}$$

7. Dew point, deg R, of fluid r if it is a wet gas.
8. Total heat-transfer rate, Btu per hr, and approximate per cent error of the heat balance if the steady-state initial conditions are being considered.

In addition to the above items, a statement may appear indicating that extrapolation of the specified f and j data for the matrix associated

with sides s and/or r was necessary to perform the calculations.

Error Messages and Additional Output

In addition to the normal output, various messages may appear in the output of a case. These messages indicate that difficulty has been encountered during execution of the case. The messages are considered below in the order of their appearance in the program.

1. ONE OF THE MATRICES SPECIFIED IN THE INPUT IS NOT CONTAINED ON THE MATRIX-DATA TAPE

This message is printed in Subroutine KEDMAT; the meaning of the message is clear. There are two possible reasons for its appearance:

a. A matrix identification number has been incorrectly entered in the input data.
b. Data for a particular matrix has been mistakenly assumed to be present on the tape.

In either situation, execution of the case is immediately halted and the entire run is terminated.

If the first reason above is responsible for the message, the case must simply be resubmitted with the correct matrix identification number. On the other hand, if the second reason is responsible for the message, the matrix-data tape must be altered by the addition of data for the matrix in question before the case can be executed successfully. The addition of data to the matrix-data tape is discussed on pages 147 through 163 of Reference 2.

2. THE TRANSIENT ANALYSIS AT TIME THETA = X.XXXXX±XX HAS NOT CONVERGED AFTER XX ITERATIONS. THE RESULTS OF THE FINAL ITERATION, INCLUDING TEMPERATURE (AND VAPOR QUALITY) DISTRIBUTIONS, ARE GIVEN BELOW -

This message is printed in Subroutine CNTRLL if a parallel-flow or a counterflow heat exchanger is being considered, or in Subroutine KROSS if a crossflow heat exchanger is being considered. The message indicates that the iteration procedure to determine the

temperature (and vapor quality) distributions in the heat exchanger has not converged within the allowable tolerance of 0.1 per cent of the temperature range (calculated as $T_{max} - T_{min}$ at $\theta = 0$) in the heat exchanger (0.002 for $X_{v/r}$) after maximum number of iterations. Also the message indicates that the temperature (and vapor quality) distributions of the final iteration are printed in addition to the normal results which would be printed if the final iteration had been convergent. The distributions are printed for both fluids and consist of the distribution at the previous value of θ, the estimated distribution at the current value of θ for the final iteration, the calculated distribution at the current value of θ for the final iteration, and the corresponding deviations between the two sets of values at the current value of θ. The distribution itself, consists of stations at the inlet and exit of each incremental section of the passage-- the inlet of a section coinciding with the exit of the preceding section when there is a preceding section.

Again, there are two possible reasons for the appearance of the message:

a. The iteration precedure does not converge at a sufficient rate for the case under consideration.

b. The iteration procedure either oscillates or diverges for the case under consideration.

An examination of the distributions following the error message should indicate which reason is applicable.

The maximum number of iterations has been set at a sufficiently large value so that even slowly converging cases should meet the allowable tolerance. In those exceptional cases where the allowable tolerance is not met, the estimated and calculated distributions should still be quite near agreement. It must then be decided if, under the circumstances, the resulting maximum deviation is an allowable tolerance so that the results accompanying the distributions may be accepted.

In general, a slow rate of convergence can be expected when the fluid in one passage tends to very closely approach the maximum or minimum temperature in the system. Decreasing the size of such heat exchangers will increase the rate of convergence without introducing a comparable error in the outlet temperatures. Hence, an alternative is available to

accepting the accompanying results when a very slow rate of convergence causes the above error message to appear.

The iteration procedure can oscillate in cases involving a condensing fluid, due to the relatively strong effect of the temperature (and quality) distributions on the heat-transfer coefficient. Decreasing the size of the spatial increments should alleviate this problem in most cases.

The above error message is allowed to appear a total of five times in a given case. If the situation causing it occurs more than five times, the calculations for the case are terminated.

MISCELLANEOUS OPERATIONAL INFORMATION

Program KRONOS occupies approximately 46,000 core locations. Thus, with an average monitor system storage of 12,000 locations, the total storage requirement is comfortably within the core capacity of 64,000 locations.

Of the approximately 46,000 locations occupied by the program, storage of the arrays containing values for each increment or station of the heat exchanger requires 23,020 locations. For counterflow and parallel-flow arrangements, these arrays are one- or two-dimensional, depending upon whether the quantity pertains to one or both sides of the heat exchanger, and allow a maximum of 1001 stations in the calculations. Occupying the same storage locations, the corresponding arrays for multipass-crossflow arrangements are two- and three-dimensional, respectively, again depending upon whether the quantity pertains to one or both sides of the heat exchanger. The sizes of the dimensions associated with the number of increments or stations are variable. They are chosen on the following basis: (a) the maximum number of stations in the x and y directions are in the ratio of the number of increments in the x and y directions obtained from the input data, (b) the arrays fill, as nearly as possible, the 1001 locations for station values or the 1000 locations for increment values.

The execution time of Program KRONOS depends primarily on the number of times θ to be examined in the analysis, the number of spatial increments, and number of iterations required for the convergence of the calculation procedure at each time. However, the execution times given below for the three sample cases discussed in the following section of this report are probably typical of most cases which will be encountered. The sample single-phase counterflow case using 10 spatial increments required approximately 20 seconds for execution to obtain results at 27 values of θ. The wet-gas crossflow case using a total of 100 spatial increments (10 in the x direction

and 10 in the y direction) required approximately 5 minutes, 24 seconds for results at 31 values of θ . The two-phase crossflow case involving the use of a total of 100 spatial increments (10 in the x direction and 10 in the y direction) required approximately 23 minutes, 41 seconds to yield results at 31 values of θ .

As was mentioned previously, part of the input data required by Program KRONOS is supplied by means of a magnetic tape called the matrix-data tape. At the start of each run, this tape must be mounted on the appropriate tape drive corresponding to the internal system logical-unit number 9. This tape-unit number has been given the Fortran-Variable name LTAPE and is assigned the value of 9 in Subroutine KEDMAT. At the conclusion of a run, the matrix-data tape should be removed and saved. The instructions necessary for mounting and saving the tape must be supplied to the computer operator upon submitting the run.

DESCRIPTION OF SAMPLE CASES

In this section, three sample cases involving the calculation of the transient thermal performance of plate-fin heat exchangers are discussed to illustrate the use of Program KRONOS. The three configurations considered are a counterflow single-phase exchanger, a two-pass crossflow wet-gas exchanger, and a two-pass crossflow Freon condenser. The procedures and decisions involved in preparing the input data are described, and completed data-input sheets and resulting computer output data are also presented.

All three cases have several aspects in common. The heat exchangers considered are all constructed of aluminum throughout (k_{met} = 100 Btu per hr ft deg R, ρ_{met} = 168 lbm per cu ft, and $C_{p_{met}}$ = 0.213 Btu per lbm deg R). In addition, the internal dimensions of the heat-transfer matrices in each exchanger correspond to those used in obtaining the experimental f and j data given on the matrix-data tape for each matrix. Therefore, the value of the hydraulic radius stored on the tape is used for each matrix; that is, there is no scaling of the dimensions of any of the matrices. Also, the values of the number of spatial increments used in each case are those set internally in the program (N_x = 10 for counterflow and $N_{x,p}$ = 5, $N_{y,p}$ = 10 for crossflow). Finally, the initial conditions in each case correspond to a steady-state situation from which a "step change" in the inlet conditions of the fluid on one side of the exchanger occurs. The step change in each variable is approximated by a steep ramp; the time interval over which the change occurs is approximately the same order of magnitude as the dwell time of the fluid involved in each case.

Example 1 - Counterflow Single-Phase Exchanger

Problem Statement

This case involves an exchanger in which a liquid stream (60 per cent ethylene glycol, designated as the s fluid) is being used to heat a gas stream (oxygen, designated as the r fluid). The pertinent specifications for both sides of the exchanger are given in Table I along with the core dimensions.

The situation to be investigated is as follows. The heat exchanger is operating at steady-state when a decrease in the inlet temperature of the glycol stream (s fluid) from the initial value of 145 deg F to a final value of 100 deg F occurs over a time interval of 0.01 hr. The problem is to compute the transient performance over a total time interval of 0.3 hr resulting from this change in operating conditions.

Preparation of Input Data

The completed data-input sheets are shown on pages 36 through 37. These contain all of the data (except those stored on the matrix-data tape) necessary to solve the problem described above. Some of the input data have been indicated previously; the remainder arise from the following considerations:

1. The total time interval to be investigated is divided into two time periods, each 0.15 hr in length. The first period ($0.0 \leq \theta < 0.15$) is subdivided into 15 increments to give a nominal time-step size of 0.01 hr; the second ($0.15 \leq \theta \leq 0.30$) is subdivided into 5 increments giving a nominal value of $\Delta\theta = 0.03$ hr. The nominal value of $\Delta\theta$ is to be used in the calculations for each period provided it falls between the minimum and maximum values calculated internally.
2. The parting-plate thickness is 0.001667 ft (0.020 in) and the thickness of the side walls is 0.00834 ft (0.10 in).
3. The fluid-property data for glycol and oxygen are given in Tables 108 and 77 of Reference 3.

Results of Analysis

The printed computer output data for this case are given on pages 38 through 70. The input data specified to the program are printed on the first five pages. These are followed by twenty-eight pages of output containing the results of the calculations. The pertinent results are also given in Figure 1, which shows the transient variation of the inlet and outlet temperatures of both fluids. It will be noted

that the curve on Figure 1 for $T_{s,out}$ versus θ rises slightly in the interval from θ=0 to about θ = 0.06, although this is thermodynamically impossible. Since the dwell time of this fluid is around 0.06 hr (in general, a relatively large value), the curve should be horizontal in this region and equal to the value at θ=0. This minor discrepancy of less than one degree is due to the inaccuracy of the finite-difference procedure at values of time less than the dwell time noted in Appendix IV of Volume I. This serves to illustrate the order of magnitude involved and points up the fact that the inaccuracies are generally negligible.

NORTHERN RESEARCH AND ENGINEERING CORPORATION

DATA INPUT SHEET

ENGINEER: MP PROJECT: Analysis of HX Transients PROJECT NO: 1135B

TITLE: Sample to Illustrate the Use of Program KRONOS SHEET: 1 OF 2

LOCATION

1 6 7 12	13 18 19 24	25 30 31 36	37 42 43 48	49 54 55 60	61 66 67 72
SAMPLE TRANSIENT ANALYSIS OF A COUNTERFLOW SINGLE-PHASE EXCHANGER					
$NAM3					
NFLO=3,	NXIN=10,	RHUNIT=1,	GC=4.169E8,		
ELX=0.333,	ELY=0.5,	ELNF=0.586,			
PP=0.001667,		DENSMP=168,	CPMP=0.213,		
SWL=0.00834,		SWT=0.00834,	DENSMW=168,	CPMW=0.213,	
PINS=5040,	NCORES=3007,	RHINS=0,			
SPLS=0.001667,		CONDMS=100,	DENSMS=168,	CPMS=0.213,	
ICOMPS=2,	NTFPS=7,				
TFPS(1)=500,520,540,560,580,600,620,					
CPXS(1)=.7168,.7337,.7499,.7653,.7799,.7937,.8067,					
VISXS(1)=23.21,14.32,9.997,7.212,5.446,4.347,3.420,					
THKXS(1)=.2252,.2246,.2231,.2220,.2211,.2206,.2192,					
ROXS(1)=67.86,67.46,66.99,66.54,66.09,65.76,65.00,					
PINR=778,	NCORER=2503,	RHINR=0,			
SPLR=0.001667,		CONDMR=100,	DENSMR=168,	CPMR=0.213,	
KPHR=1,					
ICOMPR=1,	ZR=1,	GASKR=48.2,	NTFPR=3,		
TFPR(1)=400,600,800,					
CPXR(1)=.2183,.2210,.2279,					

NORTHERN RESEARCH AND ENGINEERING CORPORATION

DATA INPUT SHEET

ENGINEER: MP PROJECT: Analysis of HX Transients PROJECT NO: 1135B

TITLE: Sample to Illustrate the Use of Program KRONOS SHEET: 2 OF 2

LOCATION

1 6 7 12	13 18 19 24	25 30 31 36	37 42 43 48	49 54 55 60	61 66 67 72
VISXR(1)=.03938,.05382,.06681,					
THKXR(1)=.01167,.01702,.02191,					
INC=2,					
NPER=2,	THPER(1)=.15,.15,		NDTH(1)=15,5,		ITHC(1)=1,1,
IMS=2,	NMS=1,	THWS(1)=0,	WSX(1)=32,		
ITS=2,	NTS=3,				
THTS(1)=0,.01,5,					
TINSX(1)=604.7,559.7,559.7,					
IMR=2,	NMR=1,	THWR(1)=0,	WRX(1)=114,		
ITR=2,	NTR=1,	THTR(1)=0,	TINRX(1)=504.7,		
$END					

** PROGRAM KRONOS - PREDICTION OF THERMAL TRANSIENTS IN COMPACT HEAT EXCHANGERS **

SAMPLE TRANSIENT ANALYSIS OF A COUNTERFLOW SINGLE-PHASE EXCHANGER

*** GENERAL INPUT DATA ***

THE FLOW ARRANGEMENT IS COUNTERFLOW
NUMBER OF CALCULATION INCREMENTS = 10

PROPORTIONALITY FACTOR FOR HYDRAULIC RADIUS = 1.00000+00
PROPORTIONALITY CONSTANT = 4.16900+08

* CORE DIMENSIONS *

LENGTH IN X DIRECTION = 3.33000-01
LENGTH IN Y DIRECTION = 5.00000-01
NONFLOW LENGTH = 5.86000-01

* PARTING-PLATE SPECIFICATIONS *

THICKNESS OF THE PLATE = 1.66700-03
DENSITY OF THE METAL = 1.68000+02
HEAT CAPACITY OF THE METAL = 2.13000-01

* SIDE-WALL SPECIFICATIONS *

WALL THICKNESS PARALLEL TO THE PARTING PLATES = 8.34000-03
WALL THICKNESS NORMAL TO THE PARTING PLATES = 8.34000-03
DENSITY OF THE METAL = 1.68000+02
HEAT CAPACITY OF THE METAL = 2.13000-01

*** FLUID INPUT DATA ***

** FLUID S **

INLET PRESSURE = 5.04000+03

THE FLUID FLOWS IN THE -X DIRECTION

* SPECIFICATIONS OF THE ASSOCIATED MATRIX *

MATRIX IDENTIFICATION NUMBER = 3007

THE VALUE OF HYDRAULIC RADIUS OBTAINED FROM THE MATRIX-DATA TAPE IS USED IN THE CALCULATIONS

SPLITTER-PLATE THICKNESS = 1.66700-03
METAL THERMAL CONDUCTIVITY = 1.00000+02
METAL DENSITY = 1.68000+02
METAL HEAT CAPACITY = 2.13000-01

* FLUID PROPERTIES *

THE FLUID IS A LIQUID

TEMPERATURE	SPECIFIC HEAT	VISCOSITY	THERMAL CONDUCTIVITY	DENSITY
5.00000+02	7.16800-01	2.32100+01	2.25200-01	6.78600+01
5.20000+02	7.33700-01	1.43200+01	2.24600-01	6.74600+01
5.40000+02	7.49900-01	9.99700+00	2.23100-01	6.69900+01
5.60000+02	7.65300-01	7.21200+00	2.22000-01	6.65400+01
5.80000+02	7.79900-01	5.44600+00	2.21100-01	6.60900+01
6.00000+02	7.93700-01	4.34700+00	2.20600-01	6.57600+01
6.20000+02	8.06700-01	3.42000+00	2.19200-01	6.50000+01

** FLUID R **

INLET PRESSURE = 7.78000+02

THE FLUID FLOWS IN THE +X DIRECTION

* SPECIFICATIONS OF THE ASSOCIATED MATRIX *

MATRIX IDENTIFICATION NUMBER = 2503

THE VALUE OF HYDRAULIC RADIUS OBTAINED FROM THE MATRIX-DATA TAPE IS USED IN THE CALCULATIONS

SPLITTER-PLATE THICKNESS = 1.66700-03
METAL THERMAL CONDUCTIVITY = 1.00000+02
METAL DENSITY = 1.68000+02
METAL HEAT CAPACITY = 2.13000-01

* FLUID PROPERTIES *

THE FLUID IS A GAS

COMPRESSIBILITY FACTOR = 1.00000+00
GAS CONSTANT = 4.82000+01

TEMPERATURE	SPECIFIC HEAT	VISCOSITY	THERMAL CONDUCTIVITY
4.00000+02	2.16300-01	3.93800-02	1.16700-02
6.00000+02	2.21000-01	5.38200-02	1.70200-02
8.00000+02	2.27900-01	6.68100-02	2.19100-02

*** TIME-RELATED INPUT DATA ***

THE INITIAL CONDITIONS CORRESPOND TO THE STEADY STATE

THE TRANSIENT INVESTIGATION IS DIVIDED INTO 2 TIME PERIODS

TIME PERIOD	LENGTH	NOMINAL NUMBER OF INCREMENTS	OPTION
1	1.50000-01	15	1
2	1.50000-01	5	1

NOTE - OPTION 0 INDICATES THE SIZE OF THE TIME INCREMENT CORRESPONDS TO THE NOMINAL NUMBER OF INCREMENTS

OPTION 1 INDICATES THE SIZE OF THE TIME INCREMENT CORRESPONDS TO THE NOMINAL NUMBER OF INCREMENTS, BUT IT IS BOUNDED BY CALCULATED MAXIMUM AND MINIMUM VALUES

OPTION 2 INDICATES THE SIZE OF THE TIME INCREMENT CORRESPONDS TO THE AVERAGE OF THE CALCULATED MAXIMUM AND MINIMUM VALUES

** FLUID S **

TIME	MASS FLOW RATE
0.00000	3.20000+01

TIME	INLET TEMPERATURE
0.00000	6.04700+02
1.00000-02	5.59700+02
5.00000+00	5.59700+02

** FLUID R **

TIME	MASS FLOW RATE
0.00000	1.14000+02

TIME	INLET TEMPERATURE
0.00000	5.04700+02

*** OUTPUT OF THE TRANSIENT ANALYSIS ***

** GENERAL OUTPUT DATA **

TRIX NUMBER 3007 (TRIANGULAR, LRAT = 21.7) ON THE S SIDE
TRIX NUMBER 2503 (WAVY, AF/A = 0.900) ON THE R SIDE

	S SIDE	R SIDE
HYDRAULIC RADIUS	2.40097-03	1.71751-03
PLATE SPACING	2.08200-02	3.44000-02
FIN SPACING	6.95000-03	4.68000-03
FIN THICKNESS	5.00000-04	5.00000-04
VOID VOLUME	3.21181-02	5.04528-02
TOTAL HEAT-TRANSFER AREA	1.27088+01	2.79079+01

CORE VOLUME	9.75690-02
CORE WEIGHT (DRY)	2.62176+00
HEAT CAPACITY OF CORE STRUCTURE	5.58434-01
HEAT CAPACITY OF SIDE WALL IN CONTACT WITH FLUID S	9.90995-02
HEAT CAPACITY OF SIDE WALL IN CONTACT WITH FLUID R	1.34722-01

** OUTPUT DATA FOR TIME THETA = 0.00000 **
(INITIAL CONDITIONS)

	S SIDE	R SIDE
MASS FLOW RATE	3.20000+01	1.14000+02
INLET TEMPERATURE	6.04700+02	5.04700+02
OUTLET TEMPERATURE	5.19151+02	5.88576+02
PRESSURE DROP	5.27345-03	7.39712-01
INLET PRESSURE	5.04000+03	7.78000+02
OUTLET PRESSURE	5.03999+03	7.77260+02
AVERAGE REYNOLDS NUMBER	4.69058-01	1.03714+02
AVERAGE HEAT-TRANSFER COEFFICIENT	4.15414+01	6.62328+00
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	9.54335-01	9.77844-01

