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INTRODUCTION

The procedures for executing INSTED®/Shell & Tubes are presented in this manual. The input file options, primary tasks, required data, and the output results are discussed, as are the online utilities that are available within the Shell & Tube heat exchanger program environment.

The Shell and Tubes program calculates the heat transfer coefficients at the inside of the tube where the tube fluid is flowing and on the outside where the shell fluid is flowing. For the case in which the outside of the tube is finned, INSTED is able to compute the effects of the fins on heat transfer and pressure drop. For the case in which there are fins inside the tube, the user must specify the fin efficiency. Alternatively, fin efficiency may be calculated with the INSTED/Fin & Fin Array program.

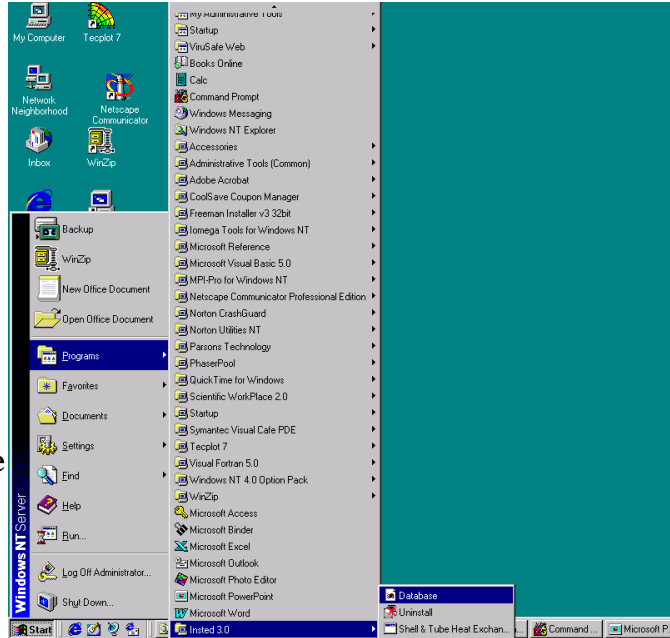
INSTED/Shell & Tubes also interfaces with INSTED/Database to obtain the thermophysical properties of the shell and tube fluids. For two-phase flow, in which case the thermophysical properties are strongly temperature-dependent, it is mandatory to select fluids from the database whose properties have been provided over a range of temperatures.

RUNNING INSTED®/Shell & Tube Program

Starting the Program

Follow this procedure to execute INSTED®/Shell & Tube:

1. Click on the Windows **Start** button
2. Select **Program**
3. Select **INSTED 4.0**
4. Select the **Shell & Tube Heat Exchanger** icon

