EFFECT OF UNCERTAINTIES UPON THE PERFORMANCE OF FEED-EFFLUENT HEAT EXCHANGER SYSTEMS

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PREFACE

A computer program is developed to estimate the effect of uncertainties upon the performance of heat exchanger systems with or without feedback. The program is used to analyze feed-effluent heat exchanger systems. Effective measures for controlling the uncertainties in the output variables are explored. A sensitivity analysis procedure for heat exchanger systems is suggested.

I am deeply indebted to my thesis adviser, Professor Kenneth J. Bell, for his intelligent guidance, inspiration and dedication to research and great human understanding. Without his help and encourement this work could not be in the present form.

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NOMENCLATURE

A - heat transfer surface area, $m^2(ft^2)$

a - effective heat transfer surface area per unit length, $m^2/m(ft^2/ft)$

C - heat capacity rate of the fluid, WC_p, W/ K (Btu/hr°F)

c_p - specific heat of the fluid, KJ/Kg K (Btu/lb°F)

D - tube diameter, m (ft)

E - exchanger heat trnasfer effectiveness

E_T - total effectiveness for more than one shell in series

$F_N(x)$ - cumulative normal distribution

$f_N(x)$ - probability density function

F_T - configuration correction factor

H - enthalpy of the fluid, W/Kg (Btu/lb)

h - film heat transfer coefficient, W/m^2 K $(Btu/hrft^2°F)$

K - thermal conductivity, W/m K (Btu/hrft °F)

LMTD - logarithmic mean temperature difference, K (°F)

m - number of shells in series

MTD - mean temperature difference, K (°F)

n - number of tube-passes per shell

N - sample size

NTU - number of heat transfer units

P - probability

Q - total heat flow rate, W (Btu/hr)

r - tube radius, m (ft)
R_f - fouling film resistance, m K/W (hrft^2°F/Btu)
s - sample standard deviation
U - overall heat transfer coefficient, W/m^2 K (Btu/hrft^2°F)
W - fluid flow rate, Kg/hr
x - random variable
$\overline{X}$ - sample mean
Z - standard normal deviate

Greek Letters

μ - population mean for a variable
σ - population standard deviation

Subscripts

i - tube inside condition
o - tube outside condition
w - tube wall condition
1 - unless otherwise specified, integer 1 refers to hotter fluid
2 - unless otherwise specified, integer 2 refers to colder fluid
min - fluid with smaller heat capacity rate
max - fluid with higher heat capacity rate

CHAPTER I

INTRODUCTION

The expected performance of a given heat exchanger or a system of heat exchangers is greatly influenced by the undertainties involved in design parameters, design procedures and in the operational conditions. For example:

1. Uncertainty in process conditions:

   Heat exchangers are designed for a nominal set of conditions chosen to represent a presumed relatively conservative operating state of the system. In fact, it is highly unlikely that the exchanger will ever operate under the nominal design conditions. In any case process stream flow rates, compositions and temperatures can all be expected to vary during the operating life time of the exchanger, and changes in weather constantly change cooling water and air temperatures.

2. Uncertainty in physical properties:

   There are substantial uncertainties in the physical properties of all but a few fluids, and the ability to predict properties of mixtures is very limited.

3. Uncertainty in the basic design correlations:

   All of the correlations for the basic fluid flow and heat transfer mechanisms in heat exchangers show scatter when compared to experimental data.

4. Uncertainty in the rating algorithms:
All heat exchanger rating procedures are constructed out of basic correlations, combined in such a way as to reflect the practical construction features of the exchanger. In the development of an algorithm, one has to decide as to how to combine and modify the basic correlations; this is an art and inevitably a further degree of uncertainty is introduced.

5. Uncertainty in manufacturing tolerances:
Exchanger construction codes allow certain tolerances which result in a difference of performance even among nominally identical units.

6. Uncertainty in fouling characteristics:
When heat exchanger apparatus has been in service for some time, a film or deposit of sediment, scale, organic growth, etc. will sooner or later develop. Heat transfer across these films is predominantly by conduction, but the designer seldom knows enough about either the thickness or the thermal conductivity of the film to treat the heat transfer resistance as a conduction problem. The additional resistances reduce the original value of the overall heat transfer coefficient, and the required amount of heat is no longer transferred by the original surface area. To overcome this change it is customary in designing equipment to anticipate the deposition of the dirt and scale by introducing a resistance R_f, called the fouling factor. The effect of including this additional

resistance is to provide an exchanger somewhat larger than initially required, so that the exchanger will still provide the desired service after it has been on stream for some time and some fouling has accumulated. Usually the designer estimates the fouling factor from a table of standard values or from experience. Therefore, this is often the greatest uncertainty of all and frequently dominates the design and the operating procedures of the exchanger.

Uncertainties in input data and design methods cause uncertainties in the performance of systems of heat exchangers. Since the uncertain quantities combine and interact algebraically highly complex and non-linear ways, the usual analytical methods would not be expected to yield useful results conveniently. Therefore, the Monte-Carlo method is used: A set of values of the independent variables is generated using a random procedure, and this set is used to calculate deterministic outcomes (dependent variables) of the system (18). Al-Zakri and Bell (1) developed a computer program for these calculations in the special case that there is no feedback in the system.

The purpose of the present thesis is to provide the extension of Al-Zakri and Bell's (1) program to include feedback which occurs in the typical heat exchanger systems. Recycle or feedback calculations generally pose convergence problems, since only in special cases can the equations be explicitly and directly solved without reiteration. A convergence scheme is developed in this thesis for feedback systems. The associated stability problem is also explored. With the present technique the computer run time does not increase significantly. The computer program developed in the present thesis can simulate a system of shell and tube heat exchangers with or without feedback. The system may also include other process elements such as fired heaters, reactors and multiproduct distillation columns. The program performs heat and mass balance calculations for any system configuration. The program is capable of calculating the required surface areas of the heat exchangers and the required heat duties of the fired heaters, or the temperatures of the effluent streams. In can also calculate the mean and the standard deviation of areas, heat duties or temperatures from which a confidence interval can be calculated corresponding to the specified confidence level. The program can provide the cumulative probability curves for each outlet stream temperature. The program can also estimate the probability that an existing system of heat exchangers can achieve the desired performance. Calculation of the sensitivity coefficients of the outcome variables to the uncertainties in the inputs will allow the designer to identify the critical features of the heat exchanger system. With this information, the designer may decide upon and test ways to limit the more extreme or undesirable consequences of system uncertainties.

Energy conservation inevitably requires heat exchange. Recovery of heat is essential to the success of many petroleum refining and chemical processes. Economic incentive for improved energy recovery in process plants has led to the increased use of feed-effluent heat exchanger systems. A typical feed-effluent exchanger system consists of the feed-effluent exchangers, a tempering exchanger and a reactor, or distillation unit or other process unit in which the process stream is modified in composition, phase and/or enthalpy. A tempering exchanger is used to adjust the process unit inlet temperature.

The feed stream enters the feed-effluent exchanger and recovers heat (or "cold") against the process unit effluent. A typical feed-effluent heat exchanger system is presented in Figure I.1.

In the present thesis, the effect of uncertainties upon the performance of three different feed-effluent heat exchanger systems are analyzed for demonstration. They are:

1. Reactor with feed-effluent heat exchanger.
2. Reactor in a platforming unit with feed-effluent heat exchanger.
3. Distillation column with feed-effluent heat exchanger.

Means to control the uncertainties in the output stream temperatures are also explored. The study shows that the most critical component in the system should be identified first; if this can be more closely controlled, the uncertainties in the output stream temperatures can be greatly reduced and the performance of the system will significantly improve.

An attempt is made to develop a sensitivity analysis to aid the designer in isolating the critical features of the feed-effluent exchanger system. Sensitivity analysis shows that the uncertainty in the overall heat transfer coefficient does not affect significantly the uncertainties of the output stream temperatures, when the uncertainties in the input stream temperatures are relatively high. The study also shows that the uncertainty in the temperature of the input stream with the higher thermal capacitance has a much stronger effect than the other.

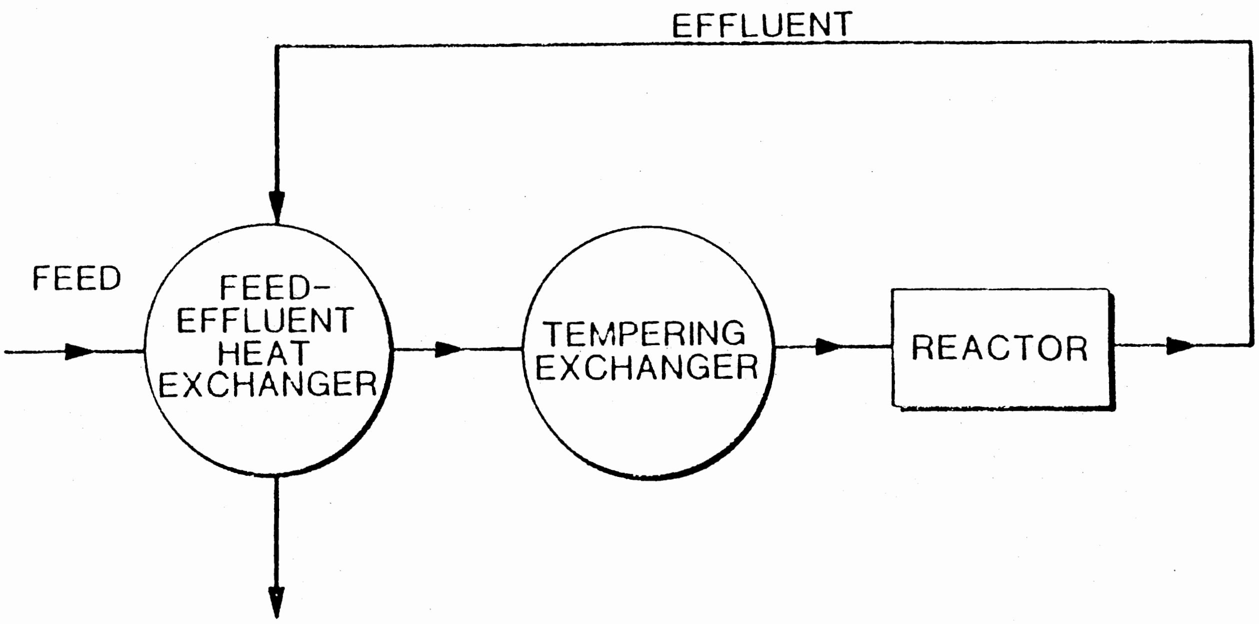


Figure I.1. Typical Feed-Effluent Heat Exchanger System

CHAPTER II

LITERATURE REVIEW

The final design of process equipment is hardly complete without the inclusion of a safety factor which takes into account the uncertainties in the design parameters, design procedures and operational conditions. Usually this overdesign has been introduced at the final design stage by simply multiplying the calculated equipment size by a safety factor. This safety factor may vary from 10 to 100 percent. The particular safety factor chosen is influenced by the previous experience and judgement of the design engineer. Although the larger the safety factor used the higher the probability that the equipment will perform adequately, economic factors must be taken into consideration. Any unnecessary increase of equipment requires excessive capital and possibly operational expenses.

All work reported in the literature regarding the design of process equipment and process systems with uncertain parameters falls into two basic categories:

1. Rigorous Mathematical Model
2. Statistical Approach

Rigorous Mathematical Model

In most of the works in this category, the investigators proposed different mathematical models for optimum design of process systems involving parameter uncertainty (7, 10, 20, 21, 22).

Wen and Chang (21) proposed two design criteria for optimal design of systems involving parameter uncertainty. One criterion is used to obtain an appropriate decision which will keep the deviation of the objective from the optimal behavior within a certain tolerance. The other assures a minimum average normalized deviation of the objective function from the optimum over the range of uncertainty. They also provided two examples to demonstrate the applicability of the proposed criteria to the optimal reactor design with uncertainty in the Kinetic constants.

Weisman and Holzman (22) proposed a mathematical model for optimal chemical and nuclear process system design when uncertainties exist. The procedure is extended to consideration of the effect of a nonlinear value for money. The basic technique is to combine all the inequality constraints into the objective function via the failure penalty concept.

Takamatsu et al. (20) proposed a method for the compensation of parameter uncertainties in the design of process systems by optimal selection of the safety factor. Dittmar and Hartman (7) enlarged the method proposed by Takamatsu et al. (20) by some considerations about the inclusion of nonlinear inequality constraints, the check of lineariability of the mathematical model and the selection of the signs of parameter deviations. The applicability of the procedures is demonstrated by the use of a simple reactor-separator system.

Grossmann and Sargent (10) proposed a strategy for optimum design of chemical plants whose uncertain parameters are expressed as bounded variables. In the proposed desing the plant specifications were met for any feasible values of the parameters while optimizing a weighted cost function which reflects the costs over the expected range of operation. The strategy is formulated as a nonlinear program and a method of solution is derived for constraints which are monotonic with the parameters. The design of a pipeline with a pump, a reactor-separator system, and a heat exchanger network, all with uncertain technical parameters, were used as illustrations. The heat exchanger network is shown in Figure II.1. The outlet temperatures T_3, T_6, T_{10}, T_{12}, T_{15} were specified as inequalities and the steam temperature T_s was controlled with a valve. A ± 20% uncertainty in the value of all the heat transfer coefficients, U_i, i = 1, 2, . . . 5, was considered.

The problem is then to choose the areas $A_k (m^2)$, i = 1, 2, . . . 5, of the heat exchangers, the steam temperatures T_s^K, K = 1, 2, . . . n, and the outlet temperatures of the cooling water T_{wo}^K, K = 1, 2, . . . n, in order to minimize the total annual cost

$$\overline{C} = \sum_{i=1}^{5} C_o A_i^{\beta} + \sum_{K=1}^{n} \sigma^K (C_s F_s^K + C_w F_w^K)$$

Where F_s^K, F_w^K, K = 1, 2, . . . n, are the steam and cooling water flow rates, and C_o, β, C_s, C_w are cost parameters.

The problem was solved for one set of values for the weights in the objective function and also the nominal design was determined.

Statistical Approach

Most of the works in this category dealt with the design of a particular item of process equipment when uncertainties exist.

Buckly (5) was one of the first to use a statistical approach to the sizing of process equipment. The method, based on the

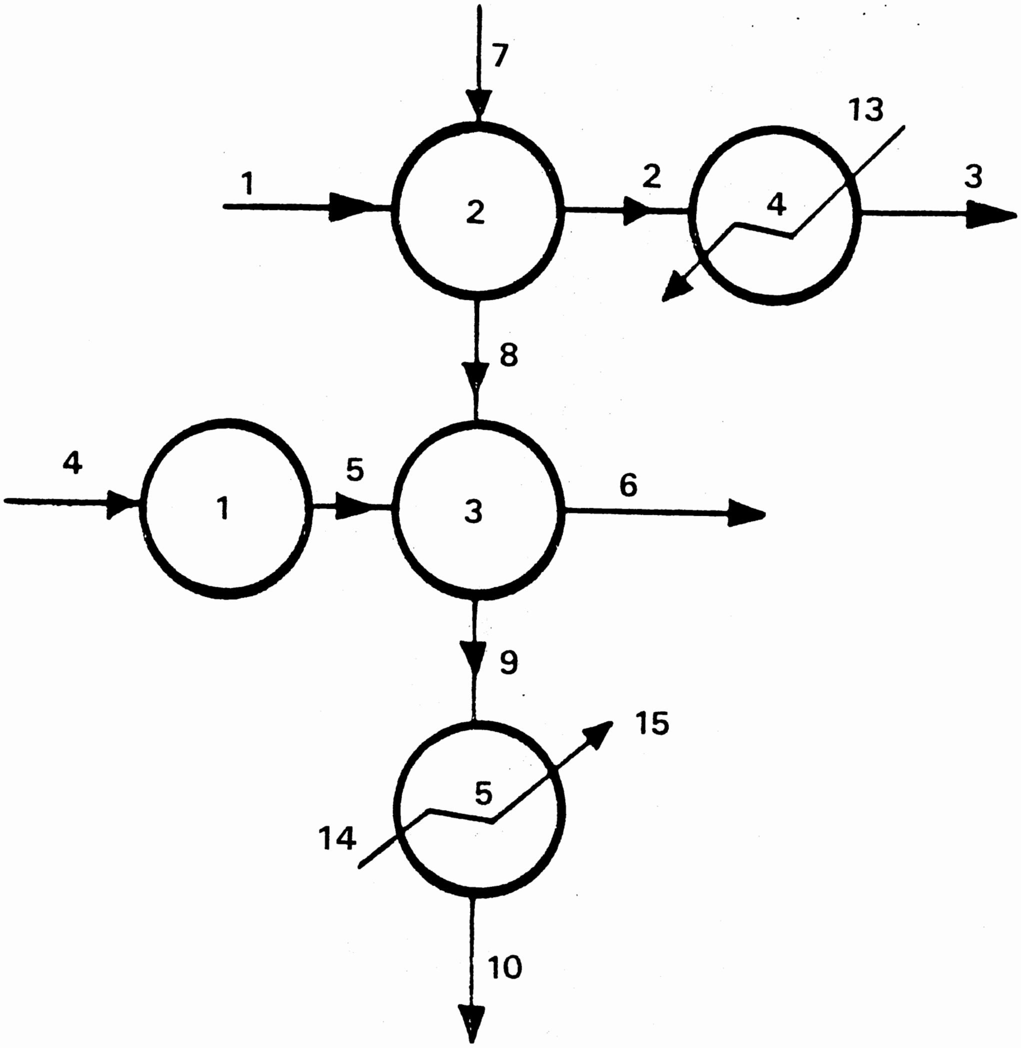


Figure II.1. Heat Exchanger Network (10) mathematics of probability, provides a quantitative evaluation of the uncertainties in the dependent variables which then permit a direct evaluation of the safety factors for a given level of confidence. The method assumes that uncertainties will follow the normal probability curve. The procedure can be stated as follows: If Y is a function of several variables say, $X_1, X_2, \ldots X_n$, and σ_{X_i} (standard deviation of X_i) is the uncertainty in the variable X_i, the uncertainty in Y due to the uncertainty in X_i is equal to $\frac{\partial Y}{\partial X_i} \sigma_{X_i}$.

The overall uncertainty in Y is σ_Y and is expressed in terms of the individual uncertainties:

$$\sigma_Y = \sqrt{\Sigma \left(\frac{\partial Y}{\partial X_i} \sigma_{X_i} \right)^2}$$

Knowing the value of Y at the average conditions, an upper limit Y' for Y is calculated based on the desired confidence level. The ratio of Y' over Y is the estimated safety factor.

Berryman and Himmelblau (4) proposed the application of the Monte Carlo simulation approach to study the effect of stochastic inputs and parameters on process analysis and design. They used the differential form of the heat exchanger design equation and integrated along the exchanger. They assumed that the densities and heat capacities of both the fluids are constant. They also assumed that no heat was removed or added to the system. The heat transfer coefficients h_i and h_o and the stream temperatures and flow rates are assumed to fluctuate randomly. Knowing the uncertainty in each variable and parameter involved, a random number generated from a normal distribution having the same mean and standard deviation of the fluctuating variable is substituted for the variable and the stochastic model for the process is solved. By repeating the simulations as often as needed, a population of the required output is generated and the mean and standard deviation of the required output is calculated, from which the overall uncertainty in the size of the heat exchanger can be determined.

Lashment and Szczepanski (17) also applied a statistical approach to binary column design to estimate overdesign factors to account for uncertainty in stage efficiencies. They have shown that the Murphee vapor efficiencies derived from the American Institute of Chemical Engineers correlation overpredict the observed efficiencies are normally distributed. Using Monte Carlo simulation they obtained the approximate statistical distribution of the number of stages required for a desired separation.

Freeman and Gaddy (9) demonstrated the concept of dependability can be used with stochastic simulation of the process variables to find the optimum overdesign of chemical process. A simple process, involving a reactor and a separator was chosen for study. This process had both variable conditions and uncertain data with two design variables, reactor volume and number of separator stages.

Al-Zakri and Bell (1) also applied a statistical approach to study the effect of uncertainties on the performance of shell and tube heat exchanger systems. For heat exchanger design they accepted the following assumptions made for the derivation of the Mean Temperature Difference (MTD):

1. The overall heat transfer coefficient is constant.
2. The flow rate is constant.
3. Specific heat is constant for each fluid.

4. There are no partial phase changes in the heat exchanger.
5. There is no heat lost or added to the system.
6. The shell fluid is assumed to be completely mixed and its temperature is constant across any cross-section.
7. For heat exchangers with more than one tube pass, area and flow are distributed uniformly among the passes.

They developed a computer program to simulate any system (without feed-back) of shell-and-tube heat exchangers with a minimum of one exchanger and a maximum of 98 exchangers in a system. Each exchanger may have one to n tubes apsses per shell (n is an even number). The program uses the Monte Carlo technique of introducing random variables into the system model. The method has been applied to a demonstration problem, a crude preheat train, to obtain the mean and standard deviation for each outlet stream temperature. The use of the method to predict the overdesign factor for each heat exchanger is also presented.

CHAPTER III

GENERAL DESCRIPTION OF PROGRAM

In the present thesis a computer program is developed to simulate a system of shell and tube heat exchangers with or without feedback. The system may also include other process elements such as fired heaters, reactors and multiproduct distillation columns. The program performs heat and mass balance calculations for any system configuration. It converges the unknown variables of the feedback streams using the successive substitution technique. The program is capable of calculating the required surface areas of the heat exchangers, required heat duties of the fired heaters, or the temperatures of the effluent streams. It can also calculate the mean and the standard deviation from which a confidence interval can be calculated corresponding to the specified confidence level. The program also provides cumulative probability curves for each outlet stream temperature. For a specified confidence level, the range of the effluent stream temperatures for an existing exchanger or system of exchangers can be estimated. The over design factor for each heat exchanger can also be calculated. The program can also estimate the probabilities that an existing system of heat exchangers can achieve the desired performance.

Calculation of the sensitivity coefficients of the outcome variables to the uncertainties in the inputs will allow the designer to identify the critical features of the heat exchanger system. With this information, the designer may decide upon and test ways to limit the more extreme or undesirable consequences of system uncertainties.

Program Processing

The execution of the program takes place into three steps. They are as follows:

1. With the selected process data provided, the program first calculates deterministically the nominal values of all the required output variables for each process element in the system. If the feedback option is specified, the program first converges the feedback stream unknown variables and then performs the deterministic calculations for the nominal values of the output variables.

2. Knowing the uncertainties in each of the input variables and the respective nominal values, a normal randum number is generated for each variable using the standard normal random number generation technique (13). Thus, during each simulation a new set of values of the independent variables is generated and this set is used to calculate deterministically the outcomes (dependent variables) of the system.

3. Repeating the calculation (step 2) up to the specified number of simulations, a sample of the dependent variable is then generated. And this sample is used to calculate the required statistics for the outcome variable. If a feedback stream is included in the system, the program converges the unknown feedback stream parameter in each of the Monte Carlo simulations and the final results are provided for the converged system. If the unknown variables of

the feedback stream can not be converged, the system is then unstable and the further execution of the program terminates at that point.

The computer program processing flow chart is shown in Figure III.1.

Convergence Scheme

The program uses the Successive Substitutions Algorithm to converge the unknown variables of the feedback streams. Successive substitutions, as the name implies, involves the solution of a previous trial being used to calculate the answer of the next. For a sample process, the relation between x_n and x_{n+1} for recycle stream variable x is illustrated in Figure III.2. Since n and n+1 correspond to successive iterations, the solution x_{n+1} will replace x_n on the $(n+2)^{th}$ iteration. The stream variable is repeatedly reestimated until $|x_{n+1} - x_n|$ becomes equal to or less than the specified tolerance Δ(Abs.$(x_{n+1} - x_n) \leqslant \Delta$). x_o, the initial guess for the recycle stream variable should be assumed as some finite value The tolerance Δ should also be set by the user.

The flowchart of the convergence scheme is presented in Figure III.3.

Description of the Process Elements

The program can simulate nine different process elements:

1. Input (INPT)
2. Output (OTPT)
3. Stream Adder (ADDR)

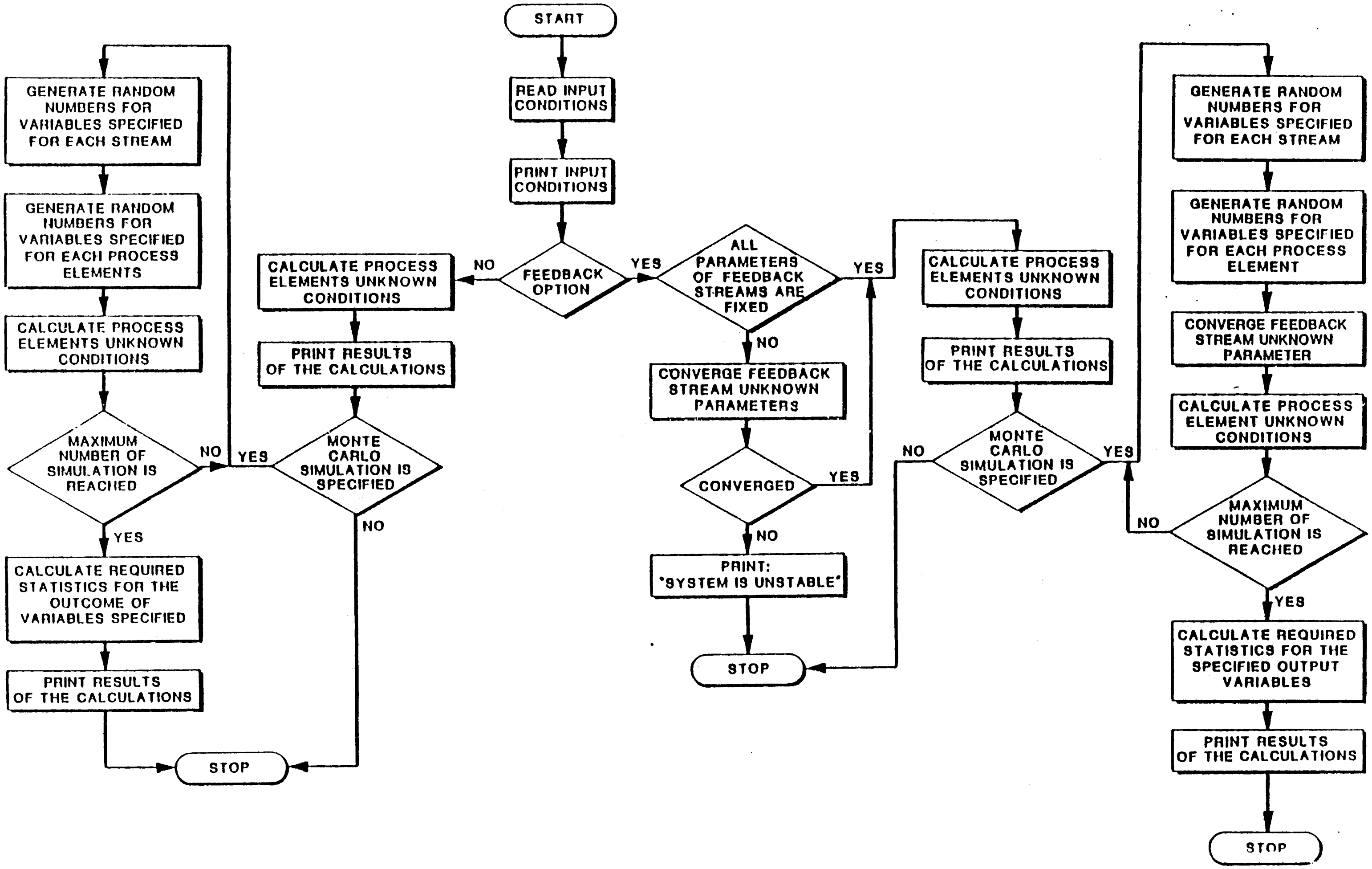


Figure III.1. Computer Program Processing Flow Chart

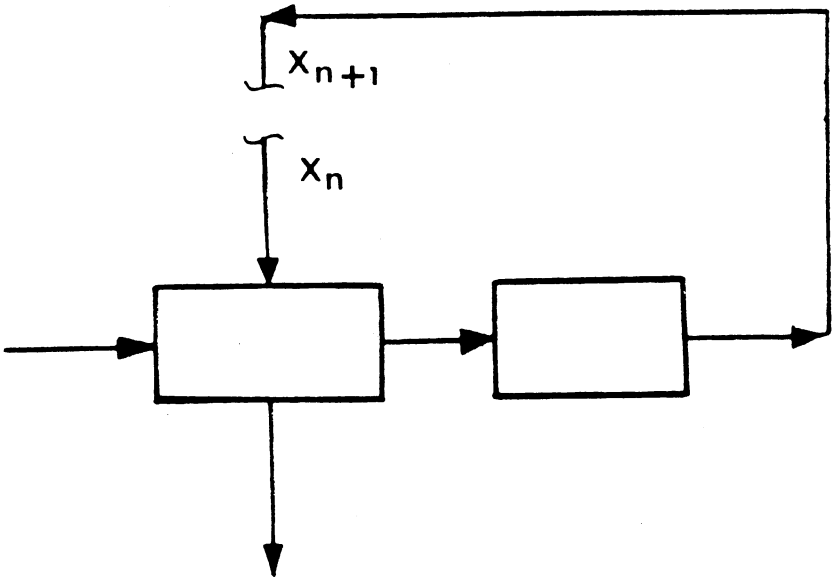


Figure III.2. Typical Feedback Stream

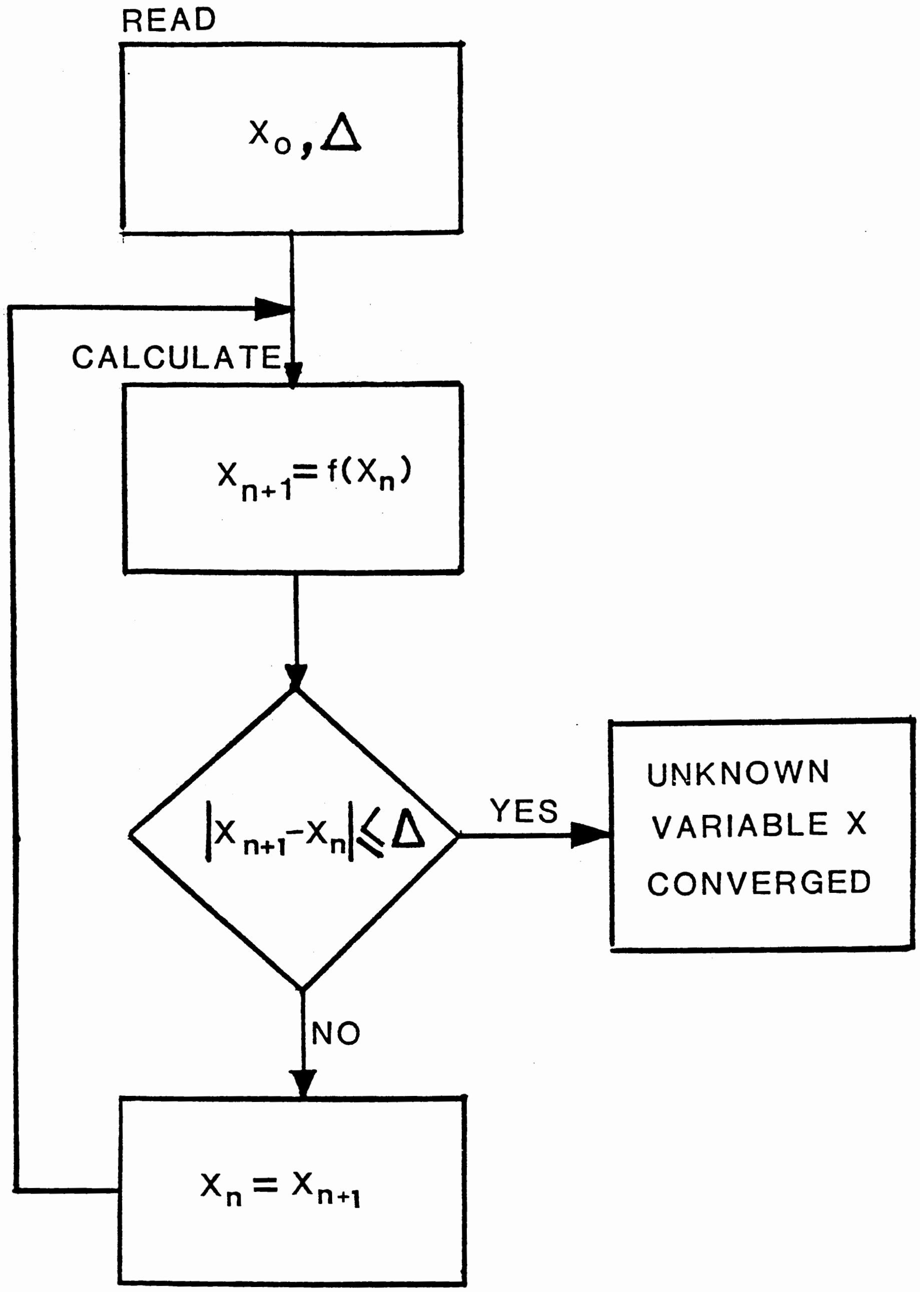


Figure III.3. Convergence Scheme Processing Flow Chart

4. Stream Divider (DVDR)
5. Heat Exchanger (HEX)
6. Heater or Condenser (HRCR)
7. Fired Heater (FRHR)
8. Reactor (RCTR)
9. Distillation Column (DSTL)

Inputs

The required inputs vary with the type of system and the process elements selected. Depending on the option selected, the program may require input of any or all of the following problem data:

- process element identification,
- feed stream flow rates, temperatures, specific heats and their standard deviations,
- heat transfer coefficients, fouling resistances and their standard deviations,
- heat exchanger sizes, heat duties and flow arrangements, and
- functional form of the relationship among the reactor inlet temperature, extent of the reaction and the reactor outlet temperature.

The user may desire to include the following control data:

- whether the system includes feedback streams or not,
- number of feedback streams,
- tolerance for convergence,
- whether the simulation is for only the deterministic model or both deterministic and stochastic models,
- number of iterations for stochastic simulation, and

- input and output units.

Outputs

Outputs are printed in the same order that the calculation is carried out and may contain any or all of the following:

- problem identification on each page of the output,
- the process element description in the same order specified by the user including calculation results for unknown variables,
- all input process data in the input system of units and the results of calculations in the output system of units specified,
- results of the Monte Carlo Simulation for either outlet temperatures or heat exchanger areas or fired heater heat duties required,
- comments if the system is unstable, and
- error comments to help the programmer to identify mistakes in input.

A complete computer program listing is given in Appendix A.

Description of Process Elements

Process Element Input (INPT). The function of the Input element is to serve as a feed tank for the whole system. It has no feed stream and all the feed streams to the system must be included as product streams from the Input element. The Input element may have a maximum 20 product streams. Stream flow rates, temperatures, specific heats and the standard deviations of these parameters serve as input data to the element.

Process Element Adder (ADDR). The function of the Adder element is to add a maximum of four feed streams into one product stream. The temperature and specific heat of the product stream are determined on the basis of a constant enthalpy process.

Process Element Divider (DVDR). The function of the Divider element is to divide one feed stream into a maximum of four product streams. All streams have identical temperature, composition and specific heat. The fraction of the feed stream going into each product stream should be specified and the sum of all fractions must be equal to unity.

Process Element Heat Exchanger (HEX). Process element Heat Exchanger Simulates a shell and tube heat exchanger where only sensible heat is exchanged between the two fluids. It is assumed that there is no phase change in either fluid at any point in the exchanger. Process Element Heat Exchanger can also simulate a feed-effluent exchanger. If the temperature, flow rate or specific heat of the recycle stream of feed-effluent exchanger is unknown and needs to be converged, the initial guess values must be specified (in the product streams of the Input Element) in order to calculate the converged values. Two feed streams and two corresponding product streams must be specified for this element. Heat transfer coefficients, fouling resistances, and their standard deviations and the flow arrangements are part of the input data. Process element HEX performs heat and mass transfer calculations. It calculates the outlet stream temperatures or the size of the heat exchanger as desired by the user.

Process Element Heater or Condenser (HRCR). Process Element heater or condenser simulates a shell and tube heat exchanger in which a one component fluid is condensed or boiled in the shell or in the tubes. The temperature of the condensing or boiling fluid is constant throughout the heat exchanger because only the latent heat is exchanged. If the outlet stream temperature needs to be calculated then either the latent heat or the isothermal stream temperature should be specified. And if the isothermal stream temperature needs to be calculated then the outlet stream temperature should be specified.

Process Element Fired Heater (FRHR). Process Element Fired Heater simulates a simple fired heater. It has one feed stream and one product stream. If the statistics of the fire heater duty are required, the outlet stream temperature should be specified.

Process Element Reactor (RCTR). Process Element Reactor simulates a simple steady state reactor model. It has one feed stream and one product stream. The change of temperature in the reactor is either a constant or a function of the extent of the reaction.

Process Element Distillation (DSTL). Process Element Distillation simulates a multicomponent distillation column. It does not perform any tray by tray calculation. Its function is to generate the uncertainty in the product streams as a function of the feed stream uncertainty. It has one feed stream and up to six product streams. Product stream temperature, flow rates and specific heats are its input data.

Process Heat Output (OTPT). The function of the Process Element Output is to serve as a product tank to the whole system. All product streams from the system are regarded as feed streams to the output element. There are no product streams for this element and as many as 20 feed streams can be specified.

A summary of all the process elements is provided in Table III.1.

Preparation of input data, in the form of card-by-card instruction along with the input data forms, is described in Appendix B.

TABLE III.1

PROCESS ELEMENTS IN THE PROGRAM

Process Element Type	Element Name	Element Identification Number	Summary of Function
Input	INPT	1	Serve as a feed tank to the whole system
Stream Adder	ADDR	2	Adds two to four streams together and gives single product stream. Constant enthalpy process.
Stream Divider	DVDR	3	Splits a single stream into two to four streams. All streams have identical composition, temperature and specific heat.
Heat Exchanger	HEX	4	Simulates shell and tube heat exchanger in sensible heat transfer service.
Fired Heater	FRHR	5	Simulates a simple fired heater.
Heater or Condenser	HRCR	6	Simulates either a heater or a condenser having a constant temperature heat source or sink.
Reactor	RCTR	7	Simulates a steady state reactor.
Distillation	DSTL	8	Simulates a multiproduct distillation column.
Output	OTPT	9	Serves as an output tank to the whole system.

CHAPTER IV

BASIC DESIGN FEATURES AND DEFINITIONS

Basic Heat Exchanger Equations

The basic heat exchanger equations fall into two categories: (1) the heat balance equation, and (2) the rate equation.

The heat balance equations are essentially a matter of thermodynamics, in which the designer must find or be given the necessary specific heat or latent heats. In the present method, the streams are assumed to be either purely sensible heat streams with a constant specific heat or isothermal latent heat streams.

The rate equation for most heat exchangers used in the process industries is:

$$Q = U_o A_o (MTD) \tag{IV-1}$$

where

Q = total rate of heat transfer

U_o = overall heat transfer coefficient based on outside heat transfer area

A_o = outside heat transfer surface area of heat exchanger

For a heat exchanger with a single tube pass in countercurrent flow:

$$MTD = LMTD = \frac{(T_1-t_2) - (T_2-t_1)}{\ln \dfrac{T_1-t_2}{T_2-t_1}} \tag{IV-2}$$

For cocurrent flow:

$$\mathrm{MTD} = \mathrm{LMTD} = \frac{(T_1-t_1) - (T_2-t_2)}{\ln \dfrac{T_1-t_1}{T_2-t_2}} \qquad \text{(IV-3)}$$

Where, T_1, T_2, t_1 and t_2 are the inlet and outlet temperatures of the hot and cold fluids respectively.

For heat exchangers with two or more tube passes:

$$\mathrm{MTD} = F_T(\mathrm{LMTD}) \qquad \text{(IV-4)}$$

where F_T is the configuration factor.

For heat exchangers with n tube passes, where n = 2, 4, 6..., the configuration factor F_T is given by

For a (1-n) heat exchanger (one shell pass and n tube passes):

$$F_T = \frac{\sqrt{R^2+1}\ \ln[(1-S)/(1-RS)]}{(R-1)\ \ln\left[\dfrac{2-S(R+1-\sqrt{R^2+1})}{2-S(R+1+\sqrt{R^2+1})}\right]} \qquad \text{(IV-5)}$$

For a (2-2n) heat exchanger (two shell-passes or two shells in series, and 2n tube passes):

$$F_T = \frac{\sqrt{R^2+1}\ \ln[(1-S)/(1-RS)]}{2(R-1)\ \ln\left[\dfrac{2/S-1-R+(2/S)\ \sqrt{(1-S)(1-RS)}+\sqrt{R^2+1}}{2/S-1-R+(2/S)\ \sqrt{(1-S)(1-RS)}-\sqrt{R^2+1}}\right]} \qquad \text{(IV-6)}$$

Where

$$R = \frac{T_1 - T_2}{t_2 - t_1}\ ; \qquad S = \frac{t_2 - t_1}{T_1 - t_1}$$

The overall heat transfer coefficient U_o is computed by

$$U_o = \frac{1}{\dfrac{1}{h_o} + \dfrac{1}{h_i}\left(\dfrac{a_o}{a_i}\right) + R_{f_i}\left(\dfrac{a_o}{a_i}\right) + R_{f_o} + \dfrac{a_o \ln(D_o/D_i)}{2\pi K_w}} \qquad \text{(IV-7)}$$

Where,

h_i = tube inside heat transfer coefficient

h_o = shell side heat transfer coefficient

R_{f_o} = shell side fouling resistance

R_{f_i} = tube side fouling resistance

D_o = tube outside diameter

D_i = tube inside diameter

a_o = tube effective outside area per unit length

a_i = tube effective inside area per unit length

K_w = tube wall thermal conductivity

Calculation of Outlet Temperatures

When both the outlet temperatures of the heat exchanger are unknown, it is convenient to calculate them using the effectiveness - NTU method. The use of the effectiveness-NTU method avoids trial and error in determining the outlet temperatures when the surface area, specific heats, heat transfer coefficients, flow rates and flow arrangements are known.

In NTU method, one first calculates the thermal capacity of both streams. Thermal capacity is defined as the mass flow rate multiplied by the specific heat of the respective stream, i.e., $C = Wc_p$. In general, two thermal capacities are calculated, C_1 and C_2. The one which is smaller is denoted by C_{min}, the other C_{max}. Then the ratio C_{min}/C_{max} lies between 0 and 1.

The effectiveness E is defined as the ratio of actual heat transferred to the maximum heat which could be transferred in a heat exchanger with an infinite surface and purely counter-current flow:

$$E = \frac{Q_{actual}}{Q_{max}} = \frac{C_1(T_1 - T_2)}{C_{min}(T_1 - t_1)} = \frac{C_2(t_2 - t_1)}{C_{min}(T_1 - t_1)} \qquad \text{(IV-8)}$$

Therefore E lies between 0 and 1.

NTU (Number of Transfer Units) is defined as

$$NTU = \frac{A_o U_o}{C_{min}} \qquad \text{(IV-9)}$$

Kays and London (14) have shown that the heat exchanger effectiveness is a function of NTU, (C_{min}/C_{max}) and flow arrangement and can be expressed as:

For cocurrent flow:

$$E = \frac{1 - \exp[-NTU(1 - \frac{C_{min}}{C_{max}})]}{1 + \frac{C_{min}}{C_{max}}} \qquad \text{(IV-10)}$$

For countercurrent flow:

$$E = \frac{1 - \exp[-NTU(1 - \frac{C_{min}}{C_{max}})]}{1 - \frac{C_{min}}{C_{max}} \exp[-NTU(1 - \frac{C_{min}}{C_{max}})]} \qquad \text{(IV-11)}$$

For counter-cocurrent flow (1-n) exchanger, n is even:

$$E = \frac{2}{(1 + \frac{C_{min}}{C_{max}}) + \sqrt{1 + (\frac{C_{min}}{C_{max}})^2} (\frac{1 + e^{-\Gamma}}{1 - e^{-\Gamma}})} \qquad \text{(IV-12)}$$

Where

$$\Gamma = NTU \sqrt{1 + (\frac{C_{min}}{C_{max}})^2}$$

For heat exchangers with m shell passes and n tube passes (n even) and an overall countercurrent flow arrangement, the total effectiveness E_T can be expressed as (14)

$$E_T = \frac{[1 - E(\frac{C_{min}}{C_{max}})/(1 - E)]^m - 1}{[1 - E(\frac{C_{min}}{C_{max}})/(1 - E)]^m - \frac{C_{min}}{C_{max}}} \qquad \text{(IV-13)}$$

Where E is the effectiveness calculated for one shell pass. Therefore, the overall calculation procedure can be described as follows:

1. Calculate C_1 and C_2.
2. Calculate NTU.
3. Depending on the flow arrangement, calculate E using one of Eq (IV.10) and Eq (IV.13).
4. Calculate outlet temperatures:

If $C_1 = C_{min}$, then:

$$T_2 = T_1 - E(T_1 - t_1)$$

$$t_2 = t_1 + E(T_1 - t_1)\frac{C_1}{C_2}$$

If $C_2 = C_{min}$, then:

$$T_2 = T_1 - E(T_1 - t_1)\frac{C_2}{C_1}$$

$$t_2 = t_1 + E(T_1 - t_1)$$

Reactor

In this study a reactor element is simulated to study the effect of uncertainty in reactor inlet temperature on the extent of the reaction.

In the reactor, a chemical reaction takes place with the release or absorption of heat; the enthalpy change is a function of the thermochemistry, the reaction temperature (a higher temperature usually leading to an exponentially increasing reaction rate), and the extent of the reaction (which is limited by thermodynamic equilibrium at the reactor exit temperature). The functional form of the relationship among the reactor inlet temperature, extent of the reaction and the reactor outlet temperature must be supplied by the user in the computer program. An example of this relationship is given in Figure V.2.

Distillation Column

In the present study a multiproduct distillation column is simulated. The cold stream recover heat against the hot product stream coming out of the distillation unit. Here we are primarily interested in the uncertainty of the product stream temperature, which affects the performance of the feed-effluent exchanger. To avoid a complex calculation, it is assumed that the nominal values of the temperature, flow rates, and specific heats of the product streams are known. It is further assumed that the uncertainty involved in the product stream temperature is directly proportional to the uncertainty in the feed stream temperature, i.e.,

$$\sigma_{T_{p_i}} = K_i \sigma_{T_F} \qquad \text{(IV-14)}$$

Where

$\sigma_{T_{p_i}}$ = temperature standard deviation of the i^{th} product stream coming out of the distillation column

σ_{T_F} = temperature standard deviation of the feed stream entering in the distillation column

K_i = constant

The value of σ_{T_F} will be calculated by the program. Constant K_i should be supplied by the designer on the basis of judgement and experience.

Definitions

Population Mean

For a discrete variable, consider a population that contains N members. As the sample size n is increased with n = N, the relative frequency f_i/n of class j becomes the probability P_j that has the value X_j in this population. Then the population mean μ can be defined as (19):

$$\mu = \sum_{j=1}^{n} P_j X_j \qquad \text{(IV-15)}$$

For a continuous random variable

$$\mu = \int x \; f(x) \; dx \qquad \text{(IV-16)}$$

where f(x) is the density function of the random variable x.

Sample Mean

The sample mean is the most commonly used estimate of the population mean. It is denoted by $\overline{X}$.

$$\overline{X} = (1/n) \sum_{i=1}^{n} x_i \qquad \text{(IV-17)}$$

Population Standard Deviation

Population standard deviation is a measure of the amount of variation of the values of X in a population and is denoted by σ, which is defined by

$$\sigma = \sqrt{\sum_{i=1}^{K} P_j (X_j - \mu)^2} \qquad \text{(IV-18)}$$

Sample Standard Deviation

The sample standard deviation, S, is most widely used as an estimator of the population standard deviation . If the sample observations have not been arranged in a frequency distribution, the formula defining S is

$$S = \sqrt{\sum_{i=1}^{n} (X_i - \overline{X})^2/(n-1)} \qquad \text{(IV-19)}$$

Coefficient of Variation

A measure often used in describing the amount of variation in a population is the coefficient of variation

$$CV = \frac{\sigma}{\mu} \times 100 \qquad \text{(IV-20)}$$

The sample estimate is $S/\overline{X}$.

The Normal Distribution

If X is a normally distributed random variable and the probability that $X < x$ is

$$P(X \leq x) = F_N(X) = \frac{1}{\sqrt{2\pi}\sigma} \int_{-\infty}^{x} e^{-(X-\mu)^2/2\sigma^2} dx \qquad \text{(IV-21)}$$

X is said to be normally distributed and the constants μ and σ are the mean and standard deviation of X respectively. $F_N(X)$ is called the cumulative normal distribution and is shown in Figure IV.1. The derivative of $F_N(X)$ with respect to X is called the probability density function where

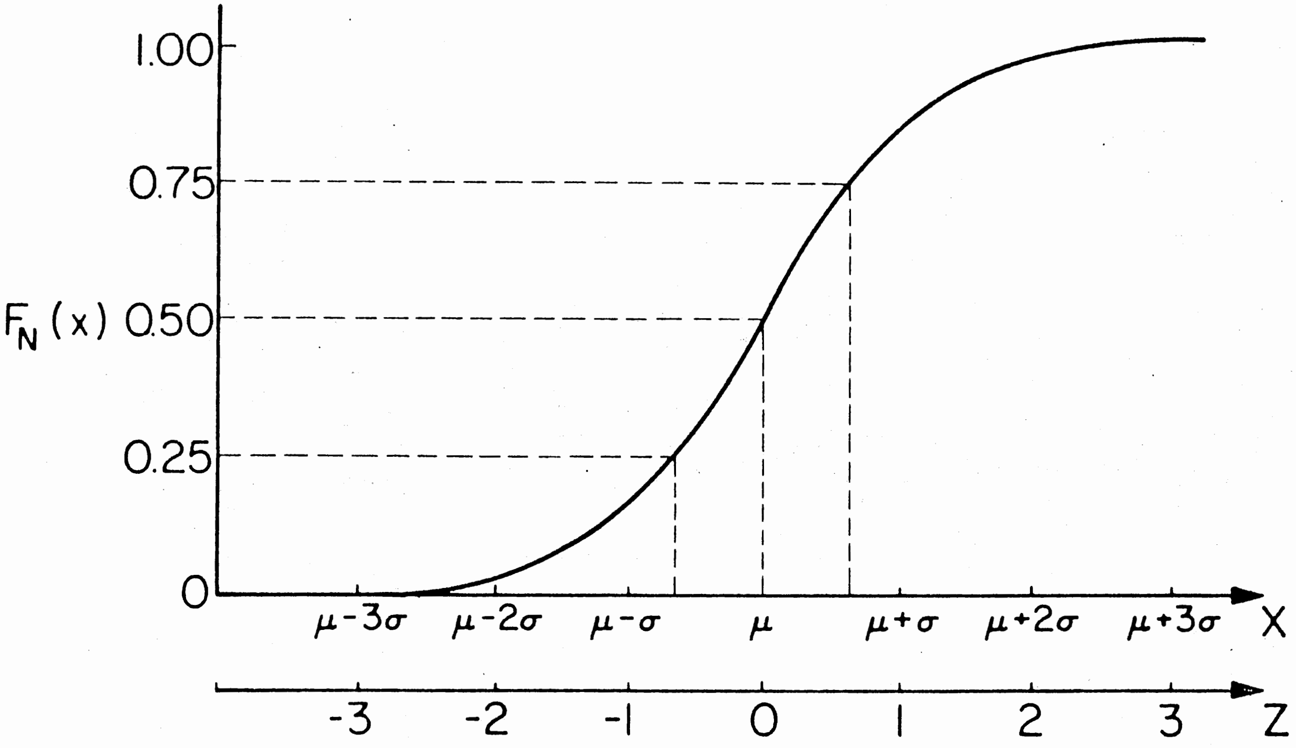


Figure IV.1. Normal Distribution Cumulative Function $F_N(x)$

$$f_N(X) = \frac{dF(x)}{dx} = \frac{1}{\sqrt{2\pi}\,\sigma} e^{-(X-\mu)^2/2\sigma^2} \qquad \text{(IV-22)}$$

The normal distribution curve (Figure IV.2) is completely specified by the mean μ and standard deviation σ where μ locates the center of the distribution and σ measures the dispersion of the individual measurements. All the standard tables in the literature for normal distribution called the standard normal distribution are for the distribution with $\mu = 0$ and $\sigma = 1$. Equation (IV-22) is rescaled to correspond to the standardized form by letting

$$Z = \frac{X - \mu}{\sigma} \qquad \text{(IV-23)}$$

and

$$f(Z) = \frac{1}{\sqrt{2\pi}} e^{-Z^2/2} \qquad \text{(IV-24)}$$

Where Z is called the standard normal deviate.

The population mean μ and population standard deviation σ are seldom known. But they can be estimated from random samples. If X is drawn from a normal population, $\overline{X}$, the sample mean, is an estimate of μ and σ, the sample standard deviation, is an estimate of σ where

$$\overline{X} = \frac{\sum_{i=1}^{N} X_i}{N} \qquad \text{(IV-25)}$$

and

$$S = \sqrt{\frac{\Sigma(X_i - \overline{X})^2}{N - 1}} \qquad \text{(IV-26)}$$

Confidence Interval

The confidence interval for a given population parameter indicates that in repeated sampling, N times, a specified (e.g. 95%) of

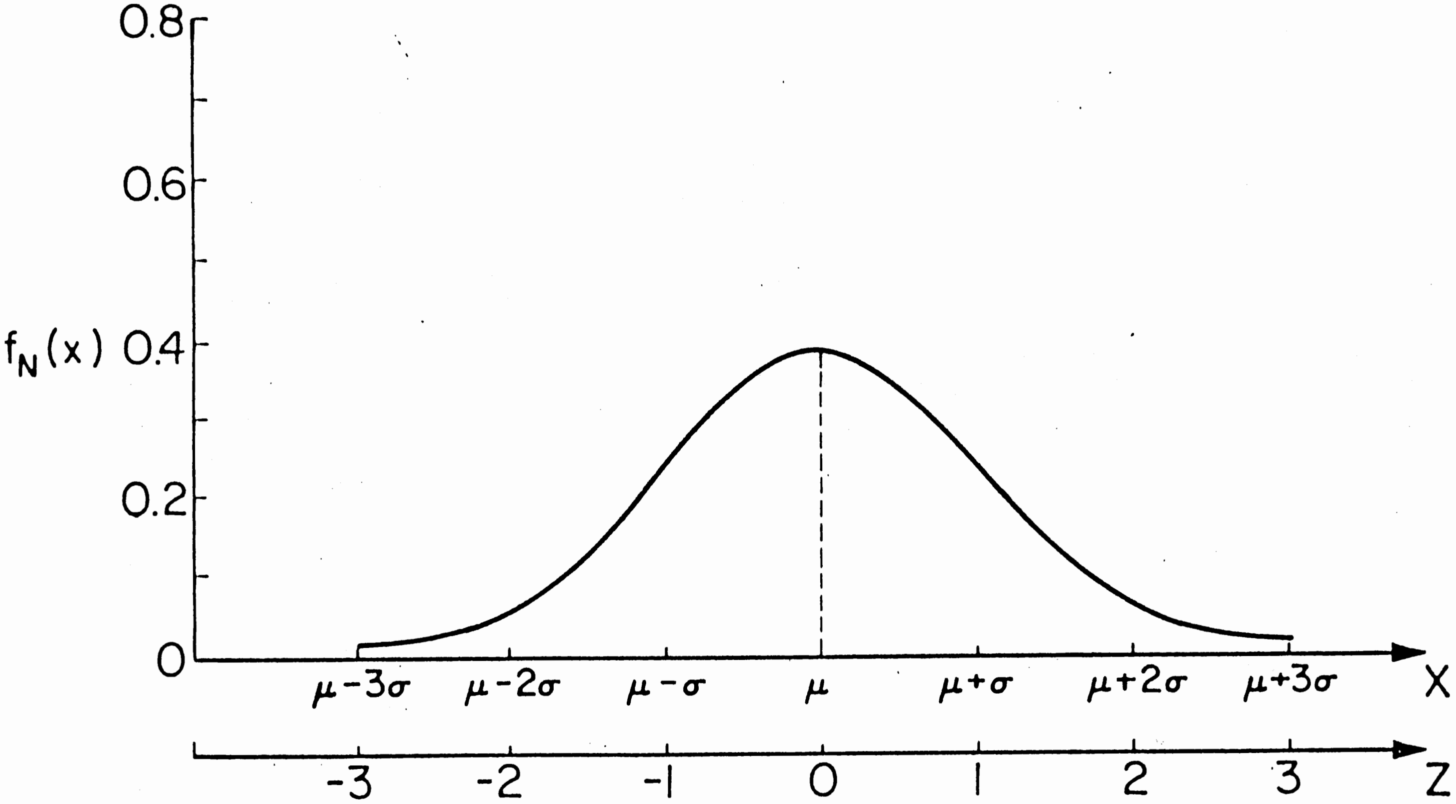


Figure IV.2. Normal Distribution Probability Density Function $f_N(x)$

the intervals computed by the same method will include the population parameter being estimated. The percentage (95%) is called the confidence level and the interval is called a 95% confidence interval. If a variable X is drawn from a normal distribution, there is 95% probability that X lies in the interval $\mu - 1.96\sigma$ to $\mu + 1.96\sigma$. This is called 95% confidence interval for X. The population mean μ and standard deviation σ can be estimated by the sample mean $\overline{X}$ and sample standard deviation s if they are not known.

The Monte Carlo Method

The Monte Carlo Method (or the method of statistical trials) consists of solving various problems of computational mathematics by means of construction of some random process for each such problem, with the parameters of the process equal to the required quantities of the problem. These quantities are then determined approximately by means of observations of the random process and the computation of its statistical characteristics, which are approximately equal to the required parameters (18).

For example if μ is the mathematical expectation of a certain random variable, the Monte Carlo Method for determining the approximate value of μ is carried out by making N series of independent tests (N - sampling) of the value of the variable x: $x_1, x_2, \ldots, x_N$ and computing the mean value

$$\overline{X} = \frac{x_1 + x_2 + \ldots + x_N}{N} \qquad \text{(IV-27)}$$

Where according to the law of large numbers

$$\overline{X} \simeq \mu \qquad \text{(IV-28)}$$

with a probability which is as close as required to unity for sufficiently large N. Accordingly the quantity $\overline{X}$ which has been determined by observation of the random process, is approximately equal to the required quantity X.

The Monte Carlo method includes various degrees of simulation ranging from the simulation of actual physical systems to investigation of classical mathematical problems such as systems of linear algebraic equations. Detailed information about the specific technique can be found in standard statistics texts (18, 19).

In the present study the following uncertainties are considered in the heat exchanger design parameters which affect the performance of the heat exchanger system:

1. Uncertainty in stream flow rate.
2. Uncertainty in inlet stream temperature.
3. Uncertainty in specific heat.
4. Uncertainty in tube inside heat transfer coefficient.
5. Uncertainty in shell side heat transfer coefficient.
6. Uncertainty in tube side fouling resistance.
7. Uncertainty in shell side fouling resistance.

The variations of the variables mentioned above are mostly concentrated around their nominal values and there is little known about their distribution. It is assumed that each variable is normally distributed. This assumption is used because the normal distribution is the most amenable to simple mathematical manipulation. The Monte Carlo method generates random numbers and provides a large number of successive solutions for the system. For each simulation a normal random number is generated for each of the above variables, and each parameter is assumed to be constant during the simulation once it has been generated. By having as many simulation as required, a set of values of the independent variable is generated and this set is used to calculate deterministic outcomes (outlet temperatures, heat exchanger areas, heat duties) of the system. Thus a sample of the dependent variable is created from which the ensemble mean and standard deviation of the outcomes of the system can be computed.

Generation of Random Numbers

The technique used in the generation of random numbers involves uniform and normal distribution. It can be described as follows (13):

1. Using an arbitrary seed, consisting of an odd integer with nine digits on the first entry, a nonrepetitive random integer is computed.

2. Using the random integers computed earlier, uniform random deviates between 0.0 and 1.0 are generated with mean and variance being 0 and 1/12 respectively (13).

3. From the uniform deviates, a normal random variable (Y) with mean 0 and variance 1.0 is computed (13).

4. The normal random variable (Y) computed is then adjusted to the given mean and standard deviation $Y' = Y\sigma + \overline{X}$, where $\overline{X}$ is the deterministic value of the variable and σ is the standard deviation.

The random numbers generated by this method have been extensively tested by chi-square tests to verify that the random numbers were truly taken from a normal distribution (13).

CHAPTER V

DEMONSTRATION PROBLEM NUMBER 1: REACTOR WITH FEED-EFFLUENT HEAT EXCHANGER

To analyze the effect of uncertainties on a feedback system, a feed-effluent heat exchanger system will be considered for demonstration. The system consists of a feed-effluent exchanger, a tempering exchanger and a reactor. A feed stream 17, at 308 K enters the feed-effluent exchanger 2, and recovers heat against the reactor effluent (stream 21). Stream 18, exiting from the feed-effluent heat exchanger enters the tempering exchanger 3 which is intended to adjust the reactor feed temperature. After adjusting the stream temperature to the required value, stream 19 enters the reactor, 4. In the reactor a chemical reaction takes place with the release of heat. The extent of the reaction is a function of the reactor inlet temperature. The change in reactor feed stream temperature is thus a function of reactor inlet temperature (e.g., Figure V.2). A schematic diagram of the system is presented in Figure V.1.

The nominal value and the uncertainties for the feed effluent heat exchanger and tempering exchanger input data are presented in Table V.1. Feed stream input conditions are presented in Table V.2. It is assumed that there are no uncertainties in the feedstream (stream 17) temperature, flow rate and specific heat. It is also assumed

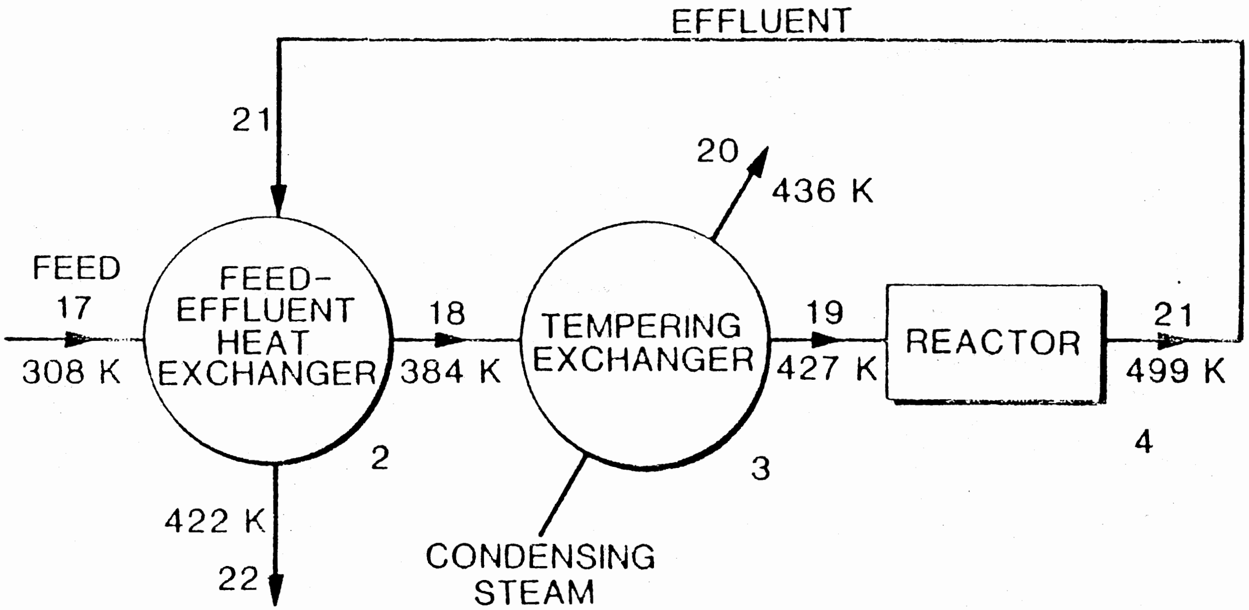


Figure V.1. Schematic Diagram of the System (Demonstration Problem No. 1)

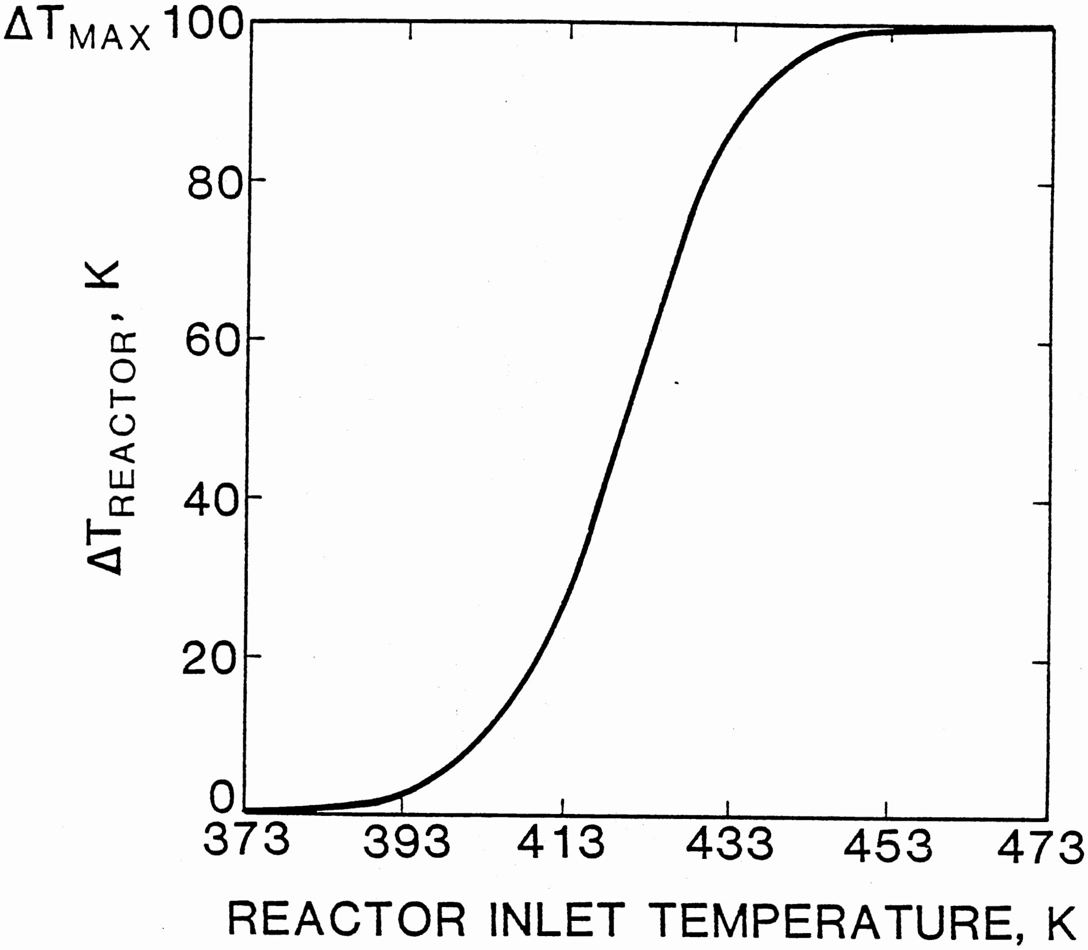


Figure V.2. $(\Delta T)_{\text{Reactor}}$ as a Function of Reactor Inlet Temperature

TABLE V.1

HEAT EXCHANGER INPUT DATA

Variables	Feed-Effluent Heat Exchanger (Element 2)	Tempering Exchanger (Element 3)
Area, m^2	153	250
Shell Side Heat Transfer Coefficient, W/m^2 K	1675	11356
Variation of Shell Side Heat Transfer Coefficient, $\pm\Delta$%	30	50
Tube Inside Heat Transfer Coefficient, W/m^2 K	2555	2555
Variation of Tube Inside Heat Transfer Coefficient, ± %	10	10
Shell Side Fouling Resistance, m^2 K/W	0.00029	0.00007
Variation of Shell Side Fouling Resistance	0.0 to 2 x Nominal Value	
Tube Inside Fouling Resistance, m^2 K/W	0.00066	0.00066
Variation of Tube Inside Fouling Resistance	0.0 to 1.5 x Nominal Value	
Tube Wall Thermal Conductivity, W/m K	56	56
Effective Tube Inside Area, m^2/m	0.0624	0.0624
Effective Tube Outside Area, m^2/m	0.0798	0.0798
Tube Inside Diameter, m	0.0202	0.0202
Tube Outside Diameter, m	0.0258	0.0258

TABLE V.1 (Continued)

Variables	Feed-Effluent Heat Exchanger (Element 2)	Tempering Exchanger (Element 3)
Number of Tube Passes	2	2
Number of Shell Passes	1	1

TABLE V.2

FEED STREAM INPUT CONDITIONS

Stream Number	Flow Rate Kg/hr	Temperature K	Specific Heat KJ/kg K
17	161603	308	2.065

TABLE V.3

RESULTS OF DETERMINISTIC CALCULATION (FOR INPUT CONDITIONS DESCRIBED IN TABLE V.1 & 2)

Stream Number	Flow Rate Kg/hr	Temperature K
18	161603	384
19	161603	427
20	7850	436
21	161603	499
22	161603	422

that the desired conversion in the reactor is 70%.

Uncertainties in the feed-effluent exchanger and tempering exchanger input data will cause uncertainties in the output stream temperatures and will affect the performance of the system. In this problem, the uncertainties in the reactor inlet stream temperature (stream 19), reactor outlet stream temperature (stream 21) and the feed-effluent exchanger output stream temperature (stream 22) will be analyzed.

The computer program developed in the present thesis is used to calculate the uncertainties in the temperatures of streams 19, 21 and 22. These uncertainties are presented in Figure V.3, V.4 and V.5, respectively. 500 simulations are used for stochastic calculation. The results of the deterministic calculation and the statistics of the output stream temperatures are given in Table V.3 and V.4 respectively.

Figure V.3 shows that the reactor inlet stream temperature varies from 420 K to 434 K (95% confidence interval), which causes variation in the extent of the reaction from 40% to 88%, whereas the desired conversion in the reactor is 70%. Thus the uncertainty in the reactor feed stream temperature severely affects the performance of the reactor.

Since the reactor outlet stream temperature (stream 21) is a function of the extent of the reaction, a variation in the extent of the reaction causes the variation in the reactor outlet stream temperature. And since this is a feedback stream, this uncertainty carries over to the system and affects the performance of the whole system.

Figure V.4 shows that the reactor outlet stream temperature (stream 21) varies from 473 K to 525 K (95% confidence interval) with mean and standard deviation being 499 K and 13.2 K respectively.

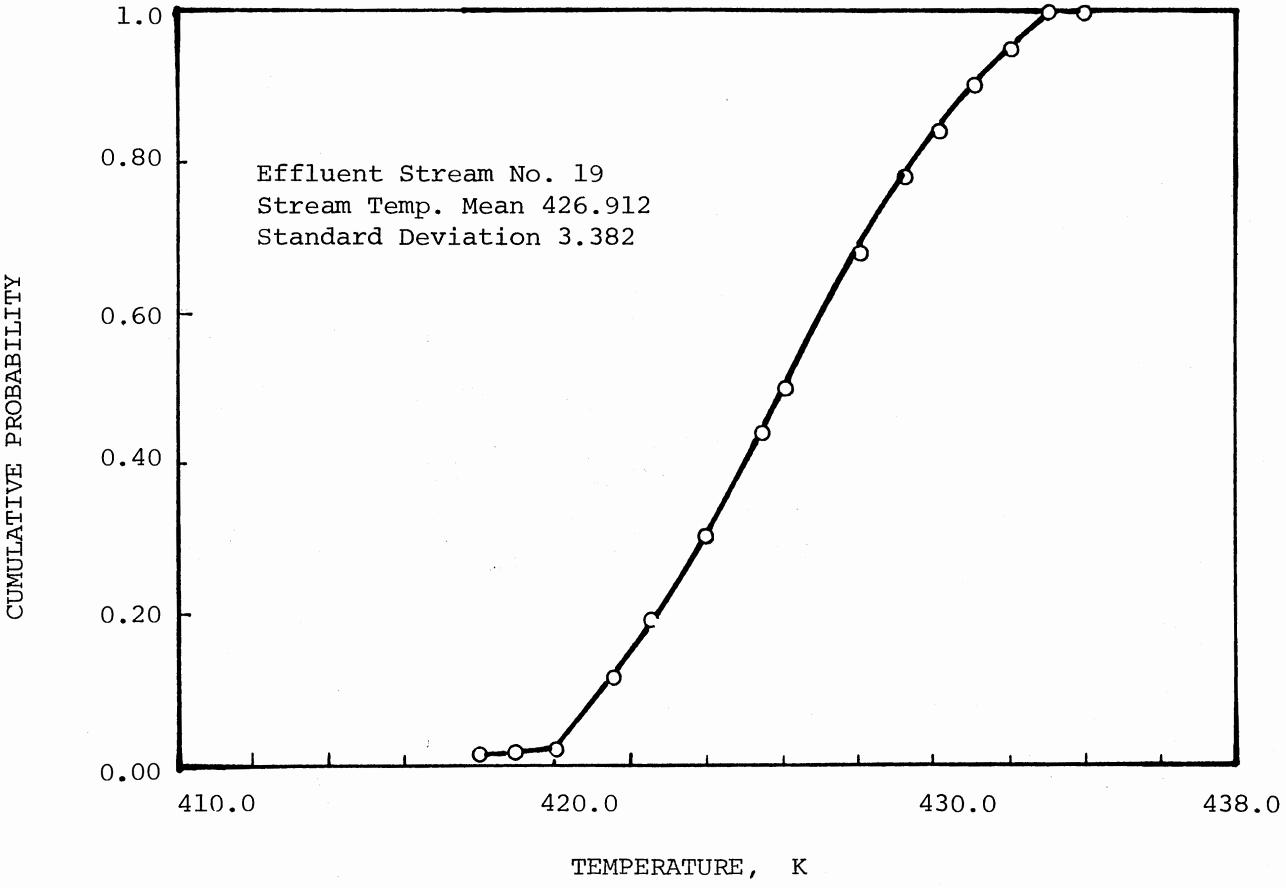


Figure V.3. Cumulative Probability of Variation of the Temperature of Stream 19

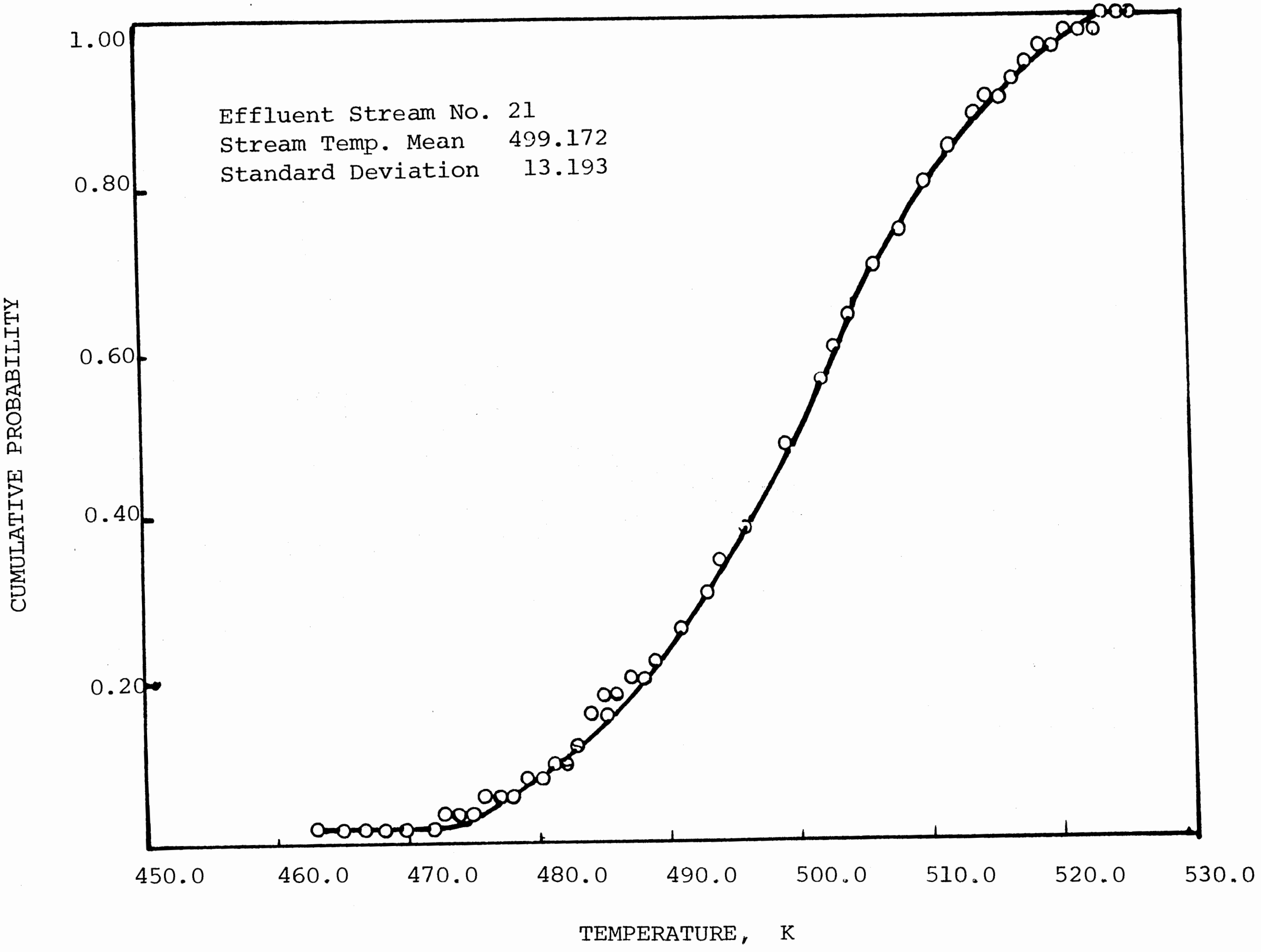


Figure V.4. Cumulative Probability of Variation of the Temperature of Stream 21

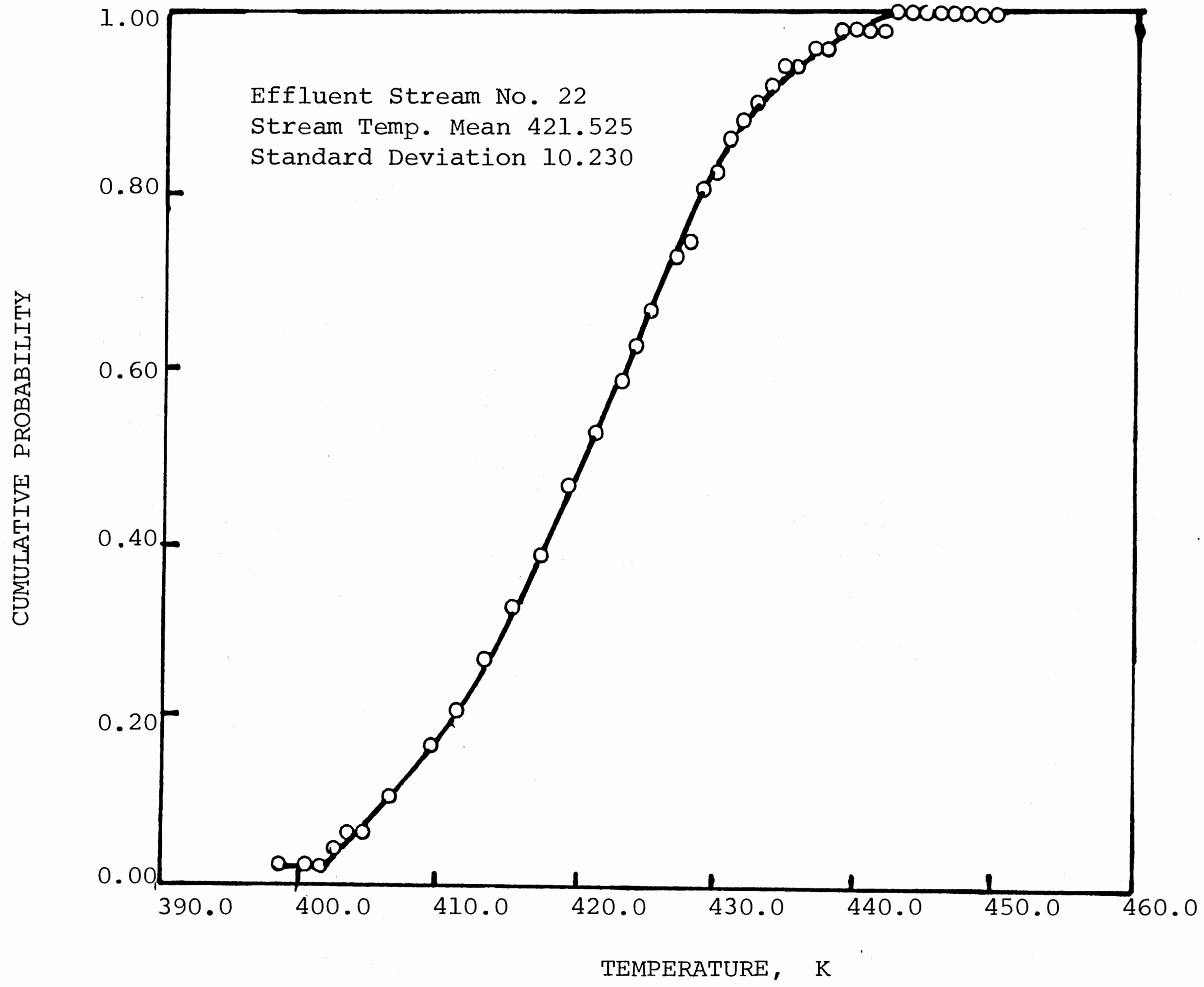


Figure V.5. Cumulative Probability of Variation of the Temperature of Stream 22

TABLE V.4

STATISTICS OF THE OUTPUT VARIABLES (FOR INPUT CONDITIONS DESCRIBED IN TABLE V.1 & 2) WHEN TEMPERATURE OF THE STREAM 19 IS ALLOWED TO VARY

Variable	Number of Simulations	Nominal Value	Mean Value	Standard Deviation	95% Confidence Interval
Temperature of Stream 19 K	500	427 K	427 K	3.4	420 K to 434 K
Temperature of Stream 21 K	500	499 K	499 K	13.2	473 K to 525 K
Temperature of Stream 22 K	500	422 K	421 K	10.2	401 K to 442 K
Conversion in the Reactor %	500	70%	64%	12.2	40% to 88%

Uncertainty in the temperature of the feed-effluent exchanger output stream (stream 22) is also very high. Figure V.5 shows that the temperature of the stream 22 varies from 401 K to 442 K (95% confidence interval).

The above analysis shows that the uncertainties in the output stream temperatures must be controlled in order to improve the performance of the system. One of the following three methods can be used to control the uncertainties in the output stream temperatures:

1. Limit the uncertainties in the feed-effluent and tempering exchanger input data, i.e., heat transfer coefficients, fouling, etc., through better correlations and design procedures.

2. Overdesign all the elements of the system (this will not limit the uncertainties but will shift the range).

3. To identify the most critical component in the system; if this component can be more closely controlled, the performance of the system will significantly improve.

The first method can be ruled out, because it requires major research programs, which are both expensive and time consuming and carry no guarantee of specific improvements.

The second method is possible but is not a very good solution. It usually means a substantial increase in capital investment.

Therefore, the possibility of applying the third method will be considered here.

Analysis of the uncertainties in the output stream temperatures indicates that the tempering exchanger is the most critical component in the system. A small variation in the tempering exchanger output stream temperature (stream 19) causes a very high variation in the reactor output stream temperature (i.e., 1 K standard deviation in the stream temperature 19 causes about 4 K standard deviation in the stream temperature 21). And since this is a feedback stream, this uncertainty feeds back to the system and severly affects the performance of the system. Therefore, by controlling the uncertainty of the temperature of the stream 19, the performance of the system can be improved.

In this system, a constant temperature heat source shell and tube heat exchanger is used as a tempering exchanger. Condensing stream (stream 20) serves for the constant temperature heat source. By controlling the temperature of the condensing stream, it might be possible to control the stream temperature 19. It is therefore necessary to know the range of the temperature over which the condensing steam 20 needs to be controlled. This range will determine whether it is feasible to apply the third method.

In order to calculate the range of the temperature over which the condensing steam 20 needs to be controlled, another computer run was made, where the stream temperature 19 was kept constant at 427°K and all other input conditions remained the same as previous run. The results of the calculation are presented in Figure V.6 and V.7.

Figure V.6 shows that the range of control of the condensing steam (stream 20) should be from 428 K to 444 K (95% confidence interval), the corresponding saturation pressure range being 5.43 bar to 8.14 bar.

Figure V.7 shows considerable improvement in the uncertainties of the temperature of output stream 22. (Standard deviation 6.3 K as opposed to 10.23 K in the previous case.)

The present study is extended to some further sensitivity analyses. In order to analyze how the uncertainty in the overall heat transfer

TABLE V.5

STATISTICS OF THE OUTPUT STREAM TEMPERATURES (INPUT CONDITIONS DESCRIBED IN TABLE V.1 & 2) WHEN TEMPERATURE OF STREAM 19 IS TO BE HELD CONSTANT AT 427 K

Stream Number	Nominal Temperature	Number of Simulations	Mean Temperature K	Standard Deviation K	95% Confidence Interval K
20	436	500	436	4.0	428 to 444
22	422	500	422	6.3	410 to 434

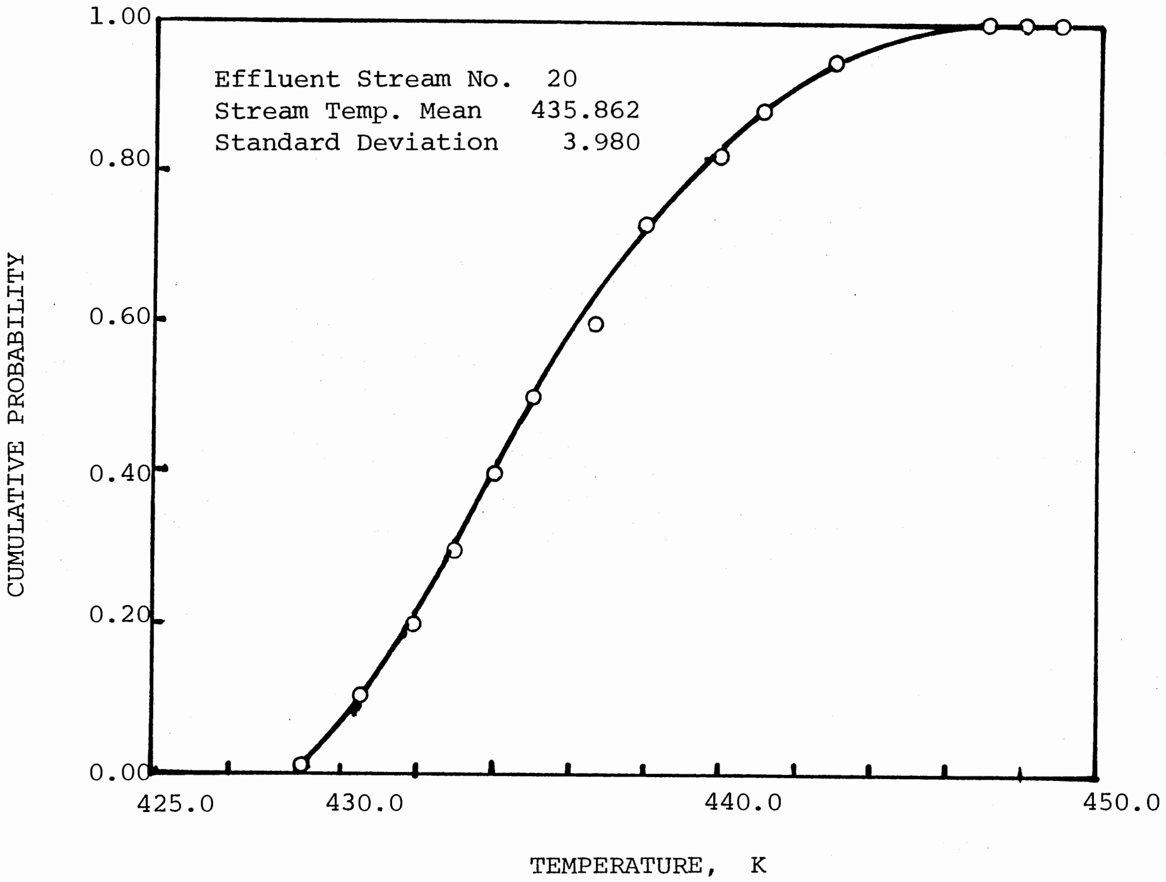


Figure V.6. Cumulative Probability of Variation of the Temperature of the Condensing Steam (Stream 20), When the Temperature of Stream 19 is to be Kept Constant at 427 K

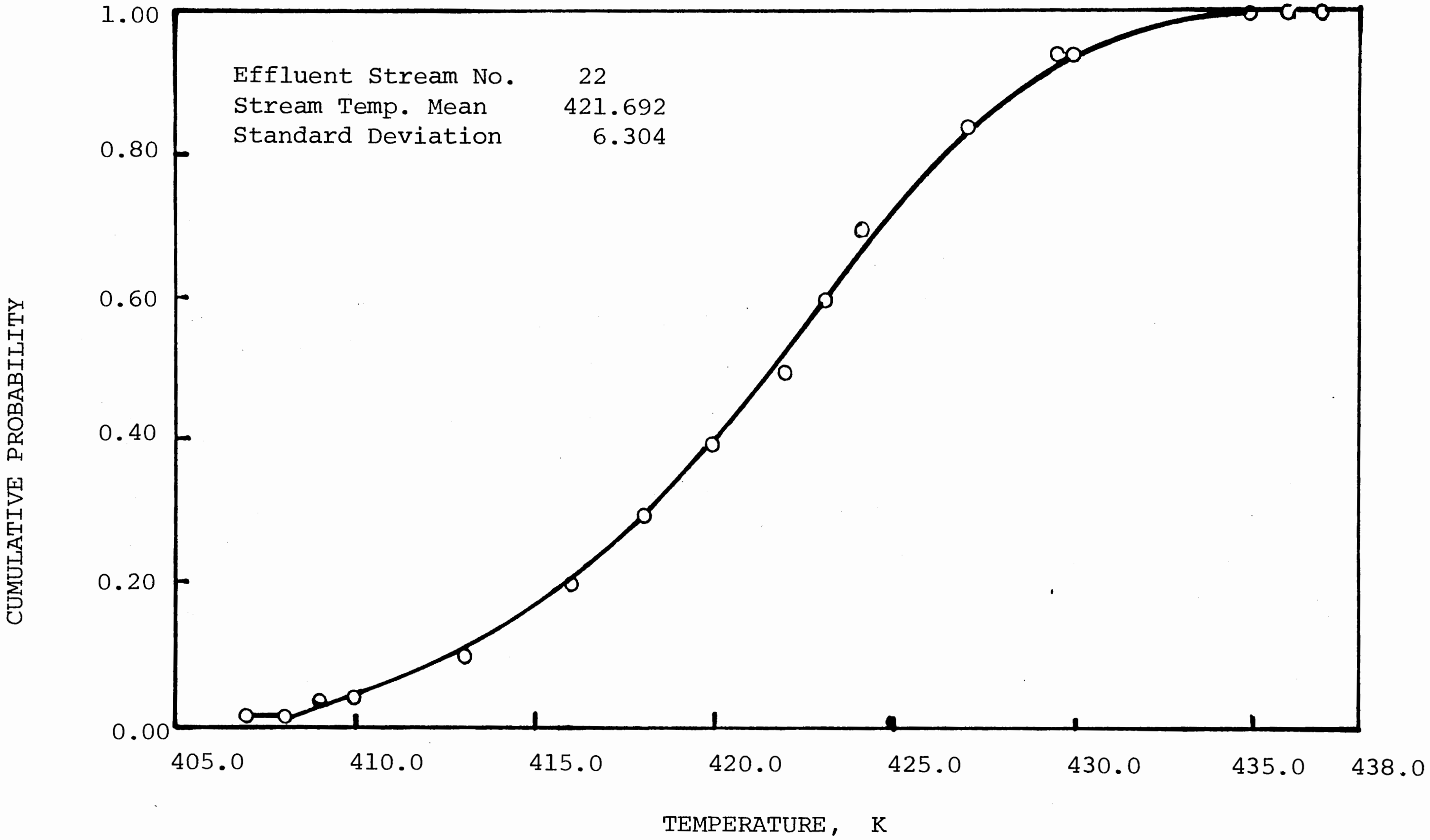


Figure V.7. Cumulative Probability of Variation of the Temperature of Stream 22 When the Temperature of Stream 19 is to be Kept Constant at 427 K coefficient of the tempering exchanger and fouling resistances in the feed-effluent exchanger affect the performance of the system, four different types of input conditions are considered. They are as follows:

Case 1

U_o (tempering exchanger) $\neq$ constant

U_o (feed effluent exchanger) $\neq$ constant

The input conditions described in Table V.6.

Case 2

U_o (tempering exchanger) $\neq$ constant

No fouling in the feed-effluent exchanger

The input conditions are described in Table V.7.

Case 3

U_o (tempering exchanger) = constant

U_o (feed-effluent exchanger) $\neq$ constant

The input conditions are described in Table V.8.

Case 4

U_o (tempering exchanger) = constant

No fouling in the feed-effluent exchanger

The input conditions are described in Table V.9.

All other input data except those specified in Table V.6 to V.9 are the same as in Table V.1 and V.2.

The results of the calculations for the above four cases are presented in Table V.10 and V.11. Comparison of these results shows that the performance of the system can be significantly improved by reducing the uncertainties associated with the fouling resistances in the feed-effluent exchanger.

TABLE V.6

INPUT CONDITION FOR CASE 1
($U_{o\ \mathrm{TEMP}} \neq$ CONSTANT)
($U_{o\ \mathrm{HEX}} \neq$ CONSTANT)

Variables	Tempering Exchanger	Feed-Effluent Exchanger
Shell Side Heat Transfer Coefficient, W/m^2 K	11356	1675
Variation of Shell Side Heat Transfer Coefficient, $\pm \Delta\%$	50	30
Tube Inside Heat Transfer Coefficient, W/m^2 K	2555	2555
Variation of Tube Inside Heat Transfer Coefficient, $\pm\Delta\%$	10	10
Shell Side Fouling Resistance, m^2 K/W	0.00007	0.00029
Variation of Shell Side Fouling Resistance	0.0 to 2 x Nominal Value	0.0 to 2 x Nominal Value
Tube Inside Fouling Resistance, m^2 K/W	0.00066	0.00066
Variation of Tube Inside Fouling Resistance	0.0 to 1.5 x Nominal Value	0.0 to 1.5 x Nominal Value

TABLE V.7

INPUT CONDITION FOR CASE 2
($U_{o\ TEMP} \neq$ CONSTANT)
(NO FOULING IN
FEED-EFFLUENT
EXCHANGER)

Variables	Tempering Exchanger	Feed-Effluent Exchanger
Shell Side Heat Transfer Coefficient, W/m^2 K	11356	1675
Variation of Shell Side Heat Transfer Coefficient, $\pm\Delta$%	50	30
Tube Inside Heat Transfer Coefficient, W/m^2 K	2555	2555
Variation of Tube Inside Heat Transfer Coefficient $\pm\Delta$%	10	10
Shell Side Fouling Resistance, m^2 K/W	0.00007	0.0
Variation of Shell Side Fouling Resistance	0.0 to 2 x Nominal Value	0.0
Tube Inside Fouling Resistance m^2 K, W	0.00066	0.0
Variation of Tube Inside Fouling Resistance	0.0 to 1.5 x Nominal Value	0.0

TABLE V.8

INPUT CONDITION FOR CASE 3
($U_{o\ TEMP}$ = CONSTANT)
($U_{o\ HEX} \neq$ CONSTANT)

Variables	Tempering Exchanger	Feed-Effluent Exchanger
Shell Side Heat Transfer Coefficient, W/m^2 K	11356	1675
Variation of Shell Side Heat Transfer Coefficient, ± Δ%	0.0	30
Tube Inside Heat Transfer Coefficient, W/m^2 K	2555	2555
Variation of Tube Inside Heat Transfer Coefficient, ± Δ%	0.0	10
Shell Side Fouling Resistance, m^2 K/W	0.00007	0.00029
Variation of Shell Side Fouling Resistance	0.0	0.0 to 2 x Nominal Value
Tube Inside Fouling Resistance, m^2 K/W	0.00066	0.00066
Variation of Tube Inside Fouling Resistance	0.0	1.5 x Nominal Value

TABLE V.9

INPUT CONDITION FOR CASE 4
($U_{o\ TEMP}$ = CONSTANT
NO FOULING IN
FEED-EFFLUENT
EXCHANGER)

Variables	Tempering Exchanger	Feed-Effluent Exchanger
Shell Side Heat Transfer Coefficient, W/m^2 K	11356	1675
Variation of Shell Side Heat Transfer Coefficient, ± Δ%	0.0	30
Tube Inside Heat Transfer Coefficient, W/m^2 K	2555	2555
Variation of Tube Inside Heat Transfer Coefficient, ±Δ%	0.0	10
Shell Side Fouling Resistance, m^2 K/W	0.00007	0.0
Variation of Shell Side Fouling Resistance	0.0	0.0
Tube Inside Fouling Resistance, m^2 K/W	0.00066	0.0
Variation of Tube Inside Fouling Resistance	0.0	0.0

TABLE V.10

STATISTICS OF THE OUTPUT VARIABLES (FOR INPUT CONDITIONS DESCRIBED IN TABLE V.6 - V.9) WHEN TEMPERATURE OF THE STREAM 19 IS ALLOWED TO VARY

Input Condition	Temperature of Stream 19 K			Temperature of Stream 21 K		
	Mean K	Standard Deviation K	95% Confidence Interval K	Mean K	Standard Deviation K	95% Confidence Interval K
$Uo_{TEMP} \neq$ Const. $Uo_{HEX} =$ Const.	427	3.4	420 to 434	499	13.2	473 to 425
$Uo_{TEMP} \neq$ Const. No Fouling In HEX	427	2.2	423 to 431	502	8.8	484 to 519
$Uo_{TEMP} =$ Const. $Uo_{HEX} \neq$ Const.	428	1.3	425 to 431	403	5.0	493 to 513
$Uo_{TEMP} =$ Const. No Fouling In HEX	427	0.50	426 to 428	499	2.0	495 to 503

TABLE V.10 (Continued)

Input Condition	Temperature of Stream 22 K			Conversion in the Reactor %		
	Mean K	Standard Deviation K	95% Confidence Interval K	Mean %	Standard Deviation %	95% Confidence Interval %
$Uo_{TEMP} \neq$ Const. $Uo_{HEX} \neq$ Const.	422	10.2	401 to 450	64.0	12.2	40 to 88
$Uo_{TEMP} \neq$ Const. No Fouling In HEX	401	6.7	388 to 414	68.5	6.9	55 to 82
$Uo_{TEMP} =$ Const. $Uo_{HEX} \neq$ Const.	416	7.8	401 to 431	76.0	5.6	65 to 87
$Uo_{TEMP} =$ Const. No Fouling In HEX	401	2.9	395 to 407	70.5	0.8	69 to 72

TABLE V.11

STATISTICS OF THE CONDENSING STEAM TEMPERATURE (FOR INPUT CONDITIONS DESCRIBED IN TABLE V.6 - V.9) WHEN THE TEMPERATURE OF STREAM 19 IS TO BE KEPT CONSTANT

Input Condition	Condensing Steam Temperature (Stream 20)		
	Mean K	Standard Deviation K	95% Confidence Interval K
$Uo_{TEMP} \neq$ Const. $Uo_{HEX} \neq$ Const.	435.86	3.98	429 to 447
$Uo_{TEMP} \neq$ Const. No Fouling in HEX	431.05	1.91	428 to 438
$Uo_{TEMP} =$ Const. $Uo_{HEX} \neq$ Const.	435.61	1.28	432 to 437
$Uo_{TEMP} =$ Const. No Fouling In HEX	430.89	0.48	430 to 432

CHAPTER VI

DEMONSTRATION PROBLEM NUMBER 2: REACTOR IN A PLATFORMING UNIT WITH FEED-EFFLUENT HEAT EXCHANGER

In this problem the effect of uncertainties in the feed-effluent exchanger on the performance of a platforming unit will be analyzed. A typical platforming unit consists of a feed-effluent heat exchanger, 4 reactors and 4 fired heaters. In each reactor, the feed stream temperature drops by 50 K due to the endothermic reaction taking place in the reactor. The fired heaters are used as tempering exchangers to adjust the reactor feed stream temperature. A schematic diagram of a typical platforming unit is shown in Figure VI.1. Feed stock (stream 16) enters the feed-effluent heat exchangers (element 2) at 450 K and recovers heat against the reactor (element 10) effluent (stream 25). Stream 17 exiting from the feed-effluent exchanger then enters the fired heater (element 3) to adjust the reactor 4 feed stream temperature to 773 K. In the reactor, chemical reaction takes place with the absorption of heat (endothermic reaction) and the reactor outlet stream temperature drops the 723 K ($\Delta T_{reactor} = 50$ K). Stream 19 coming out of reactor 4 then passes through three successive reactors (6, 8 and 10 respectively). But before entering each reactor, the stream inlet temperature is adjusted to 773 K in the fired heaters 5, 7 and 9. Finally, the reactor 10 effluent, stream 25, feeds back

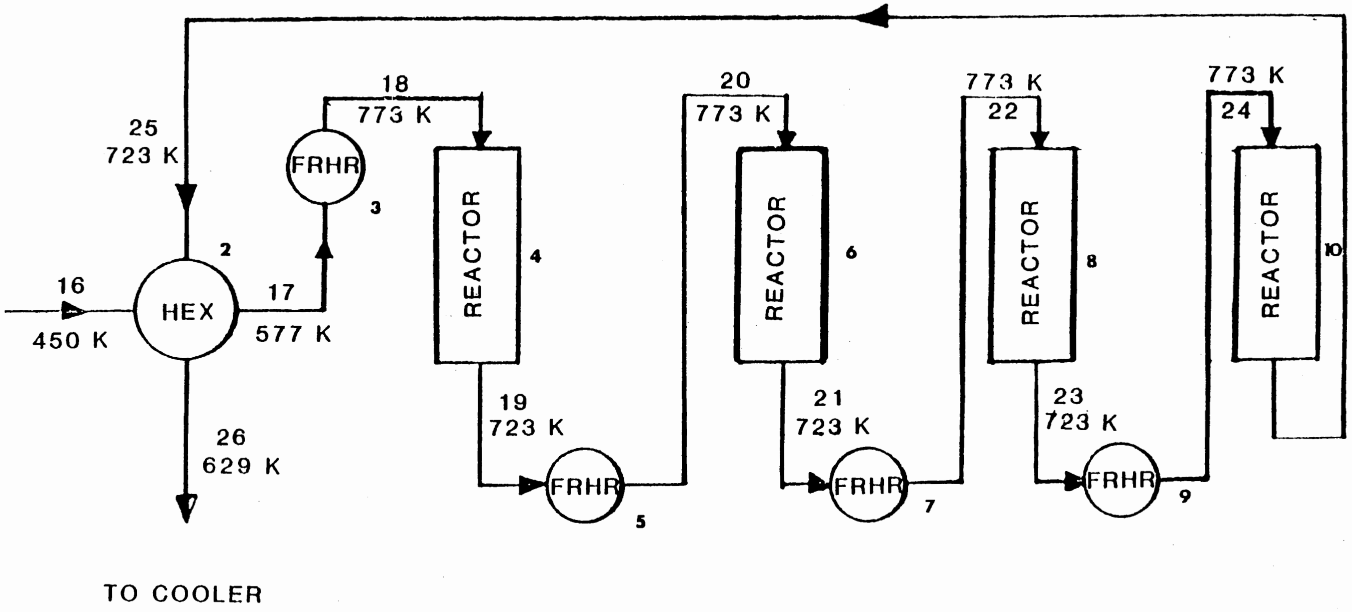


Figure VI.1. Schematic Diagram of the System (Demonstration Problem No.2) to the feed-effluent heat exchanger 2 at 723 K. The heat exchanger outlet stream 26 then goes to a cooler.

Nominal values and the uncertainties for the feed-effluent heat exchanger input data are presented in Table VI.1. Feed stream input conditions are presented in Table VI.2. The 95% confidence level is chosen for the variation in heat transfer coefficients and fouling resistances in the feed-effluent exchanger. It is assumed that there is no uncertainty in the feed stream (stream 16) temperature, flow rate and specific heat.

Uncertainties in the feed-effluent exchanger input data will cause uncertainties in the output stream temperatures and will affect the performance of the whole system. It is important that the specified reactor inlet temperature should be achieved and the variation be within a small range of the nominal values. A large variation of the reactor inlet temperature will affect the extent of the reaction in the reactor, and the reactor might not perform adequately. Therefore, in this problem, the uncertainties in the reactor inlet stream temperatures and the means to limit them will be studied.

The computer program developed in the present thesis is used to calculate the uncertainties in the temperatures of the stream 17, 18, 20, 22, 24, 25, and 26. For this part of the problem it is assumed that heat inputs in the fired heaters are constant and there is no source of uncertainty in the reactors and the fired heaters. The uncertainties in the temperatures of the stream 17, 18 and 26 are presented in Figure VI.2, VI.3 and VI.4 respectively. (The uncertainties in temperatures of streams 20, 22, 24, 25 are not shown here because all these stream

TABLE VI.1

INPUT DATA FOR FEED-EFFLUENT HEAT EXCHANGER

Variable \ Heat Exchanger	2
Area, m^2	125
Shell Side Heat Transfer Coefficient, $W/m^2\ K$	1675
Variation of Shell Side Heat Transfer Coefficient, $\pm\Delta\%$	$\pm$ 30%
Tube Side Heat Transfer Coefficient, $W/m^2\ K$	2555
Variation of Tube Side Heat Transfer Coefficient, $\pm\Delta\%$	$\pm$ 10%
Shell Side Fouling Resistance, $m^2\ K/W$	0.00029
Variation of Shell Side Fouling Resistance	0.0 to 2 x Nominal Value
Tube Inside Fouling Resistance, $m^2\ K/W$	0.00065
Variation of Tube Inside Fouling Resistance	0.0 to 1.5 x Nominal Value
Tube Wall Thermal Conductivity W/m K	52
Effective Tube Inside Area, m^2/m	0.0624
Effective Tube Outside Area, m^2/m	0.0798
Tube Inside Diameter, m	0.0202
Tube Outside Diameter, m	0.0258
Number of Tube Passes	2
Specific Heat of the Cold Fluid, KJ/Kg K	1.45
Specific Heat of the Hot Fluid, KJ/Kg K	1.95

TABLE VI.2

FEED STREAM INPUT CONDITION

Stream Number	Flow Rate Kg/hr	Temperature K	Specific Heat KJ/Kg K
16	160000	450	1.45

temperatures have the same cumulative probability curves due to the same heat inputs in the fired heater and the same ΔT's in the reactor.) 500 simulations are used for stochastic calculation. The results of the deterministic calculation are given in Table VI.3. The statistics of the output stream temperatures are provided in Table VI.4.

Figure VI.2 shows that temperature of the stream 17 varies from 561 K to 611 K (95% confidence interval). And Figure VI.3 shows that the reactors inlet stream temperatures will vary from 758 K to 808 K (95% confidence interval) with mean and standard deviation being 783 K and 12.7 K respectively.

Uncertainties in the feed-effluent heat exchanger input data cause uncertainty in the temperature of the output stream 17. The uncertainty in this stream temperature carries over to all the reactor feed stream temperatures and finally feeds back to the system. As a result the uncertainty in the output stream temperature 26 is also very high (Figure VI.4).

Uncertainties in the reactor feed stream temperatures are very high and need to be controlled. One way of controlling them is to control the temperature of the output stream 17. This can be done either by limiting the uncertainties in the feed-effluent exchanger input data i.e., heat transfer coefficients and fouling, or by adding the additional surface area required in the feed-effluent exchanger to accommodate the uncertainties involved.

As discussed in the previous problem, the first measure requires major research program which are both expensive and time consuming.

TABLE VI.3

RESULTS OF DETERMINISTIC CALCULATION (FOR INPUT CONDITIONS DESCRIBED IN TABLE VI.1 & 2)

Stream Number	Flow Rate Kg/hr	Temperature K
16	160000	450
17	160000	577
18	160000	773
19	160000	723
20	160000	773
21	160000	723
22	160000	773
23	160000	723
24	160000	773
25	160000	723
26	160000	629

TABLE VI.4

STATISTICS OF THE OUTPUT STREAM TEMPERATURES (FOR INPUT CONDITIONS DESCRIBED IN TABLE VI.1 & 2)

Stream Number	Nominal Temperature K	Number of Simulations	Mean Temperature K	Standard Deviation K	95% Confidence Interval K
17	577	500	586	12.71	561 to 611
18	773	500	783	12.71	758 to 808
20	773	500	783	12.71	758 to 808
22	773	500	783	12.71	758 to 808
24	773	500	783	12.71	758 to 808
25	723	500	733	12.71	708 to 758
26	629	500	610	11.34	588 to 633

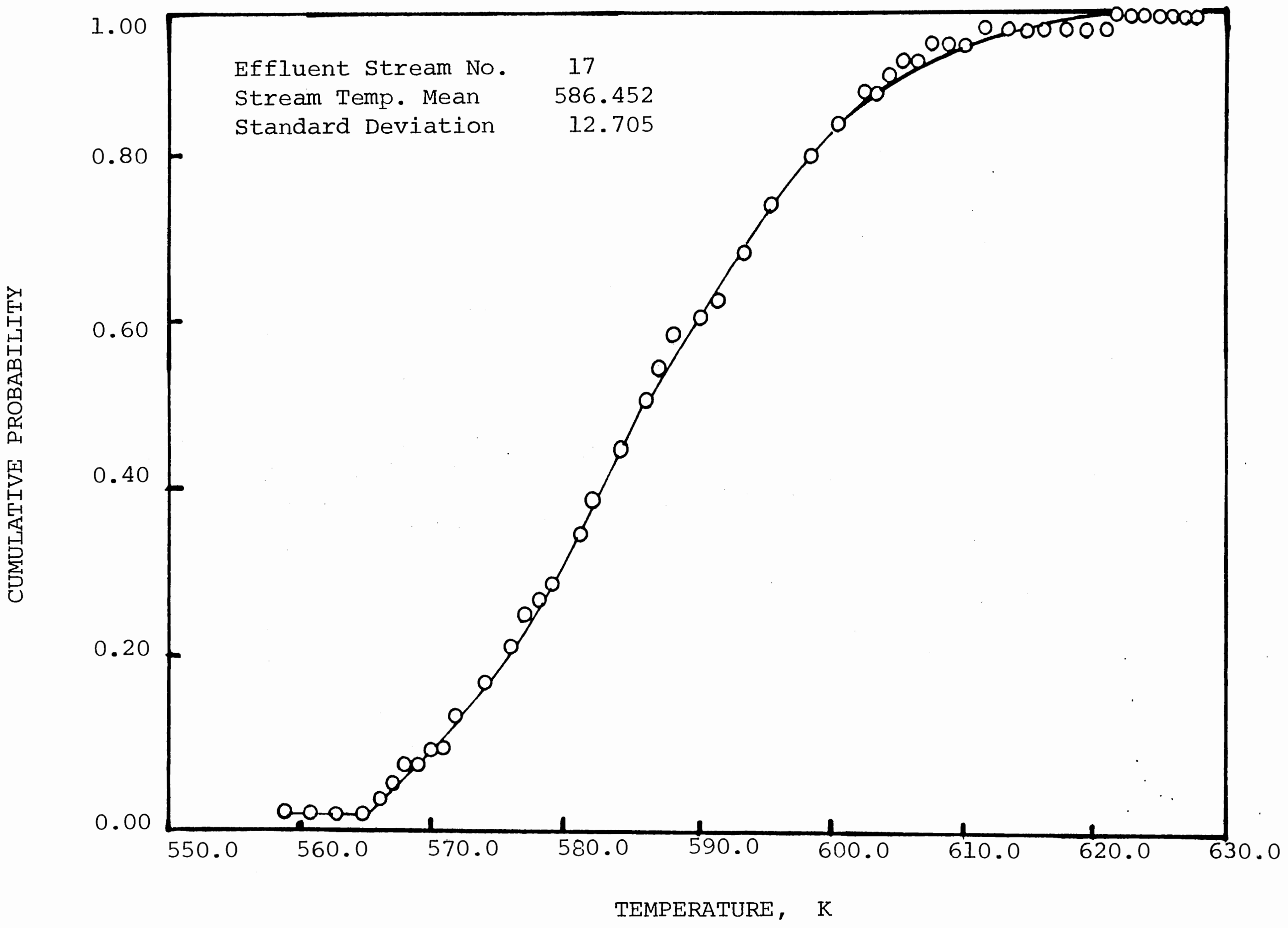


Figure VI.2. Cumulative Probability of Variation of the Temperature of Stream 17

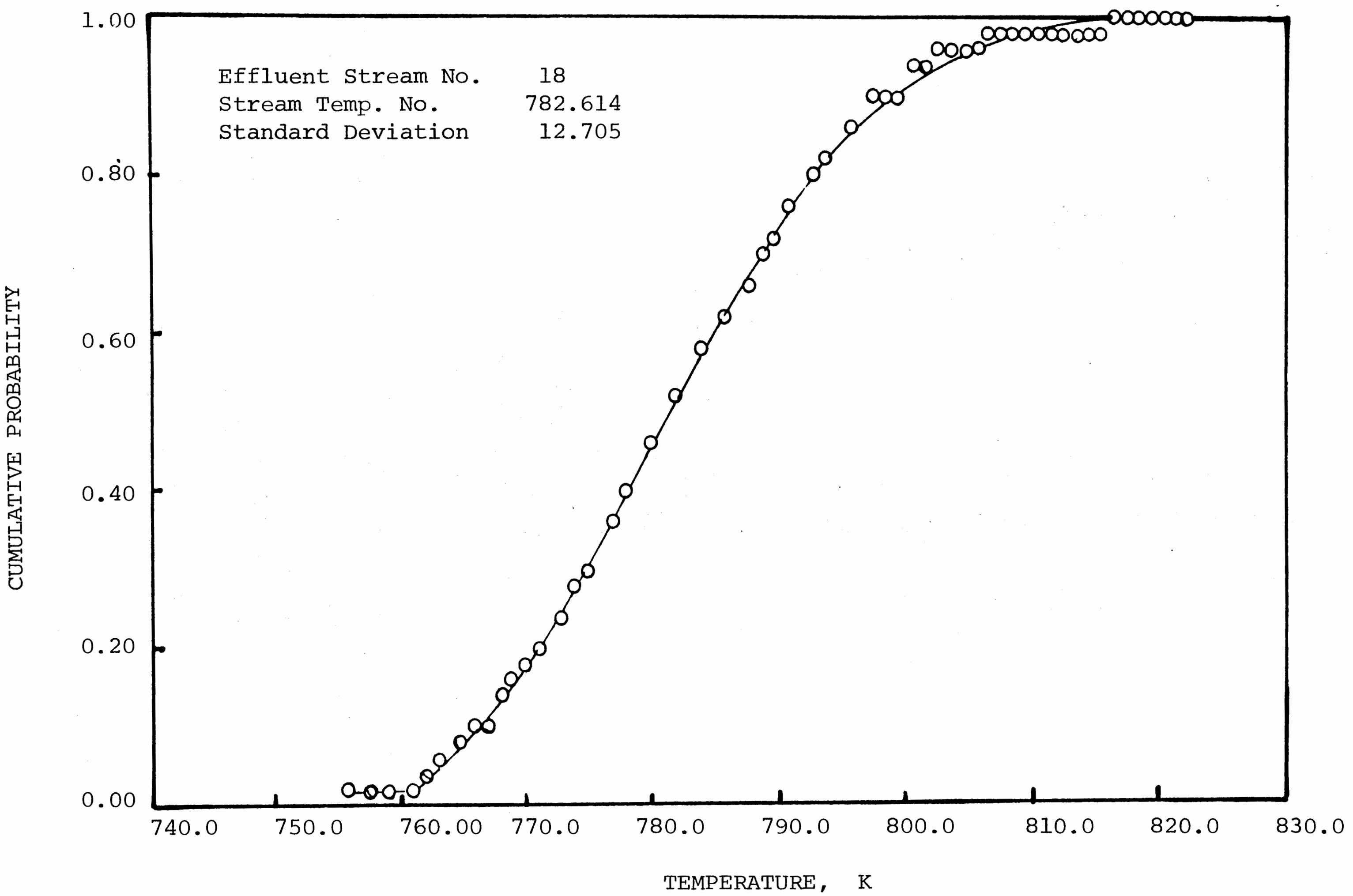


Figure VI.3. Cumulative Probability of Variation of the Temperature of Stream 18

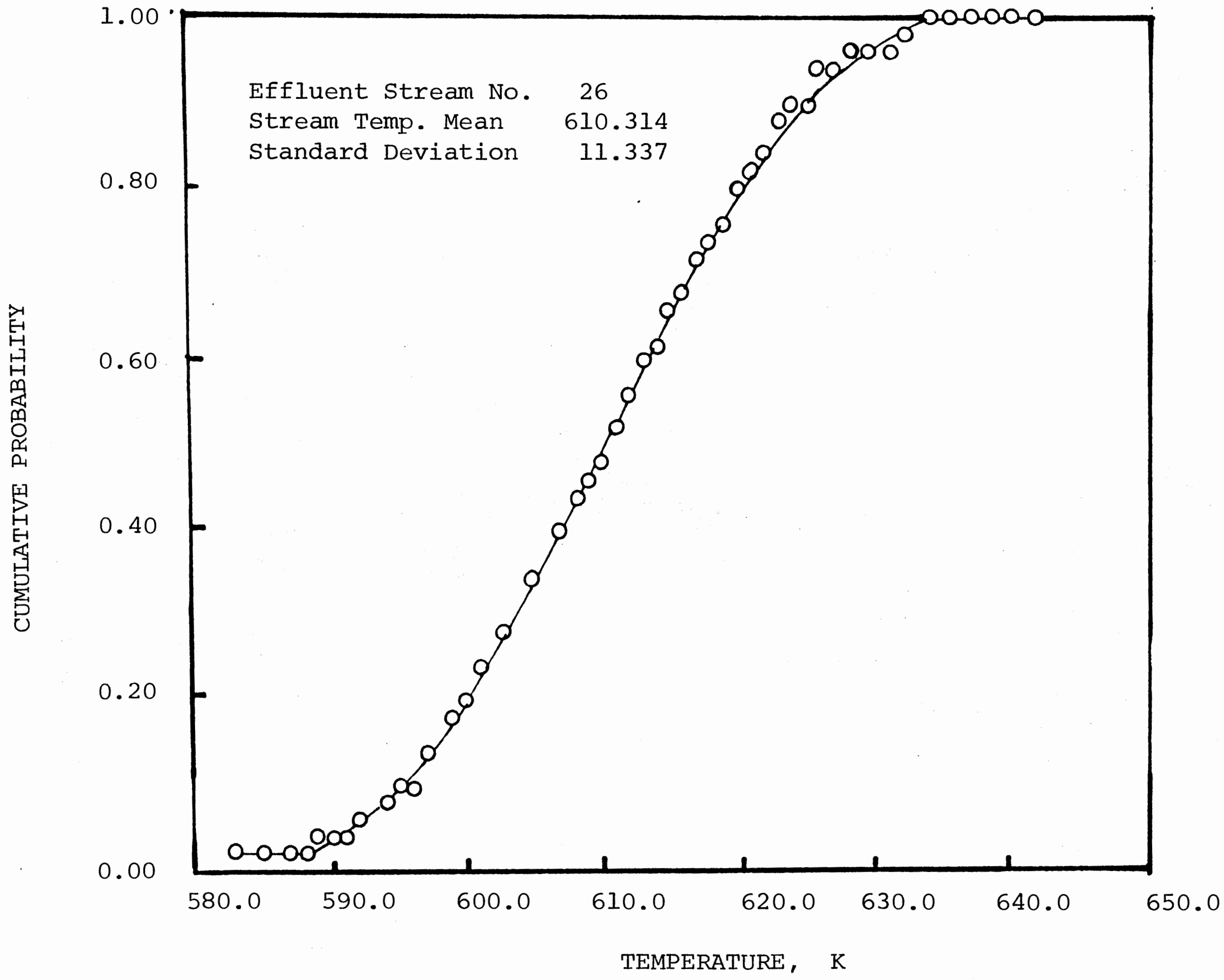


Figure VI.4. Cumulative Probability of Variation of the Temperature of Stream 26

The second measure usually means substantial increase in captial investment.

Another way to control the uncertainties in the reactor feed stream temperatures is to control the temperature of the fired heater 3 output, stream 18. The temperature of stream 18 can be controlled by controlling the amount of heat transfered in the fired heater 3.

In order to know the range of the amount of heat to be transfered to the fired heater 3, another computer run was made where the stream temperature 18 was kept constant at 773 K. All other input conditions are the same as the previous run. The results shows that the range of the amount of heat transferred to the fired heater 3 should be from 1.14×10^7 W to 1.39×10^7 W (95% confidence interval with mean heat duty and standard deviation being 1.26×10^7 W and 6.29×10^5 W respectively) in order to keep the temperature of stream 18 constant at 773 K.

However, it should be noted there that in this problem, the feed-effluent heat exchanger is considered to be the only source of uncertainties. It is assumed that there is no uncertainty in the reactors and the fired heaters. Therefore, the actual control range of the thermal duty to fired heater 3 will be higher than the above-mentioned range.

CHAPTER VII

DEMONSTRATION PROBLEM NO 3: DISTILLATION COLUMN WITH FEED-EFFLUENT HEAT EXCHANGER

In this problem, the effect of uncertainties on a crude preheat train using a feed-effluent heat exchanger system will be analyzed. A crude charge at 308 K is to be preheated to 469 K before it is fed to the distillation column. The preheating is done by utilizing the product streams from the distillation column. A schematic diagram of the crude preheat train is presented in Figure VII.1. A crude charge at 308 K (stream 10) is first divided into four parallel streams (stream 11 12, 31 and 41) and recovers heat against the distillation column product streams (stream 61, 71, 81 and 91) in a series of feed-effluent heat exchangers (heat exchangers 3, 4, 5, 6, 7, 8, 9 and 10). The four parallel streams (stream 13, 23, 33, and 43) then merge into one stream (stream 52) in an adder element and are fed into the desalter at 393 K. No heat transfer occurs in the desalter unit and stream 52 then enters the tempering exchanger 12. In the tempering exchanger the feed temperature of the distillation column (stream 53) is adjusted to the required temperature 469 K and fed to distillation column 13. The product streams of the distillation column, stream 61, 71, 81 and 91 (Gasoline, Naphtha, Kerosine and Residual Fuel respectively) serve as the feedback streams in the system. The

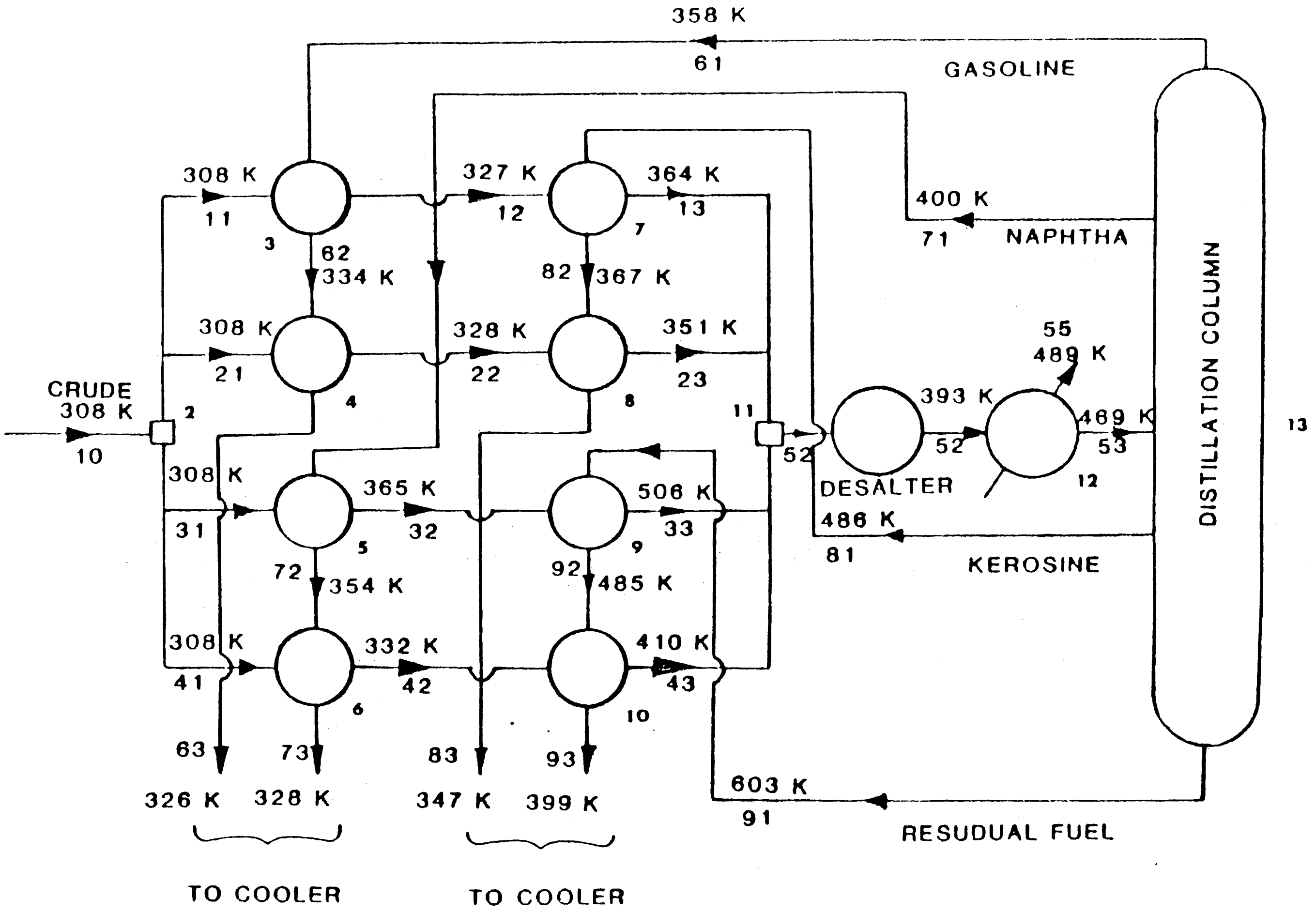


Figure VII.1. Schematic Diagram of the Crude Preheat System (Demonstration Problem No. 3) output streams 63, 73, 83 and 93 go to coolers.

The nominal values and the uncertainties for the feed-effluent heat exchangers and tempering exchanger are presented in Table VII.1. Feed stream input conditions are presented in Table VII.2. The 95% confidence level is assumed for the variation in heat transfer coefficients and fouling resistancess. It is assumed that the variation in the distillation column product stream temperature is proportional to the distillation column feed stream temperature variation (i.e., $\sigma Tp_i = K_i \sigma_{T_F}$). The coefficients K_i for product stream 61, 71, 81, and 91 are chosen to be 1.5, 2.5, 2.8 and 3.5 respectively. It is also assumed that there is no uncertainty in the feed stream (stream 10) temperature, flow rate and specific heat.

Uncertainties in the heat exchanger input data will cause uncertainties in the output stream temperatures and will affect the performance of the whole system. In this problem, the uncertainties involved in the desalter unit feed temperature (stream 52), distillation unit feed stream temperature (stream 53) and the output streams temperatures (stream 63, 73, 83 and 93) will be studied. It is important that the specified temperatures for the crude feed to desalter, crude feed to distillation unit and the output streams should be achieved and that the variations be within a small range of the nominal values.

The computer program developed in the present thesis is used to calculate the uncertainties in the temperatures of streams, 52, 53, 63, 73, 83 and 93. These uncertainties are presented in Figure VII.2, VII.3, VII.4, VII.5, VII.6 and VII.7 respectively. 500 simulations are used for stochastic calculation. The results of the deterministic calculation are

TABLE VII.1

HEAT EXCHANGER INPUT DATA

Variable \ Heat Exchanger Number	3	4	5	6	7	8	9	10	12
Area, m^2	153	153	153	153	153	153	153	153	464
Shell Side Heat Transfer Coefficient, W/m^2 K	1675	1675	1675	1675	1675	1675	1675	1675	11356
Variation of Shell Side Heat Transfer Coefficient, ± %	30	30	30	30	30	30	30	30	50
Tube Inside Heat Transfer Coefficient, W/m^2 K	2555	2555	2555	2555	2555	2555	2555	2555	2555
Variation of Tube Inside Heat Transfer Coefficient, ± %	10	10	10	10	10	10	10	10	10
Shell Side Fouling Resistance, m^2 K/W	0.00028	0.00028	0.00028	0.00028	0.00075	0.00075	0.00075	0.00075	0.00009
Variation of Shell Side Fouling Resistance	0.0 to 2 x Nominal Value								
Tube Inside Fouling Resistance, m^2 K/W	0.00066	0.00066	0.00066	0.00066	0.00066	0.00066	0.00066	0.00066	0.00066
Variation of Tube Inside Fouling Resistance	0.0 to 1.5 x Nominal Value								

TABLE VII.1 (Continued)

Variable \ Heat Exchanger Number	3	4	5	6	7	8	9	10	12
Tube Wall Thermal Conductivity, W/m K	56	56	56	56	56	56	56	56	56
Effective Tube Inside Area, m^2/m	0.0624	0.0624	0.0624	0.0624	0.0624	0.0624	0.0624	0.0624	0.0624
Effective Tube Outside Area, m^2/m	0.0789	0.0798	0.0798	0.0798	0.0798	0.0798	0.0798	0.0798	0.0798
Tube Inside Diameter, m	0.0202	0.0202	0.0202	0.0202	0.0202	0.0202	0.0202	0.0202	0.0202
Tube Outside Diameter, m	0.0258	0.0258	0.0258	0.0258	0.0258	0.0258	0.0258	0.0258	0.0258
Number of Tube Passes	2	2	2	2	2	2	2	2	2
Number of Shell Passes	1	1	1	1	1	1	1	1	1

TABLE VII.2

FEED STREAM INPUT CONDITIONS

Stream Number	Flow Rate Kg/hr	Temperature K	Specific Heat KJ/Kg K
10	323206	308	2 .064

given in Table VII.3. The statistics of the output stream temperatures are provided in Table VII.4.

Figure VII.2 shows that feed stream temperature to the desalter (stream 52) varies from 382 K to 400 K (95% confidence interval) with mean temperature and standard deviation being 291 K and 4.5 K respectively.

The range of variation of the distillation unit feed stream temperature (stream 53) is 455 K to 481 K (95% confidence interval) with mean and standard deviation being 468 K and 6.6 K respectively (Figure VII.3).

The high uncertainty in the distillation unit feed stream temperature affects the performance of the distillation column and causes the uncertainties in the distillation unit product stream temperatures. And since they are fed back to the system, these uncertainties carry over and affect the performance of the whole system. As a result the uncertainties in the output stream temperatures (stream 63, 73, 83 and 93) are also very high (Figure VII.4, VII.5, VII.6 and VII.7 respectively).

From the above analysis it is obvious that the ranges of variations in the stream temperatures 52, 53, 63, 73, 83 and 93 are quite high and they should be controlled. Again, as discussed in the previous problem, the most efficient method to control the uncertainties in the output stream temperatures is to identify the most critical component in the system by analyzing the uncertainties in all the output stream temperatures. After identifying the most critical component in the system, the possibility of more closely controlling the critical component of the system should be explored.

TABLE VII.3

RESULTS OF DETERMINISTIC CALCULATION (FOR INPUT CONDITIONS DESCRIBED IN TABLE VII.1 & 2)

Stream Number	Flow Rate Kg/hr	Temperature K
11	161603	308
12	161603	327
13	161603	364
21	48481	308
22	48481	328
23	48481	351
31	48481	308
32	48481	365
33	48481	506
41	64642	308
42	64642	332
43	64642	410
52	323206	393
53	323206	469
55	22273	489
61	161603	358
62	161603	334
63	161603	326
71	64642	400
72	48481	354
73	48481	328
81	48481	486
82	48481	367
83	48481	347
91	48481	603
92	48481	485
93	48481	399

TABLE VII.4

STATISTICS OF THE OUTPUT STREAMS TEMPERATURES FOR CONDITION WHEN
TEMPERATURE OF THE STREAM 53 ALLOWED TO VARY
(NTU OF TEMPERING EXCHANGER = 1.58)

Stream Number	Nominal Temperature K	Number of Simulations	Mean Temperature K	Standard Deviation K	95% Confidence Interval K
52	393	500	391	4.5	382 to 400
53	469	500	468	6.6	455 to 481
63	326	500	330	3.6	323 to 337
73	328	500	327	3.2	321 to 333
83	347	500	357	5.2	346 to 367
93	399	500	393	7.3	379 to 407

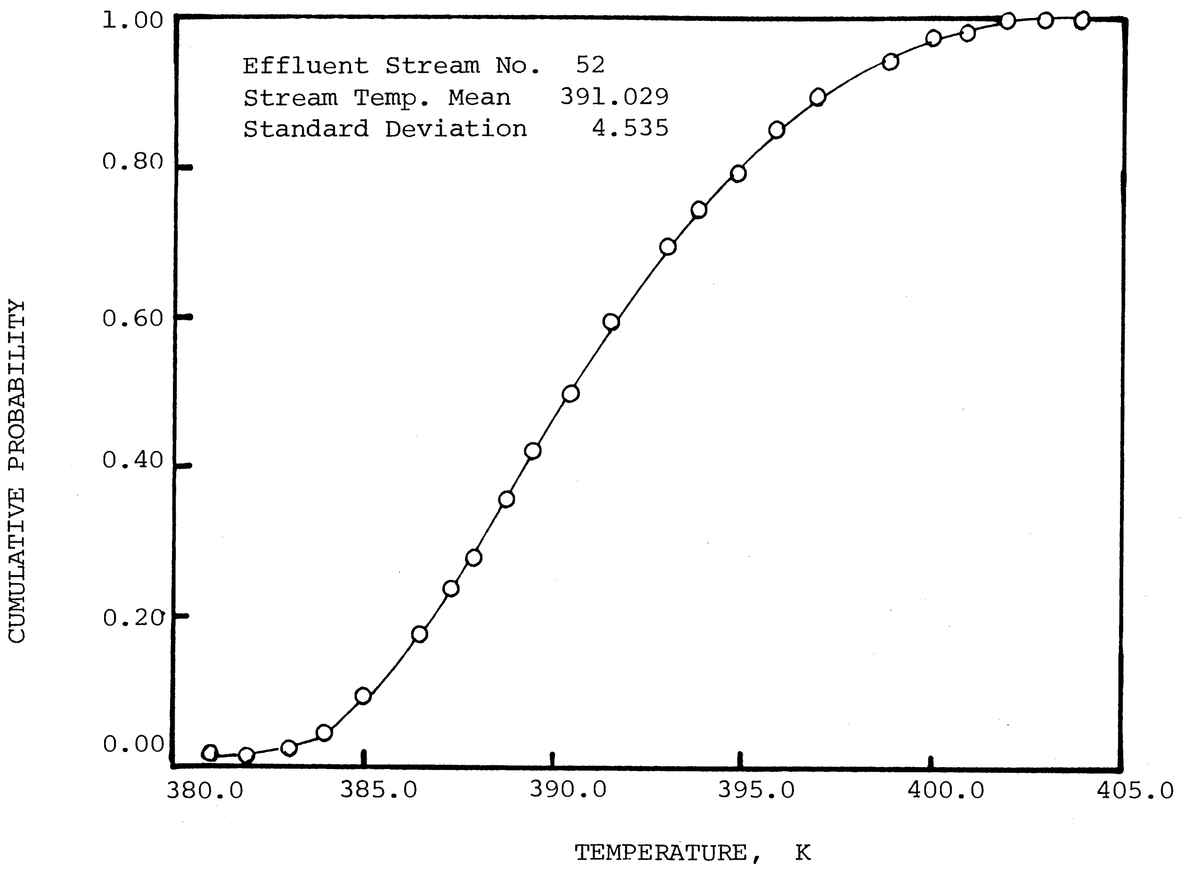


Figure VII.2. Cumulative Probability of Variation of the Temperature of Stream 52

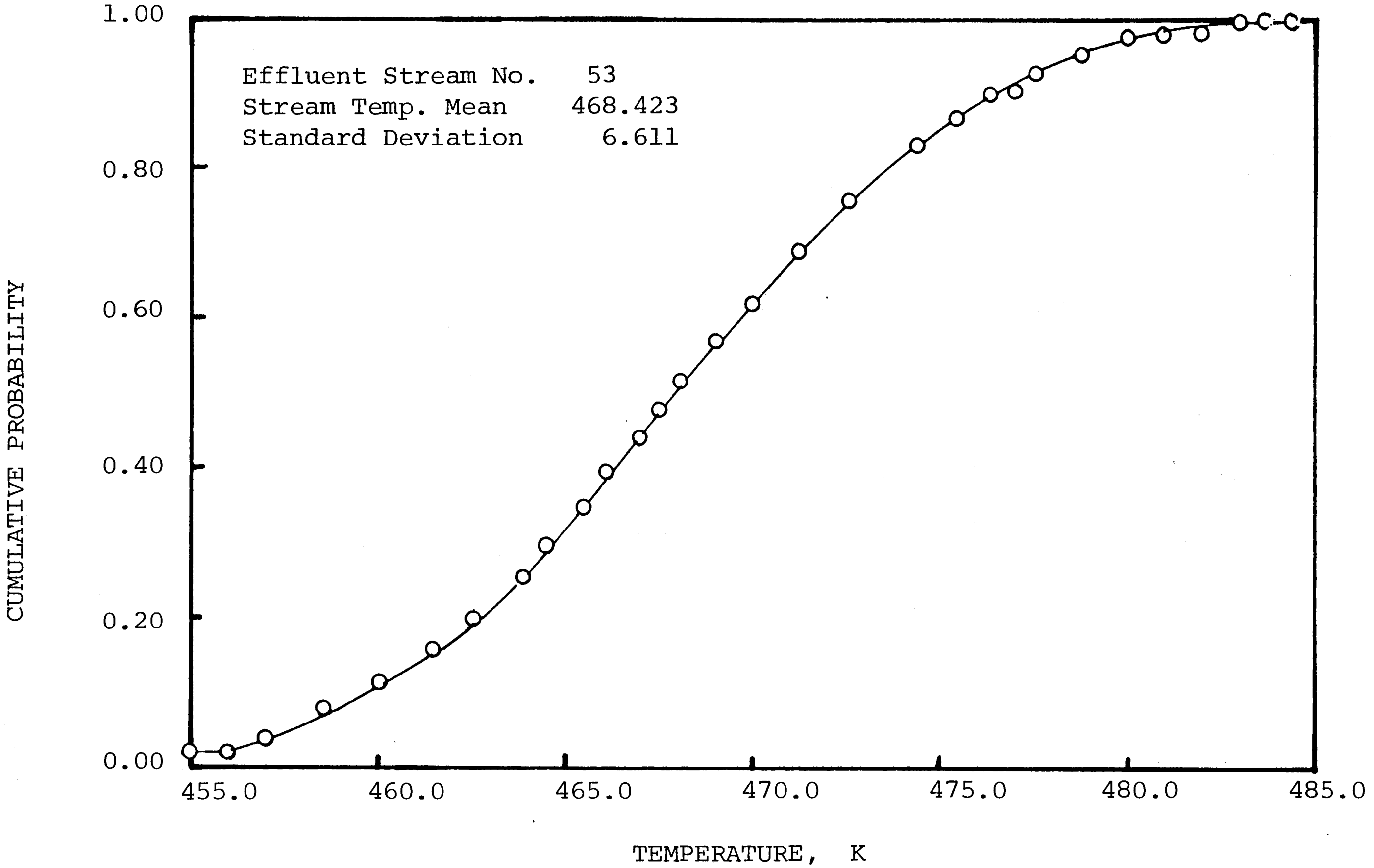


Figure VII.3. Cumulative Probability of Variation of the Temperature of Stream 53

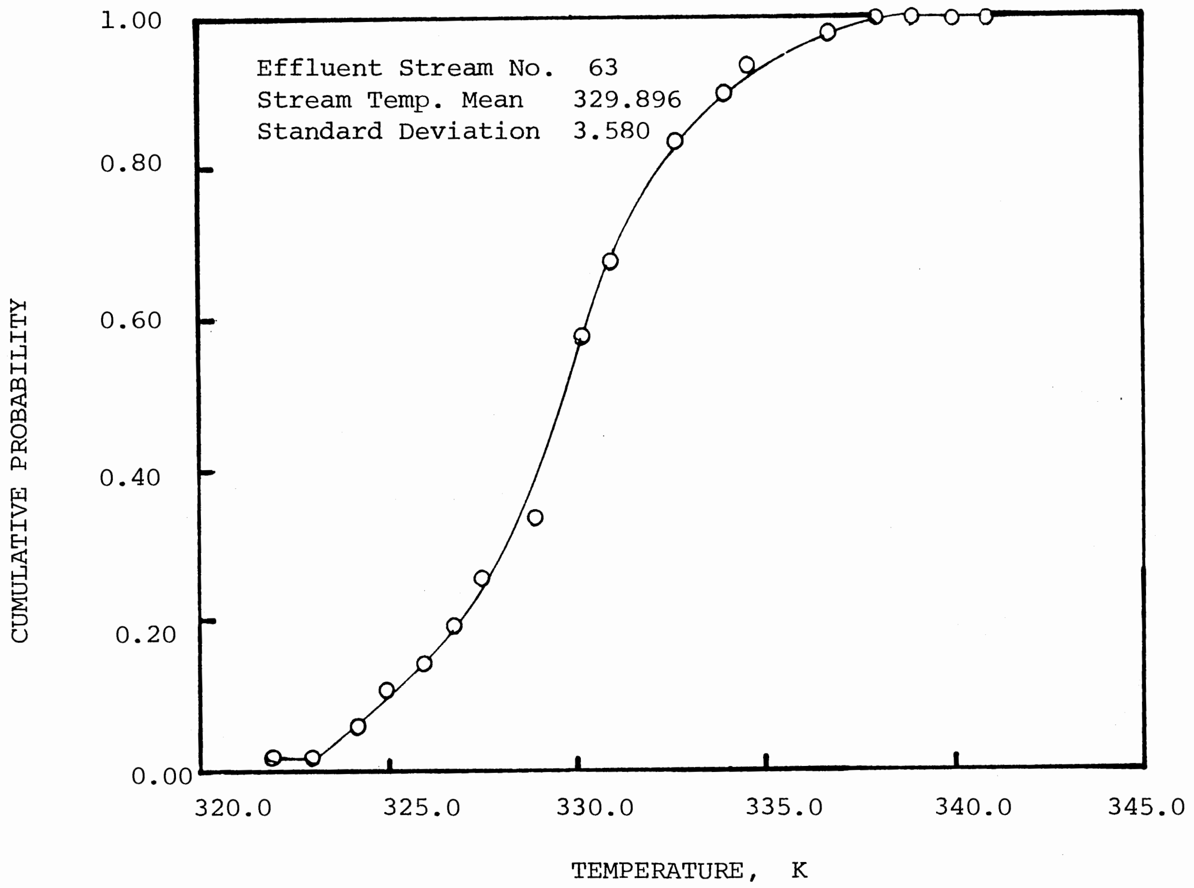


Figure VII.4. Cumulative Probability of Variation of the Temperature of Stream 63

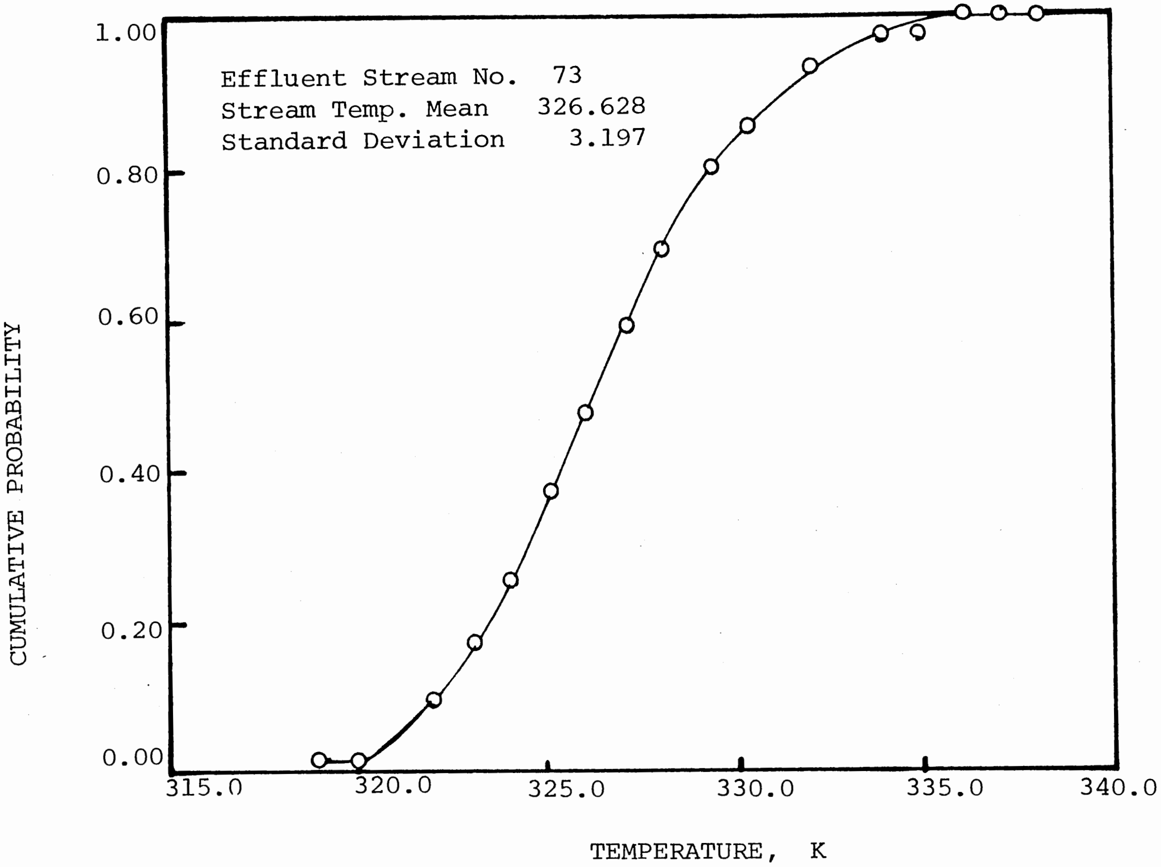


Figure VII.5. Cumulative Probability of Variation of the Temperature of Stream 73

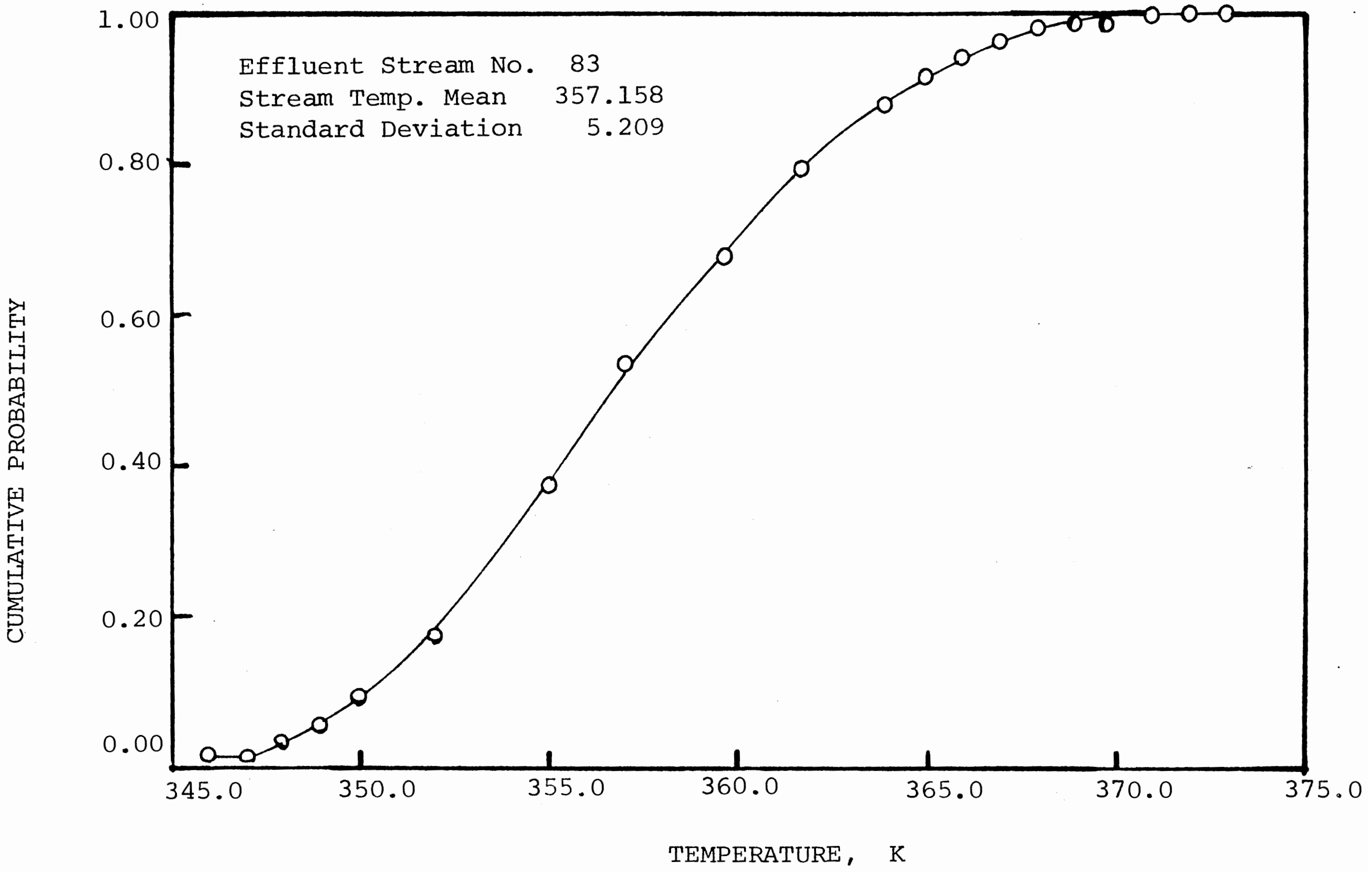


Figure VII.6. Cumulative Probability of Variation of the Temperature of Stream 83

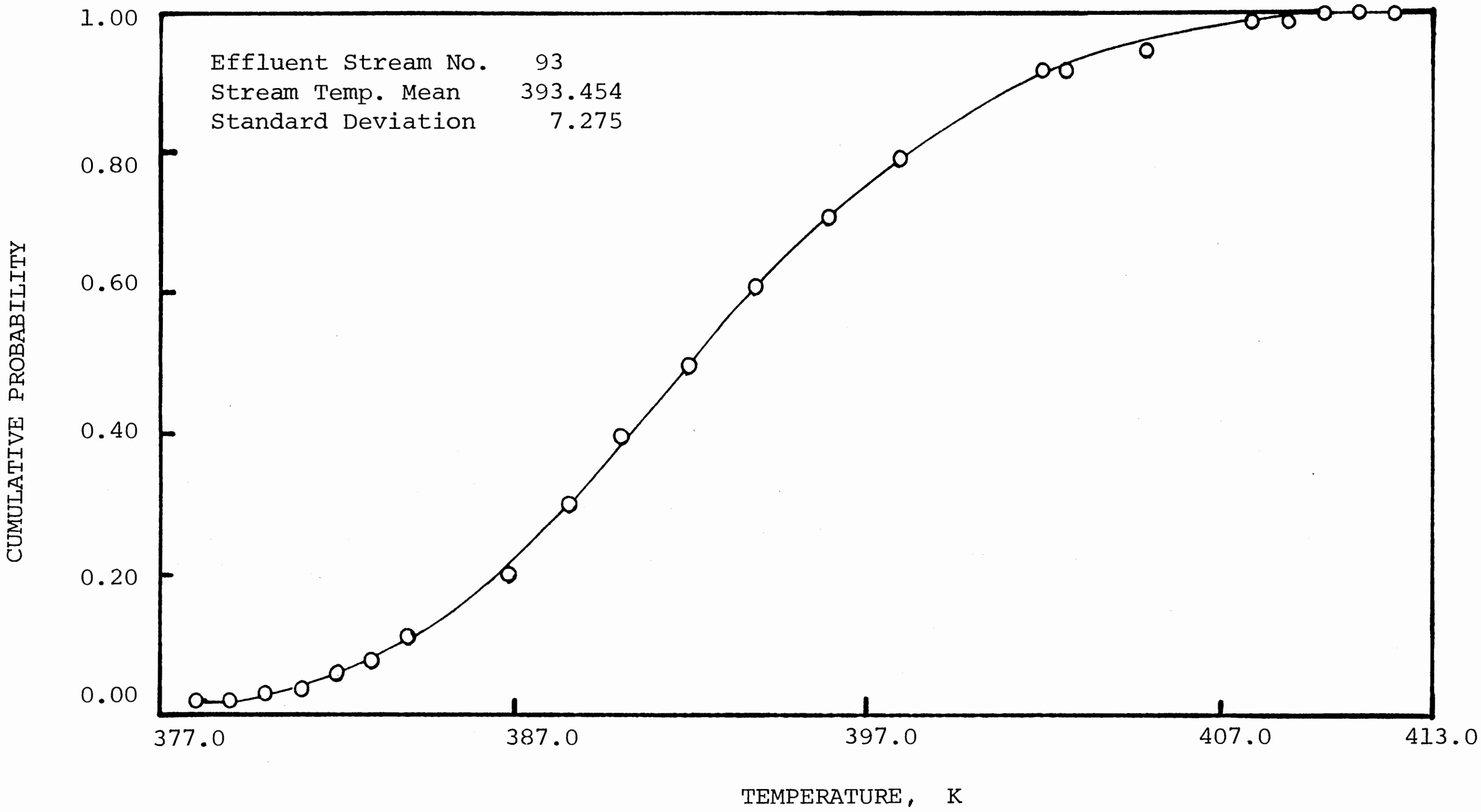


Figure VII.7. Cumulative Probability of Variation of the Temperature of Stream 93

By analyzing the uncertainties in all the output stream temperatures, it can be seen that the tempering exchanger is the most critical element in the system. Uncertainty in the output stream (stream 53) temperature of the tempering element is the most sensitive one. 1°K standard deviation in the temperature of the stream 53 causes 1.5 K, 2.5 K, 2.8 K and 3.5 K standard deviations in the temperatures of the product stream 61, 71, 81 and 91 respectively. And since these are the feedback streams, their uncertainties feedback into the system and severely affect the performance of the system. Therefore, possible ways to control the variation of steam temperature 53 need to be explored. And it is also required to find out how the system will respond if the temperature of stream 53 can be kept controlled. In other words what will be the ranges of variations in the temperatures in streams 52, 63, 73, 83 and 93 when the temperature of stream 53 is kept constant?

A constant temperature heat source shell and tube heat exchanger (Element 12) serves as a tempering exchanger (NTU = 1.58) in this system. Condensing steam (stream 55) is used for the constant temperature heat source. It might be possible to control the temperature of stream 53 by controlling the temperature of the condensing steam. It is also required to know the range of temperature over which the condensing steam 55 needs to be controlled.

Therefore, to calculate the controlling range of the temperature of the condensing steam (stream 55) another computer run was made, where the temperature of stream 53 was kept constant at 469 K. All other input conditions are the same as the previous run. The results of this run are presented in Figures VII.8, VII.9, VII.10, VII.11, VII.12 and VII.13. The statistics of the output temperature are listed in Table VII.5.

TABLE VII.5

STATISTICS OF THE OUTPUT STREAMS TEMPERATURES FOR CONDITION WHEN TEMPERATURE OF STREAM 53 IS TO BE KEPT CONSTANT AT 469 K (NTU OF TEMPERING EXCHANGER = 1.58)

Stream Number	Nominal Temperature K	Number of Simulations	Mean Temperature K	Standard Deviation K	95% Confidence Interval K
55	489	500	489	7.7	474 to 504
52	393	500	393	2.0	389 to 397
63	326	500	326	1.6	323 to 329
73	328	500	328	1.4	325 to 331
83	347	500	347	3.1	341 to 353
93	399	500	400	4.7	393 to 407

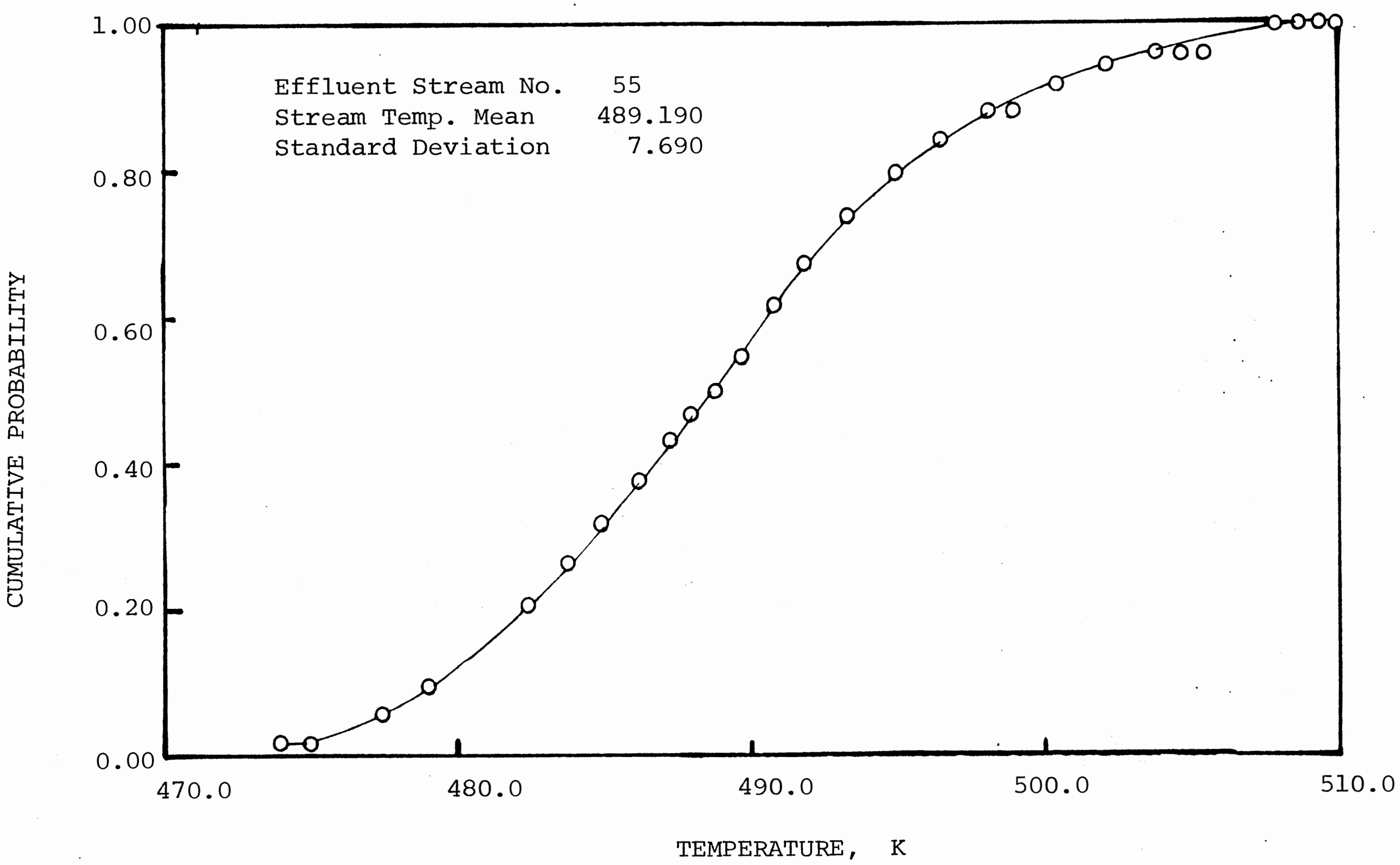


Figure VII.8. Cumulative Probability of Variation of the Temperature of the Condensing Steam (Stream 55) When the Temperature of Stream 53 is to be Kept Constant at 469 K

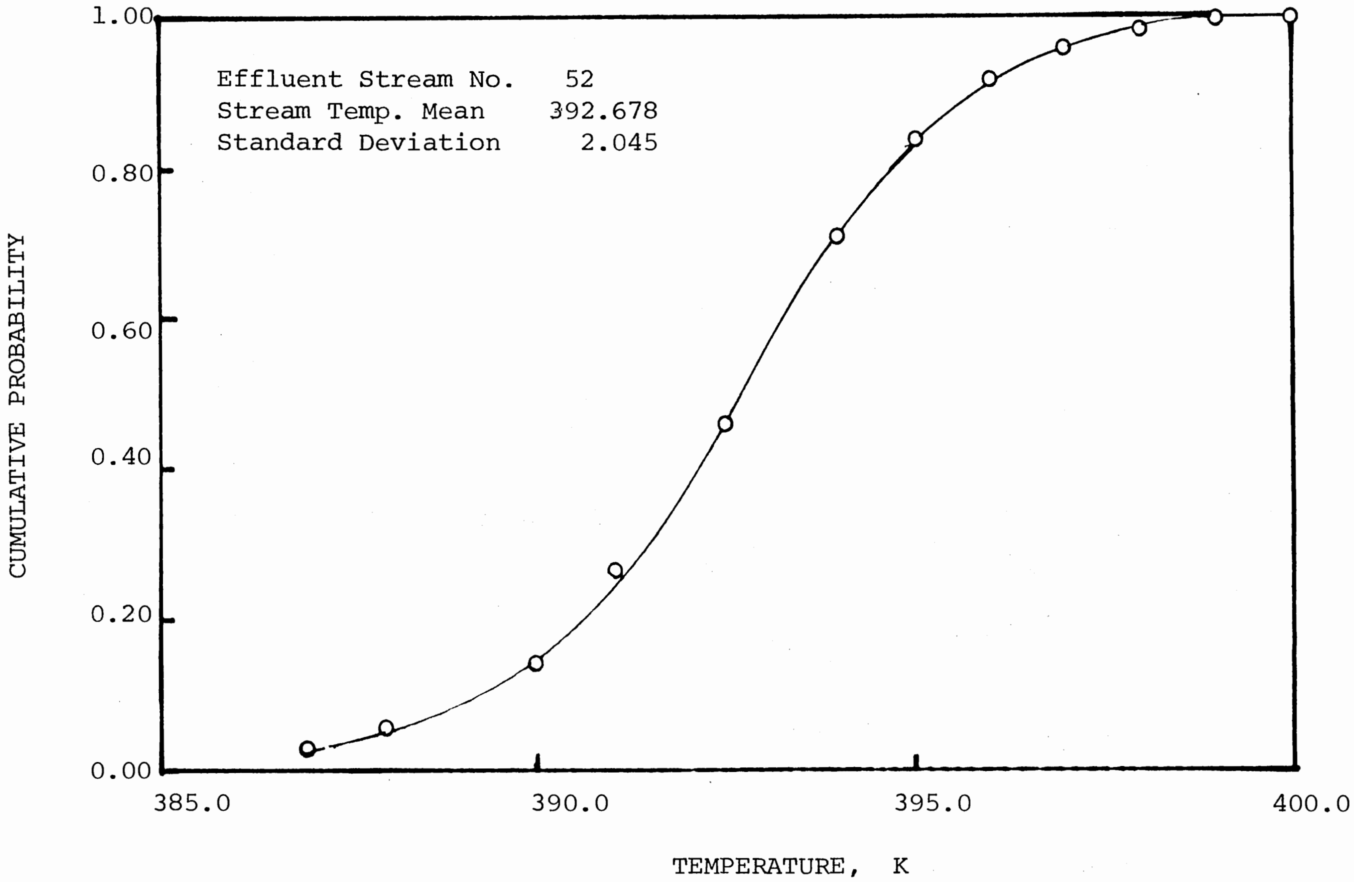


Figure VII.9. Cumulative Probability of Variation of the Temperature of Stream 52, When the Temperature of Stream 53 is to be Kept Constant at 469 K

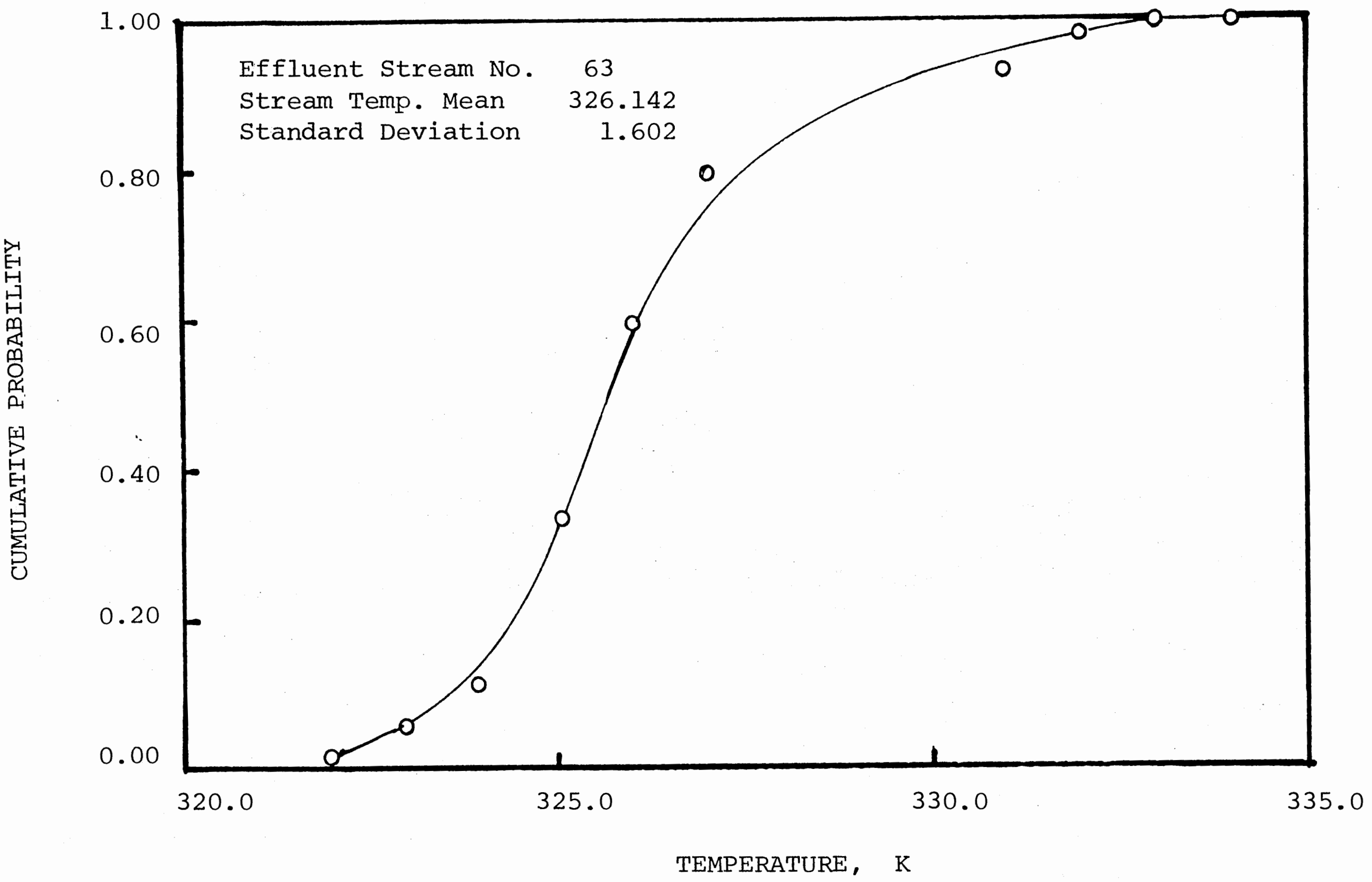


Figure VII.10. Cumulative Probability of Variation of the Temperature of Stream 63, When the Temperature of Stream 53 is to be Kept Constant at 46º K

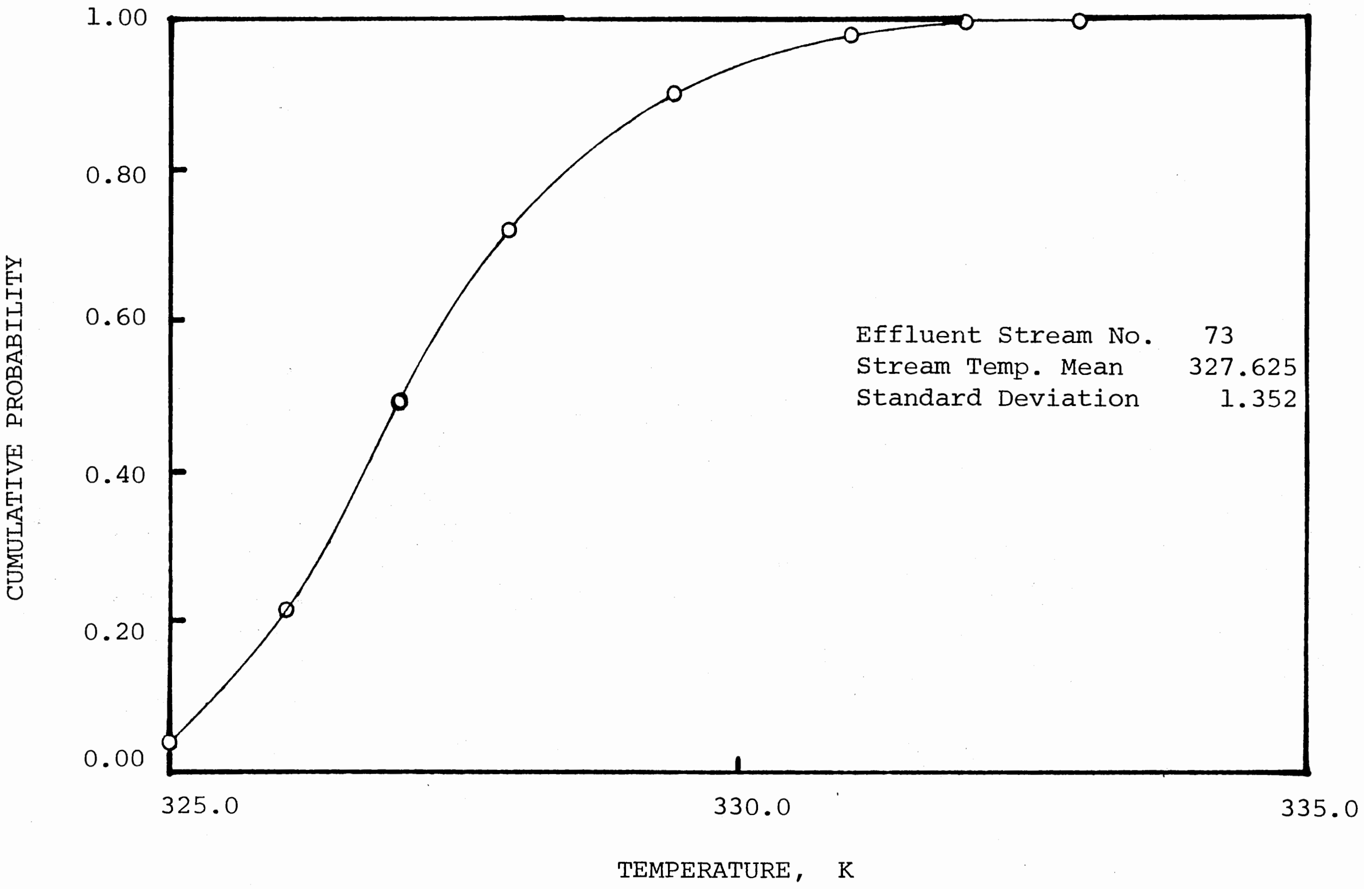


Figure VII.11. Cumulative Probability of Variation of the Temperature of Stream 73, When the Temperature of Stream 53 is to be Kept Constant at 469 K

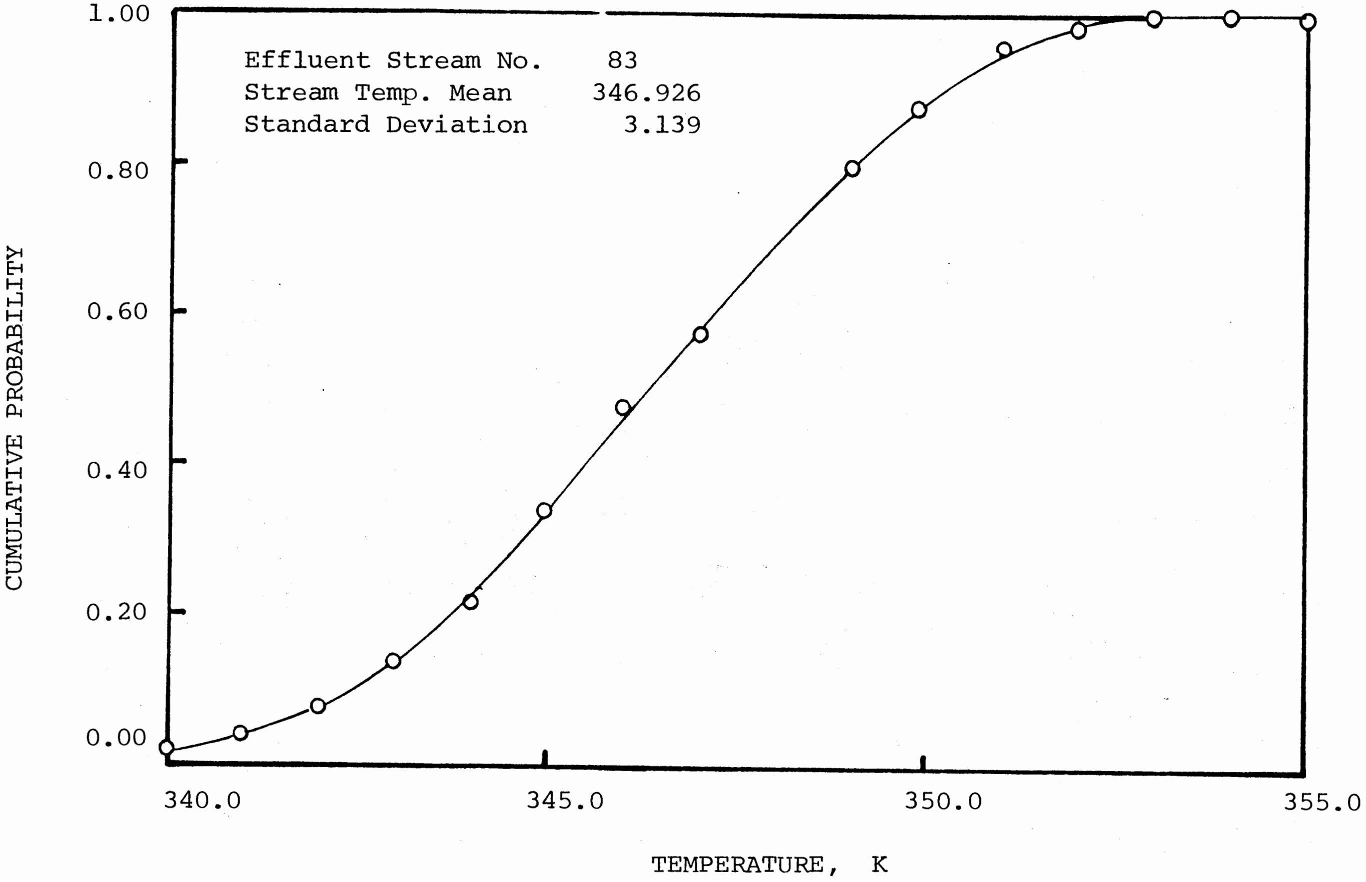


Figure VII.12. Cumulative Probability of Variation of the Temperature of Stream 83, When the Temperature of Stream 53 is to be Kept Constant at 469 K

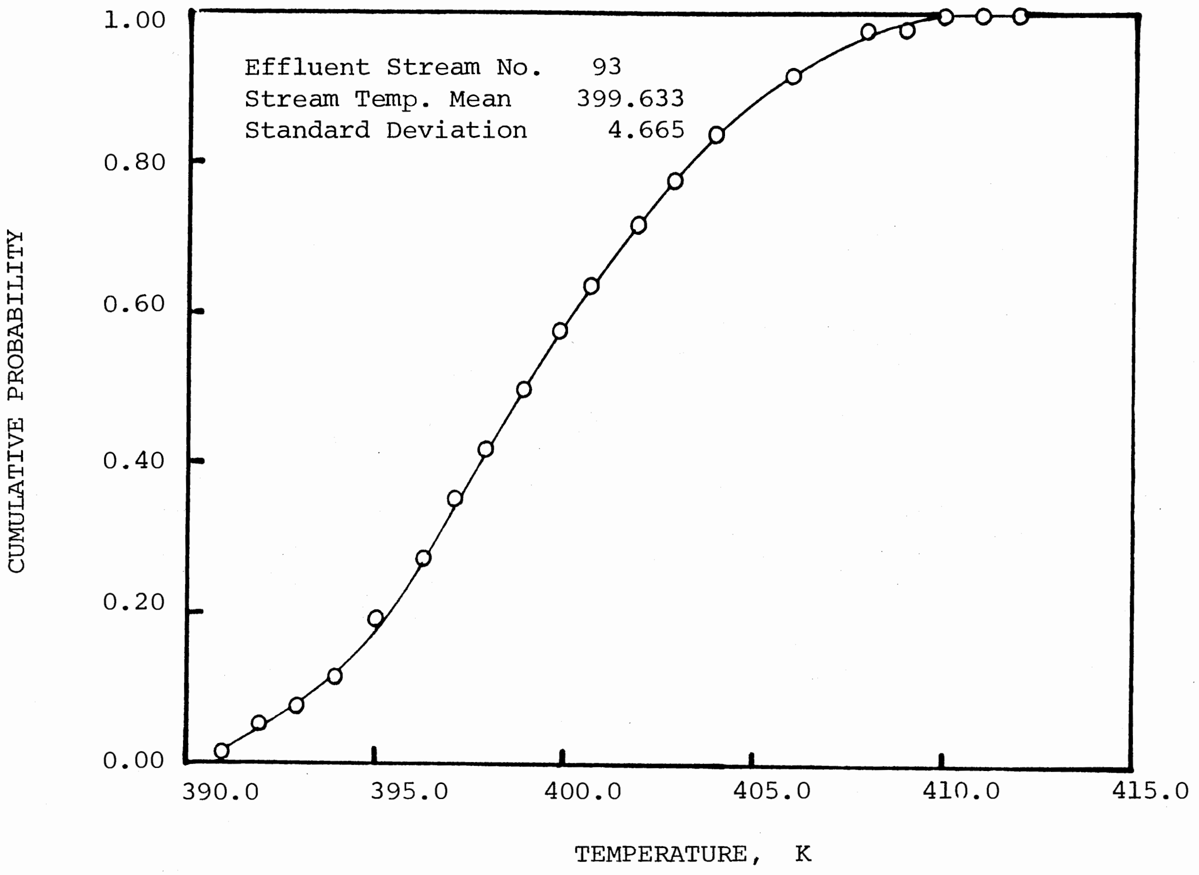


Figure VII.13. Cumulative Probability of Variation of the Temperature of Stream 93, When the Temperature of Stream 53 is to be Kept Constant at 469 K

Figure VII.9 shows that the controlling range of the temperature of the condensing steam (stream 55) should be from 474 K to 504 K (95% confidence interval). The corresponding saturation pressure range is 16 bar. to 28.5 bar.

Figure VII.10, VII.11, VII.12, VII.13 and VII.14 shows considerable reduction in the uncertainties of the temperatures of output streams 52, 63, 73, 83 and 93 respectively. The results are compared in Table VII.6.

TABLE VII.6

COMPARISON OF THE STATISTICS OF THE OUTPUT STREAMS TEMPERATURES FOR CONDITIONS WHEN TEMPERATURE OF STREAM 53 IS ALLOWED TO VARY AND TO BE KEPT CONSTANT

Stream Number	Nominal Temperature K	Number of Simulation	Temperature of Stream 53 Allowed to Vary			Temperature of Stream 53 is Constant at 469°K		
			Mean K	Standard Deviation K	95% Confidence Interval K	Mean K	Standard Deviation K	95% Confidence Interval K
52	393	500	391	4.5	382 to 400	393	2.0	389 to 397
63	326	500	330	3.6	323 to 337	326	1.6	323 to 329
73	328	500	327	3.2	321 to 333	328	1.4	325 to 331
83	347	500	357	5.2	346 to 367	347	3.1	341 to 353
93	399	500	393	7.3	379 to 407	400	4.7	393 to 407

CHAPTER VIII

SENSITIVITY ANALYSIS

In this chapter an attempt is made to develop a sensitivity analysis procedure for a typical feed-effluent heat exchanger. In a feed-effluent heat exchanger, the uncertainties in the output stream temperatures depend on 1) the uncertainties in the input stream temperatures and 2) the uncertainties in the heat exchanger design data. (For simplicity, it is assumed that there is no uncertainty in the flow rates and the specific heats of the input streams).

If the "standard deviation" of each variable is considered to be the measure of its uncertainty, then,

$$\sigma_{T_{o1}} = f(\sigma_{T_{i1}}, \sigma_{T_{i2}}, \sigma_{h_i}, \sigma_{ho_1}, \sigma_{R_{fi}}, \sigma_{R_{fo}}) \qquad \text{VIII.1}$$

also

$$\sigma_{T_{02}} = f(\sigma_{T_{i1}}, \sigma_{T_{i2}}, \sigma_{h_i}, \sigma_{h_o}, \sigma_{R_{fi}}, \sigma_{R_{fo}}) \qquad \text{VIII.2}$$

But

$$\sigma_{U_o} = f(\sigma_{h_i}, \sigma_{h_o}, \sigma_{R_{fi}}, \sigma_{R_{fo}}) \qquad \text{VIII.3}$$

Therefore,

$$\sigma_{T_{01}} = f(\sigma_{T_{i1}}, \sigma_{T_{i2}}, \sigma_{U_o}) \qquad \text{VIII.4}$$

and

$$\sigma_{T_{02}} = f(\sigma_{T_{i1}}, \sigma_{T_{i2}}, \sigma_{U_o}) \qquad \text{VIII.5}$$

Where

$\sigma_{T_{01}}$ = standard deviation of the temperature of output stream 1

$\sigma_{T_{02}}$ = standard deviation of the temperature of output stream 2

$\sigma_{T_{i1}}$ = standard deviation of the temperature of input stream 1

$\sigma_{T_{i2}}$ = standard deviation of the temperature of input stream 2

σ_{h_i} = standard deviation of the tube inside heat transfer coefficient

σ_{h_o} = standard deviation of the shell side heat transfer coefficient

$\sigma_{R_{fi}}$ = standard deviation of the tube inside fouling resistance

$\sigma_{R_{fo}}$ = standard deviation of the shell side fouling resistance

σ_{U_o} = standard deviation of the overall heat transfer coefficient

Each of the variables in equations VIII.4 and VIII.5 combine and interact algebraically in highly complex and nonlinear ways. In order to identify how sensitive is the uncertainty in the output stream temperature is with respect to the uncertainty in each of the input variable, some statistical analysis required.

For sensitivity analysis a 3^3 Factional Deisgn Experiment is considered. A feed-effluent heat exchanger is chosen for the experimental unit. All the input conditions for this experiment are presented in Table VIII.1 and VIII.2. Since it is a 3^3 factorial experiment, there will be all together 27 treatments. Each treatment is formed by one of the possible combinations of the levels of the three factors. There are three factors and each factor has three levels. Detailed information about these factors are given in Table VIII.3 and Figure VIII.1.

TABLE VIII.1

HEAT EXCHANGER INPUT DATA
(NOMINAL VALUES)

Variable	Nominal Value
Area, m^2	153
Shell Side Heat Transfer Coefficient, W/m^2 K	1675
Tube Inside Heat Transfer Coefficient, W/m^2 K	2555
Shell Side Fouling Resistance, m^2 K/W	0.00029
Tube Inside Fouling Resistance, m^2 K/W	0.00066
Overall Heat Transfer Coefficient (Based on Outside Area), W/m^2 K	438
Tube Wall Thermal Conductivity, W/m K	56
Effective Tube Inside Area, m^2/m	0.0624
Effective Tube Ooutside Area, m^2/m	0.0798
Tube Inside Diameter, m	0.0202
Tube Outside Diameter, m	0.0258
Number of Tube Passes	2
Number of Shell Passes	1

TABLE VIII.2

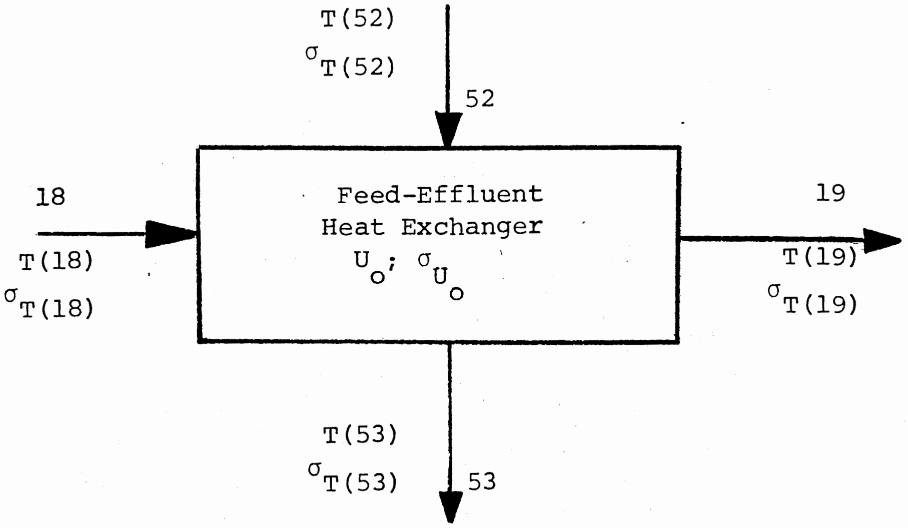
INPUT AND OUTPUT STREAM CONDITIONS (NOMINAL VALUES)

Stream Number	Flow Rate Kg/hr	Specific Heat KJ/Kg K	Temperature K
18	161600	2.065	344
19	161600	2.065	374
52	64640	2.303	444
53	64640	2.303	377

TABLE VIII.3

DEFINITION OF THE FACTORS OF THE 3^3 FACTORIAL EXPERIMENT

Factor	Definition	Level		
A	σ_{U_o}	a_o	a_1	a_2
B	$\sigma_{T(18)}$	b_o	b_1	b_2
C	$\sigma_{T(52)}$	c_o	c_1	c_2



FACTOR A (Standard deviation of the overall heat transfer coefficient, σ_{U_o}), W/m^2 K

Levels:	a_o	a_1	a_2
Values:	0	20	67

FACTOR B (Standard deviation of the temperature of input stream 18, $\sigma_{T(18)}$), K

Levels:	b_o	b_1	b_2
Values:	0	5.55	11.11

FACTOR C (Standard deviation of the temperature of input stream 52, $\sigma_{T(52)}$, K

Levels:	c_o	c_1	c_2
Values:	0	5.55	11.11

Figure VIII.1. Factorial Experiment Layout

All together 54 computer runs were made for 27 treatments. Each treatment was run twice (using two different seed integer for generation of random numbers) for replication. For each run 500 simulations were made. Results of these runs (standard deviation of the output stream temperatures, $\sigma_{T(19)}, \sigma_{T(53)}$) are presented in Table VIII.4. The results are also plotted in Figure VIII.2a to Figure VIII.4c.

In Figure VIII.2 to VIII.4, standard deviation of the output stream temperatures (average value of the two replications) $\sigma_{T(19)}$ and $\sigma_{T(53)}$ verses the standard deviation of the overall heat transfer coefficient (Factor A) are plotted, when the standard deviation of the temperature of input stream $\sigma_{T(18)}$ (Factor B) is fixed at levels at b_o, b_1 and b_2 respectively.

In Figure VIII.5 to VIII.7, standard deviation of the output stream temperatures (average value of the two replications) $\sigma_{T(19)}$ and $\sigma_{T(53)}$ verses the standard deviation of the temperature of the input stream 18, $\sigma_{T(18)}$ are plotted, when σ_{U_o} (Factor A) is fixed at levels a_o, a_1, and a_2 respectively.

In Figure VIII.9 to VIII.10, standard deviation of the output stream temperatures (average value of the two replications) $\sigma_{T(19)}$ and $\sigma_{T(53)}$ verses the standard deviation of the temperature of the input stream 52, $\sigma_{T(52)}$ are plotted, when σ_{U_o} (Factor A) is fixed at levels a_o, a_1 and a_2 respectively.

By analyzing the Figure VIII.2 to VIII.10 the following observations are made:

1. There are interactions among the three factors.

2. Factor B (variability of the temperature of the input stream 18) has the most strongest effect upon the variabilities of the output

TABLE VIII.4

RESULTS OF THE 3^3 FACTORIAL EXPERIMENT

Treatment	Input Variables			Output Variables Replication 1		Replication 2		Mean	
	σ_{U_O} W/m^2 K	$\sigma_{T(18)}$ K	$\sigma_{T(52)}$ K	$\sigma_{T(19)}$ K	$\sigma_{T(53)}$ K	$\sigma_{T(19)}$ K	$\sigma_{T(53)}$ K	$\sigma_{T(19)}$ K	$\sigma_{T(53)}$ K
a_o, b_o, c_o	0	0	0	0	0	0	0	0	0
a_1, b_o, c_o	20	0	0	0.42	0.95	0.44	0.92	0.43	0.93
a_2, b_o, c_o	67	0	0	1.53	3.43	1.51	3.42	1.52	3.42
a_o, b_1, c_o	0	5.55	0	3.93	3.75	3.89	3.79	3.91	3.77
a_o, b_1, c_o	20	5.55	0	3.84	3.77	3.83	3.75	3.83	3.76
a_2, b_1, c_o	67	5.55	0	4.11	4.95	4.12	4.96	4.11	4.95
a_o, b_2, c_o	0	11.11	0	7.87	7.51	7.87	7.52	7.87	7.51
a_1, b_2, c_o	20	11.11	0	7.64	7.35	7.66	7.32	7.65	7.33
a_2, b_2, c_o	67	11.11	0	7.98	7.98	7.96	7.99	7.97	7.98
a_o, b_o, c_1	0	0	5.55	1.67	1.85	1.68	1.89	1.67	1.87
a_1, b_o, c_1	20	0	5.55	1.67	2.04	1.69	2.01	1.68	2.02
a_2, b_o, c_1	67	0	5.55	2.18	3.82	2.15	3.87	2.16	3.84
a_o, b_o, c_2	0	0	11.11	3.35	3.70	3.36	3.70	3.35	3.70
a_1, b_o, c_2	20	0	11.11	3.27	3.74	3.25	3.77	3.26	3.75
a_2, b_o, c_2	67	0	11.11	3.53	4.98	3.50	4.99	3.51	4.98

TABLE VIII.4 (Continued)

Treatment	Input Variables			Output Variables Replication 1		Output Variables Replication 2		Mean	
	σ_{U_o} W/m^2 K	$\sigma_{T(18)}$ K	$\sigma_{T(52)}$ K	$\sigma_{T(19)}$ K	$\sigma_{T(53)}$ K	$\sigma_{T(19)}$ K	$\sigma_{T(53)}$ K	$\sigma_{T(19)}$ K	$\sigma_{T(53)}$ K
a_o, b_1, c_1	0	5.55	5.55	4.13	4.05	4.16	4.01	4.14	4.03
a_1, b_1, c_1	20	5.55	5.55	4.13	4.12	4.19	4.09	4.16	4.14
a_2, b_1, c_1	67	5.55	5.55	4.42	5.11	4.43	5.44	4.42	5.42
a_2, b_2, c_1	0	11.11	5.55	7.78	7.48	7.75	7.53	7.76	7.50
a_1, b_2, c_1	20	11.11	5.55	7.77	7.47	7.79	7.45	7.78	7.46
a_2, b_2, c_1	67	11.11	5.55	7.96	8.20	7.97	8.18	7.96	8.19
a_o, b_1, c_2	0	5.55	11.11	5.02	5.12	5.07	5.14	5.04	5.13
a_1, b_1, c_2	20	5.55	11.11	4.98	5.15	4.96	5.17	4.97	5.16
a_2, b_1, c_2	67	5.55	11.11	5.22	6.27	5.26	6.29	5.24	6.28
a_o, b_2, c_2	0	11.11	11.11	8.26	8.10	8.27	8.09	8.26	8.09
a_1, b_2, c_2	20	11.11	11.11	8.23	8.09	8.25	8.05	8.44	8.07
a_2, b_2, c_2	67	11.11	11.11	8.51	8.78	8.53	8.76	8.52	8.77

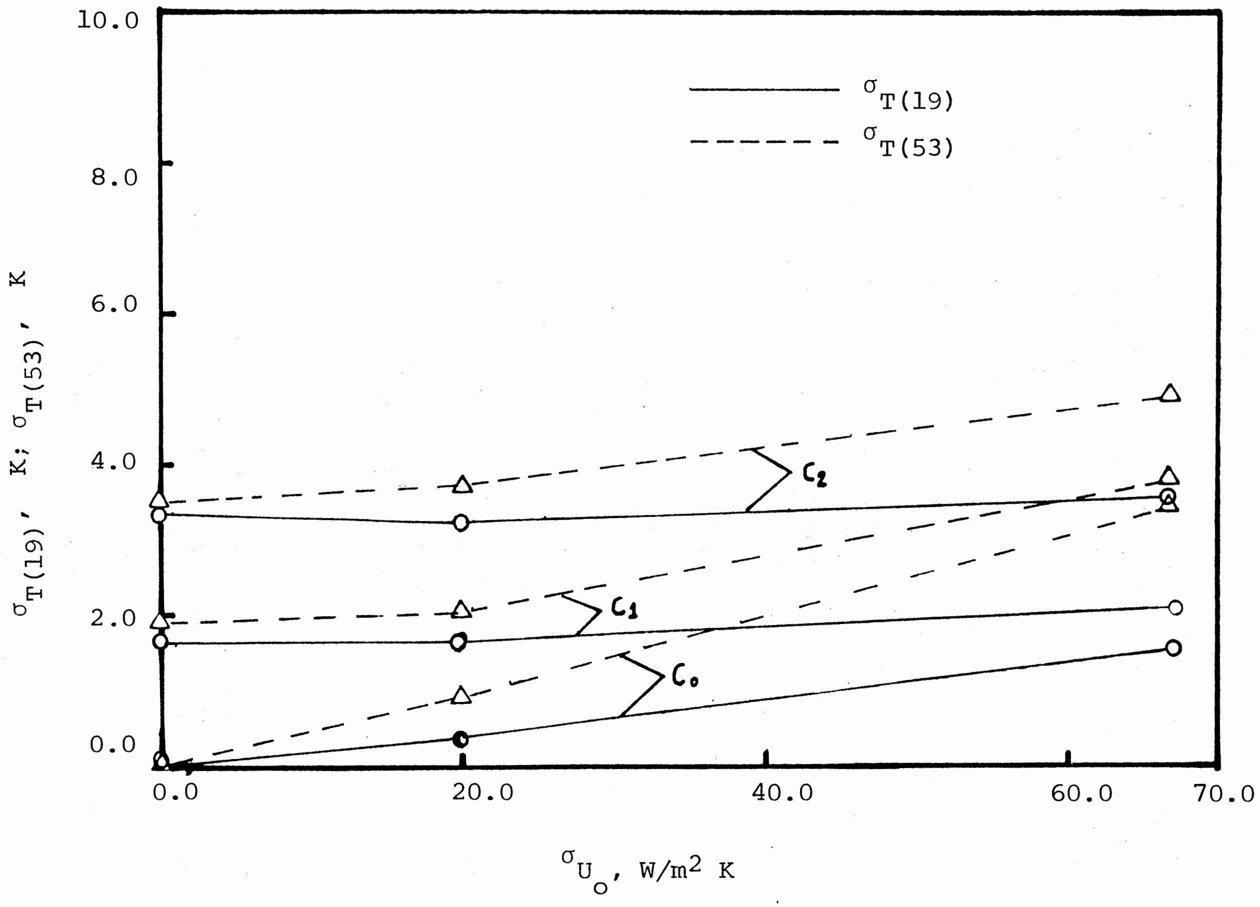


Figure VIII.2. Standard Deviation in the Temperatures of the Output Stream 19 and 53 as a Function of the Standard Deviation in the Overall Heat Transfer Coefficient, When the Standard Deviation in the Temperature of the Input Stream 18 is Fixed at Level $b_o (\sigma_{T(18)} = 0)$

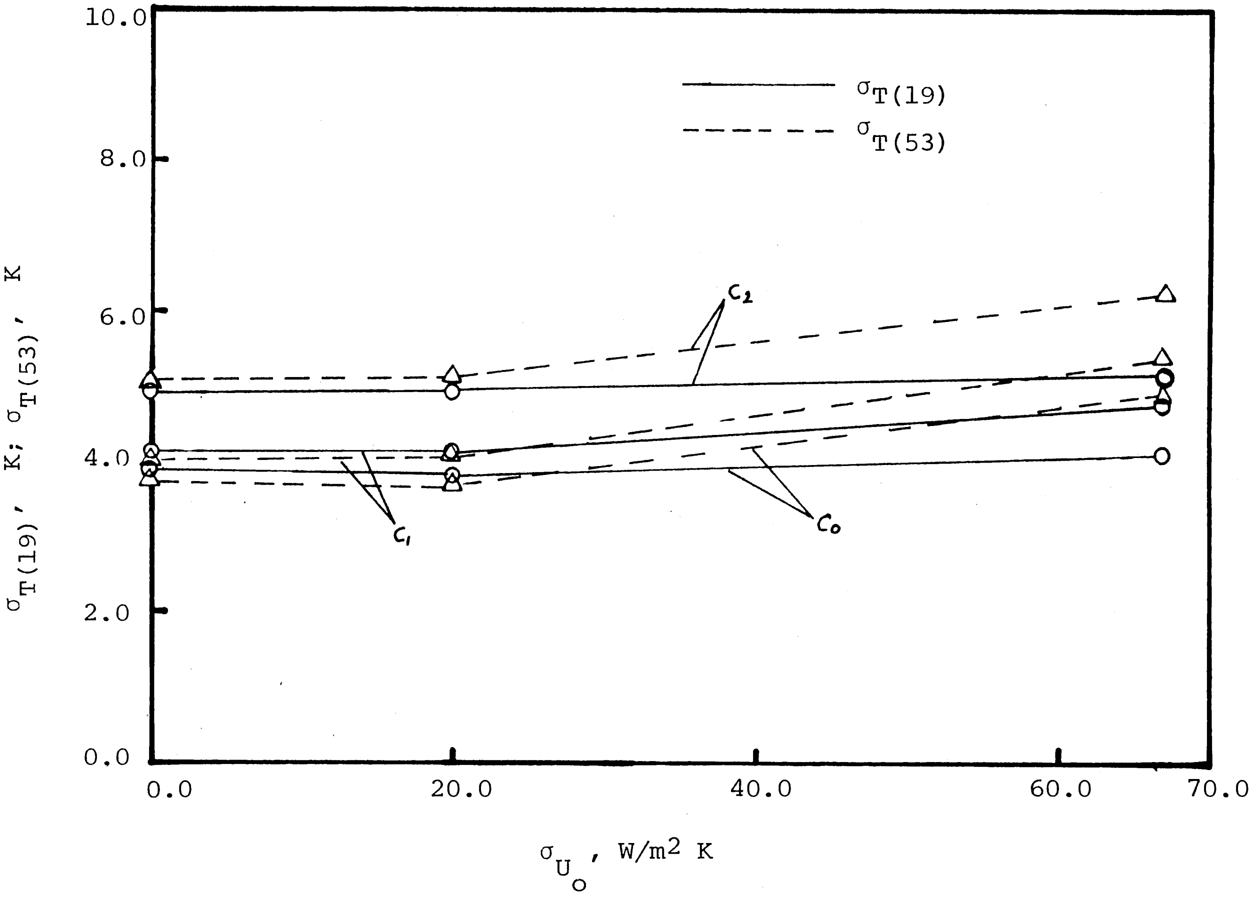


Figure VIII.3. Standard Deviation in the Temperatures of the Output Stream 19 and 53 as a Function of the Standard Deviation in the Overall Heat Transfer Coefficient, When the Standard Deviation in the Temperature of the Input Stream 18 is Fixed at Level b_1 ($\sigma_{T(18)}$ = 5.55 K)

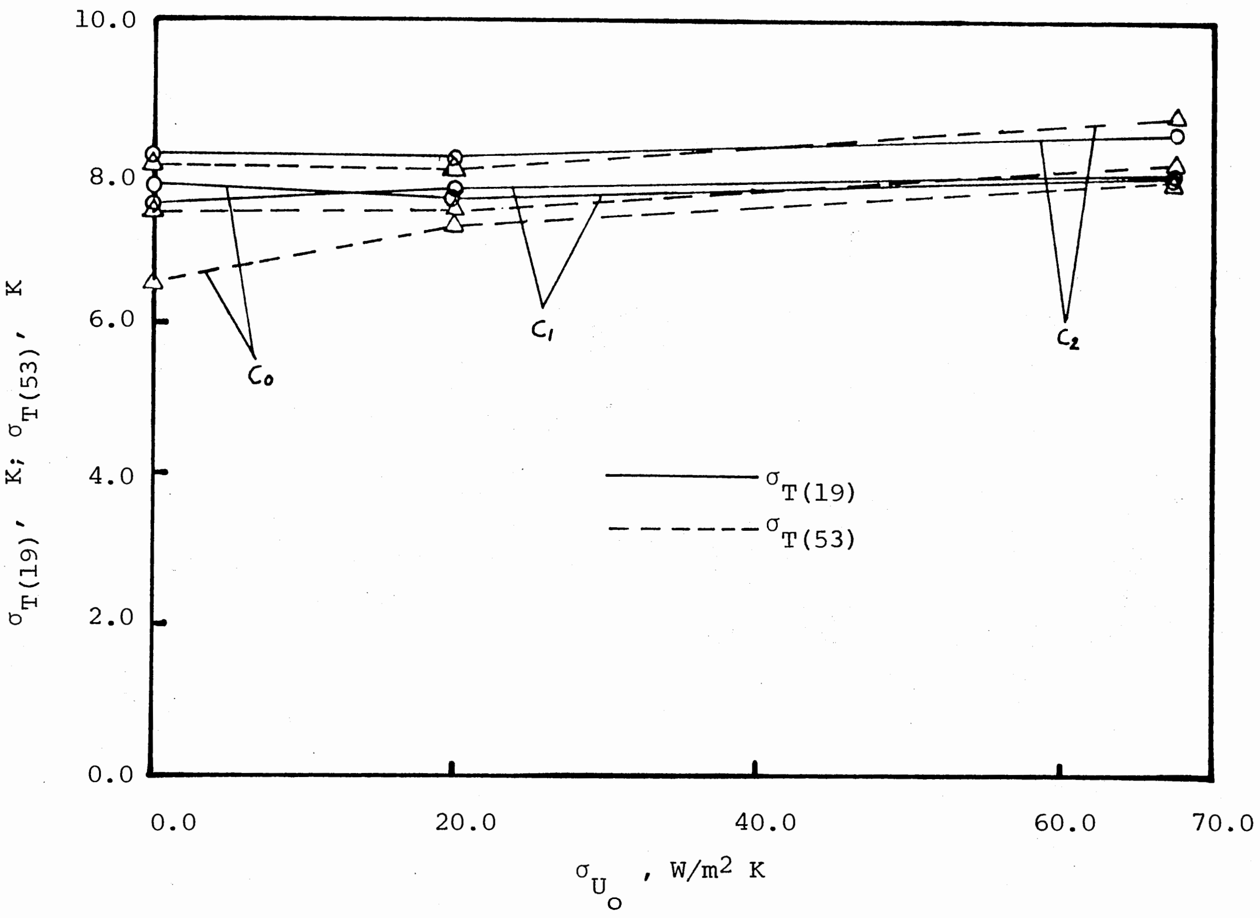


Figure VIII.4. Standard Deviations in the Temperatures of the Output Stream 19 and 53 as a Function of the Standard Deviation in the Overall Heat Transfer Coefficient, When the Standard Deviation in the Temperature of the Input Stream 18 is Fixed at Level $b_2(\sigma_{T(18)} = 11.11$ K)

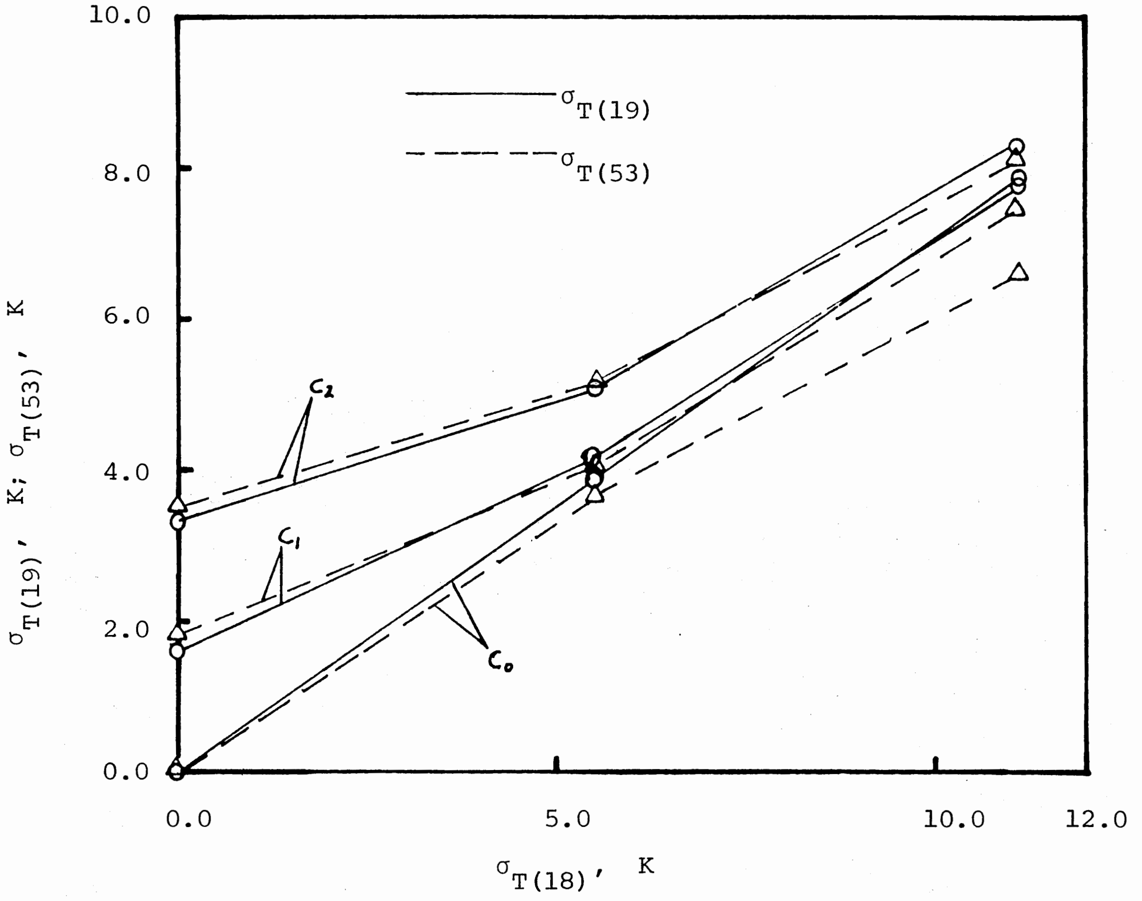


Figure VIII.5. Standard Deviations in the Temperatures of the Output Stream 19 and 53 as a Function of the Standard Deviation in the Temperature of the Input Stream 18, When the Standard Deviation in the Overall Heat Transfer Coefficient is Fixed at Level $a_o(\sigma_{U_o} = 0.0$ W/m^2 K)

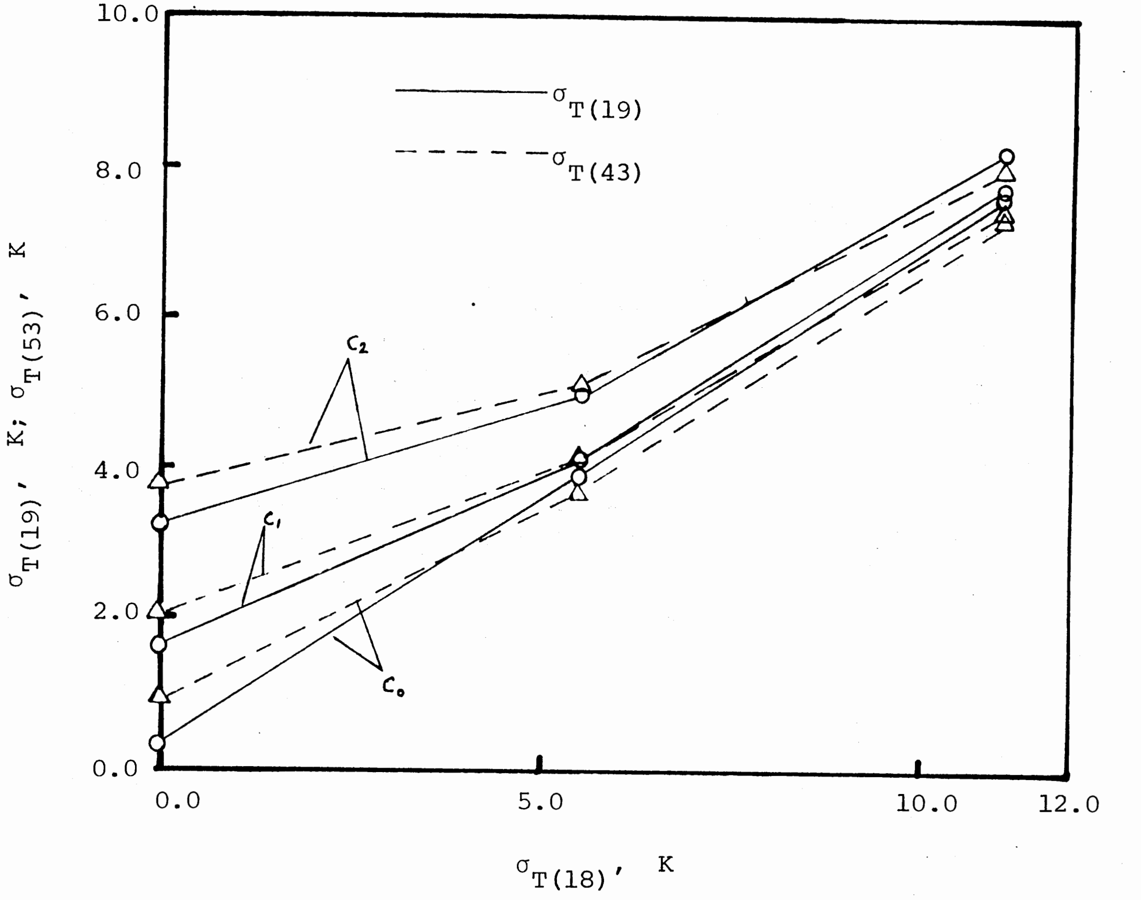


Figure VIII.6. Standard Deviations in the Temperatures of the Output Stream 19 and 53 as a Function of the Standard Deviation in the Temperature of the Input Stream 18, When the Standard Deviation of the Overall Heat Transfer Coefficient is Fixed at Level a_1 (σ_{U_o} = 20 W/m^2 K)

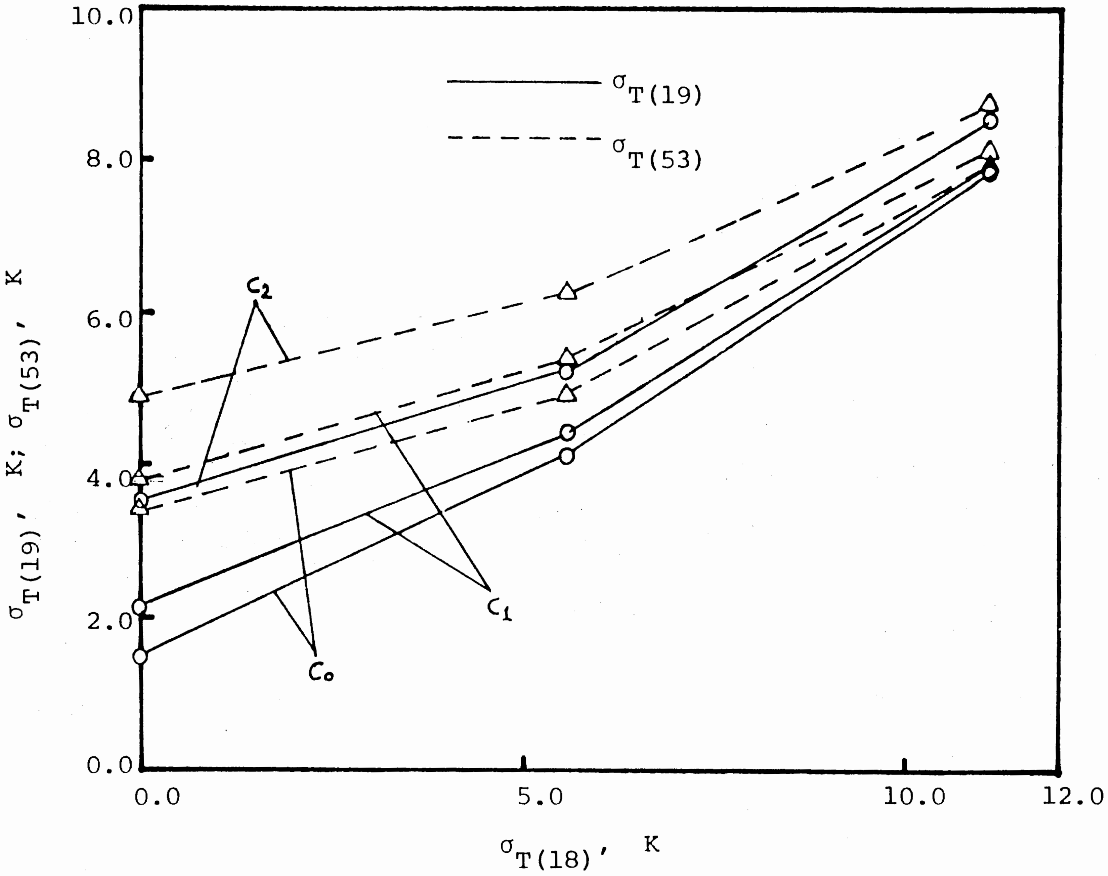


Figure VIII.7. Standard Deviations in the Temperatures of the Output Stream 19 and 53 as a Function of the Standard Deviation in the Temperature of the Input Stream 18, When the Standard Deviation of the Overall Heat Transfer Coefficient is Fixed at Level a_2 (σ_{U_O} = 67 W/m^2 K)

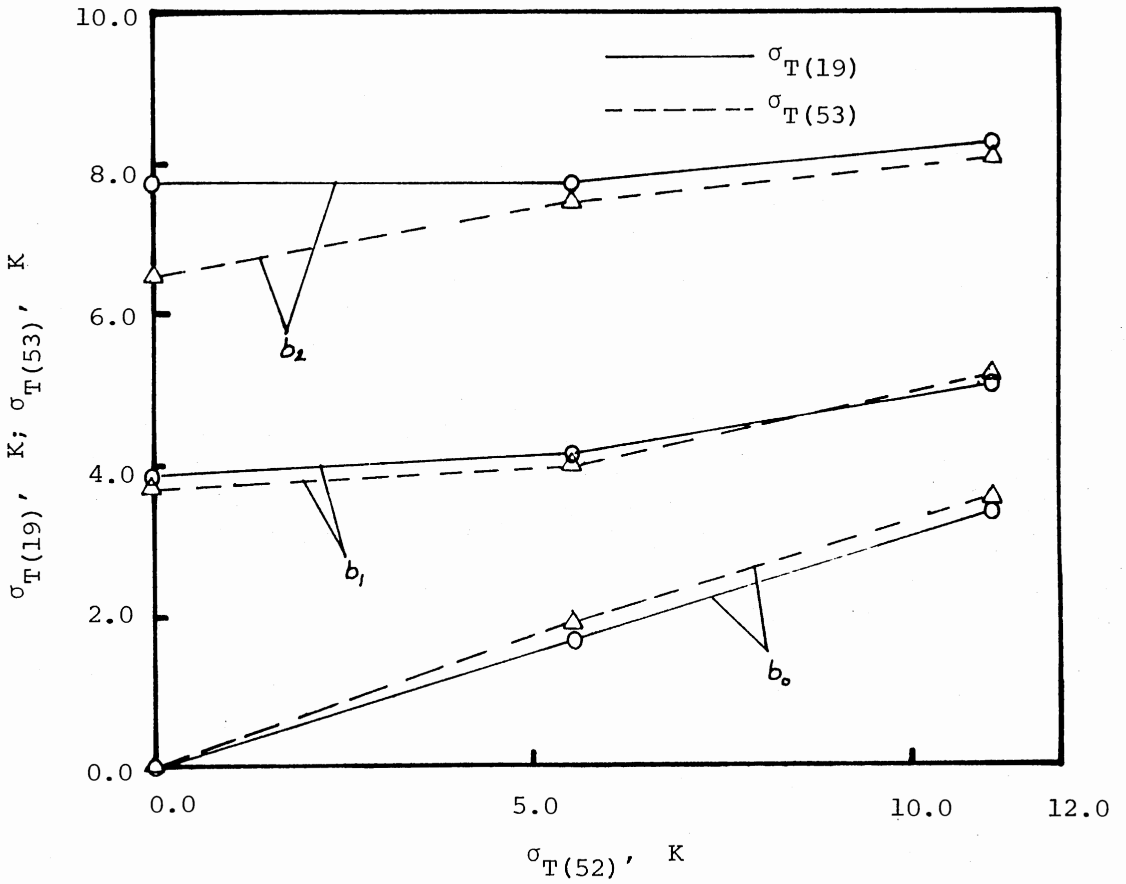


Figure VIII.8. Standard Deviations in the Temperature of the Output Stream 19 and 53 as a Function of the Standard Deviation in the Temperature of the Input Stream 52, When the Standard Deviation in the Overall Heat Transfer Coefficient is Fixed at Level a_o (σ_{U_o} = W/m^2 K)

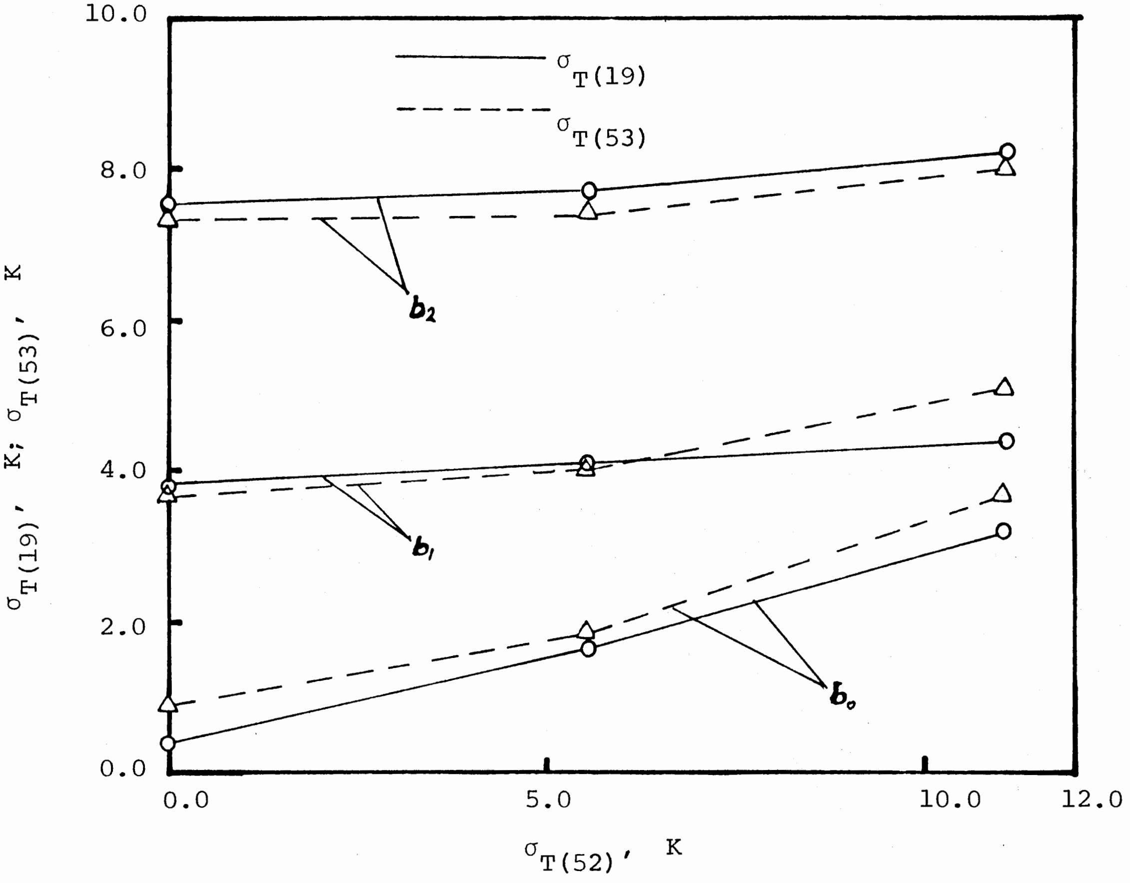


Figure VIII.9. Standard Deviationd in the Temperature of the Output Stream 19 and 53 as a Function of the Standard Deviation in the Temperature of the Input Stream 52, When the Standard Deviation in the Overall Heat Transfer Coefficient is fixed at Level a_1 (σ_{U_o} = 20 W/m^2 K)

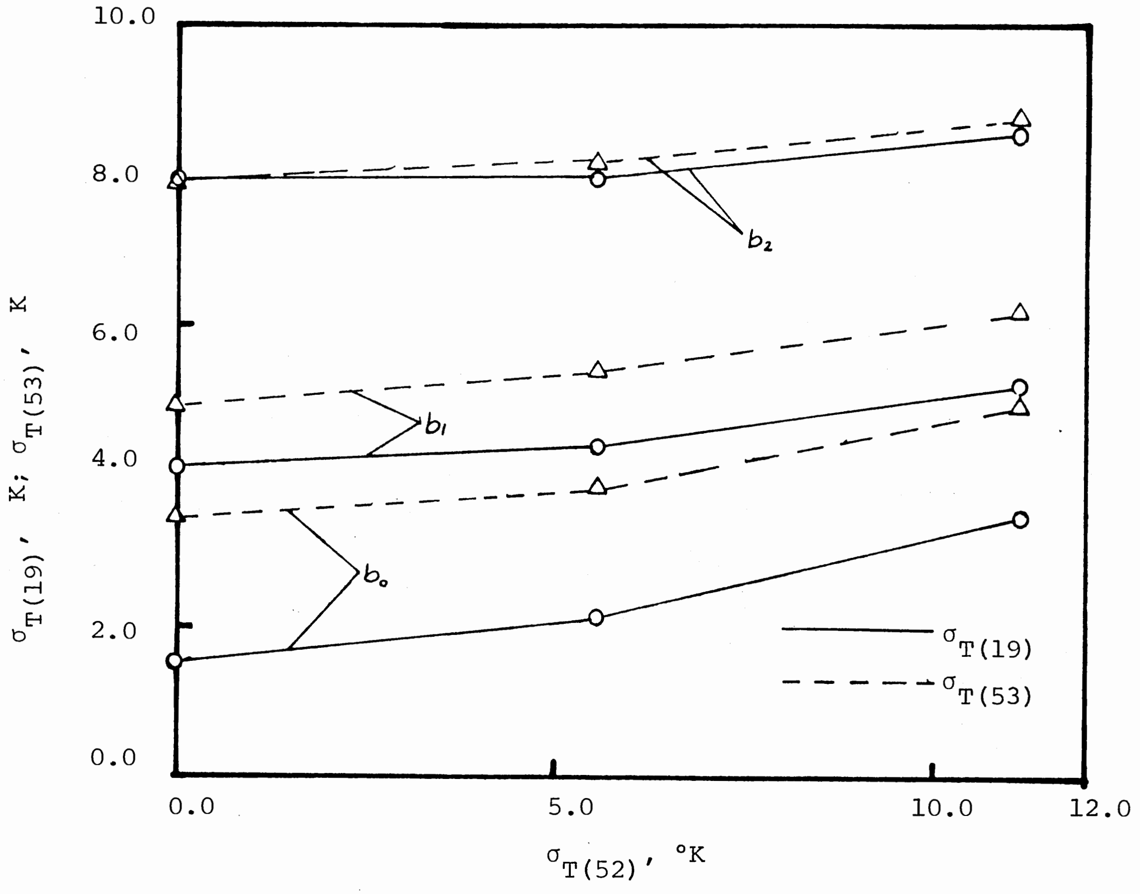


Figure VIII.10. Standard Deviations in the Temperature of the Output Stream 19 and 53 as a Function of the Standard Deviation in the Temperature of the Input Stream 52, When the Standard Deviation in the Overall Heat Transfer Coefficient is Fixed at Level a_2 (σ_{U_O} = 67 W/m^2 K) stream temperatures ($\sigma_{T(19)}$ and $\sigma_{T(53)}$).

3. Factor A (variability of the overall heat transfer coefficient) has significant effect on the variabilities of the output stream temperatures at lower levels of the factor B and C.

Results of the analysis of variance of the above factorial experiment is presented in Table VIII.5 and VIII.6. Analysis of variance for variability of the output stream temperature 19,$\sigma_{T(19)}$ (Table VIII.5) shows that there are significant interactions among all the factors. Effect of factor B is the most strongest, then followed by factor C and A.

An analysis of variance of the variability of the output stream temperature 53, $\sigma_{T(53)}$ (Table VIII.6) shows that there are significant interactions among all the factors. Effect of factor B is the strongest and the effect of factor C and A are comparable.

It is also important to note that the two output stream temperature do not have the same uncertainty in response to a given uncertainty in the input variables. The reason is the difference between the thermal capacitances of streams 18 and 52. Thermal capacitance of stream 18 (333704 KJ/hr K) is much higher than that of stream 52(148866 KJ/hr K)

On the basis of the analysis of the results of the factorial experiment, the following general conclusions can be drawn:

1. Uncertainty in the overall heat transfer coefficient affects the uncertainties in the output stream temperatures when the uncertainties in the input stream temperatures are low.

2. Uncertainty in the overall heat transfer coefficient has a stronger effect on the uncertainty of the output stream temperature with lower thermal capacitance.

TABLE VIII.5

FACTORIAL EXPERIMENT ANALYSIS OF VARIANCE
PROCEDURE CLASS LEVEL INFORMATION

```
                                    CLASS      LEVELS     VALUES

                                    A            3        0 20 67

                                    B            3        0 5.55 11.11

                                    C            3        0 5.55 11.11

                                 NUMBER OF OBSERVATIONS IN DATA SET = 54


DEPENDENT VARIABLE:  VARIABILITY OF THE TEMPERATURE OF OUTPUT STREAM 19

SOURCE                DF        SUM OF SQUARES          MEAN SQUARE        F VALUE           PR > F    R-SQUARE

MODEL                 26          363.82423333          13.99323974       53591.13           0.0001    0.999981

ERROR                 27            0.00705000           0.00026111                          STD DEV

CORRECTED TOTAL       53          363.83128333                                           0.01615893

SOURCE                DF              ANOVA SS      F VALUE        PR > F

A                      2            1.74843333      3348.06        0.0001
B                      2          332.82747778     99999.99        0.0000
A*B                    4            0.55475556       531.15        0.0001
C                      2           19.76903333     37855.60        0.0001
A*C                    4            0.28376667       271.69        0.0001
B*C                    4            7.86165556      7527.12        0.0001
A*B*C                  8            0.77911111       372.98        0.0001
```

TABLE VIII.6

FACTORIAL EXPERIMENT ANALYSIS OF VARIANCE
PROCEDURE CLASS LEVEL INFORMATION

```
                         CLASS    LEVELS    VALUES

                         A          3       0 20 67

                         B          3       0 5.55 11.11

                         C          3       0 5.55 11.11

                    NUMBER OF OBSERVATIONS IN DATA SET = 54


DEPENDENT VARIABLE:  VARIABILITY OF THE TEMPERATURE OF OUTPUT STREAM 53

SOURCE               DF      SUM OF SQUARES       MEAN SQUARE      F VALUE        PR > F    R-SQUARE

MODEL                26        299.75278148       11.52895313     31602.21        0.0001    0.999967

ERROR                27          0.00985000        0.00036481                    STD DEV

CORRECTED TOTAL      53        299.76263148                                   0.01910013

SOURCE               DF             ANOVA SS     F VALUE      PR > F

A                     2          20.56041481    28179.25      0.0001
B                     2         242.83989259    99999.99      0.0000
A*B                   4           4.22580741     2895.86      0.0001
C                     2          23.40171481    32073.42      0.0001
A*C                   4           0.67665185      463.70      0.0001
B*C                   4           6.22640741     4266.83      0.0001
A*B*C                 8           1.82189259      624.25      0.0001
```

3. Uncertainties in the output stream temperatures are most strongly affected by the uncertainty in the input stream temperature which has the higher thermal capacitance.

4. Uncertainty in the input stream temperature with the higher thermal capacitance is the most critical one for uncertainties in the output stream temperatures.

On the basis of the above sensitivity analysis and the analyses provided in Chapters V, VI and VII, the following stepwise procedure for sensitivity analysis of any heat exchanger system can be suggested:

1. Calculate the uncertainties of all the outcome variables of the system using the general computer program.

2. By analyzing the sensitivity coefficients of the outcome variables to the uncertainties in the inputs, identify the most critical component(s) in the system.

3. Compare the uncertainty in the overall heat transfer coefficient with the uncertainties in the temperatures of the input streams of the most critical element of the system.

4. If the uncertainties in the temperatures of the input stream of the most critical element are low, adopt possible measure(s) to limit the uncertainty in the overall heat transfer coefficient.

5. If the uncertainties in the temperatures of the input stream of the most critical element are very high, adopt possible measure(s) to limit the uncertainty in the temperatures of the input stream with the higher thermal capacitance.

CHAPTER IX

CONCLUSIONS AND RECOMMENDATIONS

The general computer program developed in the present study can be used to analyze the effect of uncertainties upon the performance of heat exchanger systems with or without feed-back. The porgram is used here to analyze the effect of uncertainties upon the performance of three different feed-effluent heat exchanger systems. On the basis of these analyses, the following conclusions can be drawn:

1. Uncertainties in heat exchanger input data results in uncertainties in the temperatures of the output streams. In a feed-effluent exchanger system, these uncertainties feed back to the system and severely affects the performance of the system.

2. By analyzing the uncertainties in the temperatures of all the output streams, the most critical component(s) in the system can be identified.

3. Expensive and time consuming measures to limit the uncertainties in the temperatures of the output stream (i.e., improving the quality of the heat exchanger input data through better correlations and design procedures, overdesigning the elements of the system etc.) can be avoided and the performance of the system can be significantly improved if the most critical component of the system can be identified and closely analyzed and controlled.

4. The performance of a feed-effluent heat exchanger system can

also be improved by reducing the fouling resistances (and therefore the effect of their poor predictability) in the feed-effluent heat exchanger.

5. In a feed-effluent heat exchanger, uncertainty in the overall heat transfer coefficient significantly effects the uncertainties in the temperatures of the output stream, when the uncertainties in the temperatures of the input stream are low.

6. In a feed-effluent heat exchanger, uncertainties in the output stream temperatures are most strongly affected by the uncertainty in the input stream temperature which has the higher thermal capacitance.

The following recommendations are made for further investigations and improvement of the work:

1. The technique used in the present thesis can be extended for designing other process equipment such as distillation columns, reactors, etc. For distillation column design, design variables such as K and H values, physical properties, etc., can be randomly introduced within the limit of their variations. Similarly for reactor design, physical properties, equilibrium and rate constant data can also be considered to be varied randomly.

2. The present program can be further expanded to include other types of heat exchangers and heat exchanger series, such as partial condensers.

3. More extensive work in the sensitivity analysis of the heat exchanger system is required.

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APPENDIX A

LISTING OF THE COMPUTER PROGRAM

```
C
C     THIS COMPUTER PROGRAM SIMULATES  A  SYSTEM OF SHELL AND TUBE
C     HEAT EXCHANGERS WITH OR WITHOUT FEED BACK. THE SYSTEM MAY
C     ALSO INCLUDE OTHER PROCESS ELEMENTS SUCH AS FIRED HEATERS,
C     REACTORS AND MULTIPRODUCT DISTILLATION COLUMNS. UNCERTAINTIES
C     IN THE FOLLOWING INPUT VARIABLES CAN BE INTRODUCED IN THIS
C     PROGRAM:
C
C           1) INPUT STREAM FLOW RATES
C           2) INPUT STREAM TEMPERATURES
C           3) OVERALL HEAT EXCHANGER COEFFICIENT
C           4) TUBE INSIDE HEAT TRANSFER COEFFICIENT
C           5) SHELL SIDE  HEAT TRANSFER COEFFICIENT
C           6) TUBE INSIDE FOULING RESISTANCE
C           7) SHELL SIDE  FOULING RESISTANCE
C           8) INPUT STREAM  SPECIFIC HEATS
C
C     THE PROGRAM USES THE MONTE CARLO TECHNIQUE AND GENERATES THE
C     RANDOM NUMBERS FOR THE ABOVE VARIABLES. THE PROGRAM PERFORMS
C     THE HEAT AND MASS BALANCE CALCULATIONS FOR ANY SYSTEM CONFI-
C     GURATION. IT CONVERGES THE FEED BACK STREAMS UNKNOWN VARIABLES
C     USING THE SUCCESSIVE SUBSTITUTION TECHNIQUE. THE PROGRAM IS
C     CAPABLE OF CALCULATING THE REQUIRED SURFACE AREAS OF THE HEAT
C     EXCHANGERS,EXTENT OF REACTION IN THE REACTOR ,REQUIRED HEAT
C     DUTIES OF THE FIRED HEATERS OR THE TEMPERATURES OF THE EFFLUENT
C     STREAMS. IT CAN ALSO CALCULATE THE MEANS AND STANDARD DEVIATIONS
C     OF THE OUTPUT VARIABLES FROM WHICH A CONFIDENCE INTERVAL CAN
C     BE CALCULATED CORRESPONDING TO THE SPECIFIED CONFIDENCE LEVEL. THE
C     PROGRAM ALSO PROVIDES THE CUMULATIVE PROBABILITY CURVES FOR EACH
C     SPECIFIED OUTLET STREAM TEMPERATURE. FOR A SPECIFIED CONFIDENCE
C     LEVEL THE RANGE OF THE EFFLUENT STREAM TEMPERATURES FOR AN EXIST-
C     ING EXCHANGER OR SYSTEM OF EXCHANGERS CAN BE ESTIMATED. THE
C     PROGRAM CAN ALSO ESTIMATE THE PROBABILITIES THAT AN EXISTING
C     SYSTEM OF HEAT EXCHANGERS CAN ACHIEVE THE DESIRED PERFORMANCE.
C
C
C
C
C
      DIMENSION TAV(100),LIST(100),WAV(100),ITER(100)
      REAL KW(100)
      COMMON//ID(18)
      COMMON/PHUNIT/WUNIT(2),TUNIT(2),TMUNIT(2),EUNIT(2),ALGTH(2),KUNIT(
     $100),LUNIT(100),PUNIT(2)
      COMMON/ARAV/AREA(100,500),ANL(100),IREA(100),NUD(100),NQ(100),INFN
     1A(100),IZERA(100),EXTN(100,500),ENL(100)
      COMMON/ZAK/IA,TBAR,STDV,RVAR(9),STAND(20),TMEAN(20)
      COMMON/ADAP/CPC(200),CPH(200),SCPC(200),SCPH(200),NFA(200),NSP(200
     1),EEF(500)
      COMMON/ADATA/W(200),T(200),CP(200),Q(100),UD(100),HI(100),HO(100),
     1RFI(100),RFO(100),DI(100),DO(100),TISO(100),FT(100),TP1(100),TP2(1
     200),WISO(100),HFG(100),A(100),AI(100),AO(100),KW,TDIFF(100),TIGN(1
     300),HREAC(100),CONV(100),NTEMP(100),MODEL(100)
      COMMON/STD/SW(200),ST(200),SCP(200),SHI(100),SHO(100),SRFI(100),SR
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     1FO(100),SUD(100)
      COMMON/KEYS/IERR(100),NELM(100),NXX,NETRN,NX,IPR,ISC,LX,JX,IBD,NFD
      COMMON/NUMA/NF(100),NP(100),IFD(100,20),IPD(100,20),IDN(100)
      COMMON/IOUNIT/NREAD,NPRNT,NPNCH,IIX,EPS
      COMMON/TCPP/XAR(100),YAR(100),LIMIT,TMINN,IY,TINC,NELMT
      COMMON/VAMXN/WMAX(20),WMIN(20),TMAX(20),TMIN(20),WOPT(20,500),TOPT
     $(20,500)
      COMMON/MEAN/HIM(100),HOM(100),RFIM(100),RFOM(100),WM(200),TM(200)
     1,CPM(200),UMD(100)
      COMMON//PERCT(100,4)
      COMMON//IXX
      COMMON/GUNIT/IUNIGH,NCASE,NYORD
      DATA IBK/'    '/
C
C     INITIALIZE VARIABLES
C
      NPRB=0
      NYORD=0
      IXX=0
      IIX=0
      EPS=0.0
      NFD=0
      TINC=0.0
      DO 10 I=1,18
   10 ID(I)=IBK
      DO 60 INT=1,200
      W(INT)=0.0
      T(INT)=0.0
      CP(INT)=0.0
      SW(INT)=0.0
      ST(INT)=0.0
      SCP(INT)=0.0
   60 CONTINUE
      DO 65 IHX=1,100
      AI(IHX)=0.0
      AO(IHX)=0.0
      KW(IHX)=0.0
      IREA(IHX)=0
      INFNA(IHX)=0
      IZERA(IHX)=0
      NUD(IHX)=0
      NQ(IHX)=0
      NF(IHX)=0
      NP(IHX)=0
      IDN(IHX)=0
      TP1(IHX)=0.0
      TP2(IHX)=0.0
      CPC(IHX)=0.0
      CPH(IHX)=0.0
      ANL(IHX)=0.0
      A(IHX)=0.0
      DO 66 I=1,20
      IFD(IHX,I)=0
   66 IPD(IHX,I)=0
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   65   CONTINUE
        DO 70 I=1,100
        DO 67 N=1,500
   67   AREA(I,N)=0.0
   70   CONTINUE
        NETRN=0
        NXX=0
C
C       READ INPUT
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C
C
C         ID  .................SYSTEM IDENTIFICATION
C         IBD .................FEED BACK OPTION FOR DETERMINISTIC
C                              CALCULATION
C         IHD .................FEED BACK OPTION FOR MONTE CARLO
C                              SIMULATION
C         IDD .................DISTILLATION COLUMN OPTION
C         NELMT ...............TOTAL NUMBER OF ELEMENT
C         ISC .................MONTE CARLO SIMULATION
C         LX ..................TOTAL NUMBER OF SIMULATION
C         JX ..................SEED INTEGER
C         NPRB ................CUMULATIVE PROBABILITY OPTION
C         NYORD ...............Y-ORDINATE INTERVALS
C         TINC ................TEMPERATURE INCREMENT
C         JXX .................ELEMENT NUMBER
C         IDN(JXX) ............ELEMENT IDENTIFICATION NUMBER
C         NF(JXX) .............NUMBER OF FEED STREAMS
C         NP(JXX) .............NUMBER OF PRODUCT STREAMS
C         KUNIT(JXX) ..........INPUT UNITS OPTION
C         LUNIT(JXX) ..........OUTPUT UNITS OPTION
C
C
C
C
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
        READ(NREAD,11)ID
   11   FORMAT(18A4)
        READ(NREAD,12)IBD,IHD,IDD
  12    FORMAT(3I10)
        READ(NREAD,15)NELMT,ISC,LX,JX,NPRB,NYORD,TINC
   15   FORMAT(3(6X,I4),1X,I9,2(6X,I4),F10.5)
        DO 100 I=1,NELMT
        READ(NREAD,5)IDN(JXX),JXX,NF(JXX),NP(JXX),KUNIT(JXX),LUNIT(JXX)
    5   FORMAT(6(6X,I4))
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C
C           ELEMENT NAME                 IDENTIFICATION NUMBER
C
C
```

```
C         INPUT                                 1
C         STREAM ADDER                          2
C         STREAM DIVIDER                        3
C         HEAT EXCHANGER                        4
C         FIRED HEATER                          5
C         HEATER OR CONDENSER                   6
C         REACTOR                               7
C         DISTILLATION COLUMN                   8
C         OUTPUT                                9
C
C
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      IF(IDN(JXX).EQ.1) GO TO 20
      IF(IDN(JXX).EQ.2) GO TO 35
      IF(IDN(JXX).EQ.3) GO TO 38
      IF(IDN(JXX).EQ.4) GO TO 45
      IF(IDN(JXX).EQ.5) GO TO 55
      IF(IDN(JXX).EQ.6) GO TO 45
      IF(IDN(JXX).EQ.7) GO TO 46
      IF(IDN(JXX).EQ.8) GO TO 40
      IF(IDN(JXX).EQ.9) GO TO 50
   20 CALL INPT(JXX)
      NELM(I)=JXX
      GO TO 100
  35  CALL ADDR(JXX)
      NELM(I)=JXX
      GO TO 100
  38  CALL DVDR(JXX)
      NELM(I)=JXX
      GO TO 100
   40 CALL DISTL(JXX)
      NELM(I)=JXX
      GO TO 100
   45 CALL HEX00(JXX)
   55 CALL FRHR(JXX)
      NELM(I)=JXX
      GO TO 100
      NELM(I)=JXX
      GO TO 100
  46  CALL RCTR(JXX)
      NELM(I)=JXX
      GO TO 100
   50 CALL OTPT(JXX)
      NELM(I)=JXX
  100 CONTINUE
C
C     CONVERT UNITS AND CALCULATE UNKNOWN NOMINAL CONDITIONS FOR EACH
C     ELEMENT. PRINT RESULTS
C
  888 NETRN=1
      DO 295 NXX=1,2
      DO 290 NX=1,NELMT
      JXX=NELM(NX)
```

```
      IF(IDN(JXX).EQ.1) GO TO 212
      IF(IDN(JXX).EQ.6) GO TO 222
      IF(IDN(JXX).EQ.7) GO TO 333
      IF(IDN(JXX).EQ.4) GO TO 203
      IF(IDN(JXX).EQ.8) GO TO 104
      IF(IDN(JXX).EQ.3) GO TO 207
      IF(IDN(JXX).EQ.2) GO TO 206
      IF(IDN(JXX).EQ.5) GO TO 209
      IF(IDN(JXX).EQ.9) GO TO 205
      GO TO 290
212   IF(NXX.EQ.1) CALL UNITS(JXX)
      GO TO 290
222   IF(NXX.EQ.1) GO TO 223
      CALL HEX00(JXX)
      GO TO 290
223   CALL UNITS(JXX)
      CALL HRCR(JXX)
      GO TO 290
333   IF(NXX.EQ.1) GO TO 334
      CALL RCTR(JXX)
      GO TO 290
334   CALL UNITS(JXX)
      CALL RCTR(JXX)
      GO TO 290
203   IF(NXX.EQ.1) GO TO 217
      CALL HEX00(JXX)
      GO TO 290
217   CALL UNITS(JXX)
      CALL HEX(JXX)
      GO TO 290
104   IF(NXX.EQ.1) GO TO 105
      CALL DISTL(JXX)
      GO TO 290
105   CALL UNITS(JXX)
      CALL DISTL(JXX)
      GO TO 290
206   CALL ADDR(JXX)
      GO TO 290
207   CALL DVDR(JXX)
      GO TO 290
209   IF(NXX.EQ.1) GO TO 210
      CALL FRHR(JXX)
      GO TO 290
210   CALL UNITS(JXX)
      CALL FRHR(JXX)
      GO TO 290
205   IF(NXX.EQ.1)GO TO 290
      CALL OTPT(JXX)
290   CONTINUE
295   CONTINUE
      IF(IBