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HEAT EXCHANGER SPECIFICATION

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 Subject EG&G Idaho Geothermal Reports

Dale,

OSTI has been working on a project for the last year or so to collect geothermal documents. At the STIP meeting in April, I sent out a plea to the DOE labs to identify and send to OSTI any geothermal documents that we did not already have in our database. I have a problem with a group of reports from EG&G Idaho. I am not sure you are the person correct person to ask for help on this issue. If not, maybe you can direct me to the responsible individual.

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Thanks ahead for your help,
Patty

Patty Simmons

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SUMMARY

This report presents the thermal specifications for three heat exchangers (preheater, boiler and condenser) to be used in a 60 kW prototype power plant installed at the Raft River geothermal facility. This prototype plant is unique in that it will utilize a working fluid of 90% propane - 10% isopentane (by weight) operating at super-critical pressures in a binary geothermal cycle to extract energy from a 280°F geothermal resource. Studies have shown that this super-critical cycle can provide a net performance about 20% higher than that of the optimum dual-boiling isobutane cycle currently designed for the 5 MW Raft River pilot plant.

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1.0 INTRODUCTION

This report presents the details of the analysis used to size the pre-heater, heater and condenser for the 60 kW prototype plant to be installed at the Raft River geothermal test facility. These units will be used to study a thermodynamic cycle in which a mixture of hydrocarbons (90% propane - 10% isopentane) are to be used as the working fluid to extract energy from a 280°F geothermal resource. The working fluid will be maintained at supercritical pressures in the heater units. Studies have shown¹ that this cycle will provide a net power increase of 20% over the dual-boiling isobutane cycle designed for the 5 MW Raft River test facility.

In order to fully utilize the low temperature resource and resultant close temperature approaches in the heat exchangers (pinch points were selected to be as low as 10°F), pure countercurrent flow heat exchangers (E-shells) were selected. This configuration provides the highest thermodynamic efficiency in the heat exchange process. In addition, an effort was made to minimize the effects of differential condensation (separation of the heavier component as it begins to condense) by utilizing in-tube condensation in a vertical configuration. Differential condensation results in a decrease in the already small mean temperature difference in the condenser with a corresponding severe loss in overall cycle efficiency. The study of this effect will be an important result of the prototype test program.

2.0 ANALYSIS

2.1 System Configuration

The heat exchangers used to heat the working fluid to its final temperature of about 247°F will consist of a preheater and a heater, both operating at supercritical pressures of about 660 psia. The preheater will heat 8000 lb/hr of 91°F working fluid to 195°F, and the heater will raise it to 247°F for expansion in the turbine. The countercurrent flow heat source will be 10,550 lb/hr of 280°F geothermal fluid. A condenser will use 66,750 lb/hr of 70°F cooling water to desuperheat, condense, and subcool the working fluid at 143.1 psia. The working fluid enters the condenser at 105°F and exits at 80°F. The system design and fluid state points were provided by the Geothermal Branch² and are shown on the system diagram of Figure 1.

2.2 Computer Codes

The heat exchanger sizing was performed with the ST-4 (Mod. 5.2) and CST-1 (Mod. 1.1) heat exchanger computer codes. These are proprietary codes available to EG&G as a member company of Heat Transfer Research, Inc. (HTRI) and can be used to design and rate shell-and-tube condensers and boilers (CST-1) and shell-and-tube heat exchangers (ST-4). Due to the proprietary nature of the codes, program listings cannot be published; however, documentation of input and output information is permissible.

2.3 Fluid Properties

2.3.1 Working Fluid

The working fluid used in this cycle is a 90% propane - 10% isopentane (by weight) mixture of hydrocarbons. The working fluid in the heaters is operated at a supercritical pressure (660 psia), while the condenser is operated subcritically (143.1 psia). The thermodynamic properties of the mixture were calculated by THERPP³ which uses the Modified-Benedict-Webb-Rubin equation of state. Initial computer runs used mixture transport properties calculated by hand. Part way through this study, the TRAPP

Figure 1. 60 kW test facility system diagram.

code⁴ was acquired from the National Bureau of Standards and was subsequently used to provide much more satisfactory transport properties. Tables 1 and 2 present the thermodynamic and transport properties of the mixture at the condenser pressure (143.17 psia) while Table 3 presents the fluid properties at the heater pressure (630-660 psia). Properties were also obtained at a pressure of 550 psia for use in a study of sub-critical boiling in the heater unit (Tables 4 and 5).

It can be seen that THERPP and TRAPP predict slightly different mixture densities due to different equations of state. As expected, the greatest differences occur near the critical region. The density input into the CST-1 and ST-4 codes was that calculated by the THERPP code to be thermodynamically consistent. The density differences are not felt to have a significant impact on the results of this analysis.

Figure 2 shows the heat capacity of the mixture as a function of temperature and pressure. The augmentation of heat capacity near the critical point can clearly be seen. The heaters were sized so that there were no significant property effects in the preheater unit; its outlet temperature was set at 195°F. All boiling and near-critical point property effects are to occur in the heater unit.

A working fluid fouling resistance of 0.0005 hr-ft²-°F/Btu was used in this study.

2.3.2 Geothermal Fluid and Cooling Water

Water properties were used for both the geothermal fluid and the cooling water. The built-in water properties in the HTRI codes were used. The geothermal fluid fouling resistance was selected as 0.0005 hr-ft²-°F/Btu to be consistent with observed fouling characteristics of the Raft River geothermal resource. A cooling water fouling resistance of 0.001 hr-ft²-°F/Btu was conservatively assumed.

42-381 50 SHEETS 1 SQUARE
42-382 100 SHEETS 1 SQUARE
42-389 200 SHEETS 1 SQUARE
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TABLE 1

WORKING FLUID THERMODYNAMIC
PROPERTIES, 143.17 PSIA

Propane = 1
 $P_{C1} = 617.4$ psia
 $MW_1 = 44.094$
 $w_1 = 0.90$
 $x_1 = .93641$

Isopentane = 2
 $P_{C2} = 483.0$ psia
 $MW_2 = 72.146$
 $w_2 = 0.10$
 $x_2 = .06359$

$$X_1 = \frac{\frac{w_1}{MW_1}}{\frac{w_1}{MW_1} + \frac{w_2}{MW_2}}$$

THERPP code used.

$$h_{90,550} = -795.87 \text{ B/lb}$$

Temp. (°F)	$C_{P\ell}$ (B/lb·°F)	C_{Pv} (B/lb·°F)	h_ℓ (B/lb)	$h_\ell - h_{90,550}$ (B/lb)	h_v (B/lb)	$h_v - h_{90,550}$ (B/lb)	P_ℓ (lb/443)	P_v (lb/443)	w_v	$w_{1,\ell}$	$w_{1,v}$	$x_{1,\ell}$ (x_2)	$x_{1,v}$ (x_2)
1. 105.	*.6034	.4854	*-763.66	*32.21	-646.99	148.88	*32.825	1.3046	1.0	*.60021	.90000	.71068 (.28932)	.93641 (.06359)
2. 100.	.6069	.4845	-772.17	23.70	-650.77	145.10	32.529	1.4548	.9105	.67090	.92253	.76935 (.23065)	.95118 (.04882)
3. 95.	.6104	.4838	-780.68	15.19	-654.49	141.38	32.233	1.4277	.7825	.74159	.94403	.82442 (.17558)	.96503 (.03497)
4. 90.	.6153	.4834	-790.02	5.85	-658.14	137.73	31.883	1.3974	.5474	.82193	.96455	.88307 (.11693)	.97803 (.02197)
5. 89.	.6145	.4833	-792.00	3.87	-658.86	137.01	31.806	1.3909	.4697	.83929	.96854	.89523 (.10477)	.98053 (.01947)
6. 88.	.6178	.4832	-794.02	1.85	-659.58	136.29	31.727	1.3843	.3718	.85710	.97249	.90752 (.09248)	.98300 (.01700)
7. 87.	.6191	.4832	-796.08	-0.21	-660.30	135.57	31.645	1.3776	.2436	.87539	.97642	.91996 (.08004)	.98546 (.01454)
8. 86.	.6206	.4832	-798.19	-2.32	-661.02	134.85	31.560	1.3707	.0678	.89416	.98030	.93254 (.06746)	.98787 (.01213)
9. 85.69	.6210	*.4832	-798.84	-2.97	*-661.24	*134.63	31.565	*1.3686	0	.90000	*.98150	.93641 (.06359)	*.98861 (.01139)
10. 80.	.6217	↓	-802.36	-6.49	↓	↓	31.825	↓	0	↓	↓	↓	↓

* Extrapolated

42-381 50 SHEETS 5 SQUARE
42-382 100 SHEETS 5 SQUARE
42-389 200 SHEETS 5 SQUARE
MADE IN U.S.A.

TABLE 2

WORKING FLUID TRANSPORT
PROPERTIES, 143.17 PSIA

TRAPP code used.

Propane = 1
 $\omega_1 = 0.90$
 $X_1 = 0.93641$

Isopentane = 2
 $\omega_2 = 0.10$
 $X_2 = 0.06359$

	Temp. (°F)	$X_{1,l}$	$X_{2,l}$	$X_{1,v}$	$X_{2,v}$	μ_l (cP)	μ_v (cP)	k_l (Btu-ft-h ⁻¹ °F ⁻¹)	k_v (Btu-ft-h ⁻¹ °F ⁻¹)	P_l (lb/ft ²)	P_v (lb/ft ²)
1.	105.	.71068	.28932	.93641	.06359	.10171	.00900	.05492	.01294	32.120	1.2942
2.	100.	.76935	.23065	.95118	.04882	.10401	.00894	.05555	.01281	32.320	1.2974
3.	95.	.82442	.17558	.96503	.03497	.10101	.00888	.05559	.01268	31.966	1.3017
4.	90.	.88307	.11693	.97803	.02197	.09760	.00882	.05555	.01254	31.548	1.3073
5.	89.	.89523	.10477	.98053	.01947	.09686	.00881	.05553	.01252	31.456	1.3085
6.	88.	.90752	.09248	.98300	.01700	.09609	.00879	.05550	.01249	31.360	1.3098
7.	87.	.91996	.08004	.98546	.01454	.09531	.00878	.05547	.01246	31.261	1.3112
8.	86.	.93254	.06746	.98787	.01213	.09450	.00877	.05544	.01244	31.158	1.3126
9.	85.69	.93641	.06359	.98861	.01139	.09426	.00876	.05543	.01243	31.127	1.3130
10.	80.	.93641	.06359	↓	↓	.09726	.00868	.05626	.01223	31.420	1.3386

42-381 50 SHEETS 1 SQUARE
42-382 100 SHEETS 1 SQUARE
42-389 200 SHEETS 1 SQUARE
MADE IN U.S.A.

TABLE 3

WORKING FLUID THERMODYNAMIC
AND TRANSPORT PROPERTIES, 660 PSIA

Propane $w_1 = .90$, $x_1 = .93641$
I-pentane $w_2 = .10$, $x_2 = .06359$

$$h_{90,550} = -795.87 \text{ B/lb}$$

660 psia

630 psia

THERPP								TRAPP							
Temp. (°F)	Cp (B/lb·°F)	h (B/lb)	h-h _{90,550} (B/lb)	ρ (lb/ft³)	μ (cp)	k (B/ft·h·°F)	P (lb/ft²)	Temp. (°F)	Cp (B/lb·°F)	h (B/lb)	h-h _{90,550} (B/lb)	ρ (lb/ft³)	μ (cp)	k (B/ft·h·°F)	P (lb/ft²)
1. 250.	0.9779	-617.92	177.95	7.2516	.01523	.02258	7.1927	250.	0.8821	-613.67	182.20	6.5355	.01461	.02203	6.4723
2. 232.	1.8091	-640.41	155.46	9.4652	.01770	.02430	9.8960	232.	1.2887	-632.22	163.65	7.9631	.01565	.02248	7.9652
3. 223.	3.9125	-666.26	129.61	13.931	.03394	.03437	19.206	220.	5.3515	-659.27	136.60	11.917	.03407	.03434	19.279
4. 220.	3.4100	-677.37	118.50	16.320	.03674	.03575	20.244	219.	6.0216	-667.57	128.30	13.546	.03520	.03491	19.704
5. 212.	1.7977	-697.41	98.46	20.621	.04222	.03826	22.034	212.	2.4100	-693.76	102.11	19.567	.04085	.03758	21.626
6. 200.	1.1293	-713.98	81.89	23.513	.04860	.04092	23.799	205.	1.4419	-706.45	89.42	22.086	.04506	.03941	22.866
7. 180.	0.8554	-733.27	62.60	26.094	.05772	.04430	25.881	190.	0.9794	-723.75	72.12	24.786	.05257	.04241	24.765
8. 150.	0.7170	-756.54	39.33	28.542	.07058	.04874	28.175	150.	0.7211	-756.44	39.43	28.477	.07014	.04857	28.107
9. 120.	0.6497	-776.95	18.92	30.356	.08374	.05275	29.964	120.	0.6515	-776.94	18.93	30.315	.08337	.05261	29.917
10. 90.	0.6067	-795.75	0.12	31.866	.09840	.05690	31.524	90.	0.6077	-795.78	0.09	31.836	.09807	.05678	31.489

42-381 30 SHEETS 5 SQUARE
42-382 100 SHEETS 5 SQUARE
42-389 200 SHEETS 5 SQUARE
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TABLE 4

WORKING FLUID THERMODYNAMIC
PROPERTIES, 550 PSIA

THERPP code used.

$$h_{90,550} = -795.87 \text{ B/lb}$$

Liquid Pseudo-Crit Pressures

$$P_{sc,l} = \sum_{i=1}^N x_{i,l} P_{c,i} = x_{1,l} P_{c,1} + (1-x_{1,l}) P_{c,2}$$

Propane = 1

$$P_{c,1} = 617.4 \text{ psia}$$

$$MW_1 = 44.094$$

$$\omega_1 = 0.90$$

$$x_1 = .93641$$

Isopentane = 2

$$P_{c,2} = 483.0 \text{ psia}$$

$$MW_2 = 72.146$$

$$\omega_2 = 0.10$$

$$x_2 = .06359$$

$$X_1 = \frac{\frac{\omega_1}{MW_1}}{\frac{\omega_1}{MW_1} + \frac{\omega_2}{MW_2}}$$

Temp. (°F)	$C_{p,l}$ (B/lb·°F)	$C_{p,v}$ (B/lb·°F)	h_l (B/lb)	$h_l - h_{90,550}$ (B/lb)	h_v (B/lb)	$h_v - h_{90,550}$ (B/lb)	P_l (lb/ft²)	P_v (lb/ft²)	ω_v	Mass Fraction		Mole Fract.		$P_{sc,l}$ (psia)
										$\omega_{1,l}$	$\omega_{1,v}$	$x_{1,l}$ (x_2)	$x_{1,v}$ (x_2)	
1. 250.0	↑	0.7303	↑	↑	-604.30	171.57	↑	5,0452	1.0	↑	↑	↑	↑	↑
2. 236.0	↑	0.7959	↑	↑	-614.93	180.94	↑	5,4918	1.0	↑	↑	↑	↑	↑
∞ 3. 220.0	↑	0.9821	↑	↑	-628.87	167.00	↑	6,2905	1.0	↑	↑	↑	↑	↑
4. 209.5	*1.8408	1.4825	*-696.13	99.74	-641.09	154.78	*21,575	7,3287	1.0	*.82925	.90000	.88822 (.11178)	.93641 (.06359)	602.38
5. 207.0	1.9252	1,5715	-699.08	96.79	-643.93	151.94	21,394	7,5947	.7777	.85404	.91314	.90543 (.09457)	.94506 (.05494)	604.69
6. 205.0	2.0033	1.6192	-701.44	94.43	-646.10	149.77	21,240	7,5976	.5010	.87433	.92557	.91925 (.08075)	.95315 (.04685)	606.55
7. 203.5	2.0695	1.6590	-703.21	92.66	-647.74	148.13	21,119	7,6017	.2256	.88982	.93496	.92965 (.07035)	.95922 (.04078)	607.94
8. 202.5	2.1092	*1.6872	-704.42	91.45	*-649.84	146.03	21,049	*7,6040	0	.9000	*.94126	.93641 (.06359)	.96326 (.03674)	608.85
9. 195.0	1.2635	↓	-716.15	79.72	↓	↓	23,260	↓	0	↓	↓	↓	↓	↓
10. 180.0	0.9197	↓	-731.93	63.94	↓	↓	25,573	↓	0	↓	↓	↓	↓	↓

* Extrapolated

42-381 50 SHEETS 5 SQUARE
42-382 100 SHEETS 5 SQUARE
42-389 200 SHEETS 5 SQUARE
Made in U.S.A.

TABLE 5

WORKING FLUID TRANSPORT
PROPERTIES, 550 PSIA

TRAPP code used.

Propane = 1
 $w_1 = 0.90$
 $x_1 = 0.93641$

Isopentane = 2
 $w_2 = 0.10$
 $x_2 = 0.06359$

Temp. (°F)	$x_{1,l}$	$x_{2,l}$	$x_{1,v}$	$x_{2,v}$	μ_l (Centip.)	μ_v (Centip.)	k_l (Btu-in.-hr. ⁻¹)	k_v (Btu-in.-hr. ⁻¹)	ρ_l (lb./ft. ³)	ρ_v (lb./ft. ³)
1. 250.0	↑	↑	↑	↑	↑	.01350	↑	.02116	↑	5.0034
2. 236.0	↑	↑	↑	↑	↑	.01357	↑	.02077	↑	5.4431
3. 220.0	↑	↑	↑	↑	↑	.01388	↑	.02051	↑	6.2399
4. 209.5	.88822	.11178	.93641	.06359	.04524	.01462	.03906	.02086	22.955	7.3419
5. 207.0	.90543	.09457	.94506	.05494	.04458	.01468	.03888	.02090	22.771	7.4302
6. 205.0	.91925	.08075	.95315	.04685	.04403	.01467	.03872	.02088	22.614	7.4499
7. 203.5	.92965	.07035	.95922	.04078	.04359	.01467	.03859	.02087	22.489	7.4650
8. 202.5	.93641	.06359	.96326	.03674	.04332	.01467	.03851	.02087	22.411	7.4757
9. 195.0	↓	↓	↓	↓	.04778	↓	.04039	↓	23.626	↓
10. 180.0	↓	↓	↓	↓	.05532	↓	.04333	↓	25.398	↓

Figure 2 Heat capacity of working fluid near critical point.

2.4 Cases Studied

A large number of computer runs was required to obtain a reasonably optimum final configuration for each unit. Many parameters were studied including tube size, tube spacing, fins vs. no fins, shell diameter and length, shell orientation, working fluid location, etc.

Approximately thirty runs each were needed to obtain the final heater and preheater configuration, while the condenser required about twenty-two runs.

Initially the heater unit was split into a heater-superheater dual unit. However, it was decided that it would be undesirable to potentially have the critical point occur between heat exchangers with the associated large variation in properties. Also, there would be the possibility of boiling occurring in the wrong unit, resulting in underdesign of one of the units. Also, a study showed no significant thermal advantage to the heater-superheater dual unit so a single heater was used in conjunction with the preheater.

3.0 RESULTS

3.1 Preheater

The preheater will be required to heat 8000 lb/hr of 660 psia working fluid from 90°F to 195°F with 10,550 lb/hr of geothermal brine entering at 206.3°F. This is a heat duty of 615,798 Btu/hr based on the working fluid state points and flow rate.

Initial runs were used to establish the optimum tube size and spacing. Tube diameters from 3/8" to 3/4" were investigated, with the 1/2" tube looking most promising. Runs for pitches of 0.625" and 0.688" showed the larger pitch to have a lower pressure drop without too severe a penalty in heat transfer so it was selected over the smaller spacing. Cleaning and vibration characteristics will also be better for the larger spacing. Tube layout angles of 30, 45, 60 and 90 degrees were investigated, with the 90° layout angle providing the better performance and also being easier to service. Early studies placed the high pressure working fluid on the tube side but these runs showed that the heat exchangers were relatively small in diameter, indicating that there probably would not be a severe penalty placed on shell thickness if the high pressure fluid was placed on the shell side. In addition, the working fluid film coefficient was the lowest and external fins could be used to bring the working fluid thermal resistance more in line with the geothermal fluid resistance. Since neither tube vibration or shellside pressure drop was a problem with this unit, horizontal segmental baffles were selected for their better heat transfer characteristics.

The specifications of the preheater selected for this application are detailed in Table 6 and the summary computer printout from the ST-4 code is shown in Appendix A. The preheater is a 28 foot horizontal E-shell unit with a 4.813 inch I.D. and 34.9% horizontal cut segmental baffles. The 24 Admiralty metal tubes are externally finned with 19 fins/inch and a nominal O.D. of 0.500 inch.

TABLE 6 - HEAT EXCHANGER SPECIFICATION SHEET FOR PREHEATER

1					JOB NO.
2	CUSTOMER				REFERENCE NO. <i>Run D5S</i>
3	ADDRESS				PROPOSAL NO.
4	PLANT LOCATION				DATE
5	SERVICE OF UNIT <i>PREHEATER</i>				ITEM NO.
6	SIZE <i>5 X 336</i>	TYPE <i>BEM</i>	(HORIZ.) VERT.	CONNECTED IN	
7	SQ. FT. SURF./UNIT (GROSS) <i>XXX</i>	<i>215</i>	SHELLS/UNIT <i>1</i>	SQ. FT. SURF./SHELL (GROSS) (EFF.)	
8	PERFORMANCE OF ONE UNIT				
9	SHELL SIDE		TUBE SIDE		
10	FLUID CIRCULATED	Working Fluid **		Geothermal Fluid	
11	TOTAL FLUID ENTERING	8000 lb/hr		10550 lb/hr	
12	VAPOR				
13	LIQUID				
14	STEAM				
15	NON-CONDENSABLES				
16	FLUID VAPORIZED OR CONDENSED				
17	STEAM CONDENSED				
18	DENSITY (IN/OUT) **	31.87/25.23	LB/FT ³	60.61	LB/FT ³
19	VISCOSITY	0.0984/0.0547	CP	0.355	CP
20	MOLECULAR WEIGHT				
21	SPECIFIC HEAT	0.607/0.946	BTU/LB.* F	0.909	BTU/LB.* F
22	THERMAL CONDUCTIVITY	0.0569/0.0431	BTU/HR-FT.* F	0.379	BTU/HR-FT.* F
23	LATENT HEAT	BTU/LB		BTU/LB	
24	TEMPERATURE IN	90	* F	206.3	* F
25	TEMPERATURE OUT	195	* F	147.8	* F
26	OPERATING PRESSURE	648	PSIG	188	PSIG
27	NO. PASSES PER SHELL	1		1	
28	VELOCITY	0.44	FT/SEC	4.02	FT/SEC
29	PRESSURE DROP	0.59	PSI	3.63	PSI
30	FOULING RESISTANCE (MIN.)	0.0005		0.0005	
31	HEAT EXCHANGED-BTU/HR	615 789		MTD CORRECTED* F	28.4
32	TRANSFER RATE—SERVICE	112.23		CLEAN	156.45
33	CONSTRUCTION OF ONE SHELL				
34	DESIGN PRESSURE	800	PSI	230	PSI
35	TEST PRESSURE		PSI		PSI
36	DESIGN TEMPERATURE	300	* F	300	* F
37	TUBES Admiralty***	NO. 24 O.D. 0.500	NOM. TK. 0.042	Length 336	Pitch 0.688 90°
38	SHELL Carbon Steel	I.D. 0.5563	SHELL COVER (INTEG) (REMOV)		
39	CHANNEL OR BONNET	CHANNEL COVER			
40	TUBESHEET—STATIONARY	TUBESHEET—FLOATING			
41	BAFFLES—CROSS 24	TYPE Segmental	FLOATING HEAD COVER		
42		(horizontal) Cut	IMPINGEMENT PROTECTION		
43	TUBE SUPPORTS				
44	TUBE TO TUBESHEET JOINT				
45	GASKETS				
46	CONNECTIONS—SHELL SIDE	IN 2	OUT 2	RATING 600 lb	
47	CHANNEL SIDE	IN 2	OUT 2½	RATING 150 lb	
48	CORROSION ALLOWANCE—SHELL SIDE	TUBE SIDE			
49	CODE REQUIREMENTS	ASME Sec. VIII Div. 1 "U" Stamped TEMA CLASS R or C			
50	REMARKS * AVERAGE IF ONLY ONE VALUE GIVEN				
51	**90% (Mass) Propane 10% Isopentane				
52	***Similar to Wolverine "Low Fin" Tubing - 19 Fins/inch A out/A in=4.034				
53					
54					

The total heat transfer surface area is 214.4 ft^2 , the overall design U is $112.25 \text{ Btu/ft}^2\text{-hr-}^\circ\text{F}$ and the effective ΔT is 28.4°F , for a design heat duty of 683,486 Btu/hr. Since the required heat duty is 615,798 Btu/hr, the design margin is 11 percent.

3.2 Heater

The heater will be required to heat 8000 lb/hr of 660 psia working fluid from 195°F to 247°F with 10,550 lb/hr of geothermal fluid entering at 280°F . This is a heat duty of 778,382 Btu/hr based on the working fluid state points and flow rate.

The sequence of screening runs paralleled that of the preheater unit with the same general results. The greater heat duty in the heater resulted in a somewhat larger unit than the preheater.

The specifications of the heater selected for this application are detailed in Table 7 and the summary computer printout from the ST-4 code is shown in Appendix B. The heater is a 29 foot horizontal E-shell unit with a 5.761 inch I.D. and 34.7% horizontal cut segmental baffles. The 38 Admiralty metal tubes are externally finned with 19 fins/inch and a nominal O.D. of 0.500 inch.

The total heat transfer surface area is 351.5 ft^2 , the overall design U is $120.10 \text{ Btu/ft}^2\text{-hr-}^\circ\text{F}$ and the effective ΔT is 20.6°F , for a design heat duty of 859,632 Btu/hr. Since the required heat duty is 778,382 Btu/hr the design margin is 12 percent.

Once this heater was sized an additional computer run was made to investigate the performance of the unit in a boiling mode. This mode will be applicable to low pressure (550 psia) operation, e.g., during system startup and shutdown. Since the fluid properties at 550 psia were different than those at 660 psia, maintaining the same heat duty resulted in the working fluid outlet temperature dropping from 247.0°F to 231.5°F .

**TABLE 7 - HEAT EXCHANGER SPECIFICATION SHEET
FOR VAPOR GENERATOR**

1					JOB NO.	
2	CUSTOMER				REFERENCE NO. <i>RUN D6S</i>	
3	ADDRESS				PROPOSAL NO.	
4	PLANT LOCATION				DATE	
5	SERVICE OF UNIT <i>VAPOR GENERATOR</i>				ITEM NO.	
6	SIZE <i>6 x 348</i>	TYPE <i>BEM</i>	(HORIZ.) CONNECTED IN			
7	SQ. FT. SURF./UNIT. <i>(GROSS) 352</i>	SHELLS/UNIT <i>1</i>	SQ. FT. SURF./SHELL <i>(GROSS) (EFF.)</i>			
8	PERFORMANCE OF ONE UNIT					
9		SHELL SIDE		TUBE SIDE		
10	FLUID CIRCULATED	<i>Working Fluid**</i>		<i>Geothermal Fluid</i>		
11	TOTAL FLUID ENTERING	<i>8000 lb/hr</i>		<i>10550 lb/hr</i>		
12	VAPOR					
13	LIQUID					
14	STEAM					
15	NON-CONDENSABLES					
16	FLUID VAPORIZED OR CONDENSED					
17	STEAM CONDENSED					
18	DENSITY (IN/OUT)	<i>45.23/7.62</i>	LB/FT ³	<i>59.08</i>	LB/FT ³	
19	VISCOSITY	<i>0.0547/0.0156</i>	CP	<i>0.238</i>	CP	
20	MOLECULAR WEIGHT					
21	SPECIFIC HEAT	<i>0.946/1.116</i>	BTU/LB.*F	<i>1.008</i>	BTU/LB.*F	
22	THERMAL CONDUCTIVITY	<i>0.0431/0.0229</i>	BTU/HR-FT.*F	<i>0.388</i>	BTU/HR-FT.*F	
23	LATENT HEAT		BTU/LB		BTU/LB	
24	TEMPERATURE IN	<i>195</i>	*F	<i>280</i>	*F	
25	TEMPERATURE OUT	<i>247</i>	*F	<i>206.8</i>	*F	
26	OPERATING PRESSURE	<i>648</i>	PSIG	<i>188</i>	PSIG	
27	NO. PASSES PER SHELL	<i>1</i>		<i>1</i>		
28	VELOCITY	<i>0.65</i>	FT/SEC	<i>2.61</i>	FT/SEC	
29	PRESSURE DROP	<i>0.70</i>	PSI	<i>1.77</i>	PSI	
30	FOULING RESISTANCE (MIN.)	<i>0.0005</i>		<i>0.0005</i>		
31	HEAT EXCHANGED-BTU/HR	<i>778382</i>	MTD CORRECTED * F	<i>20.6</i>		
32	TRANSFER RATE—SERVICE	<i>120.10</i>	CLEAN	<i>172.13</i>		
33	CONSTRUCTION OF ONE SHELL					
34	DESIGN PRESSURE	<i>800</i>	PSI	<i>230</i>	PSI	
35	TEST PRESSURE		PSI		PSI	
36	DESIGN TEMPERATURE	<i>300</i>	*F	<i>300</i>	*F	
37	TUBES <i>Admiralty***</i>	<i>NO.38 O.D.500 Nom Tk. .042</i>	Length <i>348</i>	PITCH <i>0.688</i>	<i>90°</i>	
38	SHELL <i>Carbon steel</i>	I.D. <i>6.625</i>	SHELL COVER		(INTEG) (REMOV)	
39	CHANNEL OR BONNET	CHANNEL COVER				
40	TUBESHEET—STATIONARY	TUBESHEET-FLOATING				
41	BAFFLES—CROSS <i>24</i>	TYPE <i>Segmental</i>	FLOATING HEAD COVER			
42		<i>(Horizontal Cut)</i>		IMPINGEMENT PROTECTION		
43	TUBE SUPPORTS	<i>(34.07% Dia.)</i>				
44	TUBE TO TUBESHEET JOINT					
45	GASKETS					
46	CONNECTIONS—SHELL SIDE	IN <i>2</i>	OUT <i>2</i>	RATING	<i>600 lb</i>	
47	CHANNEL SIDE	IN <i>2½</i>	OUT <i>2½</i>	RATING	<i>150 lb</i>	
48	CORROSION ALLOWANCE—SHELL SIDE	TUBE SIDE				
49	CODE REQUIREMENTS <i>ASME Sec. VIII Div. 1 "U" Stamped</i>	TEMA CLASS <i>R or C</i>				
50	REMARKS * AVERAGE IF ONLY ONE VALUE GIVEN					
51	<i>** 90% (Mass) Propane 10% Isopentane</i>					
52	<i>*** Similar to Wolverine "Low Fin" Tubing - 19 fins/inch, A out/A in = 4.034</i>					
53						
54						

Appendix C shows the summary computer printout from the CST-1 code used in this run. For this case the total heat transfer surface area is 351.3 ft^2 , the overall design U is $100.24 \text{ Btu/ft}^2\text{-hr-}^\circ\text{F}$, and the effective ΔT is 27.54°F , for a design heat duty of $969,802 \text{ Btu/hr}$. Since the required heat duty is $778,400 \text{ Btu/hr}$, the design margin in the boiling mode has risen to 24.6%.

3.3 Condenser

The condenser will be required to condense 8000 lb/hr of working fluid at 143.2 psia . The working fluid will enter the condenser at 105°F and exit at 80°F . Cooling water will be supplied at a flow rate of $66,750 \text{ lb/hr}$ and a temperature of 70°F . This requires a heat duty of $1,242,960 \text{ Btu/hr}$ based on the working fluid state points and flowrate.

In-tube condensation was selected early in the study to minimize the effect of differential condensation on the mean temperature difference. A vertical downflow condensation path will also aid in maintaining integral condensation. Other reasons for selecting the vertical orientation were that there is piping now available at the Raft River site for a vertical condenser, and computer simulations showed a slight performance increase over a horizontal orientation. Noranda-type internally finned tubes were selected to lower the tubeside thermal resistance relative to that on the shell side; however, the tubeside resistance still dominates and is about 58% of the total.

The specifications of the condenser selected for this application are detailed in Table 8 and the summary computer printout from the CST-1 code is shown in Appendix D. The condenser is an 18 foot vertical E-shell limit with a 15.875 inch I.D. and 19.0% cut segmental baffles. The 418 90% copper - 10% nickel tubes are internally finned in the longitudinal direction and have a nominal O.D. of 0.500 inch.

