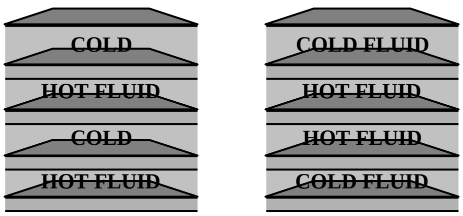
PLATE-FIN HEAT EXCHANGER PROBLEMS

Introduction

The problems that have been used to validate some of the capabilities in INSTED for the analysis of plate-fin heat exchanger are discussed in this chapter. You should consult the original sources of the various test problems in order to assess the accuracy of INSTED predictions in more detail. These sources are given, as are a few notes to aid you in your comparison exercise. You will be expected to have simulated some of these test problems before you attempt to solve more realistic engineering problems.

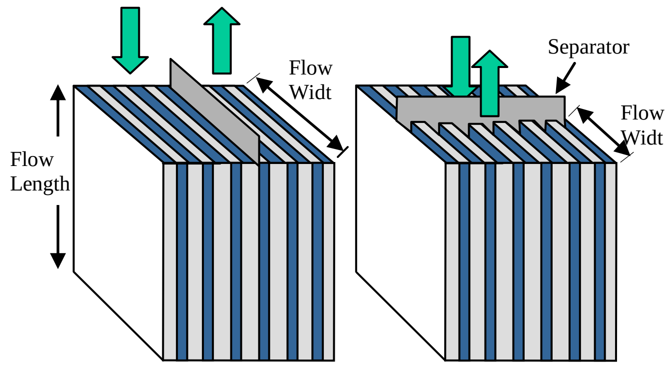
Illustration of some of the Input in INSTED



(a) Single Banking Flow

(b) Double Banking Flow Arrangement

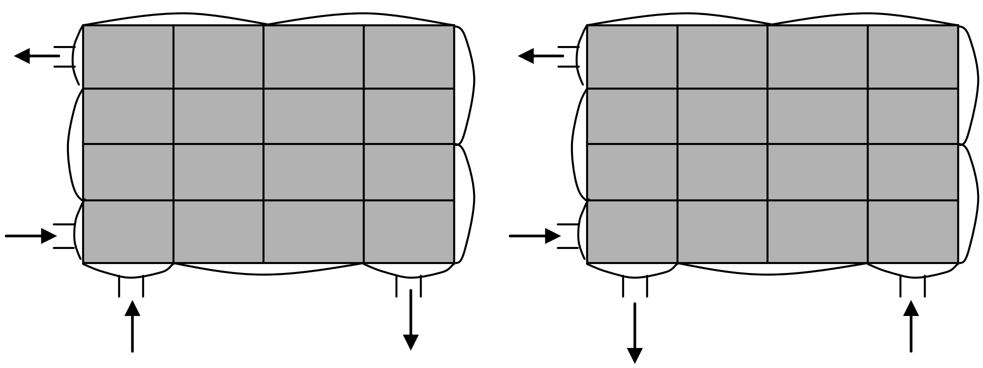
Figure 1. Stream Pair Stacking Arrangements



(a) Two partitions in core

(b) Two-pass flow in core

Figure 2. Core Partitioning and Pass



(a) Cross-Parallel Flow

(b) Cross-Counter Flow

Figure 3. Some of the Flow Arrangements in INSTED Arrangements

SAMPLE PROBLEM 1

research.inp

This test problem is designed to illustrate the use of INSTED/Plate-Fin program to compute single-phase problems with temperature-dependent thermophysical properties and with partitioning of the plates.

- **Problem Statement:**

The hot fluid is a military spec light hydraulic oil with thermophysical properties (density, specific heat, viscosity, etc,) given at a fixed temperature. The cold fluid is air, which is selected from the database. The program continuously uses the air properties at the prevalent temperatures during analysis.

The plates are 0.016″ thick and are made of Aluminum. The thermal conductivity is obtained from INSTED/Database as 179 Btu/hft^{o}F.

