

# **Software & Publications**

Heat Transfer Research, Inc. (HTRI) is the global leader in process heat transfer and heat exchanger technology. Founded in 1962, our industrial research and development consortium serves the engineering needs of over 1000 corporate member sites.

Our staff conducts application-oriented research and testing on industrially relevant equipment at our state-of-the-art facility; we use these proprietary data to develop methods and software for the thermal design and analysis of heat exchangers and fired heaters. We provide technical support to all members and offer training, consulting, and contract services to both members and non-members.

Our dedication to excellence assures customers of a distinct competitive advantage and a high level of operating confidence in equipment designed with HTRI technology.

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# Software

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HTRI methods and software—based on extensive research data collected on industrial-sized heat transfer equipment—have remained *the* industry standard for more than 40 years. Our research is ongoing and unparalleled. As we obtain and analyze new data on shell-and-tube and non-tubular heat exchangers, air coolers, heat recovery bundles, and fired heaters, we update our methods and incorporate them into the next version of our software.

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## HTRI *Xchanger Suite*<sup>®</sup>

HTRI *Xchanger Suite*, the most advanced tool for the design, rating, and simulation of heat exchangers, brings our rigorous research to end users in an integrated graphical environment. With the addition of our latest component—*Xspe*—HTRI's premier technology and expertise are available in a full complement of products for all your engineering needs.

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### *Xace*<sup>®</sup>

Design, rating, and simulation of air-cooled heat exchangers, heat recovery bundles, and air preheaters

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### *Xfh*<sup>®</sup>

Simulation of fired heaters

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### *Xhpe*<sup>®</sup>

Design, rating, and simulation of hairpin heat exchangers

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### *Xist*<sup>®</sup>

Design, rating, and simulation of single- and two-phase shell-and-tube heat exchangers, including kettle and thermosiphon reboilers, falling film evaporators, and reflux condensers

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### *Xjpe*<sup>®</sup>

Design, rating, and simulation of jacketed pipe heat exchangers

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### *Xphe*<sup>®</sup>

Design, rating, and simulation of plate-and-frame heat exchangers

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### *Xspe*<sup>®</sup>

Rating and simulation of single-phase spiral plate exchangers

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### *Xtlo*<sup>®</sup>

Graphical standalone rigorous tube layout software; also integrated with *Xist*

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### *Xvib*<sup>®</sup>

Rigorous flow-induced vibration analysis of individual tubes in a heat exchanger bundle

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## HTRI *Xchanger Suite Educational*

Customized version of *Xchanger Suite*, including *Xace*, *Xist*, and *Xphe*, for use by educational institutions

# Xchanger Suite

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HTRI *Xchanger Suite* components share many features.

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## Supporting Data

Since 1962, HTRI has collected and analyzed data from industrial-sized units. These data have been used to develop the methods and correlations integral to our software. Heat transfer and pressure drop correlations are continually reviewed and updated as part of our ongoing research program.

A partial list of HTRI data banks follows:

- high-finned tubes
- shellside single-phase
- shellside flow boiling
- plate heat exchangers
- tubeside boiling
- shellside pool boiling
- shellside condensation
- tubeside condensation
- tubeside single-phase (horizontal, inclined, vertical, and reflux)

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## Input/Output

Each *Xchanger Suite* component accepts data and can provide output in SI, U.S. Customary, MKH, and user-specified units. Most components have identical input structure: process conditions and physical properties are entered in the same way, using the same input panels. You can set units across an entire case or item by item.

Output from the various components also is similar. Process conditions, geometry, nozzles, and other common elements print in the same areas of reports.

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## Documentation

All components fully incorporate documentation as online help. You can instantaneously access explanatory text, helpful illustrations, and reference information, as well as learn how to enter specific cases.

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## Interfaces

*Xchanger Suite* components link to other software, including process simulators, mechanical design programs, physical property data banks and systems, and integrated engineering software. Direct connections are provided to some software from the graphical interface; in other cases, components create an output file specifically tailored for input to database software. All components are designed to connect easily with many applications.

HTRI *Xchanger Suite* is CAPE-OPEN-compliant. You can insert an air cooler, a heat recovery bundle, a shell-and-tube, or a plate-and-frame heat exchanger into any process simulator that supports the CAPE-OPEN 1.0 standard, giving you instant access to HTRI's technology while running the simulation.

All fluid property input panels have property grid input options that can interface with process simulator programs. Because *Xchanger Suite* is an automation server, other applications such as Microsoft® Excel can call the exchanger modules (e.g., *Xist*) directly. *Xace*, *Xist*, and *Xphe* also have a DLL interface that can call these modules.

*Xist* operates directly with process simulators such as HYSYS, PRO/II, UniSim Design, and VMGSim, as well as with Aspen Plus through CAPE-OPEN. *Xchanger Suite* also links to VMGThermo™ (included with *Xchanger Suite*), PPDS™, HYSYS®, PRO/II, UniSim Design, REFPROP, and CAPE-OPEN physical property packages for generation of physical properties and heat release curves. Further, *Xchanger Suite* can open HYSYS, UniSim Design, and PRO/II simulation files and load the heat exchangers for detailed analysis.

HTRI can assist members in developing special interfaces to our software.

## Testing

To ensure the highest quality product, each new component and all modifications to existing components undergo extensive testing against

- applicable HTRI research data
- cases designed to test all options and basic correlations and to ensure reasonable extrapolation
- cases with reported limitations
- all cases sent in as part of customer service inquiries

Our test sets are very large. For example, the test set for *Xist* contains more than 11500 cases, and the test set for *Xace* contains more than 6500 cases.

## Physical Properties

*Xchanger Suite* components offer several options for input of fluid physical properties.

- VMGThermo property generator

HTRI *Xchanger Suite* includes the comprehensive property generator package VMGThermo developed by Virtual Materials Group, Inc. With more than thirty different models and direct support for more than 5000 components, VMGThermo easily handles all physical property and heat release curve generation options.

- Property grid input

You can specify mixture properties at 30 temperatures and 12 pressures.

- Automatic fluid code

Supplying internally stored physical properties for more than 100 fluids, this data bank can be expanded to meet individual needs.

- Integration of IAPWS 1997 steam properties

For HTRI's water component, the IAPWS 1997 steam correlations generate physical property and heat release information.

- Automatic estimation for common hydrocarbon groups

- Component properties at two temperatures

- Direct interface to a user-supplied database such as DIPPR®

- HTRI Property Generator

*Xchanger Suite* contains direct interfaces to several commercial physical property/flash packages. From the suite, you can call the packages directly, generating flashes and physical properties for use in *Xace*, *Xfh*, *Xhpe*, *Xist*, *Xjpe*, *Xphe*, and *Xspe*. Built-in interfaces using the property generator include CAPE-OPEN Thermo, VMGThermo, PPDS, REFPROP, PRO/II, UniSim Design, and HYSYS.

## Program Messages

The components can display messages that describe errors in the input data and calculation inconsistencies.

Each component has a three-level message system identifying

- problems that stop the calculations
- warning messages that alert users to potential problems with cases
- informative messages that make suggestions regarding the design

## Customized Input Files

To meet your special requirements, you can customize input files containing exact specifications for

- low-finned tubes
- high-finned tubes

## Customized Input Files, continued

- plates for plate-and-frame exchangers
- pure component physical properties
- tube materials
- nozzle diameters
- air-cooler component weights
- output report language

You can also customize any input item by modifying the default file.

The Predefined Data option, available for all *Xchanger Suite* components, lets you place the geometry for your company standards for exchanger design or a standard line of exchangers into a data input file. Whenever you open a case, Predefined Data appears on the Input menu, allowing you to select the exact geometry of your unit easily.

## Special Features

- Microsoft Windows interface that supports Multiple Document Interface (MDI), which means that you can work on more than one case at a time
- Required data fields highlighted with red borders in the GUI
- Spreadsheet-style output reports that use Windows fonts and embedded graphics
- Automation server (OLE) and DLL interfaces that allow other Windows programs, such as Microsoft Excel, to call components
- 2D scaled exchanger drawing with AutoCAD export capability
- 3D scaled exchanger rendering
- Physical property profile plots for input data validation
- Output results profile plotting using 2D and 3D plots
- Automatic and user-specified design modes
- Single input/output file containing all input, incremental calculation details, output, and graphics
- Reports that may be directly exported to Microsoft Excel

## System Requirements

You must have the following equipment to run the components successfully:

- 32 bit Intel® Pentium® or compatible processor
- 64 MB memory (RAM) for Microsoft Windows 98/ME, 128 MB for Microsoft Windows 2000/XP
- available hard disk space: 374 MB for the entire suite (105 MB for base install)

*Individual component requirements (consult HTRI for specific combinations)*

- |                       |                       |
|-----------------------|-----------------------|
| – <i>Xace</i> , 31 MB | – <i>Xphe</i> , 22 MB |
| – <i>Xfh</i> , 77 MB  | – <i>Xspe</i> , 10 MB |
| – <i>Xhpe</i> , 64 MB | – <i>Xtlo</i> , 9 MB  |
| – <i>Xist</i> , 64 MB | – <i>Xvib</i> , 10 MB |
| – <i>Xjpe</i> , 64    | – VMGThermo, 37 MB    |

- SVGA (800 × 600 resolution) graphics adapter
- pointing device (e.g., mouse, touchpad)
- Microsoft Windows 98, Windows ME, Windows 2000, or Windows XP operating system
- CD-ROM drive (for program installation)

HTRI recommends an 800 MHz or faster Pentium IV with 256 MB RAM, Windows XP operating system, and an XGA graphics adapter (1024 × 768 resolution).

# Xace

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*Xace* designs, rates, and simulates the performance of air coolers and heat recovery bundles. It also simulates air-cooled heat exchangers with the fans turned off. Fully incremental, *Xace* uses HTRI's latest pointwise methods.

Methods in *Xace* are based on extensive research data taken in a wind tunnel, a full-scale air cooler, and a one-third scale model air cooler. Tubeside methods used by *Xace* are identical to those used by *Xist*.

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## Process Specifications

*Xace* provides multiple tubeside process options and a great deal of flexibility in outside process conditions.

- Air flow rate can be either volumetric or mass, or given as an approach or face velocity. Ambient pressure is specified at an altitude above sea level, air properties allow for humidity, and dehumidification is accounted for in the heat transfer calculations.
- For air-cooled heat exchangers, tubeside fluid can be condensing vapor composed of a single component or a multicomponent mixture with or without noncondensables. Fluid can enter the exchanger as superheated or saturated vapor or as a two-phase mixture and can exit as a two-phase mixture, a saturated liquid, or a subcooled liquid.
- For heat recovery bundles, tubeside fluid can be a pure component or multicomponent mixture boiling liquid. It can enter the reboiler subcooled, saturated, or partially vaporized and can contain nonboiling components and/or noncondensing components.
- A single-phase liquid or gas tubeside stream is allowed in both heat recovery bundles and air-cooled heat exchangers.
- In heat recovery bundles, hot fluid can be on the tube side, permitting the component to rate and simulate air preheater bundles.
- For heat recovery bundles, the outside fluid can be boiling for low-finned and plain tubes or condensing for high-finned, low-finned, and plain tubes.

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## Geometry Specifications

*Xace* provides for most air-cooled heat exchanger and heat recovery bundle geometries:

- forced- or induced-draft fans
- air-cooled exchangers with the fans turned off
- one to 99 tuberows
- bundles-in-parallel, bays-in-parallel, bundles-in-series  
Although the program does not handle bays-in-series, 99 tuberows per bundle allow direct simulation of most applications.
- horizontal, inclined, or vertical tubes
- plain, low-finned, high-finned, and stud-finned tubes with or without twisted tapes on staggered, inline, or equal-velocity layouts
- up to nine different tube types per bundle
- one to 2376 tubepasses
- split-pass header arrangements  
One to 24 tubepasses can be specified in each row of the exchanger bundle.
- multiple service air-coolers  
Bundles of differing geometry and tubeside process fluids with the airside fluid in parallel can be specified.

## Calculation Modes

*Xace* operates in rating, simulation, and design modes.

### Rating

You define exchanger geometry and specify process conditions. *Xace* calculates expected heat transfer coefficients and pressure drops, compares these calculations to the required heat duty, and reports the difference as under- or overdesign.

### Simulation

You define exchanger geometry and specify partial process conditions. Using an iterative procedure in the simulation mode, the program adjusts for omitted process conditions until predicted heat duty matches assumed process conditions. Two simulation options are available: calculating the exit temperatures of both streams, and calculating the flow rate and exit temperature of the cold fluid. The latter calculation option is normally used for air-cooled heat exchangers.

### Design

*Xace* contains two distinct design options: program and user-specified.

In the *program* (or classic) mode, *Xace* determines the minimum number of bays in parallel with the smallest width bundles that meet specified process conditions and optional constraints on pressure drop and velocity. *Xace* uses a unique design procedure that determines optimal face velocities, number of rows in the exchanger, and number of tubepasses. You can enter bundle width constraints, or the program can set them. A cost estimate included in the design mode allows you to select a design other than the smallest based on cost. The design process is interactive, and you have control over the allowed ranges of each geometry parameter.

In the *user-specified* (or grid) design mode, you have complete control over which geometry is varied and over what range each geometric parameter is varied. The program runs all possible permutations and automatically selects the best available design.

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## Calculation Methods

The tubeside condensation and boiling methods use HTRI's latest pointwise calculations for heat transfer and pressure drop. Airside methods reflect current wind tunnel and air-cooled heat exchanger research. With a single input code, you can access HTRI's experimentally determined f- and j-factor curves reported in the *Extended Surfaces Data Book*, or you can specify f- and j-curves for a specific tube.

*Xace* employs a three-dimensional incrementation scheme. The exchanger (rows and header geometry) is divided into small increments, each of which contains a single row and one tubepass. Localized methods and fluid properties predict the heat transfer and pressure drop in each increment. These incremental techniques allow accurate prediction of exchangers with complex geometry and hydraulics.

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## Special Features

- Airside maldistribution profiles for investigating the effects of unequal air distribution, with a special code to access HTRI airside maldistribution profiles directly, simulating the effects of walls adjacent to the heat exchanger, ground clearance, and plenum height
- A calculation option that can predict exchanger performance with total phase separation in the return headers
- Direct links to vendor-supplied fan selection software, providing you with manufacturers' fan specifications that satisfy heat exchanger requirements
- Special calculation methods that take into account airside pressure drop changes caused by fan guards, louvers, hail screens, ground clearance, and blockage under the fan
- Automatic flow quantity balancing down each tuberow of a bundle with more than one tuberow per tubepass
- A flow-regime map for all two-phase fluids in a horizontal exchanger
- A temperature maldistribution option to investigate the effect of non-uniform inlet air temperature distribution

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# Xfh

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*Xfh* simulates the behavior of fired heaters. This component calculates the radiant section performance of box and cylindrical heaters along with the performance of any convection section present. *Xfh* also designs process heater tubes and performs combustion calculations.

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## Process Specifications

*Xfh* handles the following process conditions:

- combustion
  - vapor, liquid, or solid fuels
  - vapor fuel components selected from internal data bank
  - fuel flow specification directly or by desired heat release
  - oxidant flow specification directly or by percent excess
- process fluids
  - sensible liquid, sensible vapor, or boiling fluids
  - properties specified directly or calculated from internal data bank
  - inlet conditions at specified temperature or alternately for two-phase fluids using weight fraction vapor
  - process outlet temperatures specified directly or calculated by energy balance

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## Geometry Specifications

*Xfh* accommodates the following geometries:

- radiant section
  - cylindrical or cabin/box heater
  - dimensions of radiant section and flue gas opening
  - radiant tube geometry and radiant tube layout
  - flexible specification of process flow through radiant coil
  - radiant wall loss characteristics
  - burner count, location, and geometry
- stack section
  - multiple convection bundles
  - automatic pass layout of convection bundles
  - complete control over convection tube geometry
  - stack geometry using pre-defined stack elements (e.g., straight duct sections)

## Calculation Modes

*Xfh* performs several types of calculations:

- simulation of the radiant section of cylindrical and box heaters

Box heater calculations are based on a 3D analysis using the Hottel zoning method for radiant heat transfer to the tubes and a superposition method for multiple burners using simplified jet theory for flue gas flow. Simulations of box heaters include industrial box-type furnaces, nearly rectilinear steam boilers, and auxiliary equipment. The cylindrical heater option, which uses a rigorous algorithm similar to box heater calculations, simulates cylindrical upshot heaters. Both the box and cylindrical radiant flux calculations are linked to rigorous process-side calculations that provide local and overall values for tubeside heat transfer and pressure drop.

- simulation of the convection section of fired heaters

*Xfh* calculates heat duty, flue gas and metal temperatures, and draft profiles for convection banks on a row-by-row basis. Stack fittings and sizes can be specified; *Xfh* uses API 560 methods to perform stack draft calculations.

- evaluation of heater tubes based on the API 530 procedure

*Xfh* calculates tube metal design thickness and past/future tube damage based on specified operating conditions, heat transfer coefficients inside heater tubes, and radial temperature profiles across the tube from the bulk to the metal skin.

- calculation of combustion products, mass balance, and overall heater energy balance

*Xfh* can simulate combustion of any fuel gas, fuel oil, liquid fuel, and/or solid fuel with any amount of excess air or oxygen. The oxidant can be air or any oxygen-bearing gas stream such as turbine exhaust.

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## Special Features

- Scaled graphical representation of geometry input for convenient validation
- Plotting capabilities to examine local process and radiant results graphically
- Graphical tool to lay out convection bundles and firebox tubes
- Single-zone radiant option allows quick calculations with a minimum of input
- “No tubes” option to model cases where tube geometry can not be handled via normal input
- Internal databases for gaseous fuel and process fluid components, facilitating calculations of all required properties from composition of fluid

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# Xhpe

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*Xhpe* models hairpin heat exchangers. A fully incremental program, *Xhpe* contains HTRI's latest pointwise methods for predicting condensing, boiling, and single-phase heat transfer and pressure drop. The methods are based on extensive shellside and tubeside condensation, boiling, and single-phase data.

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## Process Specifications

*Xhpe* handles the following process conditions:

- single-phase
  - vertical and horizontal shell orientations
  - shellside and tubeside
- condensation
  - shellside and tubeside
  - pure fluids and multicomponent mixtures
  - superheated, saturated, or partially condensed at inlets
  - subcooled, or partially or totally condensed at outlets
- boiling
  - horizontal units
  - shellside and tubeside
  - pure fluids and multicomponent mixtures
  - subcooled, saturated, or partially vaporized at inlets
  - superheated, or partially or totally vaporized at outlets

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## Geometry Specifications

*Xhpe* accommodates the following geometries:

- horizontal and vertical shells
- piping for horizontal thermosiphons
- one to sixteen tubepasses
- plain or longitudinally finned tubes in fixed tubesheet with or without twisted-tape inserts
- unbaffled, segmental, double-segmental, segmental with no-tubes-in-window (NTIW) baffles

All details of the shell construction can be entered. Default values based on TEMA standards and common industrial practice are available.

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**Calculation Modes**

*Xhpe* operates in rating, simulation, and design modes, automatically screening all cases for flow-induced mechanical and acoustic vibration problems.

**Rating**

You define exchanger geometry and specify process conditions. *Xhpe* calculates the expected heat transfer coefficients and pressure drops, compares these calculations to the required heat duty, and reports the difference as under- or overdesign.

**Simulation**

You define exchanger geometry and specify partial process conditions. *Xhpe* calculates expected exchanger performance and missing process conditions for zero overdesign, as well as heat transfer coefficients, pressure drops, and heat duty.

**Design**

*Xhpe* contains two distinct design options: *program* and *user-specified*.

In the *program* (or *classic*) mode, you define partial exchanger geometry and enough process conditions for *Xhpe* to calculate the required heat duty. *Xhpe* designs the missing geometry and calculates expected heat transfer coefficients and pressure drops.

In the *user-specified* (or grid) design mode, you have complete control over which geometry is varied and over what range each geometric parameter is varied. *Xhpe* runs all possible permutations and automatically selects the best available design. *Xhpe* can set the shell style, shell diameter, tube length, tubepasses, baffle spacing, baffle style, tube diameter, and tube pitch..

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**Calculation Methods**

*Xhpe* employs HTRI's latest research in a 3D incrementation scheme to model hairpin heat exchangers. The geometry (shell style, baffle spacing, tubepasses, baffle style) divides the exchanger into small increments containing crossflow or window flow and a single tubepass. Localized methods and fluid properties are used to predict the heat transfer and pressure drop in each increment. Incremental techniques allow accurate prediction of shell-and-tube heat exchangers with complex geometry and hydraulics.

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**Special Features**

- Integrated graphical tube layout tool
- Automatic and user-specified design modes

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# Xist

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*Xist* models all shell-and-tube heat exchangers. A fully incremental program, *Xist* contains HTRI's latest pointwise methods for predicting condensing, boiling, and single-phase heat transfer and pressure drop. The methods are based on extensive shellside and tubeside condensation, boiling, and single-phase data.

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## Process Specifications

*Xist* handles the following process conditions:

- single-phase
  - all shell styles
  - vertical and horizontal shell orientations
  - shellside and tubeside
- condensation
  - all shell styles available for horizontal units
  - shellside and tubeside
  - vertical downflow condensation in single shellpass or tubepass
  - tubeside inclined condensation
  - pure fluids and multicomponent mixtures
  - superheated, saturated, or partially condensed at inlets
  - subcooled, or partially or totally condensed at outlets
  - vertical intube reflux
- boiling
  - all shell styles available for horizontal units
  - shellside and tubeside
  - vertical upflow boiling in single shellpass or tubepass
  - vertical intube falling film
  - pure fluids and multicomponent mixtures
  - subcooled, saturated, or partially vaporized at inlets
  - superheated, or partially or totally vaporized at outlets
- two-phase no phase change (e.g., glycol injection)
  - all shell styles
  - vertical and horizontal shell orientations
  - shellside and tubeside

---

## Geometry Specifications

*Xist* accommodates the following geometries:

- TEMA E, F, G, H, J, K, and X shells
- horizontal, vertical, and inclined shells
- piping for horizontal and vertical thermosiphons and kettle reboilers
- one to sixteen tubepasses
- fixed and variable baffle spacing
- plain or low-finned tubes in fixed tubesheet with or without twisted-tape inserts, U-tube, or floating-head bundles
- segmental, double-segmental, segmental with no-tubes-in-window (NTIW) baffles, RODbaffles<sup>®</sup>, helical baffles, EMBaffles<sup>™</sup>, Square One<sup>®</sup> grid baffles, and no baffles

## Geometry Specifications, continued

- vertical and horizontal cut baffles
- kettles, thermosiphons, falling film evaporators, flooded evaporators, and tubeside reflux condensers

You can enter all details of the shell construction. Default values are based on TEMA standards and common industrial practices.

## Calculation Modes

*Xist* operates in rating, simulation, and design modes, automatically screening all cases for flow-induced mechanical and acoustic vibration problems.

### Rating

You define exchanger geometry and specify process conditions. *Xist* calculates the expected heat transfer coefficients and pressure drops, compares these calculations to the required heat duty, and reports the difference as under- or overdesign.

### Simulation

You define exchanger geometry and specify partial process conditions. *Xist* calculates expected exchanger performance and missing process conditions for zero overdesign, as well as heat transfer coefficients, pressure drops, and heat duty.

### Design

*Xist* contains two distinct design options: *program* and *user-specified*.

In the *program* (or *classic*) mode, you define partial exchanger geometry and enough process conditions for *Xist* to calculate the required heat duty. *Xist* designs the missing geometry, expected heat transfer coefficients, and pressure drops.

In the *user-specified* (or *grid*) design mode, you have complete control over which geometry is varied and over what range each geometric parameter is varied. The program runs all possible permutations and automatically selects the best available design. The program can set the shell style, shell diameter, tube length, tubepasses, baffle spacing, baffle style, tube diameter, and tube pitch.

### Special Calculations

*Thermosiphons:* *Xist* calculates the expected pressure drops in the inlet and outlet piping.