The total heat transfer surface area is 969.5 ft^2 , the overall design U is $120.67 \text{ Btu/ft}^2\text{-hr-}^\circ\text{F}$ and the effective ΔT is 11.88°F , for a design

TABLE 8 - HEAT EXCHANGER SPECIFICATION SHEET FOR CONDENSER

1						JOB NO.
2	CUSTOMER					REFERENCE NO. RUN CD22
3	ADDRESS					PROPOSAL NO.
4	PLANT LOCATION					DATE
5	SERVICE OF UNIT CONDENSER					ITEM NO.
6	SIZE 17 x 216	TYPE BEM		WORKS (VERT.)	CONNECTED IN	
7	SQ. FT. SURF./UNIT (GROSS) X#X	985	SHELLS/UNIT	SQ. FT. SURF./SHELL (GROSS) (EFF.)		
8	PERFORMANCE OF ONE UNIT					
9				TUBE SIDE		
10	FLUID CIRCULATED	Cooling Water		Working Fluid **		
11	TOTAL FLUID ENTERING	66750 lb/hr		8000 lb/hr		
12	VAPOR					
13	LIQUID					
14	STEAM					
15	NON-CONDENSABLES					
16	FLUID VAPORIZED OR CONDENSED					
17	STEAM CONDENSED					
18	DENSITY (IN/OUT) **	62.24/62.04	LB/FT ³	1.305/31.824	LB/FT ³	
19	VISCOSITY	0.978/0.783	CP	0.0090/0.0973	CP	
20	MOLECULAR WEIGHT					
21	SPECIFIC HEAT	1.00/1.00	BTU/LB.* F	0.485/0.613	BTU/LB.* F	
22	THERMAL CONDUCTIVITY	0.355/0.360	BTU/HR-FT.* F	0.0129/0.0563	BTU/HR-FT.* F	
23	LATENT HEAT					
24	TEMPERATURE IN	70.0	* F	106.0	* F	
25	TEMPERATURE OUT	88.6	* F	81.0	* F	
26	OPERATING PRESSURE	80	PSIG	131.	PSIG	
27	NO. PASSES PER SHELL	1		1		
28	VELOCITY	0.88	FT/SEC	2.24	FT/SEC	
29	PRESSURE DROP	1.92	PSI	0.21	PSI	
30	FOULING RESISTANCE (MIN.)	0.001		0.0005		
31	HEAT EXCHANGED-BTU/HR	1242 960	MTD CORRECTED* F	11.71		
32	TRANSFER RATE—SERVICE	109.13	CLEAN	140.51		
33	CONSTRUCTION OF ONE SHELL					
34	DESIGN PRESSURE	175	PSI	350	PSI	
35	TEST PRESSURE		PSI		PSI	
36	DESIGN TEMPERATURE ***	300	* F	300	* F	
37	TUBES 90-10 Cupro Nickel No. 418 OD 0.500 ID 0.417 Length 216 Pitch 0.688-90°					
38	SHELL Carbon Steel	I.D.	0.018.00	SHELL COVER	(INTEG) (REMOV)	
39	CHANNEL OR BONNET			CHANNEL COVER		
40	TUBESHEET—STATIONARY			TUBESHEET-FLOATING		
41	BAFFLES—CROSS 34	TYPE Segmental		FLOATING HEAD COVER		
42		(19% Diam Cut)		IMPINGEMENT PROTECTION		
43	TUBE SUPPORTS					
44	TUBE TO TUBESHEET JOINT					
45	GASKETS					
46	CONNECTIONS—SHELL SIDE	IN 3	OUT 3	RATING	150 lb	
47	CHANNEL SIDE	IN 2½	OUT 3	RATING	300 lb	
48	CORROSION ALLOWANCE—SHELL SIDE			TUBE SIDE		
49	CODE REQUIREMENTS ASME Sec. VIII Div. I "U" Stamped			TEMA CLASS R or C		
50	REMARKS * AVERAGE IF ONLY ONE VALUE GIVEN					
51	**90% (Mass) Propane 10% Isopentane					
52	***Similar to Noranda Forge Fin No. 6 Internal, Longitudinal, Integral					
53	Fins - 10 Fins = 0.050 high A out/A in = 0.701					
54						

heat duty of 1,389,836 Btu/hr. Since the required heat duty is 1,242,960 Btu/hr, the design margin is 12 percent.

4.0 CONCLUSIONS

The heat exchangers for the 60 kW test facility at Raft River have been sized. Design constraints for each heat exchanger incorporated into this study were to attain a minimum heat transfer area with a 10% design margin when fouled. Working fluid pressure drops were kept under 5 psi, while water pressure drops were less than 2 psi.

In-tube condensation was selected to improve the condenser performance by encouraging integral condensation. Hopefully, the effect of this can be checked during the test program, perhaps by varying the working fluid flow rate to vary from a high shear (good mixing for integral condensation) to a low shear (poor mixing for differential condensation) flow regime and monitoring the performance of the condenser.

5.0 REFERENCES

1. O. J. Demuth, "Analyses of Mixed Hydrocarbon Binary Thermodynamic Cycles for Moderate Temperature Geothermal Resources", PG-G-80-041, February 1981.
2. Personal communication with C. J. Bliem, Geothermal Branch, February 1981.
3. R. S. Deeds, "THERPP - A Thermodynamic Properties Program", TREE-1081, August 1979.
4. J. F. Ely and H. J. M. Hanley, "A Computer Program for the Prediction of Viscosity and Thermal Conductivity in Hydrocarbon Mixtures", Technical Note to be published, National Bureau of Standards, Boulder, CO, TBP.

APPENDIX A

COMPUTER OUTPUT OF ST-4 RUN
FOR PREHEATER

(Pages A-1 to A-4)

CARD 1 CONTROL INFORMATION				*CARD 2* SHELLSIDE INFORMATION				*CARD 3* SHELL, BUNDLE AND BAFFLE			
01	CIN	INPUT UNITS CODE	0.	01	CNSD	SCALE STRIP CODE	0.	01	NSD	SHELL ID	4.813
02	COUT	OUTPUT UNITS CODE	0.	02	CNSD	PAIRS OF STRIPS	0.	02	NSD	BAFFLE CUT (PCT)	0.00
03	CCI	CALCULATION TYPE	1.*	03	USMAX	MAX SHELL SIZE	0.000	03	ENNB	FRACF WINDOW AREA	0.000
04	CHS	FLUID ALLOCATION	2.	04	USMIN	MIN SHELL SIZE	0.000	04	HUVE	TUBE RUNS OVERLAP	0.00
05	CHR	HEAT DUTY CODE	3.	05	UMAX	MAX OVERALL CUL	0.00	05	ZCPL	NO OF CROSSPASS	0.
06	ODUTY	HEAT DUTY (1.0E6)	0.0000	06	KVO	FIN-V-SQUARED	1500.000*	06	XLBD	CENTRAL BAF SPACE	0.0000
07	CTP	TUBE PASS CODE	4.	07	CFIC	TUBE COUNT CODE	0.	07	XLBD	INLET BAF SPACING	0.0000
08	ZTPD	NO OF TUBE PASSES	1.*	08	HNTO1	INLET HEIGHT	0.000	08	XLBD	OUTLET BAF SPACE	0.0000
09	ZMSD	SHELLS IN SERIES	1.*	09	HNTO2	OUTLET HEIGHT	0.000	09	PPVN	NO VERT PASS LANE	0.
10	ZMPD	SHELLS IN PARALLEL	1.*	10	SFHS1	INLET PENALTY	1.000*	10	PPVN	NO HORIZ PASS LANE	0.
11	CSI	SHELL CONSTRUCTION	1.*	11	SFHS2	OUTLET PENALTY	1.000*	11	WPPV	WIDTH VERT LANES	0.000
12	CTBH	EXCHANGER TYPE	0.	12	CEUS	EQUAL END SPACING	0.	12	WPPV	WIDTH HORIZ LANES	0.000
13	CB1	REAR HEAD TYPE	1.	13	CNOZ	NOZZLE ORIENTATION	0.	13	XLBD	BAFFLE THICKNESS	0.0000
14	CB2	BAFFLE TYPE	1.*	14	CB3	WINDOW CONSTRUCT	0.	14	XLBD	TUBEHOLE BAF THIK	0.0000
15	BCC	BAFFLE ORIENTATION	1.	15	DBCK	CLEARANCE CODE	0.	15	GDPT	LONG BAFFLE CODE	0.
16	GOUTS	TUBESIDE STEPWISE	1.	16	CEU	BAF-SHELL CLEAR	0.0000	16	GDCL	DELTA END CORR	0.
17				17	CAU	TUBE-BAF CLEAR	0.0000	17	DDVY	MULTIPLE NOZ CODE	1.*
18	GOMEX	SERIES STEP EVAL	0.	18	CTUD	BUND-SHELL CLEAR	0.0000	18			
19	COPI	OUTPUT CODE	0.	19	GDPS	SHELLSIDE DP USE	1.	19	TEMA	TEMA SHELL STYLE	ALL*
20	CMON	MONITOR CODE	1.	20	CBMX	MAX BAF SPACING	0.000	20	CAXL	TUBESIDE AXIAL NOZ	0.
21	CARR	AUTO RATE CODE	0.	21	PMAX	TOTAL DP	0.00				

CARD 4 TUBESIDE INFORMATION				*HOT FLUID NAME -GEOLFOID**				*COLD FLUID NAME -WOKRING**			
01	TLOV	TUBE LENGTH	24.000	*CARD 6* PROCESS INFORMATION				*CARD 8* PROCESS INFORMATION			
02	TLMAX	MAXIMUM LENGTH	30.000	01	FCUN1	FLUID CONDITION	0.	01	FCUN2	FLUID CONDITION	0.
03	TLINC	LENGTH INCREMENT	1.000	02				02			
04	PT	TUBE PITCH	0.880	03	W01	FLOW RATE (1.0E3)	10.55	03	W02	FLOW RATE (1.0E3)	0.00
05	TLA	LAYOUT ANGLE	90.	04	TIND1	INLET TEMPERATURE	206.30	04	TIND2	INLET TEMPERATURE	90.00
06	ZNTD	NO OF TUBES/SHELL	0.	05	TOUT1	OUTLET TEMPERATURE	0.00	05	TOUT2	OUTLET TEMPERATURE	195.00
07	DTU	TUBE OD	0.5000	06	P11	INLET PRESSURE	200.00	06	P12	INLET PRESSURE	560.00
08	TTB	TUBE THICKNESS	0.0580	07	RFD1	FOUL RESISTANCE	0.0000	07	RFD2	FOUL RESISTANCE	0.0000
09	CMAT	TUBE MATERIAL CODE	41.	08	FL1	FOUL LAYER THICK	0.0000	08	FL2	FOUL LAYER THICK	0.0000
10	CTK	THERMAL CONDUCT	0.000	09	HCF1	HEAT TRANS COEF	0.00	09	HCF2	HEAT TRANS COEF	0.00
11	CFIN	FINNED TUBE CODE	1.	10	SF1	SAFETY FACTOR	1.000*	10	SF2	SAFETY FACTOR	1.000*
12	XNF	NO OF FINS/LENGTH	19.00	11	YIN1	INLET VAPOR QUAL	0.000	11	YIN2	INLET VAPOR QUAL	0.000
13	XFH	FIN HEIGHT	0.6570	12	YEX1	EXIT VAPOR QUALITY	0.000	12	YEX2	EXIT VAPOR QUALITY	0.000
14	DFR	FIN ROOT DIAMETER	0.3770	13	TSH1	COND DEG SUP HEAT	0.00	13	TSH2	COND DEG SUP HEAT	0.00
15	XLF	FIN THICKNESS	0.0180	14	TSC1	COND DEG SUB COOL	0.00	14	TSC2	COND DEG SUB COOL	0.00
16	FARP	SURF AREA/LENGTH	0.320								
17	TRTH	THICKNESS UNDER FIN	0.0370								

CARD 5 TUBESHEET AND VIBRATION				*CARD 7* MAXIMUM DP AND VELOCITY				*CARD 9* MAXIMUM DP AND VELOCITY			
01	TSID	TUBESHEET THICK	0.0000	01	PM1	ALLOWABLE DP	15.00	01	PM2	ALLOWABLE DP	1.00
02	CS2	EXP JOINT CODE	0.	02	VM1	MAXIMUM VELOCITY	7.00	02	VM2	MAXIMUM VELOCITY	7.00
03	CS3	DOUBLE TUBESHEET	0.	03	PNM1	MAX NOZZLE DP (PCT)	0.00	03	PNM2	MAX NOZZLE DP (PCT)	0.00
04	STRES	ALLOWABLE STRESS	0.00	04	DNZ11	INLET NOZZLE ID	0.000	04	DNZ12	INLET NOZZLE ID	0.100
05	CVIB	VIBRATION CODE	1.	05	DNZ21	OUTLET NOZZLE ID	0.000	05	DNZ22	OUTLET NOZZLE ID	0.100
06	EMOD	ELASTIC MODULUS	0.000	06	PD1	DESIGN PRESSURE	0.00	06	PD2	DESIGN PRESSURE	0.00
07	DTMAT	TUBE DENSITY	0.00	07				07			
10	RE1	0.0300*	11 RE2	08	VMIN1	MINIMUM VELOCITY	0.00	08	VMIN2	MINIMUM VELOCITY	0.00
12	CJ1	0.	13 CJ2	09	F12	PH	0.0	09	F12	PH	0.0
14	CF1	2.7918*	15 CF2	10	F22	TOTAL ALKALINITY	0.	10	F22	TOTAL ALKALINITY	0.
								11	F32	CALCIUM HARDNESS	0.
								12	F42	TOT DISSOLVED SOLID	0.

** A * INDICATES **
 ** A DEFAULT VALUE **

HTRI SHELL AND TUBE HEAT EXCHANGER PROGRAM ST-4 MOD 5.2
 INPUT DATA REPRINT US UNITS

PROBLEM DESCRIPTION-PREHEATER SHELLS (DEFINING)

HTRI VERSION
 PAGE NO- 2
 CASE-055

HOT FLUID (GEOLFLUID) 1 PHYSICAL PROPERTIES
 COMPONENT 1
 NAME GEOLFLUID

CARD 10 PHYSICAL PROPERTY CONTROL
 03 HMMN 0.0000
 04 APC 1.
 05 API 0.00
 06 AMW 0.00
 07 HCF 0.00
 08 PZERO 0.

CALCULATED PHYSICAL PROPERTY CONSTANTS
 D.B. NAME WATER
 MOL FRACT 1.0000
 WT. FRACT 1.0000
 MOL WT. 18.02
 CRIT TEMP 1165.20
 CRIT PRES 3208.20
 TEMPERATURE LIMITS
 UPPER 1165.20
 LOWER 494.69

CALCULATED MIXTURE VALUES
 MOLECULAR WEIGHT 18.02
 CRITICAL VALUES-TEMPERATURE 1165.20 PRESSURE 3208.20
 TEMPERATURE LIMITS-UPPER 1165.20 LOWER 494.69

A-2

HTRI SHELL AND TUBE HEAT EXCHANGER PROGRAM ST-4 MOD 5.2
 INPUT DATA REPRINT US UNITS

PROBLEM DESCRIPTION-PREHEATER SHELLS (DEFINING)

HTRI VERSION
 PAGE NO- 3
 CASE-055

COLD FLUID (WORKING) 1 PHYSICAL PROPERTIES PROFILE

40 PXP	ISOBARS	(K=1)	630.000	(K=2)	660.000							
FPC		0.00	0.00	0.00	0.00							
51 TYP	(K)	1=1	1=2	1=3	1=4	1=5	1=6	1=7	1=8	1=9	1=10	
	1	250.00	232.00	220.00	219.00	212.00	205.00	190.00	150.00	120.00	90.00	
	2	250.00	232.00	223.00	220.00	212.00	200.00	180.00	150.00	120.00	90.00	
43 YXP												
44 ROVP												
45 XMVVP												
46 XRVVP												
47 HVXP												
48 CPVP												
50 ROLP	1	6.5360	7.9630	11.9200	13.5500	19.5700	22.0900	24.7900	28.4800	30.3200	31.8400	
	2	7.2520	9.4650	13.9300	16.3200	20.6200	23.5100	26.0900	28.5400	30.3500	31.8700	
51 XMULP	1	.0146	.0157	.0341	.0352	.0409	.0451	.0526	.0701	.0834	.0961	
	2	.0152	.0177	.0339	.0367	.0422	.0466	.0577	.0706	.0837	.0964	
52 XKLP	1	.0220	.0225	.0343	.0349	.0376	.0394	.0424	.0486	.0526	.0568	
	2	.0226	.0243	.0344	.0358	.0383	.0409	.0443	.0487	.0528	.0569	
53 HLXP	1	182.2000	163.6500	136.6000	128.3000	102.1100	89.4200	72.1200	39.4300	18.9300	.0900	
	2	177.9500	155.4600	129.6100	118.5000	98.4600	81.8900	62.6000	39.3300	18.9200	.1200	
54 CPLP	1	.8821	1.2890	5.3920	6.0220	2.4100	1.4420	.9790	.7210	.6520	.6080	
	2	.9779	1.8090	3.9130	3.4100	1.7980	1.1290	.8550	.7170	.6550	.6070	
55 SIGP												
56 PCLP												

** CARD 42 (OXF) AND CARD 49 (PCVP) ARE NOT USED IN THE ST-4 PROGRAM **

***** GRAY ERRORS ** CALCULATIONS CONTINUE *****

06-00(1.0) *WARNING* WEIGHT ESTIMATION ROUTINE IS LIMITED TO 600 PSI (4137 KPA) AND 650 F (343 C)

HTRI SHELL AND TUBE HEAT EXCHANGER PROGRAM ST-4 MOD 5.2

HTRI VERSION

PAGE NO- 26

FINAL RESULTS

PROBLEM DESCRIPTION-PALMATER SHELLSIDE(FINNE)

HTRI VERSION

CASE-555

DESIGN CASE

COUNTERCURRENT FLOW IN A T.E.M.A. ALL SHELL WITH SEGMENTAL BAFFLES

REF. SHEET 4

*** PROCESS DATA ***				*** SHELLSIDE PERFORMANCE ***			
01 FLUID NAME	WORKING	COLD SHELLSIDE	HOT TUBESIDE	01 NUM. TUBES	X-FLUX/INCH	183.77	445.6
02 FLUID CONDITION	SENS. LIQUID	SENS. LIQUID	SENS. LIQUID	02 FILM COEF, X-FLUX/INCH	183.77	445.6	445.6
03 TOTAL FLOW RATE	(1.0E+3) (LB/HK)	6.000	10.350	03 FLUX FRACTIONS FOR HEAT TRANSFER	0.920	0.920	0.920
04 TEMPERATURE, IN/OUT (DEG F)	90.0 / 195.0	206.3 / 197.8	206.3 / 197.8	04 A = .336 B = .804 C = .111 E = .035 F = 0.000			
05 TEMPERATURE, AVERAGE/SKIN (DEG F)	142.5 / 156.4	177.1 / 167.4	177.1 / 167.4	*** SHELLSIDE HEAT TRANSFER CORRECTIONS ***			
06 PRESSURE, INLET/AVERAGE (PSIA)	660.00 / 659.50	200.00 / 192.50	200.00 / 192.50	05 TOTAL	BETA	GAMA	END
07 PRESSURE DROP, TOTAL/ALLOW (PSI)	.55 / 1.00	4.25 / 15.00	4.25 / 15.00	06	.888	.920	1.000
08 VELOCITY, CALC./MAX. ALLOW (FT/SEC)	.44 / 7.00	4.02 / 7.00	4.02 / 7.00	*** PRESSURE DROPS *** (PERCENT TOTAL DPT)			
09 FILM COEF (SAF.FACT) (BTU/HK-FT ² -F)	280.03 (1.00)	1624.31 (1.00)	1624.31 (1.00)	07 WING	83.40	NOZZLE	SHELL
10 FOULING RESISTANCE (HR-FT ² -F/BTU)	.00050	.00050	.00050	08 END	.30	(IN/OUT)	TUBE
11 DENSITY (LB/FT ³)	28.9941	60.6066	60.6066	*** H.T. PARAMETERS ***			
12 THERMAL CONDUCTIVITY (BTU/HP-FT-F)	.0497	.3792	.3792	09 WALL CORRECTION	1.312		
13 SPECIFIC HEAT CAPACITY (BTU/LB-F)	.7003	.9986	.9986	10 PRANITL NO.	2.3		
14 VISCOSITY AT AVERAGE TEMP. (CP)	.07386	.35549	.35549	11 AVERAGE REYNOLDS NO.	10107		
15 VISCOSITY AT SKIN TEMP. (CP)	.06785	.38006	.38006	12 BUNDLE INLET REYNOLDS NO.	7256		
*** OVERALL PERFORMANCE DATA *** (TUBESIDE STEPISE)				13 BUNDLE OUTLET REYNOLDS NO.	14603		
16 TOTAL HEAT DUTY REQUIRED (1.0E+6) (BTU/HK)	.615798			14 FOULING LAYER (IN)	0.00000	0.00000	
17 EFFECTIVE MTU, (LMTD)(F)(DELTA) = (DEG F)	28.50(1.00)(1.00) = 28.4			*** THERMAL RESISTANCES *** (PCT. OVERALL)			
18 F FACTOR=(TUBE)(BAFFLES)(F/C)(HOT/COLD)=(1.000)(1.000)(1.000)(.997)				15 SHELL TUBE FOULING METAL	OVERALL		
19 OVERALL COEF, RECD/CLEAN/ACTUAL (BTU/HK-FT ² -F)	101.08 / 156.45 / 112.25			16	40.08	27.88	28.25
*** CONSTRUCTION INFORMATION ***				17 TOTAL FOULING RESISTANCE			
20 NO. SHELLS SERIES 1 PARALLEL 1	TOTAL SURFACE AREA (FT ²)	215		18 DIFFERENTIAL RESISTANCE			
21 NO. PASSES SHELL 1 TUBE 1	EFF. SURF. AREA (FT ² /SHELL)	214.4		*** SHELL NOZZLE INFO. ***			
22 SHELL I.D. (IN)	4.813	TEMA SHELL TYPE	E	19 INSIDE DIAMETER (IN)	2.1		
23 BAFFLE TYPE	HORZ SEGMENTAL	NO. CROSSPASSES/SHELL PASS	24	20 VELOCITY (FT/SEC)	2.70		
24 CENTRAL SPACING (IN)	13.960	BAFFLE CUT (PCT. DIA)	34.92	21 DENSITY (LB/FT ³)	31.370		
25 INLET SPACING (IN)	13.960	CUT AREA(PCT) 1) 32.7 2) 0.0 3) 0.0		22 NOZZLE R-V-SU (LB/FT-S2)	205		
26 OUTLET SPACING (IN)	13.960	CUT HEIGHT FROM CENTER LINE (IN)	0.0	23 BUNDLE R-V-SU (LB/FT-S2)	330		
27 BAFFLE THICKNESS (IN)	.188	PUS-1) .7 2) 0.0 3) 0.0		24 HEIGHT UNDER NOZZLE (IN)	.5		
28 NO. PAIRS SEAL DEVICES	1	IMPINGEMENT PLATE INCLUDED	NO	*** TUBE NOZZLE INFO. ***			
29 TOT. TUBESHEET THICK. (IN)	1.0	PERCENT TUBES REMOVED (NONE)	0.000	25 INSIDE DIAMETER (IN)	1.0		
30 TUBE TYPE (FINS/IN)	19	TUBECOUNT PER SHELL	24	26 VELOCITY (FT/SEC)	6.14		
31 OVERALL LENGTH (FT)	28.000	TUBE PITCH (IN)	.6680	27 DENSITY (LB/FT ³)	59.989		
32 EFFECTIVE LENGTH (FT)	27.920	OUTSIDE DIAMETER (IN)	.500	*** DIAMETRAL CLEARANCES ***			
33 LAYOUT ANGLE (DEG)	90	INSIDE DIAMETER (IN)	.303	28 BAFFLE-TO-SHELL (IN)	.1000		
34 PITCH RATIO	1.654	SURFACE AREA RATIO (OUT/IN)	4.034	29 BUNDLE-TO-SHELL (IN)	.5000		
35 FIN TUBE EQ. DIA. (IN)	.416	FIN EQ. DIA. CONDENSING (IN)	0.0000	30 TUBE-TO-BAFFLE (IN)	.0400		
36 WEIGHT ESTIMATION (LB/SHELL)		DRY	449	31 MULTI-SEG. BAFFLE OV. KAP (IN)	0.000		
		WET	656	32 FIN EFFICIENCY = .947	FIN RESIST. = .00018		

HTRI ST-4 MOD 5.2		HTRI VERSION		PAGE NO- 27	
PROBLEM DESCRIPTION-PREHEATER SHELLSIDE (FINNED)		CASE NO-			
FLOW INDUCED VIBRATION ANALYSIS		SENS. LIQUID SHELLSIDE			
01 LOG DECREMENT .0300 AXIAL STRESS LOADING 0.0 (KPSI)					
02 BETA 2.792 ADDED MASS FACTOR 2.2765		POSITION IN BUNDLE----			
03 LENGTH FOR NATURAL FREQUENCY (FT)		INLET	CENTER	OUTLET	
04 LENGTH/TEMA MAXIMUM SPAN (---)		2.327	2.327	2.327	
05 NUMBER OF SPANS (---)		.731	.731	.731	
06 NATURAL FREQUENCY (FTUBE) (HZ)		24.19*	24.36	24.71	
07 FLOW VELOCITIES					
08 WINDOW (PARALLEL FLOW) (FT/SEC)		2.17	2.39	2.87	
09 WINDOW (CROSSFLOW) (FT/SEC)		.11	.12	.15	
10 C-STREAM VELOCITY (FT/SEC)		.16	.18	.21	
11 E-STREAM VELOCITY (FT/SEC)		1.12	1.23	1.40	
12					
13 CROSSFLOW VELOCITY (FT/SEC)		.40	.44	.52	
14 CRITICAL VELOCITY (FT/SEC)		1.19	1.25	1.37	
15 CROSSFLOW REYNOLDS NUMBER (---)		6622.	8622.	12814.	
16 CROSSFLOW RHU-V-SQ (LB/FT-SZ)		5.	6.	7.	
FREQUENCY RATIOS					
17 (FVXSQ)/(FTUBE) (---)		.037	.041	.049	
18					
19					
20					
DAMAGE NUMBERS					
21 RAFFLE (---)		.0017	.0021	.0025	
22 COLLISION (---)		.0024	.0026	.0032	
23 RHU/SQRT(MU) (SEE STV-1, FIG 9-6)		65.3096	66.5786	68.8308	
VIBRATION AMPLITUDES					
24 PARALLEL FLOW (IN)		.000261	.000287	.000345	
25 CROSSFLOW-INDUCED (IN)		.00036	.00040	.00046	
BUNDLE PARAMETERS AT NOZZLES					
26 IMPINGEMENT PLATE		ENTRANCE	EXIT		
27 FLOW AREA (FT ²)		NO			
28 VELOCITY (FT/SEC)		.6217	.6407		
29 RHU-V-SQ (LB/FT-SZ)		3.22	2.26		
		330.	123.		
30 TEMA E SHELL WITH HORZ SEGMENTAL BAFFLES AND FATS BUNDLE					
31 NUMBER OF INTERMEDIATE SUPPORT PLATES PER SPAN 0					
32 FINNED ADMIRALTY TUBES .5000 DIAMETER (IN) 90 DEGREE LAYOUT					
33 PITCH RATIO 1.654					
* FREQUENCY RATIOS ARE BASED ON THE LOWEST NATURAL FREQUENCY					

APPENDIX B

COMPUTER OUTPUT OF ST-4 RUN
FOR HEATER

(Pages B-4 to B-4)

HTRI SHELL AND TUBE HEAT EXCHANGER PROGRAM 31-4 MOD 3.1
 INPUT DATA PRINT US UNITS

HTRI VERSION

PAGE NO- 1
 CASE NO-

CARD 1 CONTROL INFORMATION				*CARD 2* SHELLSIDE INFORMATION				*CARD 3* SHELL, BUNDLE AND BAFFLE			
01	CIN	INPUT UNITS CODE	0.	01	CNSD	SEAL STRIP CODE	0.	01	USD	SHELL ID	0.761
02	COUT	OUTPUT UNITS CODE	0.	02	ZNSD	PAIRS OF STRIPS	0.	02	BCD	BAFFLE CUT (PCT)	0.00
03	CCI	CALCULATION TYPE	1.*	03	DSMAX	MAX SHELL SIZE	0.000	03	FNWD	FRACI WINDOW AREA	0.000
04	CHS	FLUID ALLOCATION	2.	04	DSMIN	MIN SHELL SIZE	0.000	04	NOVL	TUBE ROWS OVERLAP	0.00
05	CHB	HEAT DUTY CODE	3.	05	UMAX	MAX OVERALL COEF	0.00	05	ZCPD	NO OF CROSSPASSES	0.
06	QDUTY	HEAT DUTY(1.0E6)	0.00000	06	KVD	RHO-V-SQUARED	1500.000*	06	ALBCD	CENTRAL BAF SPACE	0.0000
07	CTP	TUBE PASS CODE	4.	07	CFTC	TUBE COUNT CODE	0.	07	XLBD1	INLET BAF SPACING	0.0000
08	ZTPD	NO OF TUBE PASSES	1.	08	INTD1	INLET HEIGHT	0.000	08	XLBD2	OUTLET BAF SPACE	0.0000
09	ZMSD	SHELLS IN SERIES	1.*	09	INTD2	OUTLET HEIGHT	0.000	09	PPVN	NO VERT PASS LANE	0.
10	ZMPD	SHELLS IN PARALLEL	1.*	10	SFHS1	INLET PENALTY	1.000*	10	PPHN	NO HORIZ PASS LANE	0.
11	CSI	SHELL CONSTRUCTION	1.*	11	SFHS2	OUTLET PENALTY	1.000*	11	WPPV	WIDTH VERT LANES	0.000
12	CTBH	EXCHANGER TYPE	0.	12	CEBS	EQUAL END SPACING	0.	12	WPPH	WIDTH HORIZ LANES	0.000
13	CB1	REAR HEAD TYPE	1.	13	CNUZ	NOZZLE ORIENTATION	0.	13	ALBU	BAFFLE THICKNESS	0.0000
14	CB2	BAFFLE TYPE	1.*	14	CB3	WINDOW CONSTRUCT	0.	14	XLBD1	TUBEHOLE BAF THIK	0.0000
15	BCC	BAFFLE ORIENTATION	1.	15	DBUC	CLEARANCE CODE	0.	15	GCFT3	LONG BAFFLE CODE	0.
16	GOUTS	TUBESIDE STEPWISE	1.	16	CEU	BAF-SHELL CLEAR	0.0000	16	GBDEL	DELTA LMTD CORR	0.
17				17	CAU	TUBE-BAF CLEAR	0.0000	17	DUYBZ	MULTIPLE NOZ CODE	1.*
18	GOMEX	SERIES STEP EVAL	0.	18	CUTD	BUND-SHELL CLEAR	0.0000	18			
19	COPI	OUTPUT CODE	0.	19	GOOPS	SHELLSIDE DP USE	1.	19	TEMA	TEMA SHELL STYLE	ALL*
20	CMON	MONITOR CODE	1.	20	CSMX	MAX BAF SPACING	0.000	20	CAXAL	TUBESIDE AXIAL NOZ	0.
21	CARR	AUTO RATE CODE	0.	21	PMAX	TOTAL DP	0.00				
CARD 4 TUBESIDE INFORMATION				**HOT FLUID NAME -GEOLUID**				**COLD FLUID NAME -WATER**			
01	TLOV	TUBE LENGTH	24.000	*CARD 6* PROCESS INFORMATION				*CARD 8* PROCESS INFORMATION			
02	TLMAX	MAXIMUM LENGTH	30.000	01	FCO1	FLUID CONDITION	0.	01	FCO2	FLUID CONDITION	0.
03	TLINC	LENGTH INCREMENT	1.000	02				02			
04	PT	TUBE PITCH	0.880	03	WD1	FLOW RATE(1.0E3)	10.55	03	WD2	FLOW RATE(1.0E3)	0.00
05	TLA	LAYOUT ANGLE	90.	04	TIHD1	INLET TEMPERATURE	200.00	04	TIHD2	INLET TEMPERATURE	175.00
06	ZNTD	NO OF TUBES/SHELL	0.	05	TIUT1	OUTLET TEMPERATURE	0.00	05	TIUT2	OUTLET TEMPERATURE	247.00
07	OTO	TUBE OD	0.5000	06	PI1	INLET PRESSURE	200.00	06	PI2	INLET PRESSURE	560.00
08	TTB	TUBE THICKNESS	0.0560	07	RFO1	FOUL RESISTANCE	0.0000	07	RFO2	FOUL RESISTANCE	0.0000
09	CMAT	TUBE MATERIAL CODE	41.	08	FL1	FOUL LAYER THICK	0.0000	08	FL2	FOUL LAYER THICK	0.0000
10	CTK	THERMAL CONDUCT	0.000	09	HC1	HEAT TRANS COEF	0.00	09	HC2	HEAT TRANS COEF	0.00
11	CFIN	FINNED TUBE CODE	1.	10	SF1	SAFETY FACTOR	1.000*	10	SF2	SAFETY FACTOR	1.000*
12	XFN	NO OF FINS/LENGTH	19.00	11	YIN1	INLET VAPOR QUAL	0.000	11	YIN2	INLET VAPOR QUAL	0.000
13	XFH	FIN HEIGHT	0.0570	12	YEX1	EXIT VAPOR QUALITY	0.000	12	YEX2	EXIT VAPOR QUALITY	0.000
14	DFR	FIN ROOT DIAMETER	0.3770	13	TSH1	COND DEG SUP HEAT	0.00	13	TSH2	COND DEG SUP HEAT	0.00
15	XLF	FIN THICKNESS	0.0180	14	TSCL	COND DEG SUB COOL	0.00	14	TSCL	COND DEG SUB COOL	0.00
16	FARF	SURF AREA/LENGTH	0.320								
17	TRTH	THICKNESS UNDER FIN	0.0370								
CARD 5 TUBESHEET AND VIBRATION				*CARD 7* MAXIMUM DP AND VELOCITY				*CARD 9* MAXIMUM DP AND VELOCITY			
01	TS1D	TUBESHEET THICK	0.0000	01	PM1	ALLOWABLE DP	15.00	01	PM2	ALLOWABLE DP	1.00
02	CS2	EXP JOINT CODE	0.	02	VM1	MAXIMUM VELOCITY	7.00	02	VM2	MAXIMUM VELOCITY	7.00
03	CS3	DOUBLE TUBESHEET	0.	03	PNM1	MAX NOZZLE DP(PCT)	0.00	03	PNM2	MAX NOZZLE DP(PCT)	0.00
04	STRES	ALLOWABLE STRESS	0.00	04	UNZ11	INLET NOZZLE ID	0.000	04	UNZ12	INLET NOZZLE ID	2.100
05	CVIB	VIBRATION CODE	1.	05	UNZ21	OUTLET NOZZLE ID	0.000	05	UNZ22	OUTLET NOZZLE ID	3.100
06	EMOD	ELASTIC MODULUS	0.000	06	PU1	DESIGN PRESSURE	0.00	06	PU2	DESIGN PRESSURE	0.00
07	DTMAT	TUBE DENSITY	0.00	07				07			
08	RE1	0.0300*	11	08	VMIN1	MINIMUM VELOCITY	0.00	08	VMIN2	MINIMUM VELOCITY	0.00
09	RE2	2.2765*	12	09	F12	TOTAL ALKALINITY	0.	09	F12	TOTAL ALKALINITY	0.
10	CF1	0.	13	10	F22	CALCIUM HARDNESS	0.	10	F22	CALCIUM HARDNESS	0.
11	CF2	2.7918*	14	11	F42	TOT DISSOLVED SOLID	0.	11	F42	TOT DISSOLVED SOLID	0.
12			15	12				12			
13											
14											

** A * INDICATES **
 ** A DEFAULT VALUE **

HOT FLUID (GEOFLUID) 1 PHYSICAL PROPERTIES
 COMPONENT 1
 NAME GEOFLUID

CARD 10 PHYSICAL PROPERTY CONTROL
 03 HMMN 0.0000
 04 APC 1.
 05 API 0.00
 06 AMW 0.00
 07 HCF 0.00
 08 PZERO 0.

CALCULATED PHYSICAL PROPERTY CONSTANTS
 U.B. NAME WATER
 MOL FRACT 1.0000
 WT. FRACT 1.0000
 MOL WT. 18.02
 CRIT TEMP 1165.20
 CRIT PRES 3208.20
 TEMPERATURE LIMITS
 UPPER 1165.20
 LOWER 494.69

CALCULATED MIXTURE VALUES
 MOLECULAR WEIGHT 18.02
 CRITICAL VALUES-TEMPERATURE 1165.20 PRESSURE 3208.20
 TEMPERATURE LIMITS-UPPER 1165.20 LOWER 494.69

COLD FLUID (WORKING) 1 PHYSICAL PROPERTIES PROFILE

40 PXP	ISOBARS	(K=1) 630.000	(K=2) 560.000								
FPC		0.00	0.00	0.00	0.00						
41 TXP	(K)	I=1	I=2	I=3	I=4	I=5	I=6	I=7	I=8	I=9	I=10
	1	250.00	232.00	220.00	219.00	212.00	205.00	190.00	150.00	120.00	90.00
	2	250.00	232.00	223.00	220.00	212.00	200.00	180.00	150.00	120.00	90.00
43 YXP											
44 ROVP											
45 XMUVP											
46 XKVP											
47 HVXP											
48 CPVP											
50 RQLP	1	6.5360	7.9630	11.9200	13.5500	19.5700	22.0900	24.7900	28.4600	30.3200	31.8400
	2	7.2520	9.4650	13.9300	16.3200	20.8200	23.5100	26.0900	28.5400	30.3800	31.6700
51 XMULP	1	.0146	.0157	.0341	.0352	.0409	.0421	.0526	.0701	.0834	.0981
	2	.0152	.0177	.0339	.0367	.0422	.0466	.0577	.0706	.0837	.0984
52 XKLP	1	.0220	.0225	.0343	.0349	.0376	.0394	.0424	.0486	.0525	.0588
	2	.0226	.0243	.0344	.0358	.0383	.0409	.0443	.0487	.0528	.0589
53 HLXP	1	182.2000	163.6500	136.6000	128.3000	102.1100	89.4200	72.1200	39.4300	18.9300	.0900
	2	177.9500	155.4600	129.6100	118.5000	98.4500	81.8900	62.6000	39.3500	18.9200	.1200
54 CPLP	1	.8821	1.2890	5.3520	6.0220	2.4100	1.4420	.9790	.7210	.6520	.6080
	2	.9779	1.8090	3.9130	3.4100	1.7780	1.1290	.8550	.7170	.6500	.6070

** CARD 42 (QXF) AND CARD 49 (PCVP) ARE NOT USED IN THE SI-4 PROGRAM **

***** GRAY ERRORS ** CALCULATIONS CONTINUE *****

06-00(1.0) *WARNING* WEIGHT ESTIMATION ROUTINE IS LIMITED TO 600 PSI (4137 KPA) AND 650 F (343 C)

FINAL RESULTS

PROBLEM DESCRIPTION-SUPHEAT-BOILER L-SHELL 2XMS

CASE-205

DESIGN CASE

COUNTERCURRENT FLOW IN A T.T.M.A. ALL SHELL WITH SEGMENTAL BAFFLES

ACT. SLEN.-7

*** PROCESS DATA ***				*** SHELLSIDE PERFORMANCE ***			
01 FLUID NAME	WORKING	COLD SHELLSIDE	HOT TUBESIDE	01 NUM. VELL. X-FLUX/WINDOW	7.537	3.40	
02 FLUID CONDITION	SENS. LIQUID	SENS. LIQUID	SENS. LIQUID	02 FILM COEF. X-FLUX/WINDOW	273.37	648.4	
03 TOTAL FLOW RATE	(1.0E+3)(LB/HR)	8.000	10.550	03 FLOW FRACTIONS FOR HEAT TRANS-CK	.913		
04 TEMPERATURE, IN/OUT (DEG F)	195.0 / 247.0	280.0 / 200.8*		04 A= .045 B= .797 C= .107 E= .040 F=0.000			
05 TEMPERATURE, AVERAGE/SKIN (DEG F)	221.0 / 227.2	243.4 / 234.9		*** SHELLSIDE HEAT TRANSFER CORRECTIONS ***			
06 PRESSURE, INLET/AVERAGE (PSIA)	660.00 / 659.50	200.00 / 192.50		05 TOTAL DELTA GAMMA LHO FIN			
07 PRESSURE DROP, TOTAL/ALLOW (PSI)	.647 / 1.00	2.307 / 15.00		06 .919 .720 1.000 .903 .999			
08 VELOCITY, CALC./MAX.ALLOW (FT/SEC)	.657 / 7.00	2.617 / 7.00		*** PRESSURE DROPS *** (PERCENT TOTAL DPT)			
09 FILM COEF (SAF.FACT) (BTU/HK-FT ² -F)	432.27 (1.00)	1269.93 (1.00)		07 WIND 75.05 NOZZLE SHELL 11.93 / 8.61			
10 FOULING RESISTANCE (HR-FT ² =F/BDT)	.00050	.00050		08 END .36 (IN/OUT) TUBE 21.23 / 13.08			
11 DENSITY (LB/FT ³)	15.4578	59.0819		*** H.T. PARAMETERS ***			
12 THERMAL CONDUCTIVITY (BTU/HK-F)	.0353	.3875		09 WALL CORRECTION	1.044	.993	
13 SPECIFIC HEAT CAPACITY (BTU/LB-F)	3.6016	1.3079		10 PRANDL. NO.	8.3	1.5	
14 VISCOSITY AT AVERAGE TEMP (CP)	.03575	.03783		11 AVERAGE REYNOLDS NO.	15702	24357	
15 VISCOSITY AT SKIN TEMP (CP)	.02626	.024881		12 BUNDLE INLET REYNOLDS NO.	11736	29149	
*** OVERALL PERFORMANCE DATA *** (TUBESIDE STEPHENSON)				13 BUNDLE OUTLET REYNOLDS NO.	38247	19799	
16 TOTAL HEAT DUTY REQUIRED (1.0E+6)(BTU/HR)		.778382		14 FOULING LAYER (IN)	0.00000	0.00000	
17 EFFECTIVE MTD, (LMTD)(F)(DELTA) = (DEG F)	20.621(1.00)(1.00) = 20.6			*** THERMAL RESISTANCES *** (PCT. OVERALL)			
18 F FACTOR=(TUBE)(BAFFLES)(F/G)(HOT/COLD)=(1.000)(1.000)(1.000)(1.000)				15 SHELL TUBE FOULING METAL OVER DES			
19 OVERALL COEF, REQD/CLEAN/ACTOAL(TBTU/HR-FT ² -F)	107.937 172.137 120.10			16 27.78 38.15 30.23 3.838 11.795			
*** CONSTRUCTION INFORMATION ***				17 TOTAL FOULING RESISTANCE	.002517		
20 NO. SHELLS SERIES 1 PARALLEL 1	TOTAL SURFACE AREA (FT ²)	352		18 DIFFERENTIAL RESISTANCE	.000982		
21 NO. PASSES SHELL 1 TUBE	EFF. SURF. AREA (FT ² /SHELL)	351.5		*** SHELL NOZZLE INFO. ***			
22 SHELL I.D. (IN)	TERA SHELL TYPE E REAR HEAD FATS			19 INSIDE DIAMETER (IN)	2.1	3.1	
23 BAFFLE TYPE HORIZ SEGMENTAL	NO. CROSSPASSES/SHELL PASS	25		20 VELOCITY (FT/SEC)	3.02	5.58	
24 CENTRAL SPACING (IN)	BAFFLE CUT (PCT. DIA)	34.70		21 DENSITY (LB/FT ³)	24.155	7.593	
25 INLET SPACING (IN)	CUT AREA(PCT) 1) 32.3 2) 0.0 3) 0.0			22 NOZZLE R-V-S2 (LB/FT-S2)	553	237	
26 OUTLET SPACING (IN)	CUT HEIGHT FROM CENTER LINE (IN)			23 BUNDLE R-V-S2 (LB/FT-S2)	445	319	
27 BAFFLE THICKNESS (IN)	PDS-1) .9 2) 0.0 3) 0.0			24 HEIGHT UNDER NOZZLE (IN)	.3	.3	
28 NO. PAIRS SEAL DEVICES	1 IMPINGEMENT PLATE INCLUDED	NO		*** TUBE NOZZLE INFO. ***			
29 TOT.TUBESHEET THICK.(IN)	PERCENT TUBES REMOVED (NONE)	0.000		25 INSIDE DIAMETER (IN)	1.0	1.0	
30 TUBE TYPE (FINS/IN)	TUBE COUNT PER SHELL	38		26 VELOCITY (FT/SEC)	8.41	6.14	
31 OVERALL LENGTH (FT)	TUBE PITCH (IN)	.6880		27 DENSITY (LB/FT ³)	58.079	59.971	
32 EFFECTIVE LENGTH (FT)	OUTSIDE DIAMETER (IN)	.500		*** DIAMETRAL CLEARANCES ***			
33 LAYOUT ANGLE (DEG)	INSIDE DIAMETER (IN)	.303		28 BAFFLE-TO-SHELL (IN)		.1000	
34 PITCH RATIO	SURFACE AREA RATIO (OUT/INT)	4.034		29 BUNDLE-TO-SHELL (IN)		.5000	
35 FIN TUBE EQ. DIA. (IN)	FIN EQ.DIA. CONDENSING (IN)	0.0000		30 TUBE-TO-BAFFLEHOLE (IN)		.0403	
36 WEIGHT ESTIMATION (LB/SHELL)	DRY NET	619 923		31 MULTI-SEG. BAFFLE OVERLAP (IN)		0.000	
				32 FIN EFFICIENCY=.929	FIN RESIST.=	.00017	

HYTRI ST-4 MOD 5.7		HYTRI VERSION		PAGE 001	
PROBLEM DESCRIPTION-SUPERHEATED STEAM (SHELL & TUBES)				CASE-005	
FLOW INDUCED VIBRATION ANALYSIS				SENS. LIQUID SHELLSIDE	
01	LOG DECREMENT	0.0300	AXIAL STRESS LOADING	0.0	(KPSI)
02	BETA	2.792	ADDED MASS FACTOR	2.2765	
03	LENGTH FOR NATURAL FREQUENCY (FT)		INLET	CENTER	OUTLET
04	LENGTH/TEMA MAXIMUM SPAN	(--)	2.312	2.312	2.312
05	NUMBER OF SPANS	(--)	.725	.725	.725
06	NATURAL FREQUENCY (FTUBE)	(HZ)	24.619	25.23	25.24
07	FLOW VELOCITIES				
08	WINDOW (PARALLEL FLOW)	(FT/SEC)	2.87	3.24	6.00
09	WINDOW (CROSSFLOW)	(FT/SEC)	.13	.21	.42
10	C-STREAM VELOCITY	(FT/SEC)	.21	.32	.66
11	E-STREAM VELOCITY	(FT/SEC)	1.19	1.07	3.80
12					
13	CROSSFLOW VELOCITY	(FT/SEC)	.42	.65	1.33
14	CRITICAL VELOCITY	(FT/SEC)	1.36	1.70	2.42
15	CROSSFLOW REYNOLDS NUMBER	(--)	10257.	14597.	33926.
16	CROSSFLOW RHO-V-SQ	(LB/FT-SQ)	4.	7.	13.
17	FREQUENCY RATIOS	(--)	.044	.068	.139
18	(FVXSQ)/(FTUBE)	(--)			
19					
20	DAMAGE NUMBERS				
21	BAFFLE	(--)	.0016	.0026	.0052
22	COLLISION	(--)	.0021	.0032	.0066
23	RHO/SGRT(MU) (SEE STV-1, FIG 4-6)		58.8376	52.5519	39.0606
24	VIBRATION AMPLITUDES				
24	PARALLEL FLOW	(IN)	.000165	.000289	.007589
25	CROSSFLOW-INDUCED	(IN)	.00031	.00048	.00100
BUNDLE PARAMETERS AT NOZZLES			ENTRANCE		EXIT
26	IMPINGEMENT PLATE		NO		NO
27	FLOW AREA	(FT2)	.0214		.0394
28	VELOCITY	(FT/SEC)	4.29		7.43
29	RHO-V-SQ	(LB/FT-SQ)	445.		419.
30	TEMA E SHELL WITH HURZ SEGMENTAL BAFFLES AND FATS BUNDLE				
31	NUMBER OF INTERMEDIATE SUPPORT PLATES PER SPAN		0		0
32	FINNED ADMIRALTY TUBES	.5000 DIAMETER (IN)			90 DEGREE LAYOUT
33	PITCH RATIO	1.654			
* FREQUENCY RATIOS ARE BASED ON THE LOWEST NATURAL FREQUENCY					

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APPENDIX C

COMPUTER OUTPUT OF CST-1 RUN
FOR HEATER (BOILING MODE)

(Pages C-1 to C-5)

HTRI SHELL AND TUBE CONDENSER PROGRAM
INPUT DATA REPRINT

US UNITS
CST-1 MOD 1.1
PROBLEM DESCRIPTION-SUPERHT. *DILER L-SHELL 2HX5

HTRI VERSION

PAGE NO- 1
CASE-0050

CARD 1 CONTROL INFORMATION
01 CIN INPUT UNITS CODE 0.
02 COUT OUTPUT UNITS CODE 0.
03 CCI CALCULATION TYPE 2.
04 CHS FLUID ALLOCATION 2.
05 CHB HEAT DUTY CODE 3.
06 ODUTY HEAT DUTY(1.0E6) 0.00000
07
08
09 CCM CALCULATION METHOD 3.
10 FLASH RIGOROUS FLASH CODE 0.
11 PURE PURE CONDENSABLE 0.
12 POOL POOL BOILING 0.
13
14 CVIB VIBRATION CODE 1.
15 EDA SHELL ORIENTATION 0.
16
17
18
19
20 CMON MONITOR CODE 9.
21 CQPI PRINTOUT CODE 0.
22 CPROF PROFILE CODE 0.
23

CARD 6 BASIC BAFFLE GEOMETRY
01 CB2 BAFFLE TYPE 1.
02 BCC BAFFLE ORIENTATION 1.
03 BCD BAFFLE CUT (PCT) 34.70
04 FNWB FRACT WINDOW AREA 0.00
05 RVDW NTW RHO-V-SQUARED 0.0
06 HOVD TUBE ROWS OVERLAP 0.00
07 ZCPD1 NO OF CROSSPASSES 25.
08 XLBCD1 CENTRAL BAF SPACE 0.000
09 XLBD1 INLET BAF SPACE 0.000
10 XLBD2 OUTLET BAF SPACE 0.000
11 XLBD BAFFLE THICKNESS 0.0000
12 XLBDT TUBEHOLE BAF THICK 0.0000
13 CBES EQUAL END SPACING 0.
14 CB5MX MAX BAF SPACING 0.00
15 CB3 BAFFLE WINDOW 0.
16
17
18
19

CARD 8 VARIABLE BAFFLE SPACING
01 ZCPD2 CROSSPASSES REG-2 0.
02 XLBCD2 BAF SPACING REG-2 0.000
03 ZCPD3 CROSSPASSES REG-3 0.
04 XLBCD3 BAF SPACING REG-3 0.000
05 ZCPD4 CROSSPASSES REG-4 0.
06 XLBCD4 BAF SPACING REG-4 0.000
07 ZCPD5 CROSSPASSES REG-5 0.
08 XLBCD5 BAF SPACING REG-5 0.000

CARD 5 BASIC SHELL DESCRIPTION
01 TLMA TLMA SHELL STYLE ALL
02 CSI SHELL CONSTRUCTION 1.
03 CBI REAR HEAD TYPE 1.
04 USD SHELL ID 5.761
05
06
07 CTP TUBEPASS CODE 0.
08 ZTPD NO OF TUBEPASSES 1.
09 ZNSD PAIRS SEAL DEVICES 0.
10 ZNSKD NO OF SEAL RODS 0.
11 DRDD SEAL ROD DIAMETER 0.0000
12 SFFMD SHELL FRICT MULTI 1.0000
13
14

CARD 7 CONSTRUCTION INFORMATION
01 SFHSD1 INLET H.T. PENALTY 1.000
02 SFHSD2 OUTLET H.T. PENALTY 1.000
03 SFHSD3 O-BEND H.T. PENALTY 0.000
04 HNTD1 INLET NOZ HEIGHT 0.000
05 HNTD2 OUTLET NOZ HEIGHT 0.000
06 DBDK CLEARANCE CODE 0.
07 CED BAFFLE-SHELL CLEAR 0.0000
08 CAD TUBE-BAFFLE CLEAR 0.0000
09 CUDL BUNDLE-SHELL CLEAR 0.0000
10 TSID TUBESHEET THICK 0.0000
11 STRES ALLOWABLE STRESS 0.00
12 CS3 DOUBLE TUBESHEET 0.
13 CS2 EXP JOINT CODE 0.
14 PPNV NO VERT PASS LANE 0.
15 PPHV NO HORIZ PASS LANE 0.
16 WPPV WIDTH VERT LANES 0.000
17 WPPH WIDTH HORIZ LANES 0.000

CARD 10 NOZZLE INFORMATION
01 UNZDS1 SHELL-INLET NOZ ID 2.100
02 UNZDS2 SHELL-OUTLET NOZ ID 3.100
03 UNZDS3 SHELL-LIQUID NOZ ID 0.000
04 UNZDT1 TUBE-INLET NOZ ID 1.000
05 UNZDT2 TUBE-OUTLET NOZ ID 1.000
06 UNZDT3 TUBE-LIQUID NOZ ID 0.000
07 ADOD ANNULAR DISTRIBUTOR 0.
08 ALCD ANN-DIST CLEARANCE 0.000
09 ADLD ANN-DIST LENGTH 0.000
10 AUSAL IN-DIST SLOT AREA 0.000
11 ADSA2 OUT-DIST SLOT AREA 0.000
12 ZNUZ1 NO NOZ SHELL INLET 1.
13 ZNUZ2 NO NOZ SHELL OUTLET 1.
14 CNUZ NOZZLE ORIENTATION 0.
15 CFTC IMPINGEMENT CODE 0.
16 RVU RHO-V-SQUARED 500.0
17 CAXAL TUBESIDE AXIAL NOZ 0.

CARD 12 TUBESHEET DESCRIPTION
01 ZNTD NO OF TUBES/SHELL 80.
02 DTU TUBE OD 0.5000
03 TTS TUBE THICKNESS 0.0000
04 TLOV TUBE LENGTH 29.000
05 PT TUBE PITCH 0.6880
06 TLA TUBESHEET PATTERN 90.
07 CMAT TUBE MATERIAL CODE 0.
08 CTR THERMAL CONDUCT 0.000
09 CFIN TUBE TYPE 1.
10
11 TLMAX MAX TUBE LENGTH 0.000
12 TLINC INCREMENT LENGTH 0.000
13 TFFMD TUBE FRICT MULTI 1.0000
14 TFFTD TUBE FRICT CODE 1.
15

CARD 13 EXTERNAL TUBE GEOMETRY
01 XNF NO OF FINS/LENGTH 19.00
02 XFH FIN HEIGHT 0.070
03 DFR FIN ROOT DIAMETER 0.370
04 XLF FIN THICKNESS 0.150
05 FAKP SURF AREA/LENGTH 0.320
06 TRTH THICKNESS UNDER FIN 0.030

CARD 18 VIBRATION INFORMATION
01 EMUD TUB ELAST MODULUS 0.00
02 DTMAT TUBE DENSITY 0.00
03 AXLU AXIAL STRESS LOAD 0.
04 AMFD ADDED MASS FACTOR 2.2765
05 SUPPD SUP PLATE/BAF SPACE 0.
06 CLDCU VIB LOG DECREMENT 0.000
07 CBFD STABILITY CONSTANT 2.7918
08

** A * INDICATES **
** A DEFAULT VALUE **

HTRI SHELL AND TUBE CONDENSER PROGRAM
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US UNITS

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PROBLEM DESCRIPTION-SUPERHIT. *BOILER L-SHELL 2HXS

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CASE-0050

HOT FLUID NAME--GEOFLUID

CARD 20 PROCESS INFORMATION

01 FCON1	FLUID CONDITION	0.
02 WDI	FLOW RATE(1.0E3)	10.55
03 TIND1	INLET TEMPERATURE	280.00
04 TOUTD1	OUTLET TEMPERATURE	0.00
05 PIND1	INLET PRESSURE	200.00
06 YIND1	INLET VAPOR QUALITY	0.000
07 YOUTD1	EXIT VAPOR QUALITY	0.000
08 SFD1	H.T. SAFETY FACTOR	1.000*
09 TSHD1	COND DEG SUP HEAT	0.00
10 TSCD1	COND DEG SUB COOL	0.00
11 RFD1	FOUL RESISTANCE	0.00050
12 FL1	FOUL LAYER THICK	0.000
13 HSUBD	SUBCOOL H.T. COEF	0.00
14 HTPZD	2-PHASE H.T. COEF	0.00

COLD FLUID NAME--WORKING

CARD 22 PROCESS INFORMATION

01 FCON2	FLUID CONDITION	2.
02 WDI	FLOW RATE(1.0E3)	8.00
03 TIND2	INLET TEMPERATURE	195.00
04 TOUTD2	OUTLET TEMPERATURE	231.50
05 PIND2	INLET PRESSURE	550.00
06 YIND2	INLET VAPOR QUALITY	0.000*
07 YOUTD2	EXIT VAPOR QUALITY	1.000
08 SFD2	H.T. SAFETY FACTOR	1.000*
09 TSHD2	BOIL DEG SUP HEAT	0.00
10 TSCD2	BOIL DEG SUB COOL	0.00
11 RFD2	FOUL RESISTANCE	0.00050
12 FL2	FOUL LAYER THICK	0.0000
13 HCD	H.T. COEFFICIENT	0.00

CARD 25 DP, VELOCITY, NOZZLE INFO

01 PMD1	HOT ALLOWABLE DP	0.00
02 PNM011	HOT MAXDP IN--NOZ	0.00
03 PNM021	HOT MAXDP OUT--NOZ	0.00
04 PD1	HOT DESIGN PRESS	200.00*
05		
06		
07 PMD2	COLD ALLOWABLE DP	0.00
08 PNM012	COLD MAXDP IN--NOZ	0.00
09 PNM022	COLD MAXDP OUT--NOZ	0.00
10 PD2	COLD DESIGN PRESS	220.00*
11 VMAX02	COLD MAX VELOCITY	0.00
12 VMIN02	COLD MIN VELOCITY	0.00
13 PHAXD	TOTAL DP	0.00

HOT FLUID (GEOFLUID) PHYSICAL PROPERTIES

CARD 31 PHYSICAL PROPERTY CONTROL

COMPONENT	NAME	VALUE
04	HMMND	1.0000
05	ZNCG	0.
06	APC	1.
07	API	0.00
08	HCF	0.00
09	AMWL	0.00
10	AMW	0.00
11	ZD	0.0000
12	UPCD	0.00
13	OTCD	0.00
14	OZCD	0.0000
15	HLGD	0.00
16	PZERO	0.

COLD FLUID (WORKING) PHYSICAL PROPERTIES

CARD 36

COMPONENT	NAME	VALUE
03	TRPV	0.00
05	PV	0.00
07	TBN	0.00
08	BRD	7.00

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HTRI SHELL AND TUBE CONDENSER PROGRAM
 INPUT DATA REPRINT

CST-1 MOD 1.1
 US UNITS

PROBLEM DESCRIPTION-SUPERHEATED BULLER L-SHELL 2HX5

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 CASE-J65C

COLD FLUID (WORKING)) PHYSICAL PROPERTIES PROFILE

40 PXP	150BARS	(K=1)	550.000					FPC	0.00	0.00	0.00	0.00
	(K)	I=1	I=2	I=3	I=4	I=5	I=6	I=7	I=8	I=9	I=10	
41 TXP	1	250.00	236.00	220.00	209.50	207.00	205.00	203.50	202.50	195.00	180.00	
42 QXFP	1	127.6300	117.0000	103.0600	90.8400	75.7400	58.2150	41.2340	27.5100	15.7800	0.0000	
43 YXP	1	1.0000	1.0000	1.0000	1.0000	.7777	.5010	.2258	0.0000	0.0000	0.0000	
44 ROVP	1	5.0452	5.4918	6.2905	7.3687	7.5747	7.5976	7.6017	7.6040	7.6040	7.6040	
45 XMUVP	1	.0100	.0100	.0100	.0100	.0100	.0100	.0100	.0100	.0100	.0100	
46 XKVP	1	.0168	.0163	.0158	.0153	.0150	.0150	.0149	.0148	.0148	.0148	
47 HVXP	1	.7303	.7959	.9821	1.4825	1.5715	1.6192	1.6590	1.6672	1.6672	1.6672	
48 CPVP	1	21.5750	21.5750	21.5750	21.5750	21.3940	21.2400	21.1190	21.0490	23.2600	25.5730	
50 ROLP	1	.0280	.0280	.0280	.0280	.0300	.0310	.0325	.0340	.0390	.0480	
51 XMULP	1	.0335	.0335	.0335	.0335	.0340	.0345	.0348	.0350	.0368	.0400	
52 XKLP	1	.0335	.0335	.0335	.0335	.0340	.0345	.0348	.0350	.0368	.0400	
53 HLXP	1	1.8408	1.8408	1.8408	1.8408	1.9252	2.0033	2.0695	2.1092	1.2635	.9197	
54 CPLP	1	594.45	594.45	594.45	594.45	597.78	600.51	602.59	608.85	608.85	608.85	
55 SIGP	1	594.45	594.45	594.45	594.45	597.78	600.51	602.59	608.85	608.85	608.85	
56 PCLP	1	594.45	594.45	594.45	594.45	597.78	600.51	602.59	608.85	608.85	608.85	

***** * WARNING MESSAGES --- CALCULATIONS CONTINUE * * * * *

05- 3(2. 0) INPUT VALUE OF CBI WILL BE OVERRIDEN BECAUSE TEMA WAS INPUT CBI INPUT VALUE WILL BE IGNORED

HTRI SHELL AND TUBE CONDENSER PROGRAM CST-1 MOD 1.1

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FINAL RESULTS PROBLEM DESCRIPTION-SUPERHEAT-HEATER 1-SHELL PHAS

RATING OF A TUBESIDE HOT COUNTERCURRENT

HORIZONTAL TEMA AEE SHELL WITH SEGMENTAL BAFFLES

REF-33EN **

**** PROCESS DATA ****				**** SHELLSIDE PERFORMANCE ****			
01 FLUID NAME	WORKING	COLD SHELLSIDE	GLCFLUID	01 NUM	VCL	X-FLW/WINDUA	3.53
02 FLUID CONDITION	BOIL. LIQUID		SENS. LIQUID	02			
03 TOTAL FLOW RATE	(1.0E+3) (LB/HR)	8.000	10.550	03 FLOW FRACTIONS FOR VAPOR PHASE			
04 WEIGHT FRACTION VAPOR, IN/OUT (--)	0.000 / 1.000	0.000 / 0.000		04 A=	.045	B= .782	C= .124
05 TEMPERATURE, IN/OUT (DEG F)	195.0 / 231.5	280.0 / 206.8		05	.920	.920	1.000
06 TEMPERATURE, AVERAGE/SKIN (DEG F)	213.3 / 216.2	243.4 / 224.5		06	.920	.920	1.000
07 PRESSURE, INLET/AVERAGE (PSIA)	550.00 / 549.66	200.00 / 198.67		07	.920	.920	1.000
08 PRESSURE DROP, TOTAL/ALLOW (PSI)	.26 / 0.00	2.25 / 0.00		08	.920	.920	1.000
09 VELOCITY, MID/MAX ALLOW (FT/SEC)	.67 / 0.00	2.59 / 0.00		09	.920	.920	1.000
10 AVERAGE FILM COEF (BTU/HK-FT ² -F)	243.51	1265.55		10	.920	.920	1.000
11 HEAT TRANSFER SAFETY FACTOR (--)	1.000	1.000		11	.920	.920	1.000
12 FOULING RESISTANCE (HR-FT ² -F/BTU)	.000500	.000500		12	.920	.920	1.000
13 OVERALL COEF, RECD/CLEAN/ACTUAL (BTU/HK-FT ² -F)	80.45 / 134.06 / 100.24			13	.920	.920	1.000
14 HEAT DUTY, REQUIRED/SPECIFIED (1.0E+6) (BTU/HK)	.77840 / 0.00000			14	.920	.920	1.000
15 EFFECTIVE OVERALL TEMPERATURE DIFFERENCE (DEG F)	27.54			15	.920	.920	1.000
**** CONDENSER PERFORMANCE CRITERIA ****				**** CONDENSATION PARAMETERS ****			
16 PRESSURE DROP RATIOS BASED ON				16	.920	.920	1.000
SPECIFIED/REQUIRED AREAS, SHELLSIDE/TUBESIDE	1.260 / 1.126			17	.920	.920	1.000
17 RATIO OF AREA SPECIFIED TO AREA REQUIRED	1.2460			18	.920	.920	1.000
18				19	.920	.920	1.000
19				20	.920	.920	1.000
20				21	.920	.920	1.000
21				22	.920	.920	1.000
22				23	.920	.920	1.000
23				24	.920	.920	1.000
24				25	.920	.920	1.000
25				26	.920	.920	1.000
26				27	.920	.920	1.000
27				28	.920	.920	1.000
28				29	.920	.920	1.000
29				30	.920	.920	1.000
30				31	.920	.920	1.000
31				32	.920	.920	1.000
32				33	.920	.920	1.000
33				34	.920	.920	1.000
34				35	.920	.920	1.000
35				36	.920	.920	1.000
36				37	.920	.920	1.000
37				38	.920	.920	1.000
38				39	.920	.920	1.000
39				40	.920	.920	1.000
40				41	.920	.920	1.000
41				42	.920	.920	1.000
42				43	.920	.920	1.000
43				44	.920	.920	1.000
44				45	.920	.920	1.000
45				46	.920	.920	1.000
46				47	.920	.920	1.000
47				48	.920	.920	1.000
48				49	.920	.920	1.000
49				50	.920	.920	1.000
50				51	.920	.920	1.000
51				52	.920	.920	1.000
52				53	.920	.920	1.000
53				54	.920	.920	1.000
54				55	.920	.920	1.000
55				56	.920	.920	1.000
56				57	.920	.920	1.000
57				58	.920	.920	1.000
58				59	.920	.920	1.000
59				60	.920	.920	1.000
60				61	.920	.920	1.000
61				62	.920	.920	1.000
62				63	.920	.920	1.000
63				64	.920	.920	1.000
64				65	.920	.920	1.000
65				66	.920	.920	1.000
66				67	.920	.920	1.000
67				68	.920	.920	1.000
68				69	.920	.920	1.000
69				70	.920	.920	1.000
70				71	.920	.920	1.000
71				72	.920	.920	1.000
72				73	.920	.920	1.000
73				74	.920	.920	1.000
74				75	.920	.920	1.000
75				76	.920	.920	1.000
76				77	.920	.920	1.000
77				78	.920	.920	1.000
78				79	.920	.920	1.000
79				80	.920	.920	1.000
80				81	.920	.920	1.000
81				82	.920	.920	1.000
82				83	.920	.920	1.000
83				84	.920	.920	1.000
84				85	.920	.920	1.000
85				86	.920	.920	1.000
86				87	.920	.920	1.000
87				88	.920	.920	1.000
88				89	.920	.920	1.000
89				90	.920	.920	1.000
90				91	.920	.920	1.000
91				92	.920	.920	1.000
92				93	.920	.920	1.000
93				94	.920	.920	1.000
94				95	.920	.920	1.000
95				96	.920	.920	1.000
96				97	.920	.920	1.000
97				98	.920	.920	1.000
98				99	.920	.920	1.000
99				100	.920	.920	1.000

