Release Notes

INSTED Ver. 9.2

TTC TECHNOLOGIES, INC.

May 01, 2018

Release Features

INSTED Ver. 9.2

The latest version of INSTED (Ver. 9.2) includes the following four enhancements and one bug fix in INSTED 9.1.

I. New "Analytic" Mode for Custom J/F Data

- In previous versions of INSTED, you could only specify custom j/f data using discrete data that you enter in Excel as functions of the Reynolds number. One limitation of this approach is that the j/f data is provided only as functions of only the Reynolds number, and the data is usually valid for only one fin geometry. If you change the fin geometry parameters such as the fin type, fin height, fin pitch, etc., you may need to provide a new set of discrete j/f data.

- In INSTED 9.2, a new "Analytic" mode has been added to allow you to enter analytical expressions on your keyboard. The expressions can be functions of many pre-defined heat exchanger geometry and flow variables. For example, if you want to specify Dittus-Boelter's correlation for j:

$$Nu = j \cdot Re \cdot \mathrm{Pr}^{1/3} = 0.023 \cdot Re^{0.8} \cdot Pr^{0.4},$$

  you can simply type the following expression in the graphics user interface (GUI) using your keyboard:

  j =
```
0.023*[1]^0.8*[2]^0.4/[1]/([2]^(1.0/3.0))
```

  Above, the pre-defined variables [1] and [2] represent Reynolds number and Prandtl number, respectively. The list of the pre-defined variables can easily be found in the GUI, as well as in the manual for the interpreter.

- In "Analytic" mode, the equation syntax supports the most commonly used mathematical operators, intrinsic functions, and math constants. Relational operators are also supported if the j/f correlations are discontinuous. For example:

$$f = \begin{cases} \dfrac{16}{Re} & \text{when } Re < 2100 & \text{fully developed laminar flow} \\ 0.0054 + 2.3 \times 10^{-8} Re^{1.5} & \text{when } 2100 \le Re \le 4000 & \text{transition flow (Bhatti \& Shah)} \\ 0.0791 Re^{-0.25} & \text{when } 4000 < Re < 10^5 & \text{fully developed turbulent flow (Blasius)} \end{cases}$$

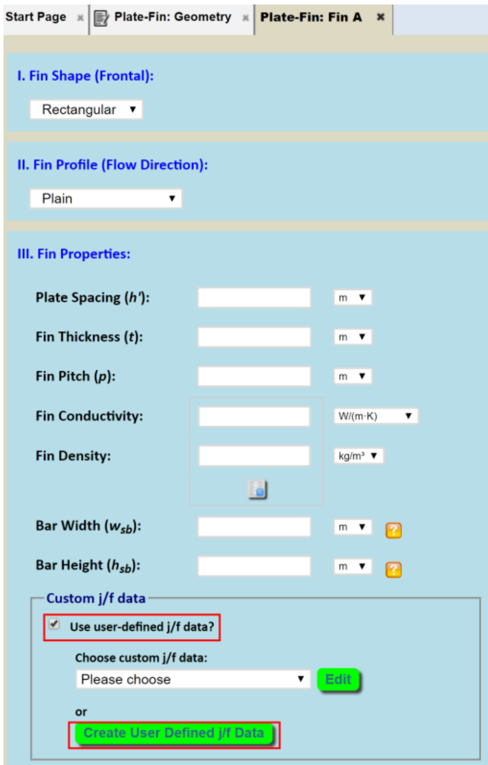
  can be typed in the GUI as:

  f =
```
([1] < 2100) ? (16 / [1]) : (([1] > 4000) ? (0.079 *
[1]^-0.25) : (0.0054 + 2.3e-8 * [1]^1.5))
```

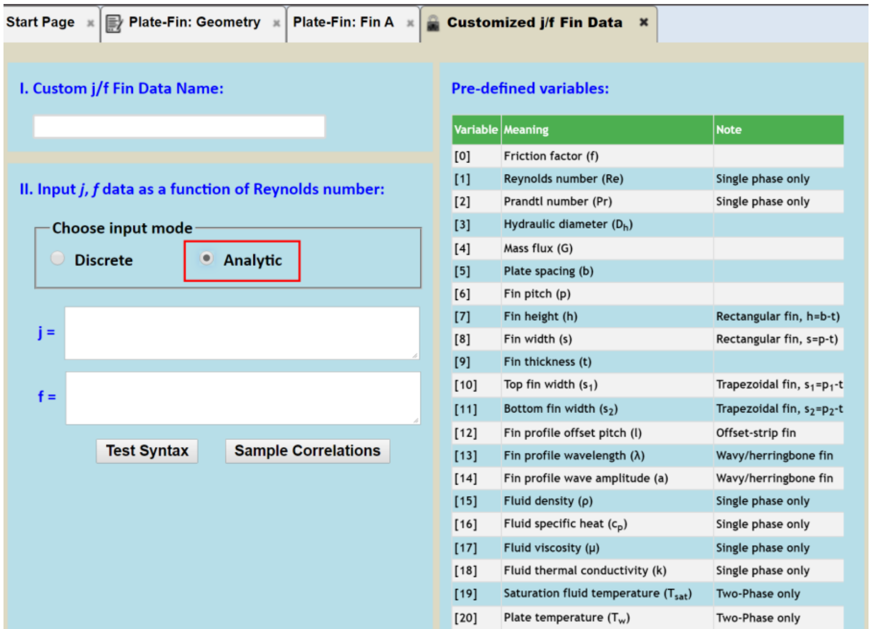
  The details of the syntax supported can be found in the "*Equation Interpreter Syntax Reference*"

- Follow the steps below to use the "Analytic" mode for custom j/f data:

  (1) In the Plate-Fin HEX geometry module, when defining the fin geometry, check the Check Box "Use User-Defined j/f Data?". Then click "Create User Defined j/f Data" button:



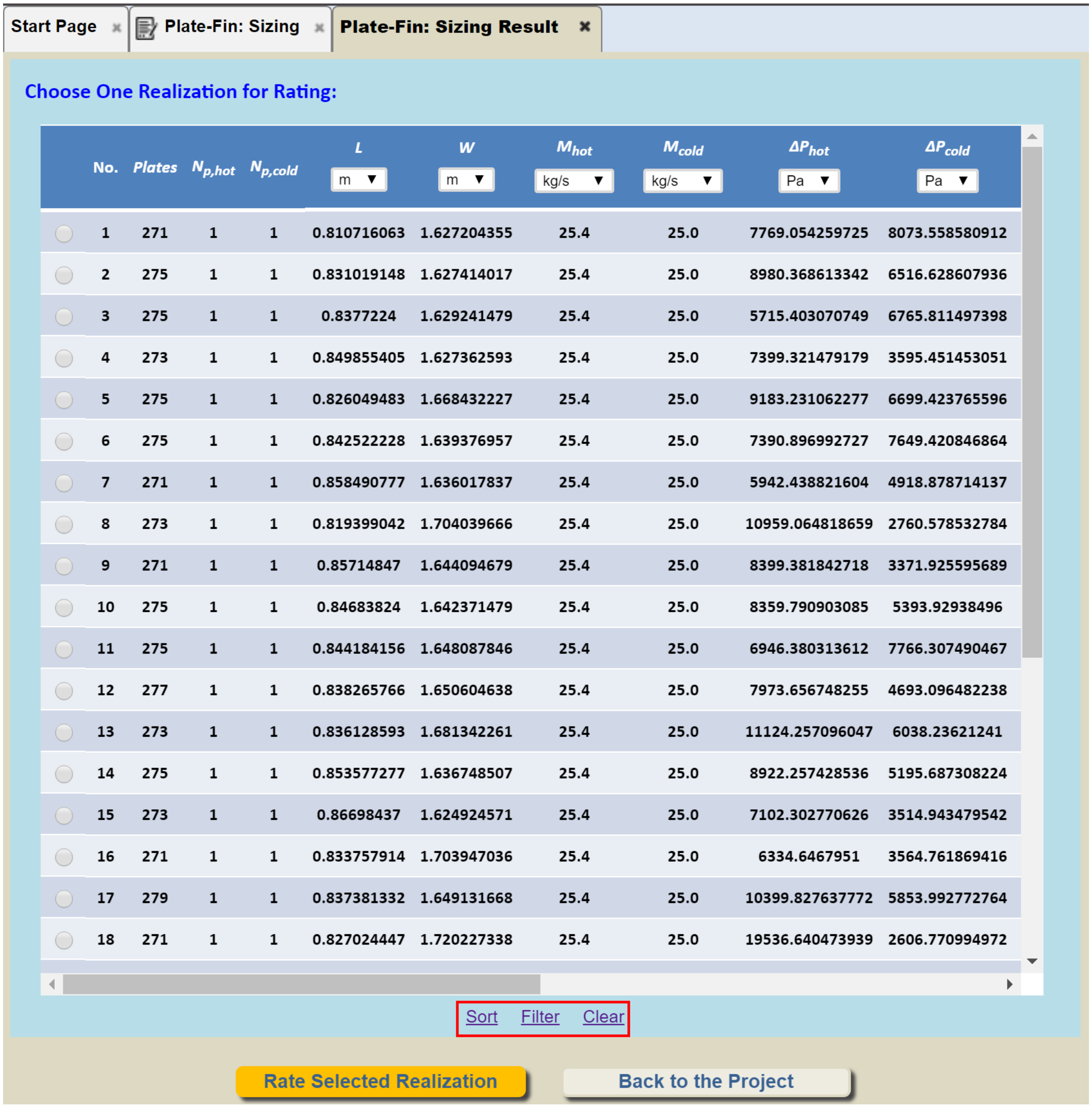
  (2) When the "Customized j/f Fin Data" tab has been opened, choose "**Analytic**" radio button in "Choose Input Mode".



