Conceptual Design of the Intermediate Heat Exchanger (IHX) for the PB-AHTR

Hyun Jin Lim and Per F. Peterson
U.C. Berkeley
Report UCBTH-09-005

May 20, 2009

Introduction

UC Berkeley has developed the PB-AHTR (Pebble Bed Advanced High Temperature Reactor) as shown in Fig. 1 [1]. The PB-AHTR uses an intermediate heat transport system to transfer the heat from reactor to power conversion system or hydrogen production system.

The modular PB-AHTR (900 MWth) adopts several components and systems that were originally developed for the Molten Salt Breeder Reactor (MSBR) program at ORNL. These include the MSBR primary pump and intermediate heat exchanger (IHX) developed and tested at multiple scales in the ORNL MSBR program [1, 2].

Several types of heat exchangers, compact plate types and shell-and-tube types, were considered for use as the PB-AHTR the IHX. To facilitate in-service inspection and reliability, the PB-AHTR adopts the MSBR shell and tube IHX design [1, 2]. There are four IHX (225 MWth/IHX) and two primary pump in the intermediate loop and each of the two primary salt pumps provides flow to two of the four IHX's. Figure 2 provides a cross sectional elevation view of IHX for the PB-AHTR.

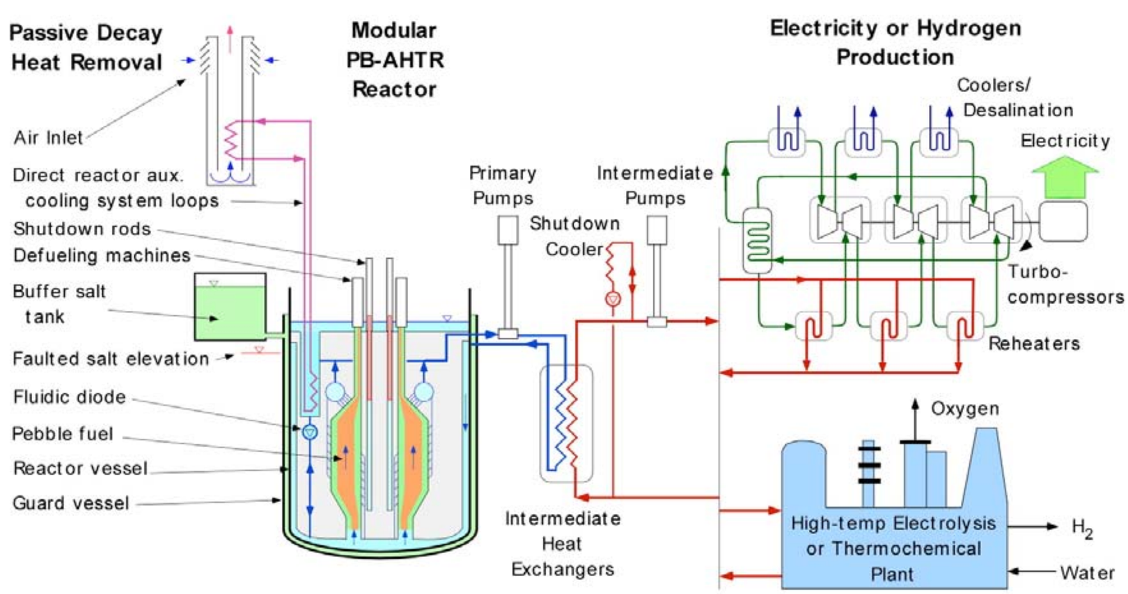


Fig. 1. Schematic of the modular PB-AHTR

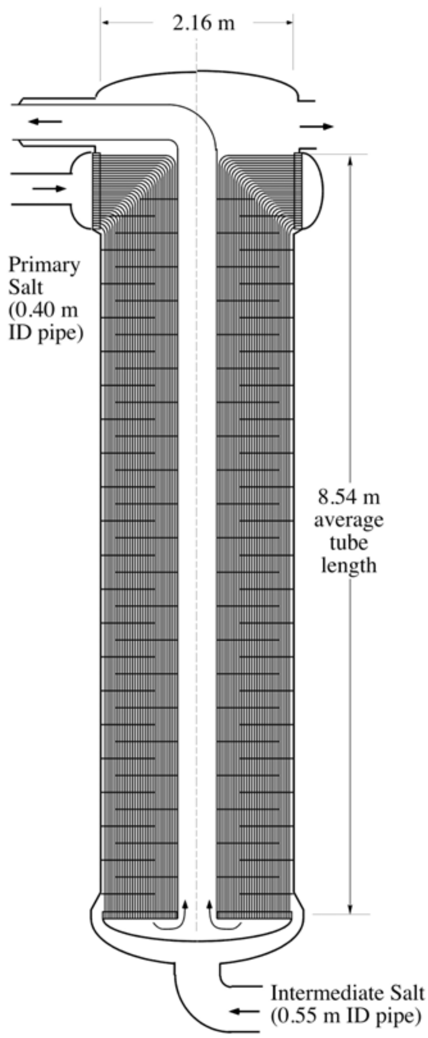


Fig. 2. Elevation view of IHX for the PB-AHTR, with inlet and outlet plenums shown schematically.

The overall conditions in the PB-AHTR system impose several specific design requirements on the IHX's [3]:

1. The entrance and exit coolant temperatures, maximum pressure drop and the total heat transfer capacity must conform to the overall system operating conditions.

2. The type of heat exchanger, general location of nozzle, height of the unit and minimum tube diameter must be compatible with various design, layout and fabrication considerations.

3. The heat exchanger must be arranged for relatively easy tube-bundle replacement by means of remote operation.

4. Flow velocities, baffle thickness, tube clearance and baffle spacing should be selected to minimize possibilities of vibration.

Based on the conditions, for application to the PB-AHTR the detailed design characteristics for shell-and-tube-type, one-pass vertical exchanger with disk-and-doughnut-baffles heat exchangers are [3]:

1. The tubes are arranged in concentric rings in the bundle and the L-shaped tubes are welded into a tube sheet. The L-shaped tubes help accommodate differential thermal expansion between tubes.

2. The tubes have a helically knurled surface to improve heat transfer and to minimize salt volume. The tubes may also have a tri-clad construction, with a high-temperature structural alloy sandwiched between thin layers of a corrosion resistant cladding material.

3. The baffles are used to hold the tubes and to control cross flow to minimize the flow-induced vibration.

4. The IHX should facilitate natural circulation flow. Thus the primary salt must flow downward and the intermediate coolant upward.

5. The primary coolant must enter and exit from the top of the IHX, because the connections on the primary loop of the PB-AHTR, which uses a pool-type reactor vessel and a guard vessel, are also high in the system.

6. Under this configuration, the primary coolant flows on the tube side and the intermediate coolant enters from the bottom, flows on the shell side, and exits the top.

The primary salt (flibe) enters the top of the IHX tube side, which uses 0.9525-cm O.D., 0.1335-cm wall thickness tubes with an inlet temperature of 704°C, exits the bottom tube sheet into a collection plenum, and then flows upward through central pipe and out from the top of IHX at a temperature of 600°C. The secondary salt (flinak) enters the bottom of IHX shell side at a temperature of 545°C and flow upward around disk and doughnut type baffles, and flow out the top of IHX at 690°C. Based on the requirements, the design calculations were performed using the PRIMEX code.

Description of the PRIMEX code

PRIMEX (PRIMary heat EXchanger) is a computer code which was developed at ORNL in 1971 for MSBR primary heat exchanger design [4]. In the MSBR design, the PRIMEX code was believed to result in an efficient and reliable design.

In 1998, the code was reconstructed at Ajou University (South Korea) as a part of development of an advanced molten salt nuclear energy complex, named AMBIDEXTER [5]. Most of the modification of the code was to meet PC operating system requirements, thus the code was updated from the original version of IBM 360/91 to MS WINDOWS. Table 1 provides a brief history of the code development and modifications.

Table 1. Development and update history of the PRIMEX code [4,5]

year	Institute	Modifications
1971	ORNL (MSBR)	Original code development, IBM 360/91
1998	Ajou Univ. (AMBIDEXTER)	Code reconstruction for PC WINDOWS
2008	UC Berkeley (PB-AHTR)	Physical Properties (flibe, flinak) insertion

A simplified flow diagram for the PRIMEX code and the definition of baffle space are shown in Figs. 3 and 4, respectively. In the code calculation, each zone between two baffles was considered as one increment length. The calculations are begun on the hot side of the heat exchanger, and increments are added until a complete heat balance is achieved [5].

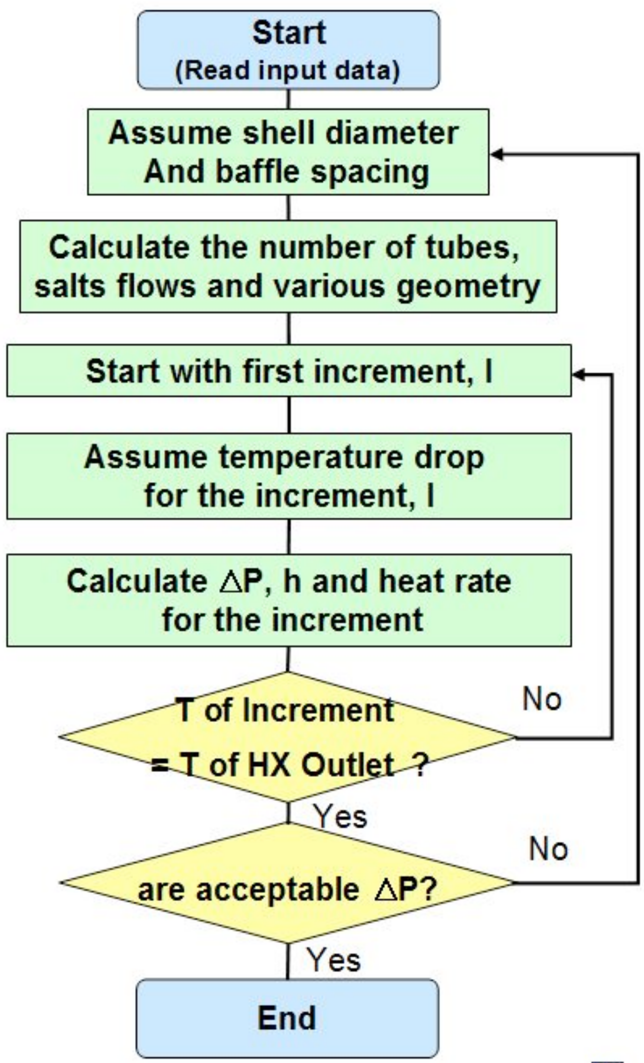


Fig. 3. The simplified flow diagram for the PRIMEX code

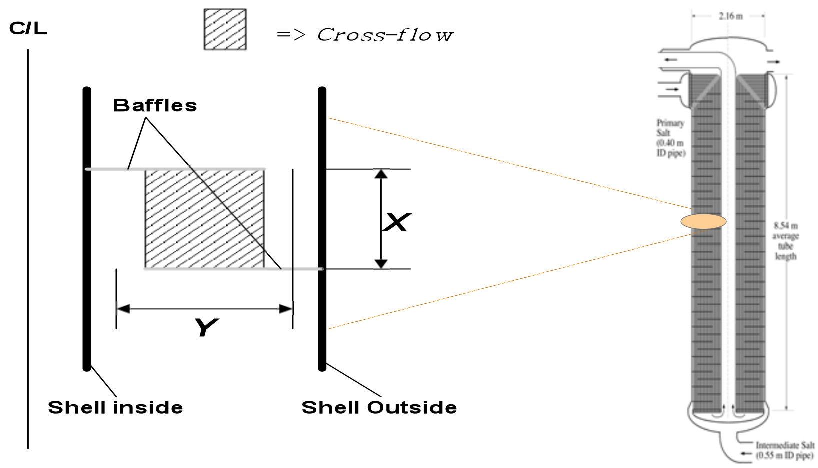


Fig. 4. The baffle space in the PRIMEX code

Design Calculations

The physical properties of the salts are given by temperature dependent equations and these equations are can be replaced when the salt types are changed. The physical properties of primary and secondary salts for the heat exchangers in the AMBIDEXTER are same as the MSBR. But the PB-AHTR case, to the properties are changed to use flibe (primary) and flinak (secondary) as the salts. The salt properties used for the PB-AHTR IHX design are listed in table 2 [6].