*Flooded evaporators:* *Xist* calculates the conditions required to keep the top of the bundle in wet-wall boiling

*Kettle reboilers:* *Xist* calculates the kettle dome diameter and internal recirculation rate.

*Exchanger trains:* *Xist* handles trains of exchangers in series and parallel. Permitted process conditions include

- both fluids in series throughout the exchanger train
- one fluid in series and the other in parallel  
The parallel fluid can be the same in each shell, or you can use a separate parallel fluid.

Each exchanger in the series can be a different type; exchanger trains are not limited to identical shells. Parallel trains are considered to be identical.

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**Calculation  
Methods**

The calculation methods in *Xist* are the result of HTRI's latest research. *Xist* employs a 3D incrementation scheme to model shell-and-tube heat exchangers. The geometry (shell style, baffle spacing, tubepasses, and baffle style) divides the exchanger into small increments containing crossflow or window flow and a single tubepass. Localized methods and fluid properties are used to predict the heat transfer and pressure drop in each increment. Incremental techniques allow accurate prediction of shell-and-tube heat exchangers with complex geometry and hydraulics.

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**Special  
Features**

- Integrated graphical tube layout tool
- Unique 3D kettle reboiler circulation model
- Trains of exchangers modeled with identical or unique geometry in each shell
- Setting plan calculations/drawing for plant layout

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# Xjpe

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*Xjpe* models jacketed pipe (single tube-in-tube) heat exchangers. A fully incremental program, *Xjpe* contains HTRI's latest pointwise methods for predicting condensing, boiling, and single-phase heat transfer and pressure drop. The methods are based on extensive tubeside condensation, boiling, and single-phase data. The heat transfer and pressure drop correlations are continually reviewed and updated as part of our ongoing research program.

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## Process Specifications

*Xjpe* handles the following process conditions:

- single-phase
    - vertical and horizontal pipe orientations
    - annulus and inner pipe
  - condensation
    - annulus and inner pipe
    - vertical upflow condensation
    - inner pipe inclined condensation
    - pure fluids and multicomponent mixtures
    - superheated, saturated, or partially condensed at inlets
    - subcooled, or partially or totally condensed at outlets
    - vertical intube reflux and downflow condensation
  - boiling
    - annulus and inner pipe
    - vertical upflow boiling
    - vertical intube falling film
    - pure fluids and multicomponent mixtures
    - subcooled, saturated, or partially vaporized at inlets
    - superheated, or partially or totally vaporized at outlets
- 

## Geometry Specifications

*Xjpe* accommodates the following geometries:

- horizontal, vertical, and inclined pipes
  - piping for horizontal and vertical thermosiphons
  - plain or longitudinally finned tubes in fixed tubesheet with/without twisted-tape inserts
  - no baffles
-

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**Calculation  
Modes**

*Xjpe* operates in rating, simulation, and design modes.

**Rating**

You define exchanger geometry and specify process conditions. *Xjpe* calculates the expected heat transfer coefficients and pressure drops, compares these calculations to the required heat duty, and reports the difference as under- or overdesign.

**Simulation**

You define exchanger geometry and specify partial process conditions. *Xjpe* calculates expected exchanger performance and missing process conditions for zero overdesign, as well as heat transfer coefficients, pressure drops, and heat duty.

**Design**

In the *user-specified* (or *grid*) design mode, you have complete control over which geometry is varied and over what range each geometric parameter is varied. *Xjpe* runs all possible permutations and automatically selects the best available design.

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**Calculation  
Methods**

*Xjpe* employs a one-dimensional incrementation scheme, based on HTRI's latest research, to model jacketed pipe heat exchangers. Localized methods and fluid properties are used to predict the heat transfer and pressure drop in each increment. Incremental techniques allow accurate prediction of complex hydraulics.

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# Xphe

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*Xphe* designs, rates, and simulates plate-and-frame heat exchangers. A fully incremental program, *Xphe* calculates each plate channel individually using local physical properties and process conditions. A unique, research-based port maldistribution procedure is used to determine the flow down each plate channel.

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## Process Specifications

*Xphe* handles the following process conditions:

- single-phase
    - laminar and turbulent flow
  - condensation
    - pure fluids and multicomponent mixtures
    - superheated, saturated, or partially condensed at the inlet
    - subcooled, or partially or totally condensed at outlets
  - boiling
    - pure fluids and multicomponent mixtures
    - subcooled, saturated, or partially vaporized at inlets
    - superheated, or partially or totally vaporized at outlets
- 

## Geometry Specifications

*Xphe* handles characteristics common to most commercially available plate-and-frame heat exchangers:

- plates with chevron angles from 0° to 90°
  - common plates  
If the plate is not available in the data bank, all details of the plate geometry can be specified.
  - up to six passes  
Any number of plates per pass are allowed.
  - cocurrent or countercurrent flow
  - up to five different plates  
The plates can be combined to yield 15 separate effective channel types in the exchanger.
- 

## Calculation Modes

*Xphe* operates in design, rating, and simulation modes.

### Rating

In the rating mode, the program calculates expected heat transfer coefficients and pressure drops for a specified geometry. These are compared to required heat duty, and the difference is reported as under- or overdesign.

### Simulation

Using an iterative procedure in the simulation mode, the program adjusts for omitted process conditions until the predicted heat duty matches assumed process conditions. For example, if the flow rates and inlet conditions are specified for both streams, the program determines exit process conditions.

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**Calculation Modes, continued****Design**

*Xphe* contains two distinct design options: *classic design* and *grid design*.

In the *classic design* mode, *Xphe* uses a unique combination of analytical and computational solutions. The analytical solution sets the basic exchanger design, including the initial number of passes and the number and combination of plates required to meet heat transfer and pressure drop limits. The computational solution fine-tunes the design for final selection. The final result of the design process is a single exchanger that satisfies all your specified criteria.

In the *grid design* mode, you have complete control over which geometry is varied and over what range each geometric parameter is varied. The program runs all possible permutations and automatically selects the best available design.

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**Calculation Methods**

HTRI validated the single-phase calculation methods used in *Xphe* with research data taken on plate-and-frame heat exchangers from three different manufacturers. Phase-change methods are based on HTRI research data taken on one plate style as well as all information available in the open literature. HTRI continues to compile additional research data at our research facility; as improved correlations are developed, the methods are incorporated into *Xphe*.

Users can specify f- and j-factor curves or data according to experiments, HTRI research, or plate manufacturer information.

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**Special Features**

- Database file available from manufacturers that includes standard plates and can be tailored to meet specific requirements and updated as new plates are introduced, with exact heat exchanger plate geometry specifications
- Full support in the GUI for a user-defined plate database, to which a new plate can be added with a single click
- Scaled 2D drawing of plate pack

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# Xspe

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*Xspe* rates and simulates single-phase spiral-plate heat exchangers. A fully incremental program, *Xspe* divides each spiral channel into multiple increments and calculates performance using local physical properties and process conditions.

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## Process Specifications

*Xspe* handles the following process conditions:

- single-phase
    - laminar and turbulent flow
    - vapor and liquid flow
- 

## Geometry Specifications

*Xspe* handles characteristics common to most commercially available spiral-plate heat exchangers:

- type I co- and countercurrent exchangers
  - area specified directly or via plate length
  - stud pitch
  - gap spacing
  - core diameter
- 

## Calculation Modes

*Xspe* operates in rating and simulation modes.

### Rating

In the rating mode, the program calculates expected heat transfer coefficients and pressure drops for a specified geometry. These are compared to required heat duty, and the difference is reported as under- or overdesign.

### Simulation

Using an iterative procedure in the simulation mode, the program adjusts for omitted process conditions until the predicted heat duty matches assumed process conditions. For example, if the flow rates and inlet conditions are specified for both streams, the program determines exit process conditions.

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## Calculation Methods

HTRI validated the single-phase calculation methods used in *Xspe* with research data taken at the HTRI research facility.

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## Special Features

- Local heat transfer and pressure drop results may be viewed in graphical (plot) form.
  - Session log can be enabled to track all runs made.
  - Scaled 2D drawing of spiral exchanger is available.
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# Xtlo

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## Layout Specifications

*Xtlo*, a graphical standalone rigorous tube layout program, handles the following layouts:

- tubepass arrangement
  - number of passes: 1, 2, 3, 4, 6, 8, 10, 12, 14, 16
  - tube layout angle: 30, 45, 60, 90 degrees
  - layout arrangement: H-style, ribbon, quadrant for 4 pass, rotated H-style, rotated ribbon, rotated quadrant
  - location of first tubepass
  - width of passlanes
  - continuous cleaning lanes and symmetry
  - number of seal strips and tie rods selected based on TEMA suggestions
  - low-finned tube parameters specified directly or read from databank
- all TEMA shell styles
- shellside nozzles
  - inlet, outlet, and liquid/vapor outlet
  - impingement devices: rods or plates
- baffles
  - single-segmental, single-segmental no-tubes-in-window (NTIW), double-segmental, and no baffles
  - horizontal and vertical cut baffles
  - user-specified baffle cut; baffle cut snaps to nearest tuberow column
- layout modification
  - tubes changed to tierods, impingement rods, or dummy tubes
  - tubes plugged graphically
  - tierods, partition seal rods, seal strips, and skid bars added outside the tube pattern
  - annotation capability

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## Drawing Specifications

Characteristics of *Xtlo* drawings are listed below:

- scale-drawing layouts
- support for all Microsoft Windows printers
- interchangeable with other programs through enhanced metafiles, AutoCAD DXF files, and HTRI files
- layout details that list specific information about layout in each pass

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## Special Features

- Fully integrated with *Xist*
- User-modifiable tube layout tool and view
- Tube locations exportable to Microsoft Excel CSV file

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# Xvib

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*Xvib* performs flow-induced vibration analysis of a single tube in a heat exchanger bundle. The program uses a rigorous structural analysis approach to calculate the tube natural frequencies for various modes and offers flexibility in the geometries it can handle.

Although *Xist* automatically checks all its cases for vibration, some cases require an in-depth analysis. *Xvib* is designed to help the expert user analyze these cases.

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## Program Capabilities

*Xvib* calculates multispan natural frequencies for straight and U-tubes using 3D structural analysis methods. The analysis includes calculation of tube deflections for the first and higher modes to predict potential vibration problems by considering fluidelastic instability and vortex shedding vibration mechanisms.

The analysis can be performed for straight or U-tubes with up to 900 spans. Supports (baffles) can be specified at any location along the tube; the number of supports is limited only by the number of spans that *Xvib* can handle. For straight tubes, you may choose not to use supports or may select a tubesheet or baffle as an end support. At the U-bend, you may also specify no supports or select a tubesheet or baffle as an end support. Analysis can be performed for up to fifteen modes, depending on the number of spans being analyzed.

You can transfer support (span) information, as well as crossflow velocities and shellside fluid densities, easily from *Xist* to *Xvib* for detailed analysis. Just drag and drop any *Xist* case into *Xvib* or right-click a tube in the *Xist* tube layout.

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## Results

Results of flow-induced vibration analysis for each mode requested include

- natural frequency of the tube
- maximum ratio of fluid gap velocity and critical velocity
- maximum tube deflections due to vibration by vortex shedding
- location of the span with the maximum amplitude due to vortex shedding

*Xvib* also generates detailed results of the vibration analysis. These include

- ratio of the fluid gap velocity and critical velocity for each node in two directions
- tube deflections due to vortex shedding at each node in three directions
- mode shapes

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# HTRI Xchanger Suite Educational

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HTRI Xchanger Suite Educational is a version of Xchanger Suite customized for use by educational institutions. It includes three powerful components for designing, rating, and simulating performance of crossflow (air coolers and heat recovery bundles), shell-and-tube, and compact (plate-and-frame) heat exchangers in one integrated environment (Xace, Xist, and Xphe, respectively).

Supported by extensive data collected for more than 40 years on our industrial-scale heat transfer equipment, this software quickly and accurately handles heat exchanger calculations.

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## Program Capabilities

### *Crossflow (Xace)*

- Design, rate, and simulate air-cooled heat exchangers (with fans on or off), heat recovery bundles, and natural draft exchangers.
- Enter any tubeside and outside process conditions.
- Access many special features, such as
  - links to vendor-supplied fan selection software
  - outside maldistribution (of both inlet air flow and temperature)
  - multiple services in one bay

### *Shell-and-tube (Xist)*

- Design, rate, and simulate shell-and-tube exchangers.
- Evaluate geometries including
  - TEMA E, F, G, H, J, K, and X shells
  - kettle and thermosiphon reboilers including piping
  - falling film evaporators
  - tubeside reflux condensers
- Analyze single-phase, condensation, and boiling processes.
- Preview rigorous tube layout using interactive drawing shown to scale.

### *Compact (Xphe)*

- Design, rate, and simulate plate-and-frame exchangers.
- Calculate each plate channel incrementally using local properties and process conditions.
- Use unique research-based port maldistribution procedure to determine flow through each plate channel.
- Analyze single-phase, condensation, and boiling processes.

## **System Requirements**

You must have the following equipment to run the components successfully:

- 32-bit Intel Pentium or compatible processor
- 64-MB memory (RAM) for Microsoft Windows 98/ME; 128 MB for Microsoft Windows 2000/XP
- available hard disk space: 260 MB
- SVGA (800 × 600 resolution) graphics adapter
- pointing device (e.g., mouse, touchpad)
- Microsoft Windows 98, Windows ME, Windows 2000, or Windows XP operating system
- CD-ROM drive (for program installation)

HTRI recommends an 800 MHz or faster Pentium IV with 256 MB RAM, Windows XP operating system, and an XGA graphics adapter (1024 × 768 resolution).

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# Publications

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HTRI publications provide member companies with information on state-of-the-art technology in heat transfer and fluid flow. HTRI publications include the *Design Manual*, research reports, and *Q* (technical bulletin). They are distributed on the HTRI e-Library CD-ROM and are also available on the HTRI secured website ([www.HTRI.net](http://www.HTRI.net)).

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## ***Design Manual***

This electronic document summarizes HTRI calculation methods, provides design recommendations, and offers practical design tips. Topics include basic methods for single-phase pressure drop and heat transfer, condensation, boiling, two-phase flow, fouling, flow-induced vibration, and design guidelines for shell-and-tube, air-cooled, and non-tubular heat exchangers. This publication provides the basis for understanding HTRI software results and contains references to research reports for detailed study.

The *Design Manual* is updated quarterly, to ensure that it reflects the very latest in HTRI research and methods.

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## **Reports**

Our technical reports describe calculation methods, research data, and/or literature reviews, as well as document and support the methods used in our software. HTRI's research data are unique in that they are obtained using fluids characteristic of those in the processing industries.

The following list of reports reflects more than 40 years of proprietary research.

*Note: Some report numbers are not sequential.*

## **Air-Cooled Heat Exchangers and Extended Surfaces**

### ***Air-Cooled Heat Exchangers***

- AC-1 Experimental Study of Air-Cooled Heat Exchanger Performance under Both Natural and Forced Draft Conditions (1980)
- AC-2 The Application of Propeller Fans to Air-Cooled Dry Heat Exchangers (1981)
- AC-3 Study of Backflow and Inert Accumulation in Air-Cooled Condensers (1981; revised 1989)
- AC-4 Design Methods which Reduce or Eliminate the Inert Blanketing in Air-Cooled Condensers (1982)
- AC-5 Airflow Problems in Forced Draft Air-Cooled Heat Exchangers (1986)
- AC-6 Air-Cooled Heat Exchanger Construction Practices (1988)
- AC-7 Airflow Performance in Induced-Draft Air-Cooled Heat Exchangers (1990)
- AC-8 Comparison of the Air-Cooler Model Performance with Forced and Induced Draft (1992)
- AC-9 Predicting Fans-Off Operation of Air-Cooled Heat Exchangers (1994)
- AC-10 Study on Effects of Tube Pitch and Row for Air-Cooled Heat Exchangers: Data and Method Improvement (1999)
- AC-11 Method Evaluation and Improvement for High-Finned Air-Cooled Heat Exchangers (2002)
- AC-12 Development of Incremental Row Correction Factors for Air-Cooled Heat Exchangers (2002)
- AC-13 Condensation of Vapors from a Gas Stream Outside High-Finned Tubes (2004)
- AC-14 Longitudinal Pitch Effect on Pressure Drop and Heat Transfer in High-Finned Tubes (2005)
- AC-15 Developing an A-Frame Exchanger Model for *Xace* (2007)
- AC-16 First Adaptation of Stream Analysis Method for Air-Cooled Heat Exchangers (2010)

### ***Air Cooler Design***

- ACD-1 HTRI Air Cooler Research Plant Description of Apparatus and Operation (1972)
- ACD-2.1 HTRI Air Cooler Performance Evaluation – Effect of Fan Tip Clearance (1972)
- ACD-2.2 HTRI Air Cooler Research Plant Effect of Obstructions to Inlet Air Flow (1972)

### ***Extended Surfaces General***

- ESG-1 Efficiency of Extended Surfaces (1971)
- ESG-2 The Testing of Ideal Tube Banks in Wind Tunnels (1971)
- ESG-3 Critical Evaluation of Effects of Finned Tube Geometry Parameters and Survey of Data Sources (1971)
- ESG-4 Survey and Evaluation of Heat Transfer and Pressure Drop Correlations for Ideal Finned Tube Banks with Staggered Tube Layouts (1972)
- ESG-5 The Effect of Tube Pitch on Pressure Drop and Heat Transfer for Large Diameter Air Cooler Tubes (1977)
- ESG-6 Isothermal Pressure Drop Tests on 2-inch Serrated and Solid Finned Tubes (1978)
- ESG-7 Heat Transfer and Pressure Drop on Air-Cooler Tubes with Plain and Expanded Slit Fins. A Proprietary Test for E. I. Du Pont de Nemours & Co. (1972; renumbered 1978)
- ESG-8 Comparison of the Performance of Inline and Staggered Banks of Tubes with Segmented Fins (1973; renumbered 1978)

***Extended Surfaces General, continued***

- ESG-9 Thermal Contact and Gap Resistances of Interference-Fit Bimetallic Finned Tubes – Background Report (1979)
- ESG-10 Parametric Study of Air-Cooler Finned Tube Bundles (1982)
- ESG-11 Fin Bond Resistance of Air-Cooled Heat Exchanger Finned Tubes (1986)
- ESG-12 Pitch and Layout Effects on Heat Transfer and Pressure Drop of High-Finned Tube Banks (1986)
- ESG-13 The Effect of Fin Serration on the Thermal Hydraulics of Air-Cooler Tubebundles (1987)
- ESG-14 Row Effects in Finned Tube Banks (1988)
- ESG-15 Heat Transfer and Pressure Drop of Large Diameter Finned Tubes (1989)
- ESG-16 Heat Transfer and Pressure Drop of Stud Finned Tubes (1992)

***Research Briefs***

- RB5-1 Row Effects in a Finned Tube Bundle of Preheater Tubes with Zero Fin-Tip Clearance (1979)
- RB5-2 Experimental Results for Large Diameter Heat Recovery Tubes with Transverse Fins (1981)
- RB5-3 Fin Bond Resistance (1981)
- RB5-4 Heat Transfer and Pressure Drop Data of Stud Fin Tubes (1986)

## Boiling

### *General Problems of Boiling, Heat Transfer, and Pressure Drop*

- BG1-1 Nucleate Pool Boiling of Hydrocarbon Mixtures (1983)
- BG1-2 Status and Critical Evaluation of Research in Boiling of Mixtures (1969)
- BG1-3 Advanced Prediction Methods for Pool Boiling of Hydrocarbon Mixtures (1984)
- BG1-4 Nucleate Pool Boiling of Hydrocarbons on Horizontal Low-Finned Tubes (1984)
- BG1-5 Nucleate Boiling of Refrigerants on Horizontal Low-Finned Tubes (1986)
- BG1-6 Nucleate Pool Boiling of Water-Hydrocarbon Mixtures (1988)
- BG1-7 Multicomponent Effect for Wide-Boiling-Range Mixtures (1989)
- BG1-8 Heat Transfer in Boiling of Multicomponent Mixtures (1992)
- BG1-9 Single Tube Boiling Data for Hydrocarbon Mixtures at High Pressure – Analysis of Paderborn Data (1992)
- BG1-10 Turndown Limits for Thermosiphon Reboilers (2003)
- BG1-11 Onset of Nucleate Boiling for Plain Surfaces (2008)
- BG1-12 Hydrodynamic Instability in Thermosiphon Reboilers (2009)

### *Boiling in Tubes*

- BT-1 Boiling Heat Transfer in a Vertical Thermosiphon Reboiler (1978)
- BT-2 Pressure Drop in Vertical Tubeside Boiling (1978)
- BT-3 Boiling of Mixtures inside Vertical Tubes (1978)
- BT-4 Two-Phase Flow Instabilities in Vertical Thermosiphon Reboilers (1978)
- BT-5 Falling Film Vaporizers (1980)
- BT-6 Vertical Thermosiphon Boiling in Spiral Plate Heat Exchangers (1982)
- BT-7 Two-Phase Flow Instability – A State-of-the-Art Review (1984)
- BT-8 Application of Advanced Mixture Boiling Methods to Vertical Thermosiphon Reboiler Design (1986)
- BT-9 Vertical Tube Falling Film Evaporation – State-of-the-Art Report (1986)
- BT-10 Falling Film Evaporation of Wide-Boiling-Range Mixtures (1989; revised 1990)
- BT-11 Film Breakdown in Falling Film Evaporation of Ethylene Glycol/Water and Ethylene Glycol/Water/I-Propanol Solutions, Preliminary Evaluation (1991)
- BT-12 Critical Heat Flux for Intube Boiling of Saturated Hydrocarbons: Review of Status and Proposed New Approach (1991)
- BT-13 Falling Film Evaporation of Aqueous Multicomponent Mixtures (1992)
- BT-14 Falling Film Evaporation Under Vacuum Conditions (1995)
- BT-15 Twisted Tape Methods and the Prediction of Field Tubeside Vaporizer Data (1999)
- BT-16 Falling Film Evaporation of Ultra-Viscous Fluids (1999)
- BT-17 Estimation of Nucleate Boiling Film Breakdown in Falling Film Evaporation (2000)
- BT-18 Tubeside Downflow Boiling Heat Transfer and Pressure Drop (2001)
- BT-19 Development of Pressure Drop and Pure Component Heat Transfer Methods for Intube Flow Boiling (2001)
- BT-20 Intube Flow Boiling Heat Transfer of Mixtures (2001)
- BT-21 Modeling Tube Wall Dryout of Horizontal Intube Flow Boiling (2002)
- BT-22 Non-Equilibrium Model for Mist Flow in Tubes (2002)
- BT-23 Evaporation inside Horizontal Enhanced Tubes (2002)

***Boiling in Tubes, continued***

- BT-24 Heat Transfer and Pressure Drop Methods for Intube Flow Boiling with Twisted Tape Inserts (2002)
- BT-25 Falling Film Flow Distribution Methods – State of the Art (2002)
- BT-26 Improved Correlation for Intube Subcooled Flow Boiling Pressure Drop (2003)
- BT-27 Film Boiling inside Tubes (2003)
- BT-28 Pressure Drop in Tubeside Falling Film Evaporators (2003)
- BT-29 Thermal Non-Equilibrium: The Effect of Noncondensable Gas on Boiling Fluids (2003)
- BT-30 Tubeside Boiling in Vertical Upflow and Downflow (2004)
- BT-31 Intube Flow Boiling of Fluids with Noncondensable Gases (2004)
- BT-32 Vaporization of Light Hydrocarbons from Nonvolatile Components (2005)
- BT-33 Boiling of Immiscible Mixtures in Vertical Tubes (2006)
- BT-34 Transition Boiling in Vertical Tubes (2007)
- BT-35 Complete Vaporization in Horizontal Tubes (2007)
- BT-36 Non-Equilibrium Dry-Wall Mist Flow Heat Transfer in Vertical Tubes (2009)
- BT-37 Convective Boiling in Tubes (2010)

***Boiling, Kettle Reboilers, Data Analysis***

- BK1-1 Thermal Design of Kettle Reboiler Bundles (1969)
- BK1-2 Analysis and Prediction of Entrainment and its Application to Kettle Reboiler Shell Sizing (1970)
- BK1-3 Boiling on the Outside of Horizontal Finned Tubes (1974)
- BK1-4 Kettle Reboiler Performance Criteria for Very Large Bundles (1976)
- BK1-5 Boiling on Tubes with Sintered Surfaces (1978)
- BK1-6 Enhanced Boiling Surfaces as Single Tubes and Tube Bundles (1983)
- BK1-7 Circulation Boiling Model for Analysis of Kettle and Internal Reboiler Performance (1982)
- BK1-8 Flooded Refrigerant Evaporators (1990)
- BK1-9 Enhanced Tubes in Kettle Reboilers (1992)
- BK1-10 Prediction of Kettle Entrainment (2005)
- BK1-11 Two-Dimensional CFD Simulations of Kettle Reboilers (2008)
- BK1-12 Three-Dimensional CFD Simulations of Kettle Reboilers (2010)
- BK1-13 Evaluation of Circulation Boiling Model for Kettles (2010)

***Crossflow Boiling Outside Horizontal Tube Bundles***

- BX-1 Horizontal Thermosiphon Reboiler Heat Transfer Performance with “E,” “G,” and “X” Shell Configurations (1985)
- BX-2 High Pressure and Multicomponent Mixture Boiling in an “E” Shell Horizontal Thermosiphon Reboiler (1986)
- BX-3 Boiling in Cross and Axial Flows Outside Tubes: A State-of-the-Art Review (1986)
- BX-4 Heat Transfer Prediction Methods for Shellside Flow Boiling in Horizontal Baffled Shell-and-Tube Heat Exchangers (1988)
- BX-5 Heat Transfer and Pressure Drop in Horizontal Thermosiphon Reboilers: Plain-Tube Bundles (1995)
- BX-6 Development of a Nucleate Boiling Suppression Factor and Mass Transfer Coefficient for Shellside Flow Boiling (1996)
- BX-7 Heat Transfer and Pressure Drop in Horizontal Thermosiphon Reboilers: Enhanced Tube Bundles (1997)

***Crossflow Boiling Outside Horizontal Tube Bundles, continued***

- BX-8 Incremental Shellside Flow Boiling Methods (1999)
- BX-9 Falling Film Evaporation on Horizontal Tubes and Tube Bundles (1999)
- BX-10 Flow Boiling Across Horizontal Plain Tube Bundle, Part I: Data and Analysis (2010)
- BX-11 The Onset of Nucleate Boiling on the Shell Side of Plain Tube Bundles (2011)

***Research Briefs***

- RB3-1 Enhanced Boiling Surfaces as Single Tubes and Tube Bundles (1981)
- RB3-2 Physical Property Based Correlation for Nucleate Pool Boiling (1981)
- RB3-3 Improved Reduced Properties Correlation for Nucleate Boiling of Pure Hydrocarbons and Comparison to the Stephan-Abdelsalam Correlation (1985)
- RB3-4 Nucleate Pool Boiling of Alcohol-Water Mixtures (1985)
- RB3-5 Falling Film Evaporators – Areas of Application and Recommendations for Future Research (1986)
- RB3-6 Update of the RTF Program Modification 7.05 for Better Prediction with Wide-Boiling-Range Mixtures (1989)
- RB3-7 The Effect of Pressure on the Nucleate Pool Boiling Mixture Correction – Initial Assessment Based on the System R22/R114 (1990)
- RB3-8 Falling Film Evaporation of Ethylene Glycol-Water Solutions, Prediction by HTRI Boiling Range Method (1990)

## Condensation

### *General Studies in Condensation*

- CG-1 Survey of Condensation Heat Transfer and Condenser Design (1969)
- CG-2 Condensation of Multicomponent Mixtures and Mixtures with Noncondensables – A Critical Review (1976)
- CG-3 Condensation of Immiscible Mixtures – A Critical Review (1976)
- CG-4 Composition Profile Method for Condensation of Vapor-Gas Mixtures (1986)
- CG-5 Condensation of Multicomponent Vapors and Vapor-Gas Mixtures (1986)
- CG-6 A Comparison Between the Resistance Proration Method and the Composition Profile Method (1991)
- CG-7 Film Theory Methods for Condensation of Multicomponent Vapors or Vapor-Gas Mixtures (1994)
- CG-8 Review of Published Methods for Tubeside Condensation (1995)
- CG-9 Reflux Condenser Design: State of the Art (1998)
- CG-10 Reflux Condensation Temperature Profiles (2002)
- CG-11 Shellside Reflux Condensers (2006)

### *Condensation in Tubes*

- CT-1 Pure Component Condensation Inside Horizontal and Inclined Tubes (1974; revised 1980)
- CT-2 Flow Regimes in Horizontal Tubeside Condensation (1975; revised 1980)
- CT-3 Condensation of Multicomponent Vapors and Mixtures with Noncondensing Gases Inside Horizontal Tubes: Resistance Proration Methods (1983)
- CT-4 Two-Phase Pressure Drop in Tubeside Condensation (1977)
- CT-5 Condensation of Pure Components in Downflow inside Vertical Tubes (1977)
- CT-6 Downflow Condensation of Mixed Vapors with Noncondensable Gases inside Vertical Tubes (1978)
- CT-7 Resistance Proration Methods for Downflow Condensation of Mixed Vapors with Noncondensing Gases inside Vertical Tubes (1982)
- CT-8 Parametric Study of the Performance Range of the Vertical Intube Condensation Unit (1987)
- CT-9 Data and Analysis of Heat Transfer Performance of Pure Component Condensation in a Vertical Tube (1996)
- CT-10 Vertical Intube Condensation of Mixtures and Pure Components in the Presence of Noncondensables—Data and RPM Improvement (1997)
- CT-11 Two-Phase Pressure Drop Method for Vertical Downflow Intube Condensation: Data and Improvements (1998)
- CT-12 Data and Analysis of Heat Transfer Performance for Multicomponent Vapors Condensing in Vertical Tubes (1999)
- CT-13 Reflux Condensation Inside Vertical Tubes (2000)
- CT-14 Improvements to Resistance Proration Method for Horizontal Tubeside Condensation of Mixed Vapors with Noncondensable Gases (2000)
- CT-15 Enhanced Tubeside Condensation Using Twisted Tape Inserts (2001)
- CT-16 Condensation of Superheated Vapor (2002)
- CT-17 Improved Composition Profile Method for Downflow Condensation of Vapor-Gas and Mixtures in Vertical Tubes (2003)
- CT-18 Modifications to Pressure Drop Method for Partial Reflux Condensation inside Vertical Tubes (2004)
- CT-19 Vertical Intube Upflow Condensation in Shear-Controlled Flow (2007)
- CT-20 Two-Phase Pressure Drop Method for Tubeside Reflux Condensation (2008)

***Condensation in Tubes, continued***

- CT-21 Tubeside Condensation Heat Transfer with Desuperheating – Pure Components (2009)
- CT-22 Tubeside Condensation Heat Transfer with Desuperheating – Mixtures (2009)
- CT-23 Condensation Pressure Drop in Micro-finned Tubes: Review of Literature Methods (2010)
- CT-24 Improved Pressure Drop Method for Condensation in Horizontal Tubes (2010)
- CT-25 Condensation Heat Transfer in Micro-finned Tubes: Review of Literature Methods (2011)
- CT-26 Flooding in Inclined Tubes (2011)
- CT-27 CFD Modeling of Intube Condensation (2011)

***Condensation on the Shell Side***

- CS-1 Shellside Condensation of Pure Components Outside Horizontal Plain Tube Bundles (1975; revised 1977)
- CS-2 Horizontal Shellside Condensation of Multicomponent Mixtures and Mixtures with Noncondensables (1976)
- CS-3 Shellside Condensation of Pure Components on the Outside of Horizontal Finned Tube Bundles (1984)
- CS-4 Comparison of Condensation of Steam on Plain and Spirally Grooved Tubes in a Baffled Shell-and-Tube Condenser (1978)
- CS-5 Shellside Condensation of Mixtures and Pure Components in the Presence of Noncondensable Gases on Horizontal Tube Bundles (1986)
- CS-6 Shellside Condensation of Immiscible Mixtures on Horizontal Tube Bundles (1987)
- CS-7 Shellside Condensation of Ethylene Glycol/Water Mixtures on Plain and Finned Tubes (1991)
- CS-8 Condensation on 11-Fins-per-Inch Tube Bundles – Comparison with Previous Results (1994)
- CS-9 Improvements to the Resistance Proration Method for Shellside Condensation of Mixtures in the Presence of Noncondensable Gases (1996)
- CS-10 Improvement of Two-Phase Pressure Drop Method for Shellside Condensation in Plain and Finned Tube Bundles (1998)
- CS-11 Application of the Rose-Briggs Method to Shell-and-Tube Finned-Tube Condenser Design (1998)
- CS-12 Shellside Crossflow Condensation for Pure Components with Noncondensable Gas (2004)
- CS-13 Shellside Crossflow Condensation of Mixtures: Vertical Downflow on Plain and Low-Finned Tubes (2005)
- CS-14 Shellside Condensation on Plain and Low-Finned Tubes in Horizontal Cross Flow (2007)
- CS-15 Shellside Reflux Condensation Methods (2011)
- CS-16 Calculating Liquid Level in Horizontal Shellside Condensers (2012)

***Research Briefs***

- RB2-1 Shellside Condensation – Plain Tube (C5) Bundle Pressure Drop Data (1980)
- RB2-2 Shellside Condensation – Plain Tube (C5) Bundle Heat Transfer Data (1980)
- RB2-3 Shellside Condensation Finned Tube Bundle Heat Transfer Data (1982)
- RB2-4 Shellside Condensation Finned Tube Bundle Pressure Drop Data (1982)
- RB2-5 Fogging in Partial Condensers (1986)
- RB2-6 Effect of Noncondensing Gas in Condensation of Vapor-Gas Mixtures (1986)
- RB2-7 Condensation of Pentane/p-Xylene Mixture in Shear Regime Inside a Tube (1991)

## Fired Heaters

### *Fired Heaters*

- FH-1 Radiant Heat Transfer to Shock Tubes in a Cylindrical Firebox (2002)
- FH-2 Considerations of Flow Patterns in Fired Heater Tubes (2003)
- FH-3 Modified Pressure Drop Methods for Large Diameter Tubes (2003)
- FH-4 Radiant Heat Transfer to Shock Tubes in Box Heaters (2005)

## Fouling

### *Basic Research in Fouling*

- F-EX-1-1 A Theoretical Study of Fouling and the Factors Which Influence It (1964; revised 1979)
- F-EX-1-3 Fouling – The Major Unresolved Problem in Heat Transfer (1972)
- F-EX-1-4 Fouling Measurement Techniques and Apparatus (1975)
- F-EX-1-5 Fouling Research on Copper and Its Alloys – Seawater Studies (1976)
- F-EX-1-6 Discussion of Cooling Tower Water Treatment as It Relates to Fouling (1975)
- F-EX-1-7 The History and Status of Research in Fouling of Heat Exchangers in Cooling Water Service (1976)
- F-EX-1-8 Plate Heat Exchanger Fouling Study (1976)
- F-EX-1-9 Seawater Studies of Fouling on Copper and Its Alloys (1978)
- F-EX-1-10 Shellside Fouling from Cooling Tower Water (1982)
- F-EX-1-11 Crystalline Fouling Studies (1982)

### *Physical and Transport Properties of Fluids*

- P-1-1 Heat Capacity and Thermal Conductivity of Oils (1964)
- P-1-2 Physical Properties of Liquids – Status of Present Knowledge and Importance in Design Methods for Heat Transfer and Fluid Flow (1971)

### *Fouling*

- F-1 The Effect of Corrosion Inhibitors on the Fouling Characteristics of Cooling Tower Water (1987)
- F-2 Final Report of the HTRI/TEMA Joint Committee to Review the Fouling Section of the TEMA Standards (1988)
- F-3 The Effects of Selected Corrosion Inhibitors on the Fouling Characteristics of Cooling Tower Water (1989)
- F-4 Design Fouling Resistances: Recommended Good Practice (1989)
- F-5 Organic Fouling – The State of the Art (1991)
- F-6 The Fouling Characteristics of a Crude Oil (1993)
- F-7 The Effect of Corrosion Inhibitors on the Fouling Characteristics of Cooling Tower Water (1995)
- F-8 Cooling Tower Water Fouling Summary (1999)
- F-9 Quantifying Petroleum Fouling of Refinery Heat Exchangers: A Literature Survey (1999)
- F-10 Fouling Data for Six Crude Oils (2001)
- F-11 Comparison of Crude Oil Fouling on Plain and Finned Tubes in Longitudinal Flow (2001)
- F-12 Improved Use of Fouling Allowances in Heat Exchanger Design (2002)
- F-13 Analysis of HTRI Crude Oil Fouling Data (2003)
- F-14 Wax Fouling (2005)
- F-15 Crude Oil Fouling Case Study: Mechanism Identification and Mitigation (2007)
- F-16 High Temperature Fouling Unit Redesign – Part I: Annular Test Section (2007)
- F-17 Tubeside and Shellside Shear Stress for Single-Phase Flow (2008)
- F-18 Designing Heat Exchangers for Fouling Service: Cooling Water and Crude Oil Preheat (2009)
- F-19 Intube Fouling: Effects of Roughness and Deposit Thermal Conductivity (2009)
- F-20 Neural Network Analysis of HTFU Crude Oil Fouling Database (2011)

### *Research Briefs*

- RB6-1 Hydrocarbon and Boiling Fouling Literature Review (1979)

## Non-Tubular Heat Exchangers

### *Agitated Vessels*

AV-1 Heat Transfer in Vessels with Mechanical Agitators (1988)

### *Plate Heat Exchangers*

- PHE-1 A Review of Present Methods for Predicting Heat Transfer and Pressure Drop in PHEs (1990)
- PHE-2 Data and Analysis of Plate Heat Exchanger Performance (1992)
- PHE-3 Data Analysis of UFX-26 Plate Heat Exchangers (1998)
- PHE-4 A Review of Present Methods for Predicting Heat Transfer and Pressure Drop in Spiral Plate Heat Exchangers (1998)
- PHE-5 Port Pressure Drop and Flow Distribution in Plate Heat Exchangers (1999)
- PHE-6 A Review of Present Methods for Predicting Phase-Change Heat Transfer and Pressure Drop in Plate Heat Exchangers (1999)
- PHE-7 Welded Plate Heat Exchangers: State of the Art (2000)
- PHE-8 Development of PHE Incremental Method for Single-Phase Flow (2001)
- PHE-9 Evaporation in Plate Heat Exchangers: Heat Transfer and Pressure Drop Methods (2004)
- PHE-10 Heat Transfer and Pressure Drop for Non-Newtonian Fluids in Plate-Type Heat Exchangers (2005)
- PHE-11 Spiral Plate Heat Exchangers: Single-Phase Methods (2005)
- PHE-12 Condensation in Plate Heat Exchangers—Heat Transfer (2006)
- PHE-13 Two-Phase Flow Regimes in Plate Heat Exchangers (2007)
- PHE-14 Condensation in Welded-Plate Heat Exchangers (2010)

### *Plate-Fin Heat Exchangers*

PFE-1 Plate-Fin Heat Exchanger Module Prototype: Design and Validation (2009)

## Shellside Flow and Vibration

### *Critical Review and Evaluation of Present Shellside Calculation Methods*

- S-SS-1-1 Review of Methods of Donohue, Kern, Bell-Delaware and C. F. Braun (1963)
- S-SS-1-3 Evaluation and Comparison of Present Shellside Methods to Experimental Data (1964; revised 1975)
- S-SS-1-4 Analysis and Evaluation of Tinker's Method (1964; revised 1978)

### *Shellside Heat Transfer and Pressure Drop Correlation Methods Development*

- S-SS-3-1 Stream Analysis Method for Prediction of Shellside Heat Transfer and Pressure Drop in Segmentally Baffled Exchangers (1967; revised 1977)
- S-SS-3-2 Parametric Response Study of Segmentally Baffled Shell-and-Tube Exchanger Performance (1967)
- S-SS-3-3 Performance of 11 Fin/Inch Medium-High Fin Tubes in Shell-and-Tube Exchangers with Segmental and Double-Segmental Baffles (1971)
- S-SS-3-4 Performance of Shell-and-Tube Heat Exchangers with Double-Segmental Baffles (Comparison with Segmental Baffles and No Baffles) (1972)
- S-SS-3-5 Tube-Baffle Leakage Flow Analysis for Integral Finned Tube Bundles (1982)
- S-SS-3-6 Improvements to the Stream Analysis Method for Prediction of Shellside Heat Transfer (Emphasis on Laminar Flow) (1985)
- S-SS-3-7 Heat Transfer Performance of Integral Low-Finned Tube Bundles; Liquid Application (1986)
- S-SS-3-8 Theoretical Method to Evaluate Shellside Temperature Profile Distortion Correction Factor,  $\delta$  (1986)
- S-SS-3-9 Improvements to the Stream Analysis Method for Prediction of Shellside Pressure Drop (1987)
- S-SS-3-10 Pressure Drop and Heat Transfer in NTIW Bundles (1992)
- S-SS-3-11 Analysis of ANL Shell-and-Tube Pressure-Drop Data and Comparison with the ST-5 Computer Program (1993)
- S-SS-3-12 Non-Segmental Baffles in Shell-and-Tube Heat Exchangers (1999)
- S-SS-3-13 Re-evaluation of the HTRI Delta Factor for Incremental Calculations (2001)
- S-SS-3-14 CFD Study of NTIW Bundles (2004)
- S-SS-3-15 Heat Transfer Performance of Shellside Single-Phase Flow for Plain and Low-Finned Tubes (2004)
- S-SS-3-16 CFD Study of Flow Distribution in TEMA X Shells (2004)
- S-SS-3-17 Heat Transfer and Pressure Drop Methods for Square One Baffles (2007)
- S-SS-3-18 CFD Simulations of Single-Phase Turbulent Shellside Flow (2008)
- S-SS-3-19 Improved Pressure Drop Method for Helical Quadrant Baffle Exchangers (2009)
- S-SS-3-20 Single-Phase Heat Transfer Outside Inline Plain and Low-Finned Tube Bundles (2009)
- S-SS-3-21 Disk-and-Doughnut Baffled Heat Exchangers: CFD Simulations and Methods (2010)
- S-SS-3-22 Stream Analysis in a Single-Segmentally Baffled Exchanger: CFD vs. *Xist* (2011)

### *Shell and Tube General*

- STG-2 Mean Temperature Difference – A Reappraisal (1976; revised 1986)
- STG-3 Heat Transfer and Pressure Drop Performance of Integral Low-Finned Tube Bundles; Effect of Fin Spacing (1981)
- STG-4 Experimental Study of the Shell Nozzle Entry Region (1981)
- STG-5 Mean Temperature Difference Correction Factor for the TEMA "H" Shell (1982)
- STG-6 Pressure Drop in Shell-and-Tube Nozzles, Headers, and Annular Distributors (1985)
- STG-7 Performance Prediction of RODbaffle Exchangers (1987)

***Shell and Tube General, continued***

- STG-8 Analysis of Data from Brine – Hydrocarbon Heat Exchangers Used in the Heber Geothermal Binary Power Plant (1988)
- STG-9 Advanced Computational Methods for Shell-and-Tube Heat Exchanger Design (1993)
- STG-10 Gas Radiative Component in the Thermal Calculation of Tubular Heat Exchangers (1994)
- STG-11 Single-Phase Heat Transfer and Pressure Drop in Double-Pipe Heat Exchangers with Longitudinal Fins (2001)
- STG-12 Heat Transfer and Pressure Drop for Two Immiscible Liquids Flowing in Tubes (2002)
- STG-13 Computational Fluid Dynamics Study of Impingement Plates (2002)
- STG-14 Two-Phase Heat Transfer and Pressure Drop in Double-Pipe Heat Exchangers with Longitudinal Fins (2003)
- STG-15 Preventing Freezing in Heat Exchangers (2004)
- STG-16 Heat Transfer and Pressure Drop Methods for Longitudinal Flow over Low-Finned Tubes (2004)
- STG-17 Annular Distributors: A Parametric Design Study (2005)

***Shell and Tube Heat Exchanger Vibration***

- STV-1 Tube Vibrations in Shell-and-Tube Heat Exchangers (1974; revised 1978)
- STV-2 Shellside Flow-Induced Tube Vibration in Typical Heat Exchanger Configurations (1986)
- STV-3 Flow-Induced Vibration in Tube Bundles with a Pitch Ratio of 1.42 (1988)
- STV-4 Flow-Induced Acoustic Vibration in Tube Bundles (1988; revised 1994)
- STV-5 Design of Shell-and-Tube Heat Exchangers to Avoid Flow-Induced Vibration Problems (1989)
- STV-6 Natural Frequencies and Mode Shapes of Straight Tubes (1991)
- STV-7 Comparison of HTRI Computer Vibration Analysis Predictions with Experience for Cases in the DOE/ANL/HTRI Vibration Data Bank (1991)
- STV-8 A Comparison: 1988 TEMA Standards Vibration Section and HTRI Vibration Analysis (1993)
- STV-9 Review of Two-Phase Flow-Induced Vibration in Heat Exchangers (1999)
- STV-10 Evaluation of Fluidelastic Instability Analysis (2000)
- STV-11 Design Guidance for Tube Vibration with Two-Phase Flows (2002)
- STV-12 Updated Methods to Predict Acoustic Vibration in Heat Exchangers (2002)
- STV-13 Methods for Calculation of Tube Vibration Amplitude (2004)
- STV-14 Updated Method for Predicting Critical Velocity for Fluidelastic Instability (2006)
- STV-15 Select Crossflow Velocity Distributions for Analyzing Tube Vibration Potential (2007)
- STV-16 Calculating Fluidelastic Instability of U-Tubes Near Inlet Nozzles (2009)

**Research Briefs**

- RB1-1 Theoretical Basis for the Shellside Temperature Profile Distortion Correction Factor (1979)
- RB1-2 Tube Vibration Tests in Industrial-Sized Shell-and-Tube Heat Exchangers (1980)
- RB1-3 HTRI Analysis of New Cases in the DOE/ANL/HTRI Tube Vibration Data Bank (1980)
- RB1-4 HTRI Computer Programs Vibration Analysis U-Bend Simulation Problem Adjustments (1980)
- RB1-5 Some Field Fixes for Shell-and-Tube Heat Exchangers with Flow-Induced Tube Vibration Problems (1981)
- RB1-6 Flow-Induced Tube Vibration Tests of Full and No-Tubes-in-Window Bundles with Six Crosspasses and 30 Degree Layout with a Tube Pitch-to-Diameter Ratio of 1.25 (1981)
- RB1-7 Proposed Approach for Prediction of Theoretical Delta Correction Mixing Factor (1981)
- RB1-8 Improvement of the Shellside Heat Transfer Tuberow Correction Factor,  $\gamma$  (1982)
- RB1-9 An Investigation of the Applicability of the ST-4 Mod. 5.30 Computer Program to Near-Critical and Supercritical Fluids (1982)
- RB1-10 FIVER – A New Design Concept to Prevent Tube Damage from Flow-Induced Vibration in Shell-and-Tube Heat Exchangers (1983)
- RB1-11 Vibration Test of Simulated U-Tube Bundle with Exit Nozzle Inside of U-Bend Tangent (1985)
- RB1-12 End Zone Effectiveness in Shell-and-Tube Heat Exchangers (1987)
- RB1-13 Additional FIVER Tests (1987)