(3) j and f equations can be typed into the textboxes. The list of the pre-defined variables (currently 35 of them) is shown on the right. Some sample j/f correlations can be found by clicking the "Sample Correlations" button to help you quickly get familiar with the math syntax. The j/f equations user input can be tested by clicking the "Test Syntax" button, to find out if an error has occurred.

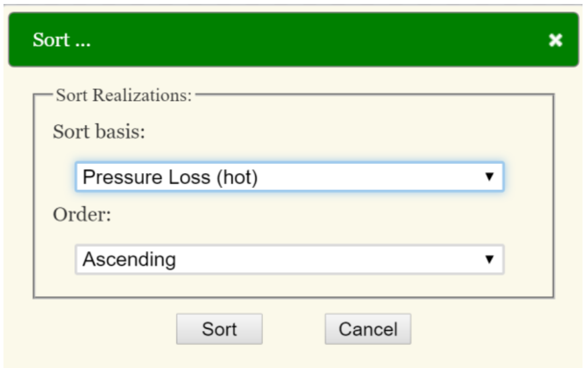
II. New "Sort/Filter" Capabilities for Sizing/Optimization Results

- In INSTED 9.2, the "Sort/Filter/Clear" buttons have been added under the table (below) of the possible realizations obtained from sizing/optimization analysis:



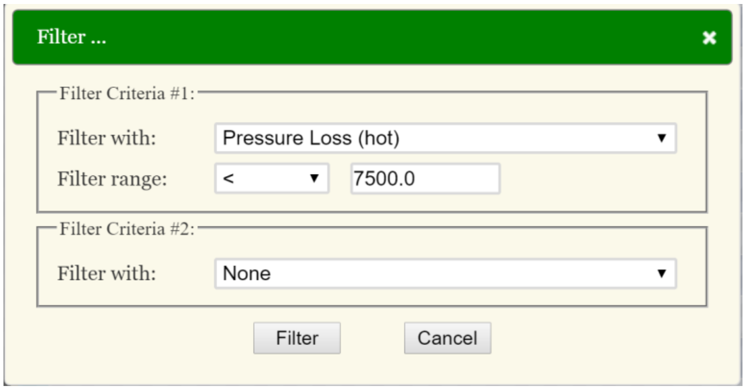
No.	Plates	$N_{p,hot}$	$N_{p,cold}$	L (m)	W (m)	M_{hot} (kg/s)	M_{cold} (kg/s)	ΔP_{hot} (Pa)	ΔP_{cold} (Pa)
1	271	1	1	0.810716063	1.627204355	25.4	25.0	7769.054259725	8073.558580912
2	275	1	1	0.831019148	1.627414017	25.4	25.0	8980.368613342	6516.628607936
3	275	1	1	0.8377224	1.629241479	25.4	25.0	5715.403070749	6765.811497398
4	273	1	1	0.849855405	1.627362593	25.4	25.0	7399.321479179	3595.451453051
5	275	1	1	0.826049483	1.668432227	25.4	25.0	9183.231062277	6699.423765596
6	275	1	1	0.842522228	1.639376957	25.4	25.0	7390.896992727	7649.420846864
7	271	1	1	0.858490777	1.636017837	25.4	25.0	5942.438821604	4918.878714137
8	273	1	1	0.819399042	1.704039666	25.4	25.0	10959.064818659	2760.578532784
9	271	1	1	0.85714847	1.644094679	25.4	25.0	8399.381842718	3371.925595689
10	275	1	1	0.84683824	1.642371479	25.4	25.0	8359.790903085	5393.92938496
11	275	1	1	0.844184156	1.648087846	25.4	25.0	6946.380313612	7766.307490467
12	277	1	1	0.838265766	1.650604638	25.4	25.0	7973.656748255	4693.096482238
13	273	1	1	0.836128593	1.681342261	25.4	25.0	11124.257096047	6038.23621241
14	275	1	1	0.853577277	1.636748507	25.4	25.0	8922.257428536	5195.687308224
15	273	1	1	0.86698437	1.624924571	25.4	25.0	7102.302770626	3514.943479542
16	271	1	1	0.833757914	1.703947036	25.4	25.0	6334.6467951	3564.761869416
17	279	1	1	0.837381332	1.649131668	25.4	25.0	10399.827637772	5853.992772764
18	271	1	1	0.827024447	1.720227338	25.4	25.0	19536.640473939	2606.770994972