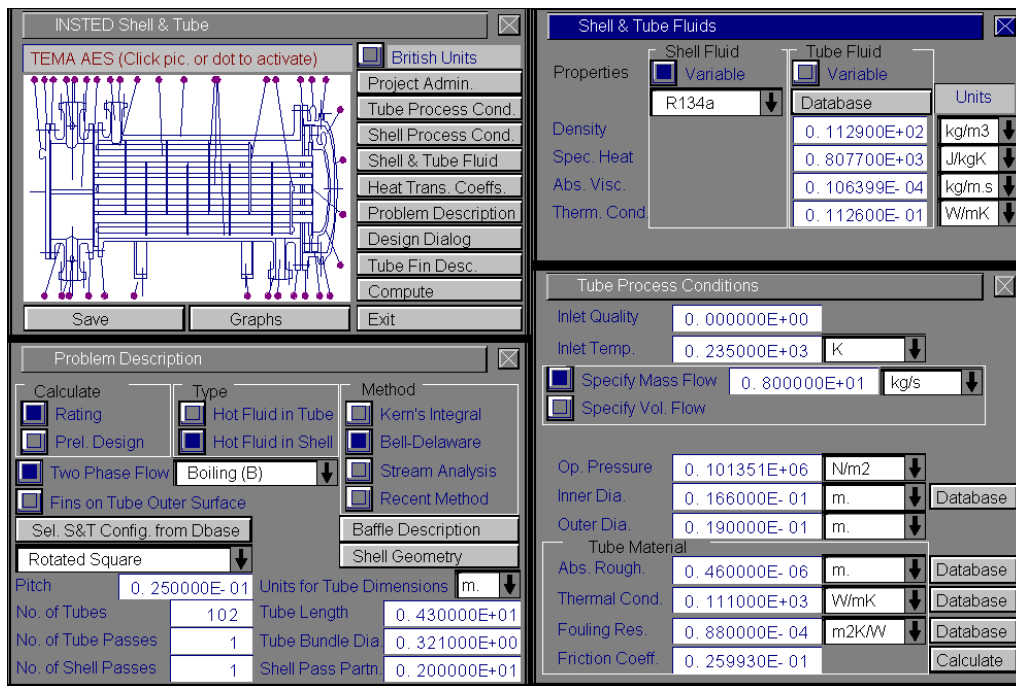


The Restart File

The Shell & Tube heat exchanger program automatically loads the previous analysis if the program was terminated normally in the previous session. This is to allow previous sessions to continue naturally. However, to initialize all input fields, select the “New Project” option which is discussed later in this manual.

PROGRAM ORGANIZATION

The INSTED®/Shell & Tube program is organized into twelve dialog boxes: Main, Project Administration, Problem Description, Shell Properties, Tube Properties, Shell & Tube Fluids, Heat Transfer Coefficients, Shell Geometry, Graphs, Design Dialog, Tube Fin Description, and the Baffle Description dialog boxes. The dialog boxes are launched from the Main dialog box. Result presentation is done also via the Main dialog box. A detailed description of each dialog box is presented later in this manual. The figure below shows the interface of the INSTED/Shell & Tube program.



Shell & Tubes

Tasks

INSTED®/Shell & Tube can be used for the following types of analysis:

- Rating (performance)
- Preliminary design

Data Required For Single-Phase Analysis

The following data may be required for a single-phase rating analysis:

- Inlet temperatures of both shell and tube fluids
- Specification of TEMA shell type
- Indication for whether the hot or cold fluid is in the shell
- Thermophysical properties (specific heat, density, absolute viscosity, thermal conductivity, and Prandtl number) for both the shell and tube fluids. These data may be supplied directly or obtained from INSTED/Database
- Inner and outer diameter of tubes (also obtainable from the Database)
- Shell inner diameter (also available in the Database)
- Tube layout
- Number of shell passes
- Number of tube passes
- Total number of tubes in the system (all tubes per pass, all passes)
- Baffle type
- Number of baffles
- Baffle spacing
- Percent baffle cut
- Baffle thickness
- Distance between tube centers
- Tube bundle diameter
- Tube pitch
- Tube fluid mass flow rate
- Shell fluid mass flow rate
- Fouling factors for the inner surfaces of the tubes
- Fouling factors for the outer surfaces of the tubes
- Fin efficiency on the inner and outer surfaces of tubes (available in INSTED/Fin & Fin Array program)

- Nozzle pressure
- Number of pairs of sealing strips
- Number of pass partitions
- Film coefficient for inner surface of tubes
 - may be obtained from INSTED/Internal Flow & Heat Transfer program
 - not required if overall U can be specified
- Tube length
- Tube-baffle clearance
- Shell-baffle clearance
- Tube-baffle leakage
- Shell-baffle leakage

Data Required for Two-Phase Analysis

In addition to the data required for single-phase analysis, the following may also be required for two-phase analysis:

- Type of two-phase flow – boiling only, condensation only, or boiling and condensation
- A temperature-dependent set of material properties for the fluid undergoing a phase change. This material must have been added to INSTED/Database as custom data. A two-phase material will contain the following information as a function of temperature:
 - Saturation temperature
 - Density, specific heat, thermal conductivity, and viscosity for both the liquid and gas
 - Critical temperature
 - Critical pressure
 - Surface tension
 - Saturation pressure
- The operating pressure of the two-phase fluid may also be required

Data Required for Preliminary Design

The input data required for preliminary design are as follows:

- Thermal conductivity of the tube material
- Thermophysical properties of the fluids
- Inlet and outlet temperatures of both fluid streams
- Flow rates of both fluid streams

Note that the preliminary design capability is limited to single-phase analysis in the current version of INSTED/Shell and Tubes.

Two-Phase Options in INSTED/Shell & Tube

Boiling in shell, single-phase in the tubes

To obtain this configuration, the cold fluid must be in the shell and two-phase boiling selected. Two-phase, temperature-dependent fluid data must be selected for the shell fluid.

Condensation in shell, single-phase in the tubes

To obtain this configuration, the hot fluid must be in the shell and two-phase condensation selected. Two-phase, temperature-dependent fluid data must be selected for the shell fluid.

Boiling in the tubes, single-phase in shell

To obtain this configuration, the hot fluid must be in the shell and two-phase boiling selected. Two-phase, temperature-dependent fluid data must be selected for the tube fluid.

