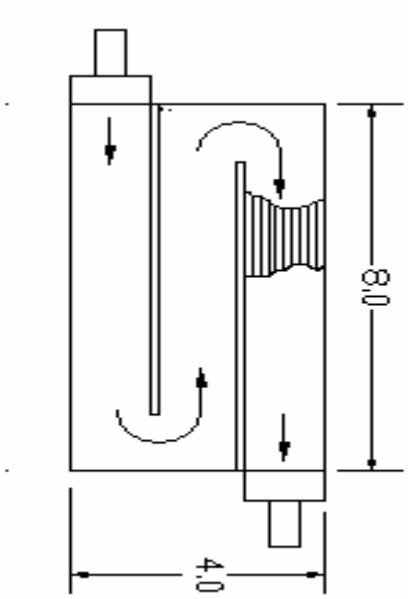
Serpentine Example

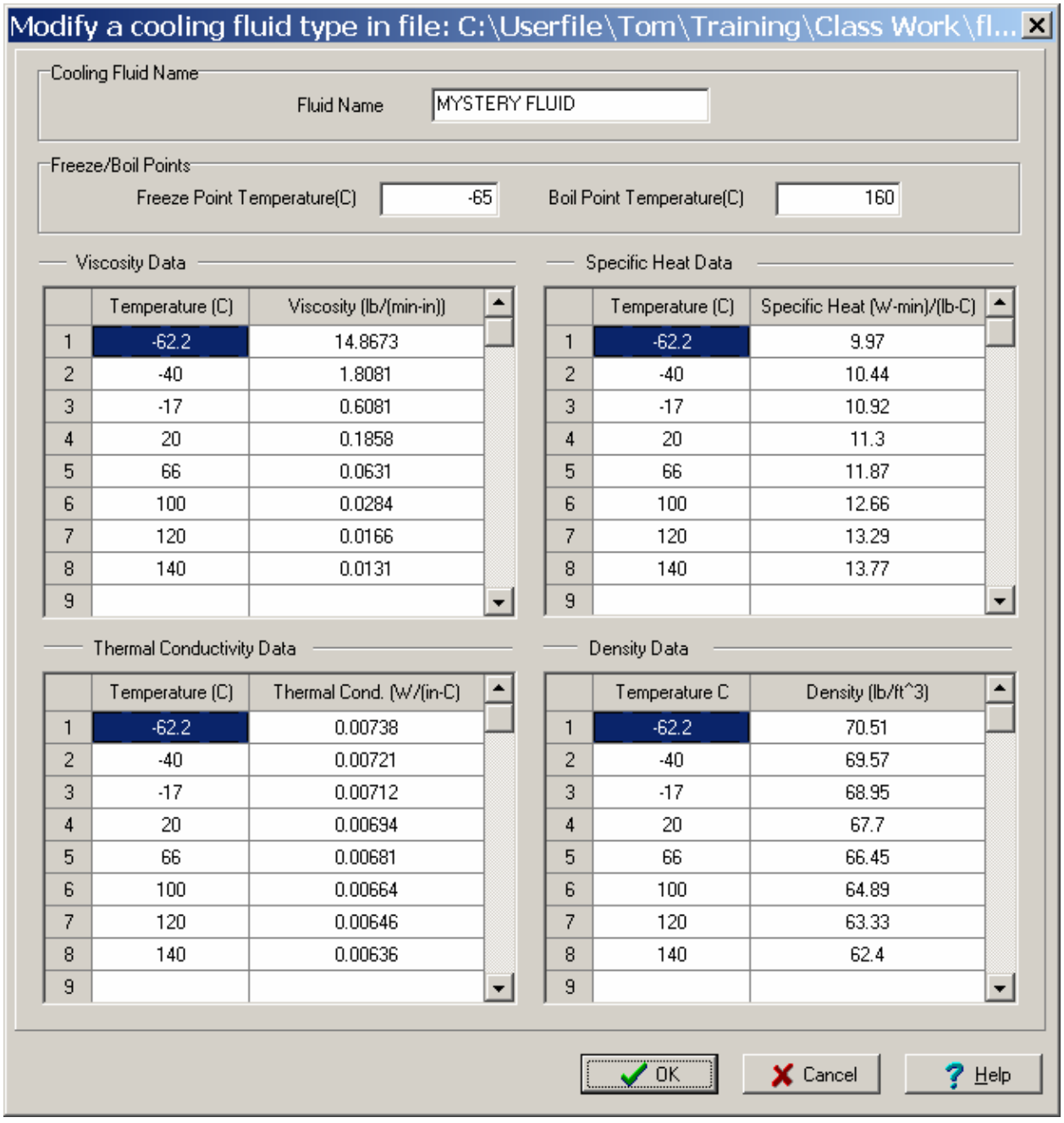
This example builds a model of a 3 pass (serpentine) cold plate shown below. The example demonstrates how to add a new cooling fluid and how to account for the added pressure drop of cooling lines and quick disconnects that are attached to cold plate. In addition, this example accounts for heat infiltration from an external environment. The cold plate design parameters are listed below:

- Add the cooling fluid listed in the table below.
- The aluminum cold plate has 3003 aluminum fins with a .062 thick 6061-T6 thick base and .04 thick cover.
- The fin style is ¼-11.1 (interrupted - lanced and offset), they are .375 and 10 fins per inch and .006 inches thick.
- Inlet fluid temperature is 37 at 60 PSI and 1.8lb/min.
- The surrounding air temperature is 150C with an effective forced convection coefficient of h=.018W/(in^2-C).
- Assume for now, 500 Watts of power is uniformly dissipation on the cold plate base.
- There is 36 inches of 3/8 coolant tubing prior to the quick disconnect which has an effective loss coefficient of 3.6. There is a quick disconnect at either end. Account for the 36 inches of tubing.

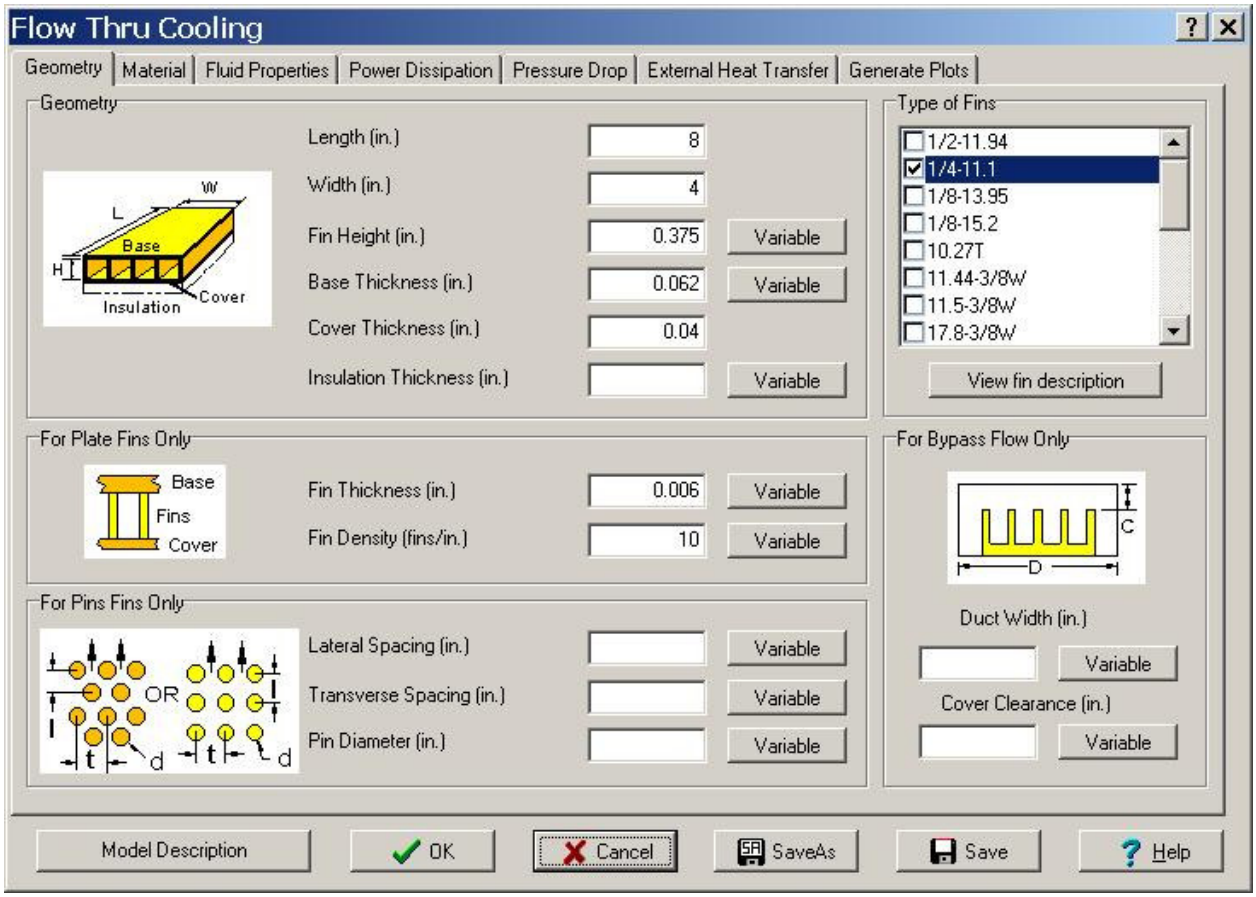


	Mystery Fluid									
Temp F	Temp C	Kinematic Viscosity cSt	Specific Gravity	Density lb/ft^3	Abosolute (dynamic) Viscosity - Centistokes	Absolute (dynamic) Viscosity - lb/(in-min)	Thermal Conductivity BTU/(hr-ft-F)	Thermal Conductivity W/(in-C)	Specific Heat (BTU/(lb-F)	Specific Heat W-Min/(lb-C)
-80	-62.2	5000	1.13	70.51	4424.78	14.8673	0.1680	0.00738	0.315	9.97
-40	-40.0	600	1.115	69.57	538.12	1.8081	0.1640	0.00721	0.330	10.44
-17	-27.2	200	1.105	68.95	181.00	0.6081	0.1620	0.00712	0.345	10.92
20	-6.7	60	1.085	67.70	55.30	0.1858	0.1580	0.00694	0.357	11.30
66	18.9	20	1.065	66.45	18.78	0.0631	0.1550	0.00681	0.375	11.87
100	37.8	8.8	1.04	64.89	8.46	0.0284	0.1510	0.00664	0.400	12.66
120	48.9	5	1.015	63.33	4.93	0.0166	0.1470	0.00646	0.420	13.29
140	60.0	3.9	1	62.40	3.90	0.0131	0.1446	0.00636	0.435	13.77
				Flash Point = 160C		Pour Point = -65C				

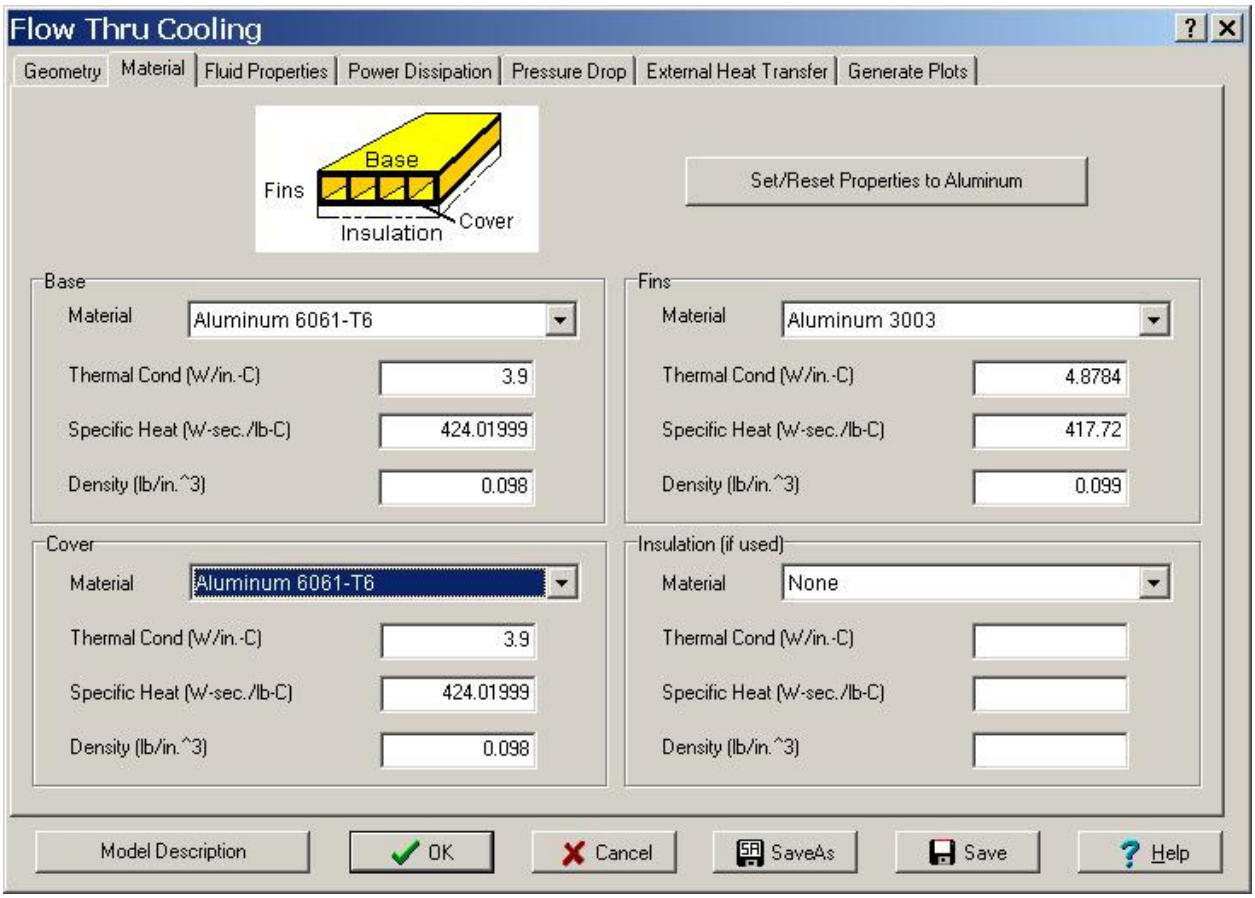
The new fluid is defined first, with the properties are taken from the previous table.