## **Tubeside Flow**

### ***Tubeside Heat Transfer and Pressure Drop Correlations***

- S-ST-1-1 Heat Transfer Correlations for Intube Turbulent Flow of Liquids and Gases (1981)
- S-ST-1-2 Tubeside Heat Transfer to Liquids and Gases ( $Pr > 0.5$ ) in Turbulent and Transitional Flow (1964; revised 1981)
- S-ST-1-3 Non-Isothermal Pressure Drop in Laminar and Transitional Flow of Liquids Inside of Tubes (1965)
- S-ST-1-4 Heat Transfer to Liquids in Laminar Flow Inside of Tubes (1965)
- S-ST-1-6 Heat Transfer Correlations in the Transition Range – Summary Report of Methods Recommended for Tube-side Calculations (1965)
- S-ST-1-8 Improved Heat Transfer Correlations for Liquids in Laminar Flow Inside of Tubes (1973)
- S-ST-1-9 A Stepwise Procedure for Determining Tubeside Heat Transfer Coefficients (1975)
- S-ST-1-10 Laminar Flow in Large Pipes (2007)
- S-ST-1-11 Evaluation of Laminar Heat Transfer Methods for Horizontal Tubes (2007)
- S-ST-1-12 Mixed Convection Heat Transfer in Vertical Tubes (2008)
- S-ST-1-13 CFD Study of Diabatic Single-Phase Laminar Liquid Flow in Horizontal Tubes (2010)
- S-ST-1-14 CFD Study of Single-Phase Laminar Mixed Convection in Inclined Tubes (2011)

### ***Tubeside Enhanced Heat Transfer and Pressure Drop***

- TE-1 Survey and Evaluation of Techniques to Augment Convective Heat Transfer (1972; revised 1978)
- TE-2 Heat Transfer and Pressure Drop Characteristics of Flow Inside Spirally Grooved Tubes in the Turbulent Regime (1979)
- TE-3 Heat Transfer and Pressure Drop Performance of Turbotec Spirally-Grooved Tube in the Laminar and Transition Regime (1978)
- TE-4 Heat Transfer and Pressure Drop Methods for Tubeside Single-Phase Flow with Twisted Tape Inserts (2002)
- TE-5 A CFD Study of Single-Phase Flows with Twisted Tape Inserts (2006)

### ***Shell-and-Tube Studies***

- STS-1 Field Data and Performance Analysis for Gas-Gas Exchangers with Glycol Injection (1972)
- STS-2 Mean Metal Temperatures in Shell-and-Tube Exchangers (1979)
- STS-3 Non-Newtonian Flow and Heat Transfer in Tubes (1988)

### ***Research Briefs***

- RB4-1 Tubeside Turbulent Flow Pressure Drop and Heat Transfer Results for General Atomic Fluted Tubes (1979)
- RB4-2 Performance Analysis of Gas-Gas Exchangers with Glycol Injection (1987)
- RB4-3 Flow and Heat Transfer with Immiscible Liquids in Tubes (1989)

## Two-Phase Flow

- TPF-1 Summary and Evaluation of Void Fraction Correlations (1973)
- TPF-2 Pressure Drop in Two-Phase Flow Across Tube Banks (1976)
- TPF-3 Two-Phase Pressure Drop in Windowflow of Baffled Tube Bundles (1977)
- TPF-4 Two-Phase Shellside Pressure Drops for Condensation on Low Integral Finned Tube Bundles (1982)
- TPF-5 Two-Phase Flow on the Shell Side of Heat Exchangers: Published Methods (1987)
- TPF-6 Multiphase CFD: U-Bends and Turnaround Headers (2004)
- TPF-7 Two-Phase Pressure Drop in Bends (2005)

## General Two-Phase Flow

- TPG-1 Principles of Gas-Liquid Two-Phase Flow Calculations (1976)
- TPG-2 Flow Distribution and Pressure Drop Calculations for Shellside Two-Phase Flow in Baffled Exchangers (1977)
- TPG-3 Generalized Two-Phase Flow Separation Model (1999)
- TPG-4 Solid-Liquid Two-Phase Flow in Slurries: Pressure Drop and Heat Transfer Methods (2006)
- TPG-5 Pressure Drop and Heat Transfer for Tubeside Bitumen-Water Froth (2009)
- TPG-6 Pressure Drop and Heat Transfer: Oil-in-Water Emulsions (2009)

## Research Briefs

- RB7-1 Two-Phase Flow Distribution in the Pass Header of a Horizontal Tubeside Condenser (1982)
- RB7-2 Vapor/Liquid Two-Phase Pressure Drop in Large Vertical Pipes (Presentation of Initial Data) (1984)
- RB7-3 The Katto Correlations for Saturated Boiling Critical Heat Flux in Vertical Tubes (1984)
- RB7-4 Two-Phase Horizontal Crossflow over Tube Banks (1986)
- RB7-5 Friction and Entrainment in Two-Phase Tube Flow (1987)
- RB7-6 Shellside Condensation Pressure Drop on 11 Fins/In. Tubebundles (1987)
- RB7-7 Start-up of Thermosiphon Reboilers (1991)
- RB7-8 Two-Phase Flow in Tubes: Condensation Data (1991)

## Reference Reports

- RR-1 Convergence Procedures: ACE-2 Computer Program Natural Draft Option (1994)
- RR-2 Stream Analysis Modification to Improve Handling of the Number and Size of Seal Rods (1995)
- RR-3 Maldistribution Effects Due to Axial Tubeside Nozzles (1995)
- RR-4 Scoping Experiments on Boiling Inception in Falling Films (1996)
- RR-5 Implementation of a Heat Exchanger Simulation Code using Advanced Computational Methods (1996)



To accommodate shorter, less complex reports, HTRI created *Q*, our technical bulletin. Some reports represent status updates for longer, more complicated projects, while others are complete in themselves. Each adds to the body of HTRI research in a unique way. Articles are listed chronologically and then cross-referenced by topic.

## 1996

- Q* 1-1 IST Incrementation Technique
- Q* 1-2 The HTRI Multipurpose Boiling Unit
- Q* 1-3 The Fouling Factor: Use and Misuse in Heat Exchanger Design
- Q* 1-4 Status of Plate Heat Exchanger Research
- Q* 1-5 New RPM for Shellside Condensation of Mixtures in the Presence of Non-condensable Gases
- Q* 1-6 Lower Design Fouling Factors for Plate Heat Exchangers
- Q* 1-7 Improved Interpolation of Physical Properties and VLE for HTRI Programs
- Q* 1-8 Current Knowledge in Two-Phase Flow-Induced Vibration
- Q* 1-9 IST Incremental Delta Correction Method
- Q* 1-10 Summary of HTRI Vertical Intube Downflow Condensation Data

## 1997

- Q* 2-1 Reflux Condenser Design
- Q* 2-2 Improved Duty Distribution Model in IST
- Q* 2-3 Air-Cooled Heat Exchanger Object Model for pdXi
- Q* 2-4 Flow Maldistribution in Plate Heat Exchangers

## 1998

- Q* 3-1 Evolution of HTRI Kettle Reboiler Design Methods
- Q* 3-2 IST Shells-in-Series Spreadsheet
- Q* 3-3 Using IST with Aspen Plus: A Seamless Interface
- Q* 3-4 Effects of Tube Pitch and Number of Rows in Air-Cooled Heat Exchanger Performance

## 1999

- Q* 4-1 Flooding Criteria for Reflux Condensation
- Q* 4-2 Object Model Based Data Storage in IST 2.0
- Q* 4-3 Flow Patterns and Boiling Paths in Horizontal Tubes
- Q* 4-4 Annular Distributors – A Design Methodology

## 2000

- Q* 5-1 Vertical Intube Dry-Wall Flow Boiling Criteria and Methods
- Q* 5-2 Enhanced Condensation using Twisted Tapes: Experimental Data
- Q* 5-3 ACE Design Procedure
- Q* 5-4 Heat Exchanger Simulation for Startup

## 2002

- Q* 6-1 Fouling of Middle Distillate Blends
- Q* 6-2 Updated Shellside Two-Phase Nozzle Pressure Drop Methods
- Q* 6-3 Comparison of Shellside Condensation Methods in *Xist* and CST
- Q* 6-4 Heat Transfer Method for Condensation of Immiscible Mixtures

## 2003

- Q 7-1 Improved *Xist*<sup>TM</sup> 2.0 Condensation Pressure Drop Method at High Vapor Fraction
- Q 7-2 Initial Comparison of Fouling on Electropolished and Commercial Surfaces
- Q 7-3 Shellside Condensation in Crossflow – Heat Transfer Comparisons of Plain and Finned Tubes
- Q 7-4 CFD Study of Inlet Zone Performance: Parallel vs. Perpendicular Segmental Baffle Cuts

## 2004

- Q 8-1 Improved Screening of Fluidelastic Instability Using Mode Shape Weighting
- Q 8-2 Improved Momentum Pressure Drop Method for Tubeside Condensation under Deep Vacuum

## 2005

- Q 9-1 Contributions Enhance Tube Vibration Data Bank
- Q 9-2 Modeling Flooded Refrigerant Evaporators in *Xist*
- Q 9-3 Modeling Intermediate Tube Supports in *Xist*<sup>®</sup>

## 2006

- Q 10-1 The Benefits of Numerical Design Optimization
- Q 10-2 Theoretical Limit of  $\theta_s$  Correction Factor

## 2007

- Q 11-1 Understanding Heat Exchanger Design Margins
- Q 11-2 Simulating Nozzle Flow in Spiral Exchangers using CFD
- Q 11-3 Observations on Mixed Turbulent Convection in Vertical Tubes
- Q 11-4 The HTRI General Cooling Water Fouling Method

## 2008

- Q 12-1 Design Guidelines for Crude Oil Preheater Fouling Mitigation

## 2009

- Q 13-1 Wall Functions for Turbulent Heat Transfer Modeling with CFD
- Q 13-2 Tubesheet Metal Temperature Calculation Method
- Q 13-3 Heat Transfer for Horizontal Tubeside Condensation: Data versus Predictions
- Q 13-4 Modeling Kettles Using *Xist*
- Q 13-5 Risk-Based Design Margin Selection for Heat Exchangers

## 2010

- Q 14-1 Flow Visualization in a Transparent Shell-and-Tube Heat Exchanger
- Q 14-2 Condensation Heat Transfer and Pressure Drop: Internal Helical Micro-finned Tube vs. Plain Tube
- Q 14-3 Modeling Fans-Off Operation in *Xace*
- Q 14-4 Improved Heat Transfer Coefficients for Calculating Tubesheet Temperature

## 2011

- Q 15-1 Flow Boiling with Limited Vaporization
- Q 15-2 Vacuum Condensation: Experimental Capability and Initial Intube Data
- Q 15-3 Initial Visualization Studies of Shellside Phase Separation

## Articles Cross-Referenced by Topic

### Air-Cooled Heat Exchangers and Extended Surfaces

- Q 2-3 Air-Cooled Heat Exchanger Object Model for pdXi
- Q 3-4 Effects of Tube Pitch and Number of Rows in Air-Cooled Heat Exchanger Performance
- Q 5-3 ACE Design Procedure
- Q 14-3 Modeling Fans-Off Operation in *Xace*

### Boiling

- Q 1-2 The HTRI Multipurpose Boiling Unit
- Q 3-1 Evolution of HTRI Kettle Reboiler Design Methods
- Q 4-3 Flow Patterns and Boiling Paths in Horizontal Tubes
- Q 5-1 Vertical Intube Dry-Wall Flow Boiling Criteria and Methods
- Q 11-3 Observations on Mixed Turbulent Convection in Vertical Tubes
- Q 15-1 Flow Boiling with Limited Vaporization

### Condensation

- Q 1-5 New RPM for Shellside Condensation of Mixtures in the Presence of Non-condensable Gases
- Q 1-10 Summary of HTRI Vertical Intube Downflow Condensation Data
- Q 2-1 Reflux Condenser Design
- Q 4-1 Flooding Criteria for Reflux Condensation
- Q 5-2 Enhanced Condensation using Twisted Tapes: Experimental Data
- Q 6-3 Comparison of Shellside Condensation Methods in *Xist* and CST
- Q 6-4 Heat Transfer Method for Condensation of Immiscible Mixtures
- Q 7-1 Improved *Xist*<sup>TM</sup> 2.0 Condensation Pressure Drop Method at High Vapor Fraction
- Q 7-3 Shellside Condensation in Crossflow – Heat Transfer Comparisons of Plain and Finned Tubes
- Q 8-2 Improved Momentum Pressure Drop Method for Tubeside Condensation under Deep Vacuum
- Q 10-2 Theoretical Limit of  $\theta_s$  Correction Factor
- Q 13-3 Heat Transfer for Horizontal Tubeside Condensation: Data versus Predictions
- Q 14-2 Condensation Heat Transfer and Pressure Drop: Internal Helical Micro-finned Tube vs. Plain Tube
- Q 15-2 Vacuum Condensation: Experimental Capability and Initial Intube Data

