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TECHNICAL MEMORANDUM

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TITLE: Modified Thermal Analyzer Digital Computer Program (TAP)

ABSTRACT

The Thermal Analyzer digital computer program (TAP) solves n-dimensional transient or steady-state heat flow problems involving any of the three modes of heat transfer, by creating an electrical analogy of the thermal problem which is to be solved, and then solving the problem by the finite differences technique. The program is coded in Fortran IV for use on the IBM-360/65 computer which is available at the Electronics Division of Aerojet-General Corporation.

The program is of a general nature and can be used to solve many unrelated complex heat transfer problems. In general, the purpose of such a program is to provide immediate access to a sophisticated analytical tool rather than having to wait until a digital computer program can be developed to solve a specific complex heat transfer problem.

KEY WORDS

thermal analysis, transient, steady-state, computer program, heat transfer

APPROVED:

DEPARTMENT HEAD



NOTE: The information in this document is subject to revision as analysis progresses and additional data are acquired.



AEROJET-GENERAL CORPORATION

1.0 SUMMARY

The purpose of this report is to describe the application and use of the TAP computer code to solve complex transient or steady-state heat transfer problems. The report contains a detailed description of the code, as well as, sample data format sheets and sample problems to assist the novice in its use in solving heat transfer problems. Some knowledge of heat transfer is essential if one is to properly utilize the code, but it is not necessary for one to be familiar with computer programming to make full use of the program's potential. Computer codes of this type are always in a state of evolution and, therefore, one should expect a number of changes to be made in the program during the useful life of this report. As these changes are made and incorporated into the basic code, every attempt will be made to update the material contained in this report.

2.0 INTRODUCTION

The Thermal Analyzer digital computer program solves n-dimensional transient or steady-state heat flow problems for any of the three modes of heat transfer by creating an electrical analogy of the thermal problem which is to be solved and, then solving the problem using the finite differences technique. Nearly all heat transfer problems are expressible in the form of such an electrical analogy where thermal resistance and thermal capacitance represent the equivalent of electrical resistance and capacitance. The thermal network is set up in the form of lumped parameters (called nodes) which represent the average values of the thermal properties of the mass which has been lumped at that point.

The program has been set up so that it is problem rather than computer oriented. This allows one to make changes in the boundary conditions and the problem without the necessity of reprogramming TAP or making extensive changes in the problem input data.

The program has been so constructed that the heat transfer associated with single phase incompressible fluid flow phenomena can in most cases be considered within reasonable accuracy.

Reactor heating can be considered by the program including reactivity feedback due to temperature changes and deadband control of reactivity, as well as, changes in reactivity due to reflector or control rod movement.

The program was originally developed at Lockheed Missiles and Space Company of Sunnyvale, California, for solving missile and space satellite heat transfer problems. It has been extensively modified by the Power Systems Department in the Electronics Division of Aerojet-General Corporation, Azusa, California, to consider decay heat removal and other heat transfer problems encountered in the SNAP-8 nuclear space power program.

3.0 GENERAL DESCRIPTION OF THE TAP PROGRAM

The Thermal Analyzer Program was not set up to solve a specific kind of heat transfer problem. It is more of a general heat transfer program which has been provided with a number of generalized options which allow it to consider a large number of unrelated complex heat transfer problems. The options available include the choice of a number of different kinds of nodes and thermal resistors, as well as a selection of special functions which perform various operations and the use of tables which can be used to describe the dependancy of any primary program parameter or any other primary program parameter.

This section has been written to give the reader some idea of the flexibility and application of the TAP computer code rather than to provide a detailed outline of the numerous options available which are, instead, described elsewhere in this report as indicated in the table below.

<u>Item</u>	<u>See Section</u>
<u>I. Nodes</u>	4.0
a. Positive Capacitance W/No Mass Transfer Across the Node Control Volume	4.1.1
b. Positive Capacitance W/Mass Transfer Across the Node Control Volume	4.1.2
c. Positive Capacitance Flow Junction	4.1.2.4
d. Zero Capacitance	4.2
e. Negative Capacitance	4.3

<u>Item</u>	<u>See Section</u>
<u>II. Thermal Resistors</u>	5.0
a. Conduction	5.1
b. Forced Convection	5.2.2
c. Natural Convection	5.2.3
d. Radiation	5.3
<u>III. Functions</u>	7.0
a. Cathode Follower W/No Time Delay	7.1
b. Radiation Resistors	7.2
c. Phase Transition	7.3
d. Natural Convection Resistors	7.4
e. Reactor Heating	7.5
f. Aerodynamic Heating	7.6
g. Arbitrary Functions	7.7
h. Output Specifications	7.8
i. Problem Constants	7.9
j. Cathode Follower Fluid Flow W/Time Delay	7.10
k. Flow Junction	7.11
l. Cathode Follower Fluid Flow Instantaneous	7.12
m. Reactivity Feedback and Deadband Control	7.13
n. Steady State and Time Advancement Option	7.14
o. Forced Convection Resistors	7.15
<u>IV. Tables</u>	8.5

Since the TAP computer code is very flexible in its potential application to heat transfer problems, the user is left with the obligation to construct his thermal network from among an infinite variety of possibilities.

3.1 Types of Problems for Which the Present TAP is Not Suitable

There are a number of heat transfer and fluid flow problems which cannot be reasonably considered by the present version of the TAP computer code. This is especially true in the case of fluid flow because the fluid flow models available in the present version of the program consider only the heat transfer and transport characteristics of the flowing fluid and does not embody the laws governing fluid flow. In most cases,

these models are sufficiently accurate to treat the heat transfer associated with flowing fluids in a reasonable manner. However, the program has not been provided with mathematical models to consider the following fluid flow phenomena.

1. Compressible flow.
2. Pressure drop calculations.
3. The hydraulics of two-phase flow.
4. The calculation of flow distribution into parallel flow channels if the flow is not distributed according to the cross sectional areas of the flow channels.
5. Any problems in which the fluid flow models available are not sufficiently accurate to describe the physical model.

The following heat transfer models are not adequately provided for in the present version of the TAP code either.

1. Boiling Heat Transfer requiring more sophistication than provided for by Function 3.
2. Reactor Heat Problems which require a more accurate reactor heating mathematical model than provided in the code or where $\delta_k > \beta + 1$

3.2 Solution Techniques

In the TAP computer code, a thermal network is set up by the user whereby the mass of the problem sample is divided into discrete lumps or nodes which are then connected together through thermal resistors. The sample should be divided into enough nodes so that a reasonable solution is possible. If, on the other hand, one divides the problem sample into a great many more nodes than is necessary, then the setup and computer time would exceed the amount of time required to obtain a reasonable solution. One need only exercise reasonable caution to insure that a reasonable thermal network is set up to satisfy the tradeoff between accuracy and economy.

In order to insure that the problem does not become unstable, the time interval between calculations can be determined from the physical problem such that the time index is not advanced beyond the point where the solution for any node in the thermal network could become unstable.

The TAP code, for the first iteration in each time step, establishes a heat balance around each positive capacitance node using the temperatures calculated in the previous time step as the first estimate of the temperatures of the nodes on the other end of the thermal resistors from the node. At the end of the iteration the new temperature calculated for each node are transferred to the data block containing the old temperatures for the nodes. After the first iteration the new temperatures replace the node temperatures in the previous time step. In subsequent iterations in a time step they replace the previous estimates. The process is continued until the new and old temperatures for the nodes in the network agree within an established error criteria.

Using this kind of discontinuous solution to describe a system which is continuous in both space and time does introduce some error into the results. However, in nearly all cases the error will be well within acceptable limits and will become negligible as the number of nodes representing the network increase toward infinity and the size of the time step is reduced toward zero.

The solution equations used in the TAP code are presented in Section 6 of this report.

3.3 Geometry (The free selection thereof)

The TAP program contains no built-in geometry. The selection of nodes is completely arbitrary within reasonable physical limitations. One limitation is that too much computer time would be used if one were to connect two nodes of finite capacity by a very small thermal resistor. In this case one would expend considerable computer time to find that the temperatures of the two nodes were nearly the same. This must be a basic consideration when connecting up the thermal network. One should always try to divide the geometry into a thermal network in a logical and realistic manner.

3.4 N-Dimensions

There is no limit on the number of resistors which can be connected to a given node. This means that, in addition, to being able to handle one, two, or three dimensional heat transfer problems; additional resistors are available to drive heat into the node or to consider more than one mode of heat transfer in a given direction.

3.5 Unit Selection

The TAP program is almost completely free in the use of any system of units. One exception is that the fixed constant in equation 4-3 must be changed if a temperature scale other than °F is used.

However, once a system of units is selected, it must be used consistently throughout the data. The dimensions required by the program are:

<u>Symbol</u>	<u>Dimension</u>
θ	Time Unit
L	Length Unit
Q	Heat Unit
T	Temperature Unit

3.6 Thermal Network Identification

The TAP program is not geometry dependent as explained in Section 3.3. Neither is it restricted in the size of the heat transfer problem which can be solved (other than the limiting factor of the computer storage which is available).

In order that the selection of the thermal network be completely arbitrary in keeping with the program philosophy, it was necessary to require that each node and thermal resistor be uniquely identified. The numbering of the nodes and thermal resistors is completely arbitrary except that:

1. Zero cannot be used as a node or resistor number.
2. Any given node or resistor number can be used only once.
3. The ID number cannot exceed the maximum allowable ID number given in the program dimension statements.

3.7 Thermal Network Center

The TAP program establishes a heat balance around each node using the temperatures calculated in the previous time step for the temperatures of nodes at the other end of the thermal resistors connected to the node. All variable primary program parameters are evaluated at the previous time. This type of solution does not establish any center for the thermal network and, therefore, heat source, heat sinks, adiabatic walls, etc. can be placed anywhere in the thermal network desired.

3.8 Variation in Parameters

The program allows for the arbitrary variation of any of the primary program parameters* with any other primary program parameter or time.

3.9 Consideration of Heat Transfer Associated with Fluid Flow

The program has been set up so that it can in most cases consider the heat transfer phenomena associated with transient or steady-state, single-phase, incompressible fluid flow. The flowing fluid mass is passed from node to node in the flow stream roughly approximating the stream velocities. To make the treatment of fluid flow completely general, in keeping with the nature of the program, it was necessary to make the following simplifications in the treatment of fluid flow.

1. If the fluid capacity of the node is greater than the amount of fluid which would pass over the node control volume in a given time step, it is sufficiently accurate to completely mix the incoming fluid with that remaining in the node.

2. If the fluid capacity of any series of nodes in a flow stream are considerably less than the amount of fluid which would pass over the node control volumes in a given time step, it is sufficiently accurate to step the fluid through such a series of nodes in one time step. The fluid remains in the node for the time step and then is advanced to the next node in the series without changing the time step index. In this way, the fluid advances stepwise through the series in any given time step.

3. If the fluid capacity is approximately equal to the amount of fluid which would pass over the node control volume in a given time step, it is sufficiently accurate to step the fluid one node per time step through the flow stream. In steady state calculations this kind of assumption can be used to describe the entire flow field with reasonable accuracy.

* The primary program parameters are, the value of any resistor, the temperature, capacitance, or internal heat generation rate for any node the average temperature or difference in temperature between any two nodes, the fluid capacity flow rate for any node, the time rate of change in temperatures of any node, the net heat flow rate over the control volume of any node or the net heat flow rate between any two nodes connected by a thermal resistor.

By properly connecting the various kinds of fluid flow nodes in a given flow stream, it should now be possible to represent with reasonable accuracy the heat transfer associated with most single-phase incompressible fluid flow fields.

3.10 Time Options (See Section 7.9)

- a. A problem can be started and terminated at any arbitrary time.
- b. The time step can be calculated by the program or given as input.
- c. The time step and print interval can be arbitrarily changed during the course of the problem to reflect changes in boundary conditions and to increase or reduce the amount of data output generated during the execution.

3.11 Steady State and Time Advancement Options (See Section 7.14)

The program contains a steady state option which if used terminates execution of the problem once steady state conditions have been achieved, within a stated accuracy, for all nodes in the thermal network. In addition, once steady state conditions have been achieved, the time advancement option if used allows the user to arbitrarily advance the time (deleting all intermediate calculations) to a predetermined time where transient conditions again exist. This procedure can be repeated up to maximum number of times for which data is provided.

3.12 Time Saving in Data Input

The TAP program has been provided with options and data setup programs which can be used to greatly reduce the amount of time and effort which would, otherwise, be required to model complex heat transfer problems.

3.12.1 Data Incrementing

The data incrementing options can be used in most of the data blocks to input data if the data meets the requirements for such incrementing. Data incrementing is discussed in Section 8.6 of this report. Using data incrementing, it is possible to replace a whole series of data input cards with the first and last card of the data series.

3.12.2 TAP Setup Program

R. Belcher, of Aerojet-General Corporation, has developed two data setup programs which can be used to generate data input in the form of a data listing and punched IBM cards for data blocks I-III.

Setup Program

The first of these programs calculates thermal resistances and capacities for 2-dimensional cross sections and assigns node numbers and resistor numbers to the network given the end points of the control volume of each node in the network.

Stacking Program

The second of these programs called the stacker program, generates the setup program cross sections any number of times in the third dimension. The node numbers and resistor of the generated sections follow sequentially from those assigned in the setup program. It connects up the various similar sections with thermal resistors in the third dimension.

These programs have been set up so that the punched card output of the setup program or the stacking program (if the problem is 3-dimensional) can be used directly as data input in data blocks I through III in the TAP code.

It will, or course, still be possible for the user to modify or add to the results of the setup or stacking program to account for variations from symmetry, complex boundary conditions, etc.

No write-up has yet been made on the setup or stacker programs for the TAP code. Therefore, any questions as to availability, use of, etc. of these programs should be directed to Mr. Belcher or Mr. N. Rumpf of the Computer Utilization Group of the Power Systems Department, Electronics Division, Aerojet-General Corporation, Azusa, California.

4.0 THE NODE TYPES AND THEIR USE IN THE THERMAL NETWORK

The Thermal Analyzer Program contains a number of different kinds of nodes, each of which has unique characteristics. The proper use of these nodes in a thermal network allows one to solve many kinds of complex heat transfer problems.

Following is a discussion of the types of nodes which are available and the use which can be made of them.

4.1 Positive Capacitance Nodes

Positive capacitance nodes can be defined as those nodes which represent a finite mass. They have a finite positive capacitance and their temperature changes during a given time step as heat is added or taken away from the node. The positive capacitance nodes may or may not have mass transfer across their control volumes. The resistance-capacitance product is determined for each positive capacitance node in the thermal network.

4.1.1 Positive Capacitance Nodes With No Mass Transfer Across the Control Volume

The positive capacitance node with no mass transfer across the control volume is used to represent the solid phase of matter or stationary fluids. During a given time step the temperatures of such nodes are determined as follows:

$$T_{\theta+\Delta\theta,i} = \frac{\Delta\theta}{C_i} \left(\sum_{j=1}^n \frac{T_{\theta,j}}{R_{ij}} + Q_{\theta,i} - T_{\theta,i} \sum_{j=1}^n \frac{1}{R_{ij}} \right) + T_{\theta,i} \quad (\text{Eq 4.1})$$

4.1.2 Positive Capacitance Nodes with Mass Transfer Across the Control Volume

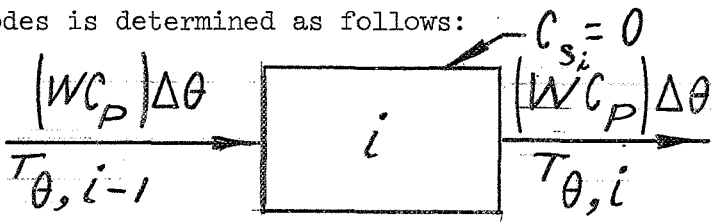
The positive capacitance node with mass transfer across the control volume is used to represent flowing fluids in either the liquid or gaseous state. Provision has been made in the program to allow a portion of the capacitance of such nodes to represent non-flowing mass. The program can consider four kinds of these nodes.

4.1.2.1 Flowing Fluid Nodes With One Time Step Delay*

If a flowing fluid node is defined in Function 10 as one in which all of the node mass is transferred across the node control volume in a given time step, the temperature of the node is determined as follows:

$$T_{\theta+\Delta\theta,i} = \frac{\Delta\theta}{C_i} \left(\sum_{j=1}^n \frac{T_{\theta,j}}{R_{ij}} + Q_{\theta,i} - T_{\theta,i-1} \sum_{j=1}^n \frac{1}{R_{ij}} \right) + T_{\theta,i-1} \quad (\text{Eq 4.2})$$

The thermal capacitance of such nodes is determined as follows:



$$C_{\theta+\Delta\theta,i} = C_{V_i} = (WC_p)_{\theta,i} \Delta\theta \quad (\text{Eq 4.3})$$

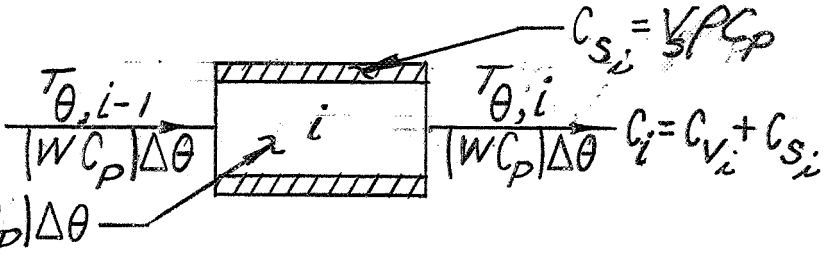
Where (WC_p) is given in a table as a function of time

There is no provision made to allow a portion of the node mass to remain stationary for this kind of node.

* Function 10 Type I

4.1.2.2 Flowing Fluid Nodes With a Specified Time Delay **

If a flowing fluid node is defined in Function 10 as one with a specified time delay, the temperature of the node is determined as follows:



$$T_{\theta+\Delta\theta,i} = \frac{\Delta\theta}{C_i} \left(\sum_{j=1}^n \frac{T_{\theta,j}}{R_{i,j}} + Q_{\theta,i} - T_{\theta+\Delta\theta,i} \text{ MIX} \sum_{j=1}^n \frac{1}{R_{i,j}} \right) + T_{\theta+\Delta\theta,i} \text{ MIX} \quad (\text{Eq 4.4})$$

Where $T_{\theta+\Delta\theta,i} \text{ MIX}$ is determined as follows:

$$T_{\theta+\Delta\theta,i} \text{ MIX} = \frac{T_{\theta,i} [C_i - (WC_p)_{\theta,i} \Delta\theta] + T_{\theta,i-1} (WC_p)_{\theta,i} \Delta\theta}{C_i} \quad (\text{Eq 4.5})$$

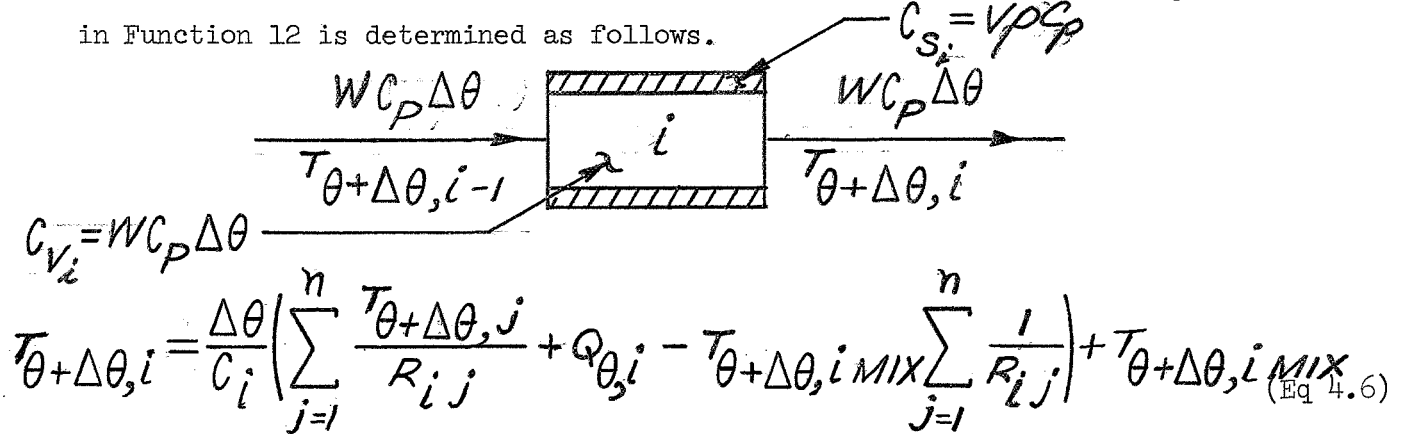
The capacitance of such nodes is given as a constant in the capacitance data block. The program allows one to represent a portion of the node mass as non-flowing. This allows one to associate pipe wall capacitance, etc., with the flowing fluid capacitance when there is a very high coefficient of heat transfer between them. That portion of the node capacitance which represents the flow cavity (C_v) is specified in Function 10. The time step $\Delta\theta$ must be such that $\Delta\theta_{\theta+\Delta\theta} < \frac{C_{V,i}}{(WC_p)_{\theta,i}}$. This restriction is provided so that no more than the entire fluid capacity in a node can be transferred out of the node in a given time step.

4.1.2.3 Flowing Fluid Nodes With No Time Delay

If a flowing fluid node is defined in Function 12, the fluid is advanced from leading to following nodes in the series until the series is completed (i.e., when the following node in the flow series is not defined in Function 12). This allows one to determine a heat balance for a flow section where the fluid is considered to advance from inlet to exit of the section in one time step regardless of the number of nodes representing the flow section. In the program this is accomplished by first treating the following nodes in Function 12 as ordinary nodes. Once the general solution has been completed for all nodes in the network the program resolves the general solution equation

for the temperatures of the following nodes in a stepwise (rather than a timewise) solution. The program allows one to represent a portion of the node mass in this function as non-flowing.

The temperature of a node defined as a following node in Function 12 is determined as follows.



$$T_{\theta+\Delta\theta, i} = \frac{\Delta\theta}{C_i} \left(\sum_{j=1}^n \frac{T_{\theta+\Delta\theta, j}}{R_{i,j}} + Q_{\theta, i} - T_{\theta+\Delta\theta, i \text{ MIX}} \sum_{j=1}^n \frac{1}{R_{i,j}} \right) + T_{\theta+\Delta\theta, i \text{ MIX}} \quad (\text{Eq 4.6})$$

where

$$T_{\theta+\Delta\theta, i \text{ MIX}} = \frac{T_{\theta+\Delta\theta, i-1} (WC_P)_{\theta, i} \Delta\theta + T_{\theta, i} C_{S_i}}{C_{S_i} + (WC_P)_{\theta, i} \Delta\theta} \quad (\text{Eq 4.7})$$

and

$$C_i = C_{S_i} + (WC_P)_{\theta, i} \Delta\theta \quad (\text{Eq 4.8})$$

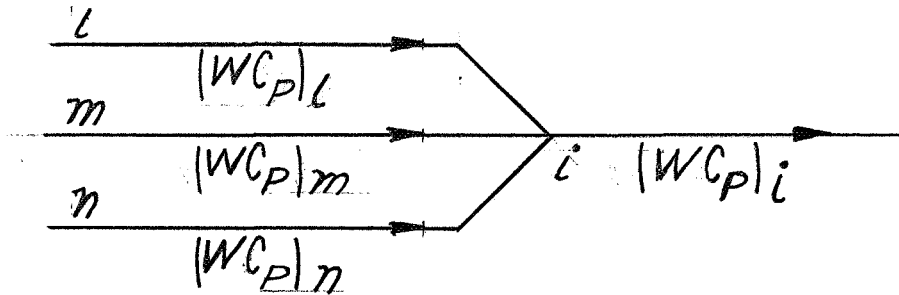
As can be seen, the previous temperature ($T_{\theta+\Delta\theta, i \text{ MIX}}$) used in this solution represents the flowing portion of the leading node at the same time as well as the non-flowing capacitance of the node at the previous time. This, in effect, advances the fluid through an entire Function 12 flow series stepwise rather than timewise.

4.1.2.4 Junction of Flow Passages

The program provides for the junction of two or more flow passages in Function 11. The solution for the temperature of the following node in Function 11 is as follows.

$$T_{\theta+\Delta\theta,i} = \frac{\Delta\theta}{C_i} \left(\sum_{j=1}^n \frac{T_{\theta,j}}{R_{i,j}} + Q_{\theta,i} - T_{\theta,h} \sum_{j=1}^n \frac{1}{R_{i,j}} \right) + T_{\theta,h} \quad (\text{Eq 4.9})$$

where



$$T_{\theta,h} = \frac{T_{\theta,l}|WC_P|_{\theta,l} + T_{\theta,m}|WC_P|_{\theta,m} + \dots + T_{\theta,n}|WC_P|_{\theta,n}}{|WC_P|_{\theta,l} + |WC_P|_{\theta,m} + \dots + |WC_P|_{\theta,n}} \quad (\text{Eq 4.10})$$

4.1.2.5 Summary of the Nodes Described in Section 4.1.2

The types of flowing fluid nodes available in the program and their use in describing flow passages are summarized in the Table below.

Section No.	Type Node	Capacitance	$T_{\theta,i}$ Replaced by	Function No.	Used to Describe	Satisfies the Following Criteria
4.1.2.1	1 Time Step Delay	$C_{\theta+\Delta\theta,i} = \frac{C_{\theta+\Delta\theta,i}}{ WC_P _{\theta,i} \cdot \Delta\theta}$	$T_{\theta,i-1}$	10	Flow passage for steady state conditions or for transient conditions where the fluid volume of the node is nearly equal to the flow rate across the node control volume	$ C_V _i \sim WC_P _{\theta,i} \cdot \Delta\theta$ and steady state problems
4.1.2.2	Specified Time Delay	$C_{\theta+\Delta\theta,i} = C_i$ given in gap. data block	$\{T_{\theta,i} C_i - WC_P _{\theta,i} \Delta\theta\} + T_{\theta,i-1}$		Flow passage for transient conditions where the fluid volume of the node is greater than the fluid flow rate across the node control volume	$ C_V _i = WC_P _{\theta,i} \cdot \Delta\theta$
4.1.2.3	No Time Delay	$C_{\theta+\Delta\theta,i} = C_S + WC_P _{i,\theta} \Delta\theta$	$\{T_{\theta,i} C_i - WC_P _{\theta,i} \Delta\theta\} / C_i$	12	Flow passage for transient conditions where the fluid volume of the node is considerably less than the fluid flow rate across the node control volume	$ C_V _i = WC_P _{\theta,i} \cdot \Delta\theta$
4.1.2.4	Junction of Flow Passages $\ell \neq m$ i - given node	$C_i = \{ WC_P _{\theta,\ell} + WC_P _{\theta,m} \} \Delta\theta$	$\{T_{\theta,\ell} WC_P _{\theta,\ell} + T_{\theta,m} WC_P _{\theta,m}\} / WC_P _i$	11	The junction of two or more flow passages for steady state or transient flow conditions	Downstream side of the junction of two or more flow streams
i-1	node upstream of the given node					
i+1	node downstream of the given node					
j	node connected by a heat transfer path to the given junction					
ℓ	one of the branches upstream of the given junction					
m	one of the branches upstream of the given junction					
θ	time θ					
$\Delta\theta$	time step $\Delta\theta$					

4.2 Zero Capacitance Nodes

Zero capacitance nodes are nodes which represent no mass and consequently have no thermal capacitance. This type of node is used to represent a point or a surface in a thermal network. They can also be used to represent nodes which have only negligible mass associated with them, so that the resistance-capacitance product for such nodes does not approach zero.

The solution equation for zero capacitance nodes is as follows.

$$T_{\theta+\Delta\theta,i} = \frac{\sum_{j=1}^n \frac{T_{\theta,j}}{R_{i,j}} + Q_i}{\sum_{j=1}^n \frac{1}{R_{i,j}}} \quad (\text{Eq 4-11})$$

The resistance-capacitance product is not determined for zero capacitance nodes.

4.3 Negative Capacitance Nodes

The temperature of a negative capacitance node is held constant during a given time step. Therefore, these nodes can be used to represent heat sources or sinks and to create various kinds of fictitious nodes to perform specific operations in the thermal network.

Some examples of the latter are:

- (1) Power Nodes
- (2) Boundary Nodes
- (3) Cathode Follower Nodes (Function 1)

No heat balance is made for the negative capacitance nodes and, therefore, the temperatures of negative capacitance nodes are independent of the heat transferred to or from these nodes.

4.3.1 Power Nodes

The TAP format allows one to create fictitious power nodes, with negative capacitance, to drive heat into real nodes. In the case of power nodes the value of the temperature of the power node is really the heat rate into the real node to which it is connected times the value of the power resistor.

$$Q_{i,\theta} = \frac{|\tau_{j,\theta} - \tau_{i,\theta}|}{R_{ij}} \quad (\text{Eq 4.12})$$

where : $\tau_{j,\theta} = Q_{i,\theta} |R_{ij}|$

$$R_{ij} \rightarrow \infty$$

Substituting into Equation 4.12 yields

$$Q_{i,\theta} = \frac{Q_{i,\theta} |R_{ij}| - \tau_{i,\theta}}{R_{ij}} = \frac{Q_{i,\theta} |R_{ij}|}{R_{ij}} = Q_{i,\theta}$$

The power resistor is assigned an arbitrarily high value (i.e., 10^{10}) to insure that the temperature of the real node is negligible compared with that of the power node.

Any number of power nodes can be connected to a given real node to describe any number of different power sources in any given node.

4.3.2 Boundary Nodes

Boundary nodes can be used to describe the boundaries of the problem. The temperature of the boundary nodes are controlled as constants, functions of time, or functions of any of the primary program parameters. By using boundary nodes, one can in many cases reduce the size of the problem to be solved without loss of accuracy.

4.3.3 Cathode Follower Nodes (With no time delay)(Function I)

The use of the cathode follower function I nodes allow one to simulate a symmetrical section without providing all of the thermal network which would be necessary if these nodes were not available in the program.

Figure 1 below represents a reactor fuel channel cross section of minimum symmetry. If one wished to set up a thermal network for it using only one rod to represent each ring of rods. The remaining rods in the ring of symmetry section could be connected as follower nodes in Function 1. If that were done, the follower nodes could simulate the actual nodes without the necessity of describing an internal thermal network for them.

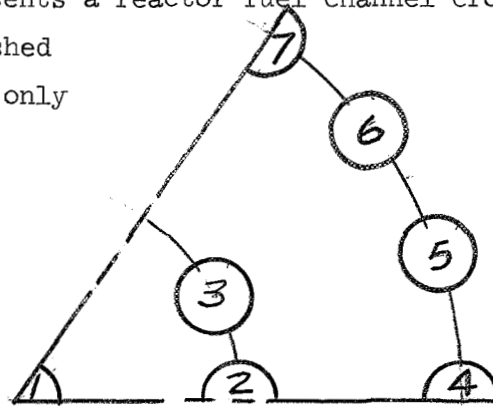


Figure 1

to set up a thermal network for it using only one rod to represent each ring of rods. The remaining rods in the ring of symmetry section could be connected as follower nodes in Function 1. If that were done, the follower nodes could simulate the actual nodes without the necessity of describing an internal thermal network for them.

For certain kinds of heat transfer problems, therefore, the cathode follower nodes, can be used to simplify the thermal network without significant loss of accuracy.

5.0 THERMAL RESISTOR TYPES AND THEIR USE _xR

A number of different kinds of thermal resistors are available in the TAP program to account for the various heat flow phenomena. In addition, fictitious resistors can be created to perform various functions in the program. By definition, a thermal resistor describes the resistance to the flow of heat by any one of the three modes of heat transfer between any two node centers. The types of thermal resistors available in the TAP program are described below.

5.1 Conduction Resistors

The term conduction resistor defines the resistance to heat flow between any two given nodes by conduction.

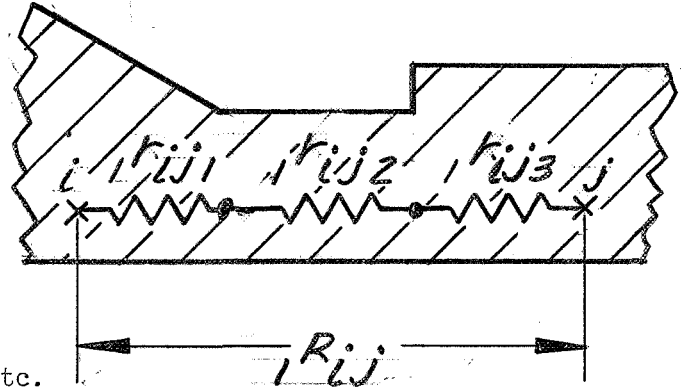
The equation for conduction resistance is as follows:

$$1R_{ij} = \frac{L_{ij}}{k_{ij} A_{ij}} \quad (\text{Eq 5-1})$$

In the program the value of $1R_{ij}$ is given as data input in the resistor data block. The above resistor $1R_{ij}$ can be the sum of any number

of resistors connected in series if the heat flow path cross section between the connected nodes is irregular.

The variation in the value of conduction resistors can be considered in the program as a function of time or any of the primary program parameters (Resistance, Temperature, Capacitance, Heat Rate or Average Temperature), etc.



5.2 Convection Resistors _{2R}

Convection resistors can be considered by the program as free or forced convection resistors for laminar or turbulent flow. Their values are either specified in the resistor data block or in the function data.

5.2.1 Simple Convection Resistors

As used here, the term simple convection resistor merely implies that the value of the convection resistor (regardless of type) is known and can be specified in the data input. In this case the value of the convection resistor is given to the program in the resistor data block as follows:

$$2R_{ij} = \frac{1}{hA} \quad (\text{Eq 5.2})$$

5.2.2 Forced Convection Resistors _{2aR}

The TAP program provides an option in function 15 to calculate forced convection resistors for turbulent flow where the Prandtl number of the fluid approaches 1. The equation solved for forced convection resistance in turbulent flow is as follows:

$$2aR_{ij} = \frac{\left(\frac{C_p \mu}{k}\right)_b^X \left(\frac{\mu_w}{\mu_b}\right)^Z \left(\frac{DG}{\mu_b}\right)^Y}{CAG C_{pb}} \quad (\text{Eq 5.3})$$

where k_b , C_{pb} and $\mu_b = f(T_b)$

$\mu_w = f(T_w)$

$G = f(\theta)$

and

CA is given in the data as a constant. X and Y are exponents on the Prandtl and Reynolds numbers respectively and are given as data input. Z is the exponent on the viscosity ratio and is given as data input.

For the normal Colburn relation the following input for turbulent flow can be used:

<u>Parameter</u>	<u>Value</u>
C	0.023
X	0.667
Y	0.2
Z	0.14

Three tables are required to describe the dependency of the thermal properties of each fluid upon temperature and one table is required to describe the variation in flow rate with time.

This equation was derived from Equation 9-10c, Reference 2, which is as follows:

$$\frac{h_L}{C_p G} \left(\frac{C_p \mu}{K} \right)^{\frac{2}{3}} \left(\frac{\mu_W}{\mu_b} \right)^{0.14} = \frac{0.023}{(DG/\mu_b)^{0.2}} \quad \begin{array}{l} \text{(Eq 9-10c} \\ \text{Ref 2)} \end{array}$$

5.2.3 Free Convection Resistors _{2b}^R

The TAP program provides an option in function 4 to calculate free convection resistors for either laminar or turbulent flow. The equation solved for free convection resistance is as follows:

$$2b^{R}_{ij} = \frac{1}{GKA_{ij}(T_i - T_j)^{M_{ij}}} \quad \text{(Eq 5-4)}$$

where

$$K = f_1 \left(\frac{(T_i + T_j)}{2} \right)$$

function of average temperature
as given in Table 1

$$G = f_2(\theta)$$

function of time as given in Table 2

This equation is derived from Equations 7-4a and 7-5b Ref. 2, which are as follows:

$$\frac{h_{2b} L}{k_f} = C \left[\frac{L^3 \rho_f^2 g \beta_f \Delta t}{\mu_f^2} \left(\frac{C_p \mu}{k} \right)_f \right]^{M_{ij}} \quad (\text{Eq 7.4a \& 7.4b, Ref 2})$$

M_{ij} and C can be taken as follows:

<u>Flow Regime</u>	<u>C</u>	<u>M</u>
Turbulent Flow	0.13	0.3333
Laminar Flow	0.59	0.25

In Table 1 the values in the above equation are evaluated at some time θ as a function of average temperature. The value of K at the given average temperature is then multiplied by the value at the given time in Table 2. Thus Table 2 effectively is a multiplier raising or lowering the value of K to account for variations in the parameters as a function of time.

5.3 Radiation Resistors ₃^R

The TAP program is provided with an option in function 2 to calculate radiation resistors. The equation used for this purpose is as follows:

$$3_{ij}^R = \frac{1}{K_{ij} [(T_i + C)^2 + (T_j + C)^2] [T_i + C + T_j + C]} \quad (\text{Eq 5.5})$$

where

$$K_{ij} = \sigma F A_{ij}$$

C = conversion constant for changing the temperature values to the corresponding absolute temperature scale (built into the program)

$$C = 459.69 \text{ } ^\circ\text{R to } ^\circ\text{F}$$

$$C = 273.16 \text{ } ^\circ\text{K to } ^\circ\text{C}$$

The values of T_i and T_j are

$$T_i = T_{\theta,i}$$

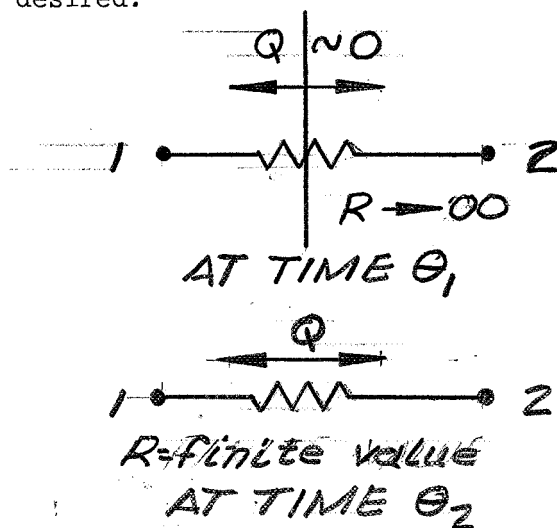
$$T_j = T_{\theta,j}$$

in time step $\theta + \Delta\theta$

5.4 Power Resistors (as well as other fictitious resistors)

Power resistors are fictitious resistors which are created for the sole purpose of driving heat from a fictitious power node into the center of a real node. They are given in the resistor data block. They are assigned an arbitrarily high value of resistance to insure that the temperature of the node receiving the heat is negligible compared with the heat rate time the value of the power resistor.

Other fictitious resistors can be used, for example, to place an adiabatic wall between two given nodes for some period of time. If the resistor is given as a function of time or one of the primary program parameters, it can be raised and lowered as desired.



5.5 Rules Governing the Use of Thermal Resistors

Following are a number of rules which must be followed in connecting the nodes in the thermal network with the various kinds of thermal resistors.

- (1) All resistors must be identified in the resistor data block as follows:

- (a) An unique resistor identification number must be assigned to each separate heat flow path.
- (b) In addition to the resistor ID number, the nodes to which the resistor is connected must be identified.
- (c) A value other than zero must be assigned to each thermal resistor even if that value is not used by the program.

(2) The resistor identification numbers are completely independent of the node identification numbers.

(3) Any number of thermal resistors of any type can be connected to a given node.

(4) If the resistor is a radiation resistor, function 2 is used to specify its value.

(5) If the resistor is a free convection resistor, function 4 is used to specify its value and if it is a forced convection resistor function 15 is used to specify its value.

(6) If the resistor is varied with time or any of the primary program parameters, function 7 is used to specify the variation.

(7) Strictly speaking, the same flow path and mode of heat transfer should not be used by more than one thermal resistor.

(8) Each node in the thermal network must be connected to at least one thermal resistor.

6.0 SOLUTION EQUATIONS

This section deals with the general solution equations used in the Thermal Analyzer Program to determine the temperatures of the various kinds of nodes in the thermal network as well as, provides the equations used by some of the functions to perform special operations on the thermal network.

6.1 The Solution Equation for the Temperature of a Positive Capacitance Node

The general solution equation to determine the temperature of a positive capacitance node is as follows:

$$T_{\theta} + \Delta\theta, i = \frac{\Delta\theta}{C_i} \left(\sum_{j=1}^n \frac{T_{\theta,j}}{R_{ij}} + Q_{\theta,i} - T_{\theta,i} \sum_{j=1}^n \frac{1}{R_{ij}} \right) + T_{\theta,i} \quad (\text{Eq 6-1})$$

6.1.1 The Solution Equation for the Temperature of a Positive Capacitance Node in a Flow Passage Where $Cv_i \approx (WCp)_i \Delta\theta$ or Where a Steady State Solution is Required (i.e., Type 1 Function 10)

If the node is a Type 1 Function 10 flowing fluid node, Equation 6-1 is modified to give the following solution equation.

$$T_{\theta} + \Delta\theta, i = \frac{1}{(WCp)_{\theta,i}} \left(\sum_{j=1}^n \frac{T_{\theta,j}}{R_{ij}} + Q_{\theta,i} - T_{\theta,i-1} \sum_{j=1}^n \frac{1}{R_{ij}} \right) + T_{\theta,i-1} \quad (\text{Eq 6-2})$$

6.1.2 The Solution Equation for the Temperature of a Positive Capacitance Node in a Flow Passage where $Cv_i \geq (WCp)_i \Delta\theta$ (i.e., Type 2 Function 10)

If the node is a Type 2 Function 10 flowing fluid node, equation 6-1 is modified to give the following solution equation.

$$T_{\theta} + \Delta\theta, i = \frac{\Delta\theta}{C_i} \left[\sum_{j=1}^n \frac{T_{\theta,j}}{R_{ij}} + Q_{\theta,i} - \left[\frac{T_{\theta,i}(C_i - (WCp)_{\theta,i} \Delta\theta) + T_{\theta,i-1}(WCp)_{\theta,i} \Delta\theta}{C_i} \sum_{j=1}^n \frac{1}{R_{ij}} \right] + \left[\frac{T_{\theta,i}(C_i - (WCp)_{\theta,i} \Delta\theta) + T_{\theta,i-1}(WCp)_{\theta,i} \Delta\theta}{C_i} \right] \right]$$

* See Section 7.16 for limitations on the use of this type of node.

6.1.3 The Solution Equation for the Temperature of a Positive Capacitance Node in a Flow Passage Where $Cv_i \ll (WC_p)_i \Delta\theta$ (i.e., Function 12) *

If the node is defined as a following node in Function 12, Equation 6-1 is modified to give the following solution equation.

$$T_{\theta+\Delta\theta,i} = \frac{\Delta\theta}{C_s + (WC_p)_{\theta,i} \Delta\theta} \left(\sum_{j=1}^n \frac{T_{\theta+\Delta\theta,j}}{R_{i,j}} + Q_{\theta+\Delta\theta,i} \right. \\ \left. - \left[\frac{T_{\theta+\Delta\theta,i-1} (WC_p)_{\theta,i} \Delta\theta + T_{\theta,i} C_s}{C_s + (WC_p)_{\theta,i} \Delta\theta} \right] \sum_{j=1}^n \frac{1}{R_{i,j}} \right) \\ + \left[\frac{T_{\theta+\Delta\theta,i-1} (WC_p)_{\theta,i} \Delta\theta + T_{\theta,i} C_s}{C_s + (WC_p)_{\theta,i} \Delta\theta} \right] \quad (\text{Eq 6-4})$$

6.1.4 The Solution Equation for the Temperature of a Positive Capacitance Node Which Serves as the Junction of Two Flow Passages (i.e., Function 11) *

If the nodes is defined as a following node in Function 11, Equation 6-1 is modified to give the following solution equation.

$$T_{\theta+\Delta\theta,i} = \frac{1}{(WC_p)_{\theta,i}} \left(\sum_{j=1}^n \frac{T_{\theta,j}}{R_{i,j}} + Q_{\theta,i} \right. \\ \left. - \left[\frac{T_{\theta,l} (WC_p)_{\theta,l} + T_{\theta,m} (WC_p)_{\theta,m} + \dots + T_{\theta,n} (WC_p)_{\theta,n}}{(WC_p)_{\theta,l} + (WC_p)_{\theta,m} + \dots + (WC_p)_{\theta,n}} \right] \sum_{y=1}^n \frac{1}{R_{i,y}} \right) \\ + \left[\frac{T_{\theta,l} (WC_p)_{\theta,l} + T_{\theta,m} (WC_p)_{\theta,m} + \dots + (WC_p)_{\theta,n}}{(WC_p)_{\theta,l} + (WC_p)_{\theta,m} + \dots + (WC_p)_{\theta,n}} \right] \quad (\text{Eq 6-5})$$

$$\text{WHERE } (WC_p)_{\theta,i} = (WC_p)_{\theta,l} + (WC_p)_{\theta,m} + \dots + (WC_p)_{\theta,n}$$

* See Section 7.16 for limitations on the use of this type of node.

6.2 The Solution Equation for the Temperature of a Zero Capacitance Node

The general solution equation to determine the temperature of a zero capacitance node is as follows:

$$T_{\theta+\Delta\theta,i} = \frac{\sum_{j=1}^n \frac{T_{\theta,j}}{R_{ij}} + Q_i}{\sum_{j=1}^n \frac{1}{R_{ij}}} \quad (\text{Eq 6-6})$$

6.3 The Solution Equation for the Temperature of a Negative Capacitance Node

a. For a negative capacitance node which is not the following node in a cathode follower series

$$T_{\theta+\Delta\theta,i} = T_{\theta,i} \quad (\text{Eq 6-7})$$

If T_i is given as a dependent variable in Function 7, then $T_{\theta,i}$ would be the value specified in the tables for T_i rather than the value of T_i from the previous time step.

b. If the negative capacitance node is given as a following node in the cathode follower, Function 1 where the temperature of node i follows the temperature of node j, then,

$$T_{\theta+\Delta\theta,i} = T_{\theta+\Delta\theta,j} \quad (\text{Eq 6-8})$$

6.4 The Calculated Time Step $\Delta\theta$

Used in this sense the term time step means that time interval which is used to advance the time in the transient solution of the problem.

The time step must be related to the physical problem, such that, $\Delta\theta$ (the time step) does not exceed the minimum thermal resistance thermal capacitance product (RC) summed around each positive capacitance node. If the time step taken $\Delta\theta$ does exceed the $(RC)_{\min}$ for the network, this will result in unstable solutions of Equation 6-1. In addition, if the problem includes Type 2 Function 10 nodes, the time step taken should not be great enough so that

$$\left[\frac{C_V}{(WC_p)} \right]_{\min} < \Delta\theta$$

if the $\Delta\theta$ used were greater than $(Cv/WCp)_{\min}$, it would mean that a node contained more fluid in a given time step than it is capable of holding and would result in a meaningless temperature being calculated for that node.

The equations used to determine the calculated time step are as follows:

First the RC product is determined for each positive capacitance node

$$(RC)_i = \frac{C_i}{\sum_{j=1}^n \frac{1}{R_{ij}}} \quad (\text{Eq 6-9})$$

Then, the value of the time step is set equal to the smallest of the RC products times a multiplying factor which is assumed to be 1 if not otherwise specified

$$\Delta\theta_{\theta} = (RC)_{\min} \text{ M.F.} \quad (\text{Eq 6-10})$$

If there are any Type 2 nodes listed as following nodes in Function 10, the $\Delta\theta$ selected above is compared with $(Cv/WCp)_{\min,\theta}$ from that function

$$\text{If } \left(\frac{Cv}{WCp} \right)_{\min,\theta} < \Delta\theta$$

then $\Delta\theta$ is reduced such that

$$\Delta\theta = \left(\frac{Cv}{WCp} \right)_{\min,\theta}$$

6.5 Reactor Heating Equations

The TAP program can consider reactor heating within the limitations specified below.

6.5.1 Reactivity Calculations of k

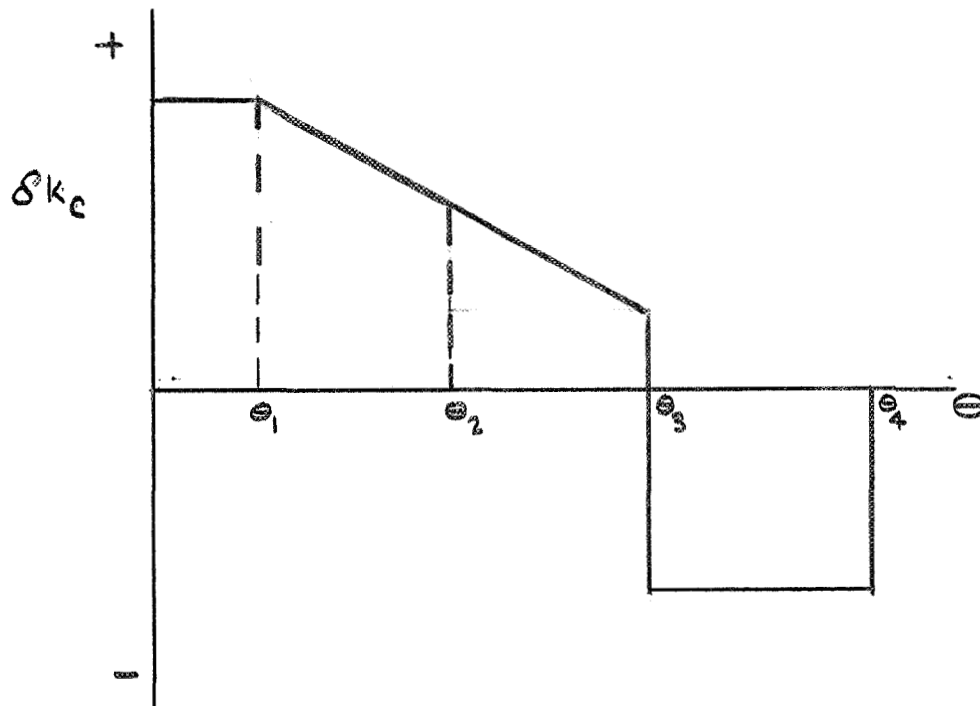
The reactivity can be varied as a function of the temperature of any three specified nodes, time and reflector or control rod position. An optional dead-band control is also provided to change relector or control rod position as the monitored temperature meets specified conditions as to magnitude and time outside the control limits.

The equation used to determine reactivity during a given time step is as follows:

$$\rho_{\theta} = \Delta_1 (T_{\theta,1} - C_1) + \Delta_2 (T_{\theta,2} - C_2) + \Delta_3 (T_{\theta,3} - C_3) + \delta k_{c,\theta} \quad (\text{Eq 6-11})$$

The parameter δk_c specifies the effects of control rod or reflector position on absolute reactivity. The value of δk_c is either specified as a function of time or can be determined by the dead-band control.

6.5.1.1 $\delta k_c = f(\theta)$ If δk_c is given in Function 5 as a variable, changes in reactivity are allowed as a function of time.



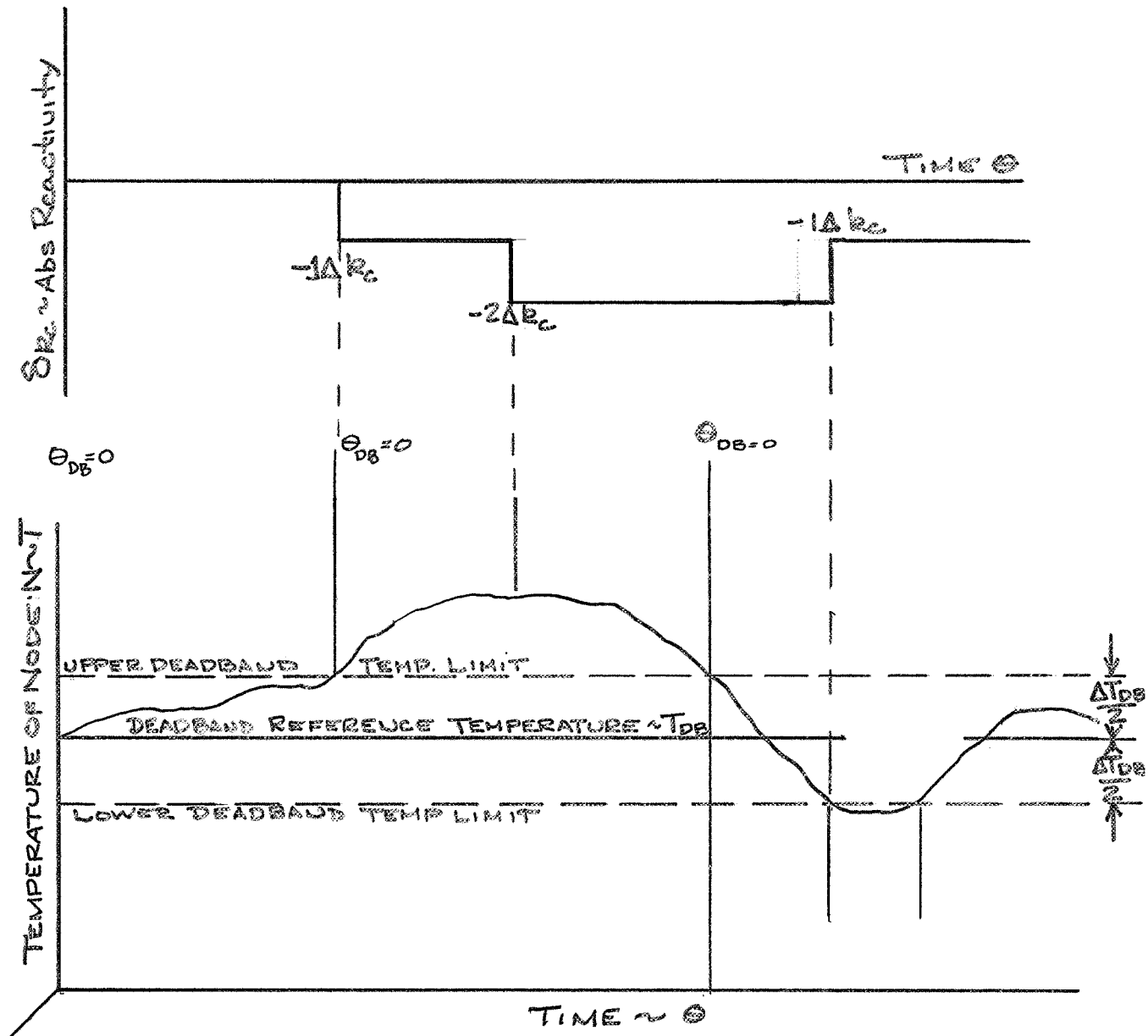
6.5.1.2 Deadband Control of k_c

If deadband control of the control rods or reflector position is specified in Function 13, it is accomplished in the following manner.

The deadband control instructions include

1. Identification of the significant node n
2. Specification of the deadband temperature level
3. Specification of the deadband temperature limit
4. Specification of the out of range time limit
5. Specification of the change in reactivity (expressed in

absolute units) caused by the movement of one control rod or reflector position



As the temperature of the monitored node (N) passes through the upper or lower deadband limits ($T_{DB} \pm \frac{\Delta T_{DB}}{2}$), the value of δk_c is increased or decreased one Δk_c unit and the deadband clock is started. If the temperature of the monitored node (N) then remains outside the deadband temperature limits for θ_{DB} time units on the deadband clock, δk_c is again changed by one Δk_c unit and the deadband clock is reset to zero time. This procedure continues until the temperature of the monitored node remains within the deadband control limits.

6.5.2 Reactor Heating $Q_{REACT,i}$

The reactor heating equations used in the program treat the special case of one average group of delay neutrons and where $\beta - \delta k \geq 0$. In addition, the heat contribution due to beta and gamma heating is considered to always represent no less than 6% of the total reactor heat generation.

The reactor heating equations in the program are as follows:

Neutron Heating

$$Q_{n,\theta+\Delta\theta,i} = P.F. Q_0 \left[\underbrace{\frac{\beta}{\beta - \delta_{k,\theta}} e^{\frac{\lambda \delta_{k,\theta}}{\beta - \delta_{k,\theta}} \left(\theta + \frac{\Delta\theta}{2} \right)}}_{\beta + \gamma \text{ Heating}} - \frac{\delta_{k,\theta}}{\beta - \delta_{k,\theta}} e^{-\left(\frac{\beta - \delta_{k,\theta}}{\ell} \right) \left(\theta + \frac{\Delta\theta}{2} \right)} \right] \quad (\text{Eq 6-12})$$

$$Q_{\beta+\gamma,\theta+\Delta\theta,i} = 6.22 \times 10^{-2} \left(\theta + \frac{\Delta\theta}{2} \right)^{-0.2} Q_0 P.F. \quad (\text{Eq 6-13})$$

If $0.06 Q_{n,\theta+\Delta\theta,i} < Q_{\beta+\gamma,\theta+\Delta\theta,i}$
Then

$$Q_{react\theta+\Delta\theta,i} = 0.94 Q_{n,\theta+\Delta\theta,i} + Q_{\beta+\gamma,\theta+\Delta\theta,i} \quad (\text{Eq 6-14})$$

If $0.06 Q_{n,\theta+\Delta\theta,i} > Q_{\beta+\gamma,\theta+\Delta\theta,i}$

Then

$$Q_{react\theta+\Delta\theta,i} = Q_{n,\theta+\Delta\theta,i} \quad (\text{Eq 6-15})$$

6.6 Aerodynamic Heating Equations

If function 6 is used, the program computes the heat rate into any specified node due to an aerodynamic boundary layer.

$$Q_{i,\theta} = h_{\theta,i} K_{\theta,i} (T_{R\theta} - T_{\theta,i} - 459.6) \quad (\text{Eq 6-16})$$

The value of $h_{\theta,i}$ in equation 6-16 is determined by whichever of the following methods is specified.

6.6.1 The Ramo-Wooldridge Equations for Aerodynamic Heating

$$h_i = \beta \left[\left(\frac{N_{Re}}{X M_\infty} \right)^{M_\infty} \right]^a M_\infty^b \frac{1}{T_R - T_\infty} \quad (\text{Eq 6-17})$$

6.6.2 The Eckert Equation for Aerodynamic Heating

$$h_i = \beta \left[\frac{S(N_{Re}/X M_\infty)^{M_\infty}}{(T_L'/T_L)^{1.69}} \right] M N_{PR}^{\frac{1}{3}} K \quad (\text{Eq 6-18})$$

β is evaluated as follows if $\beta \neq 1$

$$\beta = K_w \alpha + 1 \quad \text{where } \alpha > 0 \quad (\text{Eq 6-19a})$$

$$\beta = K \alpha + 1 \quad \text{where } \alpha < 0 \quad (\text{Eq 6-19b})$$

Then

K_w is placed in the space reserved for X_1 in Table 12 and

K is placed in the space reserved for X_2 in Table 12.

$$\alpha = -(\alpha_\lambda - \alpha_L) \quad \text{for the top surface} \quad (\text{Eq 6-20a})$$

$$\alpha = (\alpha_\lambda - \alpha_L) \quad \text{for the bottom surface} \quad (\text{Eq 6-20b})$$

α_λ is given as a function of time in Table 11 and α_L is given as input data.

The following dependencies are described in the tables given

$H = f(\theta)$ in Table 3 (expressed in feet)

$M_\infty = f(\theta)$ in Table 4

$\log_{10} N_{re}/X M_\infty = f(H)$ in Table 5

$T_\infty = f(H)$ in Table 6

$\log_{10} N_{pr}^{1/3} K = f(T)$ in Table 7

$S = f(M_\infty)$ in Table 8

$T_L/T_\infty = f(M_\infty)$ in Table 9

$M_L/M_\infty = f(M_\infty)$ in Table 10

$$T_L^1/T_L = 0.5 \left(1.0 + \frac{-T_i + 459.6}{T_L} + 0.22N \right) \quad (\text{Eq 6-21})$$

$$T_L = \frac{T_L}{T_\infty} T_\infty$$

$$N = 0.71 \frac{Z-1}{2} M_L^2 \quad (\text{Eq 6-22})$$

$$M_L = \frac{M_L}{M_\infty} M_\infty$$

$$T_{i,\theta} = T_L (1.0 + N) \quad (\text{Eq 6-23})$$

A, B, and e are input constants

6.7 Thermal Resistor Solution Equations

The equations used to determine the values of the thermal resistors for the various modes of heat transfer are presented in Section 5 of this report.

7.0 Functions (For Function Data Input See Section 8)

The Thermal Analyzer Program is provided with a number of mandatory and optional functions. These functions increase the flexibility of the program, specify the type of output desired, and specify the print interval etc. The functions available and their use are explained below.

7.1 Function 1 Cathode Follower with no Time Delay

This function sets the temperature of the following node equal to the temperature of the leading node with no time delay or $T_{0+\Delta\theta,i}$

is set equal to $T_{0+\Delta\theta,j}$

where node i is specified as the following node and node j is specified as the leading node in function 1.

7.2 Function 2 Radiation Resistors

This function converts a conduction resistor into a radiation resistor if the resistor number is specified in function 2. See equation 5.5 in Section 5.

7.3 Function 3 Phase Transition

This function holds the temperature of a specified node constant as it passes through a change of phase. The total heat required to complete the phase transition and the temperature at which it takes place are given in the function data.

7.4 Function 4 Free Convection Resistors

This function converts a conduction resistor into a free convection resistor if the resistor number is specified in function 4. See equation 5-4 in Section 5.

7.5 Function 5 Reactor Heating

This function calculates the heat generation rate Q_i in specified reactor fuel nodes. See Section 6.5 for a description of this function.

Function 13 must also be used if function 5 is used.

7.6 Function 6 Aerodynamic Heating

This function calculates the aerodynamic heat rates Q_1 for specified node. See Section 6.6 for a description of this function.

7.7 Function 7 Arbitrary Functions

This function allows one to vary any of the primary program parameters listed below with time or any other primary program parameter. The primary program parameters are

Primary Program Parameter	Class of Parameter
Value of any Resistor	1
Temperature of any Node	2
Capacitance of any Node	3
Heat Rate for any Node	4
Fluid Capacitance Flow Rate	5
Average Temperature of any 2 Nodes	6
Temperature Difference Between any 2 Nodes	7

The dependance is specified in function 7 and the variation given in tabular form in the table specified in function 7. The program performs linear interpolations between the data points in the tables.

7.8 Function 8 Output Specifications

This function specifies the quantity and type of output which is desired. A five column wide field is printed out. Pictorial representation of the data is possible by requesting the printing of fictitious data at points which would separate the real output data into a pictorial array.

7.9 Function 9 Problem Constants

The purpose of function 9 is to specify certain problem constants such as initial time, time step, print interval, cut off time etc. The nature of the problem constants and their applications are given in Section 8 of this report.

7.10 Function 10 Flowing Fluid Cathode Follower Nodes

The purpose of function 10 is to identify those nodes which are flowing fluid cathode follower nodes of a given type. Two types of function 10 flowing fluid cathode follower nodes are specified in function 10.

They are

Type I which satisfy the condition $C_v/WC_p\Delta\theta \sim 1$

Type II which satisfy the condition $C_v/WC_p\Delta\theta > 1$

If a zero appears in field 4 (i.e. starting in Col. 23) the node is taken as a type I, and solution equation 6-2 applies. However, if a value greater than zero is given, then solution equation 6-3 applies.

In a steady-state analysis type I function 10 nodes should be used to describe the entire fluid flow field except at the junction of flow streams where a function 11 node would be used for either a steady-state or transient solution. For a transient solution the nodes representing flow streams should be selected on the following basis:

1. If the node fluid capacity exceeds the amount of fluid which would pass over the node control volume in a given time step a type II function 10 node should be set up. $C_v/WC_p\Delta\theta > 1$

2. If the node fluid capacity approximately equals the amount of fluid which would pass over the node control volume in a given time step a type I function 10 node should be used. $C_v/WC_p\Delta\theta \sim 1$

3. If the node fluid capacity is much less than the amount of fluid which would pass over the node control volume in a given time step then a function 12 node should be used. $C_v/WC_p\Delta\theta \ll 1$

There is no provision in function 10 to allow any portion of the mass of a type 1 node to remain stationary.

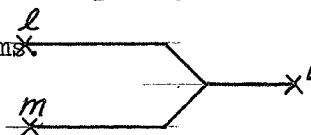
However, in the type II nodes the solid part of the node is allowed to remain stationary.

If the function 10 node is evacuated of fluid at the start of the problem time $(\theta)_f$ when the node cavity becomes filled with fluid should be specified and the node start capacitance should be given in the input as a negative value. When $\theta < \theta_f$ the node will be treated as a negative capacitance node. When $\theta \geq \theta_f$ the node will be connected into the cathode follower series with the leading node as specified and treated as a positive capacitance node with mass transfer across the node control volume. If no θ_f is specified the program will connect the node into the cathode follower series in the first iteration.

See Sections 4.1.2.1 and 4.1.2.2 for a description of function 10 nodes.

7.11 Function 11 Flow Junction Nodes

The purpose of function 11 is to specify the nodes which represent the junction of two or more flow streams.



In the figure above node i would be specified as a following node in function 11. For a function 11 node, solution equation 6-5 applies.

There is no provision in function 11 to allow any portion of the mass of a junction node to remain stationary. In other words all of the mass contained within the control volume of a function 11 junction node is pushed down-

stream over the node control volume after each time step.

See Section 4.1.2.4 for a description of function 11 nodes.

7.12 Function 12 Instantaneous Fluid Flow Cathode Follower Nodes

The purpose of function 12 is to identify those nodes in a fluid flow stream which satisfy the condition.

$$C_v/WC_p\Delta\theta \ll 1$$

For a function 12 node, solution equation 6-4 applies. This type of solution means that the temperatures for a given series of function 12 nodes is calculated stepwise rather than timewise as with the other types of nodes. In a given time step the solution advances through the series using the output of the previous step as the input to the next without having advanced the time index. In other words, the program will step through each series of function 12 nodes in each time step.

See Section 4.1.2.3 for a description of function 12 nodes.

7.13 Function 13 Reactivity Feedback and Deadband Control

The data provided in function 13 is always used in conjunction with function 5 (the reactor heating function) and provides the means for specifying the reactivity feedback data input and the information required by the deadband control device if it is used.

7.14 Function 14 Steady-state and Time Advancement Option

The purpose of function 14 is to determine the time when the thermal network approaches steady-state within a specified error criteria (Δ). If the time advancement option in function 14 is not used then the program will exit from the computer, specify that steady-state conditions have been reached and print out the steady-state temperatures for the nodes specified. If the time advancement option is used the problem will be advanced to the specified time and continue the calculations until either steady-state is reached again or the problem cut off

time is exceeded. More than one time advancement can be called and the program will continue the procedure until the problem has reached steady-state after the last time advancement or the problem cut off time is exceeded.

7.15 Forced Convection Resistors

The function converts a conduction resistor into a forced convection resistor if the resistor number is specified in function 15.

See equation 5.5 in Section 5.

7.16 Limitations on the Use of Fluid Flow Nodes

A function 10 Type I, function 11 or function 12 fluid flow node cannot be used under the following set of circumstances:

1. If time is determined from the (RC) min
2. That function 10 Type I, function 11 or function 12 node produces the (RC) min
3. The time step $\Delta\theta$ resulting from the (RC) min is less than one.

If these conditions are present the program will exit from the computer and print out an appropriate error message. The reason why this limitation is placed on these types of nodes is that under the conditions described about the time step $\Delta\theta$ would result from $\Delta\theta = \pi_i^n \Delta\theta_i$.

If (RC) min times the multiplying factor in function 9 results in a $\Delta\theta \leq 1$ then $\Delta\theta$ would be the product of a series of numbers less than one and would rapidly approach zero.

The problem can be corrected by setting the time step $\Delta\theta$ in the program $<(\text{RC}) \text{ min}$ (it would have to be less than (RC) min for the entire transient) or by changing the fluid network.

8.0 Data Input Format

Following is a description of the data input format for the present version of the Thermal Analyzer Program.

Title Card

On the first data card the word TITLE should be placed in columns 1 - 5. If no new start temperature and capacitor data block is to be generated from the last calculation from this run then column 6 should be left blank. If such output in the form of punched cards is desired a 1 should be placed in column 6. Columns 7 - 72 of the title card can be used to identify or describe the problem as desired.

The program contains five data blocks whose names and order of appearance in the data are specified below.

<u>Data Block No.</u>		<u>Description</u>
I		Resistance Specifications
II	} Combined	Initial Temperature Specifications (Given in Data Field R1)
III		Capacitance Specifications (Given in Data Field R2)
IV		Function Specifications
V		Tables

The order in which the data is placed in each data block is optional (with the exception of some of the function data noted below). However, the data blocks must appear in the order specified above.

The data fields used by the program are as follows:

<u>Field I1</u>	<u>Field I2</u>	<u>Field I3</u>	<u>Field R1</u>	<u>Field R2</u>
Cols. 1-5	Cols. 6-10	Cols. 11-15	Cols. 16-30	Cols. 31-45
Integers*	Integers*	Integers*	Real Numbers	Real Numbers

* The last digit of the integer must appear in the last column of the field

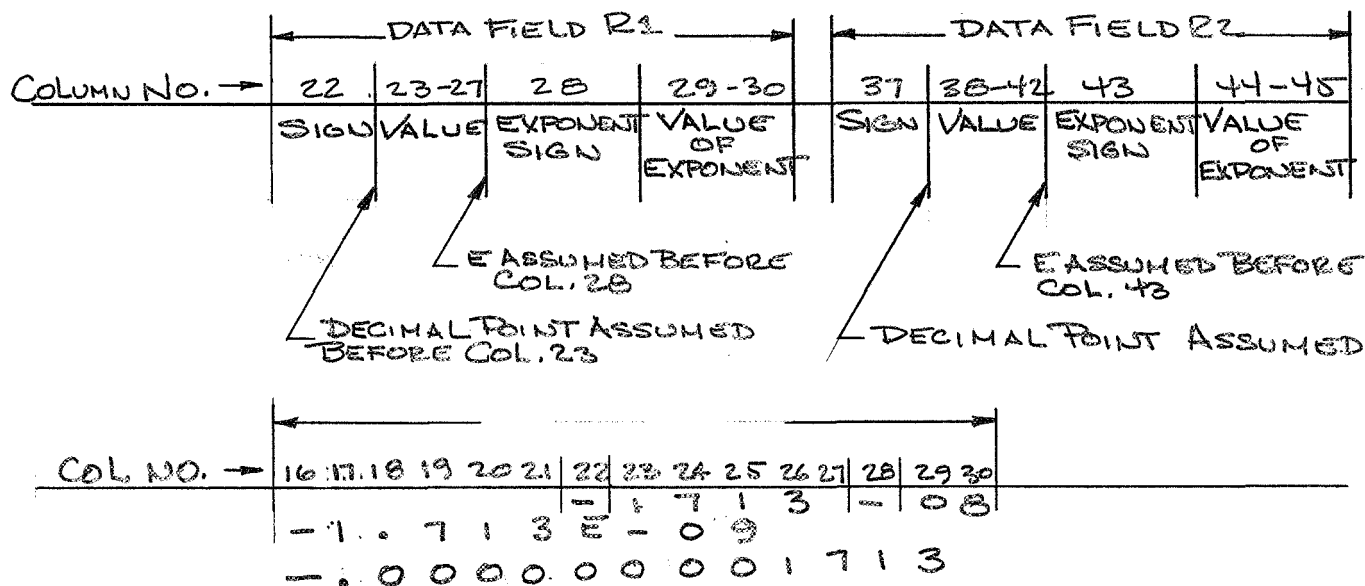
In fields R1 and R2 a floating point power of 10 format or a modified power of 10 format may be used.

If a floating point format or power of 10 format is used a decimal point must appear in the field.

If a modified power of 10 format is used a decimal point need not appear in the field because the decimal point is assumed to appear before the field starts.

If a modified power of 10 format is used the sign of the exponent appears in column 28 for field R1 and column 43 for field R2. The exponents appear in columns 29 and 30 for field R1 and columns 44 and 45 for field R2. The E is assumed to exist by the program and should not appear in the data.

The modified power of 10 format for data fields R1 and R2 for all data blocks is as follows:



The above three forms of the number -1.713×10^{-9} can all be input in fields R1 and R2. The first form is a modified version of the fortran power of 10 format allowing the user to drop off the decimal point and E since they are assumed by the program.

8.1 Resistance Specifications (Data Block I)

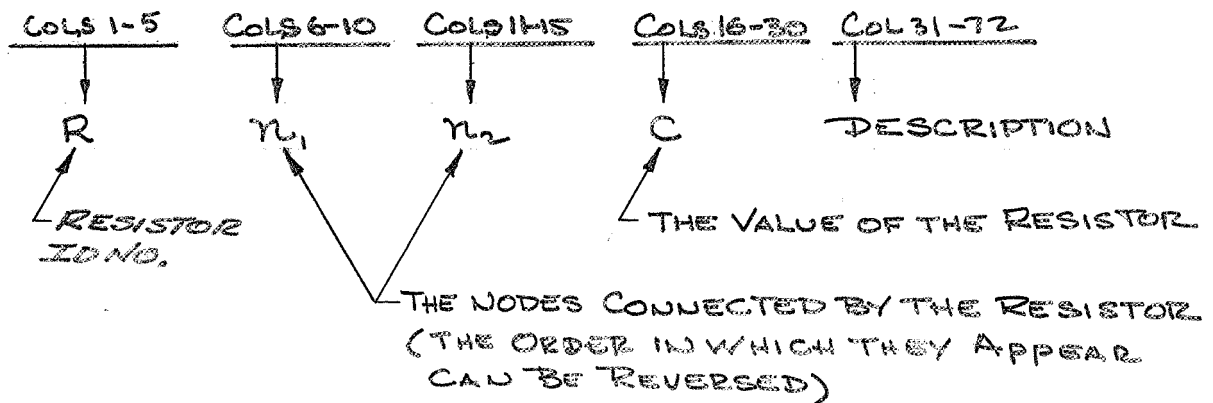
In the resistance specifications data block all thermal resistors, regardless of type, are given an unique identification number and the nodes to which they are connected are identified. In addition, a value of thermal resistance is assigned to each resistor regardless of type.

In the case of conduction and simple convections resistors, not specified in function 7, the value assigned is real, but for convection and radiation resistors or those varied in function 7 the value is fictitious and is only used to complete the data. In specifying function 15 forced convections resistors the wall nodes should be specified in data field I2 and the fluid nodes in data field I3. For all other types of resistors these two data fields are interchangeable.

The following rules apply to selecting resistors:

- (1) Any resistor number between 1 and the maximum allowed may be used, but a resistor number may appear only once in the resistor data block.
- (2) A given node may be connected to any number of resistors.
- (3) The resistor identification system is completely separate from the node numbering system.
- (4) The value of any resistor may be varied with time or any of the primary program parameters.

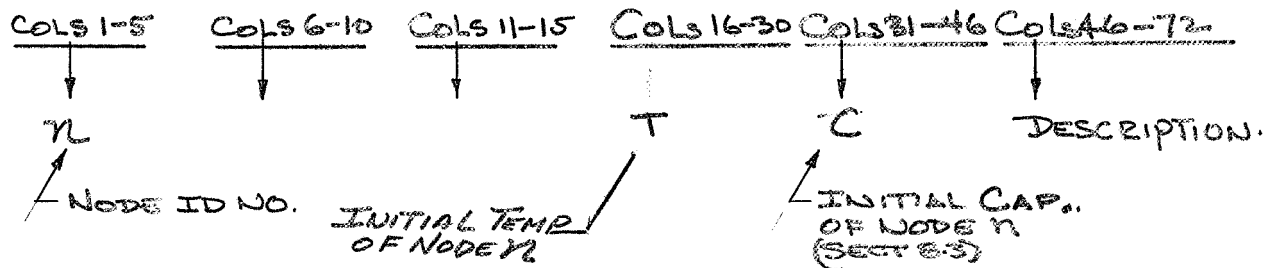
The data input for data block I would appear as follows:



8.2 Initial Temperature Specifications (Data Block II)

Every node in the thermal network must be assigned an initial temperature. In the case of power nodes the temperature specified is really a heat rate multiplied by the value of the power resistor. The temperature of any negative capacitance node may be varied as a function of time or any of the primary program parameters by using function 7.

The data input format for data block II is as follows:

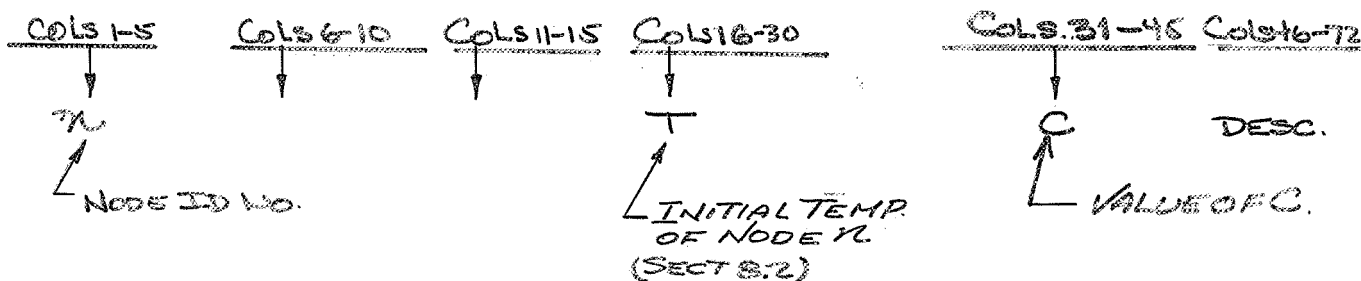


8.3 Capacitance Specifications (Data Block III)

Every node in the thermal network must be assigned a capacitance. The capacitance can be positive, zero or negative depending upon the type of node being represented. In the case of type 1 function 10, function 11 and function 12 nodes the capacitance given in this data block is not used by the program.

The term capacitance describes the heat storage capability of the mass associated with the node.

The data input format for data block III is as follows:



The capacitance of any node (other than function 10, 11, or 12 nodes which enter the tables independent of function 7) may be varied as a function of time or any primary program parameter by using function 7.

8.4 Function Specifications (Data Block IV)

The present version of the TAP program contains 15 functions (see Section 7) of which only function 9 is mandatory. However, function 8 the output specifications must also be used if the user wishes any of the results to be printed out.

The identities of these options are as follows:

<u>Function ID No.</u>	<u>Name</u>
1	Cathode Follower with no time delay.
2	Radiation Resistance Specifications.
3	Phase Transition Specifications.
4	Natural Convection Resistance Specifications.
5	Reactor Heating Specifications.
6	Aerodynamic Heating Specifications.
7	Arbitrary Functions Specifications.
8	Output Specifications.
9*	Problem Constants.
10	Flowing Fluid Cathode Follower Nodes.
11	Flow Junction Nodes.
12	Instantaneous Fluid Flow Cathode Follower Nodes.
13	Reactivity Feedback and Deadband Control.
14	Steady-state and Time Advancement Option.
15	Forced Convection Resistance Specifications.

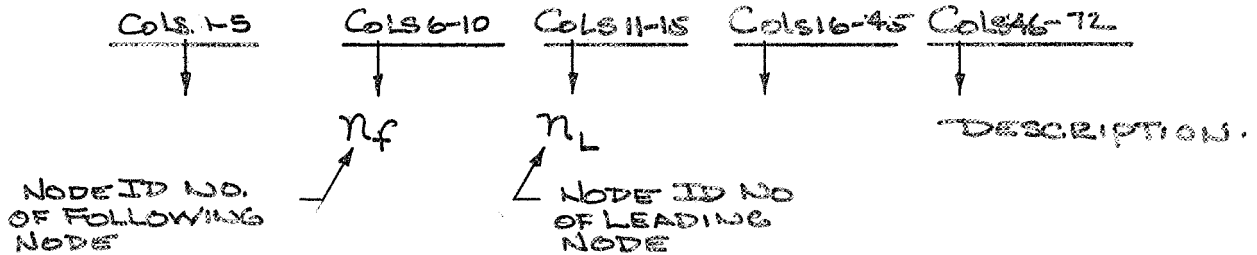
The function number must appear in the first data field on the first data card in the function. In functions 7 and 10-12 the function numbers should appear alone on the first data card.

A description of the data input for the various functions follows.

* Mandatory

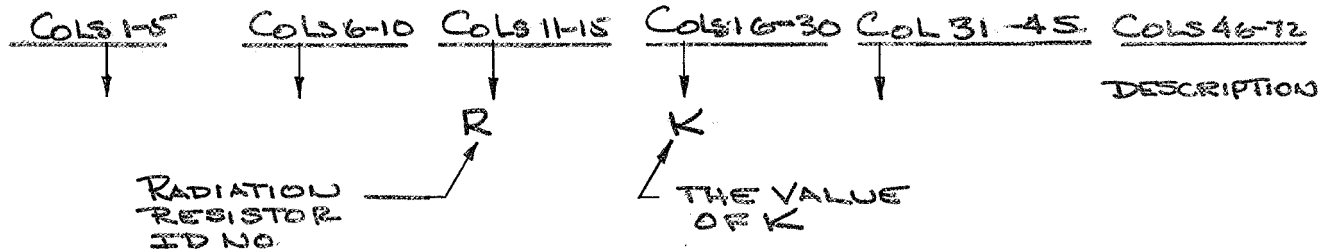
8.4.1 Cathode Follower with no Time Delay (Function 1)

The cathode follower with no time delay sets the temperature of the following node equal to that of the leading node at the end of each time step.



8.4.2 Radiation Resistance (Function 2)

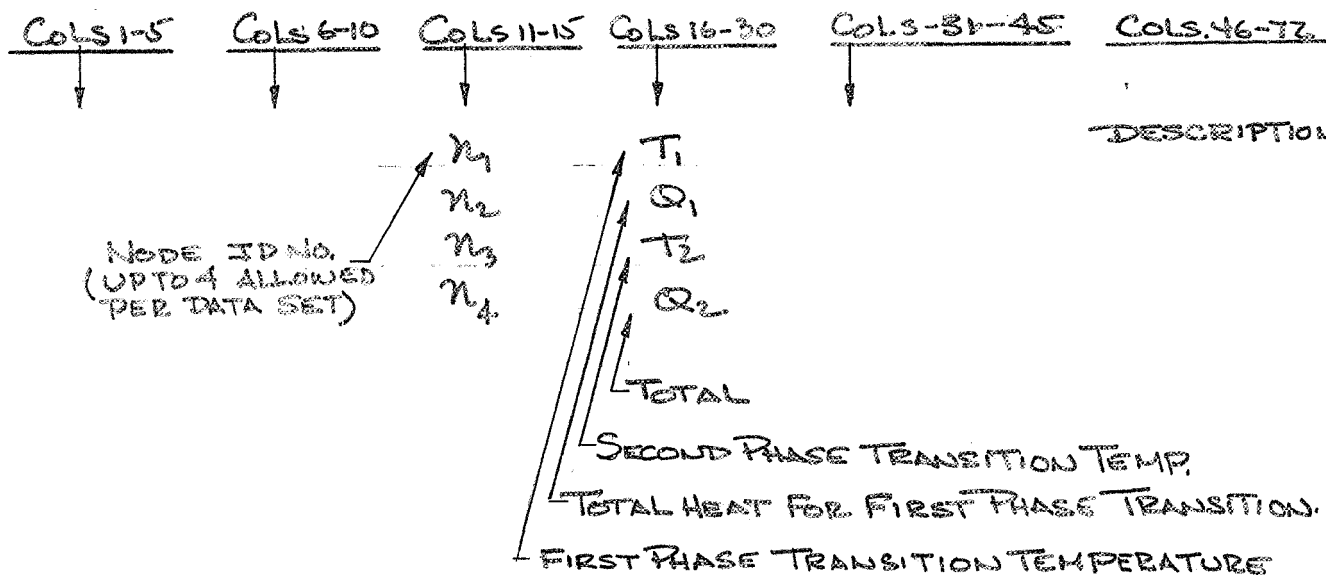
In function 2 the radiation resistor ID number is specified along with the value of K.



8.4.3 Phase Transition (Function 3)

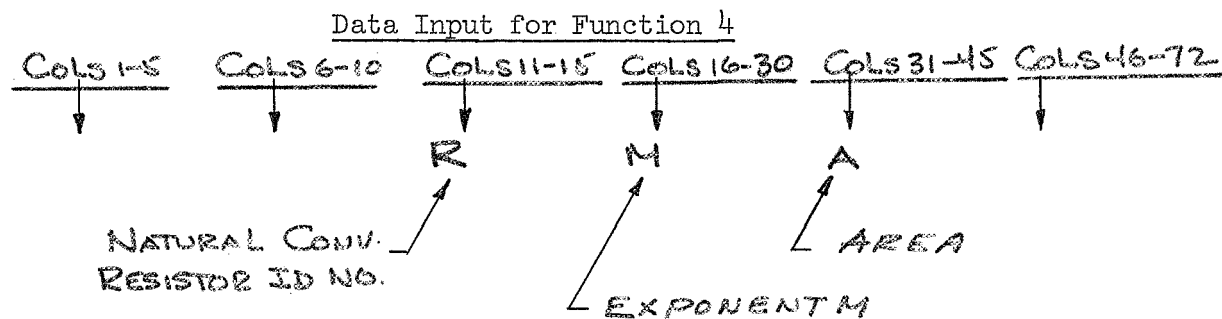
In function 3 the temperature of the specified node is held constant as it passes through a change of phase. Data must be provided for two phase transition conditions, but if it is possible for the node to pass through only one phase given the transient environment the second set of data given may be fictitious if the temperature specified for one of the phase transitions is outside the temperature range for the node.

Data Input for Function 3



8.4.4 Free Convection Resistors (Function 4)

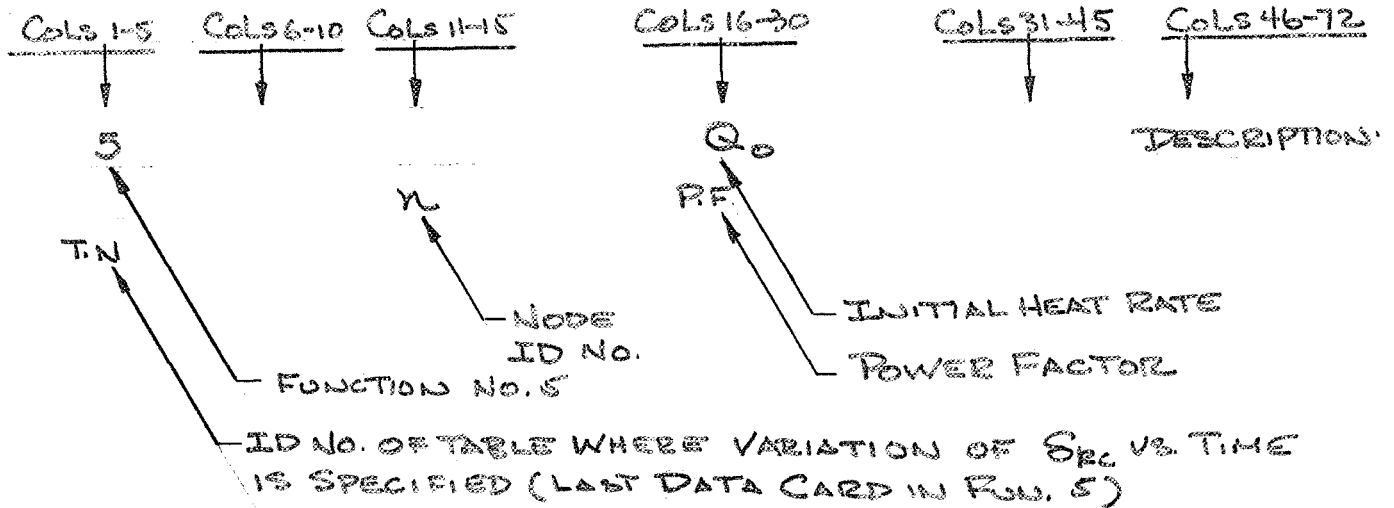
In function 4 the free convection resistor ID number is specified along with the values of A and M in equation 5-3.



8.4.5 Reactor Heating (Function 5)

In function 5 the data required for the reactor heating equations 6-12 and 6-13 are provided.

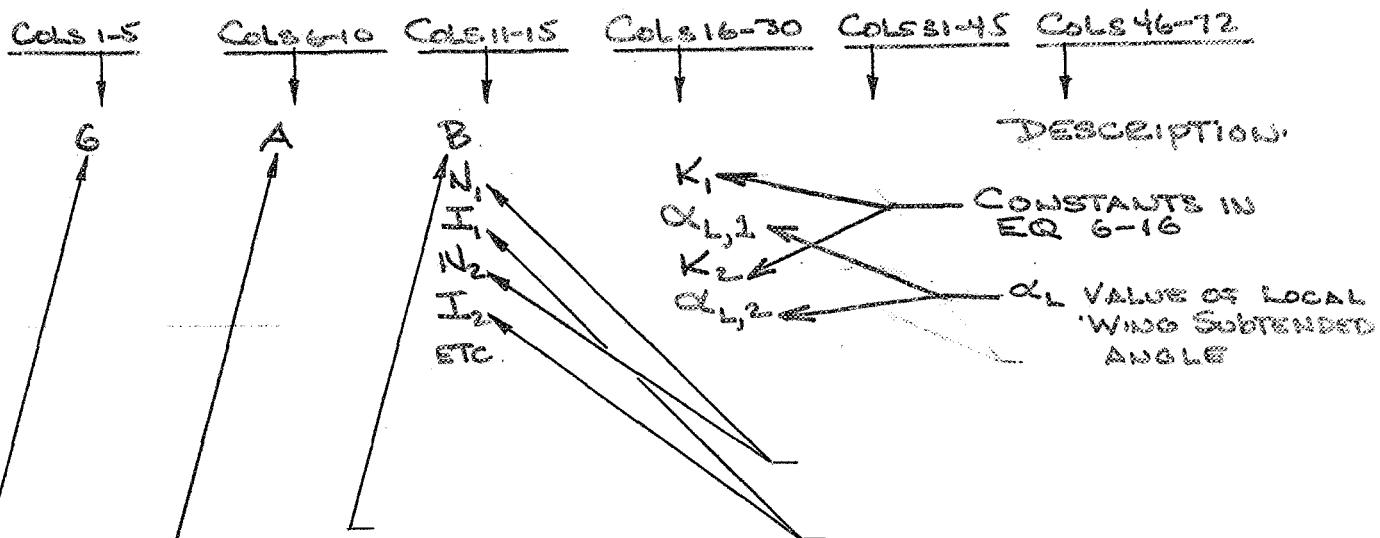
Data Input for Function 5



8.4.6 Aerodynamic Heating (Function 6)

This function provides the data needed to compute the heat rate due to an aerodynamic boundary layer input to any specified node.

Data Input for Function 6



The aerodynamic heating function requires the use of the following tables:

3-6 - If the Ramo-Woldrich Method is used

3-10 - If the Eckert Method is used

11 & 12 - If $\beta \neq 1$

with the following information given in the tables.

Table No.	Dependency Described	Aerodynamic Heating Method Considered
3	$H = f(\theta)$ altitude in feet	R-W & Eckert
4	$M_{\infty} = f(\theta)$	R-W & Eckert
5	$\log_{10} N_{RE}/XM_{\infty} = f(\theta)$	R-W & Eckert
6	$T_{\infty} = f(H)$	R-W & Eckert
7	$\log_{10}(N_{pr} K)^{\frac{1}{3}} = f(T_L')$	Eckert
8	$S = f(M_{\infty})$	Eckert
9	$T_L/T_{\infty} = f(M_{\infty})$	Eckert
10	$M_L/M_{\infty} = f(M_{\infty})$	Eckert
11	$\alpha_{\lambda} = f(\theta)$	$\beta \neq 1$ Both Methods
12	$\beta = f(\alpha)$	$\beta \neq 1$ Both Methods

Tabular Data Input for Function 6

<u>Col. 5</u>	<u>Col. 10</u>	<u>Col. 15</u>	<u>Col. 22</u>	<u>Col. 23</u>	<u>Col. 37</u>	<u>Col. 38</u>	<u>Col. 46</u>
X			$\pm$	X	$\pm$	Y	Description

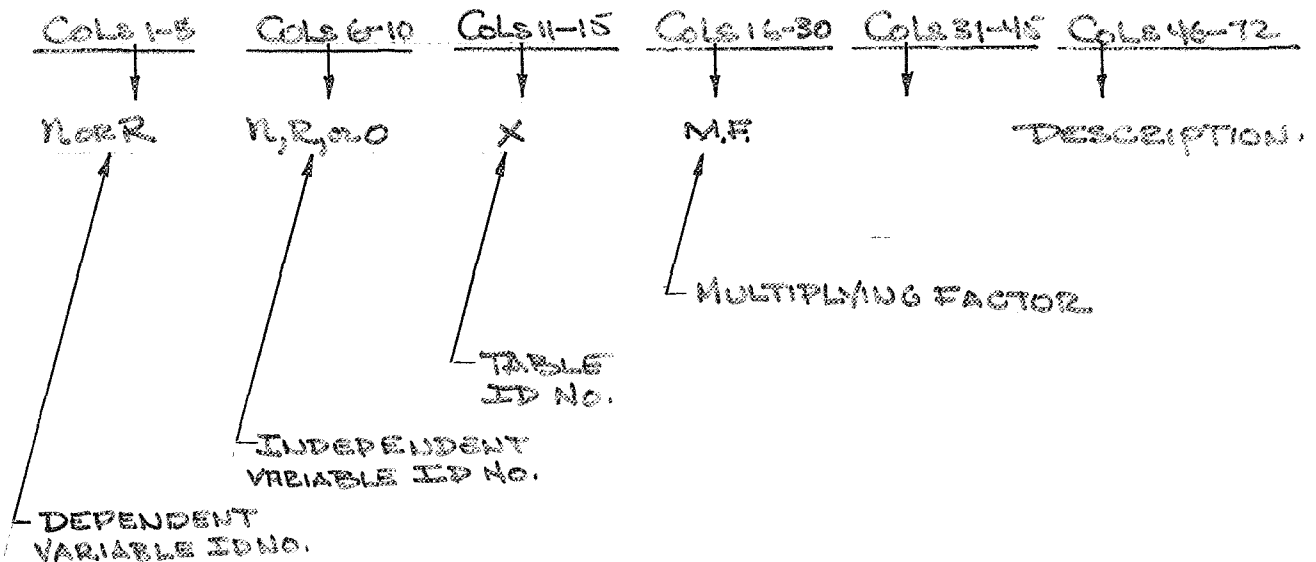

 Table ID No. on
 First Card of
 Table Only

8.4.7 Arbitrary Functions (Function 7)

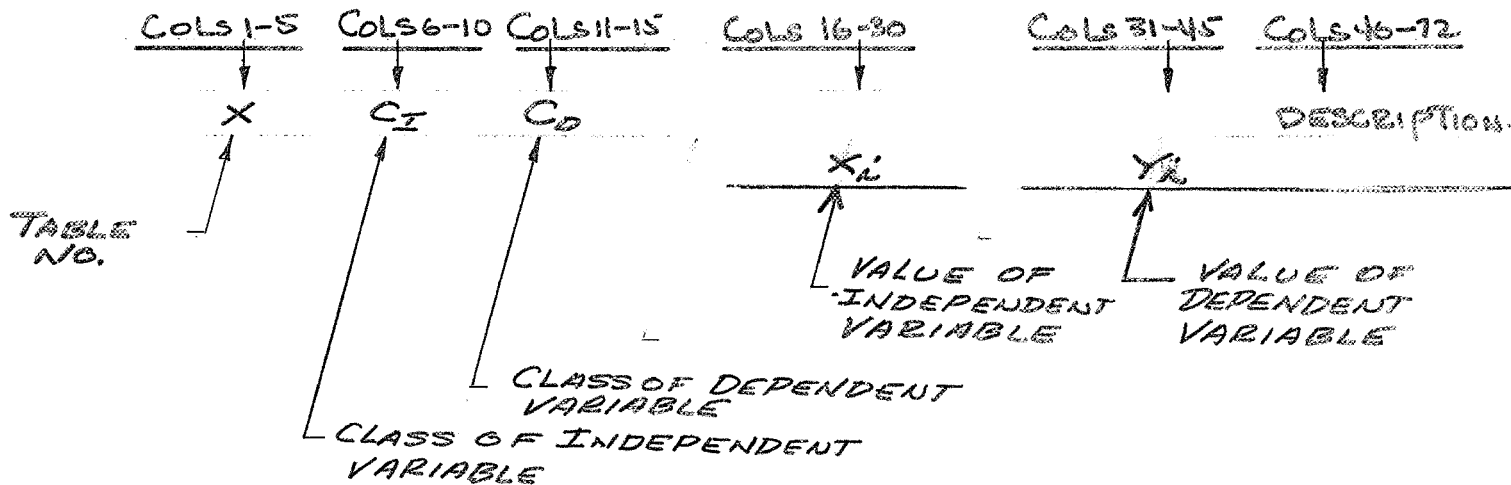
The purpose of function 7 is to identify the variation of any of the primary program parameters with any other primary program parameter or time. The primary program parameters are given below:

Class of Parameter	Primary Program Parameter
0	Time (Independent Variable Only)
1	Value of any Resistor
2	Temperature of any Node
3	Capacitance of any Node
4	Internal Heat Generation Rate for any Node
5	Fluid Capacity Flow Rate (W cp)
6	Average Temperature of any 2 Nodes
7	Difference in Temperature Between any 2 Nodes
8	Time Rate of Change in the Temperature of any Node
9	Net Heat Flow over the Node Control Volume

The Data Input for Function 7



Data Input for the Tables Used with Function 7



If tables are used in conjunction with functions 4, 6, 10, 11, 12, or 15 they will not be available for use with function 7.

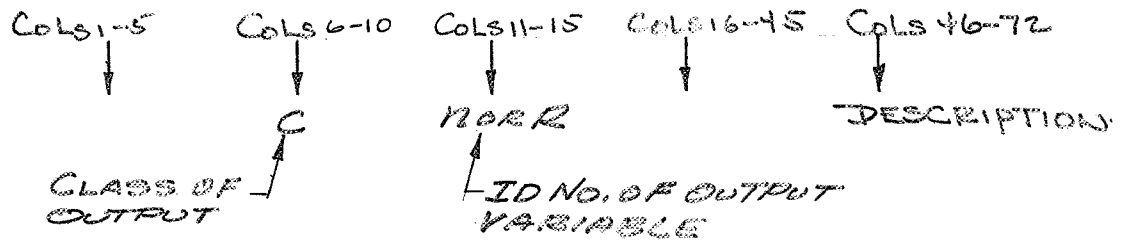
8.4.8 Output Specifications (Function 8)

In function 8 the data output required is specified. The temperature, capacitance, or heat rate for any node or the value of any resistor may be specified.

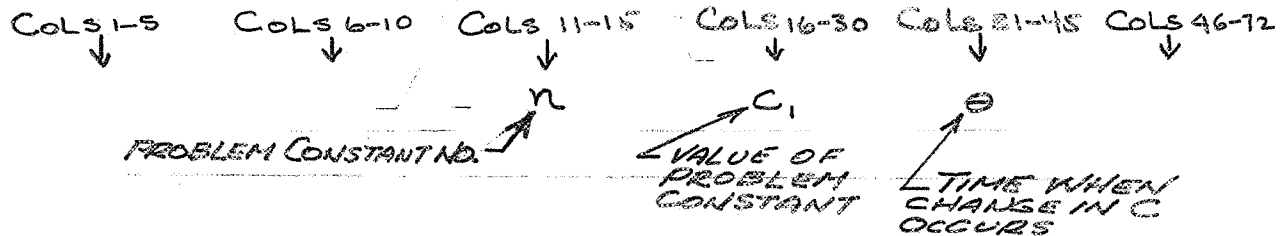
Class of Output	Parameter to be Printed Out	Symbol
1	Value of any Resistor	R
2	Temperature of any Node	T
3	Capacitance of any Node	C
4	Internal Heat Rate for any Node	Q
8 *	Time Rate of Change	TG
9 *	Net Heat Flow Over the Node	H
	Control Volume	

* To be added to the program at a later date.

Data Input for Function 8



8.4.9 Problem Constants (Function 9)



In function 9 various mandatory and optional problem constants are specified. They are:

Note M ~ Mandatory
 O ~ Optional

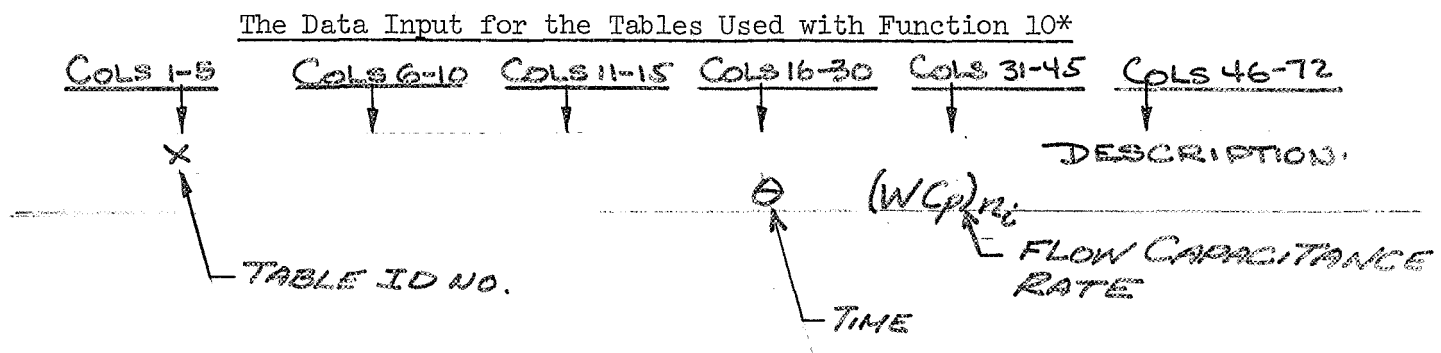
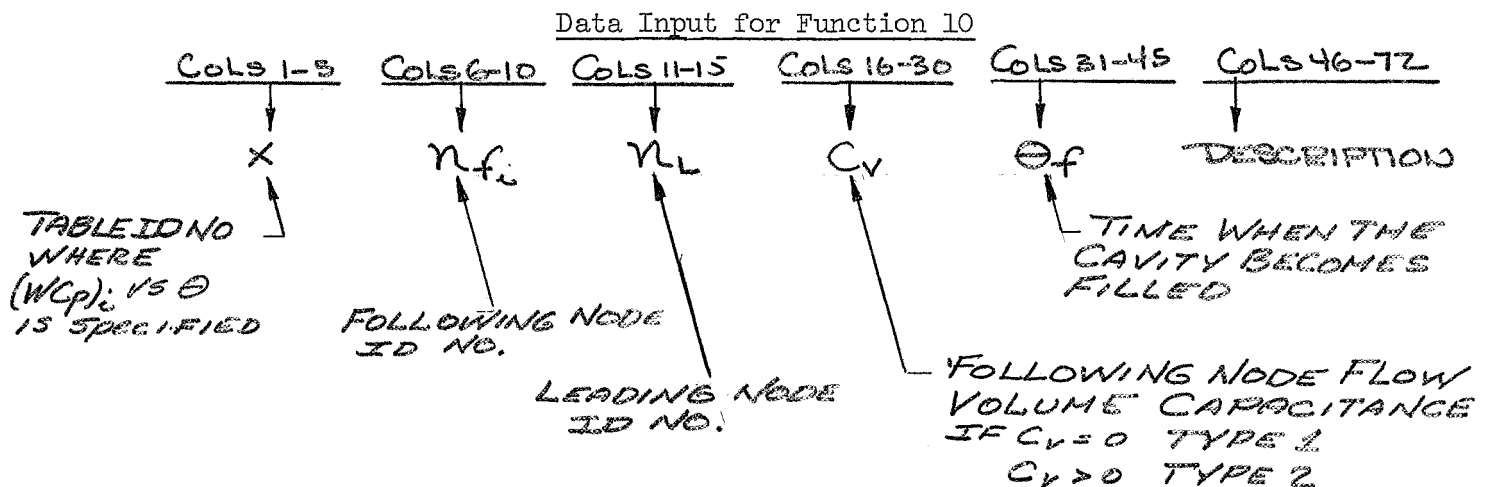
Problem Constant Number	Description	Status
1.	Time interval for printing thermal network parameter time history (input in the time units used in the problem) may be allowed to vary with time.	M
2.	$\Delta\theta$ in consistent units with the problem time dimension units. May be allowed to vary with time.	O
3.	A multiplying factor applied to the program computed $(RC)_{\min}$ product for determining $\Delta\theta$ such that $\Delta\theta = (RC)_{\min}(\text{Calc})$ where $M.F. < 1$. Do not use if problem constant 2 is specified.	O

Problem Constant Number	Description	Status
4.	Problem cutoff time (i.e. the time when calculations are completed). A time unit consistant with that used in the problem should be used.	M
5.	The value of A in equation of the aerodynamic heating routines.	0
6.	The value of b in equation of the aerodynamic heating routines.	0
7.	The value of e in equation of the aerodynamic heating routines.	0
8.	The value of 5 in equation of the aerodynamic heating routines.	0
9.	Initial time for the problem. If not entered the program will start at time zero. It should be specified in a time unit consistant with the one used in the program.	0
10.	The maximum computer execution time (in minutes of machine time), allowed for the program to have completed one data printout. If the computer runs longer than the time specified, between the completion of data input and the first printout of results, the computer will terminate the problem.	M

Problem Constant Number	Description	Status
11.	($\Delta\theta$) min allowed. If the $\Delta\theta$ computed becomes smaller than this value the problem will be terminated.	0

8.4.10 Flowing Fluid Cathode Follower Nodes (Function 10)

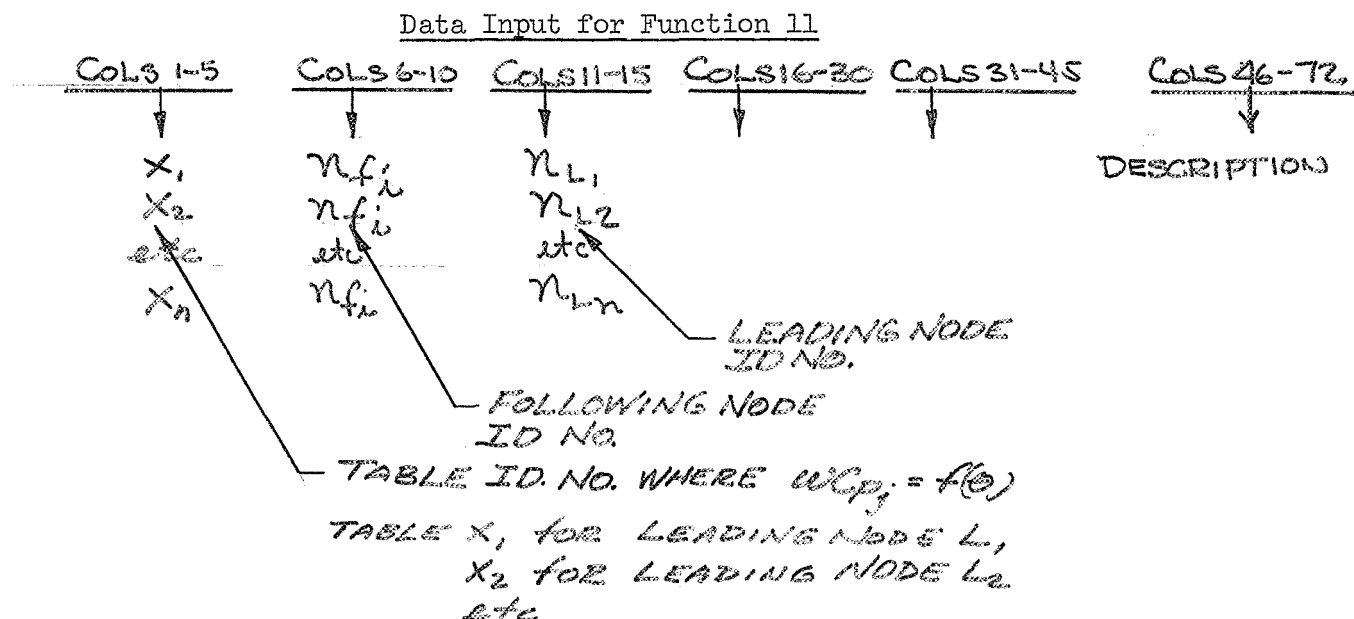
This function identifies the nodes which are type 1 and type 2 flowing fluid cathode follower nodes and specifies the table which describes the variation in flow rate with time.



* The same tables are available to functions 11 and 12 also. In other words, only one table is needed to describe each flow stream.

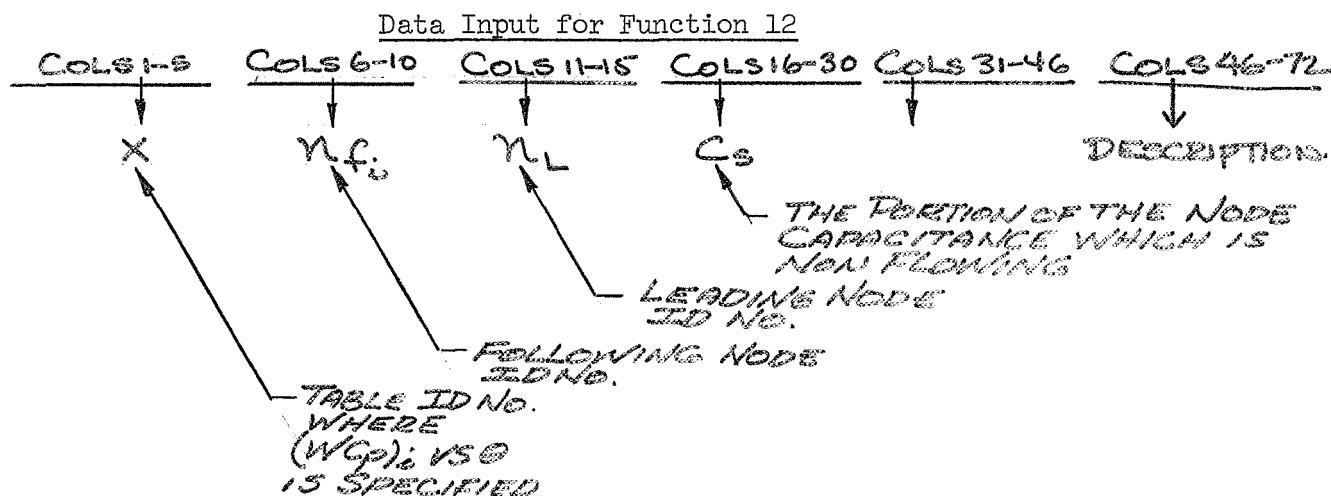
8.4.11 Flow Junction Nodes (Function 11)

This function identifies the nodes which are flow junction nodes.



8.4.12 Instantaneous Fluid Flow Cathode Follower Nodes (Function 12)

This function identifies the nodes for which a stepwise heat transfer calculation is made during each time step.



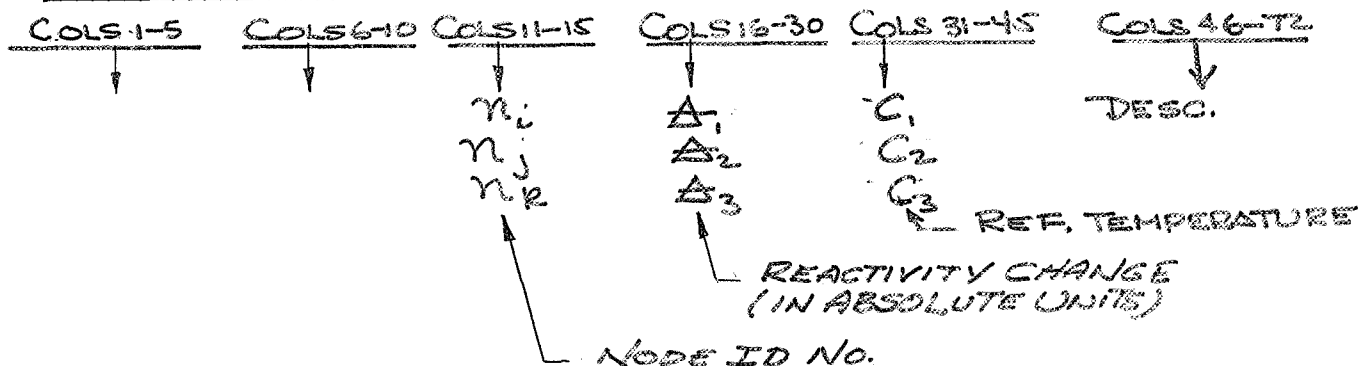
NOTE: The order in which the following nodes in the data determines the order in which the stepwise calculation occurs. Therefore, the furthest upstream Function 12 node in the series should appear first and in succeeding order to the last of that series. The order in which the various series appear is optional.

8.4.13 Reactivity Feedback and Deadband Control (Function 13)

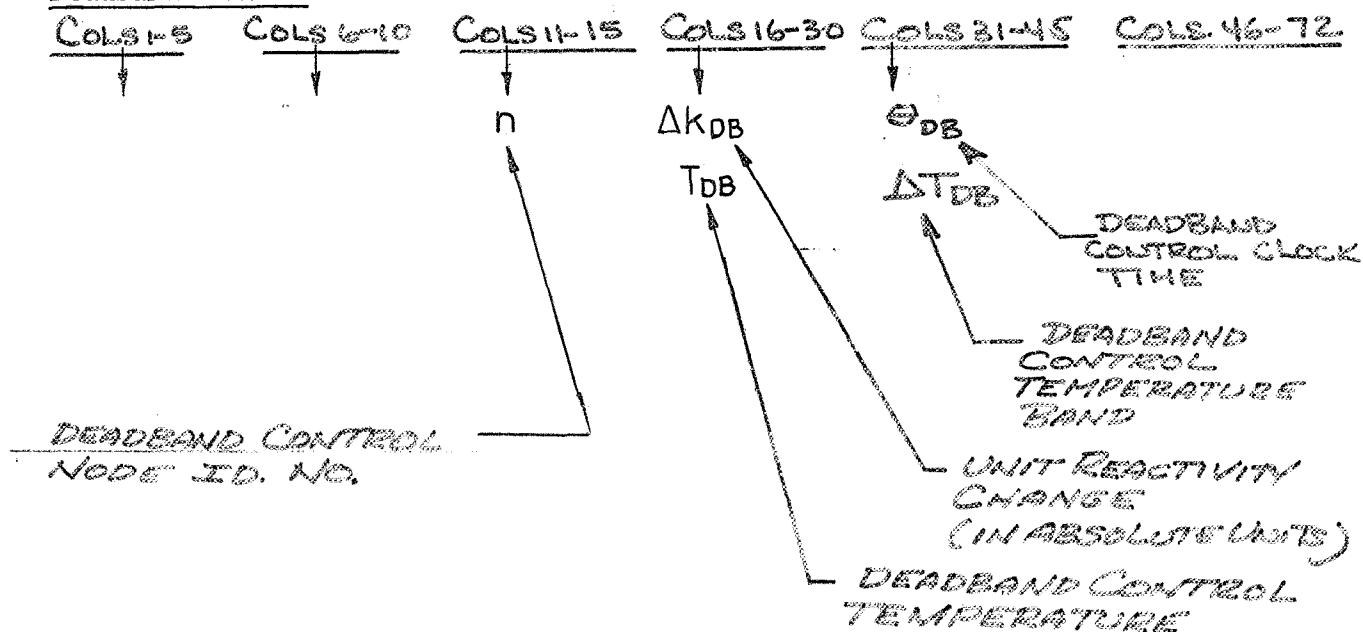
This function is used in conjunction with Function 5 and is used to specify the reactivity temperature feedback and provide the reactor deadband controller information.

Data Input for Function 13

A. Reactivity Feedback



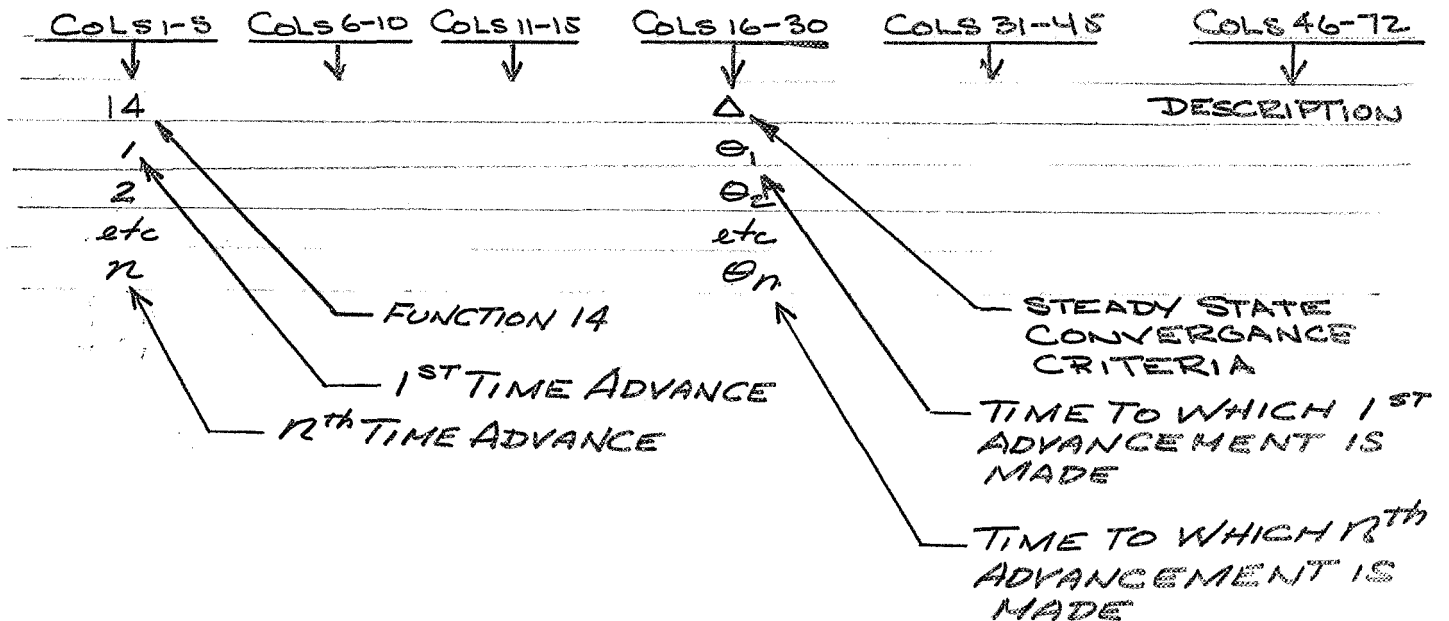
B. Deadband Control



8.4.14 Steady State and Time Advancement (Function 14)

This function specifies when the thermal network approaches steady-state conditions within a specified limit. It also can be used to advance the time to start transient calculation after the steady-state period has ended.

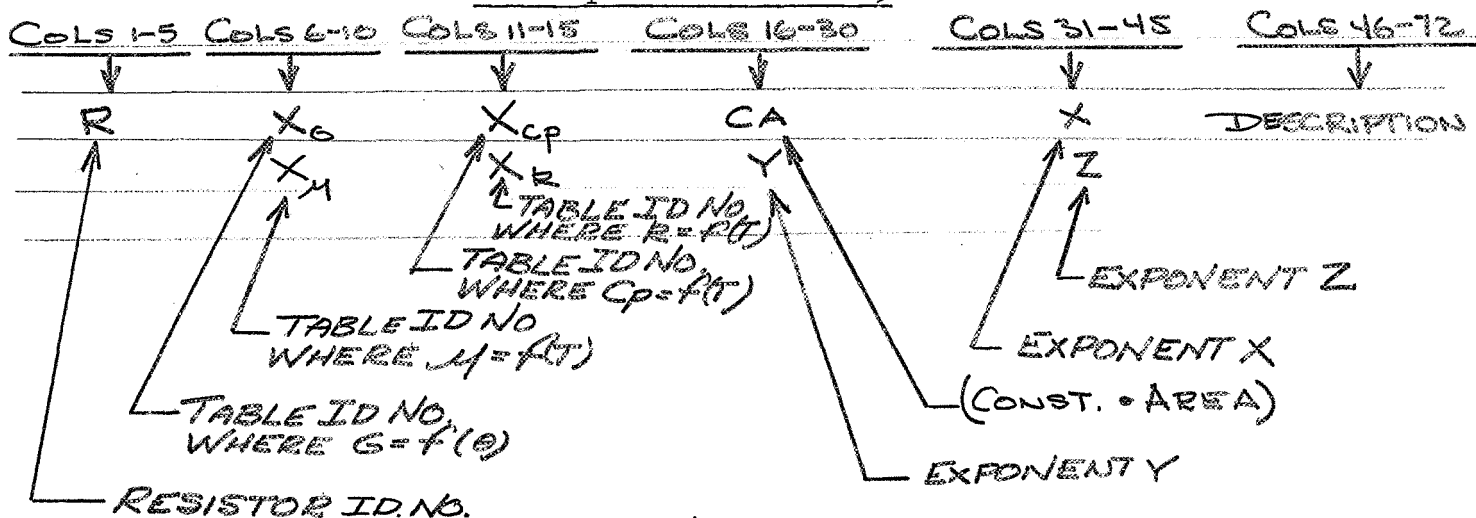
Data Input for Function 14



8.4.15 Forced Convection (Function 15)

This function is used to calculate the values of the forced convection resistors.

Data Input for Function 15



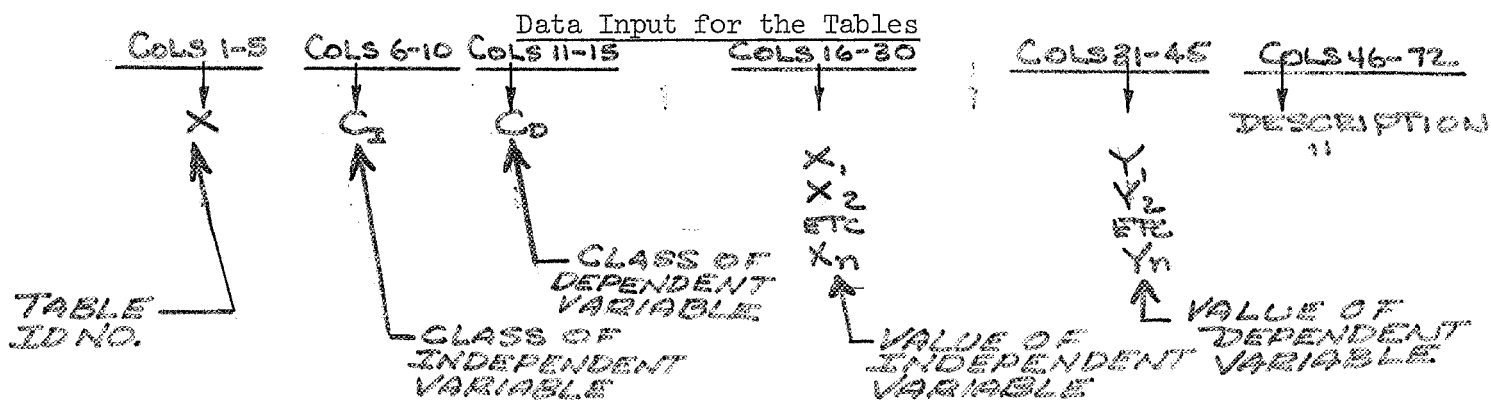
8.5 Tables (Data Block V)

The tables describe the dependancy (in tabular form) of the dependent variables on the independent variable. The tables perform linear interpolation between data points. Extrapolation of the data in the tables is not allowed and whenever the argument of an independent variable is exceeded the job will be terminated.

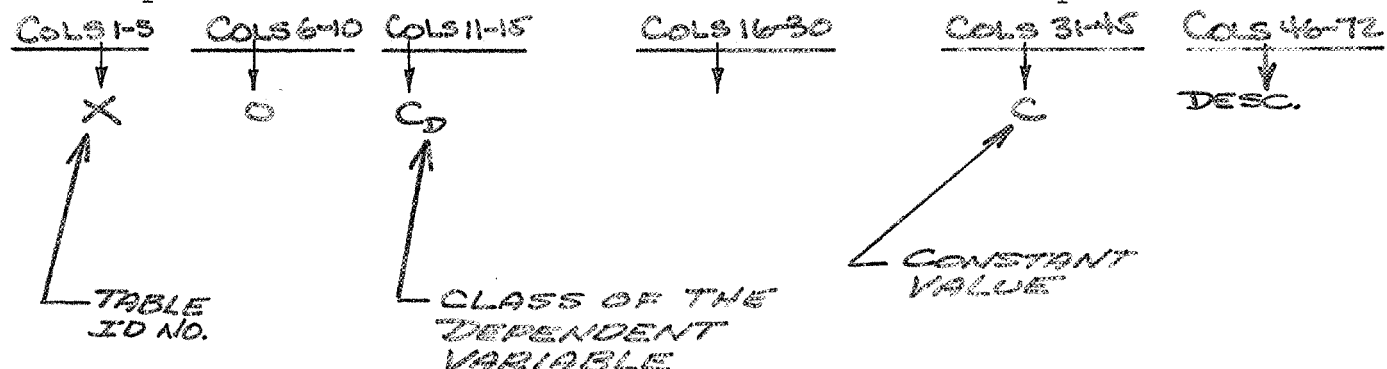
Tables which are used for other functions are not then available for use with Function 7. They are:

Function 4	use tables 1 and 2 inclusively
Function 5	use any table
Function 6	use tables 3 - 12 as required
Function 7	use any table not used by another function
Function 10, 11, 12	use any table not used by another function
Function 15	use any table required

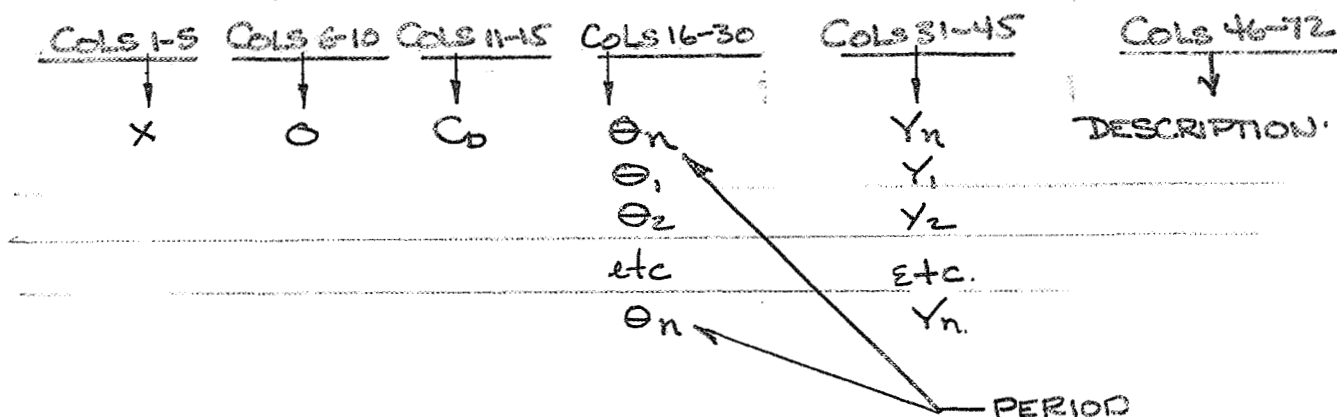
If the tables are used in conjunction with functions 4, 6, 10, 11, 12, and 15, fields 2 and 3 are left blank.



If the dependent variable is a constant then the table would be input as follows.



If the dependency is periodic the table would be input as follows.



8.6 Incrementing of Data Input

An optional data incrementing technique has been made available in the TAP code which permits the user to greatly reduce the volume of data input required for the program, if the data can meet certain conditions. Data incrementing is available for the resistor data block (data block I), the Start Temperature-Capacitor data block (combined data blocks II and III) and for a number of the functions, namely functions 1, 2, 4, 5, 7, 8, 10, and 12.

8.6.1 Resistor Data Block

Incrementing can be used in the resistor data block in any instance where the identification numbers of the resistor and the connecting nodes either increase by increments of one or remain the same through a series of resistors and the values of the resistors remain the same.

8.6.2 Start Temperature - Capacitor Data Blocks

Incrementing can be used in the Start Temperature-Capacitor data block in any instance where the node I.D. numbers increase through a series of nodes in increments of one and the values of the start temperatures and capacitors remain the same throughout the series.

8.6.3 Function Data Block

Incrementing can be used in the various functions if:

8.6.3.1 Function 1 - Cathode Follower

The leading and following nodes progress through the series of nodes with their identification numbers increasing by increments of 1 through the series.

8.6.3.2 Function 2 - Radiation Resistors

The radiation resistor progress through a series of resistors with the I.D. numbers increasing by increments of 1 through the series and values of K remain the same.

8.6.3.3 Function 4 - Free Convection Resistors

The free convection resistors progress through a series of resistors with the I.D. numbers increasing by increments of one through the series and the values of M and A remain the same.

8.6.3.4 Function 5 - Reactor Heating

The node I.D. numbers of nodes in which reactor heating occurs increase in increments of one while the multiplying factors on the power remain the same.

8.6.3.5 Function 7 - Arbitrary Functions

The I.D. numbers of the dependent and independent variables increases through the series in increments of one (unless the independent variable is time in which case the independent variable I.D. number remains zero) and the table I.D. numbers and multiplying factors remain the same.

8.6.3.6 Function 8 - Output Specifications

The class of output variables remains the same and the I.D. Number of the output variables increase in increments of one.

8.6.3.7 Function 10 - Cathode Follower Flowing Fluid Nodes

The table I.D. numbers and C_v 's remain constant and the I.D. numbers of the leading and following nodes increase in increments of one.

8.6.3.8 Function 12 - Instantaneous Fluid Flow Cathode Follower Nodes

The table I.D. numbers and C_s 's remain constant and the I.D. numbers of the leading and following nodes increase in increments of one.

Since one can save up to 90% of the time required to generate the input data for the TAP program by fully using the data incrementing option, it is in the users interest for him to become familiar with the utilization of this option. A complete description of the implementation of this option is given for each type of data on the data format sheets following.

8.7 End of Data Flags

The Thermal Analyzer program uses -1 cards, with the minus sign appearing in column 4 and the one appearing in column 5, to signal the end of each type of data.

Data Blocks I - III

A -1 card must appear at the end of each of the first three data blocks (resistance, initial temperature, and capacitance) to signal the end of each of these data blocks.

Data Block IV

A -1 card must appear at the end of each function used in the function data block to signal the end of that function. (No input of any kind is given for functions not used in the problem.)

A second -1 card must appear at the end of the last function (after the -1 card signaling the end of the function) to signal the end of the function data.

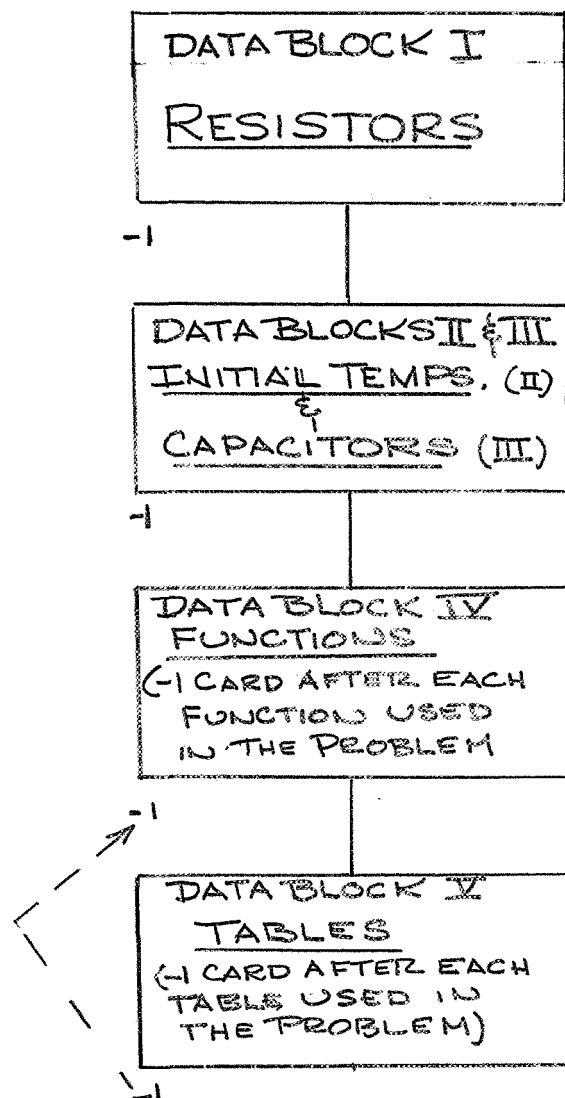
A third -1 card should be placed behind the second -1 card at the end of the function data block if and only if no tables are used in the problem.

Data Block V

A -1 card must appear at the end of each table to signal the end of each table.

A second -1 card must appear behind the first -1 card at the end of the last table to signal the end of all data.

8.8 Tap Data Input Order



NOTE: MOVE THE END OF DATA FLAG BEHIND THE
END OF FUNCTION FLAG IF NO TABLES ARE
USED IN THE PROBLEM.

8.9 Tap Parameter Dimensions (as of April 1, 1969)

Item	Dimensioned Variables	Number Allowed		
		TAP 1	TAP 3	TAP 7
Print	Print = 3 x nodes + resistors	450	1400	3099
Nodes	T, C, TR, RI, RC, Q, TDEL	100	300	700
Resistors	R, I2V, I3V	150	500	999
Functions				
1	KC	10	25	50
2	KR, EKR	50	150	250
3	IPH, PHT1, PHH1, PHT2, PHH2	10	50	50
4	ICON, EXCON, ACON	25	50	100
5	THETA, POWFAC, NODEQ, Q BETA	30	100	100
6	I2AER, ALLOC, AER, IAER	10	50	50
7	IAF2, IAF3, IAF4, FIAF5	100	150	250
8	IPR1, IPR2, PRONT	100	300	700
9.	CO.	30	30	30
Print Interval	PRTIME	5	5	5
Time Step	TYM	5	5	5
10				
Nodes	C FLUID, LTABLE, TNEW, NEW, KLEAD	50	150	250
Tables	K TABLE, CFMIN, WCP	10	10	10
11	NUNODE, INNODE	10	25	50
12				
Nodes	LLEAD, LLTABL, LNEW, CSOLID, TEMP	50	150	200
Tables	KKTABL, WCP	10	10	10
13	(1 set)			
14	ADTIME	20	20	20
15				
Tables		30	30	30
No. of Tables				
Items per Table		50	50	50

8.10 Computer Utilization

The TAP digital computer code is written in fortran IV language. Since the IBM 360/65 digital computer at Aerojet-General, Azusa, is set up for multi programming, the program has been set up in three versions, 100 nodes, 300 nodes, and 700 nodes, to conserve core space within the machine and thus reduce computer costs. The following table indicates that portion of the IBM 360/65 computer core needed for each version of the TAP code.

The user can save considerable computer time costs by using the smallest version of the TAP code which will handle his problem. The parameter dimensions (as of July 1, 1969) for each version of the program are set forth in section 8.9.

Table 8-1

Item	Version of the TAP Code		
	100 Nodes	300 Nodes	700 Nodes
Core storage available in the IBM 360/65 computer	400 K	400 K	400 K
Core storage utilized in this version of the TAP code	80 K	108 K	144 K
Core storage available for expansion of this version of the TAP code	320 K	292 K	256 K

NOTE: K denotes 10^3 bytes

$\leftarrow I_1 \rightarrow I_2 \rightarrow I_3 \leftarrow R_1$

R1

DATE	PROGRAM	O ^o

5-20

9
2

22

NO DE WHICH IS FOLLOWED
(IE. THE LEADING NODE).

node which does the following (ie the following node)

Function	ID	NUMBER

1. CATHODE FOLLOWER WITH NO TIME DELAY)

1. DATA INCREMENTING OPTION FOR FUNCTION 1.

13	13	-20	13
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17	22
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— LISTING OF NODES 15 THRU 17

LISTING OF NODES 20 THRU 24

4 THE MINDS SIGN IN FIELD I.2 IS THE INCREMENT SIGNAL

INCR	EMENT	SIGNAL
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CATHODE FOLLOWER FUNCTION

W/NO TIME DELAY

COMMENTS ALLOWED IN COLS. 46-72

THE FUNCTION DATA BLOCK

RES-15A

[illegible]

W
T
A
O

RADIATION RESISTOR FUNCTION

	5	-14
41	6261	-11
42	6261	-11
43	6261	-11
44	6261	-11

VALUE OF K (WHERE $K=0.7A$)

RADIATION RESISTOR ID NUMBER

FUNCTION NO. 2 RADIATION RESISTANCE

DATA INCREMENTING OPTION FOR FUNCTION 2

	41	6261	-11
41	6261	-11	
44	6261	-11	

RESISTORS 41 THRU 44 ALL HAVE THE SAME VALUES

LISTING OF RADIATION RESISTORS 41 THRU 44

THE MINUS SIGN IN FIELD IS
IS THE INCREMENT SIGNAL

Fractal

0
1
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4
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6
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9

[illegible]

27

22

20

2422

66

212

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28.65

NATURAL CONVECTION FUNCTION

$$\frac{2}{5}$$

36.8

A (AZEA) (FO, S-4)

EXPONENT: M (EQ 5-4)

NATURAL CONVECTION ID	ID	NUMBER

FUNCTION No. 4 (NATURAL CONVECTION RESISTANCE)

NOTE IF FUNCTION 4, IS USED, TABLES 1 AND 2 MUST BE RESERVED. FOR THIS FUNCTION AND CONSEQUENTLY THESE TABLES CANNOT THEN BE USED BY THE OTHER FUNCTIONS

DATA	INCREMENTING OPTION	FOR FUNCTION 4
1	2	3
4	5	6
7	8	9
10	11	12
13	14	15
16	17	18
19	20	21
22	23	24
25	26	27
28	29	30
31	32	33
34	35	36
37	38	39
40	41	42
43	44	45
46	47	48
49	50	51
52	53	54
55	56	57
58	59	60
61	62	63
64	65	66
67	68	69
70	71	72
73	74	75
76	77	78
79	80	81
82	83	84
85	86	87
88	89	90
91	92	93
94	95	96
97	98	99
100	101	102
103	104	105
106	107	108
109	110	111
112	113	114
115	116	117
118	119	120
121	122	123
124	125	126
127	128	129
130	131	132
133	134	135
136	137	138
139	140	141
142	143	144
145	146	147
148	149	150
151	152	153
154	155	156
157	158	159
160	161	162
163	164	165
166	167	168
169	170	171
172	173	174
175	176	177
178	179	180
181	182	183
184	185	186
187	188	189
190	191	192
193	194	195
196	197	198
199	200	201
202	203	204
205	206	207
208	209	210
211	212	213
214	215	216
217	218	219
220	221	222
223	224	225
226	227	228
229	230	231
232	233	234
235	236	237
238	239	240
241	242	243
244	245	246
247	248	249
250	251	252
253	254	255
256	257	258
259	260	261
262	263	264
265	266	267
268	269	270
271	272	273
274	275	276
277	278	279
280	281	282
283	284	285
286	287	288
289	290	291
292	293	294
295	296	297
298	299	300
301	302	303
304	305	306
307	308	309
310	311	312
313	314	315
316	317	318
319	320	321
322	323	324
325	326	327
328	329	330
331	332	333
334	335	336
337	338	339
340	341	342
343	344	345
346	347	348
349	350	351
352	353	354
355	356	357
358	359	360
361	362	363
364	365	366
36		

2333

14.6

3333

14.6

AREAS FOR RESISTORS 34 TARO 81
ALL HAVE THE SAME VALUE

EXPONENT	M'S FOR	RESISTORS	34 THRU 81
ALL HAVE THE SAME VALUES			

LISTING OF NATURAL CONVECTION REVISORS 34 THRU 51

THE MINUS SIGN IN FIELD 13
IS THE INCREMENT SIGNAL.

COMPUTING SCIENCES 80 COLUMN INPUT

DATE _____ PROGRAM NO. _____ PROGRAMMED BY _____

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
										5.1										REACTOR HEATING FUNCTION:																																																																															
150										6										NOTE:																																																																															
151										1.1.2										FUNCTION S MUST BE USED IN CONJUNCTION																																																																															
152										6										WITH FUNCTION 13																																																																															
																				Q (INITIAL HEAT RATE)																																																																															
																				POWER FACTOR																																																																															
																				NODE ID NO.																																																																															
																				FUNCTION NO. 5																																																																															
																				TABLE ID NO. OF TABLE WHERE S _K VS θ VALUES ARE GIVEN																																																																															
																				DATA INCREMENTING OPTION FOR FUNCTION S																																																																															
150										5										POWER FACTORS FOR NODES 150 THRU 152																																																																															
152										5										ALL HAVE THE SAME VALUE																																																																															
																				LISTING OF NODES (IN WHICH REACTOR HEATING OCCUR)																																																																															
																				150 THRU 152																																																																															
																				THE MINUS SIGN IN FIELD IS																																																																															
																				IS THE INCREMENT SIGNAL																																																																															

8-11-8

10-132-138

COMPUTING SCIENCES
80 COLUMN INPUT

DATE _____ PROGRAM NO. _____ PROGRAMMED BY _____

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
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I=1 BOTTOM SURFACE																																																																																																			
I=0 END OF FUNCTION FLAG																																																																																																			
B=1 B=1 DO NOT ENTER VALUES FOR I & α																																																																																																			
B=0 B=0 f(α)																																																																																																			
A=1 R-M EQUATION																																																																																																			
A=0 ECKERT EQUATION																																																																																																			
FUNCTION NO. 6																																																																																																			

11-6

[illegible]

COMPUTING SCIENCES

R4

21 PROGRAM

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6-10

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64	64
77	77
81	81
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196	196
197	197
198	198
199	199
200	200

PROBLEM CONSTANTS

TIME (USED WITH PROBLEM CONSTANTS

1. AND/OR, 2 TO VARY THE PRINT

INTERVAL OR TIME STEP

VALUE OF THE PROBLEM CONSTANT

[illegible]

✓	PROBLEM CONSTANT ID NUMBER
---	----------------------------

(PROBLEM CONSTANTS 1, 4, & 10 ARE 2)

(MANDATORY THE REST ARE OPTIONAL.)

[illegible][illegible]

FUNCTION NO 9 PROBLEM CONSTANTS

[illegible][illegible][illegible]

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
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7000	
6000	
5000	
4000	
3000	
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1000	
0	
-1000	
-2000	
-3000	
-4000	
-5000	
-6000	
-7000	
-8000	
-9000	
-10000	

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8.11.13

10-132-138

COMPUTING SCIENCES DIVISION

80 COLUMN INPUT

R1

PROGRAM NO.

PROGRAMMED BY

12	34	56	78	90	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80					
DATE																																																																															
PROGRAM NO.																																																																															
PROGRAMMED BY																																																																															
CATHODE FOLLOWER FLOW FUNCTION																																																																															
TYPE 1 FUNCTION 10 (1 STEP DELAY)																																																																															
TYPE 2 FUNCTION 10 (SPECIFIED DELAY)																																																																															
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ALWAYS SPECIFIED AS ZERO FOR TYPE 2																																																																															
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FUNCTION NO. 10																																																																															
CATHODE FOLLOWER																																																																															
FLOW FUNCTION																																																																															
NODE WHICH IS FOLLOWED (I.E. THE UPSTREAM NODE)																																																																															
NODE WHICH DOES THE FOLLOWING (I.E. THE DOWNSTREAM NODE)																																																																															
TABLE ID NO.																																																																															
(WCR) F(0) IN TABLE 6																																																																															
DATA INCREMENTING OPTION FOR FUNCTION 10																																																																															
OF IS THE SAME FOR FOLLOWER																																																																															
NODS 290 THRU 298																																																																															
IS THE SAME FOR FOLLOWER NODS 290 THRU 298																																																																															
NODS 290 THRU 297																																																																															
LISTING OF LEADING NODS 290 THRU 298																																																																															
LISTING OF FOLLOWING NODS 290 THRU 298																																																																															
THE MINUS SIGN IN FIELD 12 IS THE INCREMENT SIGN																																																																															
THE WCR TABLE ID NO. IS THE SAME FOR FOLLOWING NODS 290 THRU 298																																																																															

PROGRAMMED BY-

FOR RAIN OR SUN

DATE

80	78	77	76	75	74	73	72	71	70	69	68	67	66	65	64	63	62	61	60	59	58	57	56	55	54	53	52	51	50	49	48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
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[illegible]

0-132-138

PROGRAMMED BY:

[illegible]

[illegible]

$$\Delta = \frac{T_{\text{out},i} - T_{\text{in},i}}{T_{\text{out},i} - T_{\text{in},i}} \times \Delta \theta$$

DATE _____ PROGRAM NO. _____ PROGRAMMED BY: _____

[illegible]

8.179 DATA BLOCK V TABLES.

-80-

9. Nomenclature

<u>Symbol</u>	<u>Description</u>	<u>Units</u>
A	Area normal to the direction of heat flow	L^2
A	Surface area	L^2
a	Exponent in Raymo-Wooldrich equation for aerodynamic heating	dimensionless
AF	Arbitrary functions	dimensionless
b	Exponent in Raymo-Wooldrich equation for aerodynamic heating	dimensionless
c	Constant	dimensionless
C	Temperature scale conversion constant T	
$C()$	Total capacity	H/T
C_s	Non flowing portion of the capacitance of a node which has mass transfer across the control volume	H/T
C_v	Flowing portion of the capacitance of a node which has mass transfer across the control volume	H/T
C_1	Reactivity feedback reference temperature 1	T
C_2	Reactivity feedback reference temperature 2	T
C_3	Reactivity feedback reference temperature 3	T
CF	Cathode follower	--
C_p	Specific heat at constant pressure	H/MT
D	Diameter	L
D_h	Hydraulic diameter	L
$F()$	Black body radiant energy exchange factor	dimensionless

<u>Symbol</u>	<u>Description</u>	<u>Units</u>
$\mathcal{F}$	Gray body radiant energy exchange factor	dimensionless
G	Variables which are a function of time	-
G	Unit flow rate	M/θ_L^2
g	gravitational constant	M/θ^2
g_c	Proportionality constant	$\frac{ML}{F\theta^2}$
h	Film coefficient	$\frac{H}{\theta_L^2 T}$
H	Altitude	feet
K	Radiation constant	$\frac{H}{\theta_T^4}$
K	Variables which are a function of average temperature	-
k	Thermal conductivity	$\frac{H}{\theta_{LT}}$
L	Distance between node centers	L
l	Neutron mean free path length	L
M	Exponent	dimensionless
M	Mach number	dimensionless
M	Mass	M
m	Mass	M
M.F.	Multiplying factor	dimensionless
N	Variable in Raymo-Wooldrich aerodynamic heating equations	
$N()$	Dimensionless constant or number	
N_{nu}	Nusselt number	dimensionless
N_{pr}	Prandtl number	dimensionless
N_{re}	Reynolds number	dimensionless
P.C.	Problem constant	-

<u>Symbol</u>	<u>Description</u>	<u>Units</u>
P.F.	Power factor	dimensionless
Q	Heat rate	H/θ
Q_i	Internal heat rate in node i	H/θ
Q_o	Initial internal heat rate	H/θ
Q_{net}	Net heat flow rate across the node control volume	H/θ
Q_{react}	Reactor heat rate	H/θ
R	Thermal resistance	$\theta T/H$
r	Internal thermal resistance	$\theta T/H$
RC	Resistance capacitance product	θ
T	Temperature	T
t	Temperature	T
T_{DB}	Deadband temperature level	T
T_1	Reactivity feedback temperature 1	T
T_2	Reactivity feedback temperature 2	T
T_3	Reactivity feedback temperature 3	T
V	Volume	M/L^3
W	Mass flow rate	M/θ
(WCp)	Capacitance flow rate	$\frac{H}{\theta T}$
x	Exponent	dimensionless
y	Exponent	dimensionless
z	Exponent	dimensionless

Greek Symbols

<u>Symbol</u>	<u>Description</u>	<u>Units</u>
α	Local subtended angle of surface in aerodynamic layer	
β	Coefficient in aerodynamic heating equations	dimensionless
β	Beta heating	-
β	Coefficient of volumetric expansion	$1/T$
γ	Gamma heating	-
δ	Reactivity	
δ_{KC}	Reactivity due to control rod or reflector	
Δ	Difference between convergence criteria	
$\Delta\theta$	Time step	θ
Δ	Reactivity change due to one reflector or control rod position change	
ΔT_{DB}	Deadband control temperature range	T
A_1	Reactivity feedback coefficient 1	
A_2	Reactivity feedback coefficient 2	
A_3	Reactivity feedback coefficient 3	
ϵ	Eddy diffusivity	
ϵ	Emissivity	dimensionless
θ	Time	θ
θ_f	Time when the node cavity becomes filled with fluid	θ
λ	Decay constant	$1/\theta$
μ	Dynamic viscosity	$M/\theta L$
ν	Kinematic viscosity	L^2/θ

Symbol

Description

Units

ρ
 σ
 Σ

Density

M/L^3

Steffan Boltzman constant

$H/\theta L^2 T^4$

Sum of

-

Postsubscripts

<u>Symbol</u>	<u>Description</u>
ave	average
b	bulk
cond	conduction
conv	convection
f	film
h	junction of flow passages
i	node i
i -1	node i -1 upstream of node i
i +1	node i +1 downstream of node i
ij	between node i and node j
j	node j
k	node k
l	flow passage l
m	flow passage m
mix	mix temperature
min	minimum
n	flow passage n
n	neutron heating
r	recovery
rad	radiation
s	non flowing component of node capacitance
v	flowing component of node capacitance
w	wall

Greek Postsubscripts

<u>Symbol</u>	<u>Description</u>
<u>β</u>	beta heating
<u>γ</u>	gamma heating
Δ	difference
θ	at time θ
$\theta+\Delta\theta$	at time $\theta+\Delta\theta$
<u>∞</u>	infinity

Presubscripts for X^R

<u>Symbol for X</u>	<u>Description</u>
1	Conduction
2	Simple convection
2a	Forced convection
2b	Natural convection
3	Radiation

10.1 Sample Problem 1

<u>Description</u>	<u>Figure</u>	<u>Page</u>
Problem Description		
Drawing of Heat Exchanger	10.1	
Nodal Schematic	10.2	
Thermal Network	10.2	
Variation of Parameters	10.3	
Thermal Network Calculations	10.4	
Summary of Thermal Network	10.5	
Problem Data Input Sheets	10.6	
Computer Output	10.7	
Plotted Results	10.8	

Sample problem No. 1 consists of a thermal analysis of the tube-in-shell heat exchanger (shown in Figure 10.1) which is operating in a vacuum. The heat exchanger has a cold side bypass which is used to cool some electrical equipment that rejects heat to the bypass fluid as given in Figure 10.3. Oil is the cold side fluid and liquid eutectic sodium potassium (NaK) is used as the hot side fluid. The oil flows through the heat exchanger tubes at the constant rate of 10,000 lbm/hr while a constant flow rate of 1,000 lbm/hr of oil flows through the heat exchanger bypass line. The heat exchanger is insulated against heat loss. The shell of the heat exchanger is initially evacuated. NaK is introduced into the heat exchanger shell at the start of the transient, initially at the rate of 200 lbm/hr which then rises lineally to 2,000 lbm/hr in the first 100 seconds as shown in Figure 10.3. The NaK is introduced into the heat exchanger at a constant temperature of 1000°F. The oil is initially introduced into

the heat exchanger and bypass at a temperature of 50°F. The following assumptions were made in the analysis.

1. The NaK film coefficient $> \infty$
2. The oil film coefficient was finite and assumed
3. The heat exchanger effectiveness (UA) was assumed as follows:

<u>Section</u>	<u>UA^{BTU}/Sec-°F</u>
1	2.64×10^{-2}
2	2.69×10^{-2}
3	2.78×10^{-2}
4	2.78×10^{-2}
5	2.69×10^{-2}

4. The grid plate film coefficients were assumed as were the coefficients in the inlet and outlet plenums of the heat exchanger.

5. Radiation to the surroundings was taken into account. It was assumed that the surroundings consisted of a hard space vacuum infinite black body sink at 50°F.

Note: This problem was prepared as a sample problem for this report and, therefore, the assumptions made for the various parameters are not necessarily realistic or consistent with good heat exchanger design.

Oil - NaK Heat Exchanger

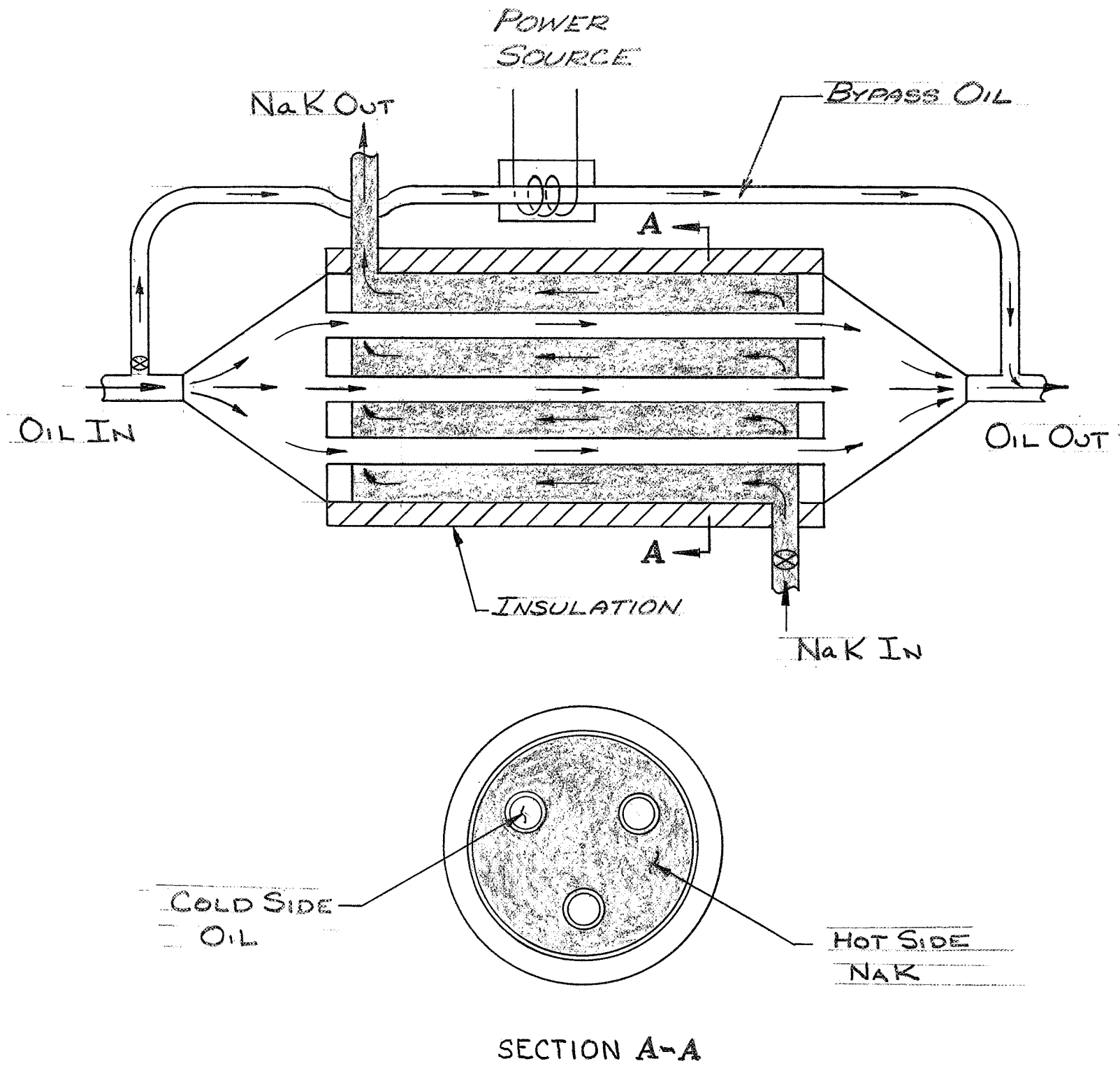


Figure 10.1

Sample Problem No. 1
Nodal Schematic and Thermal Network

Nodal Schematic and Thermal Network

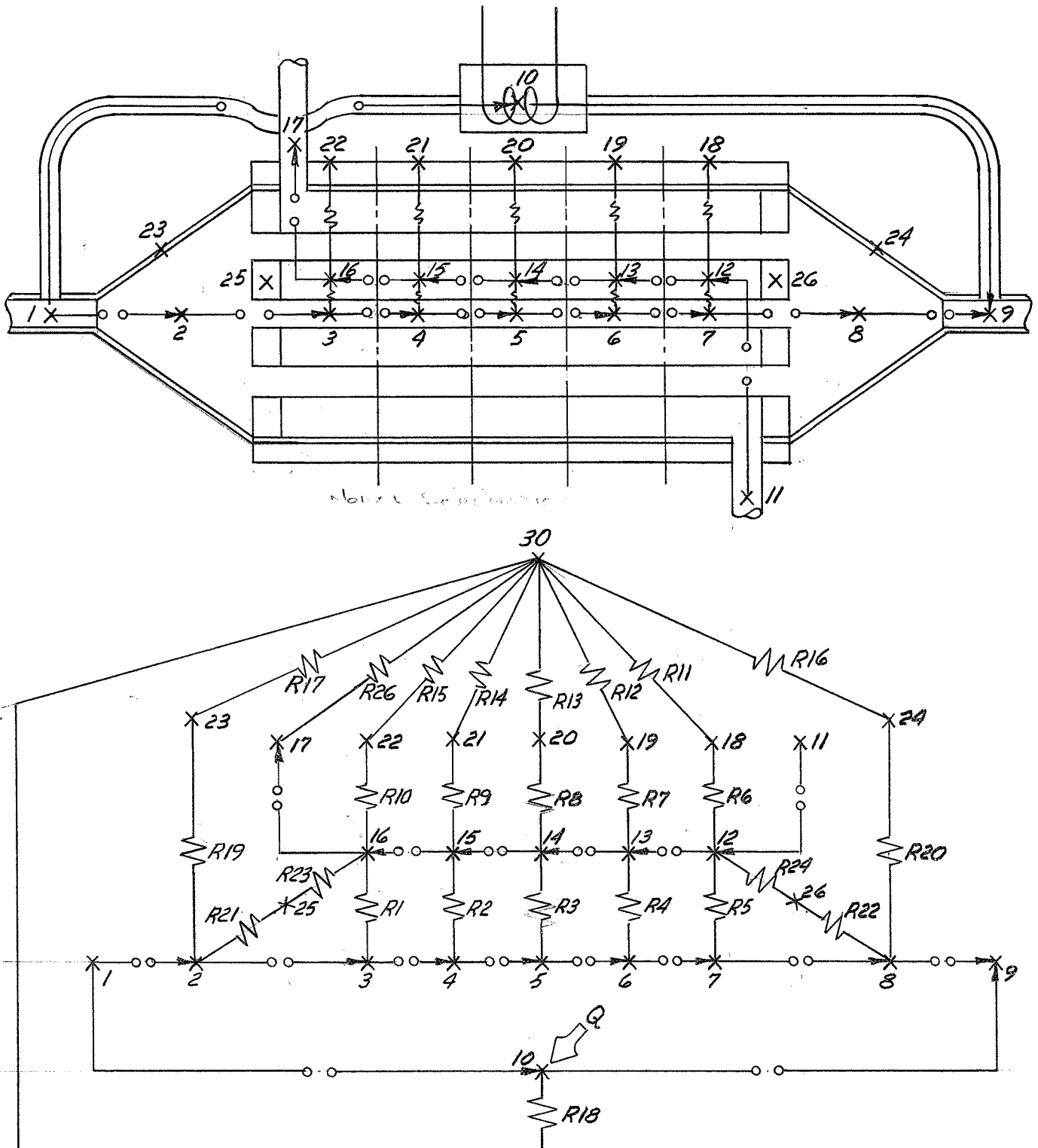
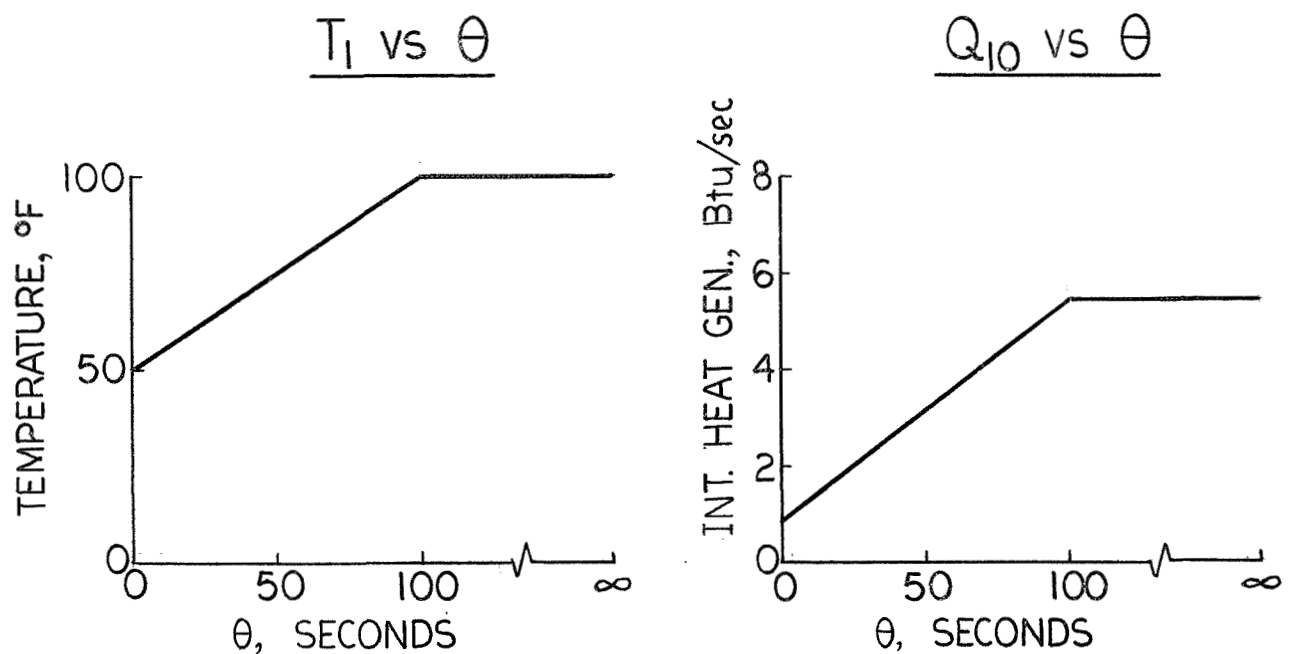


Figure 10.2

Variation of Parameters



MASS FLOW RATES

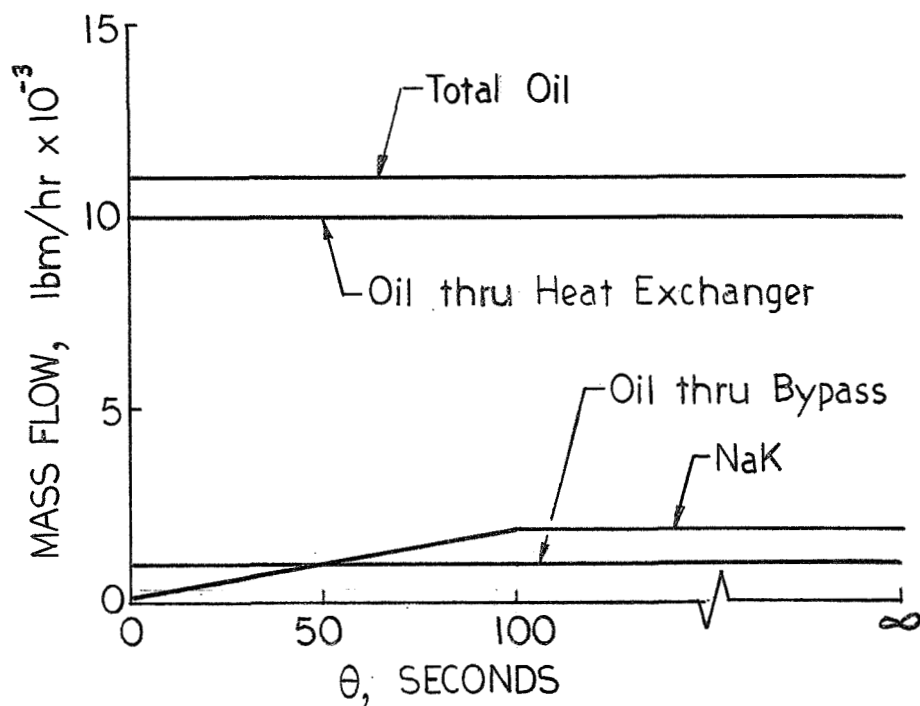


Figure 10.3



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THERMAL NETWORK CALCULATIONS

NODE 1

INFINITE SOURCE ACTING AS UPSTREAM NODE
TO COLD SIDE FLOW SERIES

$$C_1 = -1.0$$

$$T_1 = f(\Theta) \text{ IN TABLE 1 (SEE FIGURE 1)}$$

$$Q_1 = 0$$

ONLY DUMMY RESISTOR CONNECTIONS.

NODES 2 & 8

$$C_2 = \frac{V}{P_{OIL}} C_{P_{OIL}} = 1.0 \frac{\text{BTU}}{\text{OF}}$$

$$C_{V_2} = C_2$$

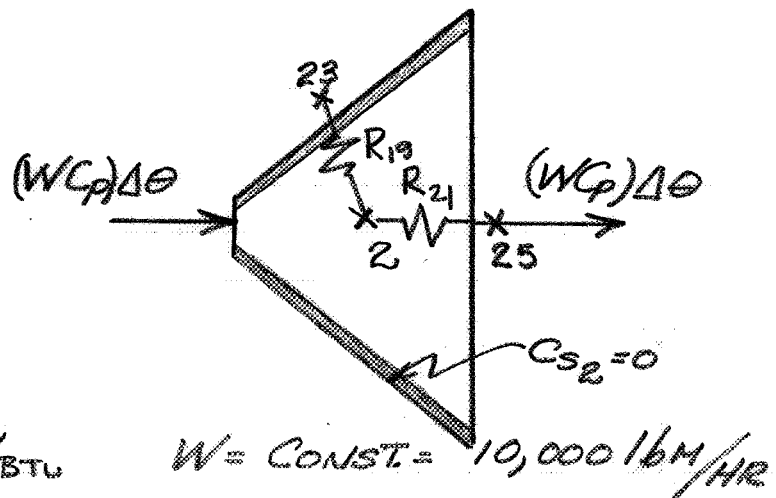
$$C_{S_2} = 0$$

$$T_2 \sim \text{CALCULATED}$$

$$Q_2 = 0$$

$$R_{19} = \frac{1}{hA} = 12.5 \text{ SEC } ^\circ\text{F}/\text{BTU}$$

$$R_{21} = \frac{1}{hA} = 94.0 \text{ SEC } ^\circ\text{F}/\text{BTU}$$



NODES 3-7

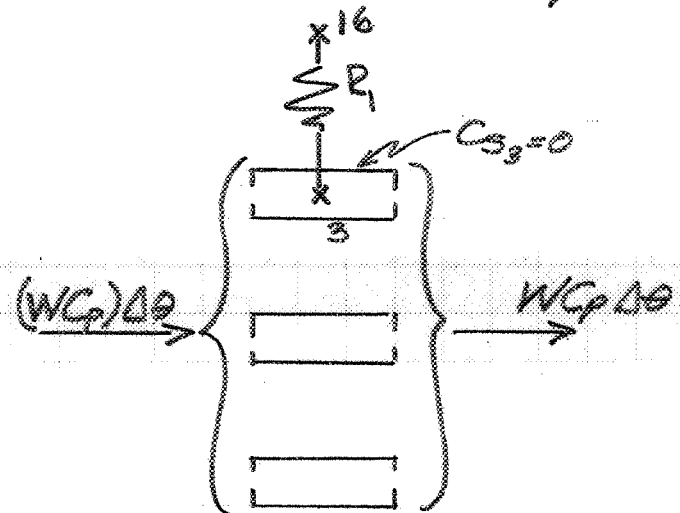
$$C_3 = (WC_p) \Delta \Theta$$

$$C_{S_3} = 0.0$$

$$T_3 \sim \text{CALCULATED}$$

$$Q_3 = 0.0$$

$$R_1 = \frac{1}{UA} = 94.0 \text{ SEC } ^\circ\text{F}/\text{BTU}$$



$$W = \text{CONST} = 10,000 \text{ lbm/hr}$$

Figure 10.4.1



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THERMAL NETWORK CALCULATIONS

NODE 9

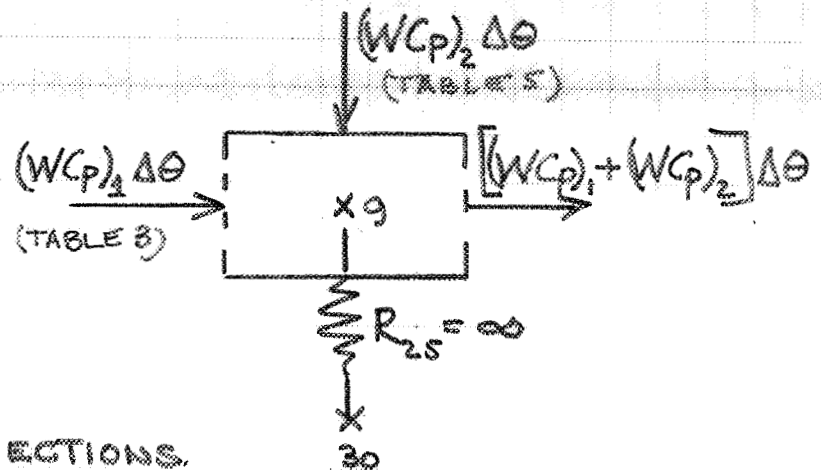
$$C_9 = [(WC_p)_1 + (WC_p)_2] \Delta \theta$$

$$C_{S_9} = 0$$

$T_9 \approx$ CALCULATED

$$Q_9 = 0.0$$

ONLY DUMMY RESISTOR CONNECTIONS.



NODE 10

$$C_{10} = C_{V_{10}} + C_{S_{10}}$$

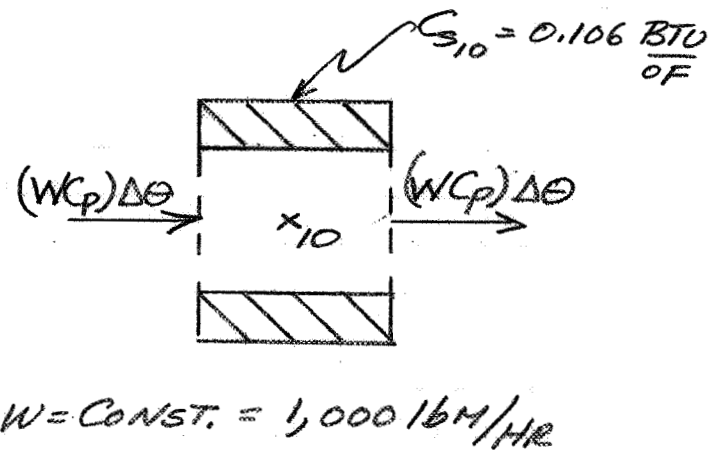
$$C_{V_{10}} = V_{OIL} C_{POIL} = 0.154 \frac{BTU}{OF}$$

$$C_{S_{10}} = V_{S.S} C_{PS} = 0.106 \frac{BTU}{OF}$$

$T_{10} \approx$ CALCULATED

$$Q_{10} = f(\theta) \text{ TABLE 2 (FIG 10.3)}$$

ONLY DUMMY RESISTOR CONNECTIONS



$$W = \text{CONST.} = 1,000 \text{ lbm/hr}$$

NODE 11

INFINITE SOURCE ACTING AS UPSTREAM NODE
TO HOT SIDE FLOW SERIES

$$C_{11} = -1.0$$

$$T_{11} = \text{CONST} = 1000^\circ F$$

$$Q_{11} = 0.0$$

ONLY DUMMY RESISTOR CONNECTIONS.



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THERMAL NETWORK CALCULATIONS

NODES 12-16

$$C_{12} = C_{V12} + C_{S12} = 0.337 \text{ BTU/}^\circ\text{F}$$

$$C_{V12} = \frac{VP}{(NAK) P_{NAK}} C_p = 0.106 \text{ BTU/}^\circ\text{F}$$

$$C_{S12} = \frac{VP}{(SS) P_{SS}} C_p = 0.231 \text{ BTU/}^\circ\text{F}$$

$T_{12} \approx \text{CALCULATED}$

$$Q_{12} = 0.0$$

$$R_5 = \frac{1}{UA} = 37.1 \frac{\text{SEC} \cdot ^\circ\text{F}}{\text{BTU}}$$

$$R_6 = \frac{L_{INS}}{K_{INS} A} = 360. \frac{\text{SEC} \cdot ^\circ\text{F}}{\text{BTU}}$$

$$\theta_f = 6.17 \text{ SECONDS (SEE BOTTOM OF PAGE)}$$

NODE 17

$$C_{17} = C_{V17} + C_{S17} = 0.963 \text{ BTU/}^\circ\text{F}$$

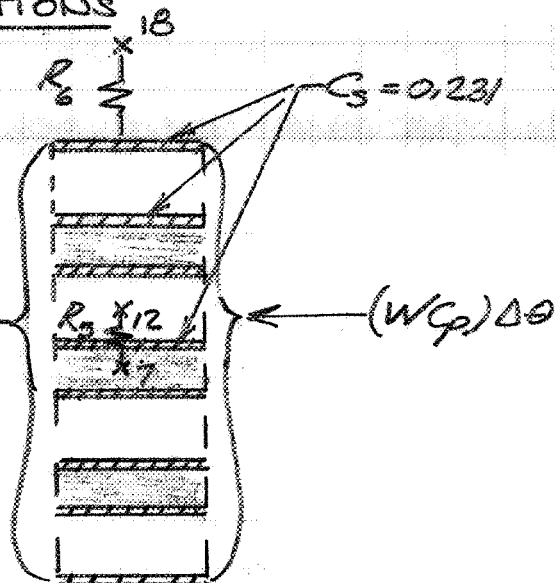
$$C_{V17} = \frac{VP}{(NAK) P_{NAK}} C_p = 0.75 \text{ BTU/}^\circ\text{F}$$

$$C_{S17} = \frac{VP}{(SS) P_{SS}} C_p = 0.213 \text{ BTU/}^\circ\text{F}$$

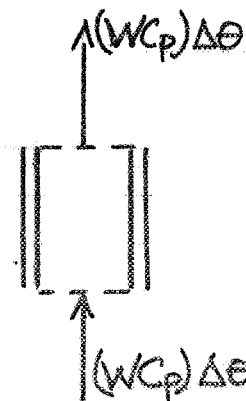
$T_{17} \approx \text{CALCULATED}$

$$Q_{17} = 0.0$$

ONLY DUMMY RESISTOR CONNECTIONS



(W = f(θ)) TABLE 4



(W = f(θ)) TABLE 4

$\theta_f \approx$ The Time Required for the Node To Fill With NAK AND THUS BE CONNECTED IN THE CATHODE FOLLOWER SERIES



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THERMAL NETWORK CALCULATIONS

$$\Theta_{f_i} = \frac{\sum_{n=0}^n C_{v_{i-n}}}{(WC_p)}$$

FOR THE NAK (HOT SIDE FLUID) THE CAPACITANCE FLOW EQUATION IS

$$(WC_p) = 1 \cdot 10^{-3} \Theta_{f_i} + 0.011 \quad \text{SEE FIGURE AND TABLE 7}$$

SUBSTITUTING (WC_p) IN THE ABOVE EQUATION GIVES

$$\Theta_{f_i}^2 + 11.0 \Theta_{f_i} - 10^3 \cdot \sum_{n=0}^n C_{v_{i-n}} = 0$$

THE ABOVE EQUATION CAN BE SOLVED TO FIND $\Theta_{f_{12}} - \Theta_{f_{17}}$

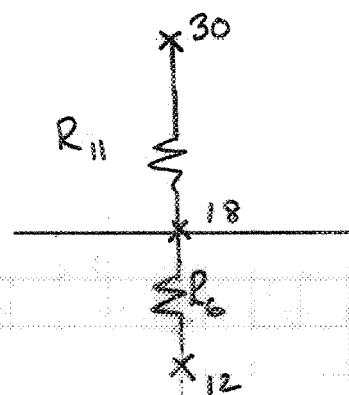
NODES 18-22

$$C_{18} = 0.0$$

$$T_{18} \sim \text{CALCULATED}$$

$$Q_{18} = 0.0$$

$$R_6 = \frac{L_{INS}}{K_{INS} A} = 360 \frac{\text{SEC-OF}}{\text{BTU}}$$



$$R_{11} = \frac{1}{K} f(T_{12}, T_{18}) \quad K = 0.7 \text{ A} = 0.476 \times 10^{-13} \text{ (FUNCTION 2)}$$

Figure 10.4.4



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THERMAL NETWORK CALCULATIONS
NODES 23 & 24

$$C_{23} = \frac{V \rho C}{V_{SS} P_{SS}} = 0.4 \frac{\text{BTU}}{^{\circ}\text{F}}$$

T_{23} ~ CALCULATED

$$Q_{23} = 0.0$$

$$R_{17} = \frac{1}{K} f(T_{23}, T_{30}) \quad K = 0.7_{17} A = 0.21 \times 10^{-12} \quad (\text{FUNCTION 2})$$

$$R_{19} = \frac{1}{hA} = 12.5 \frac{\text{SEC} - ^{\circ}\text{F}}{\text{BTU}}$$

NODES 25 & 26

$$C_{25} = \frac{V \rho C}{V_{SS} P_{SS}} = 0.13 \frac{\text{BTU}}{^{\circ}\text{F}}$$

T_{25} ~ CALCULATED

$$Q_{25} = 0.0$$

$$R_{21} = \frac{1}{hA} = 94 \frac{\text{SEC} - ^{\circ}\text{F}}{\text{BTU}}$$

$$R_{23} = \frac{1}{hA} = 27.5 \frac{\text{SEC} - ^{\circ}\text{F}}{\text{BTU}}$$

NODE 30

INFINITE SINK REPRESENTING SURROUNDINGS
CONNECTED BY RADIATION RESISTORS TO SURFACE NODES
AND BY DUMMY RESISTORS TO ALL NODES WHICH WOULD
OTHERWISE NOT BE CONNECTED TO A RESISTOR

$$C_{30} = -1.0$$

$$\frac{1}{30} = \text{CONST.} = 50 ^{\circ}\text{F}$$

$$Q_{30} = 0.0$$

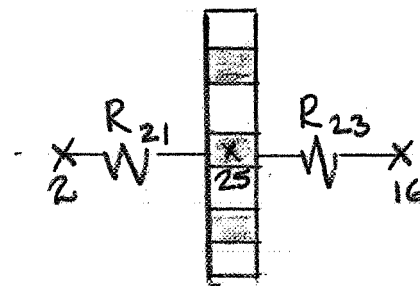
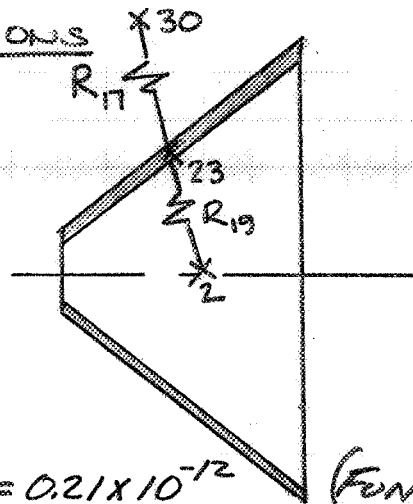


Figure 10.4.5

SAMPLE PROBLEM 1

OIL/NAK HEAT EXCHANGER

SUMMARY OF THERMAL NETWORK

NODE ID NO.	DESCRIPTION	RESISTORS TO WHICH CONNECTED AND THEIR VALUES - 2 DEG-°F/BTU	INITIAL TEMP	TEMP OF NODE IS CALCULATED	INPUT	NODE CAPACITANCES C_v BTU/°F C_s BTU/°F	NODE TYPE	θ_F VSEC	(WCP) GIVEN IN TABLE NO.	SOLUTION EQUATION NO.
1	COLD SIDE INLET	$R_{21} = 94.0 \text{ COND}$	50	X	X	1.0	NEG. CAP.	—	3	6-7 TABLE 1
2	COLD SIDE INLET PLENUM PASSAGE	$R_1 = 37.8 \text{ COND}$	50	X	X	1.0	FUN10 TYPE 2	—	3	6-3
3	COLD SIDE OIL PASSAGE	$R_2 = 37.1 \text{ COND}$	50	X	X	0.0	FUN12	—	3	6-4
4	"	$R_3 = 36.0 \text{ COND}$	50	X	X	"	"	—	3	6-4
5	"	$R_4 = 36.0 \text{ COND}$	50	X	X	"	"	—	3	6-4
6	"	$R_5 = 37.1 \text{ COND}$	50	X	X	"	"	—	3	6-4
7	"	$R_{25} = 94.0 \text{ COND}$	50	X	X	1.0	FUN10 TYPE 2	—	3	6-3
8	COLD SIDE OUTLET PLENUM PASSAGE	$R_{25} = 94.0 \text{ COND}$	50	X	X	0.055	FUN11	—	6	6-5
9	COLD SIDE OUTLET	$R_{25} = 94.0 \text{ COND}$	50	X	X	0.36	FUN10 TYPE 2	—	5	6-3
10*	HEAT EXCHANGER BYPASS	$R_8 = 110.0 \text{ COND}$	50	X	X	0.54	NEG. CAP.	—	—	6-7
11	HOT SIDE INLET	$R_8 = 110.0 \text{ COND}$	1000	X	X	0.37	FUN10 TYPE 2	6.17	4	6-3
12	HOT SIDE NAK PASSAGE (W/2) SHELL	$R_9 = 36.0 \text{ COND}$	1000	X	X	"	"	10.1	4	6-3
13	"	$R_9 = 36.0 \text{ COND}$	1000	X	X	"	"	13.2	4	6-3
14	"	$R_9 = 36.0 \text{ COND}$	1000	X	X	"	"	15.5	4	6-3
15	"	$R_9 = 36.0 \text{ COND}$	1000	X	X	"	"	18.2	4	6-3
16	"	$R_9 = 36.0 \text{ COND}$	1000	X	X	"	"	29.5	4	6-3
17	HOT SIDE OUTLET	$R_{10} = 110.0 \text{ COND}$	1000	X	X	0.75	ZERO CAP.	—	4	6-6
18	HEAT EXCHANGER SHELL SURFACE	$R_{10} = 110.0 \text{ COND}$	1000	X	X	0.0	"	—	—	6-6
19	"	$R_{11} = 36.0 \text{ COND}$	1000	X	X	0.0	"	—	—	6-6
20	"	$R_{12} = 36.0 \text{ COND}$	1000	X	X	0.0	"	—	—	6-6
21	"	$R_{13} = 36.0 \text{ COND}$	1000	X	X	0.0	"	—	—	6-6
22	"	$R_{14} = 36.0 \text{ COND}$	1000	X	X	0.0	"	—	—	6-6
23	COLD SIDE INLET PLENUM SHELL	$R_{15} = 36.0 \text{ COND}$	1000	X	X	0.0	"	—	—	6-6
24	COLD SIDE OUTLET PLENUM SHELL	$R_{16} = 12.5 \text{ COND}$	1000	X	X	0.4	POS CAP (W/100 HASSTANS)	—	—	6-1
25	COLD SIDE INLET GRID PLATE	$R_{17} = 12.5 \text{ COND}$	1000	X	X	0.4	"	—	—	6-1
26	COLD SIDE OUTLET GRID PLATE	$R_{18} = 12.5 \text{ COND}$	1000	X	X	0.13	"	—	—	6-1
30	SURROUNDINGS	$R_{22} = 94.0 \text{ COND}$	50	X	X	0.13	NEG. CAP.	—	—	6-7

Figure 10.5

* $Q_{10} = f(\theta)$ IN TABLE 2

PROGRAMMED BY-

TITLE		THERMAL ANALYSIS OF FILM/NAK HEAT EXCHANGER	
1	3	16	37.8
2	4	15	37.1
3	5	14	36.0
4	6	13	36.0
5	7	12	37.1
6	-12	18	36.0
10	16	22	36.0
11	18	30	11.0
12	19	↑	↑
13	20	↓	↓
14	21	↓	↓
15	22	↓	↓
16	24	↓	↓
17	23	↓	↓
18	10	30	11.1
19	2	23	12.5
20	8	24	12.5
21	25	2	94.0
22	26	8	94.0
23	25	16	27.5
24	26	12	27.5
25	9	30	11.1
26	17	30	11.1
27			

STK. NO. D-1-083

STK No. D-1-083

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
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1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
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1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
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1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26																																																						

Figure 10.6.2

STK. NO. D-1-083

[illegible]

Figure 10.6.3

COMPUTING SCIENCES DIVISION

80 COLUMN INPUT

DATE _____ PROGRAM NO. _____ PROGRAMMED BY _____

1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0
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Figure 10.6.4

STK. NO. D-2-083

[illegible]

Figure 10.6.5

STIS NO. D-1-083

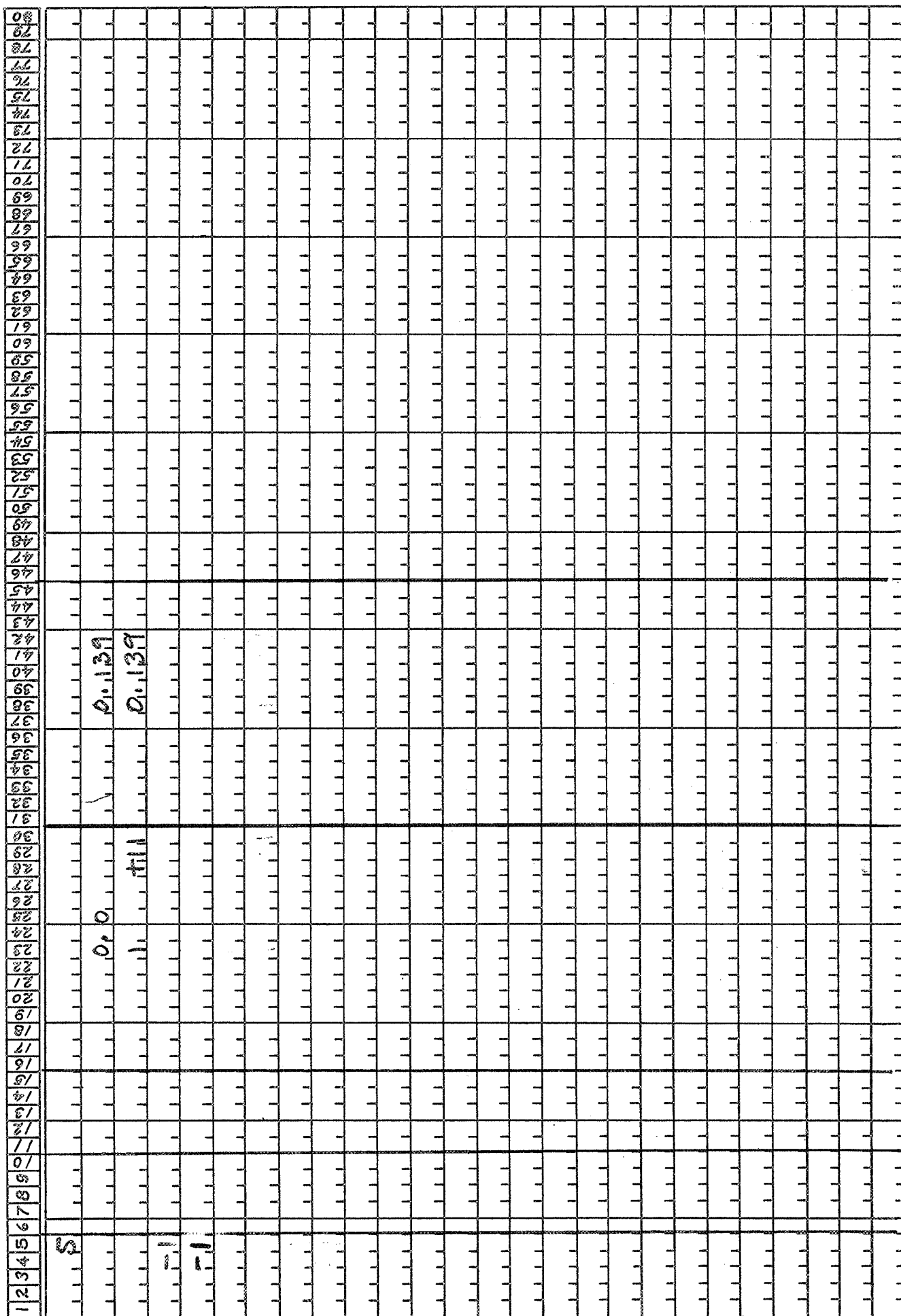


Figure 10.6.6

THERMAL ANALYSIS OF OIL-NAK HEAT EXCHANGER

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26	0	0	0.50000E 02	0.0	** GENERATED NODE **
19	0	0	0.50000E 02	0.0	** GENERATED NODE **
20	0	0	0.50000E 02	0.0	** GENERATED NODE **
21	0	0	0.50000E 02	0.0	** GENERATED NODE **
23	0	0	0.50000E 02	0.40000E 00	
24	0	0	0.50000E 02	0.40000E 00	
25	0	0	0.50000E 02	0.13000E 00	
26	0	0	0.50000E 02	0.13000E 00	
30	0	0	0.50000E 02	-0.10000E 01	
-1	0	0	0.0	0.0	
2	0	11	0.47600E-13		
0	0	12	0.47600E-13		
0	0	13	0.47600E-13		
0	0	14	0.47600E-13		
0	0	15	0.47600E-13		
0	0	16	0.21000E-12		
0	0	17	0.21000E-12		
-1	0	0	0.0		
7	0	0	0.0		
1	0	1	0.0		
10	0	2	0.0		
-1	0	0	0.0		
8	2	-1	0.0		
0	2	26	0.0		
NODES 1 TO 26 HAVE BEEN GENERATED INTERNALLY. THE INFORMATION IS THE SAME AS SHOWN FOR NODE 26					
-1	0	0	0.0		
9	0	1	0.10000E 01		
0	0	1	0.10000E 01	0.10000E 02	
0	0	1	0.50000E 01	0.50000E 02	
0	0	1	0.20000E 02	0.20000E 03	
0	0	1	0.10000E 03	0.10000E 11	
0	0	3	0.25000E 00	0.0	
0	0	4	0.10000E 06		
0	0	10	0.20000E 01		
-1	0	0	0.0		
10	0	0	0.0		
3	2	1	0.10000E 01	0.0	
3	8	7	0.10000E 01	0.0	
4	12	11	0.10600E 00	0.0	
4	13	12	0.10600E 00	0.10100E 02	
4	14	13	0.10600E 00	0.13200E 02	
4	15	14	0.10600E 00	0.15800E 02	
4	16	15	0.10600E 00	0.18200E 02	
4	17	16	0.75000E 00	0.29600E 02	
5	10	1	0.15400E 00	0.0	
-1	0	0	0.0	0.0	
11	0	0	0.0		
5	9	10	0.0		
13	9	8	0.0		
-1	0	0	0.0		

Figure 10.7.2

12	11	10	9	8	7	6	5	4	3	2	1	0	U	U
38	3	0	0	0	0	0	0	0	0	0	0	0	0	0
39	3	0	0	0	0	0	0	0	0	0	0	0	0	0
40	3	0	0	0	0	0	0	0	0	0	0	0	0	0
41	3	0	0	0	0	0	0	0	0	0	0	0	0	0
42	3	0	0	0	0	0	0	0	0	0	0	0	0	0
-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 10.7.3

THERMAL ANALYSIS OF OIL-NAK HEAT EXCHANGER

TIME =	0.0	RCMIN(	0) =0.0	DELTA THETA =0.0	
T-	1= 5.00000E 01	T-	2= 5.00000E 01	T-	3= 5.00000E 01
T-	6= 5.00000E 01	T-	7= 5.00000E 01	T-	8= 5.00000E 01
T-	11= 1.00000E 03	T-	12= 5.00000E 01	T-	13= 5.00000E 01
T-	16= 5.00000E 01	T-	17= 5.00000E 01	T-	18= 5.00000E 01
T-	21= 5.00000E 01	T-	22= 5.00000E 01	T-	23= 5.00000E 01
T-	26= 5.00000E 01			T-	4= 5.00000E 01
				T-	9= 5.00000E 01
				T-	14= 5.00000E 01
				T-	19= 5.00000E 01
				T-	24= 5.00000E 01
				T-	5= 5.00000E 01
				T-	10= 5.00000E 01
				T-	15= 5.00000E 01
				T-	20= 5.00000E 01
				T-	25= 5.00000E 01

TIME = 1.00 RCMIN(25) =2.76584E 00 DELTA THETA =1.0000E-01

T-	1= 5.04500E 01	T-	2= 5.04338E 01	T-	3= 5.04255E 01
T-	6= 5.04008E 01	T-	7= 5.10799E 01	T-	8= 5.03611E 01
T-	11= 1.00000E 03	T-	12= 8.54208E 01	T-	13= 5.00010E 01
T-	16= 5.00010E 01	T-	17= 5.00000E 01	T-	18= 8.50898E 01
T-	21= 5.00010E 01	T-	22= 5.00010E 01	T-	23= 5.00027E 01
T-	26= 5.03704E 01			T-	4= 5.04173E 01
				T-	9= 5.05130E 01
				T-	14= 5.00010E 01
				T-	19= 5.00010E 01
				T-	24= 5.00000E 01
				T-	5= 5.04090E 01
				T-	10= 5.20329E 01
				T-	15= 5.00010E 01
				T-	20= 5.00010E 01
				T-	25= 5.00011E 01

TIME = 2.00 RCMIN(25) =2.76584E 00 DELTA THETA =3.0854E-01

T-	1= 5.08457E 01	T-	2= 5.08094E 01	T-	3= 5.07946E 01
T-	6= 5.07504E 01	T-	7= 5.20880E 01	T-	8= 5.13710E 01
T-	11= 1.00000E 03	T-	12= 1.19730E 02	T-	13= 5.00342E 01
T-	16= 5.00346E 01	T-	17= 5.00000E 01	T-	18= 1.19005E 02
T-	21= 5.00342E 01	T-	22= 5.00343E 01	T-	23= 5.00872E 01
T-	26= 6.07237E 01			T-	4= 5.07799E 01
				T-	9= 5.15827E 01
				T-	14= 5.00349E 01
				T-	19= 5.00339E 01
				T-	24= 5.01078E 01
				T-	5= 5.07650E 01
				T-	10= 5.36994E 01
				T-	15= 5.00345E 01
				T-	20= 5.00346E 01
				T-	25= 5.00366E 01

TIME = 3.00 RCMIN(25) =2.76584E 00 DELTA THETA =3.0854E-01

T-	1= 5.13457E 01	T-	2= 5.12975E 01	T-	3= 5.12746E 01
T-	6= 5.12060E 01	T-	7= 5.31377E 01	T-	8= 5.24345E 01
T-	11= 1.00000E 03	T-	12= 1.50820E 02	T-	13= 5.00952E 01
T-	16= 5.00966E 01	T-	17= 5.00000E 01	T-	18= 1.49676E 02
T-	21= 5.00953E 01	T-	22= 5.00957E 01	T-	23= 5.02332E 01
T-	26= 7.63142E 01			T-	4= 5.12518E 01
				T-	9= 5.26614E 01
				T-	14= 5.00971E 01
				T-	19= 5.00944E 01
				T-	24= 5.03895E 01
				T-	5= 5.12287E 01
				T-	10= 5.49306E 01
				T-	15= 5.00962E 01
				T-	20= 5.00962E 01
				T-	25= 5.01012E 01

Figure 10.7.4

TIME =		.CO	RCMIN(	25)	=2.76584E 00	DFI	THETA =3.0854E-01		
T-	1=	5.18457E 01	T-	2=	5.17877E 01	T-	3= 5.17573E 01	T-	4= 5.17269E 01
T-	6=	5.16660E 01	T-	7=	5.41481E 01	T-	8= 5.34804E 01	T-	9= 5.37029E 01
T-	11=	1.00000E 03	T-	12=	1.79661E 02	T-	13= 5.01880F 01	T-	14= 5.01916E 01
T-	16=	5.01908E 01	T-	17=	5.00000E 01	T-	18= 1.78067F 02	T-	19= 5.01863E 01
T-	21=	5.01881E 01	T-	22=	5.01891E 01	T-	23= 5.04440E 01	T-	24= 5.08238E 01
T-	26=	9.46349E 01						T-	25= 5.01988E 01
TIME =		5.00	RCMIN(	25)	=2.76584E 00	DELTA	THETA =3.0854E-01		
T-	1=	5.23457E 01	T-	2=	5.22795E 01	T-	3= 5.22421E 01	T-	4= 5.22047E 01
T-	6=	5.21299E 01	T-	7=	5.51290E 01	T-	8= 5.45072E 01	T-	9= 5.47156E 01
T-	11=	1.00000E 03	T-	12=	2.06795E 02	T-	13= 5.03103E 01	T-	14= 5.03160E 01
T-	16=	5.03152E 01	T-	17=	5.00000E 01	T-	18= 2.04720E 02	T-	19= 5.03075E 01
T-	21=	5.03104E 01	T-	22=	5.03124E 01	T-	23= 5.07076E 01	T-	24= 5.13790E 01
T-	26=	1.14231E 02						T-	25= 5.03268E 01
TIME =		6.00	RCMIN(	25)	=2.76584E 00	DELTA	THETA =3.0854E-01		
T-	1=	5.28457E 01	T-	2=	5.27727E 01	T-	3= 5.27288E 01	T-	4= 5.26849E 01
T-	6=	5.25970E 01	T-	7=	5.60862E 01	T-	8= 5.55167E 01	T-	9= 5.57064E 01
T-	11=	1.00000E 03	T-	12=	2.32529E 02	T-	13= 5.04601E 01	T-	14= 5.04684E 01
T-	16=	5.04676E 01	T-	17=	5.00000E 01	T-	18= 2.29941E 02	T-	19= 5.04560E 01
T-	21=	5.04601E 01	T-	22=	5.04634E 01	T-	23= 5.10144E 01	T-	24= 5.20285E 01
T-	26=	1.34258E 02						T-	25= 5.04828E 01
TIME =		7.00	RCMIN(	25)	=2.76584E 00	DELTA	THETA =3.0854E-01		
T-	1=	5.33457E 01	T-	2=	5.32670E 01	T-	3= 5.32171E 01	T-	4= 5.31671E 01
T-	6=	5.30672E 01	T-	7=	5.70225E 01	T-	8= 5.65094E 01	T-	9= 5.66786E 01
T-	11=	1.00000E 03	T-	12=	2.57037E 02	T-	13= 5.06355F 01	T-	14= 5.06466E 01
T-	16=	5.06460F 01	T-	17=	5.00000E 01	T-	18= 2.53907F 02	T-	19= 5.06298E 01
T-	21=	5.06353E 01	T-	22=	5.06402E 01	T-	23= 5.13564E 01	T-	24= 5.27513E 01
T-	26=	1.54223E 02						T-	25= 5.06648E 01
TIME =		8.00	RCMIN(	25)	=2.76584E 00	DELTA	THETA =3.0854E-01		
T-	1=	5.39457E 01	T-	2=	5.37622E 01	T-	3= 5.37067F 01	T-	4= 5.36512E 01
T-	6=	5.35400E 01	T-	7=	5.79396E 01	T-	8= 5.74852E 01	T-	9= 5.76338E 01
T-	11=	1.00000E 03	T-	12=	2.80422F 02	T-	13= 5.08346E 01	T-	14= 5.08488F 01
								T-	15= 5.08418E 01

Figure 10.7.5

T- 10= 2.00000E 01	T- 11= 2.00000E 01	T- 12= 2.00000E 01	T- 13= 2.00000E 01	T- 14= 2.00000E 01	T- 15= 2.00000E 01	T- 16= 2.00000E 01	T- 17= 2.00000E 01	T- 18= 2.00000E 01	T- 19= 2.00000E 01	T- 20= 2.00000E 01	T- 21= 2.00000E 01	T- 22= 2.00000E 01	T- 23= 2.00000E 01	T- 24= 2.00000E 01	T- 25= 2.00000E 01	T- 26= 2.00000E 01
T- 10= 2.00000E 01	T- 11= 2.00000E 01	T- 12= 2.00000E 01	T- 13= 2.00000E 01	T- 14= 2.00000E 01	T- 15= 2.00000E 01	T- 16= 2.00000E 01	T- 17= 2.00000E 01	T- 18= 2.00000E 01	T- 19= 2.00000E 01	T- 20= 2.00000E 01	T- 21= 2.00000E 01	T- 22= 2.00000E 01	T- 23= 2.00000E 01	T- 24= 2.00000E 01	T- 25= 2.00000E 01	T- 26= 2.00000E 01
T- 10= 2.00000E 01	T- 11= 2.00000E 01	T- 12= 2.00000E 01	T- 13= 2.00000E 01	T- 14= 2.00000E 01	T- 15= 2.00000E 01	T- 16= 2.00000E 01	T- 17= 2.00000E 01	T- 18= 2.00000E 01	T- 19= 2.00000E 01	T- 20= 2.00000E 01	T- 21= 2.00000E 01	T- 22= 2.00000E 01	T- 23= 2.00000E 01	T- 24= 2.00000E 01	T- 25= 2.00000E 01	T- 26= 2.00000E 01
T- 10= 2.00000E 01	T- 11= 2.00000E 01	T- 12= 2.00000E 01	T- 13= 2.00000E 01	T- 14= 2.00000E 01	T- 15= 2.00000E 01	T- 16= 2.00000E 01	T- 17= 2.00000E 01	T- 18= 2.00000E 01	T- 19= 2.00000E 01	T- 20= 2.00000E 01	T- 21= 2.00000E 01	T- 22= 2.00000E 01	T- 23= 2.00000E 01	T- 24= 2.00000E 01	T- 25= 2.00000E 01	T- 26= 2.00000E 01
T- 10= 2.00000E 01	T- 11= 2.00000E 01	T- 12= 2.00000E 01	T- 13= 2.00000E 01	T- 14= 2.00000E 01	T- 15= 2.00000E 01	T- 16= 2.00000E 01	T- 17= 2.00000E 01	T- 18= 2.00000E 01	T- 19= 2.00000E 01	T- 20= 2.00000E 01	T- 21= 2.00000E 01	T- 22= 2.00000E 01	T- 23= 2.00000E 01	T- 24= 2.00000E 01	T- 25= 2.00000E 01	T- 26= 2.00000E 01
T- 10= 2.00000E 01	T- 11= 2.00000E 01	T- 12= 2.00000E 01	T- 13= 2.00000E 01	T- 14= 2.00000E 01	T- 15= 2.00000E 01	T- 16= 2.00000E 01	T- 17= 2.00000E 01	T- 18= 2.00000E 01	T- 19= 2.00000E 01	T- 20= 2.00000E 01	T- 21= 2.00000E 01	T- 22= 2.00000E 01	T- 23= 2.00000E 01	T- 24= 2.00000E 01	T- 25= 2.00000E 01	T- 26= 2.00000E 01
T- 10= 2.00000E 01	T- 11= 2.00000E 01	T- 12= 2.00000E 01	T- 13= 2.00000E 01	T- 14= 2.00000E 01	T- 15= 2.00000E 01	T- 16= 2.00000E 01	T- 17= 2.00000E 01	T- 18= 2.00000E 01	T- 19= 2.00000E 01	T- 20= 2.00000E 01	T- 21= 2.00000E 01	T- 22= 2.00000E 01	T- 23= 2.00000E 01	T- 24= 2.00000E 01	T- 25= 2.00000E 01	T- 26= 2.00000E 01
T- 10= 2.00000E 01	T- 11= 2.00000E 01	T- 12= 2.00000E 01	T- 13= 2.00000E 01	T- 14= 2.00000E 01	T- 15= 2.00000E 01	T- 16= 2.00000E 01	T- 17= 2.00000E 01	T- 18= 2.00000E 01	T- 19= 2.00000E 01	T- 20= 2.00000E 01	T- 21= 2.00000E 01	T- 22= 2.00000E 01	T- 23= 2.00000E 01	T- 24= 2.00000E 01	T- 25= 2.00000E 01	T- 26= 2.00000E 01
T- 10= 2.00000E 01	T- 11= 2.00000E 01	T- 12= 2.00000E 01	T- 13= 2.00000E 01	T- 14= 2.00000E 01	T- 15= 2.00000E 01	T- 16= 2.00000E 01	T- 17= 2.00000E 01	T- 18= 2.00000E 01	T- 19= 2.00000E 01	T- 20= 2.00000E 01	T- 21= 2.00000E 01	T- 22= 2.00000E 01	T- 23= 2.00000E 01	T- 24= 2.00000E 01	T- 25= 2.00000E 01	T- 26= 2.00000E 01
T- 10= 2.00000E 01	T- 11= 2.00000E 01	T- 12= 2.00000E 01	T- 13= 2.00000E 01	T- 14= 2.00000E 01	T- 15= 2.00000E 01	T- 16= 2.00000E 01	T- 17= 2.00000E 01	T- 18= 2.00000E 01	T- 19= 2.00000E 01	T- 20= 2.00000E 01	T- 21= 2.00000E 01	T- 22= 2.00000E 01	T- 23= 2.00000E 01	T- 24= 2.00000E 01	T- 25= 2.00000E 01	T- 26= 2.00000E 01
T- 10= 2.00000E 01	T- 11= 2.00000E 01	T- 12= 2.00000E 01	T- 13= 2.00000E 01	T- 14= 2.00000E 01	T- 15= 2.00000E 01	T- 16= 2.00000E 01	T- 17= 2.00000E 01	T- 18= 2.00000E 01	T- 19= 2.00000E 01	T- 20= 2.00000E 01	T- 21= 2.00000E 01	T- 22= 2.00000E 01	T- 23= 2.00000E 01	T- 24= 2.00000E 01	T- 25= 2.00000E 01	T- 26= 2.00000E 01
T- 10= 2.00000E 01	T- 11= 2.00000E 01	T- 12= 2.00000E 01	T- 13= 2.00000E 01	T- 14= 2.00000E 01	T- 15= 2.00000E 01	T- 16= 2.00000E 01	T- 17= 2.00000E 01	T- 18= 2.00000E 01	T- 19= 2.00000E 01	T- 20= 2.00000E 01	T- 21= 2.00000E 01	T- 22= 2.00000E 01	T- 23= 2.00000E 01	T- 24= 2.00000E 01	T- 25= 2.00000E 01	T- 26= 2.00000E 01
T- 10= 2.00000E 01	T- 11= 2.00000E 01	T- 12= 2.00000E 01	T- 13= 2.00000E 01	T- 14= 2.00000E 01	T- 15= 2.00000E 01	T- 16= 2.00000E 01	T- 17= 2.00000E 01	T- 18= 2.00000E 01	T- 19= 2.00000E 01	T- 20= 2.00000E 01	T- 21= 2.00000E 01	T- 22= 2.00000E 01	T- 23= 2.00000E 01	T- 24= 2.00000E 01	T- 25= 2.00000E 01	T- 26= 2.00000E 01
T- 10= 2.00000E 01	T- 11= 2.00000E 01	T- 12= 2.00000E 01	T- 13= 2.00000E 01	T- 14= 2.00000E 01	T- 15= 2.00000E 01	T- 16= 2.00000E 01	T- 17= 2.00000E 01	T- 18= 2.00000E 01	T- 19= 2.00000E 01	T- 20= 2.00000E 01	T- 21= 2.00000E 01	T- 22= 2.00000E 01	T- 23= 2.00000E 01	T- 24= 2.00000E 01	T- 25= 2.00000E 01	T- 26= 2.00000E 01
T- 10= 2.00000E 01	T- 11= 2.00000E 01	T- 12= 2.00000E 01	T- 13= 2.00000E 01	T- 14= 2.00000E 01	T- 15= 2.00000E 01	T- 16= 2.00000E 01	T- 17= 2.00000E 01	T- 18= 2.00000E 01	T- 19= 2.00000E 01	T- 20= 2.00000E 01	T- 21= 2.00000E 01	T- 22= 2.00000E 01	T- 23= 2.00000E 01	T- 24= 2.00000E 01	T- 25= 2.00000E 01	T- 26= 2.00000E 01
T- 10= 2.00000E 01	T- 11= 2.00000E 01	T- 12= 2.00000E 01	T- 13= 2.00000E 01	T- 14= 2.00000E 01	T- 15= 2.00000E 01	T- 16= 2.00000E 01	T- 17= 2.00000E 01	T- 18= 2.00000E 01	T- 19= 2.00000E 01	T- 20= 2.00000E 01	T- 21= 2.00000E 01	T- 22= 2.00000E 01	T- 23= 2.00000E 01	T- 24= 2.00000E 01	T- 25= 2.00000E 01	T- 26= 2.00000E 01
T- 10= 2.00000E 01	T- 11= 2.00000E 01	T- 12= 2.00000E 01	T- 13= 2.00000E 01	T- 14= 2.00000E 01	T- 15= 2.00000E 01	T- 16= 2.00000E 01	T- 17= 2.00000E 01	T- 18= 2.00000E 01	T- 19= 2.00000E 01	T- 20= 2.00000E 01	T- 21= 2.00000E 01	T- 22= 2.00000E 01	T- 23= 2.00000E 01	T- 24= 2.00000E 01	T- 25= 2.00000E 01	T- 26= 2.00000E 01
T- 10= 2.00000E 01	T- 11= 2.00000E 01	T- 12= 2.00000E 01	T- 13= 2.00000E 01	T- 14= 2.00000E 01	T- 15= 2.00000E 01	T- 16= 2.00000E 01	T- 17= 2.00000E 01	T- 18= 2.00000E 01	T- 19= 2.00000E 01	T- 20= 2.00000E 01	T- 21= 2.00000E 01	T- 22= 2.00000E 01	T- 23= 2.00000E 01	T- 24= 2.00000E 01	T- 25= 2.00000E 01	T- 26= 2.00000E 01
T- 10= 2.00000E 01	T- 11= 2.00000E 01	T- 12= 2.00000E 01	T- 13= 2.00000E 01	T- 14= 2.00000E 01	T- 15= 2.00000E 01	T- 16= 2.00000E 01	T- 17= 2.00000E 01	T- 18= 2.00000E 01	T- 19= 2.00000E 01	T- 20= 2.00000E 01	T- 21= 2.00000E 01	T- 22= 2.00000E 01	T- 23= 2.00000E 01	T- 24= 2.00000E 01	T- 25= 2.00000E 01	T- 26= 2.00000E 01
T- 10= 2.00000E 01	T- 11= 2.00000E 01	T- 12= 2.00000E 01	T- 13= 2.00000E 01	T- 14= 2.00000E 01	T- 15= 2.00000E 01	T- 16= 2.00000E 01	T- 17= 2.00000E 01	T- 18= 2.00000E 01	T- 19= 2.00000E 01	T- 20= 2.00000E 01	T- 21= 2.00000E 01	T- 22= 2.00000E 01	T- 23= 2.00000E 01	T- 24= 2.00000E 01	T- 25= 2.00000E 01	T- 26= 2.00000E 01
T- 10= 2.00000E 01	T- 11= 2.00000E 01	T- 12= 2.00000E 01	T- 13= 2.00000E 01	T- 14= 2.00000E 01	T- 15= 2.00000E 01	T- 16= 2.00000E 01	T- 17= 2.00000E 01	T- 18= 2.00000E 01	T- 19= 2.00000E 01	T- 20= 2.00000E 01	T- 21= 2.00000E 01	T- 22= 2.00000E 01	T- 23= 2.00000E 01	T- 24= 2.00000E 01	T- 25= 2.00000E 01	T- 26= 2.00000E 01
T- 10= 2.00000E 01	T- 11= 2.00000E 01	T- 12= 2.00000E 01	T- 13= 2.00000E 01	T- 14= 2.00000E 01	T- 15= 2.00000E 01	T- 16= 2.00000E 01	T- 17= 2.00000E 01	T- 18= 2.00000E 01	T- 19= 2.00000E 01	T- 20= 2.00000E 01	T- 21= 2.00000E 01	T- 22= 2.00000E 01	T- 23= 2.00000E 01	T- 24= 2.00000E 01	T- 25= 2.00000E 01	T- 26= 2.00000E 01
T- 10= 2.00000E 01	T- 11= 2.00000E 01	T- 12= 2.00000E 01	T- 13= 2.00000E 01	T- 14= 2.00000E 01	T- 15= 2.00000E 01	T- 16= 2.00000E 01	T- 17= 2.00000E 01	T- 18= 2.00000E 01	T- 19= 2.00000E 01	T- 20= 2.00000E 01	T- 21= 2.00000E 01	T- 22= 2.00000E 01	T- 23= 2.00000E 01	T- 24= 2.00000E 01	T- 25= 2.00000E 01	T- 26= 2.00000E 01
T- 10= 2.00000E 01	T- 11= 2.00000E 01	T- 12= 2.00000E 01	T- 13= 2.00000E 01	T- 14= 2.00000E 01	T- 15= 2.00000E 01	T- 16= 2.00000E 01	T- 17= 2.00000E 01	T- 18= 2.00000E 01	T- 19= 2.00000E 01	T- 20= 2.00000E 01	T- 21= 2.00000E 01	T- 22= 2.00000E 01	T- 23= 2.00000E 01	T- 24= 2.00000E 01	T- 25= 2.00000E 01	T- 26= 2.00000E 01
T- 10= 2.00000E 01	T- 11= 2.00000E 01	T- 12= 2.00000E 01	T- 13= 2.00000E 01	T- 14= 2.00000E 01	T- 15= 2.00000E 01	T- 16= 2.00000E 01	T- 17= 2.00000E 01	T- 18= 2.00000E 01	T- 19= 2.00000E 01	T- 20= 2.00000E 01	T- 21= 2.00000E 01	T- 22= 2.00000E 01	T- 23= 2.00000E 01	T- 24= 2.00000E 01	T- 25= 2.00000E 01	T- 26= 2.00000E 01
T- 10= 2.00000E 01	T- 11= 2.00000E 01	T- 12= 2.00000E 01	T- 13= 2.00000E 01	T- 14= 2.00000E 01	T- 15= 2.00000E 01	T- 16= 2.00000E 01	T- 17= 2.00000E 01	T- 18= 2.00000E 01	T- 19= 2.00000E 01	T- 20= 2.00000E 01	T- 21= 2.00000E 01	T- 22= 2.00000E 01	T- 23= 2.00000E 01	T- 24= 2.00000E 01	T- 25= 2.00000E 01	T- 26= 2.00000E 01
T- 10= 2.00000E 01	T- 11= 2.00000E 01	T- 12= 2.00000E 01	T- 13= 2.00000E 01	T- 14= 2.00000E 01	T- 15= 2.00000E 01	T- 16= 2.00000E 01	T- 17= 2.00000E 01	T- 18= 2.00000E 01	T- 19= 2.00000E 01	T- 20= 2.00000E 01	T- 21= 2.00000E 01	T- 22= 2.00000E 01	T- 23= 2.00000E 01	T- 24= 2.00000E 01	T- 25= 2.00000E 01	T- 26= 2.00000E 01
T- 10= 2.00000E 01	T- 11= 2.00000E 01	T- 12= 2.00000E 01	T- 13= 2.00000E 01	T- 14= 2.00000E 01	T- 15= 2.00000E 01	T- 16= 2.00000E 01	T- 17= 2.00000E 01	T- 18= 2.00000E 01	T- 19= 2.00000E 01	T- 20= 2.00000E 01	T- 21= 2.00000E 01	T- 22= 2.00000E 01	T- 23= 2.00000E 01	T- 24= 2.00000E 01	T- 25= 2.00000E 01	T- 26= 2.00000E 01
T- 10= 2.00000E 01	T- 11= 2.00000E 01	T- 12= 2.00000E 01	T- 13= 2.00000E 01	T- 14= 2.00000E 01	T- 15= 2.00000E 01	T- 16= 2.00000E 01	T- 17= 2.00000E 01	T- 18= 2.00000E 01	T- 19= 2.00000E 01	T- 20= 2.00000E 01	T- 21= 2.00000E 01	T- 22= 2.00000E 01	T- 23= 2.00000E 01	T- 24= 2.00000E 01	T- 25= 2.00000E 01	T- 26= 2.00000E 01
T- 10= 2.00000E 01	T- 11= 2.00000E 01	T- 12= 2.00000E 01	T- 13= 2.00000E 01	T- 14= 2.00000E 01	T- 15= 2.00000E 01	T- 16= 2.00000E 01	T- 17= 2.00000E 01	T- 18= 2.00000E 01	T- 19= 2.00000E 01	T- 20= 2.00000E 01	T- 21= 2.00000E 01	T- 22= 2.00000E 01	T- 23= 2.00000E 01	T- 24= 2.00000E 01	T- 25= 2.00000E 01	T- 26= 2.00000E 01
T- 10= 2.00000E 01	T- 11= 2.00000E 01	T- 12= 2.00000E 01	T- 13= 2.00000E 01	T- 14= 2.00000E 01	T- 15= 2.00000E 01	T- 16= 2.00000E 01	T- 17= 2.00000E 01	T- 18= 2.00000E 01	T- 19= 2.00000E 01	T- 20= 2.00000E 01	T- 21= 2.00000E 01	T- 22= 2.00000E 01	T- 23= 2.00000E 01	T- 24= 2.00000E 01	T- 25= 2.00000E 01	T- 26= 2.00000E 01
T- 10= 2.00000E 01	T- 11= 2.00000E 01	T- 12= 2.00000E 01	T- 13= 2.00000E 01	T- 14= 2.00000E 01	T- 15= 2.00000E 01	T- 16= 2.00000E 01	T- 17= 2.00000E 01	T- 18= 2.00000E 01	T- 19= 2.00000E 01	T- 20= 2.00000E 01	T- 21= 2.00000E 01	T- 22= 2.00000E 01	T- 23= 2.00000E 01	T- 24= 2.00000E 01	T- 25= 2.00000E 01	T- 26= 2.00000E 01
T- 10= 2.00000E 01	T- 11= 2.00000E 01	T- 12= 2.00000E 01	T- 13= 2.00000E 01	T- 14= 2.00000E 01	T- 15= 2.00000E 01											

TIME = 50.00 RCMIN(25) =2.76584E 00 DELTA THETA =1.5978E-01									
T-	1=	7.49199E 01	T-	2=	7.49549E 01	T-	3=	7.64316E 01	T- 5= 8.42568E 01
T-	6=	9.17947E 01	T-	7=	1.02932E 02	T-	8=	1.01864E 02	T- 10= 9.15466E 01
T-	11=	1.00000E 03	T-	12=	6.66136E 02	T-	13=	4.61456E 02	T- 15= 2.28417E 02
T-	16=	1.52547E 02	T-	17=	9.60438E 01	T-	18=	6.43619E 02	T- 20= 3.18512E 02
T-	21=	2.25854E 02	T-	22=	1.51341E 02	T-	23=	7.22045E 01	T- 25= 1.21179E 02
T-	26=	5.07651E 02							
TIME = 70.00 RCMIN(25) =2.76584E 00 DELTA THETA =6.3915E-01									
T-	1=	8.46801E 01	T-	2=	8.52030E 01	T-	3=	8.77470E 01	T- 5= 9.80284E 01
T-	6=	1.06556E 02	T-	7=	1.18000E 02	T-	8=	1.20303E 02	T- 10= 1.12336E 02
T-	11=	1.00000E 03	T-	12=	6.96686E 02	T-	13=	5.24763E 02	T- 15= 3.03864E 02
T-	16=	2.18872E 02	T-	17=	1.71914E 02	T-	18=	6.70211E 02	T- 20= 3.89051E 02
T-	21=	2.99374E 02	T-	22=	2.16468E 02	T-	23=	8.25843E 01	T- 25= 1.80405E 02
T-	26=	5.56478E 02							
TIME = 90.00 RCMIN(25) =2.76584E 00 DELTA THETA =6.3915E-01									
T-	1=	9.46800E 01	T-	2=	9.55553E 01	T-	3=	9.92724E 01	T- 5= 1.12206E 02
T-	6=	1.21870E 02	T-	7=	1.33998E 02	T-	8=	1.36549E 02	T- 10= 1.28836E 02
T-	11=	1.00000E 03	T-	12=	7.47290E 02	T-	13=	5.95774E 02	T- 15= 3.83568E 02
T-	16=	2.90860E 02	T-	17=	2.51728E 02	T-	18=	7.16026E 02	T- 20= 4.64864E 02
T-	21=	3.76416E 02	T-	22=	2.86737E 02	T-	23=	9.29391E 01	T- 25= 2.37661E 02
T-	26=	6.00751E 02							
TIME = 110.00 RCMIN(25) =2.76584E 00 DELTA THETA =6.3915E-01									
T-	1=	1.00000E 02	T-	2=	1.01363E 02	T-	3=	1.06042E 02	T- 5= 1.20764E 02
T-	6=	1.31061E 02	T-	7=	1.43512E 02	T-	8=	1.46893E 02	T- 10= 1.39168E 02
T-	11=	1.00000E 03	T-	12=	7.73163E 02	T-	13=	6.35989E 02	T- 15= 4.39071E 02
T-	16=	3.47215E 02	T-	17=	3.24248E 02	T-	18=	7.39183E 02	T- 20= 5.12004E 02
T-	21=	4.29557E 02	T-	22=	3.41350E 02	T-	23=	1.00917E 02	T- 25= 2.87015E 02
T-	26=	6.27707E 02							
TIME = 130.00 RCMIN(25) =2.76584E 00 DELTA THETA =6.3915E-01									
T-	1=	1.00000E 02	T-	2=	1.01461E 02	T-	3=	1.06256E 02	T- 5= 1.21079E 02
T-	6=	1.31392E 02	T-	7=	1.43848E 02	T-	8=	1.47372E 02	T- 10= 1.39192E 02

Figure 10.7.8

T- 11= 1.00000E 02	T- 12= 1.01463E 02	T- 13= 6.37127E 02	T- 14= 5.28133E 02	T- 15= 4.42600E 02
T- 16= 3.53437E 02	T- 17= 3.49092E 02	T- 18= 7.39703E 02	T- 19= 6.15488E 02	T- 20= 5.13949E 02
T- 21= 3.32912E 02	T- 22= 3.47348E 02	T- 23= 1.01478E 02	T- 24= 1.47443E 02	T- 25= 2.95235E 02
T- 26= 6.28979E 02				

TIME = 150.00 RCMIN(25) =2.76584E 00 DELTA THETA =6.3915E-01

T- 1= 1.00000E 02	T- 2= 1.01463E 02	T- 3= 1.06261E 02	T- 4= 1.12785E 02	T- 5= 1.21085E 02
T- 6= 1.31398E 02	T- 7= 1.43855E 02	T- 8= 1.47383E 02	T- 9= 1.46638E 02	T- 10= 1.39192E 02
T- 11= 1.00000E 03	T- 12= 7.73760E 02	T- 13= 6.37145E 02	T- 14= 5.28162E 02	T- 15= 4.42648E 02
T- 16= 3.53564E 02	T- 17= 3.52109E 02	T- 18= 7.39712E 02	T- 19= 6.15504E 02	T- 20= 5.13977E 02
T- 21= 4.32958E 02	T- 22= 3.47470E 02	T- 23= 1.01496E 02	T- 24= 1.47507E 02	T- 25= 2.95441E 02
T- 26= 6.29000E 02				

TIME = 170.00 RCMIN(25) =2.76584E 00 DELTA THETA =6.3915E-01

T- 1= 1.00000E 02	T- 2= 1.01463E 02	T- 3= 1.06262E 02	T- 4= 1.12785E 02	T- 5= 1.21086E 02
T- 6= 1.31398E 02	T- 7= 1.43855E 02	T- 8= 1.47383E 02	T- 9= 1.46639E 02	T- 10= 1.39192E 02
T- 11= 1.00000E 03	T- 12= 7.73760E 02	T- 13= 6.37145E 02	T- 14= 5.28163E 02	T- 15= 4.42649E 02
T- 16= 3.53566E 02	T- 17= 3.52395E 02	T- 18= 7.39712E 02	T- 19= 6.15504E 02	T- 20= 5.13977E 02
T- 21= 4.32959E 02	T- 22= 3.47472E 02	T- 23= 1.01496E 02	T- 24= 1.47509E 02	T- 25= 2.95445E 02
T- 26= 6.29000E 02				

Figure 10.7.9

TIME = 190.00 RCMIN(25) =2.76584E 00 DELTA THETA =6.3915E-01

T- 1= 1.00000E 02	T- 2= 1.01463E 02	T- 3= 1.06262E 02	T- 4= 1.12785E 02	T- 5= 1.21086E 02
T- 6= 1.31398E 02	T- 7= 1.43855E 02	T- 8= 1.47383E 02	T- 9= 1.46639E 02	T- 10= 1.39192E 02
T- 11= 1.00000E 03	T- 12= 7.73760E 02	T- 13= 6.37145E 02	T- 14= 5.28163E 02	T- 15= 4.42649E 02
T- 16= 3.53566E 02	T- 17= 3.52421E 02	T- 18= 7.39712E 02	T- 19= 6.15504E 02	T- 20= 5.13977E 02
T- 21= 4.32959E 02	T- 22= 3.47472E 02	T- 23= 1.01496E 02	T- 24= 1.47509E 02	T- 25= 2.95445E 02
T- 26= 6.29000E 02				

STEADY STATE VALUES FOLLOW

TIME =100001.00 RCMIN(25) =2.76584E 00 DELTA THETA =6.9146E-01

T- 1= 1.00000E 02	T- 2= 1.01577E 02	T- 3= 1.06341E 02	T- 4= 1.12833E 02	T- 5= 1.21095E 02
T- 6= 1.31361E 02	T- 7= 1.43741E 02	T- 8= 1.47661E 02	T- 9= 1.46965E 02	T- 10= 1.40000E 02
T- 11= 1.00000E 03	T- 12= 7.65784E 02	T- 13= 6.34801E 02	T- 14= 5.26259E 02	T- 15= 4.41120E 02
T- 16= 3.51518E 02	T- 17= 3.52201E 02	T- 18= 7.35924E 02	T- 19= 6.13248E 02	T- 20= 5.12130E 02
T- 21= 4.31469E 02	T- 22= 3.45859E 02	T- 23= 1.01495E 02	T- 24= 1.47492E 02	T- 25= 2.95299E 02
T- 26= 6.28979E 02				

SAMPLE PROBLEM NUMBER 1
OIL-NAK HEAT EXCHANGER

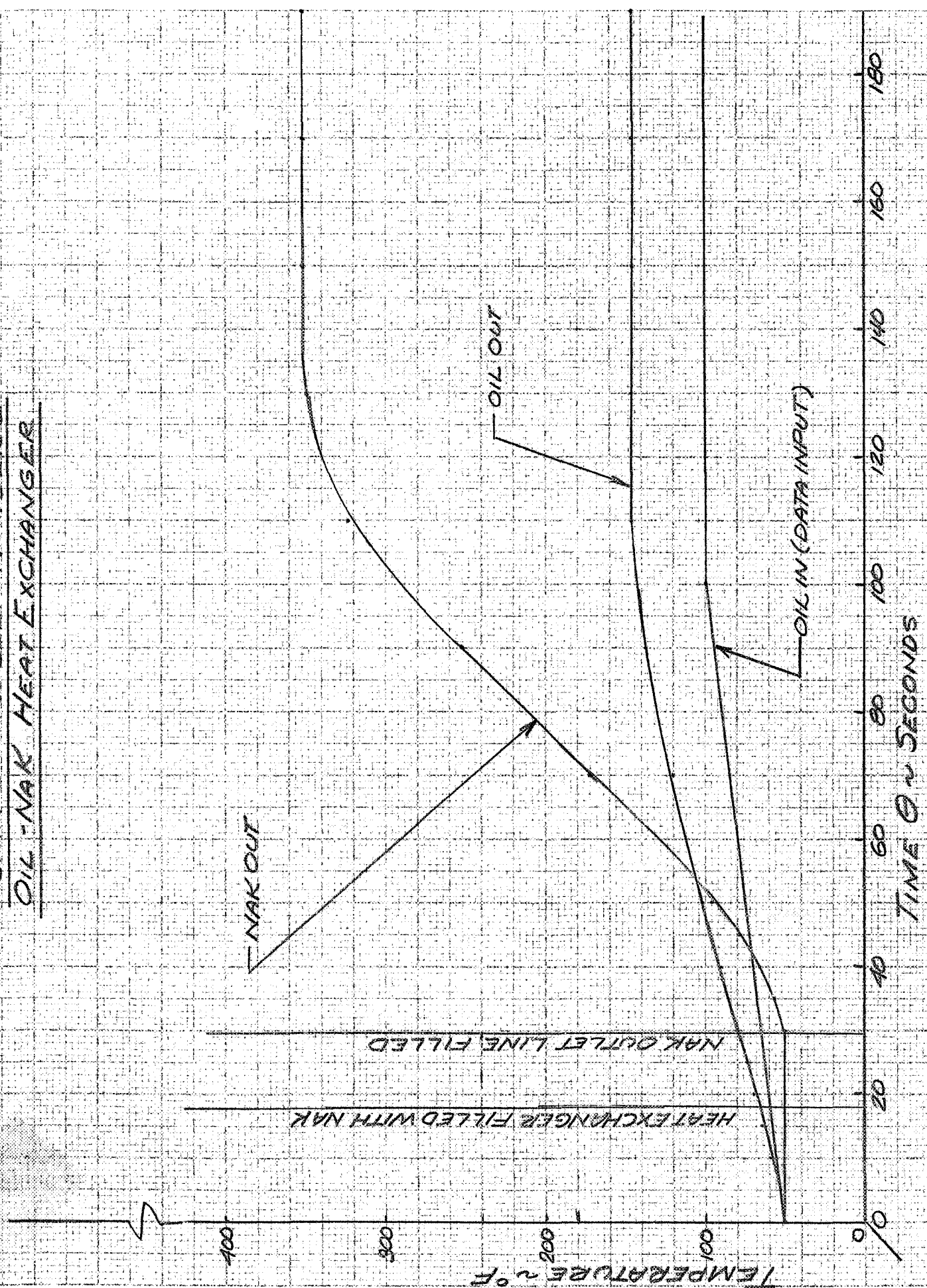


Figure 10.8