HTRI	CST-1	MUD 1.1	HTRI VERSION	PAGE NO-	11
PROBLEM DESCRIPTION-SUPERHT.*BOILER E-SHELL 2HXS			-	CASE-005.	
FLOW INDUCED VIBRATION ANALYSIS			BOIL. LIQUID SHELLSIDE		
01	LOG DECREMENT	.0300	AXIAL STRESS LOADING	0.0	(KPSI)
02	BETA	2.792	ADDED MASS FACTOR	2.2765	POSITION IN BUNDLE
03	LENGTH FOR NATURAL FREQUENCY (FT)	2.311	INLET	2.311	OUTLET
04	LENGTH/TEMA MAXIMUM SPAN (---)	.925	CENTER	.925	
05	NUMBER OF SPANS (---)	13		13	
06	NATURAL FREQUENCY(FTUBE) (HZ)	24.69*		25.29	26.01
07	FLOW VELOCITIES				
08	WINDOW (PARALLEL FLOW) (FT/SEC)	2.16		3.37	8.77
09	WINDOW (CROSSFLOW) (FT/SEC)	.14		.21	.56
10	C-STREAM VELOCITY (FT/SEC)	.25		.39	1.01
11	E-STREAM VELOCITY (FT/SEC)	1.26		1.97	5.15
12					
13	CROSSFLOW VELOCITY (FT/SEC)	.43		.67	1.73
14	CRITICAL VELOCITY (FT/SEC)	1.39		1.73	2.80
15	CROSSFLOW REYNOLDS NUMBER (---)	13102.		17052.	51100.
16	CROSSFLOW RHO-V-SQ (LB/FT-SQ)	4.		7.	17.
17	FREQUENCY RATIOS (FVXSD)/(FTUBE) (---)	.045		.070	.162
18					
19					
20	DAMAGE NUMBERS				
21	BAFFLE (---)	.0016		.0026	.0087
22	COLLISION (---)	.0020		.0032	.0083
23	RHO/SQRT(MU) (SEE SIV-1, FIG 4-6)	75.7129		55.3517	36.7466
24	VIBRATION AMPLITUDES				
25	PARALLEL FLOW (IN)	.000192		.000330	.003782
26	CROSSFLOW-INDUCED (IN)	.00031		.00048	.00128
27	SHELL PARAMETERS AT NOZZLES				
28	IMPINGEMENT PLATE	YES	ENTRANCE	EXIT	
29	FLOW AREA (FT2)	.0240		.0394	
30	VELOCITY (FT/SEC)	3.97		9.67	
31	RHO-V-SQ (LB/FT-SQ)	367			556
32	TEMA E SHELL WITH HURZ SEGMENTAL BAFFLES AND FXTS BUNLL				
33	NUMBER OF INTERMEDIATE SUPPORT PLATES PER SPAN	0			
34	FINNED ADMIRALTY TUBES .5000 DIAMETER (IN)		90 DEGREE LAYOUT		
35	PITCH RATIO	1.654			
* FREQUENCY RATIOS ARE BASED ON THE LOWEST NATURAL FREQUENCY					

C-5

APPENDIX D

COMPUTER OUTPUT OF CST-1 RUN
FOR CONDENSER

(Pages D-1 to D-6)

HTRI SHELL AND TUBE CONDENSER PROGRAM
INPUT DATA REPORT

CST-1 MOD 1.1
PROFILE DESCRIPTION- CONDENSER

HTRI VERSION

PAGE NO- 1
CASE-0022

CARD 1 CONTROL INFORMATION
01 CIN INPUT UNITS CODE 0.
02 COUT OUTPUT UNITS CODE 0.
03 CCI CALCULATION TYPE 1.
04 CHS FLUID ALLOCATION 2.
05 CHB HEAT DUTY CODE 4.
06 CDUTY HEAT DUTY(1.0E6) 0.00000
07
08
09 CCM CALCULATION METHOD 0.
10 FLASH RIGOROUS FLASH CODE 0.
11 PURE PURE CONDENSABLE 0.
12 POOL POOL BOILING 0.
13
14 CVIB VIBRATION CODE 1.
15 EOA SHELL ORIENTATION 90.

16
17
18
19
20 CMON MONITOR CODE 9.
21 COP1 PRINTOUT CODE 0.
22 CPROF PROFILE CODE 0.
23

CARD 6 BASIC BAFFLE GEOMETRY
01 CB2 BAFFLE TYPE 1.
02 RCC BAFFLE ORIENTATION 0.
03 BCO BAFFLE CUT (PCT) 0.00
04 FNBW FRACT WINDOW AREA 0.00
05 RYDW NTW RHO-V-SQUARED 0.0
06 HOVD TUPE ROWS OVERLAP 0.00
07 ZCPD1 NO OF CROSSPASSES 0.
08 XLBCD1 CENTRAL BAF SPACE 0.000
09 XLB1D INLET BAF SPACE 0.000
10 XLB2D OUTLET BAF SPACE 0.000
11 XLBD BAFFLE THICKNESS 0.0000
12 XLBDT TUBEHOLE BAF THICK 0.0000
13 CEB3 EQUAL END SPACING 0.
14 CB3MX MAX BAF SPACING 0.00
15 CB3 BAFFLE WINDOW 0.
16
17
18
19

CARD 8 VARIABLE BAFFLE SPACING
01 ZCPD2 CROSSPASSES REG-2 0.
02 XLBCD2 BAF SPACING REG-2 0.000
03 ZCPD3 CROSSPASSES REG-3 0.
04 XLBCD3 BAF SPACING REG-3 0.000
05 ZCPD4 CROSSPASSES REG-4 0.
06 XLBCD4 BAF SPACING REG-4 0.000
07 ZCPD5 CROSSPASSES REG-5 0.
08 XLBCD5 BAF SPACING REG-5 0.000

CARD 5 BASIC SHELL DESCRIPTION
01 TEMA TEMA SHELL STYLE
02 CSI SHELL CONSTRUCTION 1.
03 CCI REAK HEAD TYPE 1.
04 DSD SHELL ID 16.875
05
06
07 CTP TUBE PASS CODE 0.
08 ZTPD NO OF TUBE PASSES 1.
09 ZNSD PAIRS SEAL DEVICES 0.
10 ZNSRD NO OF SEAL RGDS 0.
11 DRUD SEAL ROD DIAMETER 0.0000
12 SFFMD SHELL FRICT MULT 1.0000
13
14

CARD 7 CONSTRUCTION INFORMATION
01 SFHSD1 INLET H.T. PENALTY 1.000
02 SFHSD2 OUTLET H.T. PENALTY 1.000
03 SFHSD3 U-BEND H.T. PENALTY 0.000
04 HNTD1 INLET NOZ HEIGHT 0.000
05 HNTD2 OUTLET NOZ HEIGHT 0.000
06 DBDK CLEARANCE CODE 0.
07 CDD BAFFLE-SHELL CLEAR 0.0000
08 CAD TUBE-BAFFLE CLEAR 0.0000
09 COTLD BUNDLE-SHELL CLEAR 0.0000
10 TSID TUBESHEET THICK 0.0000
11 STRES ALLOWABLE STRESS 0.00
12 CS3 DOUBLE TUBESHEET 0.
13 CS2 EXP JOINT CODE 0.
14 PPNV NO VERT PASS LANE 0.
15 PPHN NO HORIZ PASS LANE 0.
16 WPPV WIDTH VERT LANES 0.000
17 WPPH WIDTH HORIZ LANES 0.000

CARD 10 NOZZLE INFORMATION
01 UNZDS1 SHELL-INLET NOZ ID 0.000
02 UNZDS2 SHELL-OUTLET NOZ ID 0.000
03 UNZDS3 SHELL-LIQUID NOZ ID 0.000
04 UNZDT1 TUBE-INLET NOZ ID 0.000
05 UNZDT2 TUBE-OUTLET NOZ ID 0.000
06 UNZDT3 TUBE-LIQUID NOZ ID 0.000
07 ADCD ANNULAR DISTRIBUTOR 0.
08 ALCD ANN-DIST CLEARANCE 0.000
09 ADLD ANN-DIST LENGTH 0.000
10 ADSA1 IN-DIST SLOT AREA 0.000
11 ADSA2 OUT-DIST SLOT AREA 0.000
12 ZNUZ1 NO NOZ SHELL INLET 1.
13 ZNUZ2 NO NOZ SHELL OUTLET 1.
14 CNOZ NOZZLE ORIENTATION 0.
15 CFTC IMPINGEMENT CODE 0.
16 RVD RHO-V-SQUARED 1500.0
17 CAXAL TUBESIDE AXIAL NOZ 0.

CARD 12 TUBEFIELD DESCRIPTION
01 ZNTD NO OF TUBES/SHELL 0.
02 DTU TUBE OD 0.5000
03 ITD TUBE THICKNESS 0.0350
04 TLOV TUBE LENGTH 14.000
05 PT TUBE PITCH 0.6880
06 TLA TUBEFIELD PATTERN 90.
07 CMAT TUBE MATERIAL CODE 41.
08 CTK THERMAL CONDUCT 0.000
09 CFIN TUBE TYPE 0.
10
11 TLMAX MAX TUBE LENGTH 20.000
12 TLINC INCREMENT LENGTH 1.000
13 TFFMD TUBE FRICT MULT 1.0000
14 TFFTD TUBE FRICT CODE 0.
15

CARD 13 EXTERNAL TUBE GEOMETRY
01 XNF NO OF FINS/LENGTH 0.00
02 XFH FIN HEIGHT 0.0000
03 DFR FIN ROOT DIAMETER 0.0000
04 XLF FIN THICKNESS 0.0000
05 FARP SURF AREA/LENGTH 0.000
06 TRTH THICKNESS UNDER FIN 0.0000

CARD 18 VIBRATION INFORMATION
01 EMOD TOR ELAST MODULUS 0.00
02 DTMAT TUBE DENSITY 0.00
03 AXLD AXIAL STRESS LOAD 0.
04 AMFD ADDED MASS FACTOR 2.2765
05 SUPPD SUP PLATE/BAF SPACE 0.
06 CLOC VIB LUG DECREMENT 0.0300
07 CBFD STABILITY CONSTANT 2.7910
08

** A * INDICATES **
** A DEFAULT VALUE **

**HOT FLUID NAME--WORKING FL **			**COLD FLUID NAME--WATER **			*CARD 25* DP, VELOCITY, NOZZLE INFO		
CARD 20 PROCESS INFORMATION			*CARD 22* PROCESS INFORMATION					
01 FCON1	FLUID CONDITION	2.	01 FCON2	FLUID CONDITION	0.	01 PMD1	HOT ALLOWABLE DP	5.00
02 WDI	FLOW RATE(1.0L3)	8.00	02 WDI	FLOW RATE(1.0L3)	66.75	02 PNM011	HOT MAXDP IN--NOZ	12.50*
03 TIND1	INLET TEMPERATURE	105.00	03 TIND2	INLET TEMPERATURE	70.00	03 PNM021	HOT MAXDP OUT--NOZ	12.50*
04 TOUTD1	OUTLET TEMPERATURE	80.00	04 TOUTD2	OUTLET TEMPERATURE	0.00	04 PD1	HOT DESIGN PRESS	150.00*
05 PIND1	INLET PRESSURE	143.20	05 PIND2	INLET PRESSURE	100.00	05		
06 YIND1	INLET VAPOR QUALITY	1.000	06 YIND2	INLET VAPOR QUALITY	0.000	06		
07 YOUTD1	EXIT VAPOR QUALITY	0.000*	07 YOUTD2	EXIT VAPOR QUALITY	0.000	07 PMD2	COLD ALLOWABLE DP	2.00
08 SFD1	H.T. SAFETY FACTOR	1.700	08 SFD2	H.T. SAFETY FACTOR	1.000*	08 PNM012	COLD MAXDP IN--NOZ	5.00*
09 TSHD1	COND DEG SUP HEAT	0.00	09 TSHD2	BOIL DEG SUP HEAT	0.00	09 PNM022	COLD MAXDP OUT--NOZ	5.00*
10 TSCD1	COND DEG SUB COOL	5.69	10 TSCD2	BOIL DEG SUB COOL	0.00	10 PD2	COLD DESIGN PRESS	150.00*
11 RFD1	FOUL RESISTANCE	.00090	11 RFD2	FOUL RESISTANCE	.00100	11 VMAXD2	COLD MAX VELOCITY	0.00
12 FL1	FOUL LAYER THICK	0.0000	12 FL2	FOUL LAYER THICK	0.0000	12 VMIND2	COLD MIN VELOCITY	0.00
13 HSUBD	SUBCOOL H.T. COEF	0.00	13 HCD	H.T. COEFFICIENT	0.00	13 PMAXD	TOTAL DP	0.00
14 HTPZD	2-PHASE H.T. COEF	0.00						

COLD FLUID (WATER) PHYSICAL PROPERTIES	
CARD 31 PHYSICAL PROPERTY CONTROL	
COMPONENT	1
NAME	WATER
04 HMMND	0.0000
05 ZINC	0.
06 APC	1.
07 API	0.00
08 HCF	0.00
09 AMWL	0.00
10 AMW	0.00
11 ZU	0.0000
12 UPCD	0.00
13 UTCD	0.00
14 GZCD	0.0000
15 HGLD	0.00
16 PZERU	0.

HOT FLUID (WORKING FL) PHYSICAL PROPERTIES PROFILE

40 PXP	ISOBARS	(K=1)	143.170	FPC							
	(K)	1=1	1=2	1=3	1=4	1=5	1=6	1=7	1=8	1=9	1=10
41 TXP	1	105.00	100.00	95.00	90.00	85.00	80.00	87.00	86.00	85.69	80.00
42 CXFP	1	0.0000	14.6450	39.9460	70.8390	82.4740	97.0450	116.0102	141.9000	151.8500	155.3700
43 YXP	1	1.0000	.9105	.7825	.5474	.4697	.3718	.2436	.0078	0.0000	0.0000
44 PDVP	1	1.3046	1.4548	1.4477	1.3974	1.3904	1.3843	1.3776	1.3707	1.3661	.3666
45 XMUVP	1	.0090	.0089	.0089	.0088	.0088	.0088	.0088	.0088	.0088	.0087
46 XKVP	1	.0129	.0128	.0127	.0125	.0125	.0125	.0125	.0124	.0124	.0122
47 HVXP											
48 CPVP	1	.4854	.4845	.4838	.4834	.4833	.4832	.4832	.4832	.4832	.4832
50 ROLP	1	32.8250	32.5290	32.2330	31.8830	31.8060	31.7270	31.6450	31.5600	31.5650	31.8250
51 XMULP	1	.1017	.1040	.1010	.0976	.0969	.0961	.0953	.0945	.0943	.0973
52 KMLP	1	.0549	.0556	.0556	.0556	.0555	.0555	.0555	.0554	.0554	.0563
53 HLXP											
54 CPLP	1	.6034	.6069	.6104	.6153	.6165	.6178	.6191	.6206	.6210	.6127
55 SIGP											
56 PCLP											

***** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** *WARNING MESSAGES -- CALCULATIONS CONTINUE* ** ** ** *

05- 5(1. 0) OUTLD IS PRESENTLY NOT USED SET DOTLD = 0
20-10(3. 0) TSCD WILL BE CALCULATED BY THE PROGRAM EXCEPT IN STRAIGHT LINE PROFILE CASES SET TSCD = 0

HOT FLUID (WORKING FL) PHYSICAL PROPERTIES PROFILE

PXP	ISOBAR	(K=1)	143.17								
	(K)	1=1	1=2	1=3	1=4	1=5	1=6	1=7	1=8	1=9	1=10
TXP	1	105.00	100.00	95.00	90.00	85.00	80.00	75.00	70.00	65.00	60.00
QXFP	1	0.0000	14.6450	39.9460	70.8390	62.4740	97.0450	116.0100	141.9000	151.8500	155.3700
YXP	1	1.0000	.9105	.7825	.5474	.4677	.3718	.2436	.0678	0.0000	0.0000
ROVP	1	1.3046	1.4546	1.4277	1.3974	1.3409	1.3643	1.3776	1.3707	1.3861	.3686
XMVVP	1	.0090	.0089	.0084	.0088	.0088	.0088	.0088	.0088	.0088	.0087
XKVP	1	.0129	.0128	.0127	.0125	.0125	.0125	.0125	.0124	.0124	.0122
HVXP	1	0.0000	-4.4248	-4.8455	-7.2635	-7.7468	-8.2301	-8.7133	-9.1965	-9.3463	-12.0457
CPVP	1	.4854	.4845	.4838	.4834	.4833	.4832	.4832	.4832	.4832	.4832
ROLP	1	32.8250	32.5290	32.2330	31.8830	31.8060	31.7270	31.6450	31.5800	31.5650	31.8250
XMULP	1	.1017	.1040	.1010	.0976	.0969	.0961	.0953	.0945	.0943	.0973
XKLP	1	.0549	.0556	.0556	.0556	.0555	.0555	.0555	.0554	.0554	.0563
HLXP	1	0.0000	-3.0258	-6.0690	-9.1332	-9.7491	-10.3663	-10.9848	-11.6046	-11.7970	-15.3069
CPLP	1	.6034	.6069	.6104	.6153	.6185	.6178	.6191	.6206	.6210	.6127
SIGP	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PCLP	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
XLATP	1	136.24	136.24	178.01	120.20	142.68	143.11	143.43	143.86	143.86	143.86

COLD FLUID (WATER) PHYSICAL PROPERTIES PROFILE

PXP	ISOBAR	(K=1)	100.00								
	(K)	1=1	1=2	1=3	1=4	1=5	1=6	1=7	1=8	1=9	1=10
TXP	1	88.61	86.54	84.48	82.41	80.34	78.27	76.20	74.14	72.07	70.00
QXFP	1	16.6211	16.5538	14.4861	12.4180	10.3495	8.2805	6.2111	4.1412	2.0709	0.0000
YXP	1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
ROVP	1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
XMVVP	1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
XKVP	1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
HVXP	1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
CPVP	1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
ROLP	1	62.0369	62.0622	62.0871	62.1117	62.1359	62.1597	62.1831	62.2062	62.2290	62.2513
XMULP	1	.7834	.8020	.8213	.8413	.8621	.8836	.9059	.9290	.9531	.9780
XKLP	1	.3604	.3598	.3593	.3587	.3582	.3576	.3571	.3565	.3559	.3554
HLXP	1	0.0000	-2.0673	-4.1350	-6.2031	-8.2716	-10.3406	-12.4100	-14.4799	-16.5503	-18.6211
CPLP	1	.9996	.9998	.9999	1.0001	1.0004	1.0006	1.0008	1.0010	1.0013	1.0015
SIGP	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PCLP	1	3208.20	3208.20	3208.20	3208.20	3208.20	3208.20	3208.20	3208.20	3208.20	3208.20
XLATP	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

HTRI SHELL AND TUBE CONDENSER PROGRAM CST-1 MOD 1.1
 FINAL RESULTS PROBLEM DESCRIPTION- CONDENSER
 COOLANT DESIGN- TUBESIDE HOT COUNTERCURRENT

HTRI VERSION

PAGE NO- 45
 CASE-0022
 ALT. SOLN- 4

*** PROCESS DATA ***

	COLD SHELLSIDE	HOT TUBESIDE
01 FLUID NAME	WATER	WORKING FL
02 FLUID CONDITION	SENS. LIQUID	COND. VAPOR
03 TOTAL FLOW RATE (1.0E+3) (LB/HR)	66.750	8.000
04 WEIGHT FRACTION VAPOR, IN/OUT (--)	0.000 / 0.000	1.000 / 0.000
05 TEMPERATURE, IN/OUT (DEG F)	76.0 / 88.6	105.0 / 80.0
06 TEMPERATURE, AVERAGE/SKIN (DEG F)	79.3 / 82.0	92.5 / 85.3
07 PRESSURE, INLET/AVERAGE (PSIA)	100.00 / 99.04	143.20 / 143.10
08 PRESSURE DROP, TOTAL/ALLOW (PSI)	1.92 / 2.00	.21 / 5.00
09 VELOCITY, MID/MAX ALLOW (FT/SEC)	.88 / 0.00	2.19 / 0.00
10 AVERAGE FILM COEF (BTU/HR-FT ² -F)	737.47	240.44
11 HEAT TRANSFER SAFETY FACTOR (--)	1.000	1.700
12 FOULING RESISTANCE (HR-FT ² -B/UTU)	.001000	.000900

*** SHELLSIDE PERFORMANCE ***

01 NUM VEL, X=FLOW/WINDOW	1.70 / 2.11
02 FILM COEF, X=FLOW/WINDOW	844.9 / 750.9
03 FLOW FRACTIONS FOR HEAT TRANSFER	.590
04 A = .564 B = .467 C = .029 E = .139 F = 0.000	

*** SHELLSIDE HEAT TRANSFER CORRECTIONS ***

	TOTAL	BETA	GAMMA	END	FIN
05	.894	.894	1.000	.976	1.000

*** PRESSURE DROPS *** (PERCENT OF TOTAL)

	CROSS WINDOW	ENDS	NOZZLE	SHELL	TUBE
06	57.65	32.31	2.32	1.91	83.11
07 RECOVERY	0.00	0.00	0.00	3.81	2.19

*** CONDENSATION PARAMETERS ***

	METHOD	MODE	INLET	CENTER	OUTLET
08	PRURATION	SHEAR	CC	TRANS	CC
09	AVG MULTICOMPONENT H.T. CORR FACTOR				.6558

13 OVERALL COEF, REQD/CLEAN/ACTUAL (BTU/HR-FT ² -F)	107.90 / 160.25 / 120.67
14 HEAT DUTY, REQUIRED/SPECIFIED (1.0E+6) (BTU/HR)	1.24296 / 0.00000
15 EFFECTIVE OVERALL TEMPERATURE DIFFERENCE (DEG F)	11.88

*** CONDENSER PERFORMANCE CRITERIA ***

16 PRESSURE DROP RATIOS BASED ON SPECIFIED/REQUIRED AREAS, SHELLSIDE/TUBESIDE	1.095 / 1.016
17 RATIO OF AREA SPECIFIED TO AREA REQUIRED	1.1164

18
 19
 20 ----- SEE NEXT PAGE FOR WARNING MESSAGES -----

*** SHELL CONSTRUCTION INFORMATION ***

21 SHELL TYPE E REAR HEAD FXTS	SHELL ID (IN)	16.875
22 SHELLS SERIES 1 PARALLEL	TOTAL AREA (FT ²)	905
23 PASSES SHELL 1 TUBE	EFF. AREA (FT ² /SHELL)	969.5
24 SHELL ORIENTATION ANGLE 90	(DEGREES FROM HORIZONTAL)	
25 PAIRS OF SEALING DEVICES 3	IMPINGEMENT PLATE INCLUDED	NO
26 WEIGHT ESTIMATION (LB/SHELL)	WT	4928 DRY 3132

*** BAFFLE INFORMATION ***

	VERT SEGMENTAL	BAFFLE CUT (PCT DIA)	NO.	(PCT AREA) (IN TO C.L.)
27 TYPE				
28 CROSSPASSES/SHELLPASS	35			
29 CENTRAL SPACING (IN)	5.875	1	14.367	5.226
30 INLET SPACING (IN)	10.213			
31 OUTLET SPACING (IN)	8.526			
32 BAFFLE THICKNESS (IN)	.188			

*** TUBE INFORMATION ***

33 TUBE TYPE	PLAIN	TUBECOUNT PER SHELL	418
34 OVERALL LENGTH (FT)	18.000	PCT TUBES REMOVED (NONE)	0.00
35 EFFECTIVE LENGTH (FT)	17.719	OUTSIDE DIAMETER (IN)	.5000
36 TOTAL TUBESHEET THICK (IN)	3.4	INSIDE DIAMETER (IN)	.4300
37 AREA RATIO (OUT/IN)	1.163	PITCH (IN)	.6880 RATIO
38		LAYOUT ANGLE (DEGREES)	90

*** SHELLSIDE NOZZLES ***

	INLET	OUTLET
16 NUMBER AT EACH POSITION	1	1
17 DIAMETER (IN)	6.07	6.07
18 VELOCITY (FT/SEC)	1.48	1.49
19 PRESSURE DROP (PSI)	.07	.07
20 HEIGHT UNDER NOZZLE (IN)	.25	.25
21 NOZZLE R-V-SU (LB/FT-SZ)	137	137
22 SHELL R-V-SU (LB/FT-SZ)	695	697

*** TUBESIDE NOZZLES ***

	INLET	OUTLET
23 DIAMETER (IN)	3.07	3.07
24 VELOCITY (FT/SEC)	33.18	1.37
25 PRESSURE DROP (PSI)	.17	.00

*** DIAMETRICAL CLEARANCES (IN) ***

	BAFFLE-TO-SHELL BUNDLE-TO-SHELL	TUBE-TO-BAFFLEHOLE
29	.1214	.5000 .0312

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HTRI SHELL AND TUBE CONDENSER PROGRAM CST-1 MOD 1.1
 PERFORMANCE PROFILES PROBLEM DESCRIPTION- CONDENSER
 COOLANT DESIGN- TUBESIDE HOT COUNTERCURRENT

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*** CONDENSING SIDE PERFORMANCE PROFILE ***			ZONE A	ZONE B	ZONE C	ZONE D	ZONE E	ZONE F	ZONE G
			(INLET)						(SUBCOOL)
01	WEIGHT FRACTION VAPOR	(--)	.9721	.8265	.6009	.4947	.3328	.0907	0.0000
02	VAPOR TEMPERATURE	(DEG F)	103.4	96.7	92.8	89.3	87.7	85.9	82.8
03	WALL TEMPERATURE	(DEG F)	95.8	87.6	86.0	83.4	81.8	78.0	76.0
04	PRESSURE	(PSIA)	143.03	143.02	143.02	143.01	143.00	143.00	143.00
05	CONDENSING HEAT TRANS COEF	(BTU/HR-FT ² -F)	158.52	238.42	189.52	229.31	303.61	303.62	289.56
06	CONDENSATE FILM COEF	(BTU/HR-FT ² -F)	425.61	369.69	293.66	321.66	403.07	465.20	
07	VAPOR PHASE COEF	(BTU/HR-FT ² -F)	339.29	611.12	534.43	798.73	1230.34	874.18	
08	SENSIBLE VAPOR COEF	(BTU/HR-FT ² -F)	48.00	41.90	35.74	27.61	20.09	2.41	
09	VAPOR PHASE RESISTANCE FRACTION	(--)	.55727	.37662	.35462	.28710	.24676	.34733	
10	FLOW REGIME PARAMETER	(--)	.2212	.6233	.9209	1.3420	1.8686	5.3635	
11	VAPOR REYNOLDS NUMBER	(--)	31.36	26732	22378	16521	11644	2608	0
12	CONTROLLING REGIME		SHEAR	TRANS	GC TRANS	GC TRANS	GC TRANS	GC TURB	

*** COOLANT SIDE PERFORMANCE PROFILE ***

13									
14	BULK TEMPERATURE	(DEG F)	80.1	84.9	82.2	79.2	76.3	71.1	70.2
15	HEAT TRANSFER COEF	(BTU/HR-FT ² -F)	737.47	737.47	737.47	737.47	737.47	737.47	737.47
16									
17									

*** OVERALL PERFORMANCE PROFILE ***

18	HEAT DUTY FROM HOT INLET	(1.0E+6)(BTU/HR)	.07300	.28296	.45279	.65801	.85946	1.21450	1.24296
19	AREA FROM HOT INLET	(FT ²)	.47	1.08	.330	.519	.661	.850	.866
20	LOCAL OVERALL H.T. COEF	(BTU/HR-FT ² -F)	103.96	117.69	104.52	117.35	137.35	137.36	133.93
21	MEAN TEMP DIFFERENCE	(DEG F)	14.87	11.85	10.61	10.15	11.40	14.74	12.45
22	LOCAL HEAT FLUX	(BTU/HR-FT ²)	1545	1394	1107	1190	1565	2024	1667

HTRI SHELL AND TUBE CONDENSER PROGRAM CST-1 MOD 1.1
 COMPONENT PHYSICAL PROPERTIES PROBLEM DESCRIPTION- CONDENSER
 COOLANT DESIGN- TUBESIDE HOT COUNTERCURRENT

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*PHYSICAL PROPERTIES SHOWN WERE CALCULATED AT REFERENCE PRESSURE (PSIA) HOT FLUID 143.17 COLD FLUID 100.00

*** MIXTURE LOCAL PHYSICAL PROPERTIES ***			HOT FLUID			COLD FLUID			
17	REFERENCE TEMPERATURE	(DEG F)	105.00	69.00	85.69	17 REF. TEMP	70.00	80.34	88.61
18	VAPOR DENSITY	(LB/FT3)	1.3046	1.3909	1.3661				
19	VISCOSITY	(CP)	.00900	.00881	.00876				
20	THERMAL CONDUCTIVITY(BTU/HR-FT-F)		.0129	.0125	.0124				
21	SPECIFIC HEAT CAPACITY (BTU/LB-F)		.4854	.4833	.4832				
22	MOLECULAR WEIGHT	(LB/MOLE)	0	0	0				
23	LIQUID DENSITY	(LB/FT3)	32.825	31.806	31.565	23 LIQ. DENSITY	62.251	62.136	62.037
24	VISCOSITY	(CP)	.10171	.09666	.09426	24 VISCOSUS	.97804	.86206	.78339
25	THERMAL CONDUCTIVITY(BTU/HR-FT-F)		.0549	.0555	.0554	25 TH. COND	.3554	.3582	.3604
26	SPECIFIC HEAT CAPACITY(BTU/LB-F)		.6034	.6165	.6210	26 SP. HEAT	1.0015	1.0004	.9996
27	MOLECULAR WEIGHT	(LB/MOLE)	0	0	0	27 MOLE WT	18	18	18
28	LATENT HEAT	(BTU/LB)	136.24	142.68	143.86				
29	SURFACE TENSION	(DYNE/CM)	12.450	12.920	13.006				

*** SUBCOOLING AND SUPERHEATING MIXTURE PHYSICAL PROPERTIES ***

			HOT FLUID			SUBCOOLED ZONE		
30	REFERENCE TEMPERATURE	(DEG F)				30 REF. TEMP	80.00	
31	DENSITY	(LB/FT ³)				31 DENSITY	31.8250	
32	VISCOSITY	(CP)				32 VISCOSITY	.09726	
33	THERMAL CONDUCTIVITY	(BTU/HR-FT-F)				33 THERMAL COND	.0563	
34	SPECIFIC HEAT CAPACITY	(BTU/LB-F)				34 SPECIFIC HEAT	.6127	

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HTRI CST-1 MOD 1.1 HTRI VERSION PAGE NO- 48
 PROBLEM DESCRIPTION- CONDENSER CASE-CD22

FLOW INDUCED VIBRATION ANALYSIS SENS. LIQUID SHELLSIDE

01	LOG DECREMENT .0300 AXIAL STRESS LOADING	0.0 (KPSI)		
02	BETA 2.792 ADDED MASS FACTOR 2.2765	POSITION IN BUNDLE		
03	LENGTH FOR NATURAL FREQUENCY (FT)	INLET	CENTER	OUTLET
04	LENGTH/TEMA MAXIMUM SPAN (---)	1.341	.979	1.200
05	NUMBER OF SPANS (---)	.402	.294	.360
06	NATURAL FREQUENCY (FTUBE) (HZ)	18	18	18
07		99.04*	185.74	123.71
08	WINDOW (PARALLEL FLOW) (FT/SEC)	1.34	1.34	1.34
09	WINDOW (CROSSFLOW) (FT/SEC)	.39	.52	.43
10	C-STREAM VELOCITY (FT/SEC)	.25	.43	.30
11	E-STREAM VELOCITY (FT/SEC)	1.51	2.63	1.82
12				
13	CROSSFLOW VELOCITY (FT/SEC)	.51	.88	.61
14	CRITICAL VELOCITY (FT/SEC)	3.76	7.06	4.71
15	CROSSFLOW REYNOLDS NUMBER (---)	1995.	3935.	2963.
16	CROSSFLOW RHO-V-SQ (LB/FT-SQ)	16.	48.	23.
17	FREQUENCY RATIOS (FVXSD)/(FTUBE) (---)	.032	.042	.035
18				
19				
20				
21	DAMAGE NUMBERS			
22	BAFFLE (---)	.0023	.0038	.0027
23	COLLISION (---)	.0004	.0004	.0004
24	RHO/SQRT(MU) (SEE STV-1, FIG 9-6)	40.4634	43.0281	45.0560
25	VIBRATION AMPLITUDES			
26	PARALLEL FLOW (IN)	.000034	.000018	.000027
27	CROSSFLOW-INDUCED (IN)	.000007	.000006	.000006
28				
29	SHELL PARAMETERS AT NOZZLES	ENTRANCE	EXIT	
30	IMPINGEMENT PLATE	NU	---	
31	FLOW AREA (FT2)	.0891	.0891	
32	VELOCITY (FT/SEC)	3.34	3.35	
33	RHO-V-SQ (LB/FT-SQ)	695	697	
34				
35				
36	TEMA E SHELL WITH VERT SEGMENTAL BAFFLES AND FXTS BUNDLE			
37	NUMBER OF INTERMEDIATE SUPPORT PLATES PER SPAN	0		
38	PLAIN ADMIRALTY TUBES .5000 DIAMETER (IN)		90 DEGREE LAYOUT	
39	PITCH RATIO 1.376			

* FREQUENCY RATIOS ARE BASED ON THE LOWEST NATURAL FREQUENCY