Contents

INTRODUCTION

INSTED is the first engineering analysis computer program to integrate the classical and proven Empirical Engineering relations and the more modern technique of Computational Fluid Dynamics (CFD) and Heat Transfer into a single computing environment. The INSTED/Database is a module, which is accessible to by all the other modules in INSTED.

<u>Why You Should Use INSTED/Database</u>

- Automatic data integration
- Convenience

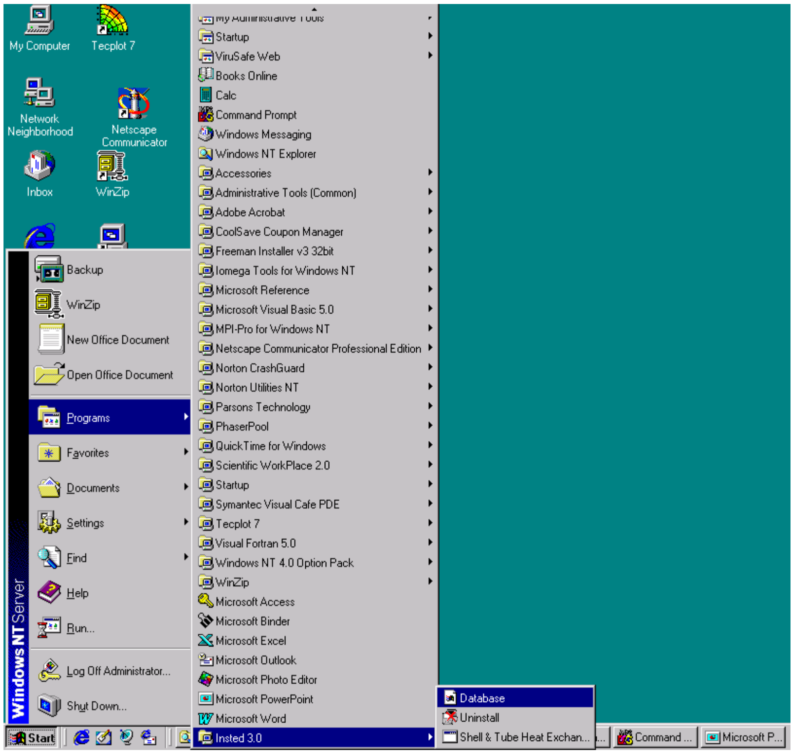
The tedious and often time consuming task of having to decipher values from graphs and charts, or read countless manuals, for reference values and engineering design parameters, is slowly becoming obsolete. With a computerized database, the required information may be accessed quickly and easily thereby simplifying the design process for a designer and making frequent or repeated data retrieval more efficient and less rigorous for the general engineer.

The INSTED Database will enhance company productivity by allowing you to make better utilization of your engineering manpower and substantially reducing the turnaround time on projects.

RUNNING THE INSTED®/DATABASE

Starting the Program

1. Select **Programs** under the Window **Start** button
2. Select **INSTED 4.0** program group under the Programs menu
3. Click the **Database** icon

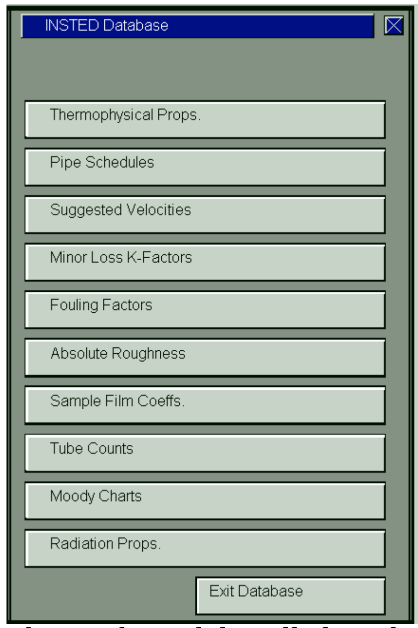


PROGRAM ORGANIZATION

The database contains the following in submodules:

1. Material properties (for various gases, liquids, and solids)
2. Numerous ASME pipe schedules and nominal diameters
3. Economic velocities for the flow of various fluids in a pipe
4. Minor loss coefficients (K-factors) for pipes
5. Fouling factors for various fluids
6. Absolute pipe roughness for several commercial pipes
7. Sample heat transfer (film) coefficients
8. Tube counts for shell and tube heat exchangers
9. Computation of friction factor in pipe flow
10. Radiation properties

The Main Dialog Box



The INSTED/Database program has a Main dialog box, as shown here. The various modules of the database are accessed from this environment. You can also exit INSTED/Database from the Main dialog box.

Note that if INSTED/Database is accessed from another INSTED program, the Main dialog will not be displayed, as the appropriate section of the database is accessed directly. During such a session, closing the called database sub-module will close the database program and transfer control back to the calling INSTED program.

The various sections of the database program and the way to extract information from them are now discussed in greater detail in the subsequent sections of this manual.

THERMOPHYSICAL PROPERTIES

The thermophysical property database contains the following information:

1. Properties of two-phase saturated organic and inorganic fluids as a function of the saturated temperature (pressure)
2. Properties of single-phase fluids at atmospheric pressure as a function of temperature
3. Properties of some single-phase fluids at atmospheric temperature and pressure
4. Properties of solids

A detailed, partial listing of the contents of INSTED/Database is provided in an appendix to the Database manual that you are currently reading.

INSTED Data versus Custom data

INSTED data are the data that come preloaded with the program. This is fairly huge. Custom data are those data that you generate yourself.

Once generated, custom data are also managed by the INSTED program and are available to you in future sessions that require INSTED/Database. The procedures to add custom data to INSTED are described later in this manual.

In the current version of INSTED, only the Thermophysical Properties module allows custom data.

Accessing Thermophysical Properties

1. Click on the "Thermophysical Properties" button in the Main dialog box
2. Select the type of property you wish to extract of the three options:-
   - Two-phase fluids
   - Single-phase fluids
   - Solids
3. Select the material whose property you wish to access
4. Click on the "Ok" button

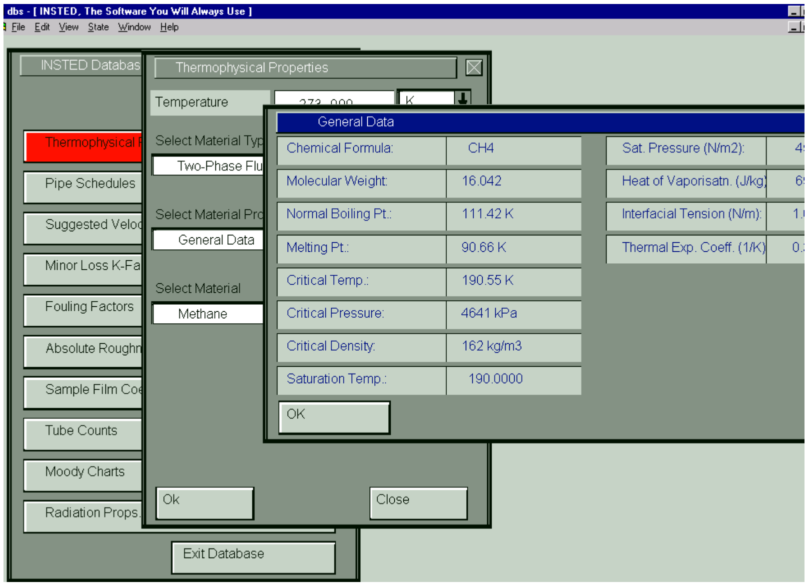
INSTED Two-Phase Fluids

The two-phase properties of various liquids and their vapors (saturated fluids) contained in the database are tabulated for a wide range of saturation temperatures and pressures, with interpolation between the temperature (pressure) values. Two-phase thermophysical property data for each fluid are separated into three groups: General Data, Vapor Data, and Liquid Data. The contents of each group are listed below.

General Data

These include:

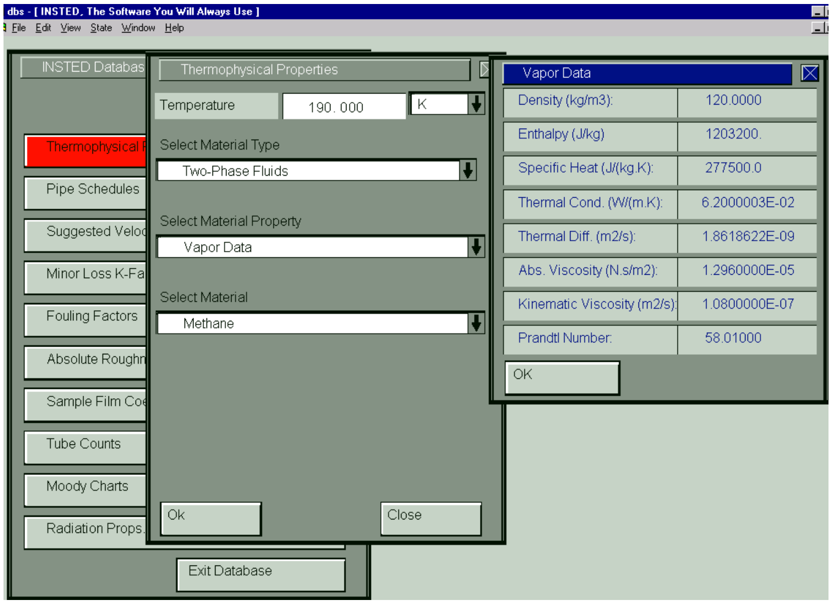
- chemical formula
- molecular weight
- boiling point and melting point at atmospheric pressure
- critical temperature
- critical pressure
- critical density
- interfacial tension
- coefficient of thermal expansion



The 'General Data' screen for methane is shown in the figure above.

Vapor Data

- vapor density (kg/m^3)
- vapor enthalpy (J/kg)
- heat of vaporization (J/kg)
- specific heat at constant pressure (J/kgK)
- absolute viscosity (Ns/m^2)
- thermal conductivity (W/mK)
- thermal diffusivity (m^2/s)
- kinematic viscosity (m^2/s)
- Prandtl number



Required Input: temperature

Data is interpolated and presented for the specified temperature.

Liquid Data

- liquid density (kg/m^3)
- liquid enthalpy (J/kg)
- heat of vaporization (J/kg)
- specific heat at constant pressure (J/kgK)
- absolute viscosity (Ns/m^2)
- thermal conductivity (W/mK)
- thermal diffusivity (m^2/s)
- kinematic viscosity (m^2/s)
- Prandtl number

Required Input: temperature
Data is interpolated and presented for the specified temperature.

INSTED Single-Phase Fluids

Single-phase fluid data are available for gases and liquids at atmospheric pressure, with variable temperature. Data are also available for certain fluids at atmospheric pressure and temperature.