	Hot Side	**Cold Side**
Flow rate (lb/min)	42.3164	58.3
Number of partitions	2	1
Number of passages	12	13
Flow length (inches)	1.6	7.752
Separator bar thickness (inches)	0.185	0.185
Passage width	Calculated by program	Calculated by program
Inlet temperature (^{o}F)	227.57	81.03
Density (lb/ft^3)	57.6	From Database for Air
Specific heat (BTU/lb^{o}F)	0.5042	From Database for Air
Conductivity (BTU/hr-ft^{o}F)	0.0732	From Database for Air
Viscosity (lb/hr-ft)	10.342	From Database for Air
Fin type	Triangular serrated profile	Triangular serrated profile
Fin pitch (inches)	0.357	0.0833
Fin height (inches)	0.126	0.42
Fin thickness (inches)	0.006	0.006
Fin material conductivity	Same as for plate	Same as for plate

- **Source:**

Proprietary.

- **Comments**

- In INSTED, choose the “Performance Analysis” task from the ‘Problem Description’ dialog box.
- Select the “Cross counter flow” arrangement from the ‘Problem Description’ dialog box.
- Select “single-banking” plate arrangement and deselect “two-phase” flow calculation from the ‘Problem Description’ dialog box.
- Change the global units to the British system from the Main dialog box.
- Enter process-related data in the ‘Process Condition’ dialog box. This includes all data except the last five items in the above input table.
- Open the ‘Fin Properties’ dialog box from the Main dialog box and enter fin and plate data which are the last five items in the above table..
- Click the “Database” button beside the input for plate conductivity to select the conductivity for the plate material from the database. You could also enter the exact value.
- Press the “Compute” button.
- View the plots and the ALPEMA sheet for the results.

- Name of data file:
  research.inp
- **Comparison of INSTED result with source**

	INSTED	**Source**
Heat transfer rate (Btu/hr)	34628	34855.7
Effectiveness	0.28085	0.28
Δp warm (psi)	0.0156	
Δp cold (psi)	9.486	

SAMPLE PROBLEM 2

twophase.inp

This test problem is designed to illustrate the use of INSTED/Plate-Fin program to compute two-phase problems. The thermophysical properties of the two-phase fluid are obtained from the database. This problem also illustrates the use of INSTED to calculate multi-pass plate-fin exchanger.

- **Problem Statement:**

The hot fluid is a proprietary fluid with thermophysical properties (density, specific heat, viscosity, etc,) given at a fixed temperature. The cold fluid is R134a. This fluid is selected from the database. The program obtains the thermophysical properties for R134a at the prevailing temperatures during execution.

The plates are 0.016″ thick and are made of Aluminum. The thermal conductivity is obtained from INSTED/Database as 179 Btu/hft^{o}F. The flow arrangement is cross counter-current.

	Hot Side	**Cold Side**
Flow rate (lb/min)	139.3	2.6
Number of passes	2	4
Number of passages	20	44
Flow length (inches)	2.25	9
Separator bar thickness (inches)	0.125	0.125
Passage width	Calculated by program	Calculated by program
Inlet temperature (^{o}F)	21	14
Density (lb/ft^{3})	113.5	From Database for R134a
Specific heat (BTU/lb^{o}F)	0.215	From Database for R134a
Conductivity (BTU/hr-ft^{o}F)	0.0381	From Database for R134a
Viscosity (lb/hr-ft)	11	From Database for R134a
Inlet Quality	Single-phase (entered as 0%)	10% (entered as 0.1)
Fin type	Triangular serrated profile	Triangular serrated profile
Fin pitch (inches)	0.0555	0.0555
Fin height (inches)	0.086	0.086
Fin thickness (inches)	0.006	0.006
Fin material conductivity	Same as for plate	Same as for plate

➢ **Source:**
Proprietary (from a valued INSTED customer).