Condensation in the tubes, single-phase in shell

To obtain this configuration, the hot fluid must be in the shell and two-phase condensation selected. Two-phase, temperature-dependent fluid data must be selected for the tube fluid.

Boiling in the tubes, condensation in shell

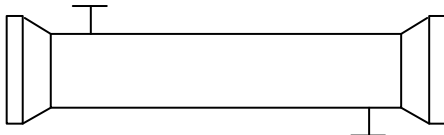
The hot fluid must be in the shell. Two-phase boiling and condensation must be selected. Two-phase, temperature dependent fluid data must be selected for both the shell and tube fluids.

Condensation in the tubes, boiling in shell

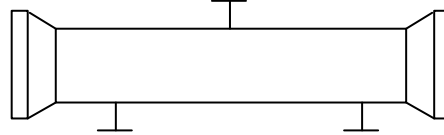
The hot fluid must be in the tube. Two-phase boiling and condensation must be selected. Two-phase, temperature dependent fluid data must be selected for both the shell and tube fluids.

Shell Types Supported by INSTED/Shell & Tube

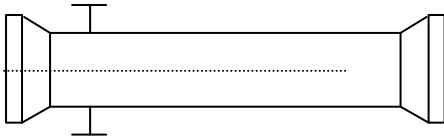
INSTED supports a variety of TEMA shells, including E, F, G, H, J, K, and X shells. Multiple tube and/or shell passes are supported for some of these equipment. Many Therocomp customers do not use TEMA shells. **Therefore, it is important that you contact Therocomp to advise on the kinds of shells you want in your installation.**



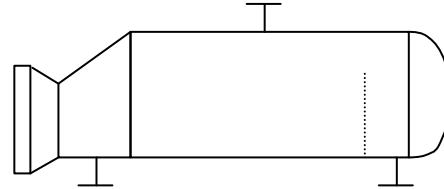
E-Type Shell



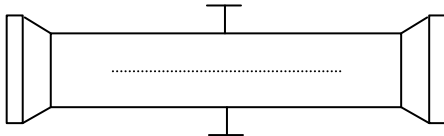
J-Type Shell



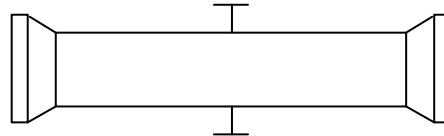
F-Type Shell



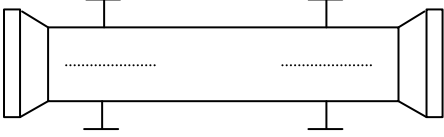
K-Type Shell



G-Type Shell



X-Type Shell



H-Type Shell

Shell & Tubes

Important Customer Information

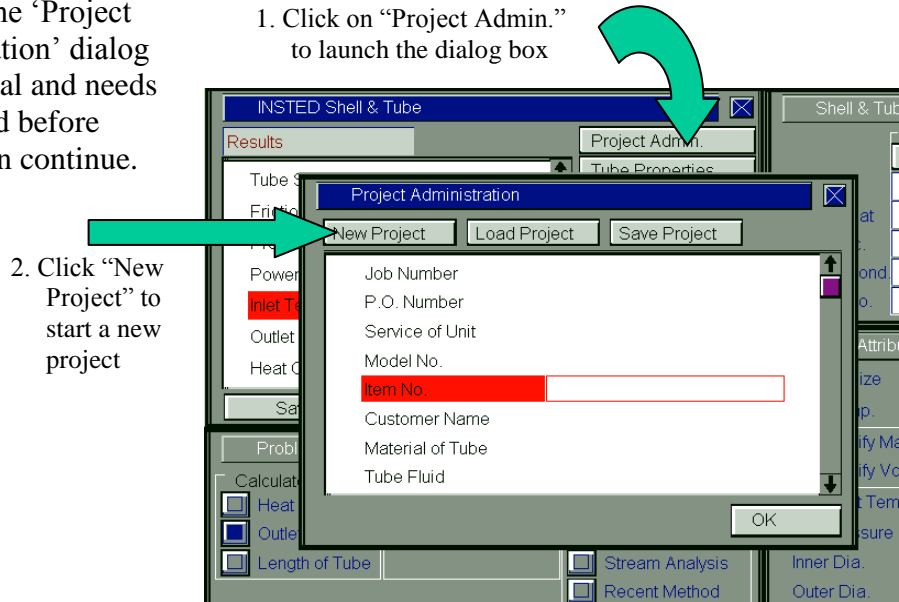
- The default installation is the E-Shell.