Data at Atmospheric Pressure

Temperature input is required. The property is interpolated for this temperature. Data are provided for:

- density (kg/m^3)
- thermal expansion coefficient (1/K)
- specific heat at constant pressure (J/kgK)
- absolute viscosity (Ns/m^2)
- thermal conductivity (W/mK)
- thermal diffusivity (m^2/s)
- kinematic viscosity (m^2/s)
- Prandtl number

Data at Atmospheric Temperature and Pressure

No input is required besides your selection of the desired material. Data are provided for:

- density (kg/m^3)
- thermal expansion coefficient (1/K)

- specific heat at constant pressure (J/kgK)
- absolute viscosity (Ns/m^2)
- thermal conductivity (W/mK)
- thermal diffusivity (m^2/s)
- kinematic viscosity (m^2/s)
- Prandtl number

INSTED Solids

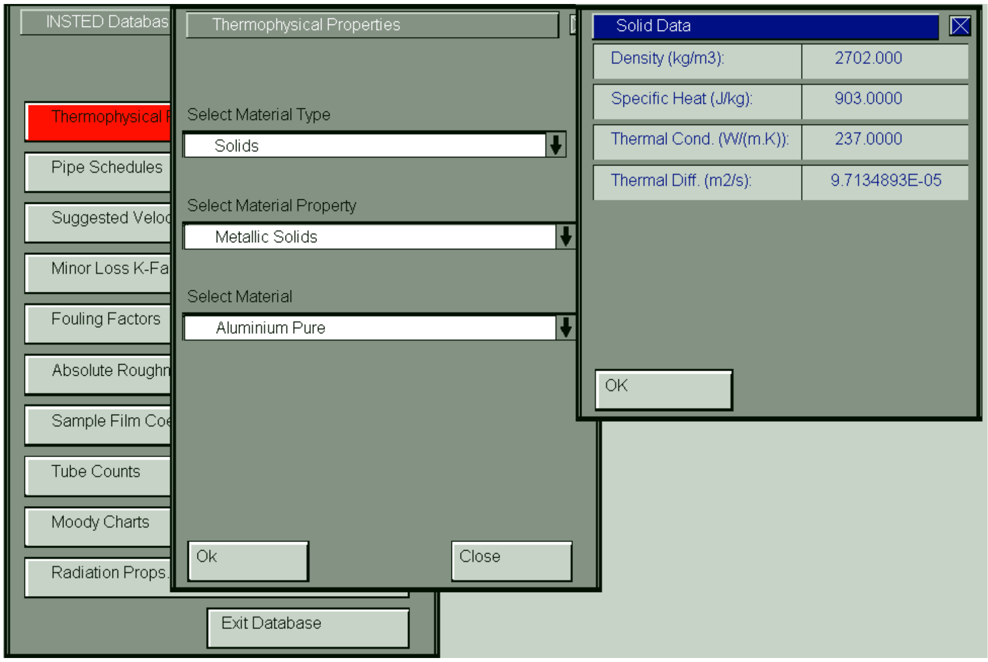
The materials for solid properties are grouped as follows:

1. metallic solids
2. non-metallic solids
3. building materials
4. insulation
5. miscellaneous

The following data are contained in the database:

- density (kg/m^3)
- specific heat (J/kgK)
- thermal conductivity (W/mK)
- thermal diffusivity (m^2/s)

The figure below shows the typical display screen for INSTED solids.



Entering Custom Data in INSTED/Database

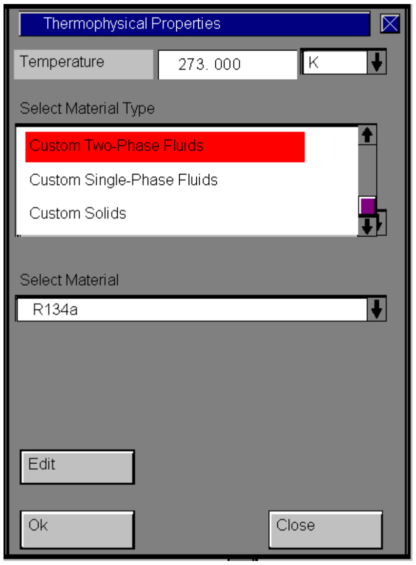
The previous sections describe the types of thermophysical property data available for a range of fluids and are preloaded into INSTED. This section describes custom data, where you edit INSTED/Database to add your own fluids. The advantages of entering your data in the database are as follows:

- These properties can be retrieved and used for analysis in other INSTED programs such as Plate-Fin heat exchanger, Internal Flow analysis, or Shell & Tube heat exchanger programs. Using the same database guarantees uniform values for the same materials or fluids.
- INSTED/Database performs the required interpolation for a specified temperature. Therefore, using INSTED obviates the need to interpolate from your tables every time you have to use the fluid or material. This is even more important when you carry out temperature-dependent calculations and need to obtain the fluid properties at several temperatures as the fluid's temperature is changed along a heat exchanger.

The following table lists the properties that may be entered in the database:

Custom Two-Phase Fluids	▪ name of data or name of fluid ▪ thermophysical properties such as density, specific heat, viscosity, conductivity, enthalpy, surface tension by temperature, saturation temperature, etc.
Custom Single-Phase Fluids	▪ name of data or name of fluid ▪ thermophysical properties such as density, specific heat, viscosity, thermal conductivity, enthalpy, surface tension, etc.
Custom Solids	▪ name of data or name of material ▪ density, specific heat, thermal conductivity, thermal diffusivity

The following procedures may be used to enter data in the Thermophysical Properties module of INSTED/Database:

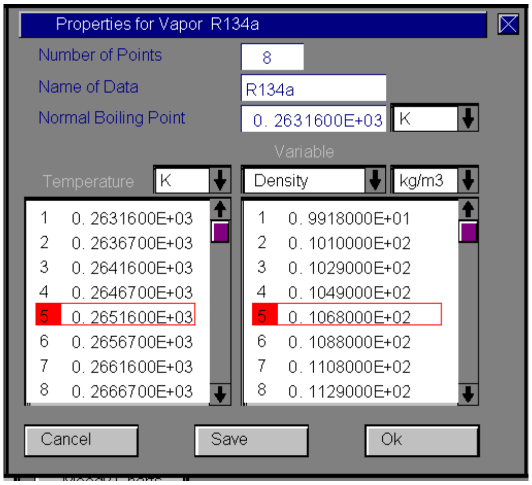


1) From the 'Thermophysical Properties' dialog box, select either 'Custom Two-Phase', 'Custom Single-Phase' or 'Custom Solids'
2) Open the 'Select Materials' drop-down to choose the fluid/solid of interest
3) To edit a previously entered data, select the material and press edit

   or

   To enter a new custom material, select the 'Define New Material' option

⇒ The 'Properties' dialog box appears, which is shown in the figure below.



4) Enter the number of data points
5) Enter a name for the data
6) For two-phase data, enter the saturation temperature
7) Enter the temperature values for which data are available
8) For each thermophysical property (density, specific heat, etc.), do the following:
   a) select the property you wish to enter or edit
   b) enter the values of the property at the temperatures you entered
9) Click the “Save” button (to save) or “Cancel” (to discard) you changes
10) Click the “Ok” button to exit this dialog box.

PIPE SCHEDULES

The INSTED®/Database allows you to access pipe dimensions for the following types of pipes

- Wrought steel and iron pipes
- Seamless copper water tubing
- Heat exchanger tubes (condenser tubes)

The wrought steel and wrought iron pipe dimensions are based on a nominal diameter and a schedule. It is important to note that the nominal diameter does not necessarily correspond to the actual inner or outer diameter of the pipe. The pipe schedule is an indication of the thickness of the pipe, where larger schedules infer thicker pipes. Therefore, two pipes with the same nominal diameter can have different pipe schedules.

Copper tubes have thinner walls and can only sustain low fluid pressures compared to wrought iron pipes. However, the dimension specifications are similar to those of wrought iron pipes.

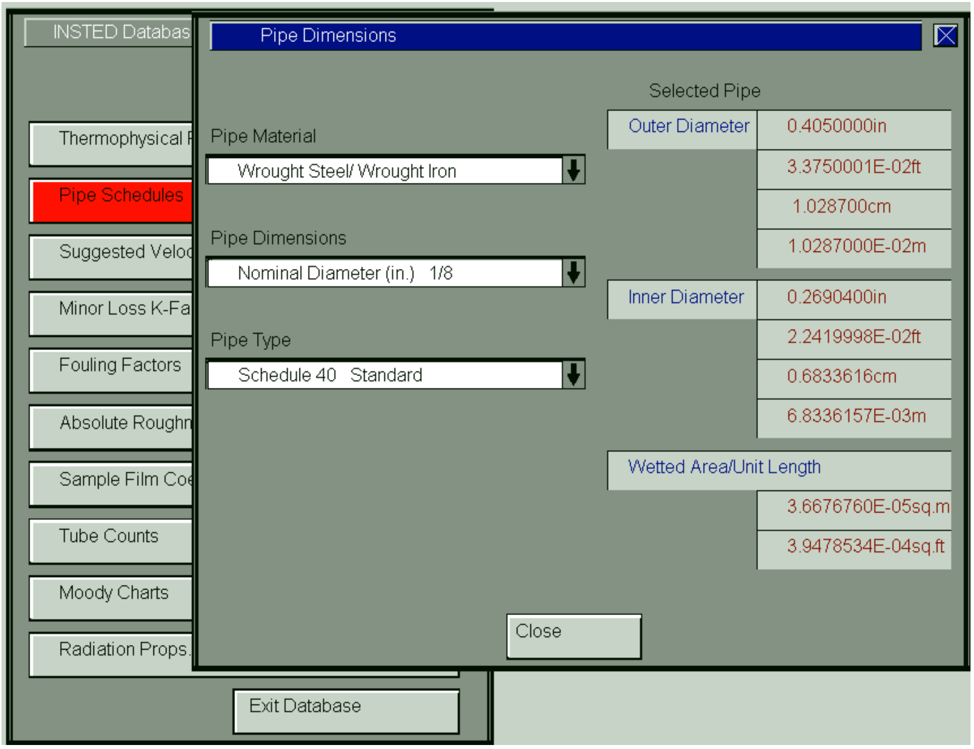
The dimension specification for condenser tubes follow the Birmingham wire gauge (BWG) standard. The outer diameter specification corresponds to the actual pipe outer diameter.

The following information is provided for each pipe:

- Actual outer diameter (in meters, inches, centimeters and feet)
- Actual inner diameter (in meters, inches, centimeters and feet)
- Wetted area per unit length (m^2 and ft^2)

Accessing Pipe Schedules

1. Click the "Pipe Schedules" button from the Main dialog box.
2. Select the "Pipe Material" (from the three classes described above)
3. Select the "Nominal diameter" or Pipe Dimensions
4. Select the "Pipe Type" (or Schedule)



Database

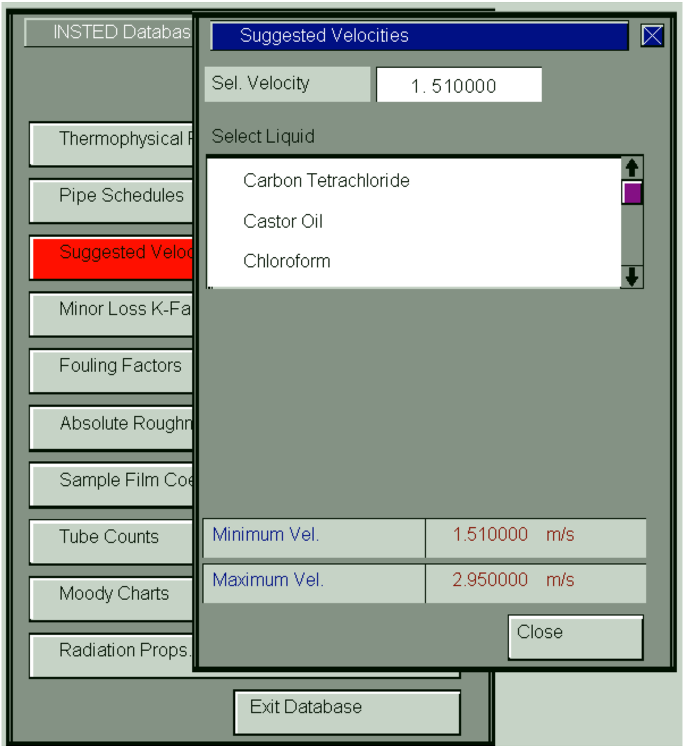
SUGGESTED VELOCITIES

Both economic and fluid dynamic constraints must be taken into consideration in order to determine the optimum velocity at which a particular fluid must move inside a pipe or duct. Some of the parameters of interest include the pipe economic diameter, pumping requirements, fluid conditions upstream and downstream of the piping system (i.e., the minimum upstream operating pressure and the maximum downstream operating pressure), and operating costs. Since pipes are available in a relatively small number of sizes, a cost analysis is feasible. Also, by using certain optimum economic diameter equations in conjunction with the various pipe sizes, reasonable economic velocities for various fluids may be calculated. These suggested velocities (or economic) velocities are available in INSTED®/Database.

The required input is a selection of the fluid of interest and the economic velocity range is suggested.

Accessing Suggested Velocities

1. Click the “Suggested Velocities” button from the Main dialog box.
2. Select the Fluid Type (from the drop-down list box)
   ⇒ The Suggested velocity range is printed at the bottom of the dialog box
3. If this data were accessed directly from some other program, e.g. the Series Piping System, you may edit the value in the edit box at the top of the screen to select the value returned to the calling program. The initial value in this box is the average velocity



MINOR LOSS K-FACTORS

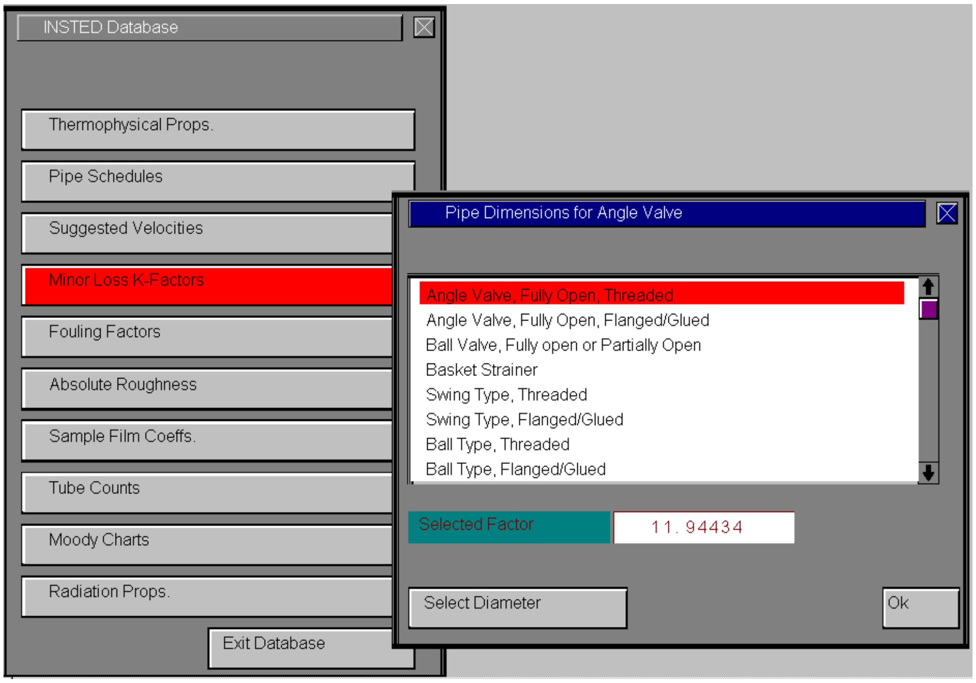
INSTED®/Database allows you to access the minor loss K-factors associated with the numerous types of minor losses (pressure losses) that a fluid may experience as it flows through various geometric fittings in a piping system. Each fitting has a minor loss K-factor associated with it.

The required input is a specification of the type of fitting. Other data that may be required include the diameter of a pipe or the angle of opening for some valves. For instance, for the convergent nozzle, the value of the inlet and outlet diameters may be required. Editboxes are presented for you to specify the values of any required data.

Note that the Series Piping System program is also designed to access the minor loss K-factors from INSTED/Database.

Accessing Minor Loss K-Factors

1. Click the "Minor Loss K-Factors" button from the Main dialog box.
2. Select the type of minor loss



Database

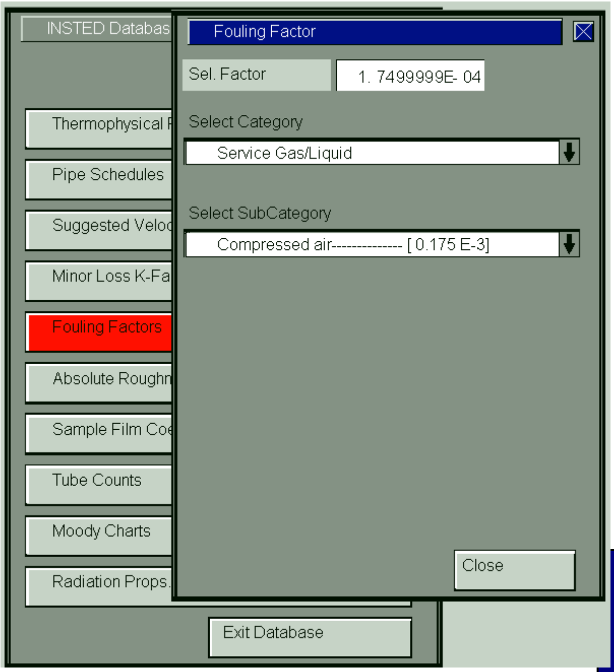
FOULING FACTORS

When residue and dirt accumulate on the tube walls of heat exchangers that have been in use for an extended period of time, the effective heat transfer coefficient will decrease. The resistances to heat flow due to the surface residues are known as fouling factors. INSTED®/Database allows you to access various heat exchanger fouling factors.

Fluids in the database are arranged into seventeen categories, including general fluids, process fluids, water system fluids, various oil refinery fluids, etc.

Accessing Fouling Factors

1. Click the "Fouling Factors" button from the Main dialog box
   ⇒ The 'Fouling Factors' dialog box is opened
2. Select a fluid category
3. Select the subcategory

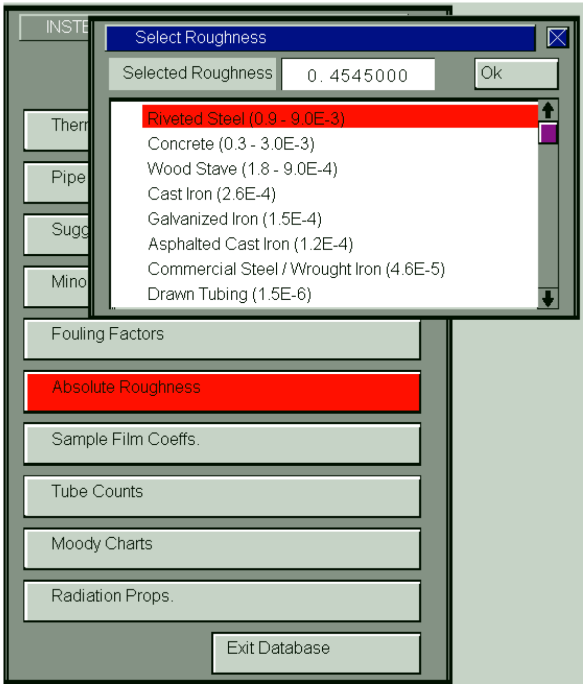


Database

ABSOLUTE ROUGHNESS

INSTED/Database contains the average absolute roughness data for various commercial pipes. The absolute roughness, ε, was determined empirically based on a comparison of the pressure drop versus volume flow rate for commercial pipes with that of experimental pipes of varying diameters with sand particles (of known diameters) attached to their surfaces. The size of the sand particles attached to the experimental pipe is denoted by ε. A commercial pipe which shows similar pressure drop versus volume flow rate behavior as an experimental pipe of a given diameter and coated with sand particles of a given dimension, is said to have an absolute roughness given by the value of ε.

The absolute roughness value is supplied in meters and can be converted to other units in all calling programs using INSTED's multi-directional, on-the-fly conversion listboxes.



Accessing Absolute Roughness Data

1. Click on the “Absolute Roughness” button on the Main dialog box.
2. Select the pipe material.
   ⇒ The absolute roughness value is displayed in the textbox at the top of the screen.

SAMPLE HEAT TRANSFER COEFFICIENTS

INSTED®/Database contains ballpark values of the heat transfer (or film) coefficients for the following:

- forced convection
- free convection
- boiling water
- condensation of water vapor at one atmosphere
- Shell and Tube heat exchanger systems (over all U-values)
- Concentric Tubes heat exchanger systems (over all U-values)

For forced and free convection, knowing the heat transfer coefficient, calculate the heat transfer rate using the following formula:

$$Q = hA(T_s - T_f)$$

Where Q is the heat transfer rate in Watts (W), h is the heat transfer coefficient in (W/m^{2}K), A is the surface area (m^2), T_s is the temperature of the surface in (K) and T_f is the "free stream" temperature in (K).

The overall heat transfer coefficient for various duties and configurations for Shell and Tube heat exchanger systems is also available in INSTED/Database. The heat load, Q, is defined as:

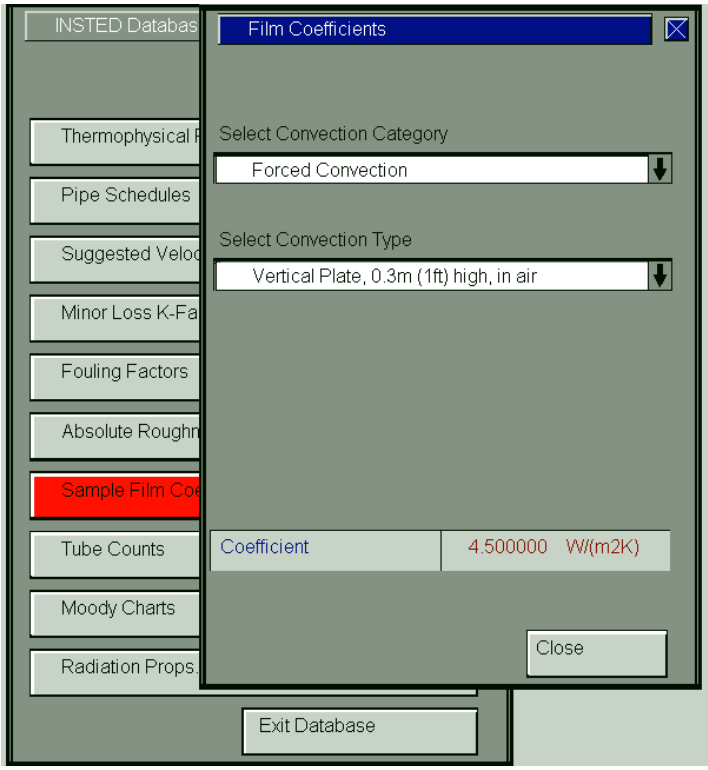
$$Q = UA\Delta T,$$

where U is the overall heat transfer coefficient, A is the heat transfer area, and ΔT is the mean temperature difference (single-phase) or some suitable average value (multi-phase).

It is often desirable to obtain a quick estimate of the size of the Shell and Tube system required for a particular duty and configuration. If the value of the overall heat transfer coefficient is known, the equation given above for the heat load may be used to calculate this size.

Accessing Heat Transfer Coefficient

1. Click the "Sample Film Coefficient" button on the Main dialog box
2. Select a category from the six groups described above
3. Select a convection type
   ⇒ The value of the sample coefficient is displayed at the bottom of the dialog box.