### Fouling

- Q 1-3 The Fouling Factor: Use and Misuse in Heat Exchanger Design
- Q 5-4 Heat Exchanger Simulation for Startup
- Q 6-1 Fouling of Middle Distillate Blends
- Q 7-2 Initial Comparison of Fouling on Electropolished and Commercial Surfaces
- Q 11-4 The HTRI General Cooling Water Fouling Method
- Q 12-1 Design Guidelines for Crude Oil Preheater Fouling Mitigation
- Q 13-5 Risk-Based Design Margin Selection for Heat Exchangers

### Non-Tubular Heat Exchangers

- Q 1-4 Status of Plate Heat Exchanger Research
- Q 1-6 Lower Design Fouling Factors for Plate Heat Exchangers
- Q 2-4 Flow Maldistribution in Plate Heat Exchangers
- Q 11-2 Simulating Nozzle Flow in Spiral Exchangers using CFD

### Shellside Flow and Vibration

- Q* 1-8 Current Knowledge in Two-Phase Flow-Induced Vibration
- Q* 1-9 IST Incremental Delta Correction Method
- Q* 4-4 Annular Distributors – A Design Methodology
- Q* 6-2 Updated Shellside Two-Phase Nozzle Pressure Drop Methods
- Q* 7-4 CFD Study of Inlet Zone Performance: Parallel vs. Perpendicular Segmental Baffle Cuts
- Q* 8-1 Improved Screening of Fluidelastic Instability Using Mode Shape Weighting
- Q* 9-1 Contributions Enhance Tube Vibration Data Bank
- Q* 9-3 Modeling Intermediate Tube Supports in *Xist*<sup>®</sup>
- Q* 10-1 The Benefits of Numerical Design Optimization
- Q* 11-1 Understanding Heat Exchanger Design Margins
- Q* 13-1 Wall Functions for Turbulent Heat Transfer Modeling with CFD
- Q* 13-2 Tubesheet Metal Temperature Calculation Method
- Q* 14-1 Flow Visualization in a Transparent Shell-and-Tube Heat Exchanger
- Q* 14-4 Improved Heat Transfer Coefficients for Calculating Tubesheet Temperature
- Q* 15-3 Initial Visualization Studies of Shellside Phase Separation

### Software

- Q* 1-1 IST Incrementation Technique
- Q* 1-7 Improved Interpolation of Physical Properties and VLE for HTRI Programs
- Q* 2-2 Improved Duty Distribution Model in IST
- Q* 3-2 IST Shells-in-Series Spreadsheet
- Q* 3-3 Using IST with Aspen Plus: A Seamless Interface
- Q* 4-2 Object Model Based Data Storage in IST 2.0
- Q* 9-2 Modeling Flooded Refrigerant Evaporators in *Xist*
- Q* 13-4 Modeling Kettles Using *Xist*

## Data Books

- Data Book 1 (1963) Shellside data collected at C. F. Braun and the University of Delaware. Data: five research bundles and two large commercial bundles tested at C. F. Braun and all data from the University of Delaware project. Fluids: light and heavy oils, air, and water. Includes more than 500 data runs.
- Data Book 1, Supplement 1 (1967) Shellside data collected at HTRI (Alhambra, California). Data: plain and low-finned tube bundles; simulated conditions of a fixed tubesheet, U-tube, split-ring, and pull-through floating head arrangements. Tests conducted without sealing strips and with one, two, and three pairs. Fluids: air, water, Alta-Vis 530, and dieseline. Includes more than 450 data runs.
- Data Book 1, Supplement 2 (1972) Shellside data collected at HTRI (Alhambra, California). Data: medium finned tubes, double-segmental baffles, and shellside parallel flow. Fluids: air, water, dieseline, and Alta-Vis 530. Includes more than 300 data runs.
- Data Book 1, Supplement 3 (1988) Data collected from 1982 to 1987 at HTRI (Alhambra, California). Data: bundles with HPTI 30 fins/inch and segmental baffles, Wolverine 19 fins/inch and double segmental baffles, plain tubes with 90-degree layout, plain tubes with 45 percent baffle cut and large ratio of baffle spacing to shell diameter. Fluids: dieseline and polybutene 20 (Alta-Vis 530). Includes more than 1,300 data runs.
- No-Tubes-in-Window (1992) Data collected in 1989 at HTRI (Alhambra, California). Data: four baffle configurations on a U-tube NTIW bundle with a 12-in. (304.8-mm) E shell. Fluids: dieseline and water. Includes more than 400 data runs.
- Tubeside (1966) Tubeside data collected at C. F. Braun and the University of Tulsa. Data: heat transfer and pressure drop in turbulent, laminar, and transition flow. Fluids: water, kerosene, acetone, benzene, n-butanol, glycerine, Alta-Vis 1060, oils, a variety of petroleum fractions, and other hydrocarbons. Includes more than 1,150 data runs.
- Condensation (1964) Condensation data collected at C. F. Braun. Data includes pure and mixed vapor condensation, partial condensation, and two-phase pressure drop. Geometry: downflow rectangular bundle, crossflow rectangular bundle, two-pass circular bundle, and crossflow multi-baffled bundle. Fluids: pentane, Freon-114, gasoline, methane/pentane, methane/propylene glycol, air/water, and air/sugar solutions. Includes more than 750 data runs.
- Intube Condensation (1975) Data collected at HTRI (Alhambra, California). Condensation in horizontal and inclined tubes (0 – 20 degrees) with two different copper tube geometries: 1 in. (25.4 mm) diameter, 24 ft (7.32 m) long; 2.125 in. (54.0 mm) diameter, 12 ft (3.66 m) long. Operating conditions: pressure range of 28 to 202 psia (193 to 1393 kPa). Fluids: water, n-pentane, i-propanol, Freon-113, gasoline, n-pentane/helium, n-pentane/carbon dioxide, n-pentane/methane, n-pentane/p-xylene, n-pentane/n-heptane, ethylene glycol/water, water/air, Freon-113/air, and gasoline/methane. Includes more than 100 data runs.
- Shellside Condensation (1994) Data collected from 1978 to 1987 at HTRI (Alhambra, California). Data: eight bundles in a horizontal E-shell configuration with plain and finned tubes (11, 19, and 30 fins/inch). Fluids: steam, n-pentane, p-xylene, i-propanol, R-11, n-pentane/p-xylene, ethylene glycol/ water, n-pentane/steam, n-pentane/cyclohexane/n-heptane/p-xylene/l-tetradecene, water/octanol/ decanol, steam/nitrogen, p-xylene/nitrogen, n-pentane/nitrogen, i-propanol/nitrogen, n-pentane/p-xylene/nitrogen, n-pentane/p-xylene/carbon dioxide, and n-pentane/cyclohexane/ n-heptane/p-xylene/l-tetradecene/nitrogen. Includes more than 1,800 data runs.
- Vertical Intube Condensation, Volume 1 (1994) Data collected in 1992 at HTRI (College Station, Texas). Data: steam, steam/nitrogen, p-xylene, p-xylene/nitrogen, p-xylene/helium, and p-xylene/carbon dioxide. Operating conditions: inlet pressure range of 0.7 to 65.0 psia (4.8 to 448 kPa). Includes more than 450 data runs.

**Data Books, continued**

- Vertical Intube  
Condensation,  
Volume 2  
(1996) Data collected from 1993 to 1994 at HTRI (College Station, Texas). Data: propylene glycol, propylene glycol/nitrogen, propylene glycol/helium, p-xylene, p-xylene/nitrogen, isopropanol and isopropanol/nitrogen from low vacuum (0.55 psia, 3.79 kPa) to high pressure (170 psia, 1172 kPa); data runs with subcooling for p-xylene and p-xylene/nitrogen. Inlet mole fraction of noncondensables up to 0.20. Includes more than 350 data runs.
- Vertical Intube  
Condensation,  
Volume 3  
(1998) Data collected from 1995 to 1996 at HTRI (College Station, Texas). Data: p-xylene/nitrogen, p-xylene/carbon dioxide, propylene glycol/nitrogen, propylene glycol/carbon dioxide, steam/nitrogen, isopropanol/nitrogen, p-xylene/n-pentane, p-xylene/n-pentane/nitrogen, p-xylene/n-pentane/n-heptane, and p-xylene/n-pentane/n-heptane/nitrogen. Operating conditions: inlet mole fraction of noncondensables from 0.15 to 0.85 and inlet test pressures from 2.0 to 94.0 psia (13.8 to 648 kPa). Includes more than 450 data runs.
- Kettle Reboiler  
(1971) Data collected at HTRI (Alhambra, California). Data: twelve bundle configurations to evaluate effect of tube pitch at constant bundle diameter, tube pitch at constant number of tubes, bundle diameter, tube diameter, tube layout angle, bundle length, finned tubes, and tube material. Fluids: hydrocarbons, alcohols, ketones, water, Freon-113, hydrocarbon mixtures, and water/alcohol mixtures. Includes more than 950 data runs.
- Vertical  
Thermosiphon  
Reboiler  
(1990) Data collected at HTRI (Alhambra, California). Data: three tube bundles with different tube diameters and typical pitch ratios (boiling inside the tubes). Fluids: propane, n-butane, i-butane, n-pentane, p-xylene, i-propanol, water, butane/propane, cyclohexane/toluene, p-xylene/n-pentane, n-octanol/n-decanol, p-xylene/n-octanol/n-decanol, nonane/decane/durene/naphthalene, ethylene glycol/water, and n-pentane/polybutene 32 (Alta-Vis 3060); sparge gas runs with nitrogen, superheated steam, helium, and carbon dioxide. Includes more than 500 data runs.
- Horizontal  
Thermosiphon  
Reboiler  
(1999) Data collected from 1982 to 1988 at HTRI (Alhambra, California). Data: four plain tube bundles, one finned tube bundle (19 fpi; 748 fins/m), and one enhanced surface tube bundle (TurboB) in E-, G-, and X-shell configurations with seven test fluids (water, n-pentane, p-xylene, n-pentane/p-xylene, ethylene glycol/water, n-pentane/1-tetradecene, n-pentane/cyclohexane/n-heptane/p-xylene/1-tetradecene). Includes more than 350 data runs for pressures ranging from 5 to 416 psia (34.5 to 2868 kPa) and exit vapor quality up to 0.9.
- Tubeside Fouling  
(1978) Data collected with the HTRI Portable Fouling Research Unit at several industrial plant locations. Fluids: cooling tower water, river water, well water, and city water. Includes more than 200 data runs.
- Extended Surfaces  
(1989) Data collected from 1978 to 1989 at HTRI (Alhambra, California) and STD Services Limited (Walsall, United Kingdom). Data: forced-draft wind tunnel, induced-draft wind tunnel, one-third scale air-cooled heat exchanger (forced- and induced-draft), and a wide variety of finned tubes.
- Plate Heat  
Exchanger,  
Volume 1  
(1995) Data collected from 1986 to 1992 at HTRI (Alhambra, California) and APV (Crawley, United Kingdom and Goldsboro, North Carolina). Data: Alfa Laval P-31 and P-32 plates with water and p-xylene; APV SR-2 and SR-3 plates with water. Includes more than 300 data runs.
- Plate Heat  
Exchanger,  
Volume 2  
(1999) Data collected from 1993 to 1997 at HTRI (College Station, Texas). Isothermal, heat transfer, and port flow maldistribution data: SWEP/Reheat UFX-26 plate heat exchangers with chevron angles of 32.5°/32.5°, 32.5°/47.5°, and 47.5°/47.5°. Fluids: water, Dowfrost (propylene glycol 95.5/water 4.5 wt %), Dowfrost and water mixture (propylene glycol 67.5/water 32.5 wt %), and polyethylene glycol 8000 and water mixture (PEG8000 50/water 50 wt %). Operating conditions:  $1 < Re < 10344$ ;  $2 < Pr < 2290$ ; port inlet velocity head up to 1.6 psi (11 kPa). Includes more than 450 isothermal pressure drop runs, more than 400 heat transfer runs, and more than 70 sets of port flow maldistribution data.