Liquid Cooled Cold Plate Trade Study

1.0 Design Parameters

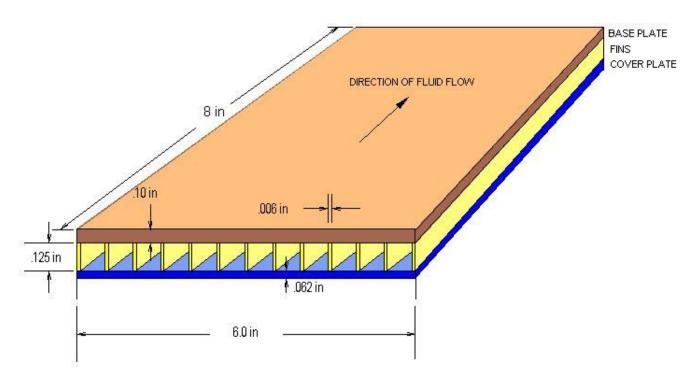
In this example we will perform a trade study of the temperature and pressure drop performance of different cold plate designs needed to cool high power electronics that dissipate 12,000 Watts. The trade study will examine finned, pinned and a tube/channel design. The parameters used in the trade study are listed below.

The purpose of this example is not to select the optimum design, but to demonstrate the flexibility of COLDPLATE and the ease with which to do this.

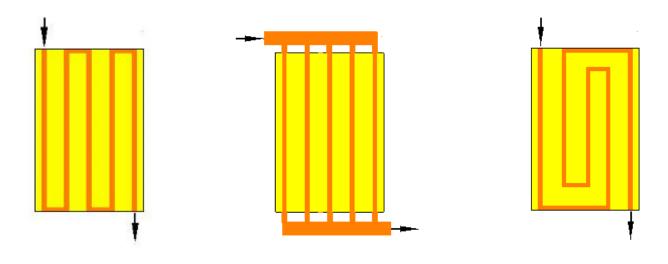
- Cold plate length L is 8 inches
- Cold plate width W is 6 inches
- Cooling fluid is water
- The inlet water temperature is 20C
- The exit fluid pressure is 100 PSI
- Vary the volume flow rate from 1 to 8 gal/minute
- 12000 Watts is uniformly distributed across the cold plate
- Base, fins and cover are made of aluminum, 6061-T6
- For the fin design, assume they are 1/8-13.95 lanced and offset fins from Kays and London's book, Compact Heat Exchangers :
 - Fin height H is .125 inches
 - Fin density is 14 fins/inch
 - Fin thickness is .006 inches
- For the pin fin design, assume they are PF9 fins from Kays and London's book, Compact Heat Exchangers :
 - Pin height H is .125 inches
 - Transverse pin spacing is .199 inches
 - Lateral pin spacing is .125 inches
- For the tube/channel design:
 - The tube flow path is .25 inches in diameter
 - Assume 100% contact between the tube and base plate and 0.0 thermal resistance between the tube and base plate.
- Base plate thickness is .1 inches for pin and lanced fins, .5 for the tube/channel design
- Cover thickness is .062 inches
- The lanced and offset fin, and pin designs are flow through design (1 pass) and 5 pass serpentine design
- The tube/channel designs will be serpentine, custom and parallel with either 5 passes or 5 parallel paths
- Assume all 5 pass/path designs have a pressure drop loss coefficient of .75 for each 90 degree turn (Kt = 8 * .75 = 6.0).

2.0 Sketches

Below is a sketch showing the geometry of the overall dimensions for both the lanced and offset design, and the pin fin designs.



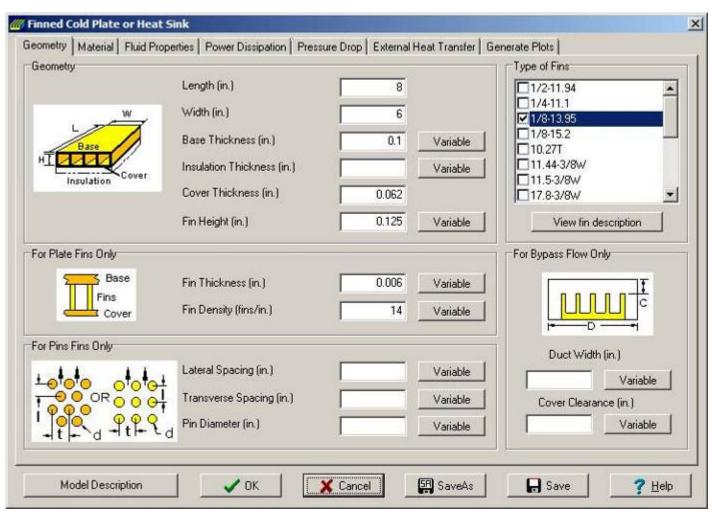
The tube flow designs: serpentine, parallel and custom are shown below. The tubes are assumed to be uniformly spaced as shown (note that this is not a necessity, the spacing can be arbitrary). The inlet and exit headers for the parallel design are assumed to be either large enough or designed so that the flow in each parallel path is equal.