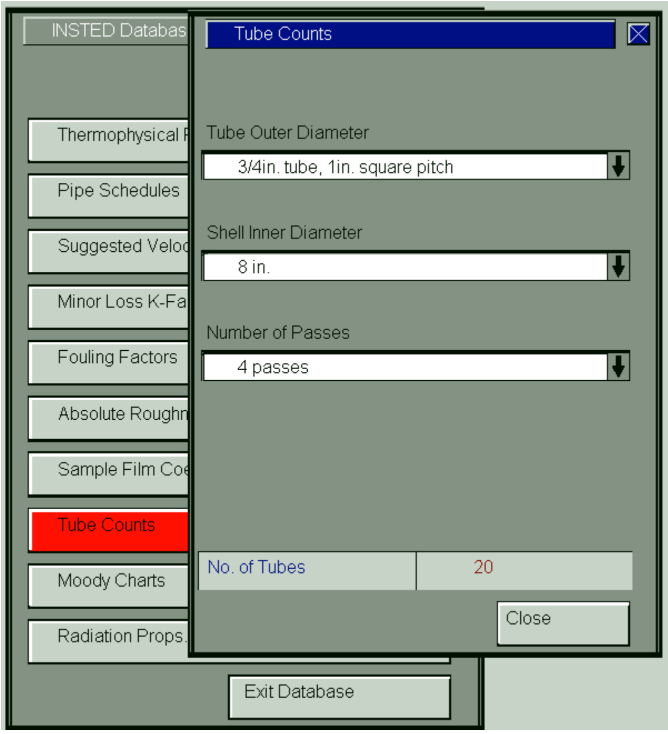
TUBE COUNTS

INSTED®/Database contains tube count data for Shell and Tube heat exchanger systems, as a function of the tube outer diameter, the tube pitch type, the inner shell diameter, and the number of tube passes.

Accessing Tube Counts

1. Click on the 'Tube Counts' button on the Main dialog box
2. Select the size of the tube outer diameter
3. Select the size of the shell inner diameter
4. Select the number of tube passes

⇒ The number of tubes will be displayed at the bottom part of the dialog box.



MOODY CHART

The Moody chart module calculates friction factors for pipe flow.

Required Data

- Absolute roughness: This may be supplied directly or obtained from INSTED/Database (Roughness module)
- Hydraulic diameter of pipe: This may also be supplied directly or obtained from INSTED/Database (Pipe Schedules)
- Reynolds number: This value is usually passed from a calling module if the Moody Chart was called externally. Programs that call the Moody chart module include the Internal Flow, Shell and Tube, and the Series Piping Systems

Friction Factor Calculation

The friction factor is computed using three different methods:

- The Darcy-Weisbach equation
- Colebrook's (non-linear) equation
- Churchill's explicit formula

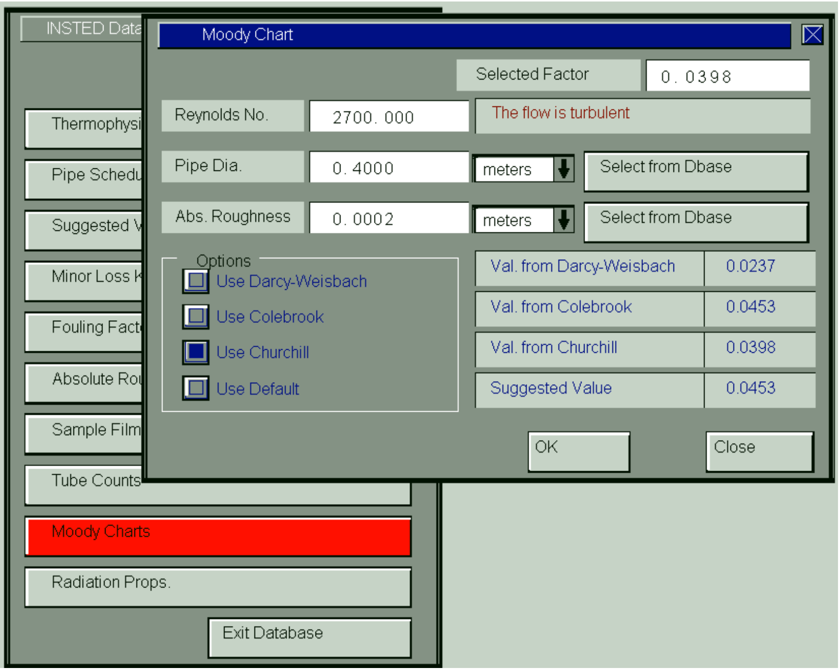
INSTED®/Database also suggests a value. For laminar flows, the Darcy-Weisbach equation usually gives the most accurate results. For turbulent flows, the Colebrook and Churchill equations are the most suitable. The Churchill formula often gives good results for moderate to high Reynolds number flows. For the Colebrook method, INSTED uses a Newton-Raphson linearization. With this approach, the results are probably not reliable if the number of iterations is low (less than two) or very high (over 100). Finally, the friction value should not exceed 0.1 for turbulent flows or go below 0.005 for both turbulent and laminar flows, except for smooth pipes, where the friction factor may be several orders of magnitude less than 1.0..

Accessing Moody Charts

1. Click on the "Moody Charts" button on the Main dialog box

⇒ The Moody chart interface appears as shown in the figure below

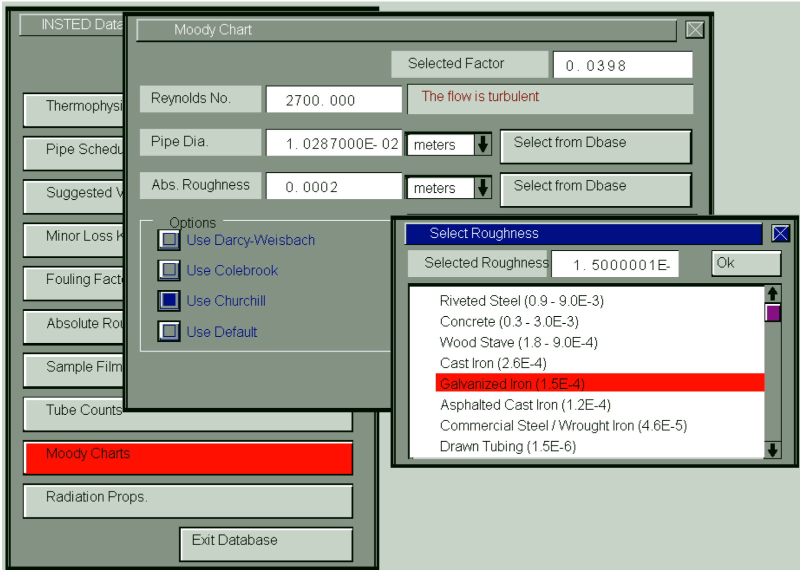
2. Enter the Reynolds number of the flow in the pipe



3. Enter the diameter of the pipe. You may also select the pipe diameter from INSTED/Database by clicking the "Select from Dbase" button
4. Enter the absolute roughness of the pipe. You may also select the absolute roughness from the INSTED/Database by clicking the "Select from Dbase" button

Database

5. Click the "Ok" button
   On the bottom right corner of the screen, the results using all the computation options are displayed together with the suggested value
6. Select which of the options you wish to adopt by clicking one of the buttons in the 'Options' group
7. The friction factor computed by the selected option is now carried over to the top textbox called 'Selected factor'. This is also the value that will be returned to a calling program, say, INSTED® Internal Flow Analysis program.



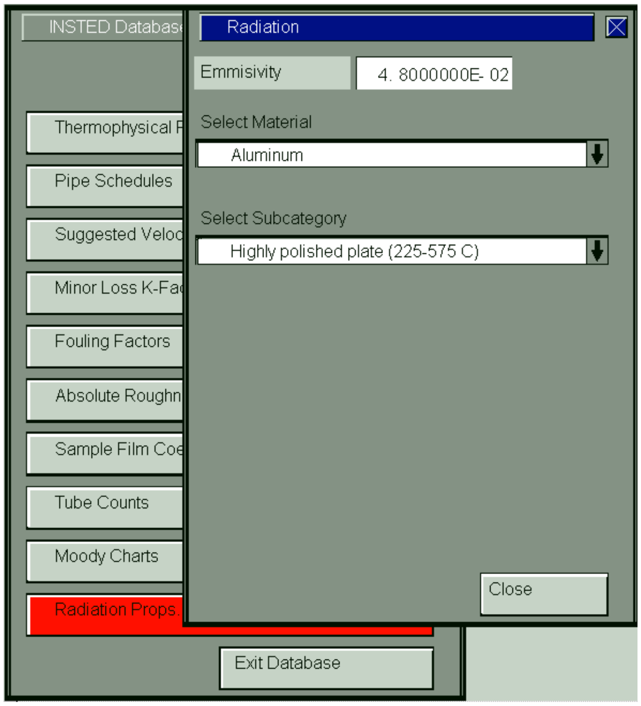
Database

RADIATION PROPERTIES

INSTED®/Database contains the normal emissivity for various surfaces.

Accessing Emissivity Data

1. Click the “Radiation Props” button on the Main dialog box
2. Select the material group whose properties you are interested in
3. Select the material (and temperature) of the desired material
4. You may edit the selected value in the top edit box. The value in this edit box will be the final value passed to a calling program, if the Radiation Properties module were by some other INSTED program



Appendix to the Database Manual

1 Introduction

In this appendix, more details are provided on the contents of INSTED/Database. This pertains only to the data that are preloaded with INSTED. No information on custom data is provided in this appendix.

2 Thermophysical Properties

Introduction

The INSTED®/Database allows you to access a very extensive database of material properties for gases, liquids, and solids. The INSTED®/Database contains thousands of entries for various engineering materials. The thermophysical property database contains the following information:

1) Properties of two-phase saturated organic and inorganic fluids as a function of the saturated temperature (pressure).

2) Properties of single-phase fluids at atmospheric pressure as a function of temperature.

3) Properties of some single-phase fluids at atmospheric temperature and pressure.

4) Properties of solids.

Note that you will often need to specify the temperature at which the properties should be evaluated. A warning message will be displayed on your screen if the temperature value you specify is not within the table range.

Two-Phase Saturated Fluids

The two-phase properties of various liquids and their vapors (saturated fluids) contained in the INSTED®/Database are tabulated for a wide range of saturation temperatures and pressures, with interpolation between the temperature (pressure) values. These properties, which are often required for heat exchanger calculations and which are contained in the INSTED®/Database, are listed below:

- liquid density (kg/m³)
- vapor density (kg/m³)
- liquid enthalpy (J/kg)
- vapor enthalpy (J/kg)
- heat of vaporization (J/kg)
- liquid specific heat at constant pressure (J/kg K)
- vapor specific heat at constant pressure (J/kg K)
- liquid viscosity (N s/m²)
- vapor viscosity (N s/m²)
- liquid thermal conductivity (W/m K)
- vapor thermal conductivity (W/m K)
- thermal diffusivity (m²/s)
- kinematic viscosity (m²/s)
- liquid Prandtl number
- vapor Prandtl number
- interfacial tension (N/m)
- coefficient of thermal expansion (1/K)

▶ Other Available Information for Two-Phase Saturated Fluids

- chemical formula
- molecular weight
- normal boiling point (K)
- melting (freezing) point (K)
- critical temperature (K)
- critical pressure (kPa)
- critical density (kg/m)

Single-Phase Fluids at Atmospheric Pressure

For gases and liquids at atmospheric pressure, values may be obtained for the following properties over a wide range of temperatures:

- density (kg/m^3)
- thermal expansion coefficient (1/K)
- specific heat at constant pressure (J/kg K)
- thermal conductivity (W/m K)
- thermal diffusivity (m^2/s)
- absolute viscosity ($N\ s/m^2$)
- kinematic viscosity (m^2/s)
- Prandtl number

Single-Phase Fluids at Atmospheric Pressure and Temperature

For gases and liquids at atmospheric pressures and temperatures, values may be obtained for the following properties:

- density (kg/m^3)
- thermal expansion coefficient (1/K)
- specific heat at constant pressure (J/kg K)
- thermal conductivity (W/m K)
- thermal diffusivity (m^2/s)
- absolute viscosity ($N\ s/m^2$)
- kinematic viscosity (m^2/s)
- Prandtl number

Solids

For solids, values are given for the following properties at normal atmospheric pressures and temperatures:

- density (kg/m^3)
- specific heat (J/kg K)
- thermal conductivity (W/m K)
- thermal diffusivity (m^2/s)

Detailed listings of the gases, liquids, and solids, whose thermophysical properties are available in the INSTED®/Database are given in the next section. The way to access the thermophysical properties will be described in a subsequent section in this chapter.