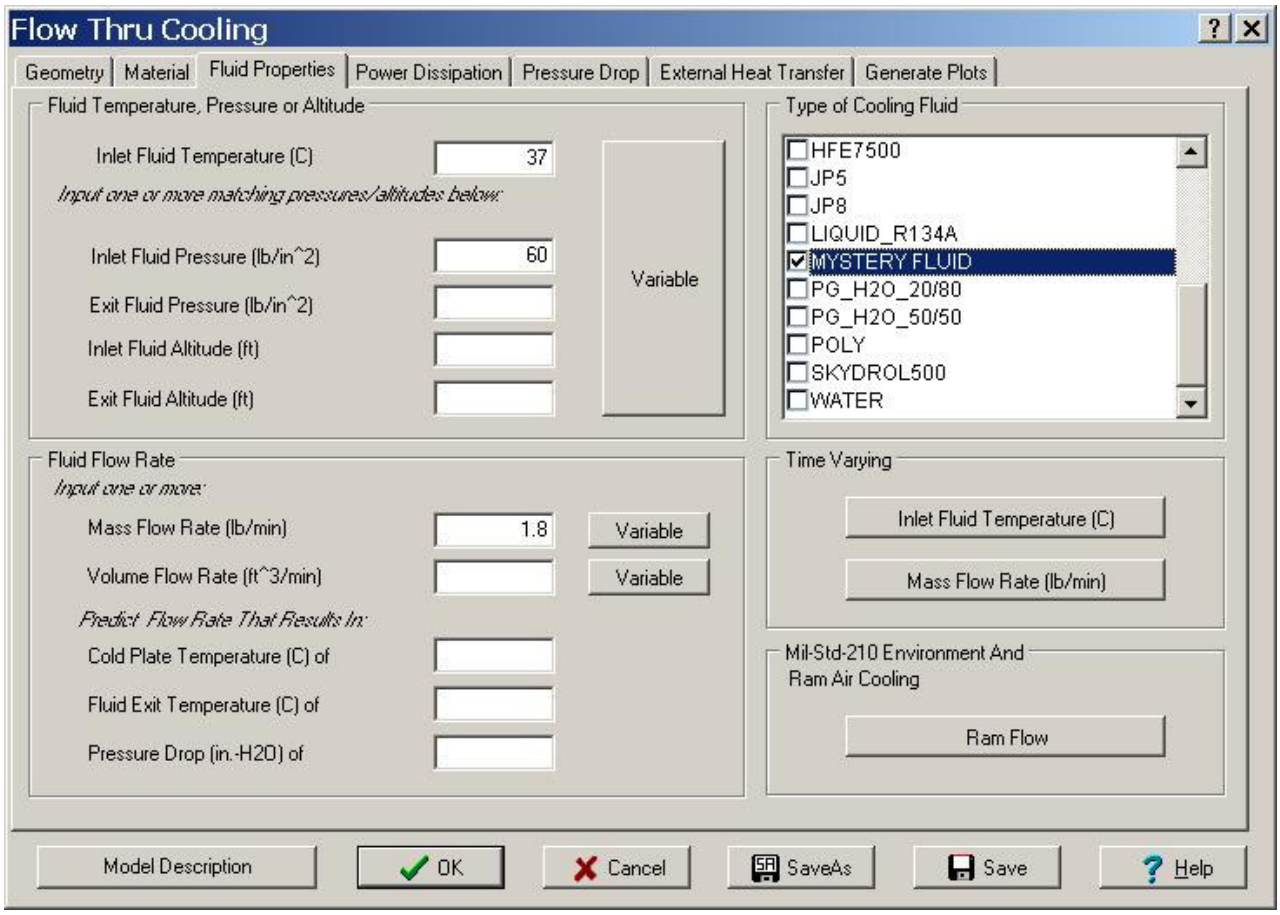
Input the geometry parameters on this tab.



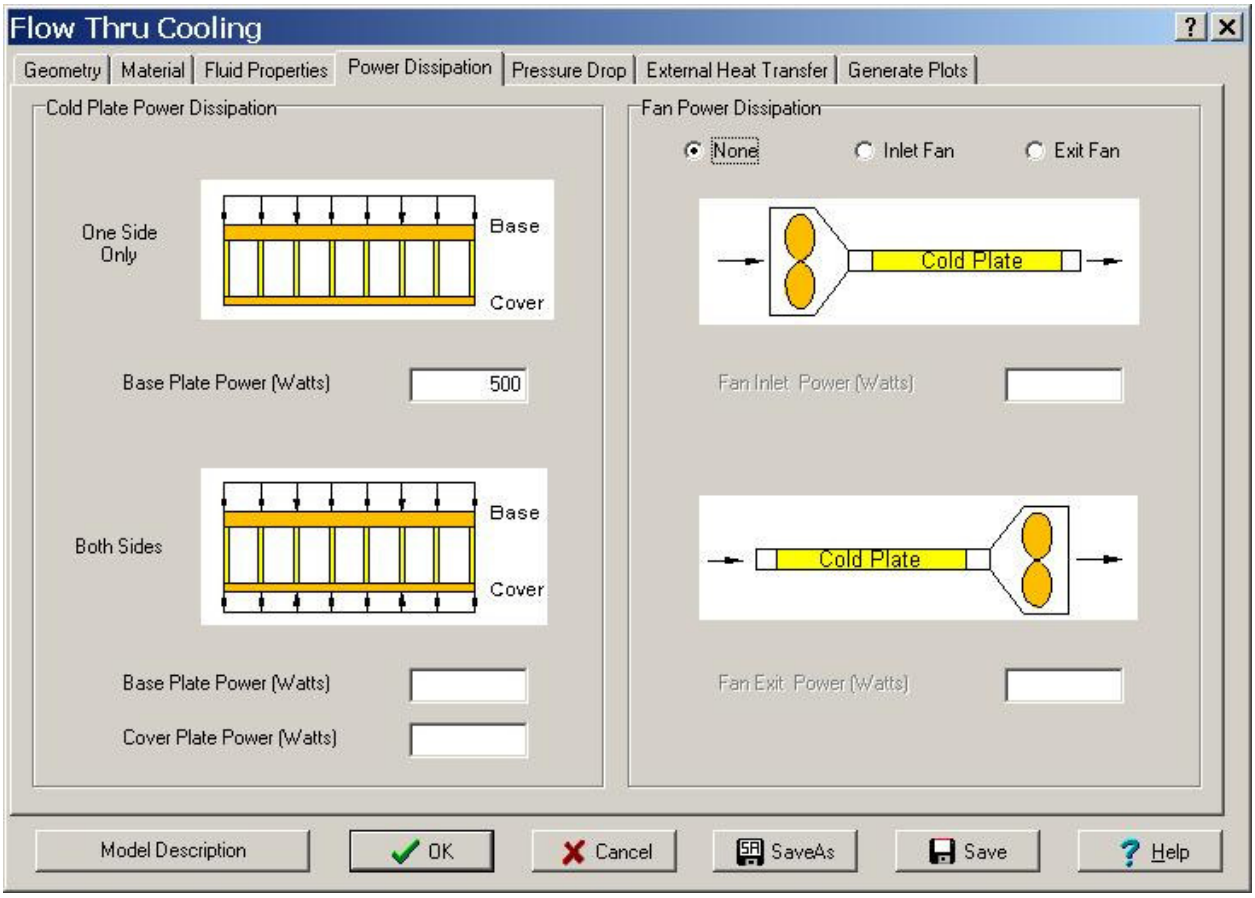
The base plate, cover and fin properties are defined here. The aluminum selected for the design are already built into the material library, so they only need to be picked from the drop down list.



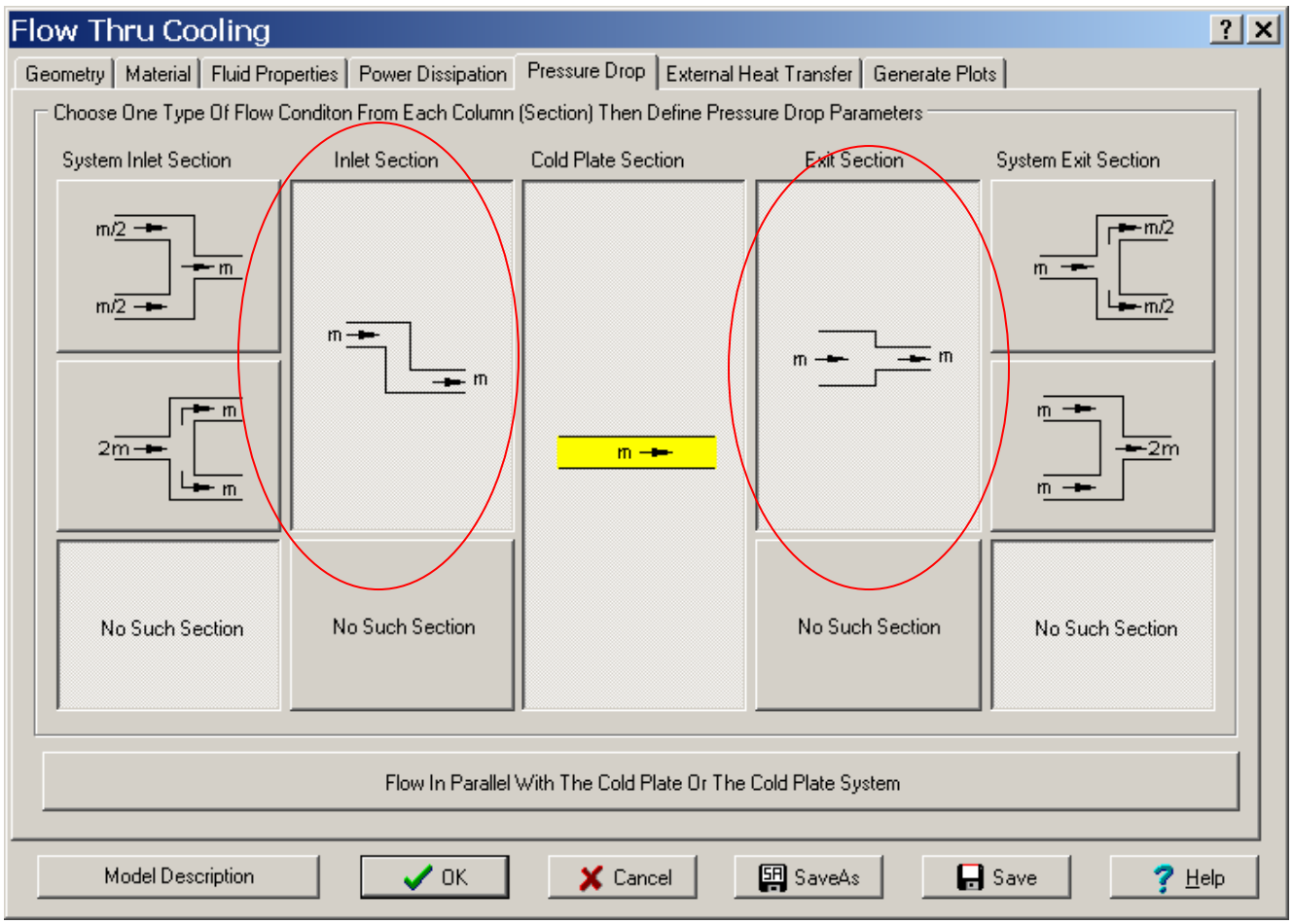
Input the Inlet fluid temperature, pressure, mass flow rate and select “Mystery Fluid” as the cooling fluid.



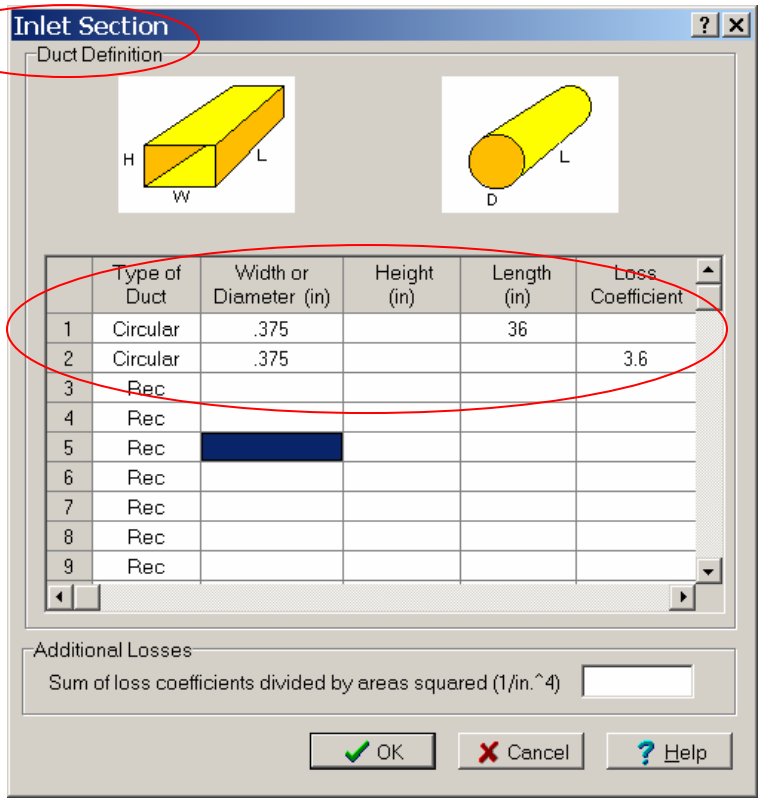
The 500 Watts of power are added here.



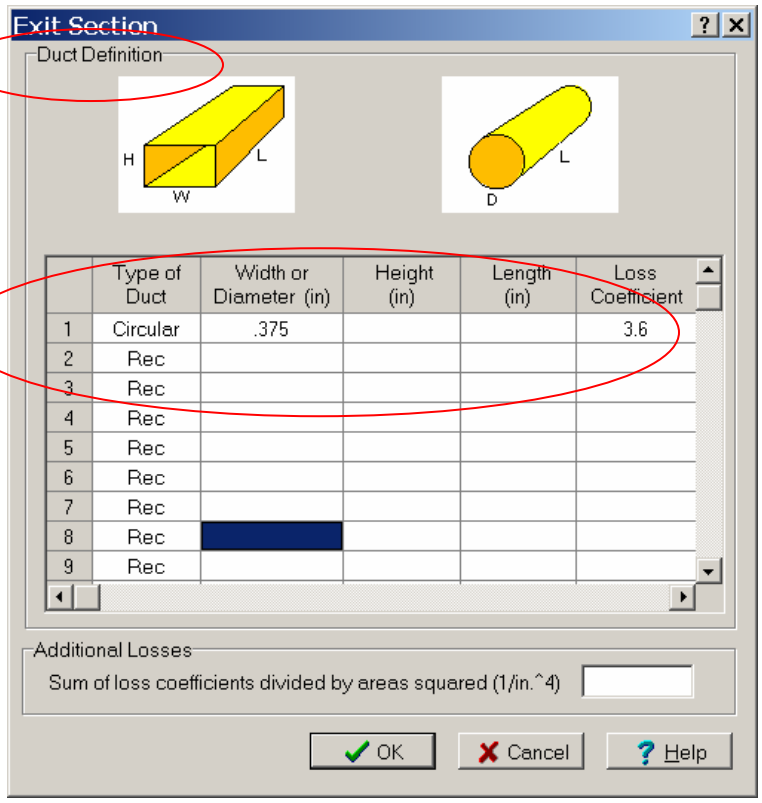
The “Inlet Section” button is selected to specify both the 36 inches of tubing and the quick disconnect just prior to the cold plate. In addition, the “Exit Section” button is selected to specify the quick disconnect just after the exit from the cold plate.



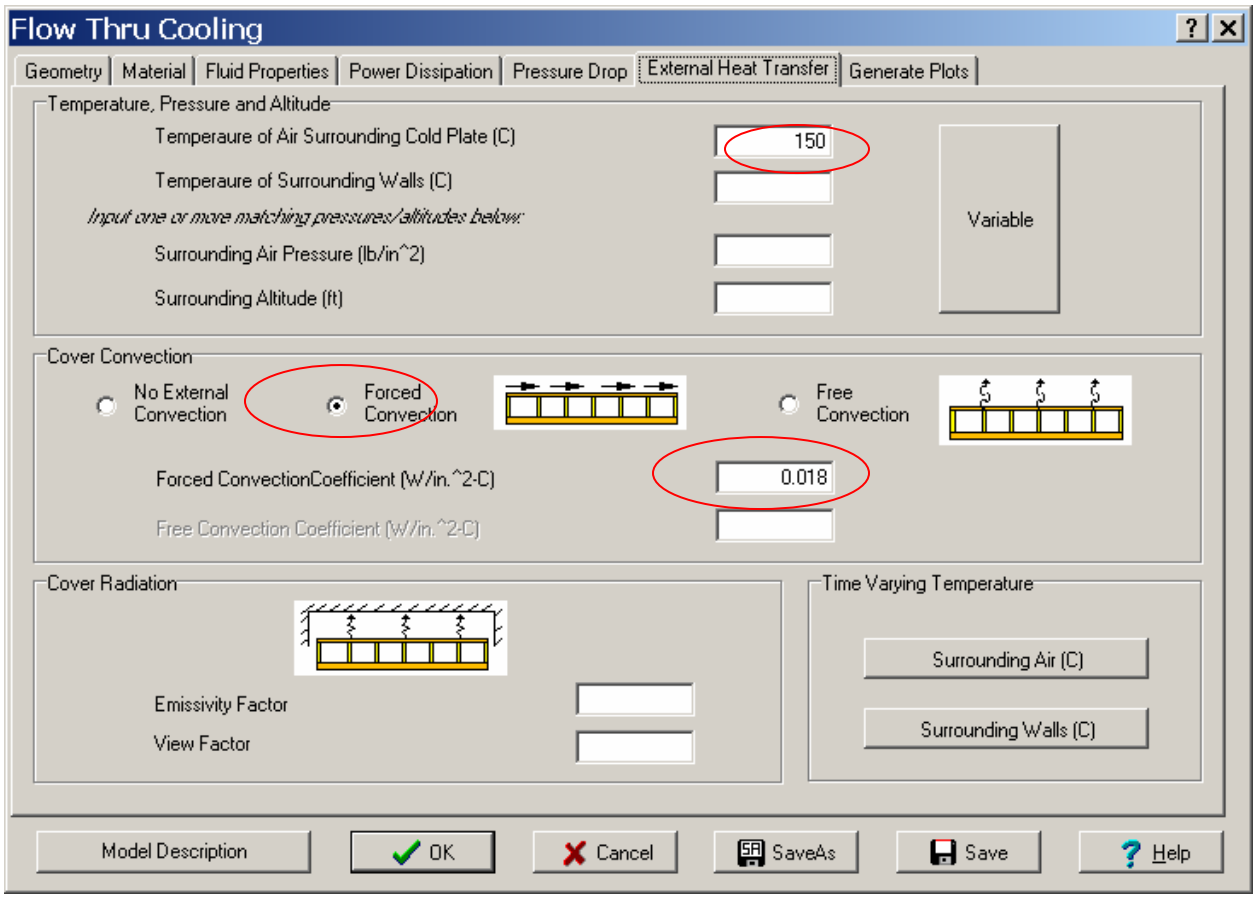
The “Inlet Section” 36 inches of tubing and quick disconnect parameters are input here.



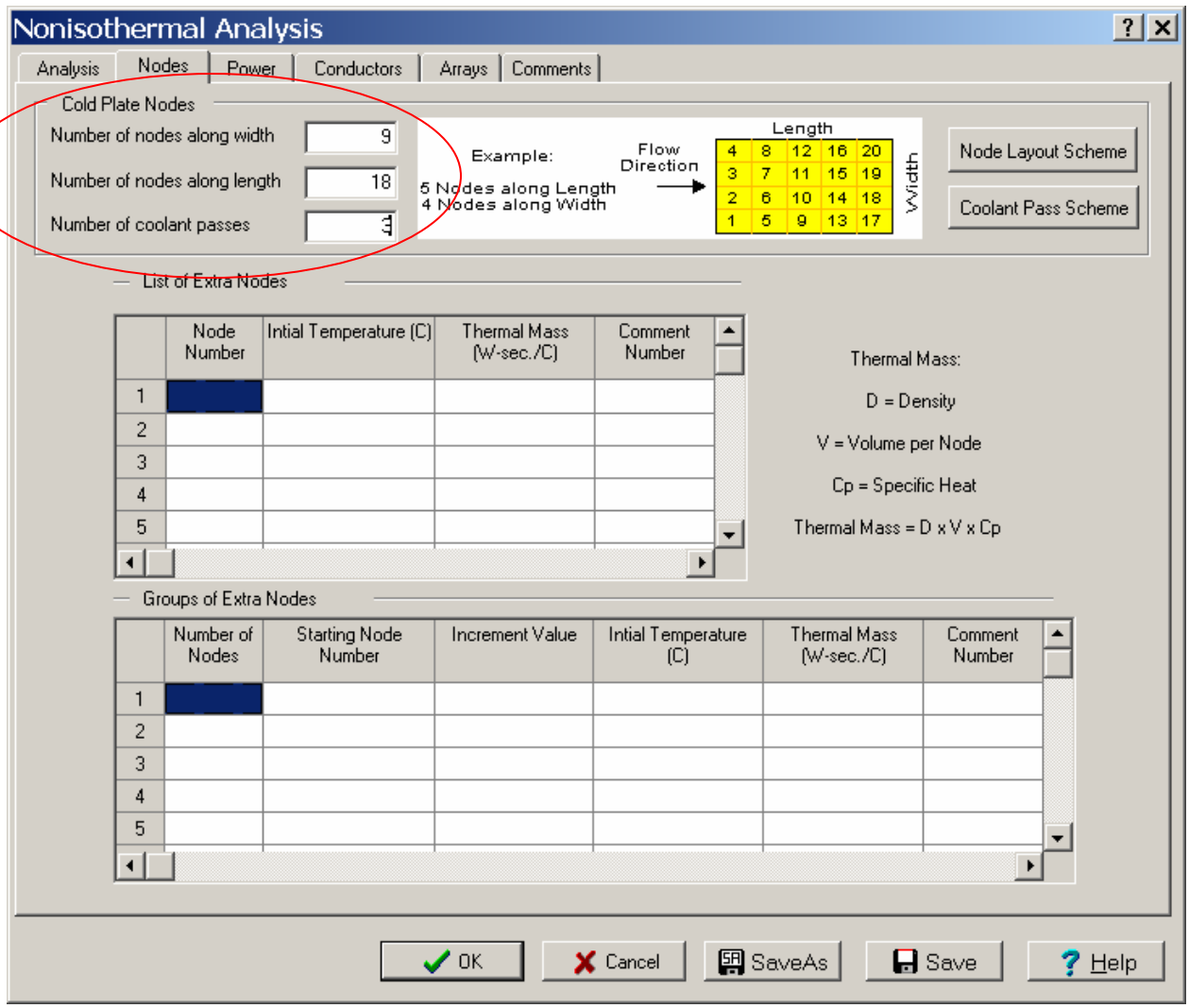
The “Exit Section” parameters are quick disconnect input here.



The heat infiltration from the external environment is input here.



Definition of the 3 passes for the serpentine path and for the number of nodes along with and length are defined below. It is that simple.



The isothermal results are shown below; they are always calculated prior to the non-isothermal analysis and are used as input to the non-isothermal analysis.

```
#####################################################################
                        HEATING ON ONE SIDE ONLY

************************ VARIABLE INPUTS ***************************
THE TYPE OF FINS SPECIFIED ARE:                      1/4-11.1
FIN HEIGHT, INCHES                                      0.375
BASE THICKNESS, INCHES                                  0.062
FIN THICKNESS, INCHES                                   0.0060
FIN DENSITY, FINS PER INCH                             10.0
STATIC INLET FLUID TEMPERATURE, DEG C                  37.0
INLET PRESSURE, LBS/IN2                                60.00
MASS FLOWRATE, LBS/MIN                                  1.80
THE POWER APPLIED TO ONE SIDE ONLY, WATTS             500.00
INSULATION THICKNESS, INCHES                            0.000
EXTERNAL AMBIENT AIR TEMPERATURE, DEG C               150.0
THE COOLING FLUID IS:                              MYSTERY FLUID

**************** INTERMEDIATE CALCULATED PARAMETERS ****************
FREE FLOW CROSS SECTIONAL AREA, IN2                     0.47
HYDRAULIC DIAMETER, INCHES                              0.150
COLDPLATE WEIGHT, LBS                                   0.83
TOTAL VOL FLOWRATE,     [GAL/MIN] FT3/MIN [     0.2]    0.03
COLDPLATE VOL FLOWRATE, [GAL/MIN] FT3/MIN [     0.2]    0.03
COLDPLATE VELOCITY, FT/SEC                              0.14
REYNOLDS NUMBER                                         6.
EQUIVALENT FRICTION LOSS COEFFICIENT, KFRICTION       592.40
INLET LOSS COEFFICIENT, KINLET                          0.83
EXIT LOSS COEFFICIENT, KEXIT                           -0.72
FILM COEFFICIENT, [BTU/(HR-FT2-F)] W/(IN2-C)  [  50.09]  0.1834
THE FIN EFFICIENCY WITH HEAT ON ONE SIDE ONLY IS        0.601
CONVECTION HEAT LOAD, WATTS                            47.08

************************** PRESSURE ********************************
INLET PRESSURE, LB/IN2                                 60.000
INLET PRESSURE DROP, LB/IN2                             0.000
ACCELERATION PRESSURE DROP, LB/IN2                      0.000
FRICTIONAL PRESSURE DROP, LB/IN2                        0.081
EXIT PRESSURE DROP, LB/IN2                              0.000
FLOWLOSS INLET PRESSURE DROPS, LB/IN2                   0.236
FLOWLOSS EXIT PRESSURE DROPS, LB/IN2                    0.009
TOTAL PRESSURE DROP, LB/IN2                             0.325
EXIT PRESSURE, LB/IN2                                  59.675

************************ THERMAL RESISTANCE ************************
THERMAL RESISTANCE FROM INLET FLUID TO COLDPLATE, C/W    0.057
THERMAL RESISTANCE FROM LOCAL FLUID TO COLDPLATE, C/W    0.027

************************** TEMPERATURES ****************************
STATIC INLET FLUID TEMPERATURE, DEG C                  37.0
STAGNATION FLUID TEMP RISE ALONG COLDPLATE, DEG C      26.0
TOTAL STAGNATION FLUID TEMP RISE, DEG C                26.0
STATIC EXIT FLUID TEMPERATURE, DEG C                   63.0
ISOTHERMAL COLDPLATE TEMPERATURE, DEG C                68.3
MAXIMUM COLDPLATE TEMPERATURE, DEG C                   77.6
```

The temperature at each node on the cold plate and fluid are calculated and shown below. The power on each node is also shown.

```
INLET FLUID TEMPERATURE=  37.0 C
 ------------    V
 | CP TEMP  |    V
 | FLD TEMP |    |
 | POWER    |    |
 | NODE NO. |    |
 ------------    |
                 |   EXT. AMB. TEMP= 150.0
                 V
```

54.1	55.1	57.7	63.7	66.7	68.3	69.3	69.9	70.2
(37.5)	(37.6)	(37.7)	(53.3)	(53.7)	(54.2)	(54.7)	(55.2)	(55.6)
3.09W	3.09W	3.09W	3.09W	3.09W	3.09W	3.09W	3.09W	3.09W
N 1	N 2	N 3	N 4	N 5	N 6	N 7	N 8	N 9
54.4	55.4	57.9	63.7	67.0	68.7	69.7	70.3	70.5
(38.1)	(38.2)	(38.3)	(52.9)	(54.9)	(55.3)	(55.8)	(56.2)	(56.1)
3.09W	3.09W	3.09W	3.09W	3.09W	3.09W	3.09W	3.09W	3.09W
N 10	N 11	N 12	N 13	N 14	N 15	N 16	N 17	N 18
54.8	55.7	58.2	63.8	67.1	69.2	70.3	70.7	70.9
(38.6)	(38.7)	(39.0)	(52.6)	(54.4)	(56.6)	(57.0)	(56.7)	(56.6)
3.09W	3.09W	3.09W	3.09W	3.09W	3.09W	3.09W	3.09W	3.09W
N 19	N 20	N 21	N 22	N 23	N 24	N 25	N 26	N 27
55.2	56.1	58.5	63.8	67.0	69.3	70.6	71.1	71.3
(39.2)	(39.3)	(39.6)	(52.2)	(54.0)	(56.1)	(57.4)	(57.2)	(57.1)
3.09W	3.09W	3.09W	3.09W	3.09W	3.09W	3.09W	3.09W	3.09W
N 28	N 29	N 30	N 31	N 32	N 33	N 34	N 35	N 36
55.7	56.6	58.8	63.8	66.9	69.2	70.9	71.5	71.7
(39.7)	(39.8)	(40.2)	(51.8)	(53.6)	(55.7)	(57.9)	(57.6)	(57.5)
3.09W	3.09W	3.09W	3.09W	3.09W	3.09W	3.09W	3.09W	3.09W
N 37	N 38	N 39	N 40	N 41	N 42	N 43	N 44	N 45
56.2	57.0	59.1	63.7	66.8	69.1	71.1	71.8	72.1
(40.2)	(40.4)	(40.8)	(51.4)	(53.2)	(55.3)	(58.3)	(58.1)	(58.0)
3.09W	3.09W	3.09W	3.09W	3.09W	3.09W	3.09W	3.09W	3.09W
N 46	N 47	N 48	N 49	N 50	N 51	N 52	N 53	N 54
56.6	57.4	59.4	63.7	66.6	69.0	71.3	72.2	72.5
(40.7)	(40.9)	(41.4)	(51.0)	(52.7)	(54.8)	(58.7)	(58.5)	(58.5)
3.09W	3.09W	3.09W	3.09W	3.09W	3.09W	3.09W	3.09W	3.09W
N 55	N 56	N 57	N 58	N 59	N 60	N 61	N 62	N 63
57.1	57.8	59.7	63.6	66.4	68.9	71.4	72.5	72.8
(41.3)	(41.5)	(42.0)	(50.6)	(52.2)	(54.3)	(59.1)	(59.0)	(58.9)
3.09W	3.09W	3.09W	3.09W	3.09W	3.09W	3.09W	3.09W	3.09W
N 64	N 65	N 66	N 67	N 68	N 69	N 70	N 71	N 72
57.5	58.2	59.9	63.5	66.2	68.8	71.6	72.8	73.2
(41.8)	(42.0)	(42.6)	(50.2)	(51.8)	(53.9)	(59.5)	(59.4)	(59.4)
3.09W	3.09W	3.09W	3.09W	3.09W	3.09W	3.09W	3.09W	3.09W
N 73	N 74	N 75	N 76	N 77	N 78	N 79	N 80	N 81

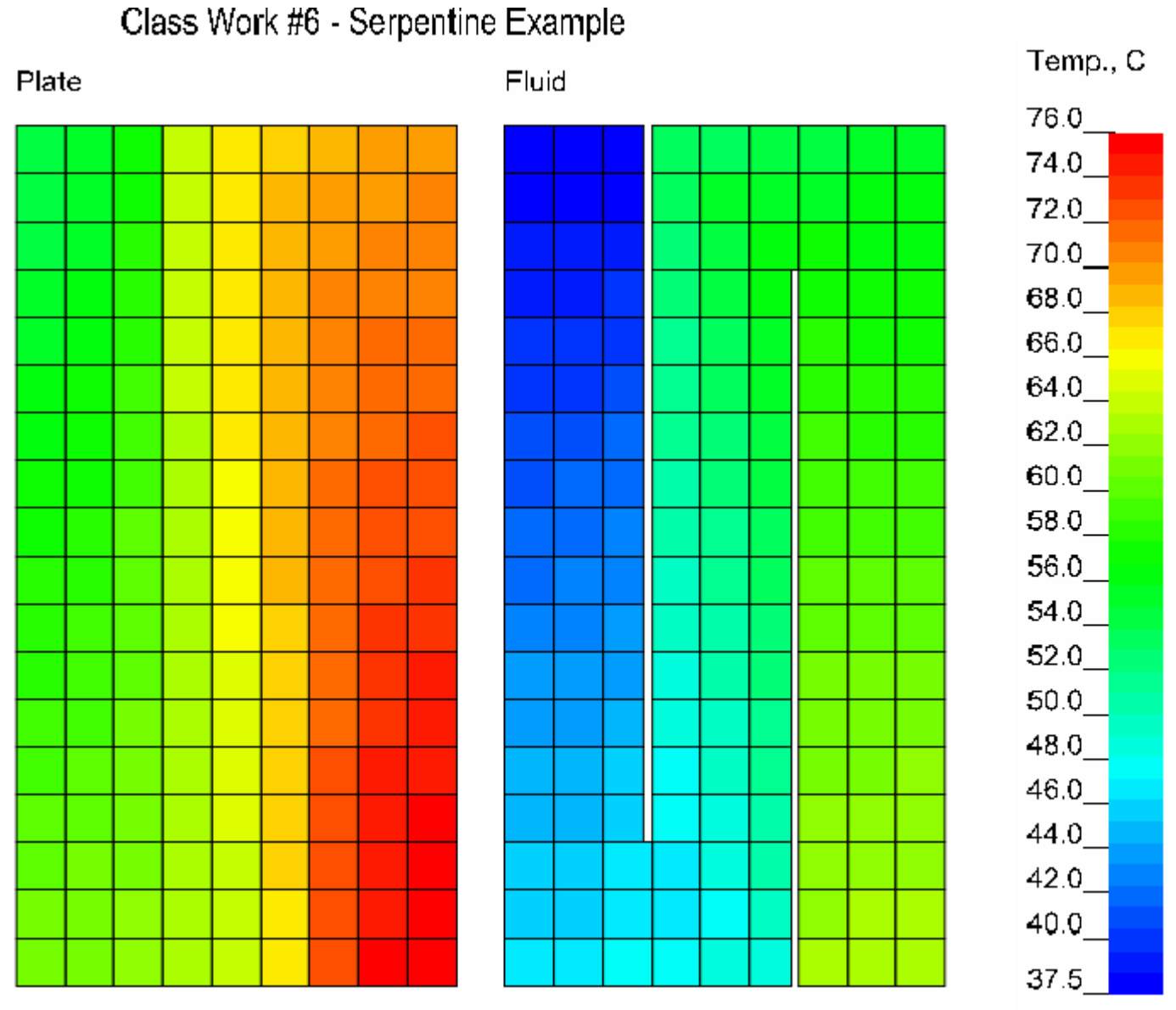
57.9	58.6	60.2	63.4	66.0	68.6	71.8	73.1	73.6
(42.3)	(42.5)	(43.1)	(49.7)	(51.3)	(53.4)	(59.9)	(59.9)	(59.8)
3.09W	3.09W	3.09W	3.09W	3.09W	3.09W	3.09W	3.09W	3.09W
N 82	N 83	N 84	N 85	N 86	N 87	N 88	N 89	N 90
58.4	59.0	60.4	63.3	65.8	68.5	71.9	73.4	73.9
(42.8)	(43.1)	(43.7)	(49.3)	(50.8)	(52.9)	(60.3)	(60.3)	(60.3)
3.09W	3.09W	3.09W	3.09W	3.09W	3.09W	3.09W	3.09W	3.09W
N 91	N 92	N 93	N 94	N 95	N 96	N 97	N 98	N 99
58.8	59.4	60.7	63.2	65.5	68.3	72.1	73.7	74.3
(43.3)	(43.6)	(44.2)	(48.8)	(50.3)	(52.3)	(60.7)	(60.7)	(60.7)
3.09W	3.09W	3.09W	3.09W	3.09W	3.09W	3.09W	3.09W	3.09W
N100	N101	N102	N103	N104	N105	N106	N107	N108
59.2	59.7	60.9	63.1	65.3	68.1	72.2	74.0	74.7
(43.8)	(44.1)	(44.8)	(48.3)	(49.8)	(51.8)	(61.0)	(61.1)	(61.2)
3.09W	3.09W	3.09W	3.09W	3.09W	3.09W	3.09W	3.09W	3.09W
N109	N110	N111	N112	N113	N114	N115	N116	N117
59.7	60.1	61.1	62.9	65.1	68.0	72.3	74.3	75.0
(44.4)	(44.6)	(45.3)	(47.8)	(49.3)	(51.3)	(61.4)	(61.6)	(61.6)
3.09W	3.09W	3.09W	3.09W	3.09W	3.09W	3.09W	3.09W	3.09W
N118	N119	N120	N121	N122	N123	N124	N125	N126
60.1	60.5	61.3	62.8	64.8	67.8	72.5	74.5	75.3
(44.9)	(45.1)	(45.8)	(47.3)	(48.8)	(50.7)	(61.8)	(62.0)	(62.1)
3.09W	3.09W	3.09W	3.09W	3.09W	3.09W	3.09W	3.09W	3.09W
N127	N128	N129	N130	N131	N132	N133	N134	N135
60.5	60.8	61.6	62.7	64.6	67.6	72.6	74.8	75.7
(45.4)	(45.6)	(46.3)	(46.8)	(48.3)	(50.1)	(62.1)	(62.4)	(62.5)
3.09W	3.09W	3.09W	3.09W	3.09W	3.09W	3.09W	3.09W	3.09W
N136	N137	N138	N139	N140	N141	N142	N143	N144
60.9	61.2	61.8	62.9	64.5	67.5	72.7	75.0	75.9
(45.9)	(46.1)	(46.6)	(47.2)	(47.7)	(49.6)	(62.4)	(62.8)	(62.9)
3.09W	3.09W	3.09W	3.09W	3.09W	3.09W	3.09W	3.09W	3.09W
N145	N146	N147	N148	N149	N150	N151	N152	N153
61.1	61.5	62.1	63.0	64.6	67.4	72.8	75.2	76.1
(46.3)	(46.8)	(47.3)	(47.8)	(48.4)	(49.0)	(62.8)	(63.2)	(63.4)
3.09W	3.09W	3.09W	3.09W	3.09W	3.09W	3.09W	3.09W	3.09W
N154	N155	N156	N157	N158	N159	N160	N161	N162

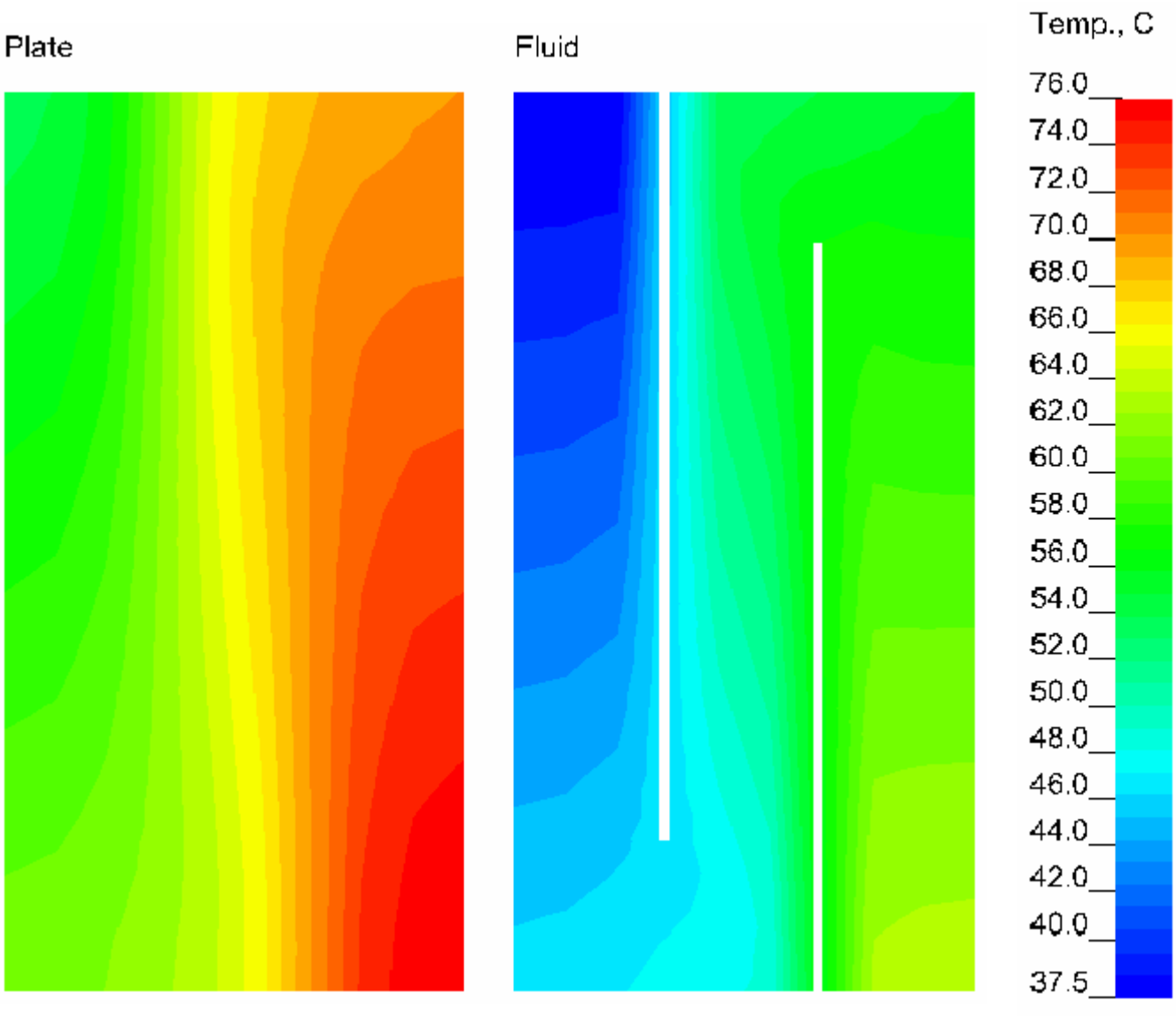
FLUID TEMPERATURE OUT= 63.1

V
V
|
|
|
|
|
|
|
V

CONVECTION HEAT LOAD= 48.55
AVERAGE COLDPLATE TEMP.= 65.7
POWER DIRECTLY ON CP= 500.00
NO. OF ITERATIONS REQUIRED= 68
ALLOW. NO. OF ITERATIONS= 1000
TEMP. RELAXATION CRITERIA=.00100
PERCENT ENGERY BALANCE= 0.0073

A color contour plot of the cold plate and cooling fluid temperatures is shown below.





Detailed Pressure Drop Results at each Section – 36 inches of tubing, quick disconnects and cold plate – are listed on the next page. They are contained in the .dlp file.

SUMMARY OF INPUTS AND RESULTS FOR ISOTHERMAL ANALYSIS AND MAXIMUM TEMPERATURE FOR NONISOTHERMAL ANALYSIS

********** LEGEND **********

FTYPE

1 RECTANGULAR FINS
2 10.27 TRI. FINS
3 PF4 PIN FINS
4 PF9 PIN FINS
5 11.44-3/8 WAVY FINS
6 11.5-3/8 WAVY FINS
7 17.8-3/8 WAVY FINS
8 3/32-12.22 L & O FINS
9 1/8-13.95 L & O FINS
10 1/8-15.2 L & O FINS
11 1/4-11.1 L & O FINS
12 1/2-11.94 L & O FINS
13 TRI FIN 12.00T
14 TEST
15 PLANE FIN 11.1

FIN STYLE

F FIN (CONVOLUTED)
P PIN FIN

FLOWS

V VOLUME-FT^3/MIN
v VOLUME-GAL/MIN
M MASS FLOW-LB/MIN
T RESULTING LB/MIN (TEMP CP)
E RESULTING LB/MIN (TEMP OUT)
P RESULTING LB/MIN (DELTA P)
R RESULTING LB/MIN (RAM FLOW)

TEMPERATURE = DEGREE C
DIMENSIONS = INCHES
WEIGHT = LBS
PRESSURE DROP = IN-H20 FOR AIR, LB/IN2 FOR LIQUIDS

FLUID

1 AIR
2 WATER
3 COOLANOL20
4 COOLANOL25
5 EG_H2O_60/40
6 EG_H2O_50/50
7 EG_H2O_40/60
8 EG_H20_30/70
9 FC75
10 GALDEN-HT110
11 HFE7100
12 HFE7500
13 JP5
14 JP8
15 LIQUID_R134A
16 PG_H2O_20/80
17 POLYALPHAOLEPHIN
18 SKYDROL 500
19 PG_H2O_50/50
20 ENGINE OIL
21 MYSTERY FLUID

TEMP

S SINGLE SIDED HEATING
B BOTH SIDED HEATING

A NUMBER FOLLOWED BY A DASH (-) INDICATES THIS VARIABLE IS NOT USED DURING THIS RUN

FLOWLOSS INPUT AND RESULTS DATA - PRESSURE DROP RESULTS

********** LEGEND **********

UNITS

WIDTH OR DIA - INCHES
HEIGHT - INCHES
LENGTH - INCHES
M-DOT - LB/MIN
RHO-XXX - LB/FT3
AREA-IN - SQ. INCHES
ALT - FEET
T-XXX - DEGREE C
P-XXX - LB/IN2
ARAMI - SQ. INCHES

DP-XXX - IN-H2O FOR AIR, LB/IN2 FOR LIQUIDS
PRESS-X - IN-H20 FOR AIR, LB/IN2 FOR LIQUIDS

COMMENTS

1 THE FRICTION FACTOR f IS MULT. BY 4 WITHIN COLDPLATE
2 DP-KI/KE INCLUDES THE AREA CHANGE EFFECT

** INPUT ** | ****************** RESULTS *********************

		FIN STYLE									TEMP					
FTYPE	FHEIGHT	FTHICK PDIA	PSPACET	FDENSITY PSPACEL	ITHICK	TEMPIN	TEMPAMB	TEMPWALL	FLOWS	FLUID	TEMPOUT	TCPISO	TCPMAX	DELTAP	WEIGHT	TMAX/NODE
11	0.375	.006F	0.000-	10.000F	0.000	37.0	150.0	0.0-	1.80M	21	63.0S	68.3S	77.6S	0.33	0.83	

**************** INPUT **************** | ** RESULTS ***

INLET FLOWLOSS INPUT AND RESULTS DATA

WIDTH OR DIA	HEIGHT	LENGTH	K	M-DOT	f	RHO-IN	RHO-EX	MACH-IN	MACH-EX	DP-ACC	DP-f	DP-K	DP-TOT	PRESS-I	PRESS-E
0.375	0.000	36.00	0.000	1.800	0.2404	67.2380	67.2380	0.000	0.000	0.000	0.227	0.000	0.227	60.00	59.77
0.375	0.000	0.00	3.600	1.800	0.0000	67.2380	67.2380	0.000	0.000	0.000	0.000	0.009	0.009	59.77	59.76
							SUB-TOTALS			0.000	0.227	0.009	0.236		

THE TOTAL PRESSURE DROP ACROSS THE INLET IS 0.236

COLDPLATE FLOWLOSS INPUT AND RESULTS DATA

WIDTH OR DIA	HEIGHT	LENGTH	K IN/EX	M-DOT	f	RHO-IN	RHO-EX	MACH-IN	MACH-EX	DP-ACC	DP-f	DP-KI/KE	DP-TOT	PRESS-I	PRESS-E
1.333	0.375	24.00	0.945 -0.836	1.800	0.9276	67.2380	66.5304	0.000	0.000	0.000	0.081	0.000 0.000	0.081	59.76	59.68

EXIT FLOWLOSS INPUT AND RESULTS DATA

WIDTH OR DIA	HEIGHT	LENGTH	K	M-DOT	f	RHO-IN	RHO-EX	MACH-IN	MACH-EX	DP-ACC	DP-f	DP-K	DP-TOT	PRESS-I	PRESS-E
0.375	0.000	0.00	3.600	1.800	0.0000	66.5304	66.5304	0.000	0.000	0.000	0.000	0.009	0.009	59.68	59.67
							SUB-TOTALS			0.000	0.000	0.009	0.009		

THE TOTAL PRESSURE DROP ACROSS THE EXIT IS 0.009

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ACCELERATION TOTAL	0.000
FRICTIONAL TOTAL	0.307
FITTING OR TURN TOTAL	0.018
THE TOTAL PRESSURE DROP ACROSS THE WHOLE SYSTEM IS	0.325

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