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE S WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE R WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EFFECTIVENESS	8.55494-01
AVERAGE TOTAL CONDUCTANCE (UA)	1.33025+02
TOTAL HEAT TRANSFER RATE	2.10170+03
PERCENT ERROR IN HEAT BALANCE	4.35409-01

** OUTPUT DATA FOR TIME THETA = 6.67689-03 **

	S SIDE	R SIDE
MASS FLOW RATE	3.20000+01	1.14000+02
INLET TEMPERATURE	5.74654+02	5.04700+02
OUTLET TEMPERATURE	5.19438+02	5.80055+02
PRESSURE DROP	5.26823-03	7.39570-01
INLET PRESSURE	5.04000+03	7.78000+02
OUTLET PRESSURE	5.03999+03	7.77260+02
AVERAGE REYNOLDS NUMBER	4.42802-01	1.03834+02
AVERAGE HEAT-TRANSFER COEFFICIENT	4.17881+01	6.61885+00
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	9.54082-01	9.77859-01

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE S WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE R WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EFFECTIVENESS	1.07720+00
AVERAGE TOTAL CONDUCTANCE (UA)	1.33159+02

** OUTPUT DATA FOR TIME THETA = 1.33605-02 **

	S SIDE	R SIDE
MASS FLOW RATE	3.20000+01	1.14000+02
INLET TEMPERATURE	5.59700+02	5.04700+02
OUTLET TEMPERATURE	5.19660+02	5.72513+02
PRESSURE DROP	5.25314-03	7.39490-01
INLET PRESSURE	5.04000+03	7.78000+02
OUTLET PRESSURE	5.03999+03	7.77261+02
AVERAGE REYNOLDS NUMBER	4.22098-01	1.03983+02
AVERAGE HEAT-TRANSFER COEFFICIENT	4.19949+01	6.61343+00
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	9.53872-01	9.77876-01

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE S WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE R WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EFFECTIVENESS	1.23297+00
AVERAGE TOTAL CONDUCTANCE (UA)	1.33245+02

** OUTPUT DATA FOR TIME THETA = 2.00499-02 **

	S SIDE	R SIDE
MASS FLOW RATE	3.20000+01	1.14000+02
INLET TEMPERATURE	5.59700+02	5.04700+02
OUTLET TEMPERATURE	5.19842+02	5.68208+02
PRESSURE DROP	5.24934-03	7.39398-01
INLET PRESSURE	5.04000+03	7.78000+02
OUTLET PRESSURE	5.03999+03	7.77261+02
AVERAGE REYNOLDS NUMBER	4.09997-01	1.04127+02
AVERAGE HEAT-TRANSFER COEFFICIENT	4.20291+01	6.60826+00
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	9.53836-01	9.77893-01

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE S WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE R WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EFFECTIVENESS	1.15469+00
AVERAGE TOTAL CONDUCTANCE (UA)	1.33197+02

** OUTPUT DATA FOR TIME THETA = 2.67428-02 **

	S SIDE	R SIDE
MASS FLOW RATE	3.20000+01	1.14000+02
INLET TEMPERATURE	5.59700+02	5.04700+02
OUTLET TEMPERATURE	5.19995+02	5.65060+02
PRESSURE DROP	5.26763-03	7.39002-01
INLET PRESSURE	5.04000+03	7.78000+02
OUTLET PRESSURE	5.03999+03	7.77261+02
AVERAGE REYNOLDS NUMBER	3.99916-01	1.04272+02
AVERAGE HEAT-TRANSFER COEFFICIENT	4.20338+01	6.60311+00
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	9.53831-01	9.77910-01

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE S WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE R WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EFFECTIVENESS	1.09745+00
AVERAGE TOTAL CONDUCTANCE (UA)	1.33125+02

** OUTPUT DATA FOR TIME THETA = 3.34388-02 **

	S SIDE	R SIDE
MASS FLOW RATE	3.20000+01	1.14000+02
INLET TEMPERATURE	5.59700+02	5.04700+02
OUTLET TEMPERATURE	5.20120+02	5.62765+02
PRESSURE DROP	5.31500-03	7.38187-01
INLET PRESSURE	5.04000+03	7.78000+02
OUTLET PRESSURE	5.03999+03	7.77262+02
AVERAGE REYNOLDS NUMBER	3.91247-01	1.04412+02
AVERAGE HEAT-TRANSFER COEFFICIENT	4.20498+01	6.59814+00
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	9.53815-01	9.77926-01

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE S WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE R WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EFFECTIVENESS	1.05573+00
AVERAGE TOTAL CONDUCTANCE (UA)	1.33066+02

** OUTPUT DATA FOR TIME THETA = 4.01377-02 **

	S SIDE	R SIDE
MASS FLOW RATE	3.20000+01	1.14000+02
INLET TEMPERATURE	5.59700+02	5.04700+02
OUTLET TEMPERATURE	5.20211+02	5.61027+02
PRESSURE DROP	5.39322-03	7.36943-01
INLET PRESSURE	5.04000+03	7.78000+02
OUTLET PRESSURE	5.03999+03	7.77263+02
AVERAGE REYNOLDS NUMBER	3.83579-01	1.04548+02
AVERAGE HEAT-TRANSFER COEFFICIENT	4.20729+01	6.59337+00
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	9.53791-01	9.77941-01

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE S WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE R WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EFFECTIVENESS	1.02413+00
AVERAGE TOTAL CONDUCTANCE (UA)	1.33014+02

** OUTPUT DATA FOR TIME THETA = 4.68392-02 **

	S SIDE	R SIDE
MASS FLOW RATE	3.20000+01	1.14000+02
INLET TEMPERATURE	5.59700+02	5.04700+02
OUTLET TEMPERATURE	5.20256+02	5.59663+02
PRESSURE DROP	5.49340-03	7.35355-01
INLET PRESSURE	5.04000+03	7.78000+02
OUTLET PRESSURE	5.03999+03	7.77265+02
AVERAGE REYNOLDS NUMBER	3.76712-01	1.04680+02
AVERAGE HEAT-TRANSFER COEFFICIENT	4.20988+01	6.58881+00
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	9.53765-01	9.77956-01

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE S WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE R WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EFFECTIVENESS	9.99328-01
AVERAGE TOTAL CONDUCTANCE (UA)	1.32968+02

** OUTPUT DATA FOR TIME THETA = 5.35430-02 **

	S SIDE	R SIDE
MASS FLOW RATE	3.20000+01	1.14000+02
INLET TEMPERATURE	5.59700+02	5.04700+02
OUTLET TEMPERATURE	5.20243+02	5.58561+02
PRESSURE DROP	5.60689-03	7.33544-01
INLET PRESSURE	5.04000+03	7.78000+02
OUTLET PRESSURE	5.03999+03	7.77266+02
AVERAGE REYNOLDS NUMBER	3.70342-01	1.04806+02
AVERAGE HEAT-TRANSFER COEFFICIENT	4.21277+01	6.58444+00
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	9.53736-01	9.77970-01

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE S WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE R WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EFFECTIVENESS	9.79300-01
AVERAGE TOTAL CONDUCTANCE (UA)	1.32927+02

** OUTPUT DATA FOR TIME THETA = 6.02491-02 **

	S SIDE	R SIDE
MASS FLOW RATE	3.20000+01	1.14000+02
INLET TEMPERATURE	5.59700+02	5.04700+02
OUTLET TEMPERATURE	5.20162+02	5.57651+02
PRESSURE DROP	5.72579-03	7.31625-01
INLET PRESSURE	5.04000+03	7.78000+02
OUTLET PRESSURE	5.03999+03	7.77268+02
AVERAGE REYNOLDS NUMBER	3.64491-01	1.04927+02
AVERAGE HEAT-TRANSFER COEFFICIENT	4.21552+01	6.58028+00
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	9.53708-01	9.77984-01

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE S WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE R WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EFFECTIVENESS	9.62749-01
AVERAGE TOTAL CONDUCTANCE (UA)	1.32888+02

** OUTPUT DATA FOR TIME THETA = 6.69572-02 **

	S SIDE	R SIDE
MASS FLOW RATE	3.20000+01	1.14000+02
INLET TEMPERATURE	5.59700+02	5.04700+02
OUTLET TEMPERATURE	5.20009+02	5.56885+02
PRESSURE DROP	5.84420-03	7.29689-01
INLET PRESSURE	5.04000+03	7.78000+02
OUTLET PRESSURE	5.03999+03	7.77270+02
AVERAGE REYNOLDS NUMBER	3.59190-01	1.05042+02
AVERAGE HEAT-TRANSFER COEFFICIENT	4.21814+01	6.57634+00
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	9.53681-01	9.77997-01

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE S WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE R WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EFFECTIVENESS	9.48811-01
AVERAGE TOTAL CONDUCTANCE (UA)	1.32851+02

** OUTPUT DATA FOR TIME THETA = 7.36673-02 **

	S SIDE	R SIDE
MASS FLOW RATE	3.20000+01	1.14000+02
INLET TEMPERATURE	5.59700+02	5.04700+02
OUTLET TEMPERATURE	5.19789+02	5.56229+02
PRESSURE DROP	5.95838-03	7.27799-01
INLET PRESSURE	5.04000+03	7.78000+02
OUTLET PRESSURE	5.03999+03	7.77272+02
AVERAGE REYNOLDS NUMBER.	3.54356-01	1.05151+02
AVERAGE HEAT-TRANSFER COEFFICIENT	4.22067+01	6.57261+00
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	9.53655-01	9.78009-01

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE S WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE R WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EFFECTIVENESS	9.36890-01
AVERAGE TOTAL CONDUCTANCE (UA)	1.32816+02

** OUTPUT DATA FOR TIME THETA = 8.03792-02 **

	S SIDE	R SIDE
MASS FLOW RATE	3.20000+01	1.14000+02
INLET TEMPERATURE	5.59700+02	5.04700+02
OUTLET TEMPERATURE	5.19512+02	5.55661+02
PRESSURE DROP	6.06628-03	7.25995-01
INLET PRESSURE	5.04000+03	7.78000+02
OUTLET PRESSURE	5.03999+03	7.77274+02
AVERAGE REYNOLDS NUMBER	3.49948-01	1.05253+02
AVERAGE HEAT-TRANSFER COEFFICIENT	4.22308+01	6.56912+00
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	9.53630-01	9.78020-01

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE S WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE R WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EFFECTIVENESS	9.26570-01
AVERAGE TOTAL CONDUCTANCE (UA)	1.32784+02

** OUTPUT DATA FOR TIME THETA = 8.70929-02 **

	S SIDE	R SIDE
MASS FLOW RATE	3.20000+01	1.14000+02
INLET TEMPERATURE	5.59700+02	5.04700+02
OUTLET TEMPERATURE	5.19190+02	5.55165+02
PRESSURE DROP	6.16699-03	7.24298-01
INLET PRESSURE	5.04000+03	7.78000+02
OUTLET PRESSURE	5.03999+03	7.77276+02
AVERAGE REYNOLDS NUMBER	3.45932-01	1.05349+02
AVERAGE HEAT-TRANSFER COEFFICIENT	4.22536+01	6.56587+00
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	9.53607-01	9.78031-01

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE S WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE R WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EFFECTIVENESS	9.17546-01
AVERAGE TOTAL CONDUCTANCE (UA)	1.32754+02

** OUTPUT DATA FOR TIME THETA = 9.38081-02 **

	S SIDE	R SIDE
MASS FLOW RATE	3.20000+01	1.14000+02
INLET TEMPERATURE	5.59700+02	5.04700+02
OUTLET TEMPERATURE	5.18840+02	5.54728+02
PRESSURE DROP	6.26030-03	7.22718-01
INLET PRESSURE	5.04000+03	7.78000+02
OUTLET PRESSURE	5.03999+03	7.77277+02
AVERAGE REYNOLDS NUMBER	3.42281-01	1.05438+02
AVERAGE HEAT-TRANSFER COEFFICIENT	4.22747+01	6.56285+00
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	9.53586-01	9.78041-01

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE S WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE R WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EFFECTIVENESS	9.09593-01
AVERAGE TOTAL CONDUCTANCE (UA)	1.32726+02

** OUTPUT DATA FOR TIME THETA = 1.01441-01 **

	S SIDE	R SIDE
MASS FLOW RATE	3.20000+01	1.14000+02
INLET TEMPERATURE	5.59700+02	5.04700+02
OUTLET TEMPERATURE	5.18386+02	5.54295+02
PRESSURE DROP	6.35152-03	7.21037-01
INLET PRESSURE	5.04000+03	7.78000+02
OUTLET PRESSURE	5.03999+03	7.77279+02
AVERAGE REYNOLDS NUMBER	3.38441-01	1.05533+02
AVERAGE HEAT-TRANSFER COEFFICIENT	4.23058+01	6.55966+00
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	9.53554-01	9.78051-01

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE S WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE R WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EFFECTIVENESS	9.01721-01
AVERAGE TOTAL CONDUCTANCE (UA)	1.32703+02

** OUTPUT DATA FOR TIME THETA = 1.10971-01 **

	S SIDE	R SIDE
MASS FLOW RATE	3.20000+01	1.14000+02
INLET TEMPERATURE	5.59700+02	5.04700+02
OUTLET TEMPERATURE	5.17784+02	5.53825+02
PRESSURE DROP	6.45154-03	7.19106-01
INLET PRESSURE	5.04000+03	7.78000+02
OUTLET PRESSURE	5.03999+03	7.77281+02
AVERAGE REYNOLDS NUMBER	3.34086-01	1.05641+02
AVERAGE HEAT-TRANSFER COEFFICIENT	4.23466+01	6.55601+00
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	9.53513-01	9.78063-01

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE S WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE R WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EFFECTIVENESS	8.93178-01
AVERAGE TOTAL CONDUCTANCE (UA)	1.32681+02

** OUTPUT DATA FOR TIME THETA = 1.20971-01 **

	S SIDE	R SIDE
MASS FLOW RATE	3.20000+01	1.14000+02
INLET TEMPERATURE	5.59700+02	5.04700+02
OUTLET TEMPERATURE	5.17200+02	5.53383+02
PRESSURE DROP	6.55751-03	7.17298-01
INLET PRESSURE	5.04000+03	7.78000+02
OUTLET PRESSURE	5.03999+03	7.77283+02
AVERAGE REYNOLDS NUMBER	3.30074-01	1.05745+02
AVERAGE HEAT-TRANSFER COEFFICIENT	4.23725+01	6.55253+00
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	9.53486-01	9.78074-01

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE S WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE R WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EFFECTIVENESS	8.85153-01
AVERAGE TOTAL CONDUCTANCE (UA)	1.32650+02

** OUTPUT DATA FOR TIME THETA = 1.30971-01 **

	S SIDE	R SIDE
MASS FLOW RATE	3.20000+01	1.14000+02
INLET TEMPERATURE	5.59700+02	5.04700+02
OUTLET TEMPERATURE	5.16675+02	5.52997+02
PRESSURE DROP	6.65600-03	7.15706-01
INLET PRESSURE	5.04000+03	7.78000+02
OUTLET PRESSURE	5.03999+03	7.77284+02
AVERAGE REYNOLDS NUMBER	3.26597-01	1.05837+02
AVERAGE HEAT-TRANSFER COEFFICIENT	4.23918+01	6.54944+00
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	9.53467-01	9.78084-01

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE S WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE R WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EFFECTIVENESS	8.78129-01
AVERAGE TOTAL CONDUCTANCE (UA)	1.32620+02

** OUTPUT DATA FOR TIME THETA = 1.40971-01 **

	S SIDE	R SIDE
MASS FLOW RATE	3.20000+01	1.14000+02
INLET TEMPERATURE	5.59700+02	5.04700+02
OUTLET TEMPERATURE	5.16206+02	5.52662+02
PRESSURE DROP	6.74354-03	7.14309-01
INLET PRESSURE	5.04000+03	7.78000+02
OUTLET PRESSURE	5.03999+03	7.77286+02
AVERAGE REYNOLDS NUMBER	3.23587-01	1.05918+02
AVERAGE HEAT-TRANSFER COEFFICIENT	4.24081+01	6.54673+00
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	9.53450-01	9.78093-01

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE S WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE R WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EFFECTIVENESS	8.72031-01
AVERAGE TOTAL CONDUCTANCE (UA)	1.32592+02

** OUTPUT DATA FOR TIME THETA = 1.50971-01 **

	S SIDE	R SIDE
MASS FLOW RATE	3.20000+01	1.14000+02
INLET TEMPERATURE	5.59700+02	5.04700+02
OUTLET TEMPERATURE	5.15791+02	5.52370+02
PRESSURE DROP	6.82113-03	7.13086-01
INLET PRESSURE	5.04000+03	7.78000+02
OUTLET PRESSURE	5.03999+03	7.77287+02
AVERAGE REYNOLDS NUMBER	3.20978-01	1.05988+02
AVERAGE HEAT-TRANSFER COEFFICIENT	4.24217+01	6.54435+00
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	9.53436-01	9.78101-01

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE S WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE R WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EFFECTIVENESS	8.66726-01
AVERAGE TOTAL CONDUCTANCE (UA)	1.32568+02

** OUTPUT DATA FOR TIME THETA = 1.76092-01 **

	S SIDE	R SIDE
MASS FLOW RATE	3.20000+01	1.14000+02
INLET TEMPERATURE	5.59700+02	5.04700+02
OUTLET TEMPERATURE	5.14852+02	5.51871+02
PRESSURE DROP	6.92676-03	7.10588-01
INLET PRESSURE	5.04000+03	7.78000+02
OUTLET PRESSURE	5.03999+03	7.77289+02
AVERAGE REYNOLDS NUMBER	3.15694-01	1.06128+02
AVERAGE HEAT-TRANSFER COEFFICIENT	4.25085+01	6.53969+00
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	9.53348-01	9.78116-01

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE S WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE R WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EFFECTIVENESS	8.57650-01
AVERAGE TOTAL CONDUCTANCE (UA)	1.32566+02

** OUTPUT DATA FOR TIME THETA = 2.03279-01 **

	S SIDE	R SIDE
MASS FLOW RATE	3.20000+01	1.14000+02
INLET TEMPERATURE	5.59700+02	5.04700+02
OUTLET TEMPERATURE	5.14139+02	5.51413+02
PRESSURE DROP	7.06827-03	7.08568-01
INLET PRESSURE	5.04000+03	7.78000+02
OUTLET PRESSURE	5.03999+03	7.77291+02
AVERAGE REYNOLDS NUMBER	3.11427-01	1.06246+02
AVERAGE HEAT-TRANSFER COEFFICIENT	4.25259+01	6.53575+00
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	9.53330-01	9.78129-01

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE S WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE R WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EFFECTIVENESS	8.49333-01
AVERAGE TOTAL CONDUCTANCE (UA)	1.32521+02

** OUTPUT DATA FOR TIME THETA = 2.33279-01 **

	S SIDE	R SIDE
MASS FLOW RATE	3.20000+01	1.14000+02
INLET TEMPERATURE	5.59700+02	5.04700+02
OUTLET TEMPERATURE	5.13585+02	5.51053+02
PRESSURE DROP	7.18317-03	7.06980-01
INLET PRESSURE	5.04000+03	7.78000+02
OUTLET PRESSURE	5.03999+03	7.77293+02
AVERAGE REYNOLDS NUMBER	3.08111-01	1.06339+02
AVERAGE HEAT-TRANSFER COEFFICIENT	4.25389+01	6.53265+00
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	9.53317-01	9.78139-01

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE S WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE R WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EFFECTIVENESS	8.42785-01
AVERAGE TOTAL CONDUCTANCE (UA)	1.32486+02

** OUTPUT DATA FOR TIME THETA = 2.63279-01 **

	S SIDE	R SIDE
MASS FLOW RATE	3.20000+01	1.14000+02
INLET TEMPERATURE	5.59700+02	5.04700+02
OUTLET TEMPERATURE	5.13202+02	5.50808+02
PRESSURE DROP	7.27095-03	7.05908-01
INLET PRESSURE	5.04000+03	7.78000+02
OUTLET PRESSURE	5.03999+03	7.77294+02
AVERAGE REYNOLDS NUMBER	3.05907-01	1.06399+02
AVERAGE HEAT-TRANSFER COEFFICIENT	4.25394+01	6.53065+00
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	9.53317-01	9.78145-01

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE S WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE R WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EFFECTIVENESS	8.45420-01
AVERAGE TOTAL CONDUCTANCE (UA)	1.32457+02

** OUTPUT DATA FOR TIME THETA = 2.93279-01 **

	S SIDE	R SIDE
MASS FLOW RATE	3.20000+01	1.14000+02
INLET TEMPERATURE	5.59700+02	5.04700+02
OUTLET TEMPERATURE	5.12931+02	5.50619+02
PRESSURE DROP	7.33308-03	7.05105-01
INLET PRESSURE	5.04000+03	7.78000+02
OUTLET PRESSURE	5.03999+03	7.77295+02
AVERAGE REYNOLDS NUMBER	3.04245-01	1.06449+02
AVERAGE HEAT-TRANSFER COEFFICIENT	4.25436+01	6.52902+00
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	9.53312-01	9.78150-01

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE S WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE R WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EFFECTIVENESS	8.50337-01
AVERAGE TOTAL CONDUCTANCE (UA)	1.32436+02

** OUTPUT DATA FOR TIME THETA = 3.23279-01 **

	S SIDE	R SIDE
MASS FLOW RATE	3.20000+01	1.14000+02
INLET TEMPERATURE	5.59700+02	5.04700+02
OUTLET TEMPERATURE	5.12745+02	5.50500+02
PRESSURE DROP	7.37744-03	7.04595-01
INLET PRESSURE	5.04000+03	7.78000+02
OUTLET PRESSURE	5.03999+03	7.77295+02
AVERAGE REYNOLDS NUMBER	3.03211-01	1.06476+02
AVERAGE HEAT-TRANSFER COEFFICIENT	4.25424+01	6.52811+00
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	9.53314-01	9.78153-01

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE S WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE R WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EFFECTIVENESS	8.53721-01
AVERAGE TOTAL CONDUCTANCE (UA)	1.32421+02

Example 2 - Crossflow Wet-Gas Exchanger

Problem Statement

This case involves an exchanger in which a humid airstream (designated as the r fluid) is being cooled and dehumidified by a dry airstream (designated as the s fluid). The pertinent specifications for both sides of the exchanger are given in Table II along with the core dimensions.

The situation to be considered is the following: While the heat exchanger is operating at steady state, the flow rate and inlet temperature and humidity of the humid airstream increases over a time interval of 10^{-4} hr from the initial to the final values given in Table II. The problem is to determine the transient performance over a total time interval of 0.0045 hr resulting from these changes.

Preparation of Input Data

The completed data-input sheets are shown on pages 73 through 74. These contain all the necessary data except those stored on the matrix-data tape. Some of the input data have already been indicated; the remainder arise from the following considerations:

1. The total time interval to be investigated is divided into two time periods, the first 5×10^{-4} hr in length and the second 4×10^{-3} hr. The first period ($0.0 \leq \theta < 5 \times 10^{-4}$) is subdivided into 5 increments to give a nominal time-step size of 10^{-4} hr; the second ($5 \times 10^{-4} \leq \theta \leq 4.5 \times 10^{-3}$) is subdivided into 20 increments giving a nominal value of $\Delta\theta = 2 \times 10^{-4}$ hr. The nominal value of $\Delta\theta$ is to be used in the calculations for each period provided it falls within the calculated minimum and maximum values.
2. The parting-plate thickness is 0.001667 ft (0.020 in) and the thickness of the side walls is 0.00834 ft (0.10 in).
3. The fluid property-data for the dry air and the vapor component (water) are given in Tables 7, 91, and 92 of Reference 3.

Results of Analysis

The printed computer output data for this case are given on pages 75 through 112. The input data specified to the program are printed on the first six pages. These are followed by thirty-two pages of output containing the results of the calculations. The pertinent results are also given in Figure 2, which shows the transient variation of the inlet and outlet temperatures of both fluids and the inlet and outlet humidity of the humid airstream (r fluid).

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DATA INPUT SHEET

ENGINEER: MP PROJECT: Analysis of HX Transients PROJECT NO: 1135B

TITLE: Sample to Illustrate the Use of Program KRONOS SHEET: 1 OF 2

LOCATION

1 6	7 12	13 18	19 24	25 30	31 36	37 42	43 48	49 54	55 60	61 66	67 72
SAMPLE TRANSIENT ANALYSIS OF A CROSSFLOW WET-GAS EXCHANGER											
$NAM3											
NFLO=1,		NPC=2,		NXPPIN=5,		NYPIN=10,					
RHUNIT=1,		GC=4.169E8,									
ELX=1,		ELY=.75,		ELNF=.896,							
PP=.001667,				DENSMP=168,		CPMP=.213,					
SWL=.00834,				SWT=.00834,		DENSMW=168,		CPMW=.213,			
PINS=4240,		NCORES=4013,		RHINS=0,							
SPLS=.001667,				CONDMS=100,		DENSMS=168,		CPMS=.213,			
ICOMPS=1,		ZS=1,		GASKS=53.3,		NTFPS=2,					
TFPS(1)=400,		600,		CPXS(1)=.2402,.2408,				VISXS(1)=.03521,.04818,			
THKXS(1)=.0153,.01662,											
PINR=2120,		NCORER=3002,		RHINR=0,							
SPLR=.001667,				CONDMR=100,		DENSMR=168,		CPMR=.213,			
KPHR=3,											
ZG=1,		GASKG=53.3,		EMWG=28.96,		NTFPG=2,					
TFPG(1)=400,		600,		CPXG(1)=.2402,.2408,				VISXG(1)=.03521,.04818,			
THKXG(1)=.0153,.01662,											
ZV=1,		GASKV=85.9,		EMWV=18.02,		NTSAT=5,		NTFPV=3,			
TSATX(1)=509.7,519.7,539.7,559.7,579.7,											

NORTHERN RESEARCH AND ENGINEERING CORPORATION

DATA INPUT SHEET

ENGINEER: MP PROJECT: Analysis of HX Transients PROJECT NO: 11358

TITLE: Sample to Illustrate the Use of Program KRONOS SHEET: 2 OF 2

LOCATION

1 6	7 12	13 16	17 24	25 28	29 36	37 42	43 48	49 54	55 60	61 66	67 72
PSATX(1)=25		.69,36.97,73		.12,136.9,24		4.2,					
HFGSTX(1)=1		066,1060,104		9,1037,1026,							
TFPV(1)=500		,550,600,		CPXV(1)=.361		5,.3983,.4351,					
VISXV(1)=.0		2346,.02550,		.02791,		THKXV(1)=.00		9368,.01048,		.01175,	
INC=2,											
NPER=2,		THPER(1)=0.0		005,0.004,		NDTH(1)=5,20,				ITHC(1)=1,1,	
IMS=2,		NMS=1,		THWS(1)=0,		WSX(1)=5280,					
ITS=2,		NTS=1,		THTS(1)=0,		TINSX(1)=509		.7,			
IMR=2,		NMR=3,		THWR(1)=0,1.		0E-4,25.0E-4,					
				WRX(1)=1854,		1908,1908,					
ITR=2,		NTR=3,		THTR(1)=0,1.		0E-4,25.0E-4,					
				TINRX(1)=559		.7,574.7,574		.7,			
IOM=2,		NOM=3,		THOM(1)=0,1.		0E-4,25.0E-4,					
				OMX(1)=.03,.		06,.06,					
$END											

```
** PROGRAM KRONOS - PREDICTION OF THERMAL TRANSIENTS IN COMPACT HEAT EXCHANGERS **

                SAMPLE TRANSIENT ANALYSIS OF A CROSSFLOW WET-GAS EXCHANGER

                          *** GENERAL INPUT DATA ***

                    THE FLOW ARRANGEMENT IS MULTIPASS CROSSFLOW
                                NUMBER OF PASSES =  2
 JMBER OF CALCULATION INCREMENTS PER PASS IN X DIRECTION =  5
.UMBER OF CALCULATION INCREMENTS PER PASS IN Y DIRECTION = 10

        PROPORTIONALITY FACTOR FOR HYDRAULIC RADIUS =   1.00000+00
                      PROPORTIONALITY CONSTANT =   4.16900+08

                            * CORE DIMENSIONS *

                     LENGTH IN X DIRECTION =   1.00000+00
                     LENGTH IN Y DIRECTION =   7.50000-01
                            NONFLOW LENGTH =   8.96000-01

                      * PARTING-PLATE SPECIFICATIONS *

                   THICKNESS OF THE PLATE =   1.66700-03
                        DENSITY OF THE METAL =   1.68000+02
                 HEAT CAPACITY OF THE METAL =   2.13000-01

                          * SIDE-WALL SPECIFICATIONS *

     WALL THICKNESS PARALLEL TO THE PARTING PLATES =   8.34000-03
       WALL THICKNESS NORMAL TO THE PARTING PLATES =   8.34000-03
                        DENSITY OF THE METAL =   1.68000+02
                 HEAT CAPACITY OF THE METAL =   2.13000-01
```

*** FLUID INPUT DATA ***

** FLUID S **

INLET PRESSURE = 4.24000+03

THE FLUID FLOWS IN THE +Y DIRECTION

* SPECIFICATIONS OF THE ASSOCIATED MATRIX *

MATRIX IDENTIFICATION NUMBER = 4013

THE VALUE OF HYDRAULIC RADIUS OBTAINED FROM THE MATRIX-DATA TAPE IS USED IN THE CALCULATIONS

SPLITTER-PLATE THICKNESS = 1.66700-03
METAL THERMAL CONDUCTIVITY = 1.00000+02
METAL DENSITY = 1.68000+02
METAL HEAT CAPACITY = 2.13000-01

* FLUID PROPERTIES *

THE FLUID IS A GAS

COMPRESSIBILITY FACTOR = 1.00000+00
GAS CONSTANT = 5.33000+01

TEMPERATURE	SPECIFIC HEAT	VISCOSITY	THERMAL CONDUCTIVITY
4.00000+02	2.40200-01	3.52100-02	1.15300-02
6.00000+02	2.40800-01	4.81800-02	1.66200-02

** FLUID R **

INLET PRESSURE = 2.12000+03

THE FLUID FLOWS IN THE +X DIRECTION

* SPECIFICATIONS OF THE ASSOCIATED MATRIX *

MATRIX IDENTIFICATION NUMBER = 3002

THE VALUE OF HYDRAULIC RADIUS OBTAINED FROM THE MATRIX-DATA TAPE IS USED IN THE CALCULATIONS

SPLITTER-PLATE THICKNESS = 1.66700-03
METAL THERMAL CONDUCTIVITY = 1.00000+02
METAL DENSITY = 1.68000+02
METAL HEAT CAPACITY = 2.13000-01

* FLUID PROPERTIES *

THE FLUID IS A WET GAS

GAS COMPONENT

COMPRESSIBILITY FACTOR = 1.00000+00
GAS CONSTANT = 5.33000+01
MOLECULAR WEIGHT = 2.89600+01

TEMPERATURE	SPECIFIC HEAT	VISCOSITY	THERMAL CONDUCTIVITY
4.00000+02	2.40200-01	3.52100-02	1.15300-02
6.00000+02	2.40800-01	4.81600-02	1.66200-02

VAPOR COMPONENT

COMPRESSIBILITY FACTOR = 1.00000+00
GAS CONSTANT = 8.59000+01

MOLECULAR WEIGHT = 1.80200+01

SATURATION TEMPERATURE	PRESSURE	LATENT HEAT OF VAPORIZATION
5.09700+02	2.56900+01	1.06600+03
5.19700+02	3.69700+01	1.06000+03
5.39700+02	7.31200+01	1.04900+03
5.59700+02	1.36900+02	1.03700+03
5.79700+02	2.44200+02	1.02600+03

TEMPERATURE	SPECIFIC HEAT	VISCOSITY	THERMAL CONDUCTIVITY
5.00000+02	3.61500-01	2.34600-02	9.36800-03
5.50000+02	3.98300-01	2.55000-02	1.04800-02
6.00000+02	4.35100-01	2.79100-02	1.17500-02

*** TIME-RELATED INPUT DATA ***

THE INITIAL CONDITIONS CORRESPOND TO THE STEADY STATE

THE TRANSIENT INVESTIGATION IS DIVIDED INTO 2 TIME PERIODS

TIME PERIOD	LENGTH	NOMINAL NUMBER OF INCREMENTS	OPTION
1	5.00000-04	5	1
2	4.00000-03	20	1

NOTE - OPTION 0 INDICATES THE SIZE OF THE TIME INCREMENT CORRESPONDS TO THE NOMINAL NUMBER OF INCREMENTS

OPTION 1 INDICATES THE SIZE OF THE TIME INCREMENT CORRESPONDS TO THE NOMINAL NUMBER OF INCREMENTS, BUT IT IS BOUNDED BY CALCULATED MAXIMUM AND MINIMUM VALUES

OPTION 2 INDICATES THE SIZE OF THE TIME INCREMENT CORRESPONDS TO THE AVERAGE OF THE CALCULATED MAXIMUM AND MINIMUM VALUES

** FLUID S **

TIME	MASS FLOW RATE
0.00000	5.28000+03

TIME	INLET TEMPERATURE
0.00000	5.09700+02

** FLUID R **

TIME	MASS FLOW RATE
0.00000	1.85400+03
1.00000-04	1.90800+03
2.50000-03	1.90800+03

TIME	INLET TEMPERATURE
0.00000	5.59700+02
1.00000-04	5.74700+02
2.50000-03	5.74700+02

TIME	INLET ABSOLUTE HUMIDITY
0.00000	3.00000-02
1.00000-04	6.00000-02
2.50000-03	6.00000-02

** OUTPUT DATA FOR TIME THETA = 0.00000 **
(INITIAL CONDITIONS)

	S SIDE	R SIDE
MASS FLOW RATE	5.28000+03	1.85400+03
INLET TEMPERATURE	5.09700+02	5.59700+02
OUTLET TEMPERATURE	5.37985+02	5.32328+02
INLET HUMIDITY	--	3.00000-02
OUTLET HUMIDITY	--	1.74627-02
PRESSURE DROP	4.73429+00	4.80269+00
INLET PRESSURE	4.24000+03	2.12000+03
OUTLET PRESSURE	4.23527+03	2.11520+03
AVERAGE REYNOLDS NUMBER	5.34803+03	1.41117+03
AVERAGE HEAT-TRANSFER COEFFICIENT	5.84460+01	7.78741+00
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	9.41130-01	9.90994-01

EFFECTIVENESS	5.65696-01
AVERAGE TOTAL CONDUCTANCE (UA)	8.00302+02
DEW POINT FOR FLUID R	5.48699+02
TOTAL HEAT TRANSFER RATE	3.64891+04
PERCENT ERROR IN HEAT BALANCE	3.07569+00

*** OUTPUT OF THE TRANSIENT ANALYSIS ***

** GENERAL OUTPUT DATA **

```
x NUMBER   4013 (  LOUVERED TRIANGULAR, SFL/DEL = 62.5, AF/A = 0.800          ) ON THE S SIDE
x NUMBER   3002 (  TRIANGULAR, LRAT = 43.2                                    ) ON THE R SIDE
```

	S SIDE	R SIDE
HYDRAULIC RADIUS	2.04121-03	2.40809-03
PLATE SPACING	2.08000-02	2.07300-02
FIN SPACING	5.58000-03	6.99000-03
FIN THICKNESS	5.00000-04	5.00000-04
VOID VOLUME	2.78658-01	2.87574-01
TOTAL HEAT-TRANSFER AREA	1.33099+02	1.16430+02

CORE VOLUME	6.72000-01
CORE WEIGHT (DRY)	1.78331+01
HEAT CAPACITY OF CORE STRUCTURE	3.79845+00
HEAT CAPACITY OF SIDE WALL IN CONTACT WITH FLUID S	5.21118-01
HEAT CAPACITY OF SIDE WALL IN CONTACT WITH FLUID R	5.11699-01

** OUTPUT DATA FOR TIME THETA = 1.16500-06 **

	S SIDE	R SIDE
MASS FLOW RATE	5.28000+03	1.85463+03
INLET TEMPERATURE	5.09700+02	5.59875+02
OUTLET TEMPERATURE	5.35866+02	5.32579+02
INLET HUMIDITY	--	3.03495-02
OUTLET HUMIDITY	--	1.76205-02
PRESSURE DROP	4.69507+00	4.80584+00
INLET PRESSURE	4.24000+03	2.12000+03
OUTLET PRESSURE	4.23530+03	2.11519+03
AVERAGE REYNOLDS NUMBER	5.34925+03	1.41132+03
AVERAGE HEAT-TRANSFER COEFFICIENT	5.84392+01	7.79036+00
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	9.41136-01	9.90990-01

EFFECTIVENESS	5.44010-01
AVERAGE TOTAL CONDUCTANCE (UA)	8.00560+02
DEW POINT FOR FLUID R	5.49051+02

** OUTPUT DATA FOR TIME THETA = 2.48500-06 **

	S SIDE	R SIDE
MASS FLOW RATE	5.28000+03	1.85534+03
INLET TEMPERATURE	5.09700+02	5.60073+02
OUTLET TEMPERATURE	5.37706+02	5.32741+02
INLET HUMIDITY	--	3.07455-02
OUTLET HUMIDITY	--	1.77149-02
PRESSURE DROP	4.72912+00	4.80994+00
INLET PRESSURE	4.24000+03	2.12000+03
OUTLET PRESSURE	4.23527+03	2.11519+03
AVERAGE REYNOLDS NUMBER	5.34867+03	1.41169+03
AVERAGE HEAT-TRANSFER COEFFICIENT	5.84425+01	7.79263+00
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	9.41133-01	9.90527-01

EFFECTIVENESS	5.55972-01
AVERAGE TOTAL CONDUCTANCE (UA)	8.00438+02
DEW POINT FOR FLUID R	5.49444+02

** OUTPUT DATA FOR TIME THETA = 4.08955-06 **

	S SIDE	R SIDE
MASS FLOW RATE	5.28000+03	1.85621+03
INLET TEMPERATURE	5.09700+02	5.60313+02
OUTLET TEMPERATURE	5.38041+02	5.32818+02
INLET HUMIDITY	--	3.12269-02
OUTLET HUMIDITY	--	1.77610-02
PRESSURE DROP	4.73533+00	4.81379+00
INLET PRESSURE	4.24000+03	2.12000+03
OUTLET PRESSURE	4.23526+03	2.11519+03
AVERAGE REYNOLDS NUMBER	5.34825+03	1.41229+03
AVERAGE HEAT-TRANSFER COEFFICIENT	5.84448+01	7.79464+00
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	9.41131-01	9.90986-01

EFFECTIVENESS	5.59957-01
AVERAGE TOTAL CONDUCTANCE (UA)	8.00955+02
DEW POINT FOR FLUID R	5.49916+02

** OUTPUT DATA FOR TIME THETA = 1.47413-05 **

	S SIDE	R SIDE
MASS FLOW RATE	5.28000+03	1.86196+03
INLET TEMPERATURE	5.09700+02	5.61911+02
OUTLET TEMPERATURE	5.36388+02	5.32687+02
INLET HUMIDITY	--	3.44224-02
OUTLET HUMIDITY	--	1.76907-02
PRESSURE DROP	4.74174+00	4.83668+00
INLET PRESSURE	4.24000+03	2.12000+03
OUTLET PRESSURE	4.23526+03	2.11516+03
AVERAGE REYNOLDS NUMBER	5.34760+03	1.41646+03
AVERAGE HEAT-TRANSFER COEFFICIENT	5.84484+01	7.80620+00
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	9.41128-01	9.90960-01

EFFECTIVENESS	5.59738-01
AVERAGE TOTAL CONDUCTANCE (UA)	8.02000+02
DEW POINT FOR FLUID R	5.52087+02

** OUTPUT DATA FOR TIME THETA = 8.70984-05 **

	S SIDE	R SIDE
MASS FLOW RATE	5.28000+03	1.90103+03
INLET TEMPERATURE	5.09700+02	5.72765+02
OUTLET TEMPERATURE	5.39454+02	5.34315+02
INLET HUMIDITY	--	5.61295-02
OUTLET HUMIDITY	--	1.87130-02
PRESSURE DROP	4.76147+00	5.00666+00
INLET PRESSURE	4.24000+03	2.12000+03
OUTLET PRESSURE	4.23524+03	2.11499+03
AVERAGE REYNOLDS NUMBER	5.34342+03	1.44044+03
AVERAGE HEAT-TRANSFER COEFFICIENT	5.84718+01	7.90437+00
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	9.41106-01	9.90861-01

EFFECTIVENESS	6.09694-01
AVERAGE TOTAL CONDUCTANCE (UA)	8.10930+02
DEW POINT FOR FLUID R	5.68095+02

** OUTPUT DATA FOR TIME THETA = 1.87098-04 **

	S SIDE	R SIDE
MASS FLOW RATE	5.28000+03	1.90800+03
INLET TEMPERATURE	5.09700+02	5.74700+02
OUTLET TEMPERATURE	5.41731+02	5.35489+02
INLET HUMIDITY	--	6.00000-02
OUTLET HUMIDITY	--	1.94802-02
PRESSURE DROP	4.60362+00	5.05111+00
INLET PRESSURE	4.24000+03	2.12000+03
OUTLET PRESSURE	4.23520+03	2.11495+03
AVERAGE REYNOLDS NUMBER	5.33574+03	1.44340+03
AVERAGE HEAT-TRANSFER COEFFICIENT	5.85147+01	7.93053+00
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	9.41067-01	9.90831-01

EFFECTIVENESS	6.03250-01
AVERAGE TOTAL CONDUCTANCE (UA)	8.13357+02
DEW POINT FOR FLUID R	5.70200+02

** OUTPUT DATA FOR TIME THETA = 2.87098-04 **

	S SIDE	R SIDE
MASS FLOW RATE	5.28000+03	1.90800+03
INLET TEMPERATURE	5.09700+02	5.74700+02
OUTLET TEMPERATURE	5.43712+02	5.36278+02
INLET HUMIDITY	--	6.00000-02
OUTLET HUMIDITY	--	2.00130-02
PRESSURE DROP	4.84029+00	5.06734+00
INLET PRESSURE	4.24000+03	2.12000+03
OUTLET PRESSURE	4.23516+03	2.11493+03
AVERAGE REYNOLDS NUMBER	5.32863+03	1.44232+03
AVERAGE HEAT-TRANSFER COEFFICIENT	5.85546+01	7.93768+00
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	9.41030-01	9.90823-01

EFFECTIVENESS	5.91102-01
AVERAGE TOTAL CONDUCTANCE (UA)	8.14061+02
DEW POINT FOR FLUID R	5.70200+02

** OUTPUT DATA FOR TIME THETA = 3.87098-04 **

	S SIDE	R SIDE
MASS FLOW RATE	5.28000+03	1.90800+03
INLET TEMPERATURE	5.09700+02	5.74700+02
OUTLET TEMPERATURE	5.45452+02	5.37009+02
INLET HUMIDITY	--	6.00000-02
OUTLET HUMIDITY	--	2.05180-02
PRESSURE DROP	4.87251+00	5.08280+00
INLET PRESSURE	4.24000+03	2.12000+03
OUTLET PRESSURE	4.23513+03	2.11492+03
AVERAGE REYNOLDS NUMBER	5.32210+03	1.44139+03
AVERAGE HEAT-TRANSFER COEFFICIENT	5.85913+01	7.94388+00
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	9.40997-01	9.90815-01

EFFECTIVENESS	5.79864-01
AVERAGE TOTAL CONDUCTANCE (UA)	8.14674+02
DEW POINT FOR FLUID R	5.70200+02

** OUTPUT DATA FOR TIME THETA = 4.87098-04 **

	S SIDE	R SIDE
MASS FLOW RATE	5.28000+03	1.90800+03
INLET TEMPERATURE	5.09700+02	5.74700+02
OUTLET TEMPERATURE	5.46981+02	5.37712+02
INLET HUMIDITY	--	6.00000-02
OUTLET HUMIDITY	--	2.10144-02
PRESSURE DROP	4.90081+00	5.09760+00
INLET PRESSURE	4.24000+03	2.12000+03
OUTLET PRESSURE	4.23510+03	2.11490+03
AVERAGE REYNOLDS NUMBER	5.31606+03	1.44056+03
AVERAGE HEAT-TRANSFER COEFFICIENT	5.86253+01	7.94947+00
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	9.40966-01	9.90809-01

EFFECTIVENESS	5.73553-01
AVERAGE TOTAL CONDUCTANCE (UA)	8.15229+02
DEW POINT FOR FLUID R	5.70200+02

** OUTPUT DATA FOR TIME THETA = 5.87098-04 **

	S SIDE	R SIDE
MASS FLOW RATE	5.28000+03	1.90800+03
INLET TEMPERATURE	5.09700+02	5.74700+02
OUTLET TEMPERATURE	5.48326+02	5.38386+02
INLET HUMIDITY	--	6.00000-02
OUTLET HUMIDITY	--	2.15019-02
PRESSURE DROP	4.92570+00	5.11165+00
INLET PRESSURE	4.24000+03	2.12000+03
OUTLET PRESSURE	4.23507+03	2.11489+03
AVERAGE REYNOLDS NUMBER	5.31047+03	1.43982+03
AVERAGE HEAT-TRANSFER COEFFICIENT	5.86568+01	7.95454+00
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	9.40937-01	9.90803-01

EFFECTIVENESS	5.94241-01
AVERAGE TOTAL CONDUCTANCE (UA)	8.15733+02
DEW POINT FOR FLUID R	5.70200+02

** OUTPUT DATA FOR TIME THETA = 7.83227-04 **

	S SIDE	R SIDE
MASS FLOW RATE	5.28000+03	1.90800+03
INLET TEMPERATURE	5.09700+02	5.74700+02
OUTLET TEMPERATURE	5.50400+02	5.39587+02
INLET HUMIDITY	--	6.00000-02
OUTLET HUMIDITY	--	2.23989-02
PRESSURE DROP	4.96410+00	5.12918+00
INLET PRESSURE	4.24000+03	2.12000+03
OUTLET PRESSURE	4.23504+03	2.11487+03
AVERAGE REYNOLDS NUMBER	5.30087+03	1.43859+03
AVERAGE HEAT-TRANSFER COEFFICIENT	5.87109+01	7.96297+00
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	9.40887-01	9.90794-01

EFFECTIVENESS	6.26154-01
AVERAGE TOTAL CONDUCTANCE (UA)	8.16573+02
DEW POINT FOR FLUID R	5.70200+02

** OUTPUT DATA FOR TIME THETA = 9.83227+04 **

	S SIDE	R SIDE
MASS FLOW RATE	5.28000+03	1.90800+03
INLET TEMPERATURE	5.09700+02	5.74700+02
OUTLET TEMPERATURE	5.52093+02	5.40701+02
INLET HUMIDITY	--	6.00000-02
OUTLET HUMIDITY	--	2.32643-02
PRESSURE DROP	4.99545+00	5.15163+00
INLET PRESSURE	4.24000+03	2.12000+03
OUTLET PRESSURE	4.23500+03	2.11485+03
AVERAGE REYNOLDS NUMBER	5.29242+03	1.43756+03
AVERAGE HEAT-TRANSFER COEFFICIENT	5.87586+01	7.97014+00
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	9.40843-01	9.90786-01

EFFECTIVENESS	6.52203-01
AVERAGE TOTAL CONDUCTANCE (UA)	8.17290+02
DEW POINT FOR FLUID R	5.70200+02

** OUTPUT DATA FOR TIME THETA = 1.18323-03 **

	S SIDE	R SIDE
MASS FLOW RATE	5.28000+03	1.90800+03
INLET TEMPERATURE	5.09700+02	5.74700+02
OUTLET TEMPERATURE	5.53448+02	5.41696+02
INLET HUMIDITY	--	6.00000-02
OUTLET HUMIDITY	--	2.40680-02
PRESSURE DROP	5.02053+00	5.17127+00
INLET PRESSURE	4.24000+03	2.12000+03
OUTLET PRESSURE	4.23498+03	2.11483+03
AVERAGE REYNOLDS NUMBER	5.28507+03	1.43670+03
AVERAGE HEAT-TRANSFER COEFFICIENT	5.88001+01	7.97618+00
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	9.40805-01	9.90779-01

EFFECTIVENESS	6.73053-01
AVERAGE TOTAL CONDUCTANCE (UA)	8.17896+02
DEW POINT FOR FLUID R	5.70200+02

** OUTPUT DATA FOR TIME THETA = 1.38323-03 **

	S SIDE	R SIDE
MASS FLOW RATE	5.28000+03	1.90800+03
INLET TEMPERATURE	5.09700+02	5.74700+02
OUTLET TEMPERATURE	5.54527+02	5.42569+02
INLET HUMIDITY	--	6.00000-02
OUTLET HUMIDITY	--	2.47949-02
PRESSURE DROP	5.04051+00	5.18806+00
INLET PRESSURE	4.24000+03	2.12000+03
OUTLET PRESSURE	4.23496+03	2.11481+03
AVERAGE REYNOLDS NUMBER	5.27896+03	1.43598+03
AVERAGE HEAT-TRANSFER COEFFICIENT	5.88347+01	7.98129+00
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	9.40773-01	9.90773-01

EFFECTIVENESS	6.89653-01
AVERAGE TOTAL CONDUCTANCE (UA)	8.18408+02
DEW POINT FOR FLUID R	5.70200+02

** OUTPUT DATA FOR TIME THETA = 1.58323-03 **

	S SIDE	R SIDE
MASS FLOW RATE	5.28000+03	1.90800+03
INLET TEMPERATURE	5.09700+02	5.74700+02
OUTLET TEMPERATURE	5.55455+02	5.43378+02
INLET HUMIDITY	--	6.00000-02
OUTLET HUMIDITY	--	2.54924-02
PRESSURE DROP	5.05767+00	5.20286+00
INLET PRESSURE	4.24000+03	2.12000+03
OUTLET PRESSURE	4.23494+03	2.11480+03
AVERAGE REYNOLDS NUMBER	5.27312+03	1.43533+03
AVERAGE HEAT-TRANSFER COEFFICIENT	5.88677+01	7.98600+00
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	9.40743-01	9.90768-01

EFFECTIVENESS	7.03917-01
AVERAGE TOTAL CONDUCTANCE (UA)	8.18882+02
DEW POINT FOR FLUID R	5.70200+02

** OUTPUT DATA FOR TIME THETA = 1.78323-03 **

	S SIDE	R SIDE
MASS FLOW RATE	5.28000+03	1.90800+03
INLET TEMPERATURE	5.09700+02	5.74700+02
OUTLET TEMPERATURE	5.56154+02	5.44088+02
INLET HUMIDITY	--	6.00000-02
OUTLET HUMIDITY	--	2.61189-02
PRESSURE DROP	5.07063+00	5.21560+00
INLET PRESSURE	4.24000+03	2.12000+03
OUTLET PRESSURE	4.23493+03	2.11478+03
AVERAGE REYNOLDS NUMBER	5.26827+03	1.43477+03
AVERAGE HEAT-TRANSFER COEFFICIENT	5.88952+01	7.99008+00
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	9.40718-01	9.90763-01

EFFECTIVENESS	7.14684-01
AVERAGE TOTAL CONDUCTANCE (UA)	8.19289+02
DEW POINT FOR FLUID R	5.70200+02

** OUTPUT DATA FOR TIME THETA = 1.98323-03 **

	S SIDE	R SIDE
MASS FLOW RATE	5.28000+03	1.90800+03
INLET TEMPERATURE	5.09700+02	5.74700+02
OUTLET TEMPERATURE	5.56728+02	5.44714+02
INLET HUMIDITY	--	6.00000-02
OUTLET HUMIDITY	--	2.66861-02
PRESSURE DROP	5.08124+00	5.22658+00
INLET PRESSURE	4.24000+03	2.12000+03
OUTLET PRESSURE	4.23492+03	2.11477+03
AVERAGE REYNOLDS NUMBER	5.26401+03	1.43429+03
AVERAGE HEAT-TRANSFER COEFFICIENT	5.89194+01	7.99357+00
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	9.40696-01	9.90759-01

EFFECTIVENESS	7.23505-01
AVERAGE TOTAL CONDUCTANCE (UA)	8.19641+02
DEW POINT FOR FLUID R	5.70200+02

** OUTPUT DATA FOR TIME THETA = 2.18323-03 **

	S SIDE	R SIDE
MASS FLOW RATE	5.28000+03	1.90800+03
INLET TEMPERATURE	5.09700+02	5.74700+02
OUTLET TEMPERATURE	5.57199+02	5.45262+02
INLET HUMIDITY	--	6.00000-02
OUTLET HUMIDITY	--	2.71961-02
PRESSURE DROP	5.08997+00	5.23600+00
INLET PRESSURE	4.24000+03	2.12000+03
OUTLET PRESSURE	4.23491+03	2.11476+03
AVERAGE REYNOLDS NUMBER	5.26031+03	1.43388+03
AVERAGE HEAT-TRANSFER COEFFICIENT	5.89404+01	7.99658+00
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	9.40677-01	9.90755-01

EFFECTIVENESS	7.30756-01
AVERAGE TOTAL CONDUCTANCE (UA)	8.19943+02
DEW POINT FOR FLUID R	5.70200+02

** OUTPUT DATA FOR TIME THETA = 2.38323-03 **

	S SIDE	R SIDE
MASS FLOW RATE	5.28000+03	1.90800+03
INLET TEMPERATURE	5.09700+02	5.74700+02
OUTLET TEMPERATURE	5.57614+02	5.45717+02
INLET HUMIDITY	--	6.00000-02
OUTLET HUMIDITY	--	2.76288-02
PRESSURE DROP	5.09765+00	5.24377+00
INLET PRESSURE	4.24000+03	2.12000+03
OUTLET PRESSURE	4.23490+03	2.11476+03
AVERAGE REYNOLDS NUMBER	5.25722+03	1.43357+03
AVERAGE HEAT-TRANSFER COEFFICIENT	5.89579+01	7.99883+00
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	9.40661-01	9.90753-01

EFFECTIVENESS	7.37140-01
AVERAGE TOTAL CONDUCTANCE (UA)	8.20172+02
DEW POINT FOR FLUID R	5.70200+02

** OUTPUT DATA FOR TIME THETA = 2.58323-03 **

	S SIDE	R SIDE
MASS FLOW RATE	5.28000+03	1.90800+03
INLET TEMPERATURE	5.09700+02	5.74700+02
OUTLET TEMPERATURE	5.57957+02	5.46135+02
INLET HUMIDITY	--	6.00000-02
OUTLET HUMIDITY	--	2.80366-02
PRESSURE DROP	5.10400+00	5.25064+00
INLET PRESSURE	4.24000+03	2.12000+03
OUTLET PRESSURE	4.23490+03	2.11475+03
AVERAGE REYNOLDS NUMBER	5.25434+03	1.43327+03
AVERAGE HEAT-TRANSFER COEFFICIENT	5.89743+01	8.00111+00
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	9.40646-01	9.90750-01

EFFECTIVENESS	7.42415-01
AVERAGE TOTAL CONDUCTANCE (UA)	8.20401+02
DEW POINT FOR FLUID R	5.70200+02

** OUTPUT DATA FOR TIME THETA = 2.78323-03 **

	S SIDE	R SIDE
MASS FLOW RATE	5.28000+03	1.90800+03
INLET TEMPERATURE	5.09700+02	5.74700+02
OUTLET TEMPERATURE	5.58240+02	5.46496+02
INLET HUMIDITY	--	6.00000-02
OUTLET HUMIDITY	--	2.83936-02
PRESSURE DROP	5.10924+00	5.25655+00
INLET PRESSURE	4.24000+03	2.12000+03
OUTLET PRESSURE	4.23489+03	2.11474+03
AVERAGE REYNOLDS NUMBER	5.25196+03	1.43301+03
AVERAGE HEAT-TRANSFER COEFFICIENT	5.89878+01	8.00305+00
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	9.40633-01	9.90748-01

EFFECTIVENESS	7.46768-01
AVERAGE TOTAL CONDUCTANCE (UA)	8.20596+02
DEW POINT FOR FLUID R	5.70200+02

** OUTPUT DATA FOR TIME THETA = 2.98323-03 **

	S SIDE	R SIDE
MASS FLOW RATE	5.20000+03	1.90800+03
INLET TEMPERATURE	5.09700+02	5.74700+02
OUTLET TEMPERATURE	5.58496+02	5.46789+02
INLET HUMIDITY	--	6.00000-02
OUTLET HUMIDITY	--	2.86886-02
PRESSURE DROP	5.11399+00	5.26136+00
INLET PRESSURE	4.24000+03	2.12000+03
OUTLET PRESSURE	4.23489+03	2.11474+03
AVERAGE REYNOLDS NUMBER	5.24997+03	1.43282+03
AVERAGE HEAT-TRANSFER COEFFICIENT	5.89992+01	8.00442+00
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	9.40623-01	9.90746-01

EFFECTIVENESS	7.50714-01
AVERAGE TOTAL CONDUCTANCE (UA)	8.20737+02
DEW POINT FOR FLUID R	5.70200+02

** OUTPUT DATA FOR TIME THETA = 3.18323-03 **

	S SIDE	R SIDE
MASS FLOW RATE	5.28000+03	1.90800+03
INLET TEMPERATURE	5.09700+02	5.74700+02
OUTLET TEMPERATURE	5.58724+02	5.47042+02
INLET HUMIDITY	--	6.00000-02
OUTLET HUMIDITY	--	2.89490-02
PRESSURE DROP	5.11819+00	5.26541+00
INLET PRESSURE	4.24000+03	2.12000+03
OUTLET PRESSURE	4.23488+03	2.11473+03
AVERAGE REYNOLDS NUMBER	5.24818+03	1.43267+03
AVERAGE HEAT-TRANSFER COEFFICIENT	5.90094+01	8.00562+00
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	9.40613-01	9.90745-01

EFFECTIVENESS	7.54210-01
AVERAGE TOTAL CONDUCTANCE (UA)	8.20860+02
DEW POINT FOR FLUID R	5.70200+02

** OUTPUT DATA FOR TIME THETA = 3.38323-03 **

	S SIDE	R SIDE
MASS FLOW RATE	5.28000+03	1.90800+03
INLET TEMPERATURE	5.09700+02	5.74700+02
OUTLET TEMPERATURE	5.58915+02	5.47279+02
INLET HUMIDITY	--	6.00000-02
OUTLET HUMIDITY	--	2.91940-02
PRESSURE DROP	5.12174+00	5.26911+00
INLET PRESSURE	4.24000+03	2.12000+03
OUTLET PRESSURE	4.23488+03	2.11473+03
AVERAGE REYNOLDS NUMBER	5.24659+03	1.43249+03
AVERAGE HEAT-TRANSFER COEFFICIENT	5.90184+01	8.00695+00
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	9.40605-01	9.90744-01

EFFECTIVENESS	7.57161-01
AVERAGE TOTAL CONDUCTANCE (UA)	8.20993+02
DEW POINT FOR FLUID R	5.70200+02

** OUTPUT DATA FOR TIME THETA = 3.58323-03 **

	S SIDE	R SIDE
MASS FLOW RATE	5.28000+03	1.90800+03
INLET TEMPERATURE	5.09700+02	5.74700+02
OUTLET TEMPERATURE	5.59087+02	5.47466+02
INLET HUMIDITY	--	6.00000-02
OUTLET HUMIDITY	--	2.93900-02
PRESSURE DROP	5.12493+00	5.27210+00
INLET PRESSURE	4.24000+03	2.12000+03
OUTLET PRESSURE	4.23488+03	2.11473+03
AVERAGE REYNOLDS NUMBER	5.24531+03	1.43238+03
AVERAGE HEAT-TRANSFER COEFFICIENT	5.90257+01	8.00781+00
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	9.40598-01	9.90743-01

EFFECTIVENESS	7.59807-01
AVERAGE TOTAL CONDUCTANCE (UA)	8.21081+02
DEW POINT FOR FLUID R	5.70200+02

** OUTPUT DATA FOR TIME THETA = 3.78323-03 **

	S SIDE	R SIDE
MASS FLOW RATE	5.28000+03	1.90800+03
INLET TEMPERATURE	5.09700+02	5.74700+02
OUTLET TEMPERATURE	5.59232+02	5.47643+02
INLET HUMIDITY	--	6.00000-02
OUTLET HUMIDITY	--	2.95781-02
PRESSURE DROP	5.12760+00	5.27485+00
INLET PRESSURE	4.24000+03	2.12000+03
OUTLET PRESSURE	4.23487+03	2.11473+03
AVERAGE REYNOLDS NUMBER	5.24415+03	1.43224+03
AVERAGE HEAT-TRANSFER COEFFICIENT	5.90323+01	8.00881+00
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	9.40592-01	9.90742-01

EFFECTIVENESS	7.62030-01
AVERAGE TOTAL CONDUCTANCE (UA)	8.21181+02
DEW POINT FOR FLUID R	5.70200+02

** OUTPUT DATA FOR TIME THETA = 3.98323-03 **

	S SIDE	R SIDE
MASS FLOW RATE	5.28000+03	1.90800+03
INLET TEMPERATURE	5.09700+02	5.74700+02
OUTLET TEMPERATURE	5.59364+02	5.47781+02
INLET HUMIDITY	--	6.00000-02
OUTLET HUMIDITY	--	2.97253-02
PRESSURE DROP	5.13004+00	5.27703+00
INLET PRESSURE	4.24000+03	2.12000+03
OUTLET PRESSURE	4.23487+03	2.11472+03
AVERAGE REYNOLDS NUMBER	5.24320+03	1.43216+03
AVERAGE HEAT-TRANSFER COEFFICIENT	5.90377+01	8.00941+00
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	9.40587-01	9.90741-01

EFFECTIVENESS	7.64060-01
AVERAGE TOTAL CONDUCTANCE (UA)	8.21243+02
DEW POINT FOR FLUID R	5.70200+02

** OUTPUT DATA FOR TIME THETA = 4.18323-03 **

	S SIDE	R SIDE
MASS FLOW RATE	5.28000+03	1.90800+03
INLET TEMPERATURE	5.09700+02	5.74700+02
OUTLET TEMPERATURE	5.59483+02	5.47900+02
INLET HUMIDITY	--	6.00000-02
OUTLET HUMIDITY	--	2.98541-02
PRESSURE DROP	5.13224+00	5.27887+00
INLET PRESSURE	4.24000+03	2.12000+03
OUTLET PRESSURE	4.23487+03	2.11472+03
AVERAGE REYNOLDS NUMBER	5.24235+03	1.43210+03
AVERAGE HEAT-TRANSFER COEFFICIENT	5.90426+01	8.00994+00
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	9.40583-01	9.90740-01

EFFECTIVENESS	7.65886-01
AVERAGE TOTAL CONDUCTANCE (UA)	8.21298+02
DEW POINT FOR FLUID R	5.70200+02

** OUTPUT DATA FOR TIME THETA = 4.38323-03 **

	S SIDE	R SIDE
MASS FLOW RATE	5.28000+03	1.90800+03
INLET TEMPERATURE	5.09700+02	5.74700+02
OUTLET TEMPERATURE	5.59589+02	5.48003+02
INLET HUMIDITY	--	6.00000-02
OUTLET HUMIDITY	--	2.99658-02
PRESSURE DROP	5.13421+00	5.28044+00
INLET PRESSURE	4.24000+03	2.12000+03
OUTLET PRESSURE	4.23487+03	2.11472+03
AVERAGE REYNOLDS NUMBER	5.24161+03	1.43203+03
AVERAGE HEAT-TRANSFER COEFFICIENT	5.90468+01	8.01042+00
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	9.40579-01	9.90740-01

EFFECTIVENESS	7.67521-01
AVERAGE TOTAL CONDUCTANCE (UA)	8.21347+02
DEW POINT FOR FLUID R	5.70200+02

** OUTPUT DATA FOR TIME THETA = 4.58323-03 **

	S SIDE	R SIDE
MASS FLOW RATE	5.28000+03	1.90800+03
INLET TEMPERATURE	5.09700+02	5.74700+02
OUTLET TEMPERATURE	5.59684+02	5.48092+02
INLET HUMIDITY	--	6.00000-02
OUTLET HUMIDITY	--	3.00636-02
PRESSURE DROP	5.13598+00	5.28179+00
INLET PRESSURE	4.24000+03	2.12000+03
OUTLET PRESSURE	4.23486+03	2.11472+03
AVERAGE REYNOLDS NUMBER	5.24097+03	1.43198+03
AVERAGE HEAT-TRANSFER COEFFICIENT	5.90505+01	8.01084+00
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	9.40576-01	9.90739-01

EFFECTIVENESS	7.68990-01
AVERAGE TOTAL CONDUCTANCE (UA)	8.21391+02
DEW POINT FOR FLUID R	5.70200+02

Example 3 - Crossflow Freon Condenser

Problem Statement

This case involves an exchanger in which a superheated vapor stream (Freon 12 designated as the r fluid) is cooled and condensed by a liquid stream (60 per cent ethylene glycol, designated as the s fluid). The pertinent specifications for both sides of the exchanger are given in Table III along with the core dimensions.

The situation to be investigated is as follows: The heat exchanger is operating at steady-state when an increase in the inlet temperature of the glycol stream (s fluid) from the initial value of 30 deg F to a final value of 40 deg F occurs over a time interval of 10^{-3} hr. The problem is to compute the transient performance of the exchanger over a total time interval of 0.082 hr resulting from this change in operating conditions.

Preparation of Input Data

The completed data-input sheets are shown on pages 115 through 116. These contain all of the necessary data, except those on the matrix-data tape. Some of the input data have been indicated previously; the remainder arise from the following considerations:

1. The total time interval to be investigated is divided into two time periods, the first 0.002 hr in length and the second 0.08 hr. The first period ($0.0 \leq \theta < 0.002$) is subdivided into 8 increments to give a nominal time-step size of 0.00025 hr; the second ($0.002 \leq \theta \leq 0.082$) is also subdivided into 8 increments giving a nominal value of $\Delta\theta = 0.01$ hr. The nominal value of $\Delta\theta$ is to be used in the calculations for each period provided it falls within the minimum and maximum values calculated.
2. The parting-plate thickness is 0.00250 ft (0.030 in) and the thickness of the side walls is 0.01667 ft (0.20 in).
3. The fluid property-data for Freon 12 and glycol are given in Tables 33, 34, 35, and 108 of Reference 3.

Results of Analysis

The printed computer output data for this case are given on pages 117 through 154. The input data specified to the program are printed on the first six pages. These are followed by thirty-two pages of output containing the results of the calculations. The pertinent results are also given in Figure 3, which shows the transient variation of the inlet and outlet temperatures of both fluids and the inlet and outlet vapor quality of the Freon stream (r fluid).

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DATA INPUT SHEET

ENGINEER: MP PROJECT: Analysis of HX Transients PROJECT NO: 1135B

TITLE: Sample to Illustrate the Use of Program KRONOS SHEET: 1 OF 2

LOCATION

1 6	7 12	13 18	19 24	25 30	31 36	37 42	43 48	49 54	55 60	61 66	67 72
SAMPLE TRANSIENT ANALYSIS OF A CROSSFLOW FREON CONDENSER											
$NAM3,											
NFLO=1,		NPC=2,		NXPPIN=0,		NYPIN=0,					
RHUNIT=1,		GC=4.169E8,									
ELX=.833,		ELY=.667,		ELNF=.8,							
PP=.0025		DENSMP=168,		CPMP=.213,							
SWL=.01667,		SWT=.01667,		DENSMW=168,		CPMW=.213,					
PINS=4240		NCORES=3006,		RHINS=0,							
SPLS=.0025,		CONDMS=100,		DENSMS=168,		CPMS=.213,					
ICOMPS=2,		NTFPS=5,									
TFPS(1)=480,		500,		520,		540,		560,			
CPXS(1)=.7002,		.7168,		.7337,		.7499,		.7653,			
VISXS(1)=40.		71,		23.21,		14.23,		9.997,		7.212,	
THKXS(1)=.2254,		.2252,		.2246,		.2231,		.2220,			
ROXS(1)=68.12,		67.86,		67.46,		66.99,		66.54,			
PINR=10436,		NCORER=3004,		RHINR=0,							
SPLR=.0025,		CONDMR=100,		DENSMR=168,		CPMR=.213,					
KPHR=2,											
TSAT=519.7,		HFGSAT=61.64,				PCRIT=85942,		PATM=2117,		GACC=4.169E8,	
ZV=1,		GASKV=12.78,		NTFPV=3,							

NORTHERN RESEARCH AND ENGINEERING CORPORATION

DATA INPUT SHEET

ENGINEER: MP PROJECT: Analysis of HX Transients PROJECT NO: 1135B

TITLE: Sample to Illustrate the Use of Program KRONOS SHEET: 2 OF 2

LOCATION

1 6	7 12	13 18	19 24	25 30	31 36	37 42	43 48	49 54	55 60	61 66	67 72
TFPV(1)=450,500,550,				CPXV(1)=.352,.3595,.3662,							
VISXV(1)=.02628,.029,.03102,						THKXV(1)=.004608,.005289,.005969					
NTFPL=3,		TFPL(1)=480,500,520,									
CPXL(1)=.2186,.2227,.2271,											
VISXL(1)=.744,.691,.6501,											
THKXL(1)=.04795,.04545,.04295,											
ROXL(1)=88.50,86.26,83.90,											
INC=2,											
NPER=2,		THPER(1)=0.002,0.08,				NDTH(1)=8,8,				ITHC(1)=1,1,	
IMS=2,		NMS=1,		THWS(1)=0,		WSX(1)=2760,					
ITS=2,		NTS=3,		THTS(1)=0,.001,2.5,				TINSX(1)=489.7,2*499.7,			
IMR=2,		NMR=1,		THWR(1)=0,		WRX(1)=600,					
ITXV=3,		NTXV=1,		THTXV(1)=0,		TINRX(1)=534.7,				XVINX(1)=1,	
SEND,											

```
** PROGRAM KRONOS - PREDICTION OF THERMAL TRANSIENTS IN COMPACT HEAT EXCHANGERS **

                SAMPLE TRANSIENT ANALYSIS OF A CROSSFLOW FREON CONDENSER

                          *** GENERAL INPUT DATA ***

                    THE FLOW ARRANGEMENT IS MULTIPASS CROSSFLOW
                                NUMBER OF PASSES =  2
NUMBER OF CALCULATION INCREMENTS PER PASS IN X DIRECTION =  5
NUMBER OF CALCULATION INCREMENTS PER PASS IN Y DIRECTION = 10

        PROPORTIONALITY FACTOR FOR HYDRAULIC RADIUS =   1.00000+00
                      PROPORTIONALITY CONSTANT =   4.16900+08

                          * CORE DIMENSIONS *

                     LENGTH IN X DIRECTION =   8.33000-01
                     LENGTH IN Y DIRECTION =   6.67000-01
                           NONFLOW LENGTH =   8.00000-01

                     * PARTING-PLATE SPECIFICATIONS *

                    THICKNESS OF THE PLATE =   2.50000-03
                       DENSITY OF THE METAL =   1.68000+02
                 HEAT CAPACITY OF THE METAL =   2.13000-01

                          * SIDE-WALL SPECIFICATIONS *

WALL THICKNESS PARALLEL TO THE PARTING PLATES =   1.66700-02
 WALL THICKNESS NORMAL TO THE PARTING PLATES =   1.66700-02
                       DENSITY OF THE METAL =   1.68000+02
                 HEAT CAPACITY OF THE METAL =   2.13000-01
```

*** FLUID INPUT DATA ***

** FLUID S **

INLET PRESSURE = 4.24000+03

THE FLUID FLOWS IN THE +Y DIRECTION

* SPECIFICATIONS OF THE ASSOCIATED MATRIX *

MATRIX IDENTIFICATION NUMBER = 3006

THE VALUE OF HYDRAULIC RADIUS OBTAINED FROM THE MATRIX-DATA TAPE IS USED IN THE CALCULATIONS

SPLITTER-PLATE THICKNESS = 2.50000-03
METAL THERMAL CONDUCTIVITY = 1.00000+02
METAL DENSITY = 1.68000+02
METAL HEAT CAPACITY = 2.13000-01

* FLUID PROPERTIES *

THE FLUID IS A LIQUID

TEMPERATURE	SPECIFIC HEAT	VISCOSITY	THERMAL CONDUCTIVITY	DENSITY
4.80000+02	7.00200-01	4.07100+01	2.25400-01	6.81200+01
5.00000+02	7.16800-01	2.32100+01	2.25200-01	6.78600+01
5.20000+02	7.33700-01	1.43200+01	2.24600-01	6.74600+01
5.40000+02	7.49900-01	9.99700+00	2.23100-01	6.69900+01
5.60000+02	7.65300-01	7.21200+00	2.22000-01	6.65400+01

** FLUID R **

INLET PRESSURE = 1.04360+04

THE FLUID FLOWS IN THE +X DIRECTION

* SPECIFICATIONS OF THE ASSOCIATED MATRIX *

MATRIX IDENTIFICATION NUMBER = 3004

THE VALUE OF HYDRAULIC RADIUS OBTAINED FROM THE MATRIX-DATA TAPE IS USED IN THE CALCULATIONS

SPLITTER-PLATE THICKNESS = 2.50000-03
METAL THERMAL CONDUCTIVITY = 1.00000+02
METAL DENSITY = 1.68000+02
METAL HEAT CAPACITY = 2.13000-01

* FLUID PROPERTIES *

THE FLUID IS A TWO-PHASE CONDENSING FLUID

SATURATION TEMPERATURE = 5.19700+02
LATENT HEAT OF VAPORIZATION = 6.16400+01

CRITICAL PRESSURE = 8.59420+04
ATMOSPHERIC PRESSURE = 2.11700+03
ACCELERATION OF GRAVITY = 4.16900+08

VAPOR PHASE

COMPRESSIBILITY FACTOR = 1.00000+00
GAS CONSTANT = 1.27800+01

TEMPERATURE	SPECIFIC HEAT	VISCOSITY	THERMAL CONDUCTIVITY
4.50000+02	3.52000-01	2.62800-02	4.60800-03
5.00000+02	3.59500-01	2.90000-02	5.28900-03
5.50000+02	3.66200-01	3.10200-02	5.96900-03

LIQUID PHASE

TEMPERATURE	SPECIFIC HEAT	VISCOSITY	THERMAL CONDUCTIVITY	DENSITY
4.80000+02	2.18600-01	7.44000-01	4.79500-02	8.85000+01
5.00000+02	2.22700-01	6.91000-01	4.54500-02	8.62600+01
5.20000+02	2.27100-01	6.50100-01	4.29500-02	8.39000+01

*** TIME-RELATED INPUT DATA ***

THE INITIAL CONDITIONS CORRESPOND TO THE STEADY STATE

THE TRANSIENT INVESTIGATION IS DIVIDED INTO 2 TIME PERIODS

TIME PERIOD	LENGTH	NOMINAL NUMBER OF INCREMENTS	OPTION
1	2.00000-03	8	1
2	8.00000-02	8	1

NOTE - OPTION 0 INDICATES THE SIZE OF THE TIME INCREMENT CORRESPONDS TO THE NOMINAL NUMBER OF INCREMENTS

OPTION 1 INDICATES THE SIZE OF THE TIME INCREMENT CORRESPONDS TO THE NOMINAL NUMBER OF INCREMENTS, BUT IT IS BOUNDED BY CALCULATED MAXIMUM AND MINIMUM VALUES

OPTION 2 INDICATES THE SIZE OF THE TIME INCREMENT CORRESPONDS TO THE AVERAGE OF THE CALCULATED MAXIMUM AND MINIMUM VALUES

** FLUID S **

TIME	MASS FLOW RATE
0.00000	2.76000+03

TIME	INLET TEMPERATURE
0.00000	4.89700+02
1.00000-03	4.99700+02
2.50000+00	4.99700+02

** FLUID R **

TIME	MASS FLOW RATE
0.00000	6.00000+02

TIME	INLET TEMPERATURE	INLET VAPOR QUALITY
0.00000	5.34700+02	1.00000+00

*** OUTPUT OF THE TRANSIENT ANALYSIS ***

** GENERAL OUTPUT DATA **

MATRIX NUMBER 3006 (TRIANGULAR, LRAT = 24.1) ON THE S SIC
MATRIX NUMBER 3004 (TRIANGULAR, LRAT = 34.2) ON THE R SIC

	S SIDE	R SIDE
HYDRAULIC RADIUS	2.16872-03	1.57330-03
PLATE SPACING	2.75000-02	2.08200-02
FIN SPACING	5.65000-03	4.19000-03
FIN THICKNESS	5.00000-04	5.00000-04
VOID VOLUME	2.08365-01	1.52922-01
TOTAL HEAT-TRANSFER AREA	9.28755+01	9.39587+01

CORE VOLUME	4.44489-01
CORE WEIGHT (DRY)	1.40460+01
HEAT CAPACITY OF CORE STRUCTURE	2.99161+00
HEAT CAPACITY OF SIDE WALL IN CONTACT WITH FLUID S	8.03656-01
HEAT CAPACITY OF SIDE WALL IN CONTACT WITH FLUID R	7.04247-01

** OUTPUT DATA FOR TIME THETA = 0.00000 **
(INITIAL CONDITIONS)

	S SIDE	R SIDE
MASS FLOW RATE	2.76000+03	6.00000+02
INLET TEMPERATURE	4.89700+02	5.34700+02
OUTLET TEMPERATURE	5.12851+02	4.92167+02
INLET VAPOR QUALITY	--	1.00000+00
OUTLET VAPOR QUALITY	--	0.00000
PRESSURE DROP	6.91827+00	4.43675-01
INLET PRESSURE	4.24000+03	1.04360+04
OUTLET PRESSURE	4.23308+03	1.04356+04
AVERAGE REYNOLDS NUMBER	7.50975+00	--
AVERAGE HEAT-TRANSFER COEFFICIENT	9.58579+01	2.02230+02
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	8.42895-01	8.49211-01

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE S WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EFFECTIVENESS	9.45178-01
AVERAGE TOTAL CONDUCTANCE (UA)	5.12211+03
TOTAL HEAT TRANSFER RATE	4.49263+04
PERCENT ERROR IN HEAT BALANCE	4.33503+00

** OUTPUT DATA FOR TIME THETA = 5.80665-04 **

	S SIDE	R SIDE
MASS FLOW RATE	2.76000+03	6.00000+02
INLET TEMPERATURE	4.95507+02	5.34700+02
OUTLET TEMPERATURE	5.12687+02	4.95269+02
INLET VAPOR QUALITY	--	1.00000+00
OUTLET VAPOR QUALITY	--	0.00000
PRESSURE DROP	6.91827+00	4.54650-01
INLET PRESSURE	4.24000+03	1.04360+04
OUTLET PRESSURE	4.23308+03	1.04355+04
AVERAGE REYNOLDS NUMBER	7.60819+00	--
AVERAGE HEAT-TRANSFER COEFFICIENT	9.57699+01	2.02227+02
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	8.43008-01	8.49212-01

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE S WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EFFECTIVENESS	1.00606+00
AVERAGE TOTAL CONDUCTANCE (UA)	5.11934+03

** OUTPUT DATA FOR TIME THETA = 1.16134-03 **

	S SIDE	R SIDE
MASS FLOW RATE	2.76000+03	6.00000+02
INLET TEMPERATURE	4.99700+02	5.34700+02
OUTLET TEMPERATURE	5.11337+02	4.97901+02
INLET VAPOR QUALITY	--	1.00000+00
OUTLET VAPOR QUALITY	--	0.00000
PRESSURE DROP	6.91827+00	4.62798-01
INLET PRESSURE	4.24000+03	1.04360+04
OUTLET PRESSURE	4.23308+03	1.04355+04
AVERAGE REYNOLDS NUMBER	7.74775+00	--
AVERAGE HEAT-TRANSFER COEFFICIENT	9.58685+01	2.02564+02
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	8.42881-01	8.49036-01

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE S WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EFFECTIVENESS	1.05141+00
AVERAGE TOTAL CONDUCTANCE (UA)	5.12479+03

** OUTPUT DATA FOR TIME THETA = 1.69345-03 **

	S SIDE	R SIDE
MASS FLOW RATE	2.76000+03	6.00000+02
INLET TEMPERATURE	4.99700+02	5.34700+02
OUTLET TEMPERATURE	5.11614+02	5.01036+02
INLET VAPOR QUALITY	--	1.00000+00
OUTLET VAPOR QUALITY	--	0.00000
PRESSURE DROP	6.91827+00	4.85189-01
INLET PRESSURE	4.24000+03	1.04360+04
OUTLET PRESSURE	4.23308+03	1.04355+04
AVERAGE REYNOLDS NUMBER	7.88411+00	--
AVERAGE HEAT-TRANSFER COEFFICIENT	9.59228+01	2.02402+02
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	8.42810-01	8.49118-01

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE S WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EFFECTIVENESS	9.61822-01
AVERAGE TOTAL CONDUCTANCE (UA)	5.12532+03

** OUTPUT DATA FOR TIME THETA = 2.21535-03 **

	S SIDE	R SIDE
MASS FLOW RATE	2.76000+03	6.00000+02
INLET TEMPERATURE	4.99700+02	5.34700+02
OUTLET TEMPERATURE	5.11174+02	5.02753+02
INLET VAPOR QUALITY	--	1.00000+00
OUTLET VAPOR QUALITY	--	0.00000
PRESSURE DROP	6.91827+00	5.04054-01
INLET PRESSURE	4.24000+03	1.04360+04
OUTLET PRESSURE	4.23308+03	1.04355+04
AVERAGE REYNOLDS NUMBER	7.99448+00	--
AVERAGE HEAT-TRANSFER COEFFICIENT	9.59830+01	2.06921+02
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	8.42733-01	8.47327-01

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE S WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EFFECTIVENESS	9.12783-01
AVERAGE TOTAL CONDUCTANCE (UA)	5.15959+03

** OUTPUT DATA FOR TIME THETA = 2.69792-03 **

	S SIDE	R SIDE
MASS FLOW RATE	2.76000+03	6.00000+02
INLET TEMPERATURE	4.99700+02	5.34700+02
OUTLET TEMPERATURE	5.11071+02	5.06173+02
INLET VAPOR QUALITY	--	1.00000+00
OUTLET VAPOR QUALITY	--	0.00000
PRESSURE DROP	6.91827+00	5.31012-01
INLET PRESSURE	4.24000+03	1.04360+04
OUTLET PRESSURE	4.23308+03	1.04355+04
AVERAGE REYNOLDS NUMBER	8.09335+00	--
AVERAGE HEAT-TRANSFER COEFFICIENT	9.60199+01	2.11832+02
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	8.42685-01	8.45547-01

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE S WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EFFECTIVENESS	8.15067-01
AVERAGE TOTAL CONDUCTANCE (UA)	5.19514+03

** OUTPUT DATA FOR TIME THETA = 3.14443-03 **

	S SIDE	R SIDE
MASS FLOW RATE	2.76000+03	6.00000+02
INLET TEMPERATURE	4.99700+02	5.34700+02
OUTLET TEMPERATURE	5.11051+02	5.08919+02
INLET VAPOR QUALITY	--	1.00000+00
OUTLET VAPOR QUALITY	--	0.00000
PRESSURE DROP	6.91827+00	5.49159-01
INLET PRESSURE	4.24000+03	1.04360+04
OUTLET PRESSURE	4.23306+03	1.04355+04
AVERAGE REYNOLDS NUMBER	8.18053+00	--
AVERAGE HEAT-TRANSFER COEFFICIENT	9.60668+01	2.18631+02
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	8.42625-01	8.43226-01

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE S WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EFFECTIVENESS	7.30603-01
AVERAGE TOTAL CONDUCTANCE (UA)	5.24266+03

** OUTPUT DATA FOR TIME THETA = 5.52540-03 **

	S SIDE	R SIDE
MASS FLOW RATE	2.76000+03	6.00000+02
INLET TEMPERATURE	4.99700+02	5.34700+02
OUTLET TEMPERATURE	5.10997+02	5.14346+02
INLET VAPOR QUALITY	--	1.00000+00
OUTLET VAPOR QUALITY	--	0.00000
PRESSURE DROP	6.91827+00	5.68413-01
INLET PRESSURE	4.24000+03	1.04360+04
OUTLET PRESSURE	4.23308+03	1.04354+04
AVERAGE REYNOLDS NUMBER	8.24961+00	--
AVERAGE HEAT-TRANSFER COEFFICIENT	9.61411+01	2.26597+02
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	8.42530-01	8.40828-01

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE S WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EFFECTIVENESS	5.81538-01
AVERAGE TOTAL CONDUCTANCE (UA)	5.29705+03

** OUTPUT DATA FOR TIME THETA = 3.87260-03 **

	S SIDE	R SIDE
MASS FLOW RATE	2.76000+03	6.00000+02
INLET TEMPERATURE	4.99700+02	5.34700+02
OUTLET TEMPERATURE	5.11518+02	5.19700+02
INLET VAPOR QUALITY	--	1.00000+00
OUTLET VAPOR QUALITY	--	4.15565-02
PRESSURE DROP	6.91827+00	5.99147-01
INLET PRESSURE	4.24000+03	1.04360+04
OUTLET PRESSURE	4.23308+03	1.04354+04
AVERAGE REYNOLUS NUMBER	8.32090+00	--
AVERAGE HEAT-TRANSFER COEFFICIENT	9.62071+01	2.26104+02
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	8.42445-01	8.41093-01

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE S WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EFFECTIVENESS	4.28571-01
AVERAGE TOTAL CONDUCTANCE (UA)	5.29631+03

** OUTPUT DATA FOR TIME THETA = 4.27882-03 **

	S SIDE	R SIDE
MASS FLOW RATE	2.76000+03	6.00000+02
INLET TEMPERATURE	4.99700+02	5.34700+02
OUTLET TEMPERATURE	5.11383+02	5.19700+02
INLET VAPOR QUALITY	--	1.00000+00
OUTLET VAPOR QUALITY	--	5.18266-02
PRESSURE DROP	6.91827+00	6.10510-01
INLET PRESSURE	4.24000+03	1.04360+04
OUTLET PRESSURE	4.23308+03	1.04354+04
AVERAGE REYNOLDS NUMBER	8.38870+00	--
AVERAGE HEAT-TRANSFER COEFFICIENT	9.62621+01	2.63635+02
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	8.42375-01	8.33682-01

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE S WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EFFECTIVENESS	4.28571-01
AVERAGE TOTAL CONDUCTANCE (UA)	5.51858+03

** OUTPUT DATA FOR TIME THETA = 4.67416-03 **

	S SIDE	R SIDE
MASS FLOW RATE	2.76000+03	6.00000+02
INLET TEMPERATURE	4.99700+02	5.34700+02
OUTLET TEMPERATURE	5.11511+02	5.19700+02
INLET VAPOR QUALITY	--	1.00000+00
OUTLET VAPOR QUALITY	--	8.15059-02
PRESSURE DROP	6.91827+00	6.25914-01
INLET PRESSURE	4.24000+03	1.04360+04
OUTLET PRESSURE	4.23308+03	1.04354+04
AVERAGE REYNOLDS NUMBER	8.45358+00	--
AVERAGE HEAT-TRANSFER COEFFICIENT	9.63379+01	2.22356+02
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	8.42278-01	8.47456-01

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE S WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EFFECTIVENESS	4.28571-01
AVERAGE TOTAL CONDUCTANCE (UA)	5.28617+03

** OUTPUT DATA FOR TIME THETA = 4.96374-03 **

	S SIDE	R SIDE
MASS FLOW RATE	2.76000+03	6.00000+02
INLET TEMPERATURE	4.99700+02	5.34700+02
OUTLET TEMPERATURE	5.11469+02	5.19700+02
INLET VAPOR QUALITY	--	1.00000+00
OUTLET VAPOR QUALITY	--	1.08356-01
PRESSURE DROP	6.91827+00	6.39397-01
INLET PRESSURE	4.24000+03	1.04360+04
OUTLET PRESSURE	4.23308+03	1.04354+04
AVERAGE REYNOLDS NUMBER	8.49261+00	--
AVERAGE HEAT-TRANSFER COEFFICIENT	9.63643+01	2.21404+02
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	8.42244-01	8.49169-01

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE S WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EFFECTIVENESS	4.28571-01
AVERAGE TOTAL CONDUCTANCE (UA)	5.28345+03

** OUTPUT DATA FOR TIME THETA = 5.22501-03 **

	S SIDE	R SIDE
MASS FLOW RATE	2.76000+03	6.00000+02
INLET TEMPERATURE	4.99700+02	5.34700+02
OUTLET TEMPERATURE	5.12053+02	5.19700+02
INLET VAPOR QUALITY	--	1.00000+00
OUTLET VAPOR QUALITY	--	1.52308-01
PRESSURE DROP	6.91827+00	6.58710-01
INLET PRESSURE	4.24000+03	1.04360+04
OUTLET PRESSURE	4.23308+03	1.04353+04
AVERAGE REYNOLDS NUMBER	8.53886+00	--
AVERAGE HEAT-TRANSFER COEFFICIENT	9.63870+01	2.20948+02
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	8.42216-01	8.49415-01

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE S WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EFFECTIVENESS	4.28571-01
AVERAGE TOTAL CONDUCTANCE (UA)	5.28140+03

** OUTPUT DATA FOR TIME THETA = 5.54120-03 **

	S SIDE	R SIDE
MASS FLOW RATE	2.76000+03	6.00000+02
INLET TEMPERATURE	4.99700+02	5.34700+02
OUTLET TEMPERATURE	5.12597+02	5.19700+02
INLET VAPOR QUALITY	--	1.00000+00
OUTLET VAPOR QUALITY	--	1.78703-01
PRESSURE DROP	6.91827+00	6.64960-01
INLET PRESSURE	4.24000+03	1.04360+04
OUTLET PRESSURE	4.23308+03	1.04353+04
AVERAGE REYNOLDS NUMBER	8.58726+00	--
AVERAGE HEAT-TRANSFER COEFFICIENT	9.64508+01	2.15191+02
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	8.42134-01	8.51798-01

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE S WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EFFECTIVENESS	4.28571-01
AVERAGE TOTAL CONDUCTANCE (UA)	5.24595+03

** OUTPUT DATA FOR TIME THETA = 5.79656-03 **

	S SIDE	R SIDE
MASS FLOW RATE	2.76000+03	6.00000+02
INLET TEMPERATURE	4.99700+02	5.34700+02
OUTLET TEMPERATURE	5.12333+02	5.19700+02
INLET VAPOR QUALITY	--	1.00000+00
OUTLET VAPOR QUALITY	--	1.95013-01
PRESSURE DROP	6.91827+00	6.70869-01
INLET PRESSURE	4.24000+03	1.04360+04
OUTLET PRESSURE	4.23308+03	1.04353+04
AVERAGE REYNOLDS NUMBER	8.60655+00	--
AVERAGE HEAT-TRANSFER COEFFICIENT	9.64856+01	2.01441+02
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	8.42090-01	8.57678-01

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE S WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EFFECTIVENESS	4.28571-01
AVERAGE TOTAL CONDUCTANCE (UA)	5.15144+03

** OUTPUT DATA FOR TIME THETA = 6.05191-03 **

	S SIDE	R SIDE
MASS FLOW RATE	2.76000+03	6.00000+02
INLET TEMPERATURE	4.99700+02	5.34700+02
OUTLET TEMPERATURE	5.12401+02	5.19700+02
INLET VAPOR QUALITY	--	1.00000+00
OUTLET VAPOR QUALITY	--	1.99088-01
PRESSURE DROP	6.91827+00	6.72154-01
INLET PRESSURE	4.24000+03	1.04360+04
OUTLET PRESSURE	4.23308+03	1.04353+04
AVERAGE REYNOLDS NUMBER	8.63129+00	--
AVERAGE HEAT-TRANSFER COEFFICIENT	9.64800+01	2.03286+02
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	8.42097-01	8.57150-01

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE S WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EFFECTIVENESS	4.28571-01
AVERAGE TOTAL CONDUCTANCE (UA)	5.16514+03

** OUTPUT DATA FOR TIME THETA = 6.67849-03 **

	S SIDE	R SIDE
MASS FLOW RATE	2.76000+03	6.00000+02
INLET TEMPERATURE	4.99700+02	5.34700+02
OUTLET TEMPERATURE	5.13351+02	5.19700+02
INLET VAPOR QUALITY	--	1.00000+00
OUTLET VAPOR QUALITY	--	1.97250-01
PRESSURE DROP	6.91827+00	6.67661-01
INLET PRESSURE	4.24000+03	1.04360+04
OUTLET PRESSURE	4.23308+03	1.04353+04
AVERAGE REYNOLDS NUMBER	8.69251+00	--
AVERAGE HEAT-TRANSFER COEFFICIENT	9.64584+01	2.06658+02
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	8.42124-01	8.56367-01

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE S WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EFFECTIVENESS	4.28571-01
AVERAGE TOTAL CONDUCTANCE (UA)	5.18971+03

** OUTPUT DATA FOR TIME THETA = 8.08638-03 **

	S SIDE	R SIDE
MASS FLOW RATE	2.76000+03	6.00000+02
INLET TEMPERATURE	4.99700+02	5.34700+02
OUTLET TEMPERATURE	5.14604+02	5.19700+02
INLET VAPOR QUALITY	--	1.00000+00
OUTLET VAPOR QUALITY	--	2.00172-01
PRESSURE DROP	6.91827+00	6.64662-01
INLET PRESSURE	4.24000+03	1.04360+04
OUTLET PRESSURE	4.23308+03	1.04353+04
AVERAGE REYNOLDS NUMBER	8.75585+00	--
AVERAGE HEAT-TRANSFER COEFFICIENT	9.64210+01	2.09548+02
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	8.42172-01	8.57057-01

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE S WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EFFECTIVENESS	4.28571-01
AVERAGE TOTAL CONDUCTANCE (UA)	5.21225+03

** OUTPUT DATA FOR TIME THETA = 1.03437-02 **

	S SIDE	R SIDE
MASS FLOW RATE	2.76000+03	6.00000+02
INLET TEMPERATURE	4.99700+02	5.34700+02
OUTLET TEMPERATURE	5.15331+02	5.19700+02
INLET VAPOR QUALITY	--	1.00000+00
OUTLET VAPOR QUALITY	--	1.77546-01
PRESSURE DROP	6.91827+00	5.46592-01
INLET PRESSURE	4.24000+03	1.04360+04
OUTLET PRESSURE	4.23308+03	1.04355+04
AVERAGE REYNOLDS NUMBER	8.71026+00	--
AVERAGE HEAT-TRANSFER COEFFICIENT	9.64598+01	2.09560+02
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	8.42123-01	8.57040-01

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE S WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EFFECTIVENESS	4.46594-01
AVERAGE TOTAL CONDUCTANCE (UA)	5.21354+03

** OUTPUT DATA FOR TIME THETA = 1.13414-02 **

	S SIDE	R SIDE
MASS FLOW RATE	2.76000+03	6.00000+02
INLET TEMPERATURE	4.99700+02	5.34700+02
OUTLET TEMPERATURE	5.15510+02	5.19700+02
INLET VAPOR QUALITY	--	1.00000+00
OUTLET VAPOR QUALITY	--	1.86171-01
PRESSURE DROP	6.91828+00	5.53252-01
INLET PRESSURE	4.24000+03	1.04360+04
OUTLET PRESSURE	4.23308+03	1.04354+04
AVERAGE REYNOLDS NUMBER	8.77092+00	--
AVERAGE HEAT-TRANSFER COEFFICIENT	9.63852+01	1.88293+02
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	8.42218-01	8.65393-01

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE S WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EFFECTIVENESS	4.51710-01
AVERAGE TOTAL CONDUCTANCE (UA)	5.05173+03

** OUTPUT DATA FOR TIME THETA = 1.24981-02 **

	S SIDE	R SIDE
MASS FLOW RATE	2.76000+03	6.00000+02
INLET TEMPERATURE	4.99700+02	5.34700+02
OUTLET TEMPERATURE	5.15664+02	5.19700+02
INLET VAPOR QUALITY	--	1.00000+00
OUTLET VAPOR QUALITY	--	1.99189-01
PRESSURE DROP	6.91828+00	5.60085-01
INLET PRESSURE	4.24000+03	1.04360+04
OUTLET PRESSURE	4.23308+03	1.04354+04
AVERAGE REYNOLDS NUMBER	8.79617+00	--
AVERAGE HEAT-TRANSFER COEFFICIENT	9.63776+01	1.94623+02
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	8.42227-01	8.63498-01

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE S WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EFFECTIVENESS	4.56110-01
AVERAGE TOTAL CONDUCTANCE (UA)	5.10268+03

** OUTPUT DATA FOR TIME THETA = 1.33866-02 **

	S SIDE	R SIDE
MASS FLOW RATE	2.76000+03	6.00000+02
INLET TEMPERATURE	4.99700+02	5.34700+02
OUTLET TEMPERATURE	5.15767+02	5.19700+02
INLET VAPOR QUALITY	--	1.00000+00
OUTLET VAPOR QUALITY	--	2.01769-01
PRESSURE DROP	6.91828+00	5.58047-01
INLET PRESSURE	4.24000+03	1.04360+04
OUTLET PRESSURE	4.23308+03	1.04354+04
AVERAGE REYNOLDS NUMBER	8.74893+00	--
AVERAGE HEAT-TRANSFER COEFFICIENT	9.64301+01	1.94590+02
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	8.42160-01	8.63515-01

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE S WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EFFECTIVENESS	4.59048-01
AVERAGE TOTAL CONDUCTANCE (UA)	5.10404+03