INSTED®/Database Contents

Note: New information is added to the INSTED®/Database on a regular basis. For updates or customized versions of the database, contact a Thaerocomp representative.

Gases Available in the INSTED®/Database

The gases, whose thermophysical properties are available in the INSTED®/Database are: methane, ethane, propane, dimethyl propane (neopentane), i-butane, n-butane, i-pentane, n-pentane, n-hexane, n-heptane, n-octane, n-nonane, n-decane, cyclopentane, cyclohexane, benzene, toluene, m-xylene, o-xylene, p-xylene, ethyl benzene, acetylene, ethylene, propylene, 1,3-butadine, 1,2- butadine, methanol, ethanol, 1-propanol, 2-propanol, n-butanol, t-butyl alcohol, phenol, refrigerant 12, refrigerant 13, refrigerant 21, refrigerant 22, ethyl ether, methyl-t-butyl ether, ethylene oxide, propylene oxide, methyl acetate, ethyl acetate, chloroform, aniline, acetic acid, acetone, dowtherm

A, dowtherm J, air, ammonia, argon, carbon dioxide, carbon monoxide, carbon tetrachloride, chlorine, fluorine, helium, hydrogen, hydrogen chloride, hydrogen fluoride, hydrogen sulfide, mercury, neon, nitrogen, oxygen, gasoline vapor, and water.

Gases at Atmospheric Pressure Available in the INSTED®/Database

The density, specific heat at constant pressure, thermal conductivity, thermal diffusivity, absolute viscosity, kinematic viscosity, and Prandtl number, based on a specified temperature are available for various gases at atmospheric pressure. The gases are air, ammonia, carbon dioxide, carbon monoxide, helium, hydrogen, nitrogen, oxygen, and water vapor.

Liquids Available in the INSTED®/Database

The liquids, whose thermophysical properties are available in the INSTED® /Database are: methane, ethane, propane, dimethyl propane (neopentane), i-butane, n-butane, i-pentane, n-pentane, n-hexane, n-heptane, n-octane, n-nonane, n-decane, cyclopentane, cyclohexane, benzene, toluene, m-xylene, o-xylene, p-xylene, ethyl benzene, acetylene, ethylene, propylene, 1,3-butadine, 1,2-butadine, methanol, ethanol, 1-propanol, 2-propanol, n-butanol, t-butyl alcohol, phenol, refrigerant 12, refrigerant 13, refrigerant 21, refrigerant 22, ethyl ether, methyl-t-butyl ether, ethylene oxide, propylene oxide, methyl acetate, ethyl acetate, chloroform, aniline, acetic acid, acetone, dowtherm A, dowtherm J, air, ammonia, argon, carbon dioxide, carbon monoxide, carbon tetrachloride, chlorine, fluorine, helium, hydrogen, hydrogen chloride, hydrogen fluoride, hydrogen sulfide, mercury, neon, nitrogen, oxygen, water, transmission fluid (Dextron II), engine oil (unused), ethylene glycol (**see the section entitled 'To Access the Thermophysical Properties of Ethylene Glycol' below**), glycerin, bismuth, glycerol, isobutyl alcohol, mobiltherm, nitrate salt (molten), calcium chloride (molten), methyl chloride, sulfur dioxide, sodium, steam, transformer oil, and turpentine.

Liquids at Atmospheric Pressure Available in the INSTED/Database

The density, thermal expansion coefficient, specific heat at constant pressure, thermal conductivity, thermal diffusivity, absolute viscosity, kinematic viscosity, and Prandtl number, based on a specified temperature are available for various liquids at atmospheric pressure. The liquids are transmission fluid (Dextron II), engine oil (unused), ethylene glycol, freon (refrigerant - 12), glycerin, mercury, acetic acid, acetone, aniline, benzene, bismuth, butyl alcohol, chloroform, ethane, ethyl acetate, ethyl alcohol, glycerol, heptane-n, hexane-n, isobutyl alcohol, methane, methyl alcohol, mobiltherm, nitrate salt (molten), octane-n, pentane-n, calcium chloride (molten), methyl chloride, sulfur dioxide, sodium, steam, toluene, transformer oil, turpentine, gasoline liquid, and water.

Two-Phase Saturated Fluids Available in the INSTED/Database

The saturated properties, listed in the introduction, for the following compounds are available in the INSTED®/Database.
Note: The saturated temperature range, in (K), and the saturated pressure range, in (kPa), are provided in parentheses next to each compound.

Paraffins

- methane (115 K - 190 K, 101 kPa - 4552 kPa)
- ethane (185 K - 290 K, 101 kPa - 3510 kPa)
- propane (235 K - 359 K, 101 kPa - 3545 kPa)

- dimethyl propane (neopentane) (285 K - 410 K, 102 kPa - 2200 kPa)
- i-butane (265 K - 390 K, 102 kPa - 2697 kPa)
- n-butane (275 K - 405 K, 103 kPa - 2739 kPa)
- i-pentane (305 K - 430 K, 102 kPa - 2070 kPa)
- n-pentane (310 K - 440 K, 102 kPa - 2103 kPa)
- n-hexane (345 K - 475 K, 102 kPa - 1859 kPa)
- n-heptane (375 K - 520 K, 102 kPa - 2046 kPa)
- n-octane (400 K - 555 K, 102 kPa - 2052 kPa)
- n-nonane (425 K - 575 K, 102 kPa - 1750 kPa)
- n-decane (450 K - 600 K, 102 kPa - 1650 kPa)

Cyclics

- cyclopentane (325 K - 490 K, 102 kPa - 3562 kPa)
- cyclohexane (355 K - 535 K, 102 kPa - 3723 kPa)

Aromatics

- benzene (355 K - 525 K, 102 kPa - 3060 kPa)
- toluene (375 K - 575 K, 102 kPa - 3450 kPa)
- m-xylene (415 K - 605 K, 102 kPa - 3052 kPa)
- o-xylene (420 K - 605 K, 102 kPa - 2750 kPa)
- p-xylene (415 K - 6054 K, 102 kPa - 3100 kPa)
- ethyl benzene (410 K - 593 K, 102 kPa - 2770 kPa)

Unsaturates

- acetylene (195 K - 290 K, 128 kPa - 4080 kPa)
- ethylene (170 K - 263 K, 102 kPa - 3240 kPa)
- propylene (230 K - 345 K, 102 kPa - 3190 kPa)
- 1,2-butadine (285 K - 400 K, 102 kPa - 2140 kPa)
- 1,3-butadine (270 K - 410 K, 102 kPa - 3350 kPa)

Alcohols

- methanol (340 K - 473 K, 102 kPa - 3970 kPa)
- ethanol (355 K - 482 K, 102 kPa - 3560 kPa)
- 1-propanol (375 K - 513 K, 110 kPa - 3402 kPa)
- 2-propanol (360 K - 478 K, 102 kPa - 3039 kPa)
- n-butanol (395 K - 530 K, 102 kPa - 2530 kPa)
- t-butyl alcohol (360 K - 480 K, 102 kPa - 2619 kPa)
- phenol (455 K - 665 K, 102 kPa - 4720 kPa)

Refrigerants

- refrigerant 12 (245 K - 365 K, 102 kPa - 2907 kPa)
- refrigerant 13 (195 K - 295 K, 102 kPa - 3320 kPa)
- refrigerant 21 (285 K - 440 K, 102 kPa - 4350 kPa)
- refrigerant 22 (245 K - 355 K, 102 kPa - 3800 kPa)

Miscellaneous

- ethyl ether (310 K - 463 K, 102 kPa - 3490 kPa)
- methyl-t-butyl ether (335 K - 480 K, 102 kPa - 2440 kPa)
- ethylene oxide (285 K - 440 K, 102 kPa - 4830 kPa)
- propylene oxide (310 K - 460 K, 102 kPa - 3450 kPa)
- methyl acetate (335 K - 490 K, 102 kPa - 3723 kPa)
- ethyl acetate (355 K - 510 K, 102 kPa - 3172 kPa)
- chloroform (335 K - 505 K, 102 kPa - 3725 kPa)
- aniline (460 K - 675 K, 102 kPa - 4050 kPa)
- acetic acid (395 K - 560 K, 102 kPa - 3590 kPa)
- acetone (330 K - 480 K, 102 kPa - 3252 kPa)
- dowtherm A (535 K - 730 K, 102 kPa - 2040 kPa)
- dowtherm J (455 K - 620 K, 102 kPa - 1870 kPa)

Inorganics and Elements

- air (80 K - 125 K, 102 kPa - 2470 kPa)
- ammonia (240 K - 390 K, 102 kPa - 8606 kPa)
- argon (90 K - 143 K, 102 kPa - 3702 kPa)
- carbon dioxide (220 K - 300 K, 518 kPa - 6712 kPa)
- carbon monoxide (85 K - 125 K, 102 kPa - 2423 kPa)
- carbon tetrachloride (350 K - 525 K, 102 kPa - 3160 kPa)
- chlorine (240 K - 394 K, 102 kPa - 5452 kPa)
- fluorine (90 K - 132 K, 102 kPa - 3159 kPa)
- helium (4.2 K - 5 K, 102 kPa - 199 kPa)
- hydrogen (25 K - 32 K, 102 kPa - 1100 kPa)
- hydrogen chloride (190 K - 305 K, 102 kPa - 5500 kPa)
- hydrogen fluoride (295 K - 445 K, 102 kPa - 4800 kPa)
- hydrogen sulfide (215 K - 360 K, 102 kPa - 7050 kPa)
- mercury (635 K - 1050 K, 102 kPa - 9230 kPa)
- neon (30 K - 43 K, 102 kPa - 2216 kPa)
- nitrogen (80 K - 120 K, 102 kPa - 2515 kPa)
- oxygen (95 K - 146 K, 102 kPa - 3591 kPa)
- water (375 K - 610 K, 102 kPa - 14044 kPa)

Metallic Solids Available in the INSTED®/Database

The metallic solids, whose thermophysical properties are available in the INSTED®/ Database are: aluminum (pure), aluminum (alloy 2024-T6, 4.5% Cu, 1.5% Mg, 0.6 % Mn), aluminum (alloy 195, cast, 45% Cu), beryllium , bismuth, boron, cadmium, chromium, cobalt, copper (pure), copper (commercial bronze, 90% Cu, 10% Al), copper (phosphor gear bronze, 89% Cu, 11% Sn), copper (cartridge brass, 70% Cu, 30% Zn), copper (constantan, 55% Cu, 45% Ni), copper/nickel (90% Cu, 10% nickel), germanium, gold, iridium, iron (pure), iron (armco, 99.75% pure), carbon (plain), carbon (AISI 1010), carbon-silicon, carbon-manganese-silicon, chromium steels (typical), stainless steel (AISI 302), stainless steel (AISI 304), stainless steel (AISI 316), stainless steel (AISI 347), lead, magnesium, molybdenum, nickel (pure), nickel (nichrome, 80% Ni, 20% Cr), nickel (inconel X-750, 73% Ni, 15% Cr, 6.7% Fe), niobium, palladium, platinum (pure), platinum (alloy, 60% Pt, 40% Rh), rhenium, rhodium, silicon, silver, tantalum, thorium, tin, titanium, tungsten, uranium, vanadium, zinc, and zirconium.