Starting a New Project

To start a new project:

1. Click the “Project Admin.” button on the Main dialog box
2. Click “New Project” on the ‘Project Administration’ dialog box
3. Fill in the administrative data for the editbox on the ‘Project Administration’ dialog box, as needed

Note that the ‘Project Administration’ dialog box is modal and needs to be closed before analysis can continue.

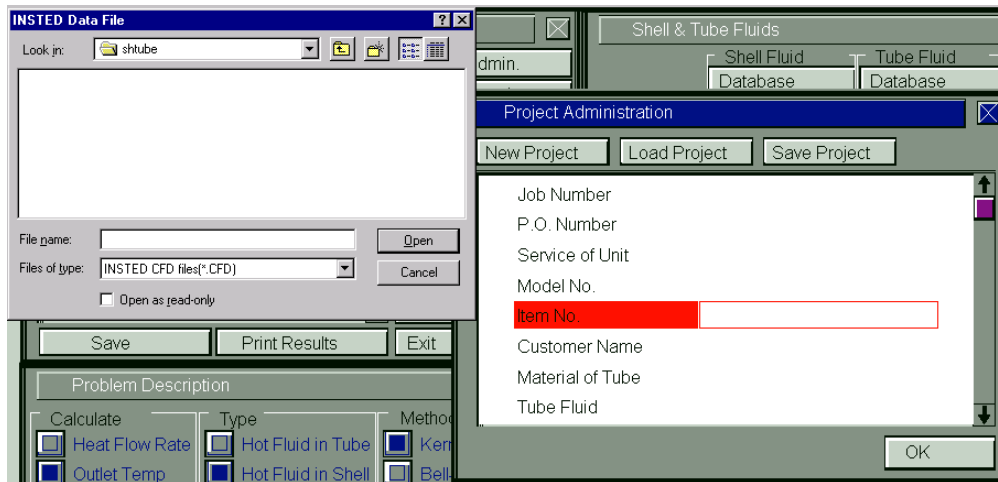


Loading an Old Project

To load an old project:

1. Click on the “Project Admin.” button on the Main dialog box
2. Click on the “Load Project” button
3. Type *.* in the file name text box on the Windows ‘File Open’ dialog box
4. Press the Enter key

5. Select the file you wish to open by locating it on the Windows file open dialog box. This dialog box is shown below



Saving a New Project

To save a new project:

1. Click on the “Project Admin.” button on the Main dialog box
 2. Click on the “Save Project” button
- ⇒ A Windows ‘File Save’ dialog box will appear
3. Select the path in which you wish to save the file
 4. Type a name for the new project file

DESCRIPTION OF THE DIALOG BOXES

This section describes the functions of the dialog boxes in INSTED®/Shell & Tubes.

The Main Program Dialog Box

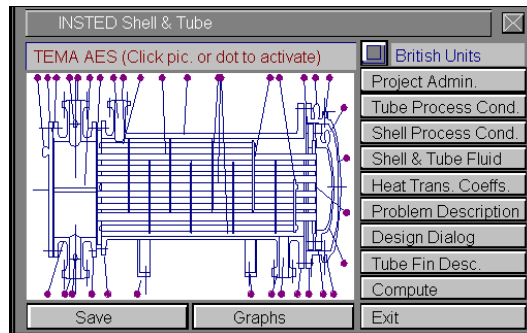
This dialog box contains twelve buttons and a radio button. The radio button, if selected, indicates that all input data and results would be based on the British units, by default. Leaving this button unselected will use SI units for all calculations, input data, and results. The functions of the buttons are described below.

Project Admin

This button opens the 'Project Administration' dialog box, which performs administrative functions, including loading and saving the session data, and initializing all data fields for starting a new session.

Tube Process Conditions

This button opens the 'Tube Process Conditions' dialog box, which contains the description of the process conditions for the tube fluid including the tube dimensions, flow conditions and material properties such as thermal conductivity and roughness.



Shell Process Conditions

This button opens the 'Shell Process Conditions' dialog box, which is similar to the 'Tube Process Conditions' dialog box and performs similar functions. However, the process conditions specified in this dialog box pertain to the shell fluid.

Shell & Tube Fluid

This button opens the 'Shell & Tube Fluids' dialog box where the fluid thermophysical properties are specified.

Heat Transfer Coeffs.

This button opens the 'Heat Transfer Coefficients' dialog box, which contains the input data fields for the film coefficients in the inner and outer surfaces of the tube and the efficiency of any fins that might have been specified for the inner and outer surfaces of the tubes.