** OUTPUT DATA FOR TIME THETA = 1.68310-02 **

	S SIDE	R SIDE
MASS FLOW RATE	2.76000+03	6.00000+02
INLET TEMPERATURE	4.99700+02	5.34700+02
OUTLET TEMPERATURE	5.15974+02	5.19700+02
INLET VAPOR QUALITY	--	1.00000+00
OUTLET VAPOR QUALITY	--	2.04986-01
PRESSURE DROP	6.91828+00	5.64811-01
INLET PRESSURE	4.24000+03	1.04360+04
OUTLET PRESSURE	4.23308+03	1.04354+04
AVERAGE REYNOLDS NUMBER	8.80860+00	--
AVERAGE HEAT-TRANSFER COEFFICIENT	9.63747+01	1.95589+02
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	8.42231-01	8.63051-01

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE S WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EFFECTIVENESS	4.64978-01
AVERAGE TOTAL CONDUCTANCE (UA)	5.10989+03

** OUTPUT DATA FOR TIME THETA = 2.50310-02 **

	S SIDE	R SIDE
MASS FLOW RATE	2.76000+03	6.00000+02
INLET TEMPERATURE	4.99700+02	5.34700+02
OUTLET TEMPERATURE	5.16131+02	5.19700+02
INLET VAPOR QUALITY	--	1.00000+00
OUTLET VAPOR QUALITY	--	2.11205-01
PRESSURE DROP	6.91828+00	5.69478-01
INLET PRESSURE	4.24000+03	1.04360+04
OUTLET PRESSURE	4.23308+03	1.04354+04
AVERAGE REYNOLDS NUMBER	8.82014+00	--
AVERAGE HEAT-TRANSFER COEFFICIENT	9.63976+01	1.98864+02
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	8.42202-01	8.62038-01

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE S WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EFFECTIVENESS	4.69466-01
AVERAGE TOTAL CONDUCTANCE (UA)	5.13594+03

** OUTPUT DATA FOR TIME THETA = 3.32310-02 **

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	S SIDE	R SIDE
MASS FLOW RATE	2.76000+03	6.00000+02
INLET TEMPERATURE	4.99700+02	5.34700+02
OUTLET TEMPERATURE	5.16168+02	5.19700+02
INLET VAPOR QUALITY	--	1.00000+00
OUTLET VAPOR QUALITY	--	2.13011-01
PRESSURE DROP	6.91828+00	5.70318-01
INLET PRESSURE	4.24000+03	1.04360+04
OUTLET PRESSURE	4.23308+03	1.04354+04
AVERAGE REYNOLDS NUMBER	8.82285+00	--
AVERAGE HEAT-TRANSFER COEFFICIENT	9.64138+01	1.99420+02
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	8.42181-01	8.61866-01

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE S WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EFFECTIVENESS	4.70504-01
AVERAGE TOTAL CONDUCTANCE (UA)	5.14069+03

** OUTPUT DATA FOR TIME THETA = 4.14310-02 **

	S SIDE	R SIDE
MASS FLOW RATE	2.76000+03	6.00000+02
INLET TEMPERATURE	4.99700+02	5.34700+02
OUTLET TEMPERATURE	5.16174+02	5.19700+02
INLET VAPOR QUALITY	--	1.00000+00
OUTLET VAPOR QUALITY	--	2.13375-01
PRESSURE DROP	6.91828+00	5.70442-01
INLET PRESSURE	4.24000+03	1.04360+04
OUTLET PRESSURE	4.23308+03	1.04354+04
AVERAGE REYNOLDS NUMBER	8.82278+00	--
AVERAGE HEAT-TRANSFER COEFFICIENT	9.64174+01	1.99474+02
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	8.42177-01	8.61850-01

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE S WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EFFECTIVENESS	4.70696-01
AVERAGE TOTAL CONDUCTANCE (UA)	5.14121+03

** OUTPUT DATA FOR TIME THETA = 4.96310-02 **

	S SIDE	R SIDE
MASS FLOW RATE	2.76000+03	6.00000+02
INLET TEMPERATURE	4.99700+02	5.34700+02
OUTLET TEMPERATURE	5.16175+02	5.19700+02
INLET VAPOR QUALITY	--	1.00000+00
OUTLET VAPOR QUALITY	--	2.13759-01
PRESSURE DROP	6.91828+00	5.70582-01
INLET PRESSURE	4.24000+03	1.04360+04
OUTLET PRESSURE	4.23308+03	1.04354+04
AVERAGE REYNOLDS NUMBER	8.82335+00	--
AVERAGE HEAT-TRANSFER COEFFICIENT	9.64178+01	1.99591+02
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	8.42176-01	8.61815-01

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE S WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EFFECTIVENESS	4.70704-01
AVERAGE TOTAL CONDUCTANCE (UA)	5.14212+03

** OUTPUT DATA FOR TIME THETA = 5.78310-02 **

	S SIDE	R SIDE
MASS FLOW RATE	2.76000+03	6.00000+02
INLET TEMPERATURE	4.99700+02	5.34700+02
OUTLET TEMPERATURE	5.16174+02	5.19700+02
INLET VAPOR QUALITY	--	1.00000+00
OUTLET VAPOR QUALITY	--	2.13924-01
PRESSURE DROP	6.91828+00	5.70634-01
INLET PRESSURE	4.24000+03	1.04360+04
OUTLET PRESSURE	4.23308+03	1.04354+04
AVERAGE REYNOLDS NUMBER	8.82330+00	--
AVERAGE HEAT-TRANSFER COEFFICIENT	9.64180+01	1.99604+02
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	8.42176-01	8.61810-01

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE S WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EFFECTIVENESS	4.70694-01
AVERAGE TOTAL CONDUCTANCE (UA)	5.14222+03

** OUTPUT DATA FOR TIME THETA = 6.60310-02 **

	S SIDE	R SIDE
MASS FLOW RATE	2.76000+03	6.00000+02
INLET TEMPERATURE	4.99700+02	5.34700+02
OUTLET TEMPERATURE	5.16174+02	5.19700+02
INLET VAPOR QUALITY	--	1.00000+00
OUTLET VAPOR QUALITY	--	2.14046-01
PRESSURE DROP	6.91828+00	5.70680-01
INLET PRESSURE	4.24000+03	1.04360+04
OUTLET PRESSURE	4.23308+03	1.04354+04
AVERAGE REYNOLDS NUMBER	8.82330+00	--
AVERAGE HEAT-TRANSFER COEFFICIENT	9.64180+01	1.99659+02
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	8.42176-01	8.61794-01

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE S WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EFFECTIVENESS	4.70677-01
AVERAGE TOTAL CONDUCTANCE (UA)	5.14264+03

** OUTPUT DATA FOR TIME THETA = 7.42310-02 **

	S SIDE	R SIDE
MASS FLOW RATE	2.76000+03	6.00000+02
INLET TEMPERATURE	4.99700+02	5.34700+02
OUTLET TEMPERATURE	5.16173+02	5.19700+02
INLET VAPOR QUALITY	--	1.00000+00
OUTLET VAPOR QUALITY	--	2.14123-01
PRESSURE DROP	6.91828+00	5.70710-01
INLET PRESSURE	4.24000+03	1.04360+04
OUTLET PRESSURE	4.23308+03	1.04354+04
AVERAGE REYNOLDS NUMBER	8.82322+00	--
AVERAGE HEAT-TRANSFER COEFFICIENT	9.64180+01	1.99676+02
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	8.42170-01	8.61790-01

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE S WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EFFECTIVENESS	4.70661-01
AVERAGE TOTAL CONDUCTANCE (UA)	5.14277+03

** OUTPUT DATA FOR TIME THETA = 8.24310-02 **

	S SIDE	R SIDE
MASS FLOW RATE	2.76000+03	6.00000+02
INLET TEMPERATURE	4.99700+02	5.34700+02
OUTLET TEMPERATURE	5.16173+02	5.19700+02
INLET VAPOR QUALITY	--	1.00000+00
OUTLET VAPOR QUALITY	--	2.14192-01
PRESSURE DROP	6.91828+00	5.70738-01
INLET PRESSURE	4.24000+03	1.04360+04
OUTLET PRESSURE	4.23308+03	1.04354+04
AVERAGE REYNOLDS NUMBER	8.82316+00	--
AVERAGE HEAT-TRANSFER COEFFICIENT	9.64180+01	1.99703+02
AVERAGE HEAT-TRANSFER SURFACE EFFICIENCY	8.42176-01	8.61782-01

EXTRAPOLATION OF THE FRICTION FACTOR AND COLBURN MODULUS DATA FOR SIDE S WAS NECESSARY TO OBTAIN THE ABOVE RESULTS

EFFECTIVENESS	4.70648-01
AVERAGE TOTAL CONDUCTANCE (UA)	5.14298+03

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

A computer program (Program KRONOS) has been written in the Fortran-V language for use with the Univac 1108 computing system. This program can be used for the prediction of the transient thermal performance of compact heat exchangers of the plate-fin variety. In general, the program will compute the variation of outlet conditions with time for each fluid in a given exchanger for prescribed initial temperature distributions and time variations in inlet temperature and flow rate. The program has been developed such that it can be used quite effectively with a minimum amount of effort and experience. The results obtained in using the program indicate that it is sufficiently general to be applied to the solution of practical problems involving the prediction of the transient behavior of compact heat exchangers.

Recommendations

The finite-difference solution procedure incorporated into the program is based on taking incremental steps along the time scale and in the physical flow plane. As described in Appendix IV of Volume I, such a procedure can yield inaccurate results for the temperature distributions at values of time less than the fluid dwell times. For the applications for which the program is intended (that is, for use as an analytical tool in the investigation of the dynamic behavior of systems containing one or more heat exchangers), the relatively minor inaccuracies at small values of time will have no significant effect on the results obtained. However, there may be other applications involving the transient analysis of compact heat exchangers where the detailed temperature distributions throughout the exchanger are required at all times, for example, in the analysis of a given configuration to determine whether the transient thermal stresses are within acceptable limits. If such applications are of interest, it is recommended that the program be altered or a new program written using a finite-difference scheme based on the method of characteristics (Ref 5 of Volume I) to compute and print

out the detailed temperature distributions at all of the desired values of time.

In the program as it now stands, the initial conditions which can be considered are confined to a start-up or a steady-state situation. In some instances it may be desirable to start the calculations from some point in time during the transient, for example, to extend the calculations for a particular case to yield results over a wider time interval. If such a feature is desirable, it is recommended that the program be altered to include an option for accepting a set of specified temperature distributions as the initial conditions. This would involve changing the output from the program to include a tape on which are written the distributions calculated at the last value of time considered for each case. This tape could then be used as input in a subsequent run to extend the solutions obtained to larger values of time.

REFERENCES

1. The Design and Performance Analysis of Compact Heat Exchangers, Volume I - Theory and Practice of Design (NREC Report No. 1095-1), Northern Research and Engineering Corporation, Cambridge, Mass., December, 1965.
2. The Design and Performance Analysis of Compact Heat Exchangers, Volume II - Design Examples and Digital Computer Programs (NREC Report No. 1095-2), Northern Research and Engineering Corporation, Cambridge, Mass., December, 1965.
3. The Design and Performance Analysis of Compact Heat Exchangers, Volume III - Design Data (NREC Report No. 1095-3), Northern Research and Engineering Corporation, Cambridge, Mass., December, 1965.
4. Heat Exchanger Surface Selection Computer Program Development (NREC Report No. 1109-1), Northern Research and Engineering Corporation, Cambridge, Mass., vol. 1, September 15, 1966.

TABLES

TABLE I

SPECIFIED DATA FOR EXAMPLE 1

	r Side	s Side
Matrix Number*	2503	3007
Inlet Pressure, lbf per sq ft	778	5040
Initial Steady-State Operating Conditions (θ = 0 hr):		
Flow Rate, lbm per hr	114	32
Inlet Temperature, deg R	504.7	604.7
Final Steady-State Operating Conditions ($\theta \geq$ 0.01 hr):		
Flow Rate, lbm per hr	114	32
Inlet Temperature, deg R	504.7	559.7

Core Dimensions:

L_x = 0.333 ft

L_y = 0.500 ft

L_{NF} = 0.586 ft

* Matrix 2503 is a single-sandwich arrangement of wavy fins; matrix 3007 is a single-sandwich arrangement of triangular fins. The geometric and performance data for both are given in Reference 3.

TABLE II

SPECIFIED DATA FOR EXAMPLE 2

	r Side	s Side
Matrix Number*	3002	4013
Inlet Pressure, lbf per sq ft	2120	4240
Initial Steady-State Operating Conditions (θ = 0 hr):		
Flow Rate, lbm per hr	1854	5280
Inlet Temperature, deg R	559.7	509.7
Inlet Absolute Humidity	0.03	--
Final Steady-State Operating Conditions ($\theta \geq 10^{-4}$ hr):		
Flow Rate, lbm per hr	1908	5280
Inlet Temperature, deg R	574.7	509.7
Inlet Absolute Humidity	0.06	--

Core Dimensions:

L_x = 1.000 ft

L_y = 0.750 ft

L_{NF} = 0.896 ft

* Matrix 3002 is a single-sandwich arrangement of triangular fins; matrix 4013 is a single-sandwich arrangement of louvered triangular fins. The geometric and performance data for both are given in Reference 3.

TABLE III

SPECIFIED DATA FOR EXAMPLE 3

	r Side	s Side
Matrix Number*	3004	3006
Inlet Pressure, lbf per sq ft	10436	4240
Saturation Temperature, deg R	519.7	--
Initial Steady-State Operating Conditions (θ = 0 hr):		
Flow Rate, lbm per hr	600	2760
Inlet Temperature, deg R	534.7	489.7
Inlet Vapor Quality	1.0	--
Final Steady-State Operating Conditions ($\theta \geq 10^{-3}$hr):		
Flow Rate, lbm per hr	600	2760
Inlet Temperature, deg R	534.7	499.7
Inlet Vapor Quality	1.0	--

Core Dimensions:

L_X = 0.833 ft

L_Y = 0.667 ft

L_{NF} = 0.800 ft

* Matrices 3004 and 3006 are both single-sandwich arrangements of triangular fins. The geometric and performance data are given in Reference 3.

TABLE IV

NONDIMENSIONAL LOCAL HEAT-TRANSFER COEFFICIENT FOR A SINGLE-COMPONENT CONDENSING VAPOR

τ_v^*	$Pr_\ell = 1$		$Pr_\ell = 10$	
	h^*	Re_ℓ	h^*	Re_ℓ
1.0	0.50	10	0.50	10
	0.094	1,700	0.094	1,600
	0.16	2,100	0.33	2,000
	0.28	100,000	0.63	8,000
			1.10	100,000
5.0	1.06	10	1.06	10
	0.17	600	0.17	600
	0.24	700	0.41	800
	0.34	100,000	0.63	3,500
			1.20	100,000
10.0	1.46	10	1.40	10
	0.27	300	0.38	190
	0.30	400	0.50	260
	0.36	100,000	0.53	400
			1.20	100,000
50.0	3.50	10	3.40	10
	0.41	450	0.81	180
	0.54	550	0.92	300
	0.46	100,000	1.00	1,500
			1.39	100,000

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FIGURES

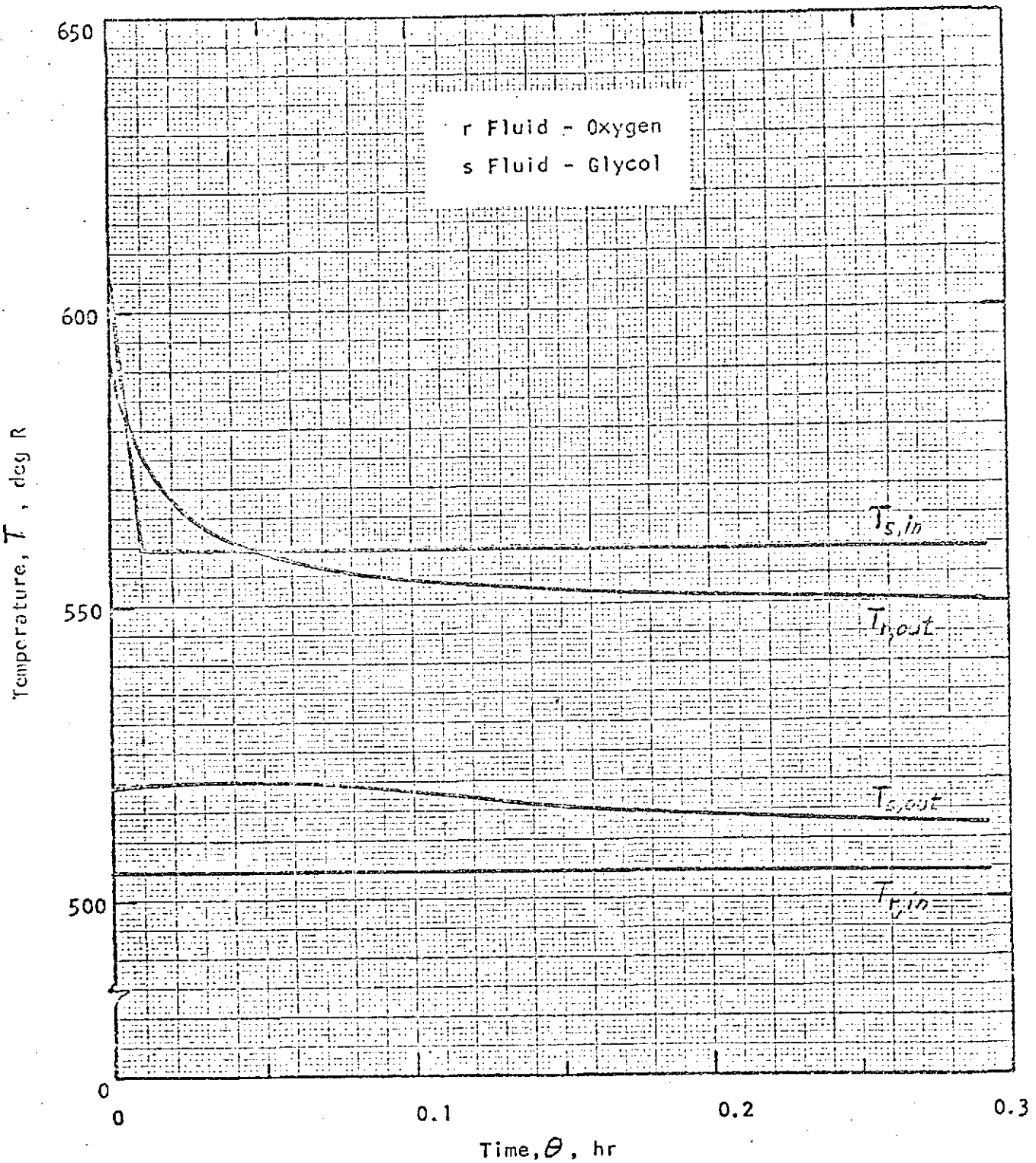


FIGURE 1 - TRANSIENT VARIATIONS OF INLET AND OUTLET TEMPERATURES FOR A SINGLE-PHASE COUNTERFLOW HEAT EXCHANGER (RESULTS OF EXAMPLE 1)

