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TWO-PHASE/TWO-PHASE HEAT EXCHANGER SIMULATION ANALYSIS

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SUMMARY

The capillary pumped loop (CPL) system is one of the most desirable devices to dissipate heat energy in the radiation environment of the Space Station providing a relatively easy control of the temperature. A condenser, a component of the CPL system, is linked with a buffer evaporator in the form of an annulus section of a double tube heat exchanger arrangement: the concentric core of the double tube is the condenser; the annulus section is used as a buffer between the conditioned space and the radiation surrounding but works as an evaporator. A CPL system with this type of condenser is modeled to simulate its function numerically. Preliminary results for temperature variations of the system are shown and more investigations are suggested for further improvement.

INTRODUCTION

A capillary pumped loop (CPL) system consists of an evaporator pump, a condenser, a subcooler, a vapor transport line, a liquid transport line and a storage tank with a possible starter pump (Ku and others, 1986; Neiswanger and others,1987; Kim, 1990). The condenser structured as a concentric core of a double tube heat exchanger dissipates heat energy to an evaporator, which is the annulus section of the double tube exchanger, so that the fluid in the core condenses while the fluid in the annulus section evaporates. A CPL system equipped with a condenser having a two-phase/two-phase double tube heat dissipation structure is to be simulated numerically. A schematic block diagram is shown in Fig.1 and illustrates the control devices of its flow.

The system has two different types of evaporator pumps, each of which has twelve units of evaporator pumps, double two-phase heat exchanger (call DBTPHX) system, which has six DBTPHX units as shown in Fig.2, a subcooler next to the DBTPHX system with a non-condensible gas collector, long liquid and vapor lines, a sub-system of control devices consisting of valves and fluid meters and a reservoir with a starter pump. In order to have a manageable simulation system, certain assumptions are made: (1) A cold plate evaporator pump replaces a hybrid evaporator so that two identical cold plate evaporator pumps are a set of evaporator pumps; (2) fan-shape inlet and exit sections of the DBTPHX (Fig.2) are assumed to be an assembly of six straight tubes in the same level of elevation; (3) the non-condensible gas(NCG) collector in the subcooler does not affect the performance of the system; (4) the flow control devices for the system is not included in the model in question; and (5) the storage tank behaves as an infinite source with constant properties. Such assumptions result in the block diagram as shown in

Fig.3.

Starting from the end of the subcooler, a few key points are identified as J1001, J1002,...,J1005 along with the Line 101, Plen 999, evaporator, Line 401, TEMP2C condenser, TEMP3C evaporator, TEMP2C subcooler and R114 chiller. A code known as SINDA'85/FLUINT (Cullimore and others, 1989) is employed for the simulation scheme and similar notations to those of SINDA'85/FLUINT are used in Fig.3. Details of these components consisting of an entire simulation model are illustrated in the following sections.

EVAPORATOR PUMP SYSTEM

Cross-sections of the evaporator pump in two directions are shown in Figs.4a and 4b. Fig.4c illustrates how the liquid flow evaporates. The cold plate evaporator pump(EVP) with twelve(12) EVP's, twelve isolators are shown in Fig.4d, and a simplified model is indicated within the cross-hatched area in Fig.4d with one unit of the heat-pump and an isolator attached to it. Fig.4e explains the cross-section of the circular heat-pump and attached plates. Based on this figure of the combined cross-section, an approximate method for the extended surface theory is used. Namely, at the mid point of the plate, the temperature is the maximum and the temperature at the tube is a fixed temperature. Therefore, an approximate fin efficiency is used for an average temperature(or conductance) as far as the plate is concerned. The radial cross-section of the EVP has 40 internal grooves in the outer shell. From a header, liquid enters the isolator, permeates the porous layer, reaching the core of the EVP. Once the liquid reaches the groove surface through permeation, heat transfer from the outside causes vaporization of the liquid. Evaporated fluid is pushed to the grooves(Fig.4c) and to the vapor header and enters the vapor transport line. Cullimore (1989) successfully demonstrated a numerical model by using a MACRO command, CAPPMP. Therefore, his method is employed for the EVP system. The capacity of the EVP system is assumed to be 400 watts.

DOUBLE TWO-PHASE HEAT-EXCHANGER SYSTEM

In the DBTPHX, the condenser is a inner circular tube coupled with an evaporator which is the annulus section of the DBTPHX. The inner tube has axial grooves internally and externally and porous material layers occupy the space next to the grooves in the annular section and the core section, respectively, so that liquid, from capillary action can permeate the grooves and the porous layers.

Six DBTPHXs connected in parallel function as the condenser and are designated as TEMP2C. The layer of porous material, Porex, enhances condensation in the internal grooves. Six DBTPHX evaporators connected in parallel are designated as TEMP3C. The layer of Porex directs the liquid flow in one desired direction. Porex has a permeability of 2.3x10E-13.

From the inlet of TEMP2C a vapor enters internal grooves of the internal tube, condenses on the surface of the porous layer and permeates the porous layer, reaches the core cavity and leaves the TEMP2C from the core section of the DBTPHX. From the inlet of TEMP3C (the exit side of TEMP2C), liquid flows into the annulus section where the porous layer is placed. The porous layer has grooves in the metal outer shell side. As the liquid permeates the porous layer, it reaches the external grooves of the internal tube, starts evaporating because of heat transferred from the condenser, then is pushed into the grooves, leaving TEMP3C from the annulus section. From this exit, it is possible for a mixture of saturated liquid and vapor to leave TEMP3C.