- If you click the “Sort” button, a new dialog box will appear to enable you choose the field for which the list in the table should be ordered. For example, the following setting will order the list of realizations by hot stream pressure drop in ascending order:



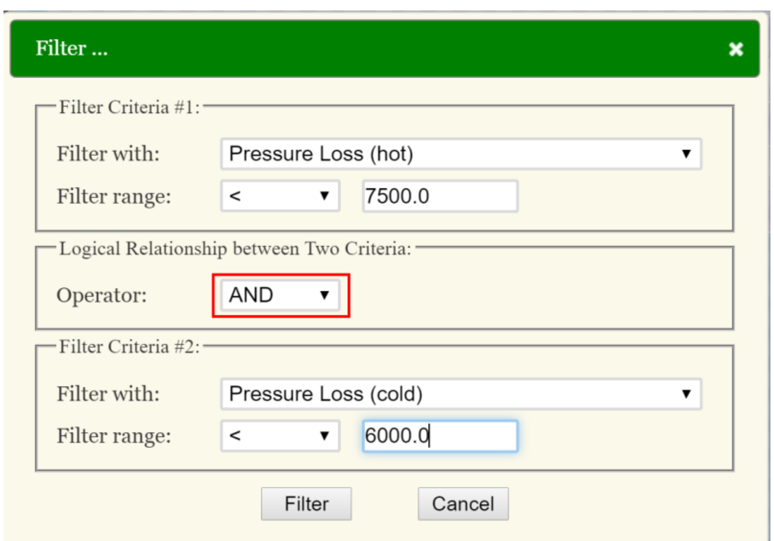
No.	Plates	$N_{p,hot}$	$N_{p,cold}$	L (m)	W (m)	M_{hot} (kg/s)	M_{cold} (kg/s)	ΔP_{hot} (Pa)	ΔP_{cold} (Pa)
3	275	1	1	0.8377224	1.629241479	25.4	25.0	5715.403070749	6765.811497398
7	271	1	1	0.858490777	1.636017837	25.4	25.0	5942.438821604	4918.878714137
27	271	1	1	0.859279963	1.666356581	25.4	25.0	6162.996553583	4681.977484485
25	271	1	1	0.832534785	1.717483063	25.4	25.0	6309.722165268	3438.135032869
16	271	1	1	0.833757914	1.703947036	25.4	25.0	6334.6467951	3564.761869416
11	275	1	1	0.844184156	1.648087846	25.4	25.0	6946.380313612	7766.307490467
15	273	1	1	0.86698437	1.624924571	25.4	25.0	7102.302770626	3514.943479542
6	275	1	1	0.842522228	1.639376957	25.4	25.0	7390.896992727	7649.420846864
4	273	1	1	0.849855405	1.627362593	25.4	25.0	7399.321479179	3595.451453051
30	271	1	1	0.859830913	1.668139042	25.4	25.0	7598.398144587	5415.810918932
21	271	1	1	0.867283203	1.645169037	25.4	25.0	7727.496655303	3798.572333389
1	271	1	1	0.810716063	1.627204355	25.4	25.0	7769.054259725	8073.558580912
12	277	1	1	0.838265766	1.650604638	25.4	25.0	7973.656748255	4693.096482238
22	275	1	1	0.856791838	1.641991539	25.4	25.0	8152.60041813	6868.838909232
10	275	1	1	0.84683824	1.642371479	25.4	25.0	8359.790903085	5393.92938496
9	271	1	1	0.85714847	1.644094679	25.4	25.0	8399.381842718	3371.925595689
29	273	1	1	0.866172901	1.642353637	25.4	25.0	8548.547812272	4999.735058987
23	273	1	1	0.852980764	1.662478217	25.4	25.0	8681.859237757	7240.373090178

- If you click the "Filter" button, a new dialog box will appear to enable you to set filter conditions. Only the realizations for which the filter conditions are satisfied will be displayed. For example, the following setting will cause the GUI to display only the realizations for which the hot stream pressure drop is smaller than 7500 Pa.