3.1 Lanced and Offset Fins, and Pin Fin Models

The geometry for the lanced and offset fin (1/8-13.95) design is input on Geometry Tab sheet. The pin fin design could also be input here and modeled at the same time. It's not done here for clarity.

📶 Create/Open Model		×
Create a New Model -		
	 Finned Cold Plate or Heat Sink 	✓ OK <u>Î</u> <u>C</u> lose
<u>J</u>	C Tube/Channel Cold Plate	
	O Open an Existing Model	<u>? H</u> elp



FOR MORE INFORMATION, VISIT OUR WEB SITE: EPAC-INC.COM Tel: (603) 533-9011

The geometry for the pin fins (PF4) design is input on this tab sheet. Again, the pin fin design could have been inputted with the lanced and offset fins.

eometry	Length (in.)	8		Type of Fins
- VV	Width (in.)	6		□ 1/8-15.2 □ 10.27T
Base	Base Thickness (in.)	0.1	Variable	□ 11.44-3/8₩ □ 11.5-3/8₩
HI Cover	Insulation Thickness (in.)		Variable	17.8-3/8W
Insulation	Cover Thickness (in.)	0.062		□ 3/32-12.22 ✓ PF4
	Fin Height (in.)	0.125	Variable	View fin description
or Plate Fins Only				For Bypass Flow Only
Base	Fin Thickness (in.)		Variable	I
Fins Cover	Fin Density (fins/in.)		Variable	
or Pins Fins Only				Duct Width (in.)
	Lateral Spacing (in.)	0.125	Variable	Variable
	Transverse Spacing (in.)	0.199	Variable	Cover Clearance (in.)
	Pin Diameter (in.)	0.065	Variable	Variable

Select 6061-T6 aluminum properties on the Material tab sheet. This is the same for all designs except the cover and fins are not used for the tube designs.

eometry Mate	rial Fluid Properties Power Dissipation	Pressure Drop External Hea	at Transfer Generate Plots	
	Fins Base Insulation Cover		Set/Reset Properties to Aluminum	
Base	modulon	Fins		
Material	Aluminum 6061-T6	✓ Material	Aluminum 6061-T6	*
Thermal Co	nd (W/inC)	3.9 Thermal Co	ond (W/inC)	3.9
Specific He	eat (W-sec./lb-C) 424.019	99 Specific He	eat (W-sec./lb-C) 4	24.01999
Density (lb/	in.^3) 0.0	98 Density (lb.	/in.^3)	0.098
Cover		Insulation (if u	sed)	
Material	Aluminum 6061-T6	▼ Material	None	•
Thermal Co	ond (W/inC)	3.9 Thermal Co	ond (W/inC)	
Specific He	eat (W-sec./lb-C) 424.019	99 Specific He	eat (W-sec./lb-C)	
Density (Ib/	/in.^3) 0.0	98 Density (lb.	/in.^3)	

The temperature, pressure, flow rate and water as the fluid are input on the Fluid Properties tab sheet. The variable flow rate from 1 to 8 GPM with 8 different values is input by selecting the variable button next to Volume Flow Rate text box and filling in the values. These inputs are the same for all models.

		leat Transfer Generate Plots
Fluid Temperature, Pressure or Altitude		Type of Cooling Fluid
Inlet Fluid Temperature (C) 20 <i>Input one or more matching pressures/altitudes below:</i> Inlet Fluid Pressure (Ib/in^2) 100 Exit Fluid Altitude (ft) Exit Fluid Altitude (ft)	Variable	HFE7500 JP5 JP8 LIQUID_R134A MYSTERY FLUID PG_H20_20/80 PG_H20_50/50 POLY SKYDROL500 WATER
Fluid Flow Rate Input one or more Mass Flow Rate (Ib/min)	Variable	Time Varying
Volume Flow Rate (gal/min) 1	Variable	Minimum value 1
Predict Flow Rate That Results In:		Maximum value 8
Cold Plate Temperature (C) of Fluid Exit Temperature (C) of		Number of values 8
Pressure Drop (inH2O) of		✓ OK

The 12,000 watts of power dissipation are input on the Power Dissipation tab sheet. It will automatically be uniformly distributed across the cold plate base. Note, that the power does not have to be uniform, it can be non-uniform, temperature or time dependent. These inputs are the same for all models.

Finned Cold Plate or Heat Sink	
Geometry Material Fluid Properties Power Dissipation Pressure Dr	op External Heat Transfer Generate Plots
Cold Plate Power Dissipation	Fan/Pump Power Dissipation
	None C Inlet Fan C Exit Fan
One Side Only Cover	
Base Plate Power (Watts)	Fan Inlet Power (Watts)
Both Sides	
Base Plate Power (Watts)	Fan Exit. Power (Watts)

To account for the pressure drop due to the turn losses in both the lanced and offset fins, and pin fin serpentine designs, the total loss coefficient of 6.0 along with the inside dimension of 6 by .125 inches of the cold plate are specified on the Inlet Section Duct Definition form, these values also could have been input on the Exit Section. The location chosen only becomes important when modeling hi-speed compressible air flow and density changes need to be accounted for.

	Conditon From Each Column	n (Section)	i nen Derine	Pressure Drop Pa	arameters		
System Inlet Section	Inlet Section	Finned C	Cold Plate Se	ction Exit 9	ection	System E	xit Section
m/ <u>2 -</u>		M Inlet S	ection				
- - m		DuctD	efinition				
m/ <u>2</u>	m						
			н			61	
[r ➡ m	m		" <mark></mark>				
2m-							
L e m			Type of	Width or	Height	Length	Loss
			Duct	- Diameter (in)	(in)	(in)	Coefficient
		15	Rec 🛃	6	.125		6
		2	Rec				
		3	Rec				
No Such Section	No Such Section	4	Rec				
		5	Rec				
		6	Rec				
		7	Rec				
		8	Rec				
	Flow In Parallel	9	Rec				
		10	Rec				
		-					
Model Description	✓ ок	A delition	nal Losses-				

That's all the input needed for the lanced and offset fin, and pin fin models except to specify the number of nodes in the model used in determining the temperatures along the width and length of the cold plate. The Nonisothermal Analysis form as shown below is used to do this.

Because we are going to be modeling both flow through (1 pass) and serpentine cold plates, then the nodes should be kept somewhat square to simulate the correct path length. In addition, since there are 5 passes in the serpentine models and the number of nodes along the width has to be divisible by the number of passes, then 25 nodes along the width is a reasonable value to use. Also, since the length is 8 inches versus a width of 6 inches and we want to keep the nodes somewhat square, then 32 or 33 nodes along the length is appropriate.

Note as shown below; the only difference between a flow through model and serpentine model other than the pressure drop coefficient is the inputting of 1 versus 5 for the number of coolant passes. With a value of 5, the cold plate will automatically be divided into 5 equal width flow paths (see the color contour output plot later in this paper).

At this point, the lanced and offset fin, and pin fin models with both flow through and serpentine paths are ready to run. The results for these four models are discussed later along with the tube flow models.

Number	ate No of nod of nod of coo	les along wid les along lenj lant passes	th 25 gth 32 1	Cold Plate Number of n	Nodes Power	Conductors		out Scheme
[- Lis	t of Extra No Node Number	Intial Temperature (C)	Thermal Mass (W-sec./C)	Comment A	Thermal M	fass:	
	1					D = Der	nsitu	
	2					V = Volume pe	r Node	
	3					and the second		
	4					Cp = Specifi	c Heat	
	5					Thermal Mass = [)xVxCp	
	6			10	•			
-	Gr	oups of Extra	Nodes					
		Number of Nodes	Starting Node Number	Increment Value	Intial Temperature (C)	Thermal Mass (W-sec./C)	Comment Number	-
	1							
	2							
	3	î î						
	4							
	5							
	6							-

3.2 Tube Models

The geometry and thermal resistance from tube to base plate for the 3 different types of tube models are the same and are input on the Geometry tab sheet shown below.

Create/Open Model	×
Create a New Model	✓ OK <u>I</u> <u>C</u> lose
Tube/Channel Cold Plate	
O Open an Existing Model	<u>? H</u> elp
Tube/Channel Cold Plate	×
Geometry Material Fluid Properties Power Dissipation Pressure Drop External Heat Transfer G	enerate Plots
Geometry W Length (in.) 8 Width (in.) 6 Note that the set of	
Image: Constant of the mail Resistance from Tube to Base (C-in/W) 0 Image: Constant of the mail Resistance from Tube in Contact with Base 100 Image: Constant of the mail Resistance from Tube in Contact with Base 100	
Model Description V OK SaveAs	Save ? Help

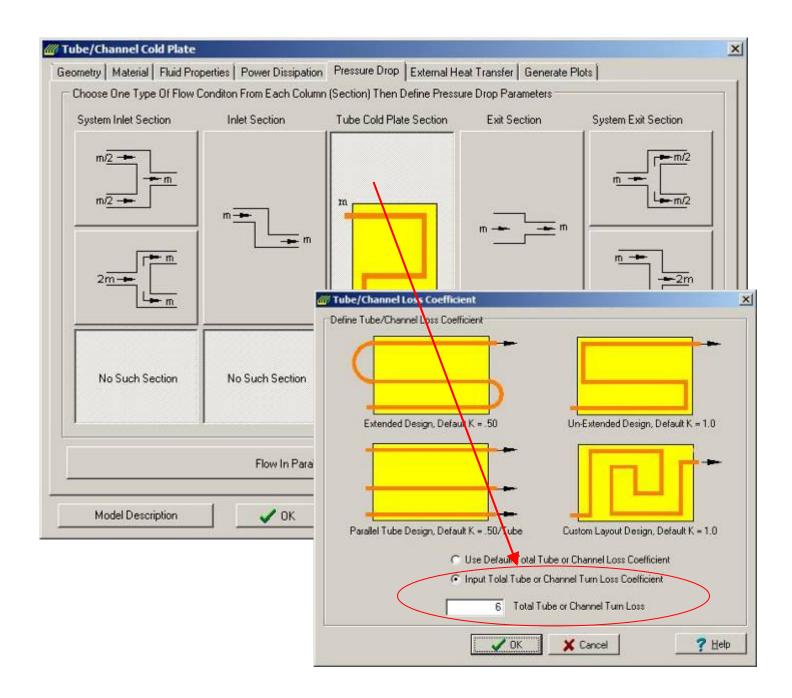
FOR MORE INFORMATION, VISIT OUR WEB SITE: EPAC-INC.COM Tel: (603) 533-9011

Select 6061-T6 aluminum properties on the Material tab sheet.

eometry Mate	rial Fluid Properties	Power Dissipation Pressure	Drop External Heat Transfer Generate Plots
			Set/Reset Properties to Aluminum
Base Material		4.70	Base Plate
	Aluminum 606	1-T6 •	
	at (W-sec./lb-C)	424.01999	
Density (Ib/	in.^3)	0.098	Insulation
			Insulation (if used)
			Material None
			Thermal Cond (W/inC)
			Specific Heat (W-sec./lb-C)
			Density (Ib/in.^3)

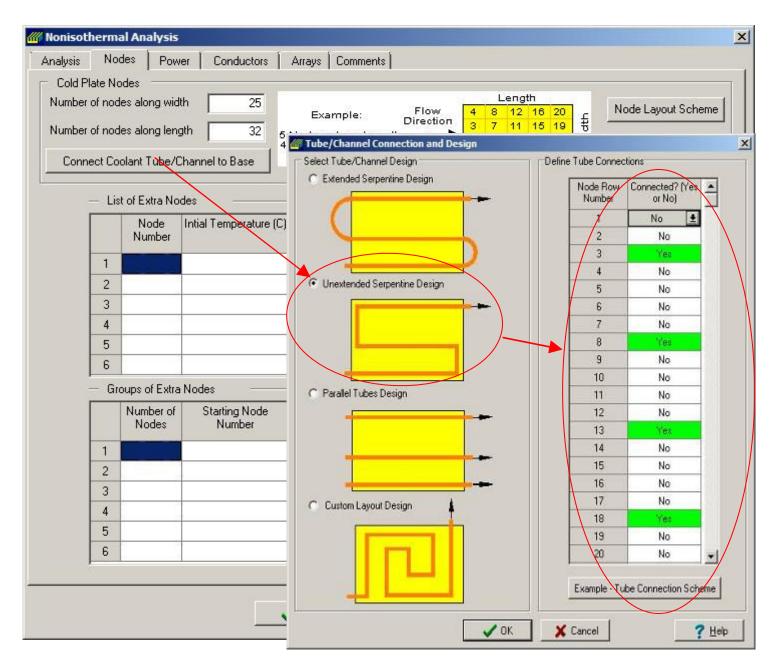
To account for the pressure drop due to the turn losses within the tube model designs, the Pressure Drop tab is selected and then the Tube Cold Plate Section button is selected bringing up the Tube/Channel Loss Coefficient form. The total loss coefficient of 6 is inputted here.