Heat transfer experience with the salts is limited because no experiments have been performed for correlating the heat transfer behavior of coolant salt in the shell side of the heat exchanger, but the MSRE and some experiments showed that basically the primary salt (fuel salt in MSRE) behaves very similarly to conventional fluids [3].

As described earlier, the tubes in the heat exchanger are helically indented to improve heat transfer performance. Some experimental results performed by C. G. Lawsin, et al. [7] indicate that this indentation is expected to result in an improvement by a factor of 2 in the tube-side heat transfer coefficient. For the tube outside, an enhancement factor of 1.3 was recommended but it was based on some assumptions [3].

Table 2. Summary of properties of the primary and secondary salts [6]

	Melting point (°C)	Density (g/cm^3)	Heat capacity (J/kg K)	Viscosity (cP)	Th. conductivity (W/m K)	Pr (at T=600° C)
$LiF\text{-}BeF_2$ (66-34)	458	$2.28-4.884E-4\times T$	2380	$0.116\exp\left(\frac{3755}{T+273}\right)$	1.1	20.4
NaF-$NaBF_4$ (8-92)	385	$2.2521-7.11E-4\times T$	1500	$0.0877\exp\left(\frac{2240}{T+273}\right)$	0.5	3.4
LiF-NaF-KF (flinak)	454	$2.53-7.3E-4\times T$	1880	$0.04\exp\left(\frac{4170}{T+273}\right)$	1	10

In the code calculation, the overall heat transfer coefficient, U_O, is given by

$$U_O = \frac{1}{\frac{1}{h_O} + \frac{1}{h_W} + \frac{1}{h_i}\left(\frac{d_O}{d_i}\right)} \tag{1}$$

where for turbulent flow,

$$\frac{h_i d_i}{k_i} = 0.217(Re)^{0.8}(Pr)^{0.33}\left(\frac{\mu_b}{\mu_i}\right)^{0.14}(EF_i) \tag{1-a}$$

$$h_W = \left(\frac{k}{d_O t}\right)\frac{d_O - d_i}{ln\frac{d_O}{d_i}} \tag{1-b}$$

$$\frac{h_O d_O}{k_O} = 0.128(D_{eq})^{0.6}(Re)^{0.6}(Pr)^{0.33}\left(\frac{\mu_b}{\mu_i}\right)^{0.14}(EF_O) \tag{1-c}$$

The enhancement factors, EF_i and EF_O, are

$EF_i = 2.0$ and $EF_O = 1.3$ for Reynolds numbers $(Re) \geq 10{,}000$

$EF_i = 1.0$ and $EF_O = 1.0$ for Reynolds numbers $(Re) \leq 1{,}000$

For $1{,}000 \leq Re \leq 10{,}000$,

$$EF_i = 1.0 + \left(\frac{Re - 1000}{9000}\right)^{0.5} \quad \text{and} \tag{1-d}$$

$$EF_O = 1.0 + 0.3\left(\frac{Re - 1000}{9000}\right)^{0.5} \tag{1-e}$$

The pressure drop at the inside tubes (ΔP_i) is calculated by

$$\Delta P_i = f\frac{L}{D_i}\frac{\rho V^2}{2}(EF_i) \tag{2}$$

and the pressure drops for the shell side with baffle region are calculated for the cross-flow zone and the window zone. The pressure drop for the cross-flow zone is

$$\Delta P_{cross-flow} = 0.6 r_B \frac{\rho V_m^2}{2}(PLF)(EF) \tag{3}$$

and the pressure drop at the window zone is calculated by

$$\Delta P_{window} = (1 + 0.6 r_w)\frac{\rho V_z^2}{2}(PLF)(EF) \tag{4}$$

Calculation Result and Analysis

Similar to commercial heat exchanger design codes, total heat capacity, inlet-outlet temperatures of primary and secondary coolant, tube diameter, IHX shell diameter and maximum pressure drops in the tube and shell sides are required as main input parameters for the PRIMEX calculation. Also, British Thermal Units (BTU) are used in the code.

Among the input data which significantly affect the heat exchanger design are the physical properties of salts and their variation with temperature, the heat transfer correlations, the enhancement factors assumed for the knurled tubes and the leakage factors associated with fabrication clearances [4].

Once the inlet and outlet temperatures of the primary and secondary salts are determined, the maximum pressure drop and allowable IHX diameter are the major input parameters to determine the tube length and shell diameter of the IHX [3].

For the baseline IHX design for the PB-AHTR, a lower LMTD is desired than was used in the MSBR to increase the power conversion efficiency and thus a substantially larger surface area is used comparing the MSBR case, as shown in Fig. 5 [6]

Initial calculations were performed with some different shell diameter and tube length cases. As the result, the optimal inlet temperature for the intermediate salt will be around the 550°C value and it is clear that shorter IHX designs have lower effectiveness and thus require more surface area to achieve the same LMTD. On the other hand, shorter IHX designs have smaller pressure drop, which is also valuable. In all cases the primary salt volume in the tubes was relatively small compared to the total primary salt volume.

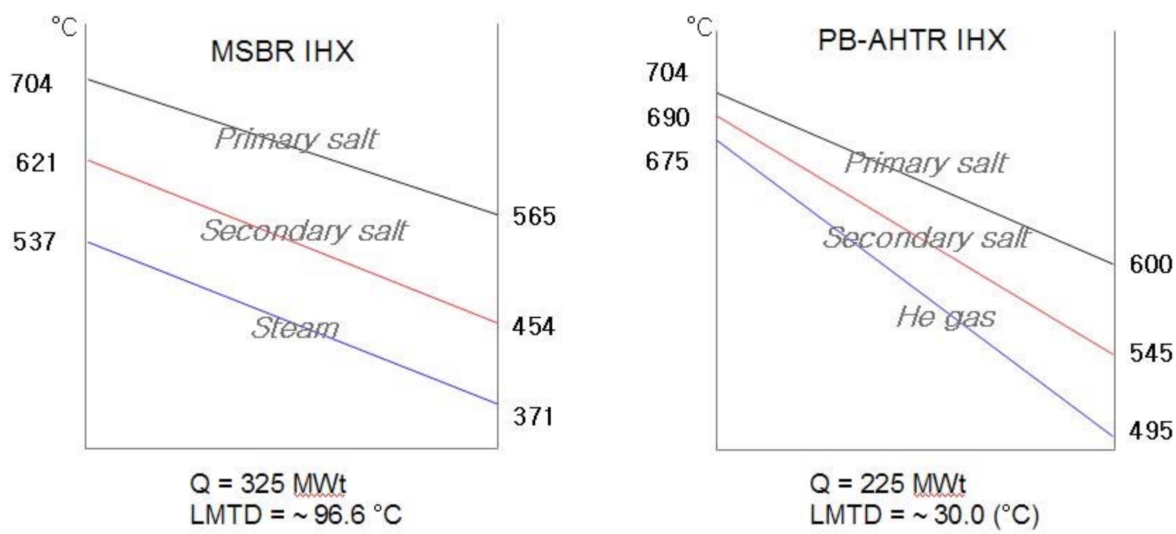
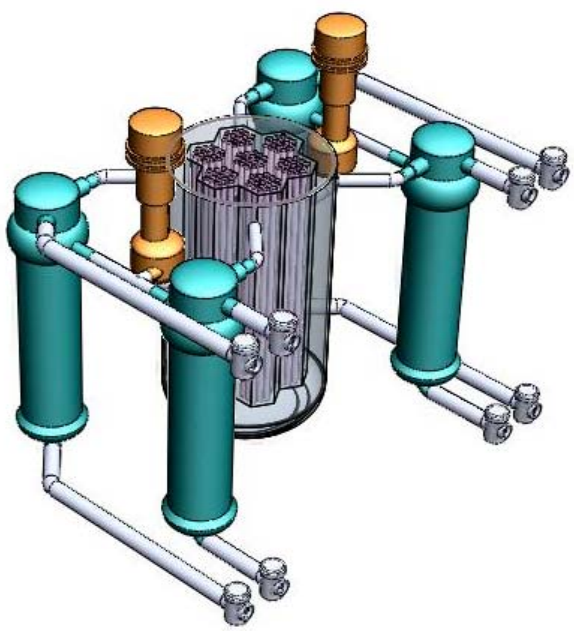


Fig. 5. Primary salt, intermediate salt, and power conversion fluid temperatures in the MSBR IHX and the PB-AHTR IHX

Table 3 shows the calculation results for the IHX. There are three candidate approaches to meet the physical arrangement with reactor vessel and primary loop for the PB-AHTR plant [6]. From the perspective of the physical arrangement, there is no difference between the 1.98-m diameter and the 2.35-m diameter designs, since this difference is very small compared to the distances needed between the IHX's and the reactor vessel.

The IHX height is a more important parameter, since it varies more, but the current reactor design can likely accommodate the full range of optimized lengths with minor impacts. Thus the IHX can be optimized independently from the physical arrangement.

Fig. 6 shows the 3-D view for the PB-AHTR primary loop arrangement and the baseline IHX design with 8.54-m long tubes and a 2.16-m shell diameter. The physical arrangement was developed by U.C. Berkeley seniors in the 2008 NE-170 senior design class [8].



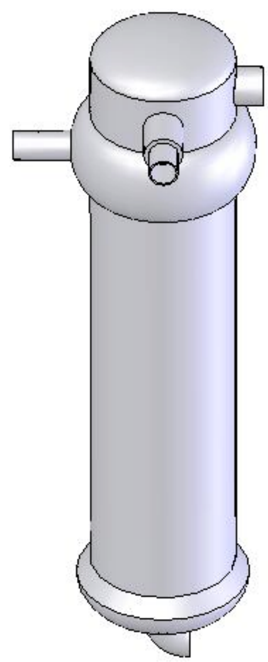


Fig. 6. The 3-D drawings of the PB-AHTR primary loop and the baseline IHX design [8].

Table 3. Design Data for PB-AHTR IHX, for 3 different point designs with different average tube lengths.