No.	Plates	$N_{p,hot}$	$N_{p,cold}$	L (m)	W (m)	M_{hot} (kg/s)	M_{cold} (kg/s)	ΔP_{hot} (Pa)	ΔP_{cold} (Pa)	W
3	275	1	1	0.8377224	1.629241479	25.4	25.0	5715.403070749	6765.811497398	3.15
7	271	1	1	0.858490777	1.636017837	25.4	25.0	5942.438821604	4918.878714137	3.14
27	271	1	1	0.859279963	1.666356581	25.4	25.0	6162.996553583	4681.977484485	3.16
25	271	1	1	0.832534785	1.717483063	25.4	25.0	6309.722165268	3438.135032869	3.15
16	271	1	1	0.833757914	1.703947036	25.4	25.0	6334.6467951	3564.761869416	3.13
11	275	1	1	0.844184156	1.648087846	25.4	25.0	6946.380313612	7766.307490467	3.13
15	273	1	1	0.86698437	1.624924571	25.4	25.0	7102.302770626	3514.943479542	3.14
6	275	1	1	0.842522228	1.639376957	25.4	25.0	7390.896992727	7649.420846864	3.1
4	273	1	1	0.849855405	1.627362593	25.4	25.0	7399.321479179	3595.451453051	3.1

- Note that in the current version of INSTED, a maximum **2 filter conditions** are allowed. You can choose the logical operation (AND or OR) between the two filter conditions. For example, the following settings will show only the realizations for which the hot stream pressure drop is smaller than 7500 Pa **and** the cold stream pressure drop is smaller than 6000 Pa.

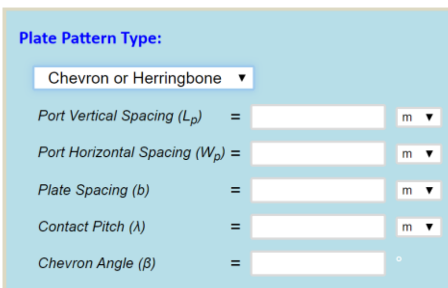


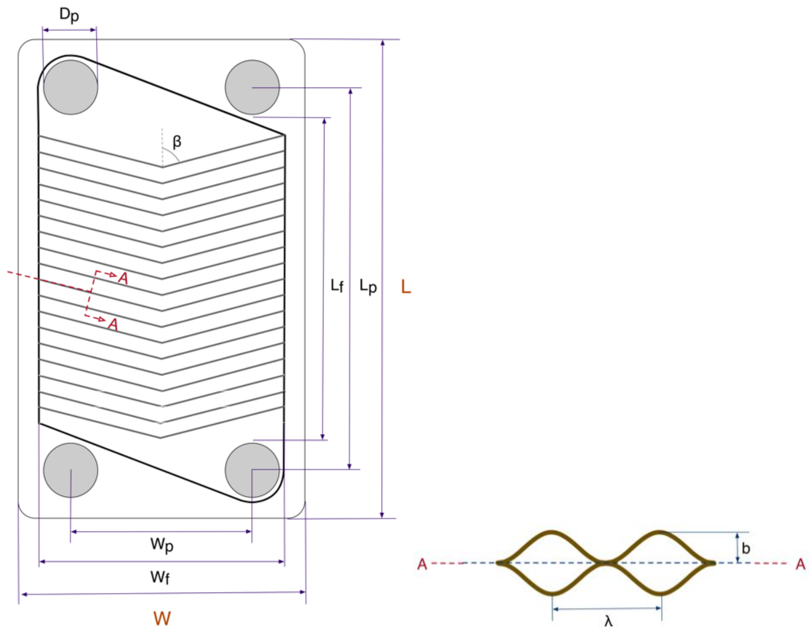
	No.	Plates	$N_{p,hot}$	$N_{p,cold}$	L (m)	W (m)	M_{hot} (kg/s)	M_{cold} (kg/s)	ΔP_{hot} (Pa)	ΔP_{cold} (Pa)	W
○	7	271	1	1	0.858490777	1.636017837	25.4	25.0	5942.438821604	4918.878714137	3.14
○	27	271	1	1	0.859279963	1.666356581	25.4	25.0	6162.996553583	4681.977484485	3.16
○	25	271	1	1	0.832534785	1.717483063	25.4	25.0	6309.722165268	3438.135032869	3.15
○	16	271	1	1	0.833757914	1.703947036	25.4	25.0	6334.6467951	3564.761869416	3.13
○	15	273	1	1	0.86698437	1.624924571	25.4	25.0	7102.302770626	3514.943479542	3.14
○	4	273	1	1	0.849855405	1.627362593	25.4	25.0	7399.321479179	3595.451453051	3.1