Figs. 5a and 5b show an axial cross-section and a radial cross-section, respectively. Six of the fan-shaped inlet and exit sections are represented by a single straight tube of the same size at the same elevation then duplicates six times.The core section from which the liquid leaves TEMP2C has an isolator then a liquid header follows. Due to heat transfer from TEMP2C to TEMP3C across the metal tube, it is plausible to consider that the quality of condenser fluid changes from unity to zero, while the quality of evaporator fluid changes from zero to unity. For simplicity, the variations of fluid quality in TEMP2C and TEMP3C are assumed to be linear as shown in Fig.6. To the mid point of TEMP2C, and TEMP3C, the qualities remain unchanged then change linearly to the locations from the mid point of the DBTPHX. In the present study, the length of the DBTPHX is divided into ten segments. Accordingly, the quality will be assigned for TEMP2C and TEMP3C.

SUBCOOLER AND R114 CHILLER

The subcooler of the CPL has a complicated structure for a vapor trap to cope with non-condensible gas in the subcooler. Considering that the amount of noncondensible gas is relatively small in comparison with the flow rate, the vapor trap is not modeled in the present study. In the location of the trap, a flat plate is placed. Similarly to the evaporator pump plate, the half of the plate with the attached subcooler and the R114 chiller is considered to be like a fin having the minimum temperature at the mid point of the contacting area between the subcooler and the chiller (see Fig.7). The fin efficiency is assumed to be 80 per cent. The temperature variation along the transverse direction is assumed to be rather small in comparison to that in the direction of the tube axis. For each leg of the subcooler and the chiller a uniform temperature is assumed to exist and the 180 degree bends connecting four legs are considered to be adiabatic. This is to be handled with a MACRO command of SINDA'85/FLUINT.

The subcooled liquid passes through the liquid transportation line which is considered adiabatic. A pressure drop through this passage is added to the system pressure loss. The liquid then enters the evaporator pump.

The liquid reservoir is added to the system model as a plenum, holding all the properties as constant. A mixing process in the reservoir may not result in constant properties, nonetheless, it is assumed a steady state process.

INPUT FILE FOR THE COMPUTER PROGRAM

An input file for SINDA'85/FLUINT was constructed based on the following Headers:

1. Header Options Data
2. Header Node Data,Plate
3. Header Conductor Data,Plate
4. Header Control Data
5. Header Source Data,Plate
6. Header Flow Data,TEMP2C
7. Header Flow Data,TEMP3C
8. Header Flow Data,STLTS
9. Header Flogic 0,TEMP2C
10. Header Flogic 0,TEMP3C
11. Header Flogic 1,TEMP2C
12. Header Flogic 2,TEMP2C
13. Header Variables 1,Plate
14. Header Output Calls, TEMP2C
15. Header Operation Data
    Build DBTPHX,Plate
    Build DBTPHX,TEMP2C,TEMP3C,STLTS
    Call Fastic
    Call Fwdbck
16. Conditional Call for Restar
17. Header Subroutine Data if any
18. End of data

Details of these headers are explained in the manual(Cullimoreand others,1989). Diffusion submodels consist of the evaporator tube, its plate with the web,the internal tube, the external tube of the DBTPHX and its subcooler and chiller bodies with the plates. All of these submodels are represented by a diffusion model, PLATE. Node and Conductor Data sections have the initial temperature,capacitance and conductance of these submodels. The fluid submodels are TEMP2C, TEMP3C,and STLTL. TEMP2C represents the evaporator pump, condenser, its subcooler and the transportation lines. TEMP3C represents the buffer evaporator and STLTL represents the refrigerant chiller. Transportation lines for liquid and vapor are adiabatic. The numbers for nodes,conductors, lumps and connections of the EVP's are in 200's and the remaining numbers used for the thermal and fluid submodels are listed in Table 1.

Using the standard notation for SINDA'85/FLUINT, one unit of EVP is illustrated in Fig. 8 by using the notations of the code, whereby the macro command CAPPMP is applicable.

A symbolic diagram is drawn for the condenser/TEMP2C, the evaporator/TEMP3C, the subcooler/TEMP2C, and the R114 chiller in Fig. 9 with an aid of the standard notations of SINDA'85/FLUINT for DBTPHX. The fluid transportation lines are modeled by a MACRO command LINE. The subcooler/R114 chiller is modeled by a MACRO command HX.

Table 1 Diffusion and Fluid Model Identifications
by a Range of Numbers

Liquid Transportation Line	100 to 199
Evaporator	200 to 299
Vapor Transportation Line	400 to 499
Condenser/TEMP2C	500 to 599
Subcooler/TEMP2C	600 to 699
Evaporator/TEMP3C	700 to 799
R114 Chiller	800 to 899
Storage Tank	900 to 999

RESULTS and DISCUSSIONS

A start-up performance is run as the first trial with a prepared file shown above. With a surrounding temperature of 6.6 C,every component of the CPL system is at the same temperature except the storage tank which is at 29 C. A heat load of 400 w is applied to the cold plate EVP, and for a certain time period, performance of the system is simulated. Computation is divided into two time zones: the first 2 minutes and the following 28 minutes. In the 2 minute duration, the first step of the calculation was Fastic's procedure to obtain a stable initial condition for the entire system. Thus, reaching a stable condition, the Fwdbck procedure takes over the computation. The Fastic scheme provides computations in an instantaneous equilibrium. The Fwdbck process involves an implicit temperature expression in the way of the Crank-Nicolson(1947) computation process(Cullimore and others,1989). This way,temperature-histories at the EVP plate, the DBTPHX plate and the chiller are plotted for the first 2 minutes in Fig.10. Fig.11 exhibits temperature histories at those locations for the following 23 minutes with the FWDBCK scheme. Some of the results by Neiswanger and others(1987) seem to show that the trend of temperature rise is similar.