Problem Description

This button opens the 'Problem Description' dialog box, where you specify the type of analysis desired (rating or preliminary design). It is also in this dialog box that you specify whether the hot fluid is in the tube or shell. Other data to be specified in this dialog box include the method of calculating the shell-side heat transfer coefficient, tube layout, tube pitch, number of tubes and tube passes, number of shell passes, tube length, tube bundle diameter, and shell pass partitions. The "Baffle Description" button that opens up the 'Baffle Description' dialog box is also located in the 'Problem Description' dialog box as well as the "Shell Geometry" button that opens up the 'Shell Geometry' dialog box where the shell type is specified.

Design Dialog

This button opens up the 'Design Dialog' box, which contains the input data fields for the design limits and constraints that are used in a design task.

Tube Fin Desc.

This button opens up the ‘Tube Fin Description’ dialog box, which contains the input data fields for specifying fins on the outside of the tubes.

Compute

The “Compute” button tells INSTED to compute the results. This assumes that all required input data for the task have been specified. If this is not the case, the computation may not be successful and the missing input is indicated, via a (warning) message box.

Graphs

The “Graphs” button opens the ‘Graphs’ dialog box for graphical display of results. x - y plots of temperature, pressure drop, heat flux, and quality can be viewed from this dialog box. The TEMA specification sheet can be viewed here, as well.

To Save

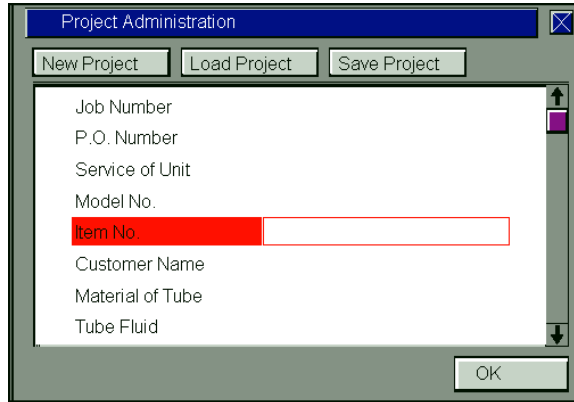
Click on the “Save” button, which is conveniently situated on the Main dialog box. To safeguard work done in the session, it is advisable to intermittently perform a save operation. Note that an error occurs if no project has been loaded and previously saved using the “Save Project” button in the ‘Project Administration’ dialog box. The procedure for saving a new project has been described in a previous section of this manual.

Exit

Press this button to close the program and end the current session. All session data are stored and are automatically retrieved on restarting the program.

The Project Administration Dialog Box

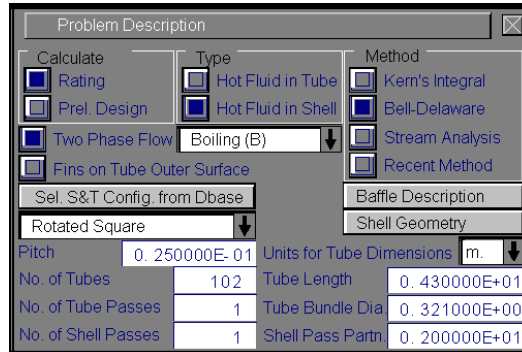
In the previous section, we have covered much of the functions of the 'Project Administration' dialog box, including loading an existing project, saving a new project, or starting a new project.



The Project Administration dialog box contains a description of the project including job number, customer names etc. This dialog box is similar in all the INSTED programs and data from it are shared during an integrated session involving several programs of the INSTED suite of engineering programs.

The Problem Description Dialog Box

The functions of this dialog box have been described earlier in this manual. The dialog box is shown on the right.



Methods of computing shell-side film coefficient

INSTED®/ Shell & Tubes provides three calculation options for the shell-side film coefficient: the Kern's integral method, the Bell-Delaware method and the Stream Analysis method. Select one of these options under the 'Method' group.

Note that although the Kern method is very simple to implement, it has the following limitations”

- (a) It is limited to a baffle cut of 25%
- (b) It assumes uniform baffle spacing
- (c) It does not allow for leakages in the calculation of the shell-side heat transfer coefficient and pressure drop.

Tube configuration

The tube pitch and arrangement can be specified in the drop down listbox on this dialog. It can also be selected from the INSTED/Database program by clicking the “Sel. S&T Config from Dbase” button.

The Baffle Description Dialog Box

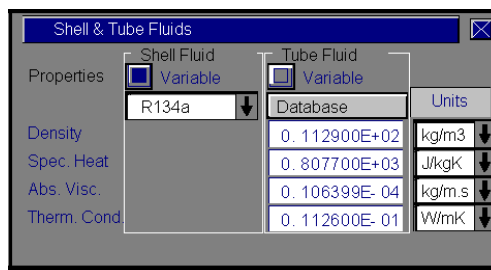
The 'Baffle Description' dialog box is a child of the 'Problem Description' dialog box. It can be accessed by clicking the “Baffle Description” button in the latter dialog box.

Baffle Description	
No. of Baffles	15
<input checked="" type="checkbox"/> Uniform Baffle Spacing	Units for Baffle Dim. m.
Baffle Spacing	0.304800E+00
Baffle Thickness	0.000000E+00
Shell Baffle Cl.	0.000000E+00
Tube Baffle Cl.	0.000000E+00
Shell Baffle Lkge.	0.000000E+00
Tube Baffle Lkge.	0.000000E+00
% Baffle Cut	25
Ok	

The number of baffles, baffle spacing (ends and center), shell-baffle clearance, and baffle cut should be specified in this dialog box.

The Shell & Tube Fluid Properties Dialog Box

This dialog box contains input data fields for the shell and tube fluid thermophysical properties, such as density, specific heat, viscosity, and thermal conductivity. The fluid properties could also be selected from INSTED/Database by selecting the “Database” buttons in this dialog box.



Specifying the properties directly in this dialog box implies that properties are not temperature-dependent and will be used over the process temperature range. To use temperature-dependent thermophysical properties during analysis, the “Variable” radio button must be selected. In this case, you will need to select from a list of custom data that you must have previously generated in INSTED/Database.

To include a fluid in this list, you must define the properties of the fluid in the “Custom Two-Phase Fluid” or “Custom Single-Phase Fluid” section of the database. The procedure for adding fluids to INSTED/Database is described in the database section of this manual.

A fluid undergoing two-phase flow must be defined as temperature-dependent and the ‘Custom Two-Phase Fluid’ option must have been used to generate its data in INSTED/Database.

The Tube Process Conditions Dialog Box

This dialog box contains a description of the tube-side process conditions.

The following data should be specified: the inlet (and outlet temperature, if known), the mass/volume flow rate, tube inner and outer diameters, and other data such as the fouling factor, operating pressure, and nozzle size. Some of the required data may be obtained from INSTED/Database.

The 'Shell Process Conditions' dialog box is similar to the 'Tube Process Conditions' dialog box just described.

Friction Coefficient

The friction coefficient on the inner surface of the tubes may be specified in this dialog box or obtained from INSTED/Database, where the values of pipe roughness and the flow rate are used to calculate the friction factor. These values may be altered in the Database program, if desired.

The Heat Transfer Rate Dialog Box

This dialog box prompts you for the heat transfer information including total U (if known), film coefficients, and fin efficiency. The values of the film coefficients and fin efficiency may be specified by you or calculated by INSTED.

Film Coefficients

The film coefficient on the tube inner surface may be specified, obtained from INSTED/Database or calculated with INSTED/Shell & Tubes. To compute tube film coefficient using INSTED/Shell & Tube's internal procedure, click on the "Compute Tube Film Coeff." button and a calculation is performed using the tube length, inlet temperatures, and tube fluid thermophysical properties that you specified in the Shell and Tube environment.

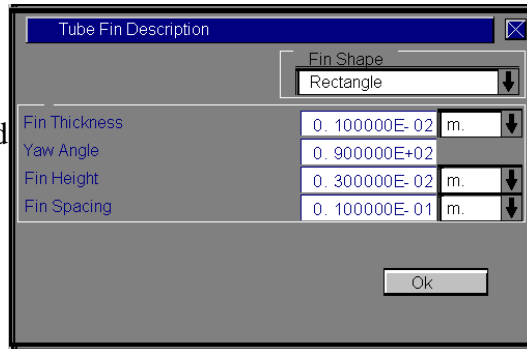
The tube outer surface (or shell) film coefficient is calculated by the Kern's method, the Bell-Delaware method, or the Stream Analysis method. The specification of the desired method is done via the 'Problem Description' dialog box. This has been discussed previously.