- By clicking the "Clear" button, the filter settings will be removed and the list of realizations will appear in the default order.

III. New Geometry Parameters to Define Chevron Corrugation in Plate-Frame Module

- In INSTED 9.1, for the Chevron/Herringbone type of plate corrugation in the Plate-Frame module, only overall "Plate Height (L)" and "Plate Width (W)" are the required inputs for the plate. To improve on the calculation of the heat transfer area, two new geometry parameters: "Port Vertical Spacing (L_p)" and "Port Horizontal Spacing (W_p)," have been added for both the hot and cold streams.





- With the above definition of L_p and W_p the heat transfer surface is defined by the dimensions:

$$L_f = L_p - D_p$$
$$W_f = W_p + D_p$$

where D_p is the port diameter.

IV. Port Pressure Loss has been added in Plate-Frame Module

- In INSTED 9.1, only the frictional pressure loss for the streams is accounted for. In INSTED 9.2, the port pressure loss has been added to the total pressure loss calculation.

V. Bug Fixes

- In the Plate-Fin Rating module, the flow inlet and outlet minor loss factors were not correctly read into the solver when the "Discrete" calculation method was used. (The bulk method does not have this problem.) This bug has been fixed in INSTED 9.2.

INSTED J/F Equation Interpreter Syntax Reference

Ver. 1.0

TTC TECHNOLOGIES, INC.

May 01, 2018

Introduction

The new INSTED Release (INSTED Version 9.2) allows you to provide your own custom data for the Colburn factor j and Fanning friction factor f by simply typing the analytical expressions for j and f directly on the keyboard of your computer during an INSTED session. INSTED can interpret (parse) the typed expressions and evaluate the j and f values inside the INSTED solver at runtime. This manual gives you the details of the syntax for the mathematical expressions and operators that the INSTED equation interpreter supports. The manual starts with the basic arithmetic operators supported. Then the concept of pre-defined variables will be introduced. The list of supported intrinsic functions is also given. Lastly, relational operations to support discontinuous equations will be presented.

Limitations of the INSTED Equation Interpreter

The limitations of the current INSTED equation interpreter are itemized below:

- Only real scalar numbers are supported. Complex numbers or matrices are not supported.
- All real number are treated as double precision in order to reduce truncation errors during analysis.
- The equation string must be a single line string. Multi-line strings are not supported.
- There is currently no limit on the length on the equation string.
- White spaces will be ignored.

Basic Arithmetic Operators

The following arithmetic operators are supported:

Operators	Explanation
+	Addition
-	Subtraction / Unary Subtraction
*****	Multiplication
/	Division
%	Modulus
^	Power

Scientific Notation

Scientific notation is supported. For example, -2.5×10^5 can be written as

$-2.5e5 \quad or \quad -2.5E5 \quad or \quad -2.5E+5 \quad or \quad -2.5E+05$, etc.

Math Constants

The following math constants are supported

Constants	Syntax
π constant	$pi \quad or \quad PI$
Euler's constant	$e \quad or \quad E$

Intrinsic Functions

The following intrinsic functions are supported:

Intrinsic Functions	Syntax			Note
Absolute value	$\mathrm{abs}(x)$	or	$ABS(x)$	
Power function	$\mathrm{pow}(x, y)$	or	$POW(x, y)$	
Exponential function	$\exp(x)$	or	$EXP(x)$	
Square root function	$\mathrm{sqrt}(x)$	or	$SQRT(x)$	
Sign function	$\mathrm{sign}(x)$	or	$SIGN(x)$	
Natural logarithm	$\log(x)$	or	$LOG(x)$	
Common logarithm (base 10)	$\log 10(x)$	or	$LOG10(x)$	
Sine function	$\sin(x)$	or	$SIN(x)$	x in radian
Cosine function	$\cos(x)$	or	$COS(x)$	x in radian
Tangent function	$\tan(x)$	or	$TAN(x)$	x in radian
Inverse sine function	$\mathrm{asin}(x)$	or	$ASIN(x)$	return value in radian
Inverse cosine function	$\mathrm{acos}(x)$	or	$ACOS(x)$	return value in radian
Inverse tangent function	$\mathrm{atan}(x)$	or	$ATAN(x)$	return value in radian
Hyperbolic sine function	$\sinh(x)$	or	$SINH(x)$	x in radian
Hyperbolic cosine function	$\cosh(x)$	or	$COSH(x)$	x in radian
Hyperbolic tangent function	$\tanh(x)$	or	$TANH(x)$	x in radian
Inverse hyperbolic sine function	$\mathrm{asinh}(x)$	or	$ASINH(x)$	return value in radian
Inverse hyperbolic cosine function	$\mathrm{acosh}(x)$	or	$ACOSH(x)$	return value in radian
Inverse hyperbolic tangent function	$\mathrm{atanh}(x)$	or	$ATANH(x)$	return value in radian

Pre-Defined Variables

The j/f correlations are usually functions of heat exchanger geometry and/or flow and heat transfer variables such as Reynolds number, Prandtl number, fin height, fin pitch, etc. In the INSTED equation interpreter, these variables are predefined in the form "$[i]$", where "i" is an integer. For example, in the Plate-Fin module, "[1]" represents Reynolds number and "[2]" represents Prandtl number. The complete list of pre-defined variables in the Plate-Fin module is presented in the table below:

Variable	Meaning	Note	Unit
[0]	Friction factor (f)	Some j correlations use f as one of arguments	-
[1]	Reynolds number (Re)	Single phase only	-
[2]	Prandtl number (Pr)	Single phase only	-
[3]	Hydraulic diameter (D_h)		$[m]$
[4]	Mass flux (G)		$[kg/(s\cdot m^2)]$
[5]	Plate spacing (b)		$[m]$
[6]	Fin pitch (p)		$[m]$
[7]	Fin height (h)	rectangular fin, $h = b - t$	$[m]$
[8]	Fin width (s)	rectangular fin, $s = p - t$	$[m]$
[9]	Fin thickness (t)		$[m]$
[10]	Top fin width (s_1)	trapezoidal fin only, $s_1 = p_1 - t$	$[m]$
[11]	Bottom fin width (s_2)	trapezoidal fin only, $s_2 = p_2 - t$	$[m]$
[12]	Fin profile offset pitch (l)	offset-strip fin only	$[m]$
[13]	Fin profile wavelength (λ)	wavy/herringbone fin only	$[m]$
[14]	Fin profile wave amplitude (a)	wavy/herringbone fin only	$[m]$
[15]	Fluid density (ρ)	single phase only	$[kg/m^3]$
[16]	Fluid specific heat (c_p)	single phase only	$[J/(kg\cdot K)]$
[17]	Fluid viscosity (μ)	single phase only	$[kg/(m\cdot s)]$
[18]	Fluid thermal conductivity (k)	single phase only	$[W/(m\cdot K)]$
[19]	Saturation fluid temperature (T_{sat})	two-phase only	$[K]$
[20]	Plate temperature (T_w)	two-phase only	$[K]$
[21]	Saturation fluid pressure (P_{sat})	two-phase only	$[Pa]$
[22]	Liquid phase fluid density (ρ_l)	two-phase only	$[kg/m^3]$
[23]	Liquid phase fluid specific heat $(c_{p,l})$	two-phase only	$[J/(kg\cdot K)]$
[24]	Liquid phase fluid viscosity (μ_l)	two-phase only	$[kg/(m\cdot s)]$
[25]	Liquid phase fluid thermal conductivity (k_l)	two-phase only	$[W/(m\cdot K)]$
[26]	Gas phase fluid density (ρ_g)	two-phase only	$[kg/m^3]$
[27]	Gas phase fluid specific heat $(c_{p,g})$	two-phase only	$[J/(kg\cdot K)]$
[28]	Gas phase fluid viscosity (μ_g)	two-phase only	$[kg/(m\cdot s)]$
[29]	Gas phase fluid thermal conductivity (k_g)	two-phase only	$[W/(m\cdot K)]$
[30]	Surface tension (σ)	two-phase only	$[N/m]$
[31]	Critical pressure (p_{crit})	two-phase only	$[Pa]$
[32]	Heat of vaporization (h_{lg})	two-phase only	$[J/kg]$
[33]	Local quality (x)	two-phase only	-
[34]	Boiling number (Bo)	two-phase only	-
[35]	Martinelli parameter (X_{tt})	two-phase only	-

Conditional Expressions

In INSTED, conditional expressions are in the form:

$$(logic\ condition)\ ?\ a: b$$

If the $logic\ condition$ is true, the conditional expression returns the value of a, else, the condition expression returns the value of b.