Type	Shell-and-tube one-pass vertical exchanger with disk and doughnut baffles		
Number of required	Four		
Heat transfer rate per unit (MWth)	225.0		
Primary salt	flibe (Li_2BeF_4)		
Secondary salt	finak (LiF-NaF-KF)		
Tube Material	Tri-clad Alloy 800H/Hastelloy N		
Inlet temperature of primary salt (°C)	704.0		
Outlet temperature of primary salt (°C)	600.0		
Inlet temperature of secondary salt (°C)	545.0		
Outlet temperature of secondary salt (°C)	690.0		
Outside diameter of tubes (cm)	0.9525		
Wall thickness of tubes (cm)	0.1335		
Mass flow rate of primary salt (kg/sec)	905.87		
Mass flow rate of secondary salt (kg/sec)	823.60		
Central tube(up-comer) diameter (cm)	55.0		
Wall thickness of IHX shell(cm)	1.27		
Total tube length(m)	9.36	8.54	7.99
Total number of tubes	7822	9465	11249
IHX approx. length(m)	8.80	7.98	7.39
Nominal IHX diameter (m)	1.98	2.16	2.35
Primary salt volume in tubes(m^3)	2.70	2.99	3.32
Total heat transfer area based on tube O.D(m^2)	2194.20	2418.99	2695.30
Tube side avg. heat transfer coeff. (W/ m^2 °C)	7997.84	6556.83	5474.00
Shell side avg. heat transfer coeff. (W/ m^2 °C)	12943.56	11992.93	10853.75
Pressure drop in tube side (bar)	2.20	1.39	0.93
Pressure drop in shell side (bar)	1.90	1.43	0.95
Total mass of tubes per IHX module (kg)*	22438.12	24772.59	27543.68
Approx. total mass of IHX module (kg) **	29170.00	32204.00	35806.00
Uniform baffle spacing (m)	0.183	0.192	0.210

*, ** Cold state (at 26°C) mass, primary and secondary salt masses are not included.

** The total mass of the IHX is assumed to be 130% of the tube mass. Four modules provide a total capacity of 900 MWth.

Conclusion and Remarks

This report describes the design requirements and PRIMEX code results for the PB-AHTR IHX modules. The baseline 900-MWth reactor design has four IHX modules with 8.54-m long tubes and 2.16-m diameter shells. The IHX design data is summarized in Table 3 and can used for the transient analyses of the PB-AHTR.

The calculation results from the PRIMEX code will result in more reliable design to minimize the volume of primary salt and structural materials, compared to what can be achieved by normal hand calculations. Also, the code can be applied in the future for the design of the PB-AHTR Direct Reactor Auxiliary Cooling System heat exchangers (DHXs).

However, the some models and input data that have a significant effect on the design of IHX still involve significant uncertainties: the heat transfer correlations, the enhancement factors for the helically indented tubes, the baffle leakage factors related to the fabrication clearance, etc. Also, more detailed design and verification are required for the detailed design stage of the PB-AHTR. Test data from a reduced-area, reduced length IHX from a Liquid Salt Component Test Facility would be helpful in validating these models and input data.

Nomenclature

h_i	heat transfer coefficient inside tube, $\text{Btu/hr}\cdot\text{ft}^2\cdot°\text{F}$
h_w	heat transfer coefficient across the tube wall, $\text{Btu/hr}\cdot\text{ft}^2\cdot°\text{F}$
h_o	heat transfer coefficient outside tube, $\text{Btu/hr}\cdot\text{ft}^2\cdot°\text{F}$
d_i	tube inside diameter, ft
d_o	tube outside diameter, ft
k_i	thermal conductivity of fluid inside tube, Btu/hr·ft·°F
k	thermal conductivity of tube wall, Btu/hr·ft·°F
k_o	thermal conductivity of fluid out tube, Btu/hr·ft·°F
t	tube wall thickness, ft
Re	Reynolds number
Pr	Prandtl number
μ_b	viscosity at temperature of bulk fluid, lb/ hr·ft
μ_i	viscosity of fluid at temperature of inside surface of tube, lb/ hr·ft
r_B	number of cross-flow restrictios
ρ	density of fluid, lb/ft3
V	flow velocity in the tube side, ft/sec

V_m	cross-flow velocity of fluid, ft/sec
PLF	pressure drop leakage factor taken as 0.5
EF	enhancement factor outside helically indented tubes taken as 1.3
r_w	number of restriction in the window zone
V_z	mean flow velocity, ft/sec

References

1. Philippe Bardet et al., "Design, Analysis and Development of the Modular PB-AHTR," Proceedings of ICAPP '08, Anaheim, CA USA, June 8-12, 2008.
2. "The Development Status of Molten-Salt Breeder Reactors," ORNL-4812, pp. 205, August 1972.
3. John L. Anderson et al., "Conceptual Design Study of A Single-Fluid Molten-Salt Breeder Reactor," Oak Ridge National Laboratory, ORNL-4541, June 1971.
4. C. E. Bettis et al., "Computer Programs for MSBR Heat Exchangers," Oak Ridge National Laboratory, ORNL TM-2815, April 1971.
5. Hyun Jin Lim, "Conceptual Design Study on the AMBIDEXTER Heat Transport System," M.S. Thesis, Ajou University, February 1999.
6. Aurelie Niquille, "Modeling and Transient Analysis for the Modular Pebble Bed Advanced High Temperature Reactor (PB-AHTR)," M.S. Report, UC Berkeley, December 2007.
7. C. G. Lawsin, et al., " Enhanced Heat Transfer Tube for Horizontal Condenser with Possible Application in Nuclear Power Plant Design," Transactions of the American Nuclear Society, Vol. 9, No. 2, 1966.
8. D. Caron, et al., "A Modular Pebble-Bed Advanced High Temperature Reactor," NE-170 Senior Design Project, UC Berkeley Thermal Hydraulics Laboratory, Report UCBTH-08-001, May 16, 2008.

Appendix 1. PRIMEX code (Fortran Source)

```
PROGRAM PRIMEXPBAHTR

      REAL LK,LAWO1, LAWO3,HEATL
      DIMENSION TFO(1000),TCI(1000),VM1(1000),VM2(1000),VWO1(1000),
     1VWO3(1000), RENTO(1000),PRNTO(1000),RENSO1(1000),RENSO2(1000),
     2RENSO3(1000),VM3(1000),PDSO(1000),NT(1000),BJ(3),HSO1(1000),
     3HSO2(1000),HSO3(1000),AHSO(1000),HTO(1000),UOA(1000),TCO(1000),
     4TFI(1000),HEAT(1000),TWDT(1000),PDTO(100),TUBLN(100),V1(100),
     5V2(1000),V3(1000),VW1(1000),VW3(1000),
     6R(1000), FACT(1000), TCPI(1000), TOTAL(1000), CASM(6), CTM(6),
     7CWT(1000),FWT(1000),AVWT(1000)
      DATA CASM /18000,18000,17000,13000,6000,3500/
      DATA CTM /800,900,1000,1100,1200,1300/
***** INPUT DATA******
      OPEN (2,FILE='INPUT.TXT',FORM='FORMATTED')
      READ (2,100) HEATL
  100 FORMAT (1F10.0)
      READ (2,110) CTO,FTO,ETF,ETC
  110 FORMAT(4F10.0)
      READ (2,120) PRDT,PRDS
  120 FORMAT (2F10.0)
      READ (2,130) RA5,RA8MAX
  130 FORMAT(2F10.1)
**************************************************************
* HEATL  : Total heat load (BTU/HR)
* PRDT   : Tube side allowable Pressuree Drop (PSI)
* PRDS   : Shell       "            "
* CTO    : Coolant Salt Outlet Temp. (F)
* FTO    : Fuel Salnt Inlet Temp.
* ETF    : Fuel Salt Outlet Temp.
* ETC    : Coolant Salt Inlet Temp.
* RA5    : RADIUS, COOLANT CENTRAL DOWNCOMER
* RA8MAX : RADIUS, ANTICIPATED H.X OUTER
```

```
**************************************************************

**** DEFAULT INPUT DATA ******

      DTR = 0.03125      !Tube Diameter

      WTHK = 0.00438    ! 150% of 0.00292(MSBR Case) with Prof. Peterson

      CUT3 = 0.4

      CUT4 = 0.4

      TPIN = 25920.                 ! Tube side Inlet Pressure (Psi)

      SPOUT = 4896.        ! Shell side Outlet Pressure (Psi)

      LK = 0.8

      PLK = 0.52

      WCOND = 11.6

      ARC = 60.0

      KASES = 1.

      KENTB = 1.

      KTBST = 0.

      DIA = DTR

      ICNPT = 6

      RPI= 2.0*DIA

      BCPI= RPI


 1007 FORMAT(1H , 7X, 1HI, 8X, 3HCTM, 7X, 4HCASM//(4X,I5,2F12.2))

 1008 FORMAT(22H HEAT LOAD REQUIRED=    ,F12.0, 2X, 8H(BTU/HR))

 1009 FORMAT(43H ALLOWABLE TOTAL TUBE-SIDE PRESSURE DROP=    ,F10.0,2X,

     110H(LB/SQ-FT) )

 1010 FORMAT(44H ALLOWABLE TOTAL SHELL-SIDE PRESSURE DROP=    ,F10.0,

     12X,10H(LB/SQ-FT) )

 1011 FORMAT(23H TUBE INLET PRESSURE=    ,F10.0, 2X, 10H(LB/SQ-FT))

 1012 FORMAT(24H SHELL OUTLET PRESSURE=    ,F10.0, 2X, 10H(LB/SQ-FT))

 1013 FORMAT(33H HIGH TEMP. OF SHELL SIDE FLUID=    ,F10.2, 2X, 3H(F))

 1014 FORMAT(33H HIGH TEMP. OF TUBE SIDE FLUID=    ,F10.2, 2X, 3H(F))

 1015 FORMAT(32H LOW TEMP. OF TUBE SIDE FLUID=    ,F10.2, 2X, 3H(F))

 1016 FORMAT(32H LOW TEMP. OF SHELL SIDE FLUID=    ,F10.2, 2X, 3H(F))

 1017 FORMAT(32H HEAT TRANSFER LEAKAGE FACTOR=    ,F10.5)

 1018 FORMAT(27H PRESSURE LEAKAGE FACTOR=    ,F10.5)

 1019 FORMAT(35H CONDUCTIVITY OF TUBE WALL METAL=    ,F10.5, 2X,
```

```
     113H(BTU/HR-FT-F))
1020 FORMAT(37H ARC OF FOUR BENDS FOR FLEXIBILITY=     ,F10.5, 2X, 9H(DEG
     1REES))
1021 FORMAT(34H INSIDE RADIUS OF OUTER ANNULUS=     ,F10.5, 2X, 6H(FEET))
1022 FORMAT(41H DISTANCE BETWEEN SHELL WALL AND TUBES=     ,F10.5, 2X, 6
     1H(FEET))
1023 FORMAT(49H MAXIMUM ANTICIPATED OUTER RADIUS OF EXCHANGER=
     1 ,F10.5,2X,6H(FEET))
1024 FORMAT(23H NUMBER OF CASES RUN=     ,I4)
1025 FORMAT(25H USE OF ENHANCED TUBES=     ,I4,2X,32H(ONE IF ENHANCED TUB
     1ES ARE USED))
1026 FORMAT(1H ,36HUSE OF STRESS ANALYSIS SUBROUTINE=     ,I4,2X,19H(ONE
     1IF TO BE USED))
1027 FORMAT(29H OUTSIDE DIAMETER OF TUBES=     ,F10.5, 2X, 6H(FEET))
1028 FORMAT(27H WALL THICKNESS OF TUBES=     ,F10.5, 2X, 6H(FEET))
1029 FORMAT(16H RADIAL PITCH=       ,F10.5, 2X, 6H(FEET))
1030 FORMAT(25H CIRCUMFERENCIAL PITCH=       ,F10.5, 2X, 6H(FEET))
1031 FORMAT(22H INNER BAFFLE CUT3=       ,F10.5, 2X, 10H(PER CENT))
1032 FORMAT(22H INNER BAFFLE CUT4=       ,F10.5, 2X, 10H(PER CENT),//)
1033 FORMAT(25H TOTAL HEAT TRANSFERED=     ,F12.0,2X,8H(BTU/HR),
     12X,1H(,F5.1,9H PERCENT))
1034 FORMAT(29H MASS FLOW RATE OF COOLANT=     ,F10.0,2X,7H(LB/HR))
1035 FORMAT(26H MASS FLOW RATE OF FUEL=     ,F10.0,2X,7H(LB/HR))
1036 FORMAT(34H SHELL-SIDE TOTAL PRESSURE DROP=     ,F10.2,2X,9H(LB/SQIN)
     1,2X, 1H(,F5.1,9H PERCENT))
1037 FORMAT(33H TUBE-SIDE TOTAL PRESSURE DROP=     ,F10.2,2X,9H(LB/SQIN)
     1,2X, 1H(,F5.1,9H PERCENT))
1038 FORMAT(24H NOMINAL SHELL RADIUS=     ,F7.4,2X,4H(FT))
1039 FORMAT(26H UNIFORM BAFFLE SPACING=     ,F7.4,2X,4H(FT))
1040 FORMAT(40H TUBE FLUID VOLUME CONTAINED IN TUBES=     ,F7.2,1X,12H(CU
     1BIC FEET))
1041 FORMAT(1H 46HTOTAL HEAT TRANSFER AREA BASED ON TUBE O.D.=       ,
     1F12.2,2X,6H(SQFT))
1042 FORMAT(25H TOTAL NUMBER OF TUBES=     ,F6.0)
1043 FORMAT(21H TOTAL TUBE LENGTH=     ,F6.2,2X,4H(FT))
1044 FORMAT(29H HEAT EXCH. APPROX. LENGTH=     ,F6.2,2X,6H(FEET))
```

```
 1045 FORMAT(35H STRAIGHT SECTION OF TUBE LENGTH=     ,F6.2,2X,4H(FT))
 1046 FORMAT(38H RADIUS OF THERMAL EXPANSION CURVES=     ,F6.2,2X,6H(FEET)
     1)
 1047 FORMAT(31H BERGLIN MODIFICATION FACTOR=     ,F5.2)

 1090 FORMAT(1H ,3X,1HI,8X,3HTCI,9X,3HTCO,9X,3HCWT,9X,3HTFI,9X,3HTFO,9X
     1,3HFWT//13X,1HF,11X,1HF,11X,1HF,11X,1HF,11X,1HF,11X,1HF
     2//(1X,I3,4X,6E12.4))

 1091 FORMAT(1H   ,3X,1HI,8X,4HTWDT,9X,2HV1,10X,2HV2,10X,2HV3,9X,3HVW1,9X
     1,3HVW3//13X,1HF,21X,6HFT/SEC//(1X,I3,4X,6E12.4))

 1092 FORMAT(1H   ,3X,1HI,8X,4HPDSO,8X,4HPDTO,8X,5HRENTO,7X,5HPRNTO,6X,
     16HRENSO1,6X,6HRENSO2//16X,7HLB/SQFT//(1X,I3,4X,6E12.4))

 1093 FORMAT(1H   ,3X,1HI,7X,6HRENSO3,7X,3HHTO,9X,4HAHSO,8X,3HUOA,9X,4HHE
     1AT//32X,13HBTU/HR/SQFT/F,14X,6HBTU/HR//(1X,I3,4X,5E12.4))


 1051 FORMAT(27H TUBE WALL AVERAGE TEMP.=     ,F10.2)
 1052 FORMAT(28H SHELL SIDE AVERAGE TEMP.=     ,F10.2)
 1053 FORMAT(1H 34HP STRESS AT TUBE OD AND TUBE ID =   ,2F10.2,1X,
     19H(LB/SQIN),//,18H(SHOULD NOT EXCEED,F10.2,3H   ))
 1054 FORMAT(1H 36HP+Q STRESS AT TUBE OD AND TUBE ID =   ,2F10.2,1X,
     19H(LB/SQIN),//,18H(SHOULD NOT EXCEED,F10.2,3H   ))
 1055 FORMAT(1H 38HP+Q+F STRESS AT TUBE OD AND TUBE ID =   ,
     12F10.2,1X,9H(LB/SQIN),//,18H(SHOULD NOT EXCEED,F10.2,3H   ))
C
C        READ IN AND PRINT OUT INPUT DATA
      KEY7=1
      VM1(1)=0.
      VM2(1)=0.
      VM3(1)=0.
      VWO1(1)=0.
      VWO3(1)=0.
```

```
      RENSO1(1)=0.
      RENSO2(1)=0.
      RENSO3(1)=0.
      HSO1(1)=0.
      HSO2(1)=0.
      HSO3(1)=0.
      HEFI=1.
      HEFO=1.
C

    1 CONTINUE
      HSFCT=1.
      IF(FTO.LT.CTO) HSFCT=-1.
      open (5,file='output.txt')
C       write (5,1007) (K,CTM(K),CASM(K),K=1,ICNPT)
      write (5,1008) HEATL
      write (5,1009) PRDT
      write (5,1010) PRDS
      write (5,1011) TPIN
      write (5,1012) SPOUT
      write (5,1013) CTO
      write (5,1014) FTO
      write (5,1015) ETF
      write (5,1016) ETC
      write (5,1017) LK
      write (5,1018) PLK
      write (5,1019) WCOND
      write (5,1020) ARC
      write (5,1021) RA5
      write (5,1022) DTR
      write (5,1023) RA8MAX
      write (5,1024) KASES
      write (5,1025) KENTB
      write (5,1026) KTBST
      write (5,1027) DIA
      write (5,1028) WTHK
```

```
      write (5,1029) RPI
      write (5,1030) BCPI
      write (5,1031) CUT3
      write (5,1032) CUT4
C     BEGIN GEOMETRY CALCULATIONS FOR SINGLE ANNULUS COUNTER FLOW
C     DISC AND DOUGHNUT BAFFLED HEAT EXCHANGER
      ARCR=0.017453*ARC
      ATUBE=(3.14159*(DIA**2.0))/4.0
      GFTT=1./3600.
      GFT=1./144.
      DIAI=DIA-2.0*WTHK
      FATUB=(3.14159*(DIAI**2.0))/4.0
      KEY1=0
      PERC1=0.99
    2 IF(KEY1.GT.0) BSOI=0.5*(BSL+BSH)
      KEY2=0
      PERC2=0.99
      RA8L=RA5
      RA8H=RA8MAX
    3 RA8=0.5*(RA8L+RA8H)
      RJ8=(RA8-RA5-2.*DTR)/RPI+1.
      IJ8=RJ8
      RIJ8=IJ8
      IF(RJ8-RIJ8-0.5)4,4,5
    4 J8=IJ8
      TRPI=(RA8-RA5-2.*DTR)/(RIJ8-1.)
      CPI=BCPI*RPI/TRPI
      GOTO 6
    5 J8=IJ8+1
      TRPI=(RA8-RA5-2.*DTR)/RIJ8
      CPI=BCPI*RPI/TRPI
    6 DO 7 I=1,J8
      R(I)=RA5+DTR+TRPI*(I-1)
      FACT(I)=6.28318*R(I)
      NT(I)=FACT(I)/CPI
      TCPI(I)=FACT(I)/NT(I)
```

```
      IF(I.EQ.1) TOTAL(I)=NT(I)

      IF(I.NE.1) TOTAL(I)=TOTAL(I-1)+NT(I)

    7 CONTINUE

      NTO=TOTAL(J8)

      SNT=NTO

      RA52=RA5**2

      RA82=RA8**2

      RA6=(RA52+CUT4*(RA82-RA52))**.5

      J6=(RA6-R(1))/TRPI+1.

      RA6=R(J6)+.5*TRPI

      RA7=(RA82-CUT3*(RA82-RA52))**.5

      J7=(RA7-R(1))/TRPI+1.

      RA7=R(J7)+.5*TRPI

      RA62=RA6**2

      RA72=RA7**2

      RB1=0.5*(J8-J7)

      RB2=J7-J6

      RB3=0.5*J6

      SUM1=TOTAL(J8)-TOTAL(J7)

      SUM2=TOTAL(J7)-TOTAL(J6)

      SUM3=TOTAL(J6)

      ISUM1=SUM1

      ISUM2=SUM2

      ISUM3=SUM3

      BSMAX=1.5*((RA8-(RA8-RA7)/2.)-(RA5+(RA6-RA5)/2.))

      BSMIN=0.2*(RA8-RA5)

      IF(BSMIN.LT.0.1667) BSMIN=0.1667

      APO1=3.14159*(RA82-RA72)-ATUBE*SUM1

      APO3=3.14159*(RA62-RA52)-ATUBE*SUM3

      LAWO1=6.28318*RA7-.5*DIA*(NT(J7)+NT(J7+1))

      LAWO3=6.28318*RA6-.5*DIA*(NT(J6)+NT(J6+1))

      HW=2.*WCOND/(DIA*(ALOG(DIA/DIAI)))

!     CSPHAV=0.36

!     FSPHAV=0.324

!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!

                  CSPHAV=0.45
```

```
                  FSPHAV=0.568
      ! 0.45   : Avg. Cp of LiF-NaF-KF(Secondary Salt)
      ! 0.568 : Avg. Cp of LiF-BeF2 (Primary Salt)
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
      QC=HEATL/(CSPHAV*(CTO-ETC))
      QF=HEATL/(FSPHAV*(FTO-ETF))
      GTO=QF/(NTO*FATUB)
      KEY3=0
      XPRMAX=6.0
      XPRMIN=0.
    8 EXPRAD=0.5*(XPRMIN+XPRMAX)
      IF(KTBST.EQ.0) EXPRAD=1.77
      IF(KEY1.EQ.0) BSH=BSMAX
      IF(KEY1.EQ.0) BSL=BSMIN
      IF(KEY1.EQ.0) BSOI=0.5*(BSL+BSH)
      CURVES=0.069813*ARC*EXPRAD+0.4*(RA8-RA5)+.25*BSOI
      IT=0
      KFINAL=0
    9 I=1
      TSUM=0.
      SSUM=0.
      THEATO=0.0
      TPDTO=0.0
      TPDSO=0.
      TFO(I)=FTO
      TCI(I)=CTO
      TIF=-5.0
      TIC=-5.0
      CDTF=0.
      FDTF=0.
      BSO=BSOI
      BRL1=BSO/((RA8-(RA8-RA7)/2.)-(RA5+(RA6-RA5)/2.))
      GBRL=0.77*BRL1**(-.138)
      AWO1=BSO*LAWO1
      AWO3=BSO*LAWO3
      AW1=SQRT(AWO1*APO1)
```

```
      AW2=(AWO1+AWO3)/2.
      AW3=SQRT(AWO3*APO3)
      GSO1=QC/AW1
      GSO2=QC/AW2
      GSO3=QC/AW3
      BSO=CURVES
      EQVBSO=CURVES+13.*(DIA+DIAI)
      KEY4=0
   10 KEY5=0
   11 ATC=TCI(I)+(TIC/2.0)
      CFT=ATC+CDTF*HSFCT
      ATF=TFO(I)+TIF/2.
      FFT=ATF-FDTF*HSFCT
      FI=I
      TUBLN(I)=(FI-1.)*BSOI+CURVES
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!!!!!!!!!!! For PB-AHTR in UC Berkeley !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!!!!!!!!!!!!!!!         by Hyun Jin Lim !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!!!!!!!!!!!!!!!                Jan. 2008 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
C Temeprature conversion form C to F
      ATCT=0.55*(ATC-32.)
      CFTT=0.55*(CFT-32.)
      ATFT=0.55*(ATF-32.)
      FFTT=0.55*(FFT-32.)
!     CVIS=0.2121*EXP(4032./(460.+ATC))
       CVIS=2.4161*(0.04*EXP(4170./(273.+ATCT)))
       ! 2.4161 : CONVERSION FACTOR, FROM cP TO lb/ft*hr

!     CVISW=0.2121*EXP(4032./(460.+CFT))
       CVISW=2.416*(0.04*EXP(4170./(273.+CFTT)))

!     CDEN=141.37-0.02466*ATC
       CDEN=62.43*(2.53-0.00073*ATCT)
       ! 62.43 : CONVERSION FACTOR, FROM g/m**3 TO lb/ft**3
```

```
!         CCON=0.240
          CCON=0.5779*1.
          ! 0.5779 : CONVERSION FACTOR, FROM W/mK TO Btu/hr ft f
          ! "Nuclear Sytems" Vol 1. pp 644

!         CSPH=0.36
          CSPH=0.45

!         FVIS=0.2637*EXP(7362./(460.+ATF))
          FVIS=2.416*(0.116*EXP(3755./(273.+ATFT)))

!         FVISW=0.2637*EXP(7362./(460.+FFT))
          FVISW=2.416*(0.116*EXP(3755./(273.+FFTT)))

!         FDEN=234.97-0.02317*ATF
          FDEN=62.43*(2.28-0.000488*ATFT)

!         FCON=0.70
          FCON=0.5779*1.1
!         FSPH=0.324
          FSPH=0.568

C         write(5,*) CVIS
C          write        CVISW
c        write   CDEN
c        write   FVIS
c        write   FVISW

!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!


         VISK=(CVIS/CVISW)**0.14
         FVISK=(FVIS/FVISW)**0.14
         DCVIS=DIA/CVIS
         CCDEN=1./CDEN
```

```
      QCCDEN=QC*CCDEN
C     CALCULATE REYNOLDS AND PRANDTL NUMBER TUBE SIDE
      RENTO(I)=DIAI*GTO/FVIS
      PRNTO(I)=FVIS*FSPH/FCON
      IF((KENTB.EQ.1).AND.(RENTO(I).GT.1001.).AND.(I.NE.1))
     1 HEFI=1.+((RENTO(I)-1000.)/9000.)**0.5
      PDTO(I)=(.0028+.25*RENTO(I)**(-.32))*EQVBSO*GTO**2*HEFI/(DIAI*FDEN
     1 * 417182400.)
C     CALCULATE HEAT TRANSFER COEFFICIENT TUBE SIDE
      HTO(I)=FCON/DIAI*.0217*(RENTO(I)**.8)*(PRNTO(I)**.3333)*FVISK*HEFI
      GOTO 15
   12 IF(RENTO(I).LT.2100.) GOTO 14
   13 HTO(I)=FCON/DIAI*.089*(RENTO(I)**.6666-125.)*(PRNTO(I)**.3333)
     1 *FVISK*HEFI*(1.+.3333*(DIAI/TUBLN(I)**.6666))
      GOTO 15
   14 HTO(I)=FCON/DIAI*(4.36+(0.025*RENTO(I)*PRNTO(I)*DIAI/TUBLN(I))/(1.
     1+0.0012*RENTO(I)*PRNTO(I)*DIAI/TUBLN(I)))
   15 IF(I.EQ.1) GOTO 16
C     CALCULATE FLOW AREAS SHELL SIDE
      VWO1(I)=QCCDEN/AWO1
      VWO3(I)=QCCDEN/AWO3
      VM1(I)=GSO1*CCDEN
      VM2(I)=GSO2*CCDEN
      VM3(I)=GSO3*CCDEN
C     CALCULATE PRESSURE DROPS SHELL SIDE
      DP1=(1.+.6*RB1)*CDEN*VM1(I)**2
      DP2=.6*RB2*CDEN*VM2(I)**2
      DP3=(1.+.6*RB3)*CDEN*VM3(I)**2
      RENSO1(I)=GSO1*DCVIS
      RENSO2(I)=GSO2*DCVIS
      RENSO3(I)=GSO3*DCVIS
      IF((KENTB.EQ.1).AND.(RENSO2(I).GT.1001.))
     1 HEFO=1.+0.3*((RENSO2(I)-1000.)/9000.)**0.5
       PDSO(I)=(DP1+DP2+DP3)*PLK*HEFO/834624000.
      IF(I.EQ.2) PDSO(1)=PDSO(2)
```

```
C       CALCULATE BJ FACTOR AND SHELL SIDE COEFFICIENT
        BJ(1)=(0.346*RENSO1(I)**(-0.382))/GBRL
        BJ(2)=(0.346*RENSO2(I)**(-0.382))/GBRL
        BJ(3)=(0.346*RENSO3(I)**(-0.382))/GBRL
        HSO1(I)=(CSPH*GSO1*BJ(1)*((CCON/(CSPH*CVIS))**.66))*VISK/LK
        HSO2(I)=(CSPH*GSO2*BJ(2)*((CCON/(CSPH*CVIS))**.66))*VISK/LK
        HSO3(I)=(CSPH*GSO3*BJ(3)*((CCON/(CSPH*CVIS))**.66))*VISK/LK

        AHSO(I)=(((HSO1(I)*SUM1)+(HSO2(I)*SUM2)+(HSO3(I)*SUM3))/SNT)/HEFO

        GOTO 17

     16 PDSO(I)=0.
        APO=3.14159*(RA82-RA52)-SNT*ATUBE
        EQVDIA=4.*APO/(3.14159*SNT*DIA+6.24318*(RA8+RA5))
        GSO=QC/APO
        RENSO=GSO*DCVIS
        PRESO=CVIS*CSPH/CCON
        AHSO(I)=0.128*CCON*VISK*(12.*EQVDIA*RENSO)**0.6*PRESO**0.33/DIA

     17 UOA(I)=1.0/((1.0/AHSO(I))+1.0/(DIA/DIAI*HTO(I))+(1.0/HW))

        A=QF*FSPH
        B=QC*CSPH
        D=UOA(I)*SNT*BSO*3.14159*DIA
        P=-HSFCT*(D*(A-B))/(A*B)
        PBAR=EXP(P)
        C=(B-A)*PBAR
        TCO(I)=((TCI(I)*(B*PBAR-A))-(TFO(I)*A*(PBAR-1.)))/C
        TFI(I)=((TCO(I)-TCI(I))*B/A)+TFO(I)
        HEAT(I)=-A*(TFI(I)-TFO(I))
        TWDT(I)=(HEAT(I)/NTO)*ALOG(DIA/DIAI)/(2.0*3.14159*BSO*WCOND)
        CTIF=TFI(I)-TFO(I)
        CTIC=TCO(I)-TCI(I)

        CTX1=ABS(CTIF-TIF)
```

```
      CTX2=ABS(CTIC-TIC)
      IF(CTX1.LE.(3.0).AND.CTX2.LE.(3.0)) GOTO 18

      TIF=CTIF
      TIC=CTIC
      KEY5=KEY5+1
      IF(KEY5.GT.50) GOTO 37
      GOTO 11

   18 THEATO=THEATO+HEAT(I)
      TPDTO=TPDTO+PDTO(I)
      TPDSO=TPDSO+PDSO(I)
      IF(I.EQ.2) TPDSO=TPDSO+PDSO(1)
      CDTF=(((HEAT(I))/NTO)/BSO)/(3.14159*DIA*AHSO(I))
      FDTF=CDTF*AHSO(I)/HTO(I)
      FWT(I)=ATF-FDTF*HSFCT
      CWT(I)=ATC+CDTF*HSFCT
      AVWT(I)=0.5*(FWT(I)+CWT(I))
      TSUM=TSUM+AVWT(I)
      SSUM=SSUM+ATC

      IF (KFINAL.EQ.1.AND.I.EQ.IT) GOTO 20



      ETX1=ABS(ETF-TFI(I))
      ETX2=ABS(TFI(I)-TFO(I))/2.
      IF((ABS(ETX1).LE.ABS(ETX2)).OR.(TFI(I).LE.ETF)) GOTO 19

      I=I+1
C     write(5,*) I
      IF(I.GT.1000) GOTO 30
      IF(I.EQ.2) ATC1=ATC
      TFO(I)=TFI(I-1)
      TCI(I)=TCO(I-1)
      BSO=BSOI
      EQVBSO=BSO
```

```
      KEY4=KEY4+1
      IF(KEY4.GT.500000) GOTO 36
      GOTO 10

   19 KFINAL=1
      IT=I
      FIT=IT
      DCURVE=CURVES*((HEATL-THEATO)/HEAT(1))
      CURVES=CURVES+DCURVE
      GOTO 9

   20 TUBLEN=(FIT-1.)*BSOI+CURVES
      HEXLEN=(FIT-1.)*BSOI+4.*EXPRAD*SIN(ARCR)+DCURVE+0.25*BSMAX
      STRLEN=(FIT-1.)*BSOI+DCURVE+.25*BSMAX

   21 IF( KTBST.EQ.0) GOTO 24
      T1=FWT(1)
      T2=CWT(1)
      PDTO1=PDTO(1)
      PDSO1=PDSO(1)
      TSUM=TSUM-AVWT(1)
      SSUM=SSUM-ATC1
      TAVT=( CURVES*AVWT(1)+BSOI*TSUM)/TUBLEN
      SAVT=((HEXLEN-BSOI*(FIT-1.))*ATC1+BSOI*SSUM)/HEXLEN



      CALL TUBSTR (TPIN,SPOUT,PDTO1,PDSO1,T1,T2,
     1            HEXLEN,EXPRAD,DIAI,DIA,ARC,SAVT,TAVT,
     2            T11,T12,T13,T24,T25,T36,T37,T38,T49,T410,DT, BM,ASM,
     3            ST,STP,SQP,SLPR,SLPG,SLLO,SLLI,STTO,STTI,TM,CASM,CTM,
     4            P1,P2,SA,R1,R2,TL,RB, AA1,AA2,AA3,AA4,AA5,BB1,BB2,
     5            BB3,BB4,BB5)
```

```
      KEY3=KEY3+1
      IF(KEY3.GT.1000) GOTO 35
      IF((T24.LT.0.0).OR.(T12.LT. 0.0)) GOTO 22
      IF((T24.GT.(.08*ASM)).AND.(T12.GT.(.08*ASM))) GOTO 23
      GOTO 24

   22 XPRMIN=EXPRAD
      GOTO 8

   23 XPRMAX=EXPRAD
      GOTO 8

   24 VOL = 0.7854*(DIAI**2.0)*NTO*TUBLEN

C       CHECK OF TUBE AND SHELL PRESSURE DROPS
      KET2 =   KEY2 + 1
      IF(PERC2.LE.0.1) GOTO 33
      IF(TPDTO.LT.(PERC2*PRDT)) GOTO 25
      IF(TPDTO.GT.PRDT) GOTO 26
      GOTO 27
   25 IF(RA8.LE.(RA5+0.005)) GOTO 34
      RA8H =RA8
      IF(KEY2.NE.30)GOTO 3
      RA8L=RA8L-0.2
      PERC2=PERC2-0.01
      KEY2=10
      GOTO 3
   26 IF(RA8.GE.(RA8MAX-0.005)) GOTO 34
      RA8H=RA8H+0.2
      PERC2 = PERC2 - 0.01
      KEY2=10
      GOTO 3
   27 KEY1=KEY1+1
      IF(PERC1.LE.0.1) GOTO 32
      IF(TPDSO.LT.(PERC1*PRDS)) GOTO 28
      IF(TPDSO.GT.PRDS)GOTO 29
```

```
      GOTO 38
   28 IF(BSOI.LE.(BSMIN+0.005))GOTO 31
      BSH =BSOI
      IF(KEY1.NE.30)GOTO 2
      BSL=BSL-0.1
      PERC1=PERC1-0.01
      KEY1=10
      GOTO 2
   29 IF(BSOI.GE.(BSMAX-0.005)) GOTO 31
      BSL =BSOI
      IF(KEY1.NE.30) GOTO 2
      BSH=BSH+0.1
      PERC1= PERC1 - 0.01
      KEY1=10
      GOTO 2
C
C     PRINT EXIT SIGNALS
   30 write (5,1057) BSO
 1057 FORMAT(39H1BAFFLE SPACINGS EXCEEDE 75 WITH BSO =   ,F5.2,2X,4H(FT))
      GOTO 38
   31 write (5,1058)
 1058 FORMAT(20H1BSOI = MAX. OR MIN.)
      GOTO 38
   32 write (5,1059)
 1059 FORMAT(48H1 PERC1 FOR SHELL PRESSURE DROP IS LESS THEN 0.1)
      GOTO 38
   33 write (5,1060)
 1060 FORMAT(48H1 PERC2 FOR TUBE PRESSURE DROP IS LESS THEN 0.1   )
      GOTO 38
   34 write (5,1061)
 1061 FORMAT(29H1 SHELL RADIUS = MAX. OR MIN.)
      GOTO 38
   35 write (5,1062) KEY3
 1062 FORMAT(6H1KEY3= ,I5)
      GOTO 38
   36 write (5,1063) KEY4
```

```
 1063 FORMAT(16HERROR!! KEY4 =       ,I5,//)
      GOTO 38
   37 write (5,1064) KEY5
 1064 FORMAT(6H1KEY5= ,I5)
      GOTO 38

C



C     END OF CASE, PRINT OUTPUT
   38 DO 39 I = 1,IT
      V1(I) = VM1(I)*GFTT
      V2(I) = VM2(I)*GFTT
      V3(I) = VM3(I)*GFTT
      VW1(I) = VWO1(I)*GFTT
      vw3(I) = VWO3(I)*GFTT
   39 CONTINUE
      TTDSO = TPDSO*GFT
      TTDTO = TPDTO*GFT
      TPPERC=TPDTO*100./PRDT
      SPPERC=TPDSO*100./PRDS
      HTPERC=100.*THEATO/HEATL
      AREA=3.1459*DIA*SNT*TUBLEN
      ASM3=3.*ASM
      PSTO=AA1
      PQSTO=AA2
      PQFSTO=AA3
      PSTI=BB1
      PQSTI=BB4
      PQFSTI=BB5
C
      write (5,1033) THEATO,HTPERC
      write (5,1034) QC
      write (5,1035) QF
      write (5,1036) TTDSO,SPPERC
      write (5,1037) TTDTO,TPPERC
```

```
      write (5,1038) RA8
      write (5,1039) BSOI
      write (5,1040) VOL
      write (5,1041) AREA
      write (5,1042) SNT
      write (5,1043) TUBLEN
      write (5,1044) HEXLEN
      write (5,1045) STRLEN
      write (5,1046) EXPRAD
      write (5,1047) GBRL
      write (5,1051) TAVT
      write (5,1052) SAVT
      write (5,1053) PSTO,PSTI,ASM
      write (5,1054) PQSTO,PQSTI,ASM3
      write (5,1055) PQFSTO,PQFSTI,SA


      write (5,1090)(I,TCI(I),TCO(I),CWT(I),TFI(I),TFO(I),FWT(I),I=1,IT)
      write (5,1091) (I,TWDT(I),V1(I),V2(I),V3(I),VW1(I),VW3(I),I=1,IT)
      write(5,1092)(I,PDSO(I),PDTO(I),RENTO(I),PRNTO(I),RENSO1(I),RENSO2
     1(I),I=1,IT)
      write (5,1093) (I, RENSO3(I),HTO(I),AHSO(I),UOA(I),HEAT(I),I=1,IT)
      close(5)

C
C        LOOP FOR ADDITIONAL CASES IF REQUIRED
   40 CONTINUE
      KEY7=KEY7+1
      IF(KEY7.GT.KASES)GOTO 41
      GOTO 1
   41 CONTINUE
      STOP
      END

      SUBROUTINE TUBSTR(TPIN,SPOUT,PDTO1,PDSO1,T1,T2,
     1 HEXLEN,EXPRAD,DIAI,DIA,ARC,SAVT,TAVT,
```

```
     2 T11,T12,T13,T24,T25,T36,T37,T38,T49,T410,DT,BM,ASM,
     3 ST,STP,SQP,SLPR,SLPG,SLLO,SLLI,STTO,STTI,TM,CASM,CTM,
     4 P1,P2,SA,R1,R2,TL,RB,AA1,AA2,AA3,AA4,AA5,BB1,BB2,BB3,BB4,BB5)
      DIMENSION CASM(6),CTM(6)
      GFT=1./144.
      P1=(TPIN-.5*PDTO1 )*GFT
      P2=(SPOUT +.5*PDSO1 )*GFT
      R1=6.*DIAI
      R2=6.*DIA
      TL   =12.*HEXLEN
      RB=12.*EXPRAD
      A=0.017452*ARC
CC    DETERMINE AVERAGE CHANGE IN TEMPERATURE OF SHELL(DTS) AND TUBE(DTT)
      DTS = SAVT-70.
      DTT = TAVT-70.
CC    CALCULATE PRESSURE AND TEMPERATURE DIFFERNTIAL ACROSS TUBE WALL
      DP = P1-P2
      DT = T1-T2
CC    AND AVERAGE TEMPERATURE OF TUBE WALL
      TM = (T1+T2)/2.
C     CALCULATE MOMENT OF INERTIA TUBE CROSSECTION(AMI)
      AMI = 0.785298*(R2**4-R1**4)
CC    CALL SUBROUTINE TO DETERMINE ALLOWABLE STRESS(ASW)
      CALL LAGR (CASM,CTM,ASM,TM,2,6     ,IERR)
CC    ESTABLISH MATERIAL PROPERTIES CONSTANTS
      SA= 25000.0
      EM = 25000000.0
      PR = 0.3
      TE = 0.0000078
      SE = 0.0000076
CC    CALCULATE AXIAL LOAD AND MOMENT DUE TO LOGITUDNAL EXPANSION
      DY = TL*(TE*DTT-SE*DTS)
      RM = (R2+R1)/2.
      TW = R2-R1
      AL = TW*RB/RM**2
      AL2 = AL**2
```

```
      AK = (1.+12.*AL2)/(10.+12.*AL2)
      AA = 2.*A
      P = 25000000.*AK*AMI*DY/(RB**3*(AA*COS(AA)-3.*SIN(AA)+4.*A))
      BM = P*RB*(1.-COS(A))
CC     CALCULATE Q STRESS DUE TO P
      SQP = -P/(6.28318*RM*TW)
CC     CALCULATE Q STRESS DUE TO M
      B1 = 6./(5.+6.*AL2)
      B2 = BM/(AK*AMI)
      B3 = (R2/RM)**2
      B4 = (R1/RM)**2
      B5 = 1.5*RM*B2*AL*B1
      SLLO = R2*B2*(1.-B1*B3)
      SLLI = R1*B2*(1.-B1*B4)
      STTO = B5*(1.-2.*B3)
      STTI = B5*(1.-2.*B4)
CC     CALCULATE F STRESS DUE TO TUBE WALL TEMPERATURE DROP
      ST = 139.*DT
      SLI = -ST
      STI = -ST
      SLO =   ST
      STO =   ST
CC     CALAULATE STRESS DUE TO PRESSURE
CC     HOOP
      STP = DP*RM/TW
CC     LONGITUDNAL
      SLPR = STP/2.
      SLPG = 0
CC     RADIAL
      SRPI = -P1
      SRPO = -P2
CC     P STRESS TUBE OD BEND OD
      A11 =AMAX1(STP,SLPR,SRPO)
      A12 =AMIN1(STP,SLPR,SRPO)
      AA1 = A11-A12
      T11 = ASM - ABS(AA1)
```

```
CC      P+Q STRESS TUBE OD BEND OD
        A13 =AMAX1(STP+STTO,SLPR+SQP+SLLO,SRPO)
        A14 =AMIN1(STP+STTO,SLPR+SQP+SLLO,SRPO)
        AA2 =A13-A14
        T12 =3*ASM- ABS(AA2)
CC      P+Q+F STRESS TUBE OD BEND ID
        A15 =AMAX1(STP+STTO+STO,SLPR+SQP+SLLO+SLO,SRPO)
        A16 =AMIN1(STP+STTO+STO,SLPR+SQP-SLLO+SLO,SRPO)
        AA3 = A15-A16
        T13 = SA - ABS(AA3)
CC      P STRESS TUBE OD DEND ID
CC      SAME AS P STRESS AT TUBE OD BEND OD - T11)
CC
CC      P+Q STRESS TUBE OD BEND ID
        A22 =AMAX1(STP+STTO,SLPR+SQP-SLLO,SRPO)
        A23 =AMIN1(STP+STTO,SLPR+SQP-SLLO,SRPO)
        AA4 = A22-A23
        T24 = 3*ASM- ABS(AA4)
CC      P+Q+F STRESS TUBE OD BEND ID
        A24 =AMAX1( STP+STTO+STO,SLPR+SQP-SLLO+SLO,SRPO)
        A25 =AMIN1( STP+STTO+STO,SLPR+SQP-SLLO+SLI,SRPO)
        AA5 = A24-A25
        T25 = SA - ABS(AA5)
CC      P STRESS TUBE ID BEND OD
        B11 =AMAX1(STP,SLPR,SRPI)
        B12 =AMIN1(STP,SLPR,SRPI)
        BB1 = B11-B1
        T36 = ASM- ABS(BB1)
CC      P+Q STRESS TUBE ID BEND OD
        B13 =AMAX1(STP+STTI,SLPR+SQP+SLLI,SRPI)
        B14 =AMIN1(STP+STTI,SLPR+SQP+SLLI,SRPI)
        BB2 = B13-B14
        T37 = 3*ASM- ABS(BB2)
CC      P+Q+F STRESS TUBE ID BEND OD
        B15 =AMAX1(STP+STTI+STI,SLPR+SQP+SLLI+SLI,SRPI)
        B16 =AMIN1(STP+STTI+STI,SLPR+SQP+SLLI+SLI,SRPI)
```

```
      BB3 = B15-B16
      T38 = SA -ABS(BB3)
CC     P STRESS TUBE ID BEND ID
CC     SAME AS P STRESS AT TUBE ID BEND OD -- T36
CC
CC     P+Q STRESS TUBR ID BEND ID
      B23 =AMAX1(STP+STTI,SLPR+SQP-SLLI,SRPI)
CC
      B24 =AMIN1(STP+STTI,SLPR+SQP-SLLI,SRPI)
      BB4 = B23-B24
      T49 = 3*ASM- ABS(BB4)
CC     P+Q+F STRESS TUBE ID BEND ID
      B25 =AMAX1(STP+STTI+STI,SLPR+SQP-SLLI+SLI,SRPI)
      B26 =AMIN1(STP+STTI+STI,SLPR+SQP-SLLI+SLI,SRPI)
      BB5 = B25-B26
      T410 = SA-ABS(BB5)
CC
CC
      RETURN
      END

      SUBROUTINE LAGR (FX,X,FXP,XP,N,NPT,IER)
      DIMENSION FX(NPT),X(NPT)
C     SUBROUTINE USES LARGRANGIAN INTERPOLATION TO A DESIRED DEGREE
C     POLYNOMIAL
C     FX = FUNCTION OF INDEPENDENT VARIABLES
C     X = INDEPENDENT VARIABLE
C     FXP = ESTIMATE OF FX AT XP
C     XP = VALUE OF X FOR WHICH INTERPOLATION IS DESIRED
C     N = DEGREE OF POLINOMIAL USED IN INTERPOLATION
C     NPT = NUMBER OF POINT-PAIRES IN TABLE
C     IER = COUNTER TO REPORT TYPE OF EXECUTION
C
C     CHECK TO SEE IF XP IS A TABLE ENTRY

      DO 2 K = 1 ,NPT
```

```
      IF(XP.NE.X(K)) GOTO 2
    1 FXP = FX(K)
      IER = 3
      RETURN
    2 CONTINUE
C     DETERMINE IF EXTRAPOLATION IS REQUIRED
      IF(XP.LT.X(1)) GOTO 4
    3 IF(XP.GT.X(NPT)) GOTO 5
      GOTO 6
    4 L1 = 1
      L2 = NPT
      GOTO 15
    5 L1 = NPT - N
      L2 = NPT
      GOTO 15
    6 IER = 2
C     DETERMINE IF SUFFICIENT DATA IS PRESENT FOR DEGREE OF POLINOMIAL
      M = N + 1
      IF(M.LE.NPT) GOTO 8
    7 IER = 1
      RETURN
C     DETERMINE NEXT HIGHEST POINT
    8 DO 9 K = 2,NPT
      K1 = K
      IF(XP.LT.X(K)) GOTO 10
    9 CONTINUE
C     DETERMINE THE LOWER POINTS REQUIRED
   10 L = M/2
   11 L2 = K1+L-1
      IF(L2.LE.NPT) GOTO 13
   12 K1 = K1 - 1
      GOTO 11
   13 L1 = K1 + L -M
      IF(L1)14,14,15
   14 K1 = K1 + 1
      L2 = L2 + 1
```

```
      GOTO 13
C     INTERPOLATION BY LARGRANGIAM METHOD (SEE MATHMATICS OF PHYSICS
C     AND MODERN ENGINEERING , SOKOLNIKOFF AND REDHEFFER, PAGES 699,700)
   15 FXP = 0.0
      DO 18 K = L1,L2
      PKX = 1.0
      PKXK = 1.0
      DO 17 I = L1,L2
      IF(I.EQ.K) GOTO 17
   16 PKX = PKX*(XP - X(I))
      PKXK = PKXK*(X(K) - X(I))
   17 CONTINUE
   18 FXP = FXP + FX(K)*PKX/PKXK
      RETURN
      END
```

Appendix 2. Sample output

HEAT LOAD REQUIRED= 767731500. (BTU/HR)

ALLOWABLE TOTAL TUBE-SIDE PRESSURE DROP= 3000. (LB/SQ-FT)

ALLOWABLE TOTAL SHELL-SIDE PRESSURE DROP= 3000. (LB/SQ-FT)

TUBE INLET PRESSURE= 25920. (LB/SQ-FT)

SHELL OUTLET PRESSURE= 4896. (LB/SQ-FT)

HIGH TEMP. OF SHELL SIDE FLUID= 1274.00 (F)

HIGH TEMP. OF TUBE SIDE FLUID= 1300.00 (F)

LOW TEMP. OF TUBE SIDE FLUID= 1112.00 (F)

LOW TEMP. OF SHELL SIDE FLUID= 1013.00 (F)

HEAT TRANSFER LEAKAGE FACTOR= .80000

PRESSURE LEAKAGE FACTOR= .52000

CONDUCTIVITY OF TUBE WALL METAL= 11.60000 (BTU/HR-FT-F)

ARC OF FOUR BENDS FOR FLEXIBILITY= 60.00000 (DEGREES)

INSIDE RADIUS OF OUTER ANNULUS= .90000 (FEET)

DISTANCE BETWEEN SHELL WALL AND TUBES= .03125 (FEET)

MAXIMUM ANTICIPATED OUTER RADIUS OF EXCHANGER= 4.00000 (FEET)

NUMBER OF CASES RUN= 1

USE OF ENHANCED TUBES= 1 (ONE IF ENHANCED TUBES ARE USED)

USE OF STRESS ANALYSIS SUBROUTINE= 0 (ONE IF TO BE USED)

OUTSIDE DIAMETER OF TUBES= .03125 (FEET)

WALL THICKNESS OF TUBES= .00438 (FEET)

RADIAL PITCH= .06250 (FEET)

CIRCUMFERENCIAL PITCH= .06250 (FEET)

INNER BAFFLE CUT3= .40000 (PER CENT)

INNER BAFFLE CUT4= .40000 (PER CENT)

TOTAL HEAT TRANSFERED= 759291500. (BTU/HR) (98.9 PERCENT)

MASS FLOW RATE OF COOLANT= 6536667. (LB/HR)

MASS FLOW RATE OF FUEL= 7189574. (LB/HR)

SHELL-SIDE TOTAL PRESSURE DROP= 20.82 (LB/SQIN) (99.9 PERCENT)

TUBE-SIDE TOTAL PRESSURE DROP= 20.17 (LB/SQIN) (96.8 PERCENT)

NOMINAL SHELL RADIUS= 3.5500 (FT)

UNIFORM BAFFLE SPACING= .6292 (FT)

TUBE FLUID VOLUME CONTAINED IN TUBES= 105.65 (CUBIC FEET)

TOTAL HEAT TRANSFER AREA BASED ON TUBE O.D.= 26145.44 (SQFT)

TOTAL NUMBER OF TUBES= 9465.

TOTAL TUBE LENGTH= 28.10 (FT)

HEAT EXCH. APPROX. LENGTH= 26.18 (FEET)

STRAIGHT SECTION OF TUBE LENGTH= 20.05 (FT)

RADIUS OF THERMAL EXPANSION CURVES= 1.77 (FEET)

BERGLIN MODIFICATION FACTOR= .87

TUBE WALL AVERAGE TEMP.= .00

SHELL SIDE AVERAGE TEMP.= .00

P STRESS AT TUBE OD AND TUBE ID = .00 .00 (LB/SQIN)

(SHOULD NOT EXCEED .00)

P+Q STRESS AT TUBE OD AND TUBE ID = .00 .00 (LB/SQIN)

(SHOULD NOT EXCEED .00)

P+Q+F STRESS AT TUBE OD AND TUBE ID = .00 .00 (LB/SQIN)

(SHOULD NOT EXCEED .00)

I	TCI	TCO	CWT	TFI	TFO	FWT
	F	F	F	F	F	F
1	.1274E+04	.1257E+04	.1287E+04	.1288E+04	.1300E+04	.1288E+04
2	.1257E+04	.1253E+04	.1264E+04	.1285E+04	.1288E+04	.1269E+04
3	.1253E+04	.1248E+04	.1260E+04	.1281E+04	.1285E+04	.1266E+04
4	.1248E+04	.1243E+04	.1256E+04	.1278E+04	.1281E+04	.1262E+04
5	.1243E+04	.1239E+04	.1252E+04	.1275E+04	.1278E+04	.1257E+04
6	.1239E+04	.1234E+04	.1248E+04	.1271E+04	.1275E+04	.1253E+04
7	.1234E+04	.1228E+04	.1243E+04	.1267E+04	.1271E+04	.1249E+04
8	.1228E+04	.1223E+04	.1238E+04	.1263E+04	.1267E+04	.1244E+04
9	.1223E+04	.1218E+04	.1233E+04	.1259E+04	.1263E+04	.1239E+04
10	.1218E+04	.1212E+04	.1228E+04	.1255E+04	.1259E+04	.1234E+04
11	.1212E+04	.1206E+04	.1223E+04	.1251E+04	.1255E+04	.1229E+04
12	.1206E+04	.1200E+04	.1218E+04	.1246E+04	.1251E+04	.1224E+04

13	.1200E+04	.1193E+04	.1212E+04	.1242E+04	.1246E+04	.1219E+04
14	.1193E+04	.1187E+04	.1206E+04	.1237E+04	.1242E+04	.1213E+04
15	.1187E+04	.1180E+04	.1200E+04	.1232E+04	.1237E+04	.1207E+04
16	.1180E+04	.1173E+04	.1194E+04	.1227E+04	.1232E+04	.1201E+04
17	.1173E+04	.1166E+04	.1188E+04	.1222E+04	.1227E+04	.1195E+04
18	.1166E+04	.1158E+04	.1179E+04	.1217E+04	.1222E+04	.1187E+04
19	.1158E+04	.1151E+04	.1172E+04	.1211E+04	.1217E+04	.1180E+04
20	.1151E+04	.1143E+04	.1165E+04	.1205E+04	.1211E+04	.1173E+04
21	.1143E+04	.1134E+04	.1158E+04	.1199E+04	.1205E+04	.1166E+04
22	.1134E+04	.1126E+04	.1151E+04	.1193E+04	.1199E+04	.1159E+04
23	.1126E+04	.1117E+04	.1143E+04	.1187E+04	.1193E+04	.1151E+04
24	.1117E+04	.1108E+04	.1135E+04	.1181E+04	.1187E+04	.1143E+04
25	.1108E+04	.1099E+04	.1127E+04	.1174E+04	.1181E+04	.1135E+04
26	.1099E+04	.1090E+04	.1118E+04	.1167E+04	.1174E+04	.1126E+04
27	.1090E+04	.1080E+04	.1109E+04	.1160E+04	.1167E+04	.1118E+04
28	.1080E+04	.1070E+04	.1100E+04	.1153E+04	.1160E+04	.1109E+04
29	.1070E+04	.1060E+04	.1091E+04	.1146E+04	.1153E+04	.1100E+04
30	.1060E+04	.1049E+04	.1080E+04	.1138E+04	.1146E+04	.1089E+04
31	.1049E+04	.1038E+04	.1070E+04	.1130E+04	.1138E+04	.1079E+04
32	.1038E+04	.1027E+04	.1061E+04	.1122E+04	.1130E+04	.1069E+04
33	.1027E+04	.1016E+04	.1050E+04	.1114E+04	.1122E+04	.1059E+04

I	TWDT	V1	V2	V3	VW1	VW3
	F		FT/SEC			
1	.3005E+01	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
2	.9683E+01	.1750E+01	.2826E+01	.1923E+01	.2604E+01	.3090E+01
3	.1001E+02	.1749E+01	.2824E+01	.1921E+01	.2602E+01	.3088E+01
4	.1038E+02	.1747E+01	.2821E+01	.1920E+01	.2600E+01	.3085E+01
5	.1076E+02	.1745E+01	.2819E+01	.1918E+01	.2597E+01	.3082E+01
6	.1114E+02	.1744E+01	.2816E+01	.1916E+01	.2595E+01	.3079E+01
7	.1154E+02	.1742E+01	.2813E+01	.1914E+01	.2592E+01	.3076E+01
8	.1195E+02	.1740E+01	.2811E+01	.1912E+01	.2590E+01	.3073E+01
9	.1237E+02	.1739E+01	.2808E+01	.1910E+01	.2587E+01	.3070E+01
10	.1280E+02	.1737E+01	.2805E+01	.1908E+01	.2584E+01	.3066E+01
11	.1325E+02	.1735E+01	.2802E+01	.1906E+01	.2581E+01	.3063E+01

12	.1370E+02	.1733E+01	.2798E+01	.1904E+01	.2578E+01	.3059E+01
13	.1417E+02	.1731E+01	.2795E+01	.1902E+01	.2575E+01	.3056E+01
14	.1465E+02	.1728E+01	.2791E+01	.1899E+01	.2572E+01	.3052E+01
15	.1514E+02	.1726E+01	.2788E+01	.1897E+01	.2569E+01	.3048E+01
16	.1564E+02	.1724E+01	.2784E+01	.1894E+01	.2565E+01	.3044E+01
17	.1615E+02	.1722E+01	.2780E+01	.1892E+01	.2562E+01	.3040E+01
18	.1665E+02	.1719E+01	.2776E+01	.1888E+01	.2557E+01	.3035E+01
19	.1718E+02	.1716E+01	.2772E+01	.1886E+01	.2554E+01	.3030E+01
20	.1772E+02	.1714E+01	.2768E+01	.1883E+01	.2550E+01	.3026E+01
21	.1827E+02	.1711E+01	.2763E+01	.1880E+01	.2546E+01	.3021E+01
22	.1883E+02	.1708E+01	.2759E+01	.1877E+01	.2542E+01	.3017E+01
23	.1939E+02	.1706E+01	.2755E+01	.1874E+01	.2538E+01	.3012E+01
24	.1996E+02	.1703E+01	.2750E+01	.1871E+01	.2534E+01	.3007E+01
25	.2054E+02	.1700E+01	.2745E+01	.1868E+01	.2529E+01	.3001E+01
26	.2112E+02	.1697E+01	.2740E+01	.1864E+01	.2525E+01	.2996E+01
27	.2171E+02	.1694E+01	.2735E+01	.1861E+01	.2520E+01	.2991E+01
28	.2231E+02	.1691E+01	.2730E+01	.1858E+01	.2516E+01	.2985E+01
29	.2290E+02	.1687E+01	.2725E+01	.1854E+01	.2511E+01	.2980E+01
30	.2347E+02	.1684E+01	.2719E+01	.1850E+01	.2505E+01	.2973E+01
31	.2407E+02	.1680E+01	.2714E+01	.1846E+01	.2500E+01	.2967E+01
32	.2466E+02	.1677E+01	.2708E+01	.1842E+01	.2495E+01	.2961E+01
33	.2525E+02	.1673E+01	.2703E+01	.1839E+01	.2490E+01	.2955E+01

I	PDSO	PDTO	RENTO	PRNTO	RENSO1	RENSO2
	LB/SQFT					
1	.9497E+02	.8122E+03	.3159E+04	.1216E+02	.0000E+00	.0000E+00
2	.9497E+02	.6559E+02	.3106E+04	.1237E+02	.3152E+04	.5090E+04
3	.9478E+02	.6558E+02	.3084E+04	.1246E+02	.3117E+04	.5033E+04
4	.9458E+02	.6557E+02	.3062E+04	.1255E+02	.3081E+04	.4975E+04
5	.9438E+02	.6556E+02	.3039E+04	.1265E+02	.3044E+04	.4915E+04
6	.9416E+02	.6555E+02	.3015E+04	.1274E+02	.3005E+04	.4854E+04
7	.9394E+02	.6554E+02	.2990E+04	.1285E+02	.2966E+04	.4790E+04
8	.9372E+02	.6552E+02	.2965E+04	.1296E+02	.2926E+04	.4725E+04
9	.9348E+02	.6551E+02	.2939E+04	.1307E+02	.2884E+04	.4658E+04
10	.9324E+02	.6550E+02	.2912E+04	.1319E+02	.2842E+04	.4589E+04

11	.9299E+02	.6549E+02	.2885E+04	.1332E+02	.2798E+04	.4519E+04
12	.9273E+02	.6547E+02	.2856E+04	.1345E+02	.2753E+04	.4447E+04
13	.9246E+02	.6546E+02	.2827E+04	.1359E+02	.2707E+04	.4372E+04
14	.9218E+02	.6545E+02	.2797E+04	.1374E+02	.2660E+04	.4296E+04
15	.9190E+02	.6543E+02	.2766E+04	.1389E+02	.2612E+04	.4219E+04
16	.9160E+02	.6542E+02	.2734E+04	.1406E+02	.2563E+04	.4139E+04
17	.9130E+02	.6541E+02	.2701E+04	.1423E+02	.2513E+04	.4058E+04
18	.9092E+02	.6539E+02	.2660E+04	.1444E+02	.2450E+04	.3957E+04
19	.9060E+02	.6538E+02	.2626E+04	.1463E+02	.2398E+04	.3873E+04
20	.9027E+02	.6536E+02	.2591E+04	.1483E+02	.2345E+04	.3787E+04
21	.8992E+02	.6535E+02	.2554E+04	.1504E+02	.2291E+04	.3700E+04
22	.8957E+02	.6533E+02	.2518E+04	.1526E+02	.2236E+04	.3611E+04
23	.8921E+02	.6532E+02	.2480E+04	.1550E+02	.2180E+04	.3521E+04
24	.8884E+02	.6530E+02	.2441E+04	.1574E+02	.2124E+04	.3429E+04
25	.8845E+02	.6529E+02	.2402E+04	.1600E+02	.2066E+04	.3337E+04
26	.8806E+02	.6527E+02	.2362E+04	.1627E+02	.2008E+04	.3243E+04
27	.8766E+02	.6526E+02	.2321E+04	.1656E+02	.1949E+04	.3148E+04
28	.8724E+02	.6524E+02	.2279E+04	.1686E+02	.1890E+04	.3052E+04
29	.8682E+02	.6522E+02	.2237E+04	.1718E+02	.1830E+04	.2955E+04
30	.8631E+02	.6520E+02	.2187E+04	.1757E+02	.1761E+04	.2844E+04
31	.8587E+02	.6518E+02	.2143E+04	.1793E+02	.1700E+04	.2746E+04
32	.8541E+02	.6517E+02	.2099E+04	.1831E+02	.1640E+04	.2648E+04
33	.8494E+02	.6515E+02	.2054E+04	.1871E+02	.1579E+04	.2550E+04

I	RENSO3	HTO	AHSO	UOA	HEAT
			BTU/HR/SQFT/F		BTU/HR
1	.0000E+00	.1191E+04	.3197E+03	.2395E+03	.5019E+08
2	.3463E+04	.1307E+04	.2264E+04	.6965E+03	.1278E+08
3	.3424E+04	.1296E+04	.2250E+04	.6930E+03	.1321E+08
4	.3385E+04	.1289E+04	.2246E+04	.6912E+03	.1370E+08
5	.3344E+04	.1281E+04	.2242E+04	.6893E+03	.1419E+08
6	.3302E+04	.1274E+04	.2237E+04	.6873E+03	.1470E+08
7	.3259E+04	.1266E+04	.2232E+04	.6852E+03	.1523E+08
8	.3215E+04	.1258E+04	.2227E+04	.6831E+03	.1577E+08
9	.3169E+04	.1250E+04	.2222E+04	.6808E+03	.1633E+08

10	.3122E+04	.1242E+04	.2217E+04	.6785E+03	.1690E+08
11	.3074E+04	.1233E+04	.2211E+04	.6761E+03	.1748E+08
12	.3025E+04	.1224E+04	.2205E+04	.6736E+03	.1808E+08
13	.2975E+04	.1214E+04	.2199E+04	.6710E+03	.1870E+08
14	.2923E+04	.1205E+04	.2193E+04	.6682E+03	.1933E+08
15	.2870E+04	.1195E+04	.2187E+04	.6654E+03	.1998E+08
16	.2816E+04	.1184E+04	.2180E+04	.6625E+03	.2063E+08
17	.2761E+04	.1174E+04	.2173E+04	.6594E+03	.2131E+08
18	.2692E+04	.1161E+04	.2163E+04	.6556E+03	.2197E+08
19	.2635E+04	.1149E+04	.2156E+04	.6523E+03	.2267E+08
20	.2577E+04	.1138E+04	.2148E+04	.6488E+03	.2338E+08
21	.2517E+04	.1126E+04	.2139E+04	.6453E+03	.2411E+08
22	.2457E+04	.1114E+04	.2131E+04	.6416E+03	.2484E+08
23	.2395E+04	.1101E+04	.2122E+04	.6378E+03	.2559E+08
24	.2333E+04	.1088E+04	.2112E+04	.6338E+03	.2634E+08
25	.2270E+04	.1075E+04	.2102E+04	.6296E+03	.2711E+08
26	.2206E+04	.1061E+04	.2092E+04	.6254E+03	.2788E+08
27	.2142E+04	.1047E+04	.2082E+04	.6209E+03	.2865E+08
28	.2076E+04	.1033E+04	.2071E+04	.6163E+03	.2944E+08
29	.2011E+04	.1018E+04	.2060E+04	.6115E+03	.3022E+08
30	.1935E+04	.1001E+04	.2046E+04	.6059E+03	.3097E+08
31	.1868E+04	.9861E+03	.2034E+04	.6007E+03	.3176E+08
32	.1802E+04	.9704E+03	.2021E+04	.5954E+03	.3254E+08
33	.1735E+04	.9544E+03	.2008E+04	.5899E+03	.3332E+0899