Note that the inside tube diameter will be used in the pressure drop calculations.

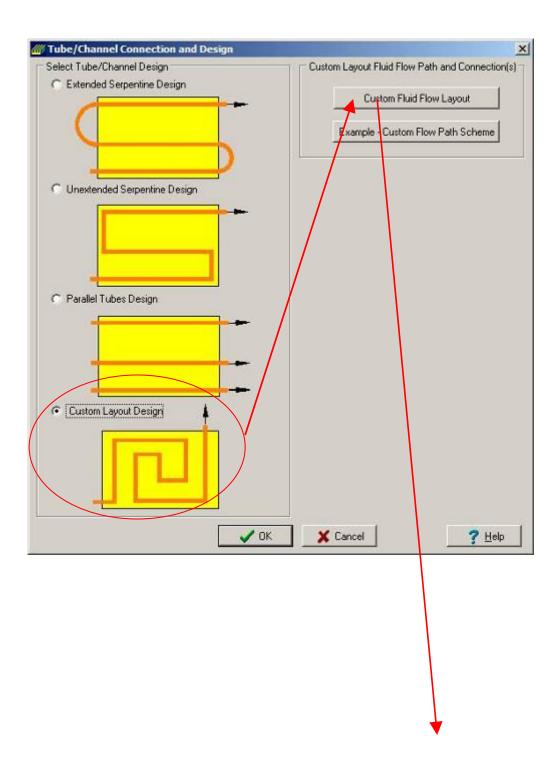


The same number of nodes for both the width and length are used on the Nonisothermal Analysis form. In addition, for the tube models we need to indentify which Node Row Number the fluid flow tube is connected to. This is done by clicking on the Connect Coolant Tube/Channel to Base button, then selecting the appropriate type of tube design radio button and then selecting Yes for Node Row Numbers 3,8,13,18 and 23. The tube will be automatically tied to each node on each of the node row numbers. In addition, for the Serpentine design, the tube will also be tied to nodes between each of the node row numbers. The program will use the resistance values that were input on the Geometry Tab sheet to tie the tube to the base plate.

Both the Serpentine and Parallel tube models are specified in this manner, to switch from one to next, just select the appropriate radio button.



The custom tube design model is setup by selecting the Custom Layout Design radio button, then clicking the Custom Fluid Flow Layout button to bring up the Custom Fluid Flow Layout Table form.



On this form, you draw the tube layout by clicking on or using the up/down/left or right arrow button to route the tube layout. The tube will automatically be tied to each base plate node underneath it. The program will use the resistance values that were input on the Geometry Tab sheet.

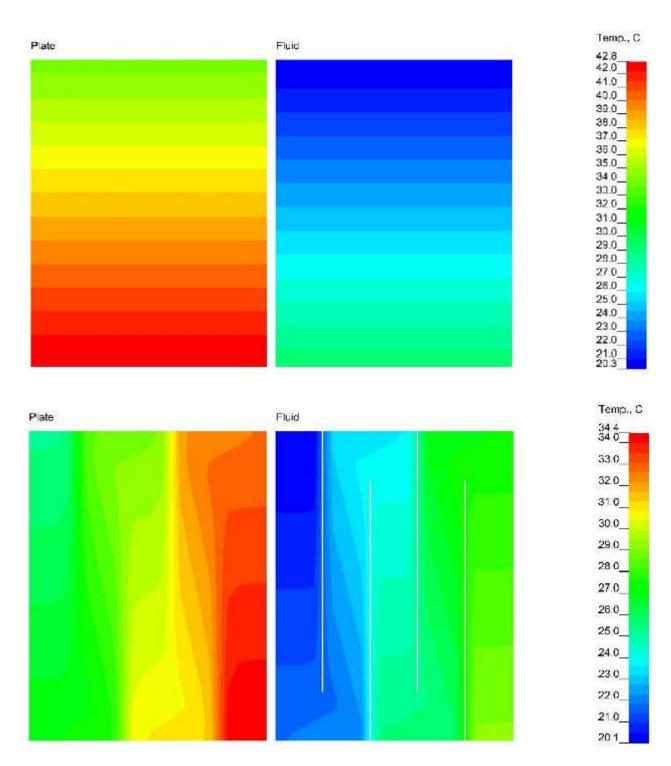
Once you are done with this form and select OK you are returned to the Tube/Channel Connection form. From there you can select any of the radio buttons to toggle between any of the different types of tube models with out have to re-input any data. These model are now finished and ready to run.