Tube Inner Surface Fin Efficiency from INSTED Fin Analysis Program

For finned tubes, surface fin efficiency may be obtained from the INSTED/Fin & Fin Array program. Variables required for the calculation are passed to INSTED/Fin & Fin Array program while the desired fin type is selected in the program environment. On completion of the analysis in INSTED/Fin & Fin Array program, the results are passed back to the Shell and Tube program.

Tube Fin Description Dialog Box

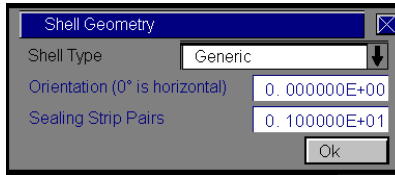
For fins on the tube outer surface, INSTED calculates the effects of the fins on the heat transfer coefficient and pressure drop. The required input data include the fin type, fin thickness, fin pitch or spacing, fin height, and yaw angle. These variables should be specified in this dialog box.



The fin types supported by INSTED have already been listed in the Tube Bank sections of this manual.

Shell Geometry Dialog Box

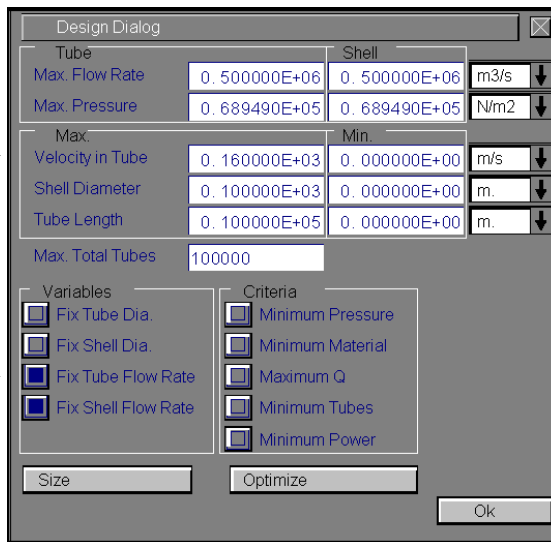
The type of shell, and its orientation are specified in this dialog box. The number of sealing strip pairs is also entered in this dialog box.



Design Dialog Box

The design dialog box provides the environment for the specification of the process limits (constraints) to be imposed during analysis. The design criteria should also be specified.

The dialog box on the right shows that an upper limit has been placed on the flow rates in the tubes and in the shell. Also, the velocities in both streams, the shell diameter, and the tube length are required to stay within a window. A restriction is placed on the total number of tubes.



The dialog box shows that some of the following variables could be kept fixed: tube diameter, shell diameter, tube flow rate, and shell flow rate, while the criteria could required that some of the following quantities be minimized: operating pressure, material, heat flow rate, number of tubes, or power.

The design calculations use a combination of iteration and rating calculations to suggest systems that satisfy the various criteria and constraints.

Important Information for Customers

Note that the design capability in INSTED/Shell & Tube is provided to customers on a one-to-one basis, as the procedure depends on the specifics of the customer's equipment. For example, tube, tube layout, and tube count data must be provided by the customer in order for the procedure to provide useful results.

RUNNING A SAMPLE PROBLEM

This section illustrates the use of the INSTED/Shell & Tube program. A sample problem best illustrates the procedure.

Procedure for Performing a Sample Rating Calculation

The current sample problem illustrates the use of INSTED/Shell and Tube to rate a single-phase multi-pass shell and tube heat exchanger.

Problem Statement

In a facility where electricity is generated, condensed (distilled) water is to be cooled by means of a shell and tube heat exchanger. Distilled water enters the exchanger at 100°F at a flow rate of 170,000 lbm/hr. Heat will be transferred to raw water (from a nearby lake) which is available at 65°F and 150,000 lbm/hr. Preliminary calculations indicate that it may be appropriate to use a heat exchanger that has a 17¼ in. inside diameter shell, and a ¾ in. OD., 18 BWG tubes that are 16ft long. The tubes are laid out on a 1-in. triangular pitch, and the tube fluid will make two passes. The exchanger contains baffles that are spaced 1 ft apart. The number of tubes is 196, the number of shell passes is 1, and the number of baffles is 15. The number of tube passes is 2. From 2 tube passes and 196 total number of tubes, the total number of tubes per pass is 98.

The inner heat transfer coefficient of the tubes may be obtained from INSTED and the value will be 4052.09 W/m²K.

The friction factor for the shell material may be taken as 0.2774 or computed from the Database using roughness typical of the material

Analyze the proposed exchanger to determine its suitability.

Source

William @. Janna. "Design of Fluid Thermal Systems". PWS-Kent Publishing, Boston, Page 275.