➢ **Comments**

- In INSTED, choose the "Performance Analysis" task from the 'Problem Description' dialog box.
- Select the "Cross counter-flow" arrangement from the 'Problem Description' dialog box.
- Deselect "single-banking" plate arrangement. Also select the "two-phase" flow calculation option from the 'Problem Description' dialog box.
- Change the global units to the British system from the Main dialog box.
- Enter process-related data in the 'Process Condition' dialog box. This includes all data except the last five items in the above table, which go into the 'Fin Properties' dialog box.
- Open the 'Fin Properties' dialog box from the Main dialog box and enter fin and plate data.
- Click the "Database" button beside the input for plate conductivity to select the conductivity for the plate material from the database. You could also enter the exact value.
- Compute
- Check plots and ALPEMA sheet to analyze results.

➢ **Comparison of INSTED result with source**

The heat transfer rate calculated with INTED/Plate-Fin is 9878.8 Btu/hr, whereas in the source the target heat load was specified as 10,000 Btu/hr.

♦ Name of data file:
Twophase.inp

SAMPLE PROBLEM 3

hewitt.315

This test problem is designed to illustrate the use of INSTED/Plate-Fin program to compute single-phase problems with thermophysical properties obtained at a single, representative temperature.

➢ **Problem Statement:**
A cross flow plate-fin heat exchanger is designed for the gas turbine cycle illustrated in the table below. It uses heat form the turbine exhaust gases at 460^{o}C to preheat air leaving the compressor at 300^{o}C. The flow rates of gas and air are respectively, 25.0 and 25.4 kg/s, and the dimensions of the heat exchanger are as shown in the figure. What are the temperatures of air and gas leaving the heat exchanger and what are the corresponding pressure drops for the two streams?

	Warm Stream	**Cold Stream**
Density (kg/m^3)	0.54	4.86
Specific heat (J/kg^K)	1060	1060
Viscosity (kg/ms)	0.000032	0.000032
Conductivity (W/mK)	0.05	0.05
Flow Length (m)	0.9	1.8
Number of passages/passes	150/1	150/1

Plate thickness (m)	0.0003	0.0003
Plate conductivity (W/mK)	150	150
Fin type	Plain Rectangle	Plain Rectangle
Fin pitch (m)	0.002	0.002
Fin height (m)	0.0057	0.0057
Fin thickness (m)	0.00015	0.00015
Fin material conductivity (W/mK)	Same as for plate	Same as for plate

➢ **Source:**

Hewitt, G. F., Shires, G. L., Bott, T. R. Process Heat Transfer, CRC Press. 1998. Pages 321-323.

➢ **Comments**

- In INSTED, choose the "Performance Analysis" task.
- The gas is the hot fluid while air is the cold fluid in the 'Process Condition' dialog box.
- Enter the thermophysical properties for both the hot and cold fluids as given above in the 'Process Condition' dialog box.
- Enter the fin properties including the pitch, height, thickness and fin type in the 'Fin Properties' dialog box.

➢ **Comparison of INSTED result with source**

In the table below, 'c' refers to the cold fluid while 'h' refers to the hot fluid.

Variable	**Hewitt**	**INSTED**	**Difference**
Velocity (h) (m/s)	33.90	33.935	< 1%
Velocity (c) (m/s)	7.42	7.422	< 1%
Δp (h) (Pa)	6845	6862	< 1%
Δp (c) (Pa)	4337	4321	< 1%
Friction factor (h)	0.0164	0.016396	< 1%
Friction factor (c)	0.0122	0.0121709	< 1%
Re(h)	1590	1589.1	< 1%
Re(c)	3130	3128.1	< 1%
Heat trasfer coeff. (h)	129	127.77	< 1%
Heat trasfer coeff. (c)	209	208.068	< 1%
U (W/m^{2}K)	239	233.49	< 1%
Q (W)	3.10×10^6	3.1226×10^6	< 1%
Mean Temp. Diff. (K)	27	27.52	< 1%
Temp. out (h) (K)	618	617.18	< 1%
Temp. out (c) (K)	690	690.99	< 1%

Explanation of differences in results

- Agreement between the two sets of results is apparent. The largest difference is observed in the pressure drop, which is due to the differences in the methods used for calculating the friction factor. The source uses simple equations for j & f calculations. These equations are a function only of Reynolds number. INSTED uses a more complete equation which is a function of Reynolds number and the fin geometry.
- Differences in the heat transfer coefficient result from the fact that INSTED allows for the thermal conductivity of the plate material, which is neglected in the source. This difference also affects the values obtained for Q, U, and the outlet temperatures.