Non-Metallic Solids Available in the INSTED®/Database

The non-metallic solids, whose thermophysical properties are available in the INSTED®/ Database are: aluminum oxide (sapphire), aluminum oxide (polycrystalline), beryllium oxide, boron, carbon (diamond IIa, insulator), pyroceram (corning 9606), silicon carbide, silicon dioxide (polycrystalline, fused silica), silicon nitride, sulfur, thorium dioxide, and titanium dioxide (polycrystalline).

Building Materials Available in the INSTED®/Database

The thermophysical properties for the following building materials are available in the INSTED®/Database.

Building Boards

- plywood
- sheathing (regular density)
- acoustic tile
- hardboard (siding)
- hardboard (high density)
- particle board (low density)
- particle board (high density)
- wood (hard wood- oak, maple)
- wood (soft wood- fir, pine)

Masonry Materials

- cement mortar
- brick (common)

Plastering Materials

- gypsum plaster (sand aggregate)

Insulation Materials Available in the INSTED®/Database

The thermophysical properties for the following insulation materials are available in the INSTED®/Database.

- blanket and bat
- board and slab
- loose fill
- urethane (foamed-in-place materials)

Miscellaneous Solids Available in the INSTED®/Database

The miscellaneous solids, whose thermophysical properties are available in the INSTED®/ Database are: asphalt, bakelite, brick (chrome brick at 470 K), brick (fire clay burnt at 1700K and 750K), brick (fire clay brick), clay, coal (anthracite), concrete (stone mix), cotton, fruits (banana, 76% water), fruits (apple, 75% water), glass (plate, soda lime), glass (pyrex), ice (at 253K and 273K), paper, paraffin, rock (granite, barre), rock (limestone, salem), rock (marble, halston), rock (quartzite, sioux), rock (sandstone, berea), rubber (vulcanized, soft), sand, soil, wood (fir, cross grain), wood (oak, cross grain), wood (yellow pine, cross grain), wood (oak, radial), and wood (fir, radial).

3 Pipe Dimensions

Introduction

The INSTED®/Database allows you to access pipe dimensions for the following:

- wrought steel and wrought iron pipes
- seamless copper water tubing
- heat exchanger tubes (condenser tubes)

The wrought steel and wrought iron pipe dimensions or specifications are based on a nominal diameter and a schedule. It is important to note that the nominal diameter does not necessarily correspond to the actual inner or outer pipe diameter. The pipe schedule is an indication of the thickness of the pipe. As the schedule number increases, the pipe wall thickness increases. Therefore, a given pipe nominal diameter can have several pipe schedules.

Copper may be used for tubes or pipes. Tubes have thinner walls and can only sustain low fluid pressures compared to pipes. The dimension specifications for copper water tubing are similar to the dimension specifications for wrought steel and wrought iron pipes.

The dimension specifications for heat exchanger or condenser tubes follow the Birmingham Wire Gage (BWG) standard. The outer diameter specification corresponds to the actual pipe outer diameter.

Based on your selection, from the INSTED®/Database, of a nominal diameter (outer diameter for condenser tubes) and a schedule, the following information may be obtained:

- actual outer diameter in
  - inches (in.)
  - feet (ft)
  - centimeters (cm)
  - meters (m)
- actual inner diameter in
  - inches (in.)
  - feet (ft)
  - centimeters (cm)
  - meters (m)
- wetted area per unit length in
  - feet squared (ft^2)
  - meters squared (m^2)

The listings of the nominal diameters (outer diameters for condenser tubes) and schedules available in the INSTED®/Database, are provided in the next section.

INSTED®/Database Contents

The INSTED®/Database allows you to access pipe dimensions for wrought steel and wrought iron pipes, seamless copper water tubing, and condenser tubes.

Note: New information is added to the INSTED®/Database on a regular basis. For updates or customized versions of the database, contact a Thaerocomp representative.

Nominal Diameters for Wrought Steel and Wrought Iron Pipes

The following nominal diameters for wrought steel and wrought iron are available in the INSTED®/Database.

- 1/8
- 1/4
- 3/8
- ½
- ¾
- 1
- 1 ¼
- 1 ½
- 2
- 2 ½
- 3
- 3 ½
- 4
- 5
- 6
- 8
- 10
- 12
- 14
- 16
- 18
- 20
- 22
- 24
- 26
- 28
- 30
- 32
- 34
- 36
- 38
- 40

Schedules for Wrought Steel and Wrought Iron Pipes

The following schedules are available in INSTED®/Database for wrought steel and wrought iron pipes. The schedules are for each of the nominal diameters listed above for wrought steel and wrought iron pipes:

- (std)
- (xs)
- (xxs)
- 20, 20(std)
- 30, 30(std)
- 40, 40(std)
- 60, 60(xs)
- 80, 80(xs)
- 100
- 120, 120(xxs)
- 140, 140(xxs)
- 160

Note: The following abbreviations have been used:
std - standard
xs - extra strong
xxs - extra extra strong

Nominal Diameters for Seamless Copper Water Tubing

The following nominal diameters for seamless copper water tubing are available in the INSTED®/ Database.

- ¼

- 3/8
- ½
- 5/8
- ¾
- 1
- 1 ¼
- 1 ½
- 2
- 2 ½
- 3
- 3 ½
- 4
- 5
- 6
- 8
- 10
- 12

Schedules for Seamless Copper Water Tubing

The following schedules are available in the INSTED®/Database for seamless copper water tubing. These schedules are available for each of the nominal diameters listed above.

- U&GP: Underground use and General Plumbing
- INTP: Interior Plumbing
- SFIT: For use with Soldered Fittings

Outer Diameters for Condenser Tubes

The following outer diameters are available in the INSTED®/Database for condenser tubes:

- 5/8 in.

- ¾ in.
- 7/8 in.
- 1 in.
- 1 1/8 in.
- 1 ¼ in.

Birmingham Wire Gage (BWG) Schedules for Condenser Tubes

The following Birmingham Wire Gage schedules are available in the INSTED®/Database for condenser tubes. These BWG schedules are for each of the outer diameters listed above.

- BWG 12
- BWG 13
- BWG 14
- BWG 15
- BWG 16
- BWG 17
- BWG 18
- BWG 19
- BWG 20
- BWG 21
- BWG 22
- BWG 23
- BWG 24

4 Suggested Velocities

Introduction

Both economic and fluid dynamic constraints must be taken into consideration in order to determine the optimum velocity at which a particular fluid must move inside a pipe or duct. Some of the parameters of interest include, the pipe economic diameter, pump requirements, fluid conditions upstream and downstream of the piping system (i.e., the minimum upstream operating pressure and the maximum downstream operating pressure), and operating costs. Since pipes are available in a relatively small number of sizes, a cost analysis is feasible. In addition, by using certain optimum economic diameter equations in conjunction with the various pipe sizes, reasonable economic velocities for various fluids may be calculated.

A list of the fluids whose suggested velocities may be obtained from the INSTED®/ Database is provided in the next section.

Note: The suggested velocity ranges pertain to the flow of fluids in pipes.

INSTED®/Database Contents

Note: New information is added to the INSTED®/Database on a regular basis. For updates or customized versions of the database, contact a Thaerocomp representative for assistance.

Supported Fluids

Suggested velocity ranges are available in the INSTED®/Database for the following fluids:

- acetone
- ethyl alcohol
- methyl alcohol
- propyl alcohol
- benzene
- carbon disulphide
- carbon tetrachloride
- castor oil
- chloroform
- decane
- ether
- ethylene glycol
- R-11
- glycerine
- heptane
- hexane
- kerosene
- linseed oil
- mercury
- octane
- propane
- propylene
- propylene glycol
- turpentine
- water

5 Minor Loss K-Factors

Introduction

INSTED®/Database allows you to access the minor loss K-factors associated with the numerous types of minor losses (pressure losses) that a fluid may experience as it flows through various geometric fittings in a piping system. Each fitting has a minor loss K-factor associated with it.

A detailed listing of the fittings, whose minor loss K-factors may be obtained from the INSTED®/Database, is provided in the next section.

INSTED®/Database Contents

Note: New information is added to the INSTED®/Database on a regular basis. For updates or customized versions of the database, contact a Thaerocomp representative.

Pipe Fittings Available in the INSTED®/Database

The INSTED®/Database provides values for the minor loss K-factors for the following pipe fittings:

- angle valve (fully open, threaded)
- angle valve (fully open, flanged or glued)
- ball valve (fully or partially open)
- basket strainer

- check valve (swing type, threaded)
- check valve (swing type, flanged or glued)
- check valve (ball type, threaded)
- check valve (ball type, flanged or glued)
- check valve (lift type, threaded)
- check valve (lift type, flanged or glued)
- convergent outlet or nozzle
- coupling (threaded)
- coupling (flanged or glued)
- elbow (45°, threaded)
- elbow (45°, flanged or glued)
- elbow (90°, threaded, regular)
- elbow (90°, threaded, long radius)
- elbow (90°, flanged or glued, regular)
- elbow (90°, flanged or glued, long radius)
- foot valve
- inward projecting pipe
- inlet (square-edged)
- inlet (re-entrant/sudden exit)
- inlet (well-rounded)
- gate valve (fully open, threaded)
- gate valve (fully open, flanged or glued)
- gate valve (partially open, all sizes)
- globe valve (fully open, threaded)
- globe valve (fully open, flanged or glued)
- return bend (threaded, regular)
- return bend (flanged or glued, regular)
- return bend (flanged or glued, long radius)
- sudden contraction
- sudden expansion
- T-joint (threaded, line flow)
- T-joint (threaded, branch flow)
- T-joint (flanged or glued, line flow)
- T-joint (flanged or glued, branch flow)

6 Fouling Factors

Introduction

When residue and dirt accumulate on the tube walls of heat exchangers that have been in use for an extended amount of time, the rate of heat transfer between fluids within the heat exchanger will decrease. This decrease results, since the resistance to heat flow, which is caused by the residue, increases. These resistances are also known as fouling factors. The INSTED®/Database allows you to access various heat exchanger fouling factors. The fouling factors or resistances can be used to define a 'dirty or design coefficient' based on the overall heat transfer coefficient'.

The next section will provide a detailed listing of the fluids for which fouling factor data is available in the INSTED®/Database.

INSTED®/Database Contents

Note: New information is added to the INSTED®/Database on a regular basis. For updates or customized versions of the database, contact a Thaerocomp representative.

Fouling Factors Available in the INSTED®/Database

The INSTED®/Database provides fouling factors associated with the following fluids:

- **General:**

Database

- air
- brine
- alcohol vapor
- diesel engine exhaust
- engine oil
- organic vapors
- organic liquids
- refrigerant liquid
- water
  - city water
  - distilled water
  - sea water
  - well water

Water Systems

- sea water
- brackish water
- treated cooling tower
- artificial spray pond
- closed loop treated water
- river water
- engine jacket water
- distilled water
- closed cycle condensate
- treated boiler feed water
- boiler blowdown water

Service Liquids

- No. 2 fuel oil
- No. 6 fuel oil
- transformer oil

- engine tube oil
- refrigerants
- hydraulic fluid
- industrial organic HT
- ammonia
- ammonia (oil bearing)
- methanol solutions
- ethanol solutions
- ethanol glycol solutions

Service Gas/Liquid

- steam
- exhaust steam
- refrigerant
- compressed air
- ammonia
- carbon dioxide
- coal flue gas
- natural gas flue gas

Process Gas

- acid gas
- solvent vapor
- stable overhead products

Process Liquid

- MEA and DEA solutions
- DEG and TEG solutions
- stable side draw
- bottom products
- caustic solutions

▸ Natural Gas and Petroleum

- natural gas
- overhead products
- lean oil
- rich oil
- natural gasoline
- liquefied petroleum gases

▸ Oil Refinery: Crude and Vacuum Unit Gas/Vapors

- atmospheric tower overhead vapor
- light naphthas
- vacuum overhead vapors

▸ Oil Refinery: Crude and Vacuum Liquid

- crude oil
- gasoline
- naphtha
- light distillates
- kerosene
- light gas oil
- heavy gas oil
- heavy fuel oil
- vacuum tower bottoms
- atmospheric tower bottoms

▸ Oil Refinery: Cracking and Coking Unit Coke

- overhead vapors
- light cycle oil
- heavy cycle oil

- light coker gas oil
- heavy coker gas oil
- bottoms slurry oil
- light liquid products

▸ Oil Refinery: Catalytic Reforming, Hydrocracking, and Hydro-desulfurization Streams

- reformer charge
- reformer effluent
- hydrocharger charge
- effluent
- recycle gas
- liquid product over 50°C
- liquid product 30 to 50°C

▸ Oil Refinery: Light Ends Processing

- overhead vapors and gases
- liquid product
- absorption oils
- alkylation trace acid
- reboiler streams

▸ Oil Refinery: Visbreaker

- overhead vapors
- visbreaker bottoms

▸ Oil Refinery: Naphtha Hydrotreater

- feed
- effluent
- naphthas

- overhead vapor

Oil Refinery: Catalytic Hydrodesulfurizer

- charge
- effluent
- HT separator overhead
- stripper charge
- liquid products

Oil Refinery: HF Alky Unit

- alkylate
- depropanizer bottoms
- main fractionator overhead
- main fractionator feed
- other process streams

Crude Oil Refinery

- 120°C
- 120 to 180°C
- 180 to 230°C
- greater than 230°C

7 Absolute Roughness

Introduction

INSTED®/Database contains the average absolute roughness for various commercial pipes. The absolute roughness, ε, was determined empirically based on a comparison of the pressure drop versus volume flow rate for commercial pipes with that of experimental pipes of varying diameters with sand particles (of known diameters) attached to their surfaces. The size of the sand particles attached to the experimental pipe is denoted by ε. A commercial pipe which shows similar pressure drop versus volume flow rate behavior as an experimental pipe of a given diameter and coated with sand particles of a given dimension, is said to have an absolute roughness given by the value of ε.

A listing of the materials, whose absolute roughness may be obtained from the INSTED® /Database, is provided in the next section.

INSTED®/Database Contents

Note: New information is added to the INSTED®/Database on a regular basis. For updates or customized versions of the database, contact a Thaerocomp representative.

The INSTED®/Database contains the absolute roughness for the following surfaces:

- riveted steel
- concrete
- wood stave

- cast iron
- galvanized iron
- asphalted cast iron
- commercial steel/wrought iron
- drawn tubing
- glass

8 Sample Heat Transfer Coefficients

Introduction

INSTED®/Database contains approximate values of heat transfer or film coefficients for the following situations:

- Forced convection
- Free convection
- Boiling water
- Condensation of water vapor at one atmosphere
- Shell and Tubes heat exchanger systems (overall U-values)
- Concentric Tubes heat exchanger systems (overall U-values)

For forced and free convection, knowing the heat transfer coefficient, the heat transfer rate may be calculated from the following formula:

$$Q = hA\,\Delta T,$$

where Q is the heat transfer rate in watts (W), h is the heat transfer coefficient (W/m²K), A is the surface area of the solid (m²), and ΔT (K) is the characteristic temperature difference $(\Delta T = T_s - T_w)$

The overall heat transfer coefficients for various duties and configurations for the Shell and Tubes heat exchanger systems are also available in INSTED® /Database. The heat load, Q, is defined as

$$Q = U A \Delta T,$$

where U is the overall heat transfer coefficient, A is the heat transfer area, and ΔT is the mean temperature difference. (Single-phase) or some suitable average value (multi-phase).

It is often desirable to obtain a quick estimate of the size of a Shell and Tubes heat exchanger system required for a particular duty and configuration. If the value for the overall heat transfer coefficient is known, the equation given above for the heat load may be used to calculate this size. In general, the value of the overall heat transfer coefficient varies with the fluid enthalpy. However, empirically determined estimates for U are useful for approximate heat exchanger calculations.

Detailed listings of the situations for which heat transfer coefficients may be obtained from the INSTED®/Database, are provided in the next section. The next section also contains a list of the cold and hot side fluid configurations for Shell and Tubes heat exchanger systems, whose heat transfer coefficients may be obtained.

INSTED®/Database Contents

Note: New information is added to INSTED®/Database on a regular basis. For updates or customized versions of the database, contact a Thaerocomp representative for assistance.

Forced and Free Convection

The flow situations, for which heat transfer coefficients are available in INSTED®/Database are:

▸ Free Convection

Note: The heat transfer coefficients, available in INSTED®/Database for the free convection situations listed below, are based on a temperature difference of 30°C.

- vertical plate, 0.3 m (1 ft) high, in air
- horizontal cylinder, 5 cm diameter, in air
- horizontal cylinder, 2 cm diameter, in water

▸ Forced Convection

- airflow at 2.0 m/s, over a 0.2 m square plate
- airflow at 35.0 m/s, over a 0.75 m square plate
- air at 2.0 atmospheres flowing in a 2.5 cm diameter tube at 10.0 m/s
- water at 0.5 kg/s flowing in a 2.5 cm diameter tube
- airflow across a 5 cm diameter cylinder, at a velocity of 50 m/s

▸ Boiling Water

An approximate range for the heat transfer coefficients for boiling water is available in the INSTED®/Database for the following situations:

- in a pool or container
- flowing in a tube

▸ Condensation of Water Vapor at One Atmosphere

An approximate range for the heat transfer coefficients for the condensation of water vapor at one atmosphere is available in the INSTED®/Database for the following situations:

- vertical surfaces

- outside horizontal tubes

Shell and Tubes Heat Exchanger Systems

The ***Q/ΔT*** values, the cold side fluid, and the hot side fluid configurations for shell and tubes heat exchanger systems, that are available in the INSTED® /Database, are given below. Cost data is provided and is described in a subsequent section. The procedures to obtain overall U data and the cost data for concentric tube heat exchangers follow those for the shell and tubes heat exchanger system.

Options for *Q/ΔT*

The following options are available in the INSTED®/Database, where Q is the heat transfer rate and ***ΔT*** is the mean temperature difference:

- 1,000 W/K
- 5,000 W/K
- 30,000 W/K
- 100,000 W/K
- 1,000,000 W/K

Options for the Cold Stream

For each ***Q/ΔT*** option listed above, the following options are available for the cold side fluid:

- low-pressure gas (1 bar)
- high-pressure gas (20 bar)
- treated cooling water
- low-viscosity organic liquid
- high-viscosity liquid
- boiling water
- boiling organic liquid

Options for the Hot Stream

For each ***Q/ΔT*** option listed above, the following options are available for the hot side fluid:

- low-pressure gas (1 bar)
- high-pressure gas (20 bar)
- process water
- low-viscosity organic fluid
- high-viscosity liquid
- condensing steam
- condensing hydrocarbon
- condensing hydrocarbon with inert gas

9 Tube Counts

Introduction

A Shell and Tubes heat exchanger system consists of a cylindrical shell, which contains tube sheets. The tube sheets are used to hold tubes in position. Inlets and outlet nozzles are attached to the shell for the inflow and outflow of the shell fluid and the tube fluid. Baffles may be placed within the shell to direct the shell fluid flow around the tubes. The baffles are also used to support the tubes. Depending on the location of the inlet and outlet for the tube fluid, the tube fluid can be made to pass one or more times through the tubes. This is referred to as the number of tube passes. The tube pitch is the distance between adjacent tube centers. A square, triangular, rotated square, rotated triangular tube pitch configuration may be used, depending on how the tubes are positioned within the shell. The tube count specifies the maximum number of tubes that may be housed within a shell of a specified inner diameter, without significantly weakening the tube sheet.

The INSTED®/Database contains tube counts for shell and tubes heat exchanger systems, as a function of the tube outer diameter, the tube pitch type, the inner shell diameter, and the number of tube passes. Listings of the information required to determine the tube count, namely, the tube outer diameters, the pitch type, the inner shell diameters, and the number of tube passes that are available in the INSTED®/Database are provided in the next section.

INSTED®/Database Contents

Note: New information is added to INSTED®/Database on a regular basis. For updates or customized versions of the database, contact a Thaerocomp representative.

Outer Tube Diameters and Pitch Type

The outer tube diameters and pitch type configurations available in the INSTED®/Database are as follows:

- 3/4 in. outer tube diameter, 1 in. square pitch
- 1 in. outer tube diameter, 1 1/4 in. square pitch
- 3/4 in. outer tube diameter, 15/16 in. triangular pitch
- 3/4 in. outer tube diameter, 1 in. triangular pitch
- 1 in. outer tube diameter, 1 1/4 in. triangular pitch

Shell Inner Diameters

The following shell inner diameters are available in the INSTED®/Database:

- 8 in.
- 10 in.
- 12 in.
- 13 1/4 in.
- 15 1/4 in.
- 17 1/4 in.
- 19 1/4 in.
- 21 1/4 in.
- 23 1/4 in.
- 25 in.
- 27 in.
- 29 in.
- 31 in.

- 33 in.
- 35 in.
- 37 in.
- 39 in.

Tube Passes

The following tube passes are available in the INSTED®/Database for tube count:

- 1
- 2
- 4
- 6
- 8

10 Moody Chart

Introduction

The Moody Chart environment in INSTED®/Database is an important part of the internal flow analysis module. The calculation of a friction factor (which is accomplished in the Moody Chart environment) is required for the calculation of the pressure loss due to friction.

Graphs of data exist, which may be used to predict the friction factor as a function of the pipe relative roughness (ε /D) and Reynolds number (Re). These graphs are known as Moody Charts.

The methods used in INSTED® to calculate the friction factor and the way to access the friction factors are provided in this section. The data required from the user for the friction factor calculation is discussed next.

Data Required

In order to calculate the friction factor the following input are required:

- **absolute roughness:** This may be obtained from the Absolute Roughness task in the INSTED®/Database. See the chapter entitled 'Absolute Roughness'.
- **hydraulic diameter:** If the database is accessed online during an analysis, this value is passed directly by the calling module. If the database is used as a stand-alone module, you must provide this value. **Note: An equivalent diameter or an equivalent radius should not be used.**

- **Reynolds number:** If the database is accessed online during an analysis, this value is passed directly by the calling program. If the database is used as a stand-alone module you must provide this value when you are prompted for it.

Friction Factor Determination

For laminar flows, the Darcy-Weisbach equation is used to compute the friction factor, *f*. For turbulent flows, the friction factor is calculated using Colebrook's (non-linear) equation and Churchill's explicit formula. Colebrook's formula supposedly gives more accurate *f* values. However, its non-linearity may cause the solution to diverge or to behave unpredictably. INSTED® uses Newton-Raphson linearization. Churchill's formula is explicit, and has been known to give accurate predictions of *f* for a wide range of Reynolds numbers. When possible, INSTED® uses the three approaches mentioned above to compute *f*. The INSTED®/Database will also provide a suggested value for *f*. Therefore, you will have four options to choose from. The options are provided because of the non-linear dependence of *f* on Reynolds number and diameter.

For laminar flows, the Darcy-Weisbach formula is usually the best choice. In moderate to high Reynolds number flows, Churchill's formula often gives correct solutions. With Colebrook's approach, the results are probably not reliable if the number of Newton-Raphson iterations is low (i.e., one) or high (i.e., over one hundred). Finally, the *f* value should normally not exceed 0.1 for turbulent flows or go below 0.005 for both turbulent and laminar flows except for very smooth surfaces.

INSTED®/Database Contents

Note: New information is added to INSTED®/Database on a regular basis. For updates or customized versions of the database, contact a Thaerocomp representative.

Methods Used to Calculate the Friction Factor

The INSTED®/Database calculates the friction factor using the following three methods:

- Darcy-Weisbach (laminar flows)
- Colebrook (turbulent flows)
- Churchill (turbulent flows)

A wide range of Reynolds numbers, pipe diameters, and absolute roughness values may be used as input for the calculation. If input values are used which are not covered in the range provided by the database, a warning message will appear on the screen.

11 Radiation Properties

Introduction

The INSTED®/Database contains the following radiation properties:

1) Extinction coefficients of fluids, κ_t.
2) Scattering albedo of soots, ω_o.
3) Total normal emissivity of surfaces, ε_T.

Note that only the data in item (3) above is available to customers in the current version of INSTED/Database.

▸ Extinction Coefficients, κ_t

For the extinction coefficients of fluids, the INSTED®/Database uses the wide band modes to approximate the spectrum for a number of bands. A weighted average based on Planck's distribution is used to produce a scalar value for the extinction coefficients. This portion of the database requires the values of the temperature, the pressure, and the composition of the combustion gases. INSTED® will prompt you for this data.

▸ Scattering Albedo of Soot, ω_o

INSTED®/Database gives an equation for calculating the scattering albedo, ω_o, from combustion. Note that the combustion gases are non-scattering. Therefore, for the combustion gases, $\omega_o = 0$.

Total Normal Emissivity of Surfaces, ε_T

INSTED®/Database gives the total normal emissivity for various metals and their oxides and for various refractories, building materials, paints, and other miscellaneous surfaces. The emissivities are provided for a specified temperature or a temperature range.

Detailed listings of the materials, whose total normal emissivities are given in INSTED®/Database, are provided in the next section.

INSTED®/Database Contents

Note: New information is added to the INSTED®/Database on a regular basis. For updates or customized versions of the database, contact a Thaerocomp representative for assistance.

The INSTED®/Database contains the total normal emissivities for the following surfaces:

Metals and their Oxides

- Aluminum (highly polished plate, 98.3% pure; commercial sheet; rough polish; rough plate; oxidized at 600°C; heavily oxidized; aluminum oxide, 275°C-500°C; aluminum oxide, 500°C-825°C)
- Al-surfaced roofing
- Aluminum alloys (alloy 75 ST: A, B_1, C; alloy 75 ST: A^c; alloy 75 ST: $B^c{}_1$; alloy 75 ST: C^c; alloy 24 ST: A, B_1, C; alloy 24 ST: A^c; alloy 24 ST: $B^c{}_1$; alloy 24 ST: C_c)
- Calorized surfaces, heated at 600°C (Copper; Steel)
- Antimony, polished
- Bismuth, bright

Database

- Brass (highly polished: 73.2% Cu, 26.7% Zn; highly polished: 62.4% Cu, 36.8% Zn, 0.4% Pb, 0.3% Al; highly polished: 82.9% Cu, 17.0% Zn; polished: 100°C; polished: 40°C-315°C; rolled plate, natural surface; rolled plate, rubbed with coarse emery; dull plate; oxidized by heating at 600°C)
- Chromium (polished: 40°C-1100°C; polished: 100°C)
- Copper (carefully polished electrolytic copper; polished: 115°C; polished 100°C; commercial emeried, polished, pits remaining; commercial, scraped shiny, not mirror-like; plate heated long time, covered with thick oxide layer; plate heated at 600°C; cuprous oxide; molten copper)
- Dow metal (A, B_1, C; A^c; B^c_1; C^c)
- Gold, pure, highly polished
- Inconel (Types X and B: surface A, B_2,C; Type X: surface A^c; Type X: surface B^c_2; Type X: surface C^c; Type B: surface A^c; Type B: surface B^c_2; Type B: surface C^c)
- Iron and steel, not including stainless (**metallic surfaces, or very thin oxide layer:** electrolytic iron, highly polished; steel, polished; iron, polished; iron, roughly polished; iron, freshly emeried; cast iron, polished; cast iron, newly turned; cast iron, turned and heated; wrought iron, highly polished; polished steel casting; ground sheet steel; smooth sheet iron; mild steel: A, B_2, C; mild steel: A^c; mild steel: B^c_2; mild steel: C^c; **oxide surfaces**: iron plate, pickled, then rusted red; iron plate, completely rusted; iron, dark gray surface; rolled sheet steel; oxidized iron; cast iron, oxidized at 600°C; steel, oxidized at 600°C; smooth, oxidized electrolytic iron; iron oxide; rough ingot iron; sheet steel, strong, rough oxide layer; sheet steel, dense, shiny oxide layer; cast plate, smooth; cast plate, rough; cast iron, rough, strongly oxidized; wrought iron, dull oxidized; steel plate, rough; molten surfaces: cast iron; mild steel; steel, several different kinds with 0.25-1.2% C, slightly oxidized surface; steel, 1500°C-1650°C; steel, 1520°C-1650°C; pure iron; armco iron)

- Lead (pure, 99.96%, unoxidized; gray oxidized; oxidized at 150°C)
- Magnesium (magnesium oxide, 275°C-825°C; magnesium oxide, 900°C-1705°C; magnesium, polished)
- Mercury
- Molybdenum (filament; massive, polished; polished, 35°C-260°C; polished, 540°C-1370°C; polished, 2750°C)
- Monel metal (oxidized at 600°C; K monel 5700: A, B_2, C; K monel 5700: A^c; K monel 5700: $B^c{}_2$; K monel 5700: C^c)
- Nickel (electroplated, polished; technically pure, 98.9% Ni, Γ Mn, polished; polished; electroplated, not polished; wire; plate, oxidized by heating at 600°C; nickel oxide)
- Nickel alloys (chromnickel; copper-nickel, polished; nichrome wire, bright; nichrome wire, oxidized; nickel-silver, polished; nickelin, 18-32% Ni, 55-68% Cu, 20% Zn, gray oxidized; Type ACI-HW, 60% Ni, 12% Cr, smooth, black, firm adhesive oxide coat from service)
- Platinum (pure, polished plate; strip; filament; wire)
- Silver (polished, pure; polished, 40°C-370°C; polished, 100°C)
- Stainless steel (polished; Type 301: A, B_2, C; Type 301: A^c; Type 301: $B^C{}_2$; Type 301: C^c; Type 316: A, B_2, C; Type 316: A^c; Type 316: $B^C{}_2$; Type 316: C^c; Type 347: A, B_2, C; Type 347: A^c; Type 347: $B^C{}_2$; Type 347: C^c; Type 304: 8% Cr, 18% Ni, light silvery, rough, brown after heating; Type 304: 8% Cr, 18% Ni, after 42h heating at 525°C; Type 310: 25% Cr, 20% Ni, brown, splotched, oxidized from furnace service; Type 310: 25% Cr, 20% Ni, allegheny metal no. 4, polished; Type 310: 25% Cr, 20% Ni, allegheny alloy no. 66, polished)
- Tantalum filament
- Thorium oxide, 275°C-500°C; thorium oxide, 500°C-825°C
- Tin (bright tinned iron; bright; commercial tin-plated sheet iron)
- Tungsten (filament, aged; filament; polished coat)

- Zinc (commercial 99.1% pure, polished; oxidized by heating at 400°C; galvanized sheet iron, fairly bright; galvanized sheet iron, gray oxidized; zinc, galvanized sheet)

Refractories, Building Materials, Paints, and Miscellaneous

- Alumina (99.5-85%, Al_2O_3, 0-12% SiO_2, 0-1% Fe_2O_3)
  - Mean grain sizes (10µm; 50µm; 100µm)
- Alumina on Inconel
- Alumina-silica, showing effect of Fe (80-58% Al_2O_3, 16-38% SiO_2, 0.4% Fe_2O_3; 36-26% Al_2O_3, 50-60% SiO_2, 1.7% Fe_2O_3; 61% Al_2O_3, 35% SiO_2, 2.9% Fe_2O_3)
- Asbestos (board; paper)
- Brick (Red, rough, but no gross irregularities; grog brick, glazed; building; fireclay; white refractory)
- Carbon (filament; rough plate, 100°C-320°C; rough plate,320°C-500°C; graphite, 100°C-320°C; graphite, 320°C-500°C; candle soot; lampblack-waterglass coating, thin layer on iron plate; lampblack-waterglass coating, thick coat; lampblack, 0.075 mm or thicker; lampblack, rough deposit; lampblack, other blacks; graphite, pressed, filed surface)
- Carborundum (87% SiC, density 2.3 g/cm^3)
- Concrete tiles
- Concrete, rough
- Enamel, white fused, on iron
- Glass (smooth; pyrex, lead, and soda)
- Gypsum, 5mm thick on smooth or blackened plate)
- Ice (smooth; rough crystals)
- Magnesite refractory brick
- Marble, light gray, polished
- Paints, lacquers, varnishes (white enamel varnish on rough iron plate; black shiny lacquer, sprayed on iron; black shiny shellac on tinned iron sheet; black matte shellac; black or white lacquer; flat black lacquer; oil paints, 16 different

kinds, all colors; aluminum paints and lacquers, 10% Al, 22% lacquer body, on rough or smooth surface; aluminum paints and lacquers, other Al paints, varying age and Al content; aluminum paints and lacquers, Al lacquer, varnish binder, on rough plate; aluminum paints and lacquers, Al paint, after heating at 325°C; lacquer coatings, 0.025-0.37 mm thick on aluminum alloys; clear silicone vehicle coatings, 0.025-0.375 mm, on mild steel; clear silicone vehicle coatings, 0.025-0.375 mm, on stainless steels, 316, 301, 347; clear silicone vehicle coatings, 0.025-0.375 mm, on Dow metal; clear silicone vehicle coatings, 0.025-0.375 mm, on Al alloys 24 ST, 75 ST; aluminum paint with silicone vehicle, two coats on Inconel)

- Paper (white; thin, pasted on tinned or blackened plate; roofing)
- Plaster, rough lime
- Porcelain, glazed
- Quartz (rough, fused; glass, 1.98 mm thick; glass, 6.88 mm thick; opaque)
- Rubber (hard, glossy plate; soft, gray, rough, reclaimed)
- Sandstone
- Serpentine, polished
- Silica (98% SiO_2, Fe-free)
  - Grain sizes (10µm; 70-600µm)
- Silicon carbide
- Slate
- Soot, candle
- Water
- Wood (sawdust; oak, planed; beech)
- Zirconium silicate