Comments

- In INSTED, choose the 'Outlet Temperature' task
- Hot fluid (distilled water) is in the shell. Raw water is in the tubes
- For the fouling factors, a value of $0.00015 \text{ m}^2\text{K/W}$ may be assumed
- Use the Kern's method to calculate the shell-side heat coefficient

Name of Data File

The input data for the present sample problem are contained in the file
`\insted30\concentric\samples\janna.275`.

Instructions for running a sample file

Sample files for INSTED/Shell & Tubes are located in of the installation drive. To run the sample file 'janna.275', follow these procedures:

1. From the 'Project Admin' dialog box, click on the "Load Project" button
2. Locate the directory `\insted30\shtube\samples\` on the installation drive
3. Type " *.* " in the filename position and press Enter
→ A list of the files present in the directory is displayed
4. Select the file 'janna.275' and click on the "Ok" button
5. Click "Compute" on the Main dialog and wait for computation to end
6. Click "Graphs" to open the 'Graphs' dialog box
7. Click "TEMA Sheet" to view the results on the TEMA sheet
8. On the top left corner of the screen, select File/Print, to obtain a hard copy of the TEMA sheet results
9. Click any point on the TEMA sheet to exit the sheet

Procedure for Performing a Preliminary Design Calculation

The current sample problem illustrates the use of INSTED/Shell and Tube for single-phase preliminary design calculations.

Problem Statement

Recommend a suitable shell-and-tube heat exchanger configuration for the following service. The information given in the answer should be complete enough either for preliminary pricing and plant layout or for entering into the Delaware method.

Design a shell and tube heat exchanger to heat 49,800 bpd (597,000 lb/hr) of 34° API Midcontinent crude from 125°F to 180°F, using 13,200 bpd (152,000 lb/hr) of 28° API gas oil at 410°F, cooling it to 220°F. Pressure drop is limited to 15 psi on each side.

The properties of the fluids are:

	Hot Fluid (315°F)	Cold Fluid (150°F)
Density (lbm/ft ³)	49.3	51.2
Specific Heat (Btu/lbm°F)	0.58	0.51
Viscosity (bulk) (lbm/fth)	2.90	7.0
Viscosity (wall) (lbm/fth)	7.5 (200°F)	4.4 (200°F)
Thermal Conductivity (Btu/hr ft°F)	0.061	0.071

The fouling factor for both crude and gas oil will be taken as 0.002 hrft²F/Btu for each stream.

Source

1. Bell, K. J., *Section 3.1.4. of Heat Exchanger Design Handbook*, 1998
2. Bell, K. J. *Personal Communication*

Comments

In addition, the following are also to be taken into consideration:

TEMA standards apply. Preferably place the hot fluid in the tubes since the hotter fluid is more likely to foul.

The data for this sample problem is also located in the file
\insted30\shtube\samples\prelimd.inp

Important Information for Customers

Before you proceed, please refer to the section “Required Data for Preliminary Design”.

Name of Data File

The input data for the present sample problem are contained in the file
\insted30\concentric\samples\prelimd.inp.

Procedure for Preliminary Design

1. Select the “Prel. Design” button in the ‘Problem Description’ dialog box
2. Enter the appropriate data in the following dialog boxes – ‘Tube Properties’, ‘Shell Properties’, ‘Shell and Tube Fluids’, ‘Heat Transfer Coeffs.’
Alternatively, you could load the data (for the above problem) from the sample data subdirectory via the ‘Project Admin’ dialog box.
3. Click on the “Design Dialog” button to open up the associated dialog box. Provide the bounds (min, max) on velocity, shell diameter and tube length that should be enforced. Also enter the maximum allowed flow rate and pressure. (It is advised to be initially generous with the constraints in order not to reject all design possibilities at the first design attempt.) Click “Ok” on this dialog box when you are done.
4. Click “Compute” on the Main dialog box. Various design realizations are listed in a table.
5. Use the mouse to select the design you prefer most. Then click the “Select One Solution” button. This design is accepted. You are now ready to do a detailed rating calculation. (Note that clicking “Ok” without selecting one of the design options rejects all the realizations. You could at this point alter some values or relax/tighten some constraints and try again.)

LIMITATIONS OF INSTED/SHELL & TUBES

The following are the limitations of the current version of INSTED/Shell & Tube program:

- Preliminary design as discussed in this manual can only be done for single-phase problems.
- The saturation temperature for a two-phase analysis is assumed independent of temperature and pressure.
- Steady state conditions are supported