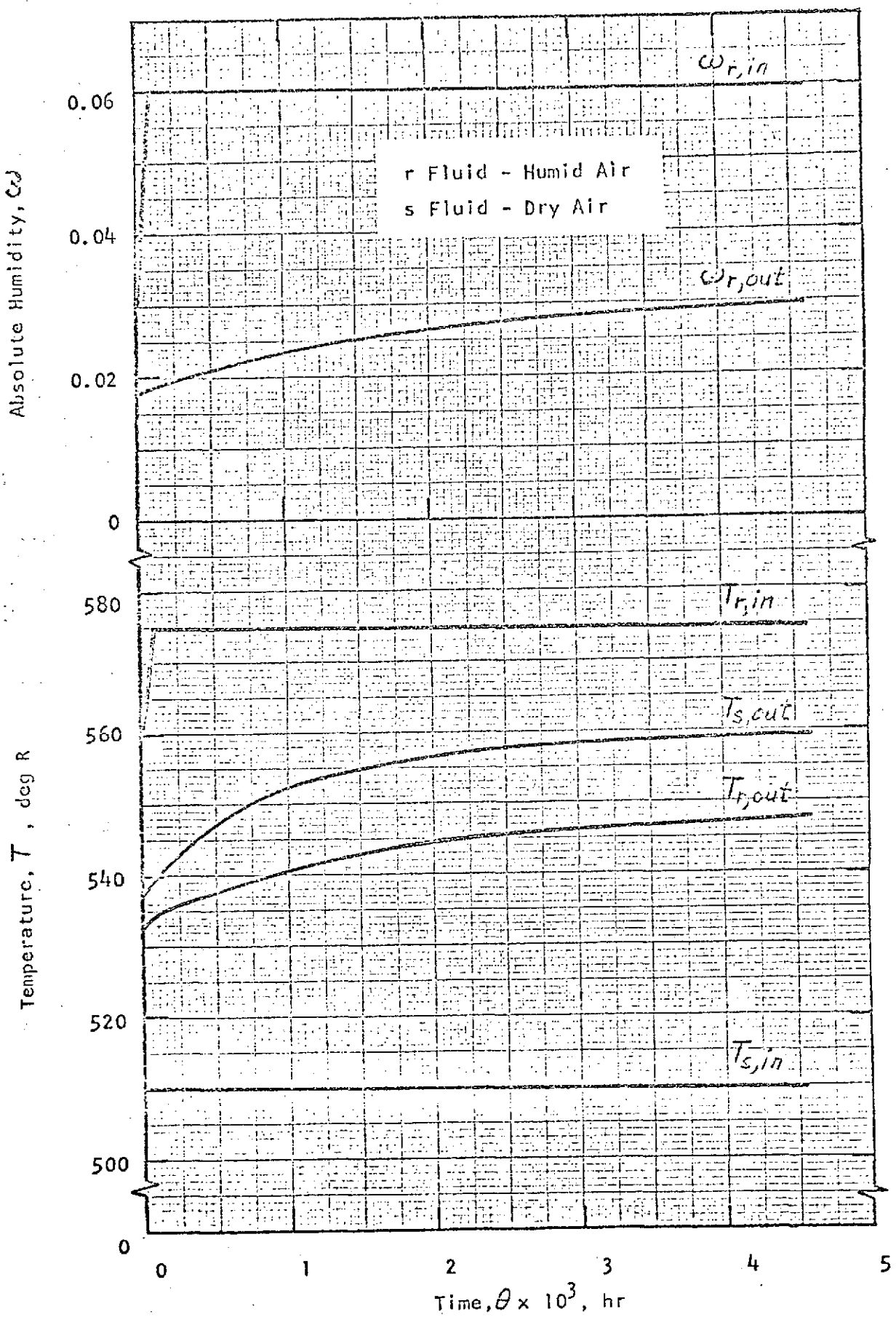


FIGURE 2 - TRANSIENT VARIATIONS OF INLET AND OUTLET TEMPERATURES AND HUMIDITY FOR A WET-GAS CROSSFLOW HEAT EXCHANGER (RESULTS OF EXAMPLE 2)

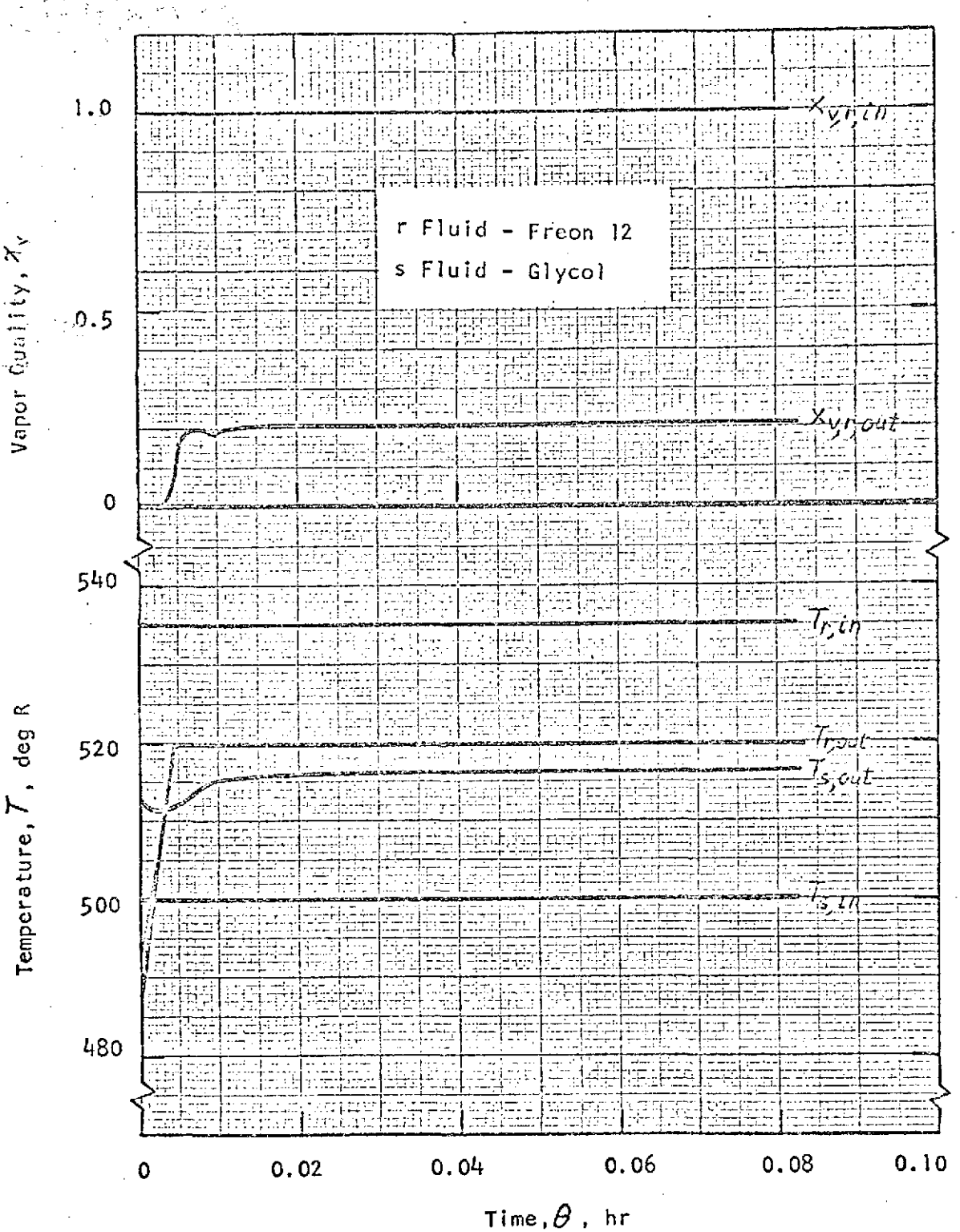


FIGURE 3 - TRANSIENT VARIATIONS OF INLET AND OUTLET TEMPERATURES AND QUALITY FOR A CROSSFLOW FREON CONDENSER (RESULTS OF EXAMPLE 3)

NOMENCLATURE

Symbol	Description	Units
A	Heat-transfer area	sq ft
A_c	Minimum free flow area	sq ft
A_f/A	Ratio of fin to total heat-transfer area	- -
A_H	Heat-transfer area per unit area in the flow plane for a matrix	- -
$A_{sw,\ell}$	Heat-transfer area of side wall parallel to parting plates	sq ft
$A_{sw,t}$	Heat-transfer area of side wall normal to parting plates	sq ft
a	Parting-plate thickness	ft
a_{sp}	Splitter-plate thickness	ft
$a_{sw,\ell}$	Plate thickness of side wall parallel to parting plates	ft
$a_{sw,t}$	Plate thickness of side wall normal to parting plates	ft
b	Plate spacing (distance between adjacent plates) for a matrix	ft
$\overline{C}_w$	Total heat capacity of exchanger core structure	Btu per deg R
$\overline{C}_{sw}$	Heat capacity of side wall in contact with one fluid	Btu per deg R
c_p	Specific heat	Btu per lbm deg R
f	Fanning friction factor	- -
G	Mass velocity (w/A_c)	lbm per hr sq ft
g	Acceleration due to gravity	ft per hr^2
g_c	Proportionality constant in Newton's Law (4.169×10^8)	ft lbm per lbf hr^2
H	Enthalpy per unit mass	Btu per lbm
h	Heat-transfer coefficient	Btu per hr sq ft deg R
h_{fg}	Latent heat (heat of vaporization)	Btu per lbm
j	Colburn modulus	- -
k	Thermal conductivity	Btu per hr ft deg R

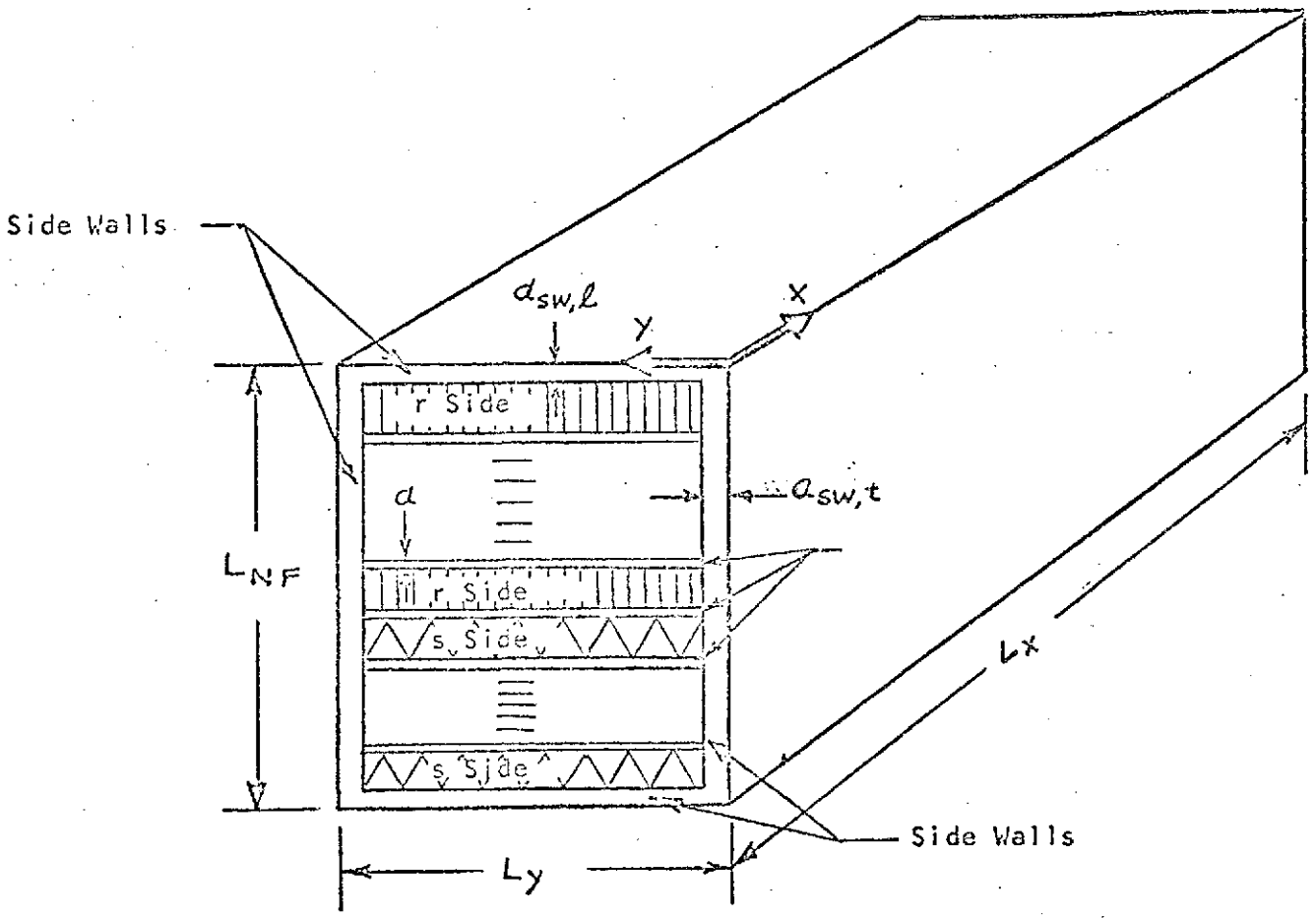
Symbol	Description	Units
L	Flow length or total heat-exchanger core dimension	ft
ℓ_F	Effective fin length	ft
M	Molecular weight	lbm per lbm-mole
N_L	Number of layers or sandwiches for a matrix	- -
N_P	Number of passes in a multipass crossflow exchanger	- -
N_V	Rate of condensation from a wet gas	lbm per hr
$\overline{N}_{V,W}$	Fraction of condensation from a wet gas occurring on separating walls and attached fins	- -
N_X	Total number of length increments into which the x dimension (L_x) of an exchanger is divided	- -
$N_{Y,P}$	Total number of length increments into which the y dimension per pass (L_y) of a crossflow exchanger is divided	- -
Pr	Prandtl number ($\equiv c_p \mu / k$)	- -
p	Pressure	lbf per sq ft
R	Gas constant	ft lbf per lbm deg R
Re	Reynolds number ($\equiv 4 r_h G / \mu$)	- -
r_h	Hydraulic radius ($\equiv A_c L / A$)	ft
s_f	Fin spacing	ft
T	Temperature	deg R
U_T	Heat-transfer conductance on one side	Btu per hr deg R
V	Volume	cu ft
$(V_f/V)_{int}$	Ratio of metal volume to total volume between plates for a matrix	- -
V_{void}	Void volume on one side	cu ft
W	Fluid inventory on one side	lbm
w	Mass flow rate	lbm per hr
x	Coordinate axis of exchanger	ft

Symbol	Description	Units
x_v	Vapor quality (mass-fraction vapor) of a single-component condensing fluid	- -
y	Coordinate axis of exchanger	ft
Δ_p	Pressure drop	lbf per sq ft
Δx	Length increment in x direction	ft
Δy	Length increment in y direction	ft
$\Delta\theta$	Time increment	hr
δ	Effective fin thickness	ft
η_f	Fin efficiency	- -
η_o	Heat-transfer surface efficieny	- -
θ	Time	hr
θ'	Time at beginning of time step	hr
θ_d	Dwell time of one fluid in heat exchanger ($\cong W/w$)	hr
μ	Dynamic viscosity	lbm per hr ft
ξ	Distance along flow direction of s fluid	ft
ρ	Density	lbm per cu ft
σ'	Ratio of minimum free-flow area to total face area for one side	- -
σ_{int}	Ratio of minimum free-flow area to face area between adjacent plates	- -
τ_v	Vapor shear stress	lbf per sq ft
ω	Absolute humidity of a wet gas (lbm moisture/lbm dry gas)	- -

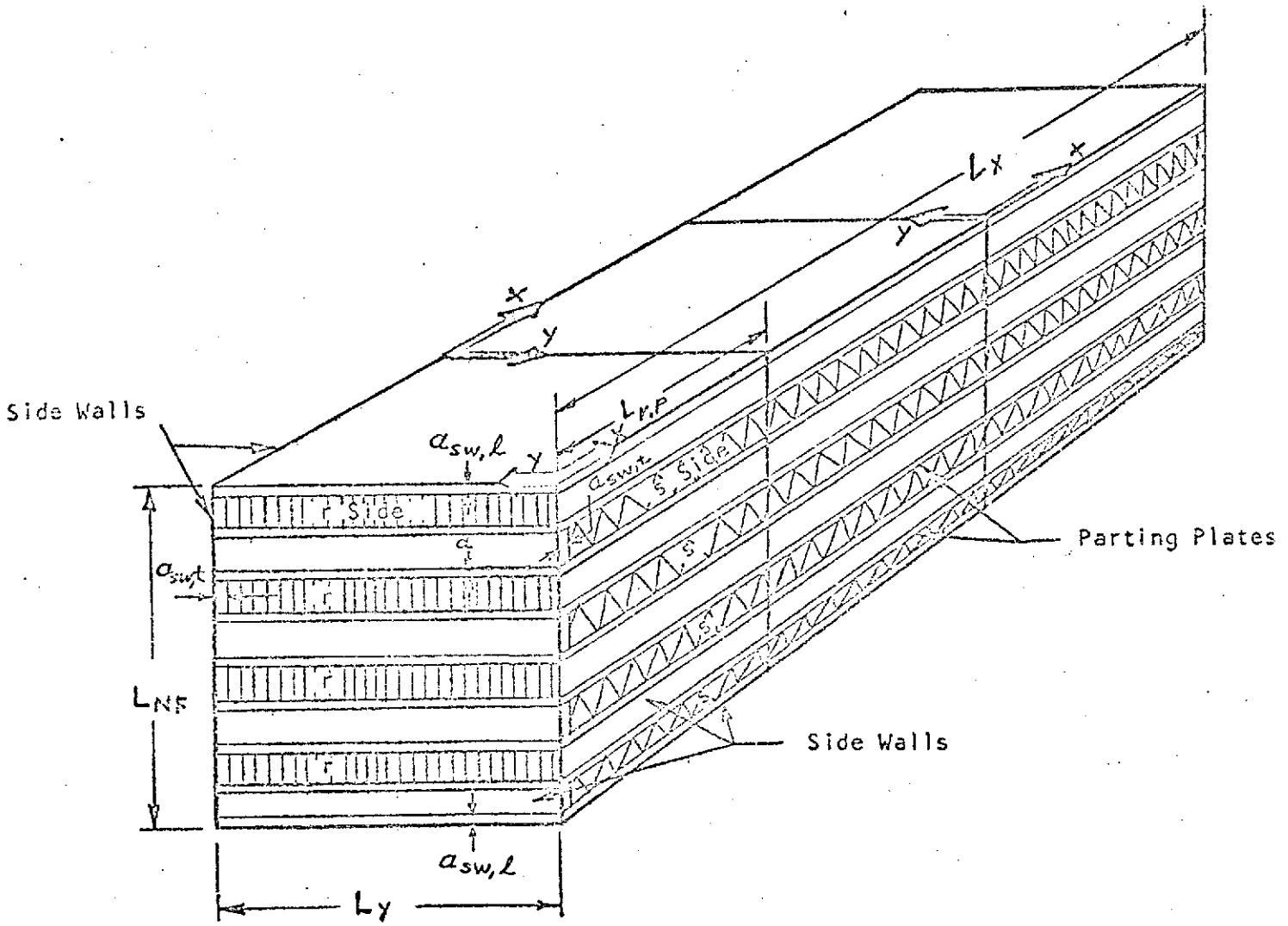
Subscript	Description
ave	Average quantity
DP	Value at dew point of wet gas
g	Gas component of wet gas
i	Station or section in the x direction
in	Inlet
j	Station or section in the y direction for a crossflow configuration
ℓ	Liquid

Subscript	Description
m	Mean
max	Maximum
met	Metal
min	Minimum
NF	Nonflow dimension
out	Outlet
r	One side or fluid of heat exchanger
s	Other side or fluid of heat exchanger
sat	Value at saturated conditions
sw	Side wall
v	Vapor
w	Separating wall
x	Coordinate axis of exchanger
y	Coordinate axis of exchanger

Superscript	Description
o	Quantity nondimensionalized by hydraulic radius
$'$	Value at beginning of time step ($\theta' = \theta - \Delta\theta$)
$\wedge$	Table of values



Parallel Flow and Counterflow



Multipass Crossflow