At about 25 minutes, a steady state is reached: the highest temperature at the evaporator plate is 39.7 C and the fluid temperature of the evaporator pump is 38.4 C. This tendency should be compared with that of an experimental result if any.

Results of shorter segments of DBTPHX were not included and the accuracy of the current result has not been established with respect to the segment size.Other parameters like the pressure,quality, heat transfer also have not been included. Other operating conditions such as starting from a usual standard condition and a combination of Fwdbck initially and STDSTL operations have not yet been tested with this input file.

These analyses are ongoing at present and will continue until satisfactory results are obtained within a reasonable error limit.

In the process of computation, it was necessary to use the Fastic scheme initially with the linear relationship for the quality along the half length from the mid point in both TEMP2C and TEMP3C sides of DBTPHX. As a result, a stable result was obtained within a few number of iterations in the Fastic calculation. Thereby, the Fwdbck procedure was carried out further,eventually to lead to a steady state condition.

CONCLUDING REMARKS

A CPL system with a DBTPHX condenser was analyzed to simulate performance of the system with simplifying assumptions. The maximum temperature at the evaporator plate reached 39.7 C. Further parameter studies should be done for better results of temperature, pressure and quality distributions.No experimental results have been compared to the present results. That comparison will be critical for refining the input file.

In general, improvements can be made by increasing the number of the segments for the DBTPHX for more accurate solution, because the process of Fwdbck gives stable solutions but does not provide accurate solutions. Similarly, the evaporator pump and the chiller legs should be divided into several segments and search for better solutions for performance simulation is desirable. Other modeling methods for the DBTPHX may be tested and their results should be compared with the result presented here.

The effect of the neighboring isolators on the liquid flow, and precise heat convection coefficients at the evaporating and condensing surfaces in the grooves and porous layers are not available. Those values that come from the subroutine are the convection coefficients for the usual boiling and condensing conditions over a flat plate or cylinder(ASHRE,1989; Chen, 1963). The heat transfer coefficients used in this paper may yield first order approximate performances, however,the average heat transfer coefficient obtained from the NASA experiment (Neiswanger and McIntosh, 1987; Cullimore, 1989) will be used for further testing. Finally, deleting the simplifying assumptions in making a working model will yield a satisfactory simulation.

ACKNOWLEDGEMENT

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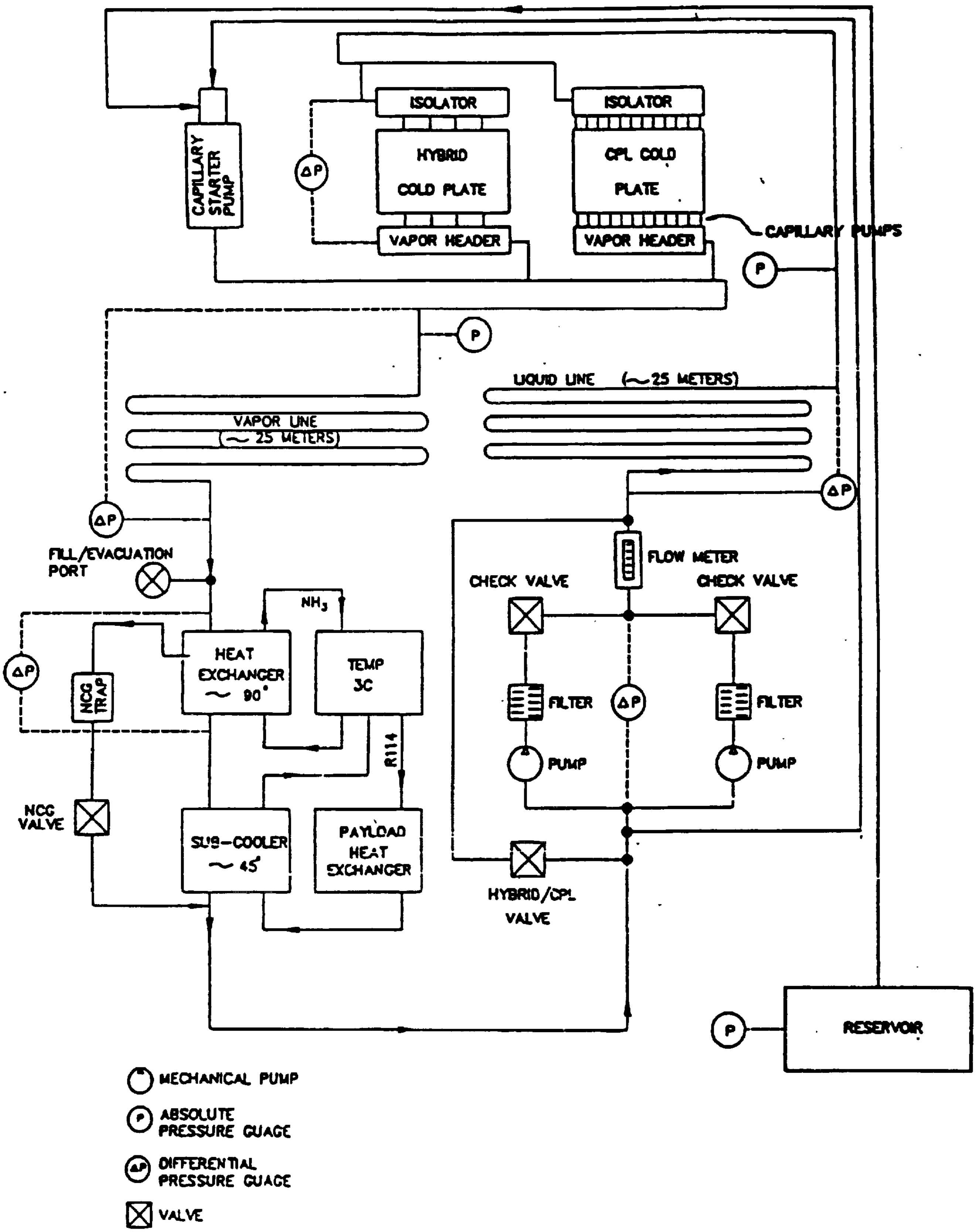

Fig.1 A Capillary Pumped Loop System with a Double Two-Phase Heat Exchanger

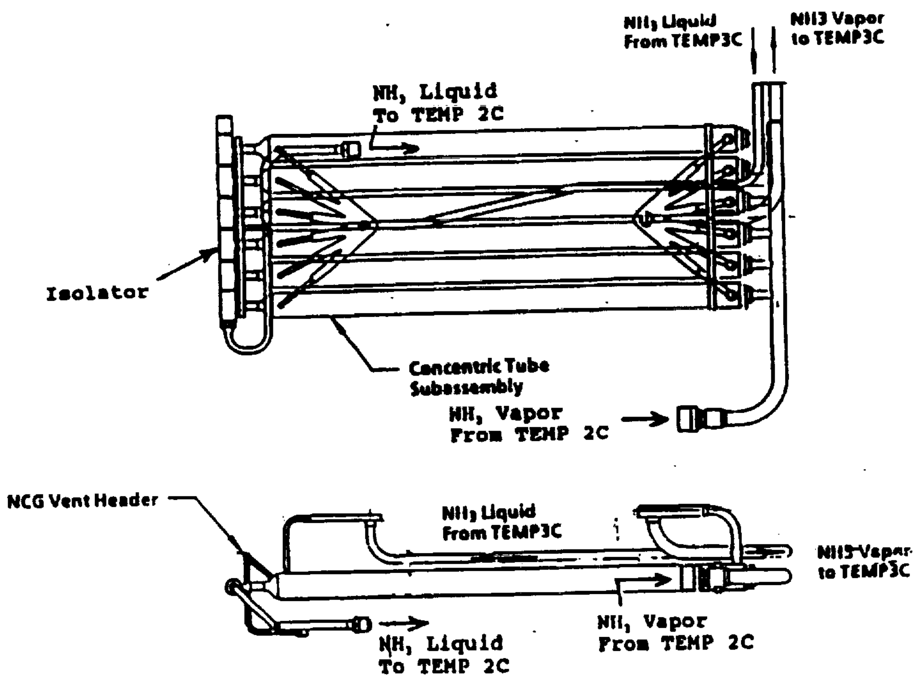

Fig.2 A Double Two-Phase Heat Exchanger and and Its Front and Elevation Views

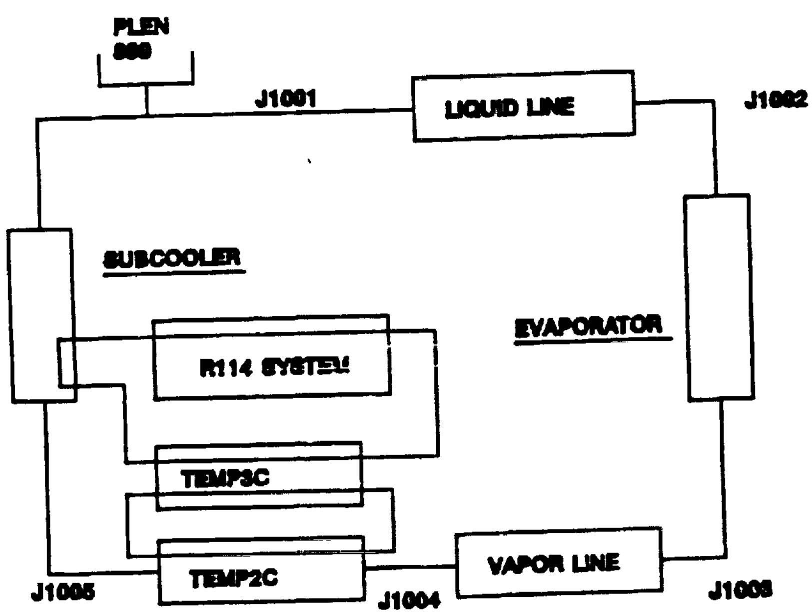

Fig.3 A Simplied Block Diagram for the CPL System

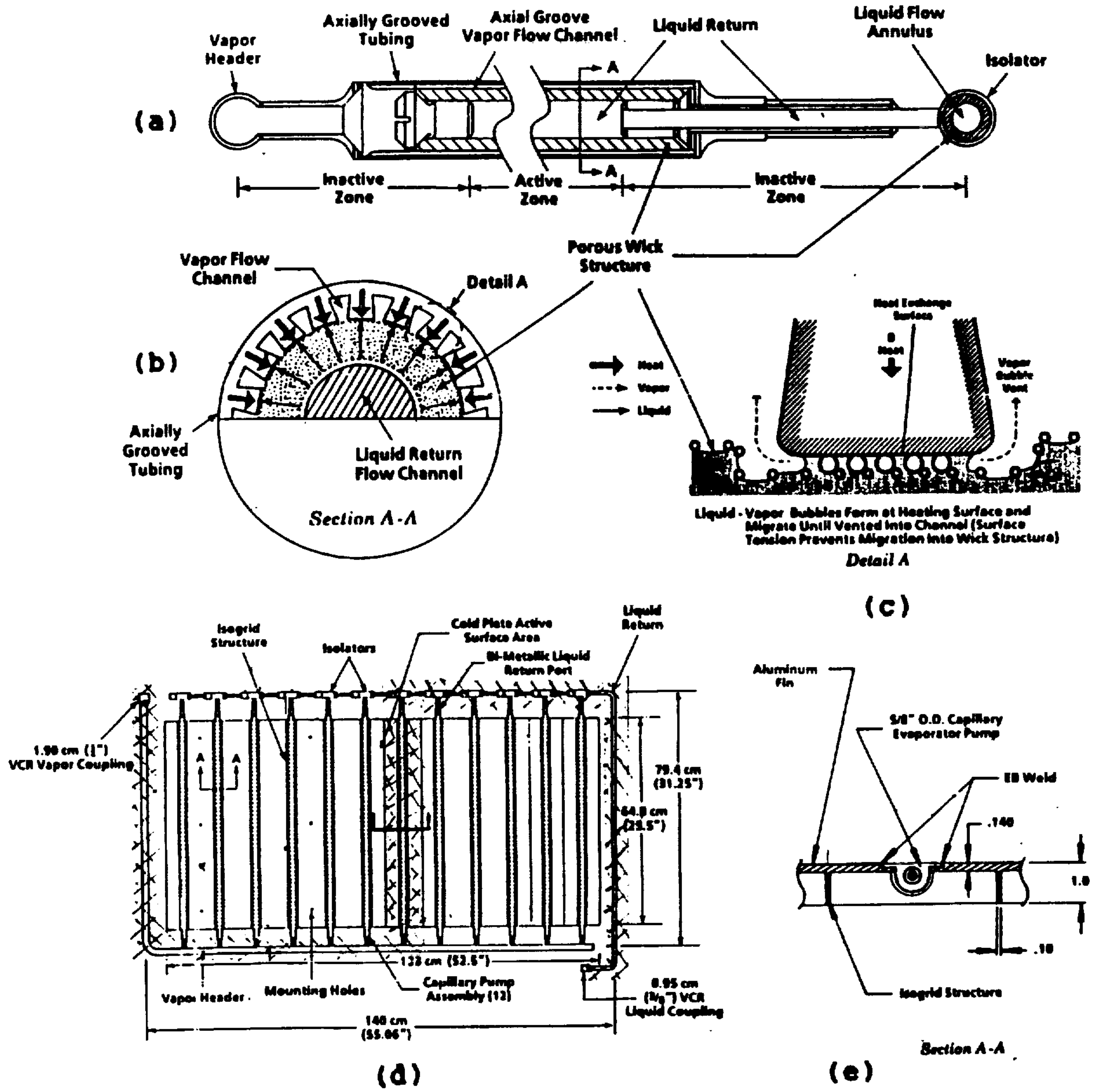

Fig.4 A Cold Plate Heat Pump Evaporator System(a)Axial Cross-Section(b)Radial Cross-Section of Heat Pump Unit(c)Vaporriazation at the Groove Surface(d)Twelve Heat Pumps,its Isolators and a Simplified Model in the Shaded Area and (e)a Cross-Section of the Circular Heat Pump and Plate

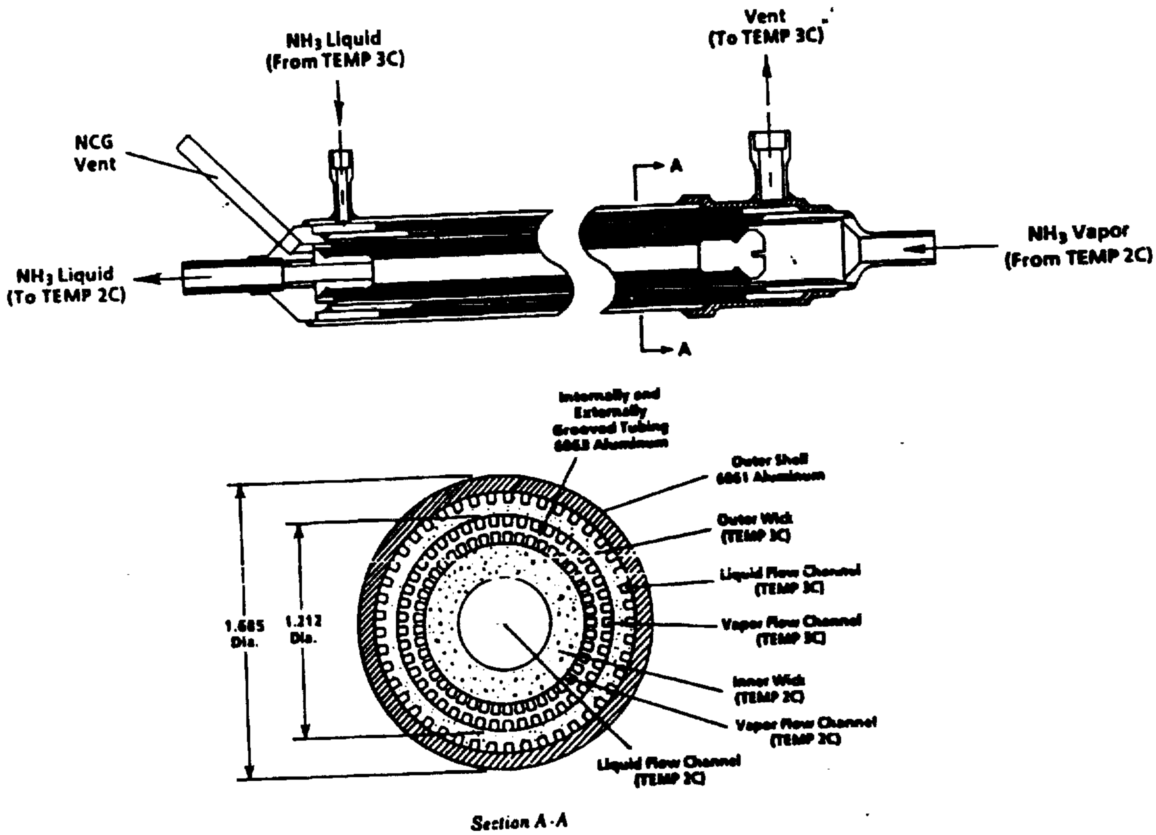

Fig.5 Double Two-Phase Heat Exchanger/TEMP2C,TEMP3C
(a)Radial Cross-Section of a DBTPHX
(b)Axial Cross-Section of a DBTPHX

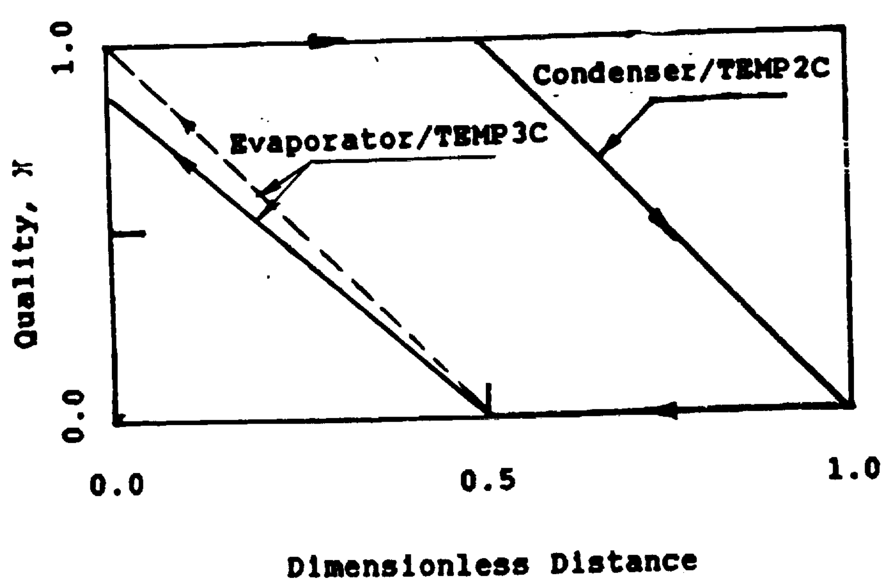

Fig.6 Initial Quality Variations in TEMP2C and TEMP3C of DBTPHX

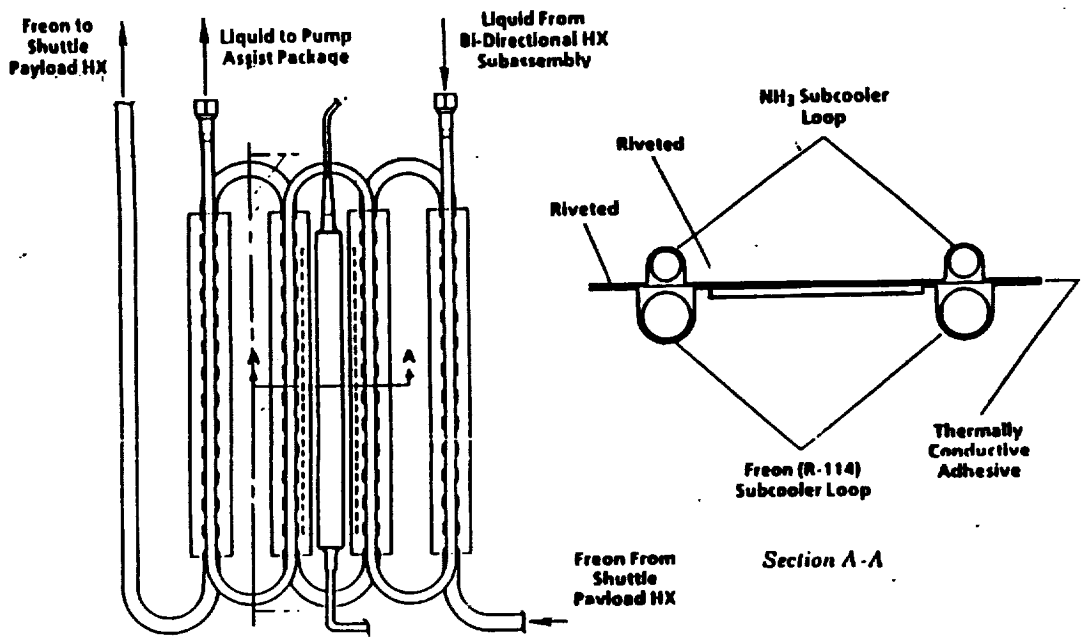

Fig.7 Subcooler/TEMP2C,R114 Chiller and Modified Mid-Section Deleting NCG Trap

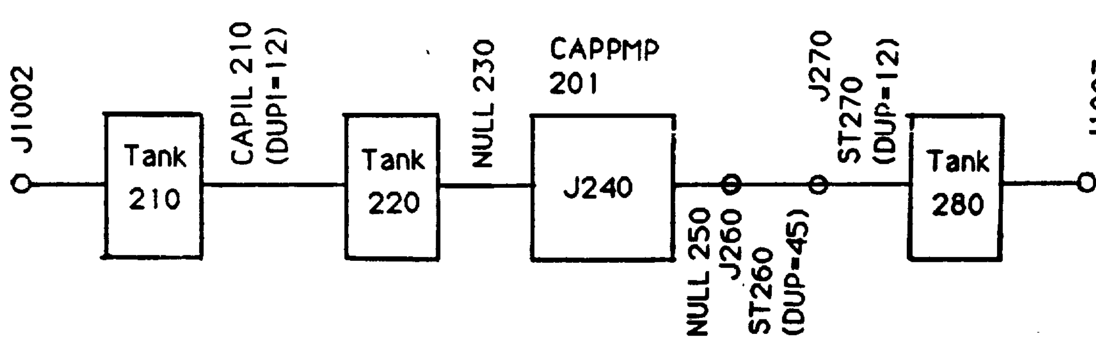

Fig.8 Block Diagram of CAPPMP for the Evaporator System

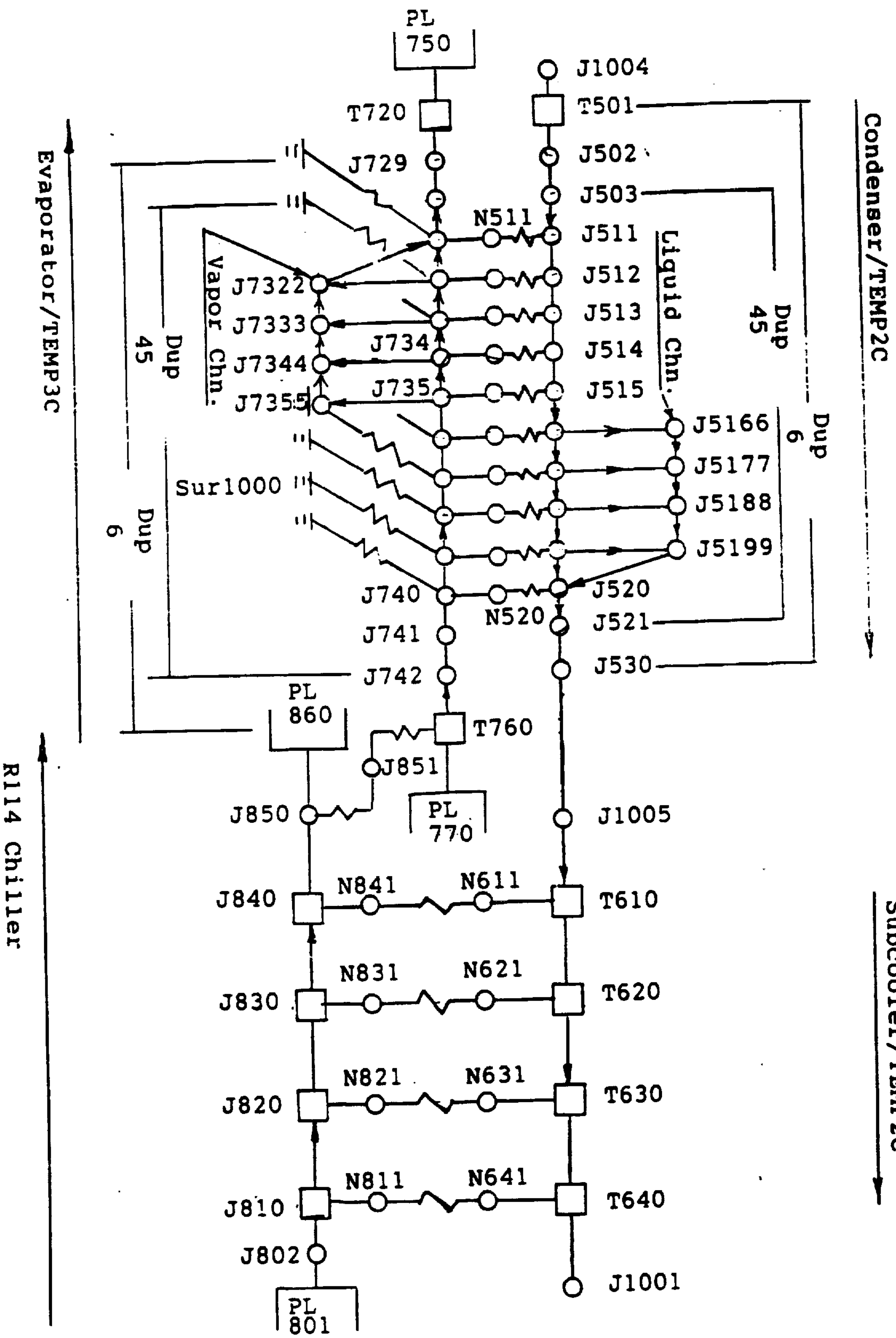

Fig.9 Block Diagram of Condenser,Subcooler/TEMP2C,Evaporator/TEMP3C and R114 Chiller

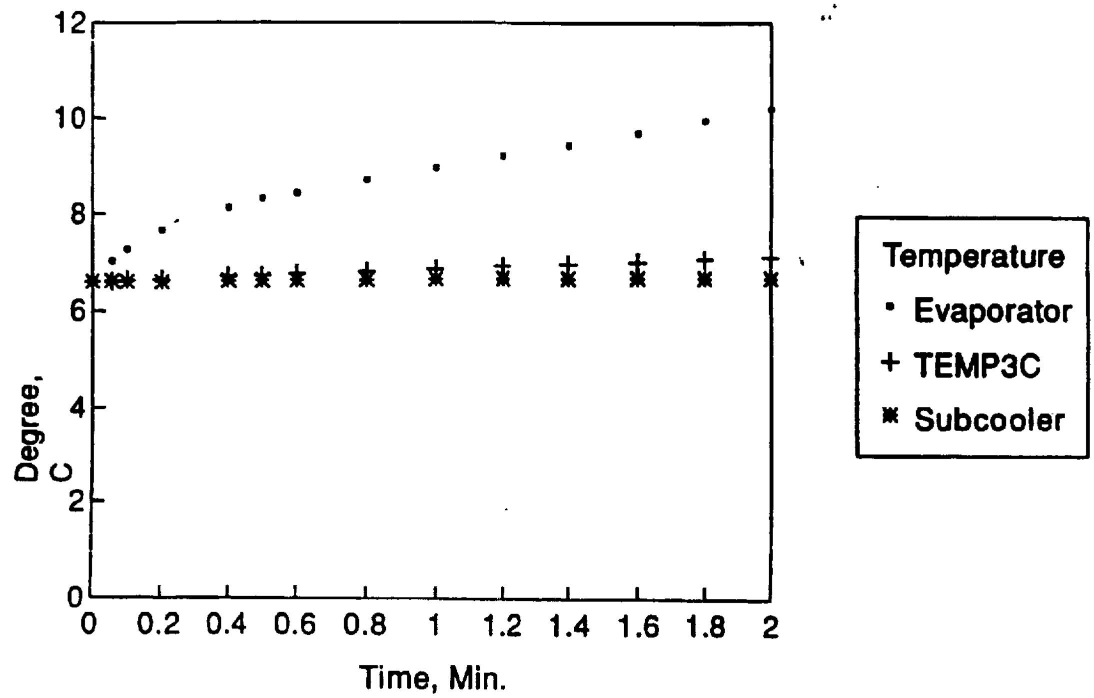

Fig.10 Temperature-Histories at Evaporator,TEMP3C and Subcooler for the First Two Minutes

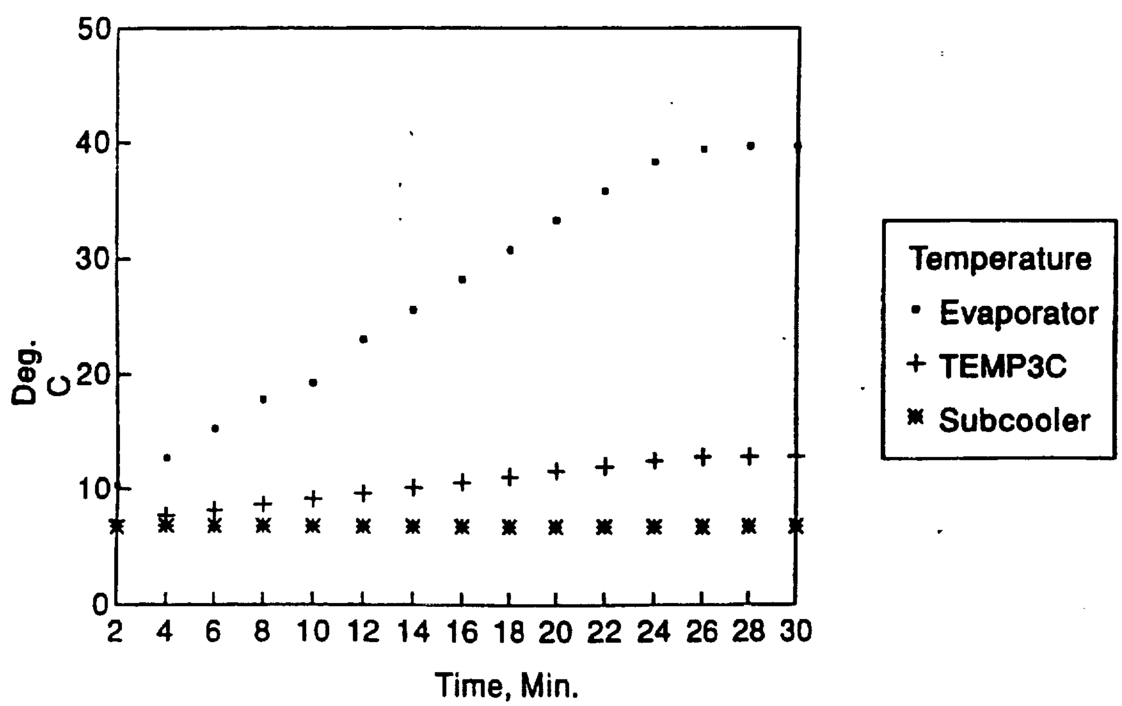

Fig.11 Temperature-Histories at Evaporator,TEMP3C and Sucooler for 30 Minutes