For example: The following expression

$$(\sin(PI/4) > 0.5)\ ?\ -1: 0.5$$

will return value of -1.

Boolean Operators

The following Boolean operators are supported

Boolean Constants	Syntax
True	$true$ or $TRUE$
False	$false$ or $FALSE$

Relational Operators

The following relational operators are supported:

Comparators	Explanation
>	larger than
>=	larger than or equal to
<	smaller than
<=	smaller than or equal to
==	equal to
!=	not equal to

Logical Operators

The following logical operators are supported:

Logical Relations	Explanation
&&	logic AND
||	logic OR
!	logic NOT

For example, the following expression

$$!\,(\sin(PI/4) > 0.5\ ||\ \cos(0)\ == 1)\ ?-1 : 0.5$$

will return 0.5.

More Examples

1. Dittus-Boelter correlation for j:

$$Nu = j \cdot Re \cdot \mathrm{Pr}^{1/3} = 0.023 \cdot Re^{0.8} \cdot Pr^{0.4}$$

In INSTED, the following expression can be typed on the keyboard for j:

j =
```
0.023*[1]^0.8*[2]^0.4/[1]/([2]^(1.0/3.0))
```

2. The correlations by Manglik and Bergles (1995) for j and f (offset-strip fin):

$$\begin{aligned} j &= 0.6522 Re^{-0.5403} \alpha^{-0.1541} \delta^{0.1499} \gamma^{-0.0678} \times \\ &\quad (1 + 5.269 \times 10^{-5} Re^{1.34} \alpha^{0.504} \delta^{0.456} \gamma^{-1.055})^{0.1} \end{aligned}$$

$$\begin{aligned} f &= 9.6243 Re^{-0.7422} \alpha^{-0.1856} \delta^{0.3053} \gamma^{-0.2659} \times \\ &\quad (1 + 7.699 \times 10^{-8} Re^{4.429} \alpha^{0.92} \delta^{3.767} \gamma^{0.236})^{0.1} \end{aligned}$$

where

$$\alpha = \frac{s}{h}, \ \delta = \frac{t}{l}, \ \gamma = t/s$$

In INSTED, the following expressions can be typed on the keyboard for the above correlations for j and f:

j =
```
0.6522*[1]^(-0.5403)*([8]/[7])^(-0.1541)*
([9]/[12])^0.1499*([9]/[8])^(-0.0678)*(1.0+5.269e-5*
[1]^1.34*([8]/[7])^0.504*([9]/[12])^0.456*
([9]/[8])^(-1.055))^0.1
```

f =
```
9.6243*[1]^(-0.7422)*([8]/[7])^(-0.1856)*
([9]/[12])^0.3053*([9]/[8])^(-0.2659)*(1.0+7.699e-8*
[1]^4.429*([8]/[7])^0.92*([9]/[12])^3.767*
([9]/[8])^0.236)^0.1
```

3. Discontinuous function example:

$$f = \begin{cases} \dfrac{16}{Re} & \text{when } Re < 2100 & \text{fully developed laminar flow} \\ 0.0054 + 2.3 \times 10^{-8} Re^{1.5} & \text{when } 2100 \le Re \le 4000 & \text{transition flow (Bhatti \& Shah)} \\ 0.0791 Re^{-0.25} & \text{when } 4000 < Re < 10^5 & \text{fully developed turbulent flow (Blasius)} \end{cases}$$

In INSTED, the following can be typed on the keyboard for f:

f =
```
([1] < 2100) ? (16 / [1]) : (([1] > 4000) ? (0.079 *
[1]^-0.25) : (0.0054 + 2.3e-8 * [1]^1.5))
```

Reference

Manglik, R. M. and Bergles, A. E. "Heat Transfer and Pressure Drop Correlations for the Rectangular Offset-Strip-Fin Comact Heat Exchangers," Experimental Thermal and Fluid Science, Vol. 10, 1995, pp. 171-180