- Name of data file:
  hewitt.315

SAMPLE PROBLEM 4

che.510

This problem involves the use of INSTED/Plate-Fin program to compute single-phase problems with thermophysical properties obtained at a single, representative temperature. The *j* and *f* factors in the source are obtained from performance charts of the fins while INSTED computes them using generalized equations (Note that INSTED also allows the user to specify *j* and *f* data, such as those obtained from charts).

- **Problem Statement:**

A gas-to-air, single-pass, cross-flow heat exchanger has overall dimensions of 0.3m x 0.6m x 0.898m. Plain triangular fins and strip fins are employed on the gas and air, respectively. The table below shows the thermophysical properties, geometry, and surface characteristics. Both the fins and plates (parting sheets) are made from Aluminum with k = 190 W/mK. The plate thickness is 0.4mm. The gas (process air) flows in at 1.2 m^3/s and 240^{o}C. The makeup air on the other side flows in at 0.6 m^3/s and 4^{o}C. Both fluids are at 110 kPa inlet pressure. Determine the heat transfer rate, outlet fluid temperatures and pressure drops on each side. Use properties of air for the gas (process air).

	Warm Stream	**Cold Stream**
Density (kg/m^3)	0.7468	1.3827
Specific heat (J/kgK)	1022	1013
Viscosity (kg/ms)	0.0000241	0.0000214
Conductivity (W/mK)	0.03385	0.03132
Flow Length (m)	0.3	0.6
Number of passages/passes	66/1	67/1
Fin type	Wavy with plain profile	Rectangular serrated profile
Fin pitch (m)	0.0012776	0.001626
Fin height (m)	0.00635	0.00635
Fin thickness (m)	0.000152	0.006
Offset (m)		0.00318
Fin material conductivity (W/mK)	Same as for plate	Same as for plate

- **Source:**

Shah, K. R.. Compact Heat Exchanger Design Procedures. Pages 495-535.

- **Comments**
  - In INSTED, choose the “Performance Analysis” task.
  - The process air is the hot fluid while air is the cold fluid.

- Enter in the ‘Process Condition’ dialog box the thermophysical properties for both the hot and cold fluids as given above.
- Enter the fin properties including the pitch, height thickness and fin type in the ‘Fin Properties’ dialog box.

- **Comparison of INSTED result with source**

  In the table below, ‘c' refers to cold fluid property or result while ‘h' refers to hot fluid result.

Variable	**CHE**	**INSTED**	**Difference**
Colburn factor (h)	0.013	0.0126913	2.3%
Colburn factor (c)	0.017	0.0163615	3.8%
Δp (h) (Pa)	321	261.66	18.5%
Δp (c) (Pa)	1672	1311.4	22%
Friction factor (h)	0.055	0.025	54%
Friction factor (c)	0.065	0.0653	< 1%
Re(h)	321	376.96	17.4%
Re(c)	786	829.77	5.57%
Heat trasfer coeff. (h) (W/m^2K)	70.44	79.79	13.27%
Heat trasfer coeff. (c) (W/m^2K)	154.82	156.6	1.1%
UA (W/K)	6259	6608.5	5.5%
Q (W)	160,100	162,030	1%
NTU	7.45	7.864	5.5%
Temp. out (h) (K)	338.35	336.25	< 1%
Temp. out (c) (K)	467.65	469.96	< 1%

Explanation of differences in results

- Agreement between the two sets of results is apparent. The largest difference is observed for the pressure drop, which is due to the differences in the values of the Reynolds number. INSTED uses a more accurate geometric formula for calculating the Reynolds number. Secondly, in the source, a correction is made for the effect of variable material property while, INSTED calculation was set up to use fixed thermophysical properties for this sample problem.
- Differences in the heat transfer coefficient results from the fact that INSTED allows for the thermal conductivity of the plate material. This contribution is neglected in the source. This difference also affects the values obtained for *Q*, *U* and the outlet temperatures.

- Name of data file:
  che.510