aw Fluid Flow Path	1	2	3	4	5	6	7																	24	25
Fluid Intel	26	27		29	30	31	32		34	35	36	37.	38	39	40	41	42	43	44	45	45	47		49	50
Fluid Flow Path	51	52		54	55	56	57		59	60	61	62	63	64	65	66	87	68	69	70	71	72		74	75
The identical state	76	77		79	80	81	82		84	85	86	87	88	89	90	91	92	93	94	95	96	97	-	99	100
Fluid Exit	101	102		104	105	105	107		109	110	111	112	113	114	115	116	117	118	119	120	121	122		124	125
Delete Path	125	127		129	130	131	132		134	135	135	137	-996	13	1 aut	- 41	14	121	144	145	145	147	102	149	150
Done	151	152		154	155	156	157		159	160	161	162		164	165	165	167		169	170	171	172		174	175
	176	177		179	180	181	162		184	185	188	187		189	190	191	192		194	195	196	197	18	199	200
Trace Flow Path	201	202		204	205	206	207		209	210	211	212		214	215	216	217		219	220	221	222		224	225
Trace Path Quickly	225	227		229	230	231	232		234	235	235	237		239	24D	241	242		244	245	245	247		249	250
Repaint Layout	251	252		254	255	256	257		259	260	261	262		264	265	265	267		269	270	271	272		274	275
Clean Up	276	277		279	280	281	282		284	285	285	287		289	290	291	292		294	295	296	297		299	300
	301	302		304	305	306	307		309	310	311	312		314	315	316	317		319	320	321	322		324	325
Delete All	326	327		329	330	331	332		334	335	335	337		339	340	341	342		344	345	345	347		349	350
	351	352		354	355	356	357		359	360	361	362		364	365	366	367		369	370	371	372		374	375
	376	377		379	380	381	382		384	385	386	387		389	390	391	392		394	395	396	397	100	399	400
	401	402		404	405	405	407		409	410	411	412		414	415	416	417		419	420	421	422		424	425
	426	427		429	430	431	432		434	435	435	437		439	440	441	442		444	445	445	447		449	450
	451	452		454	455	456	457		459	460	461	462		464	465	466	467		469	470	471	472		474	475
	478	477		479	480	481	482		484	485	485	487		489	490	491	492		494	495	496	497		499	500
	501	502		504	505	506	507		509	510	511	512		514	515	516	517		519	520	521	522		524	525
	526	527		529	530	531	532		534	535	536	537		539	54D	541	542		544	545	546	547		549	550
	551	552		554	555	556	557		559	560	561	562		564	565	566	567		569	570	571	572		574	575
	576	577		579	580	581	582		584	585	585	587		589	590	591	592		594	595	596	597		599	600
	601	602		604	605	606	607		609	610	611	612	613	614	615	616	617		619	620	521	622		624	625
	826	627		629	630	631	632	173	634	635	636	637	12	639	640	541	642		644	645	546	647		649	650
	651	652	251	654	655	656	857		850	6.0	881	01	163	664	665	666	667		669	670	671	672		674	675
	676	677	64	679	680	681	682	683	684	685	686	687	688	689	690	591	692		694	695	696	697		699	700
	701	702		704	705	706	707	708	709	710	711	712	713	714	715	716	717		719	720	721	722		724	725
	726			729	730	731		733		735			738	739	740	741	3.97.0		744	745	746			749	750
	251	752		754	755	756	757	758	759	760	761		763	764	765	766	100		769	770	771	772		774	775
	776	777		l a	(ER	-21	- 8-	(III)	E(1)	ПÞ	11	111	2.6	771	120	12	(4)		794	795	796	797	738	799	800

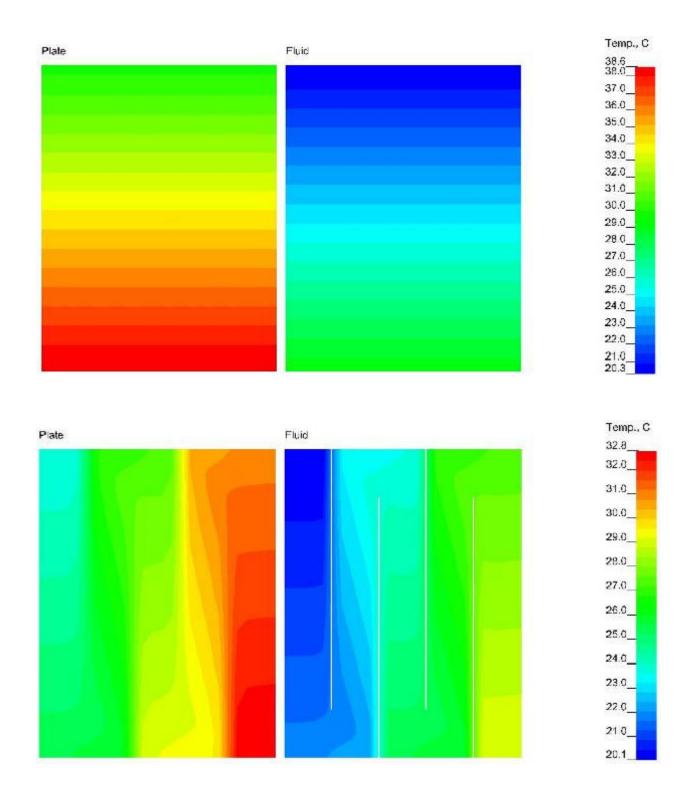
4.1 Color Contour Results at 6 gal/min

Color contour results at 6 gal/min are shown in the following figures for each type of model.

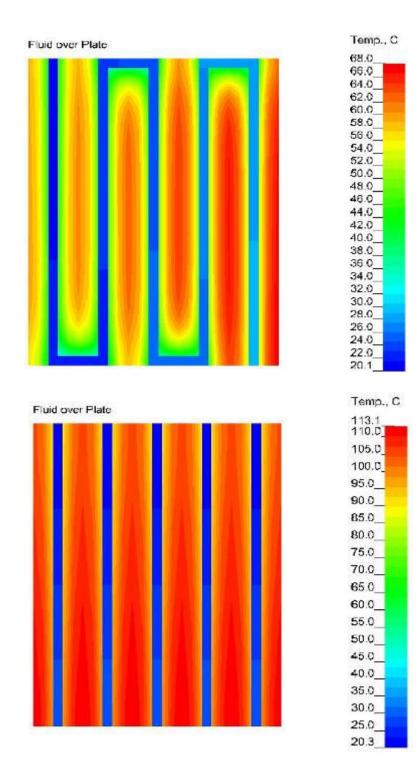
Shown directly below are the lanced and offset models results, the first is the flow through model followed by the 5 pass serpentine model. Since the power was uniformly distributed, the temperature across the width is uniform for the flow through model.



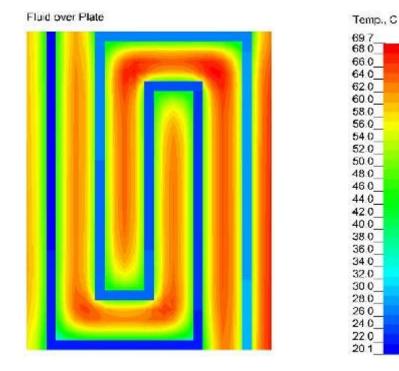
Shown directly below are the pin fin models results, the first are the flow through model followed by the 5 pass serpentine model. Again, since the power was uniformly distributed, the temperature across the width is uniform for the flow through model.



The results shown here are first the serpentine tube model then the parallel tube model.

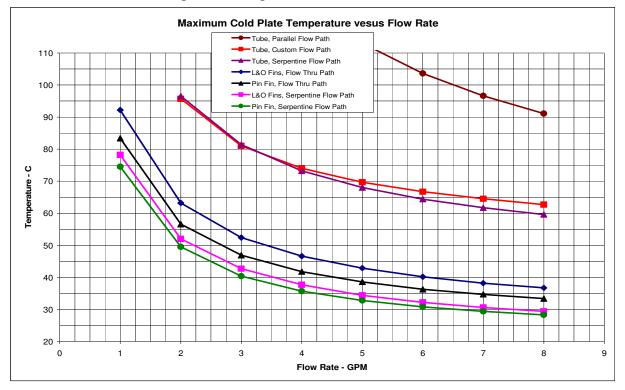


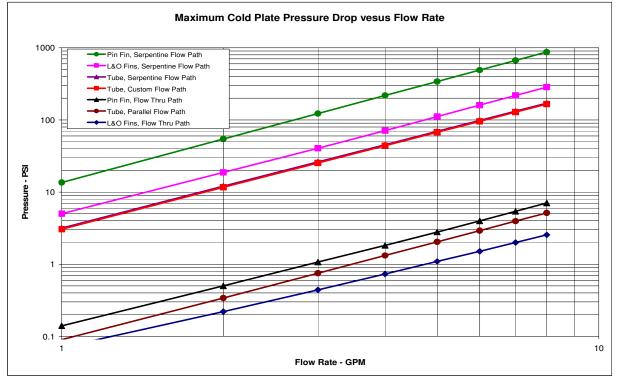
Finally, shown below are the results for the custom tube layout model.



4.2 XY Plot Results

The plots below summarize the temperature and pressure drop results as a function of the water volume flow rate for all models. As stated at the beginning of this report, it was not its purpose to optimize the design; however, it is pretty clear that the best cooling approach must take into account not only the resulting temperature but also the pressure drop. Not only are there limits on allowable temperature but also on allowable pressure drop.





FOR MORE INFORMATION, VISIT OUR WEB SITE: EPAC-INC.COM Tel: (603) 533-9011

5.0	
Table	
Results	

For reference, shown here is the summary of results for the Lanced and Offset model with serpentine path. The results cover the entire flow rate range from 1 to 8 gal/min.

**	******	****	*****	*****	****	****	* * * * * * * * *	****								
	****				7.0b /			******								
**	****				(603) GING ANALY.			*****								
	****	******	********	*******	******	******	*******	*****								
					- Lanced a											
*	FTY FTY RECTA 2 10.27 3 PF4 F 4 PF9 F 5 11.44 6 11.5- 7 17.8- 8 3/32- 9 1/8-1 10 1/8-1 11 1/4-1	PE NGULAR F 'TRI. FI IN FINS -3/8 WAVY 3/8 WAVY 3/8 WAVY 12.22 L 3.95 L & 5.2 L & 1.1 L & 1.94 L & 'IN 12.00	YY FINS FINS FINS C FINS C FINS C FINS O FINS O FINS C FINS T	FI FFI PPI TTU	**************************************	********* TTED)	LEGEND * F V VOLUM M MASS T RESUI E RESUI P RESUI R RESUI E C	AND MAXIMUM TLOWS IE-FT^3/MIN ME-GAL/MIN FLOW-LB/MI TING LB/MI TING LB/MI TING LB/MI TING LB/MI	I I IN (TEMP IN (TEMP IN (DELT) IN (RAM)	CP) OUT) A P) FLOW)	********** FLUID 1 AIR 2 WAT 3 COO 5 EG_ 6 EG_ 7 EG_ 9 FC7 10 GAL 11 HFE 12 HFE 13 JP5 14 JP8 15 LIQ 16 PG_ 17 POL 18 SKY 19 PG_ 20 ENG	ER LANOL20 LANOL25 H2O_60/ H2O_50/5 H2O_40/ H2O_30/7 5 DEN-HT11 7100 7500	T S SI B BO 00 00 00 00 00 00 00 00 00 00 00 00 00	******* EMP	******* ED HEAT HEATIN(****** ING G
	A	NUMBER F	OLLOWED B	BY A DASH	(-) INDIC	ATES THI	S VARIABI	LE IS NOT U	ISED DUR	ING TH						
* * * * * *	*******	*****	******	******	** INPUT *	*****	* * * * * * * * *	*******	*****	* * * * * *	* * * * * * * * 	* * * * * * * * *	** RESU	LTS ****	******	* * * * * * * * * *
FTYPE	FHEIGHT		FIN STYL	FDENSII	Y ITHICK	TEMPIN	TEMPAMB	TEMPWALL	FLOWS		 TEMPOUT 				WEIGHT	TMAX/NODE
9F	0 125	0065	0 000-	14 0005	0.000-	20 0	0.0-	0.0-	1 0.77	2	 66.0S	67 09	 78 1 °	5.00	1 01	78.2/ 800
					0.000-						42.9S					52.0/ 800
9F					0.000-						35.2S					42.7/ 800
9F					0.000-						31.4S					37.7/ 800
9F					0.000-		0.0-				29.15					34.4/ 800
9F					0.000-			0.0-								32.2/ 800
9F								0.0-								30.6/ 800
9F	0.125	.006F	0.000-	14.000F	0.000-	20.0	0.0-	0.0-	8.0v	2	25.7S	27.3S	29.4S	284.28	1.01	29.4/ 800

Copyright ©EPAC-INC.COM

FOR MORE INFORMATION, VISIT OUR WEB SITE: EPAC-INC.COM Tel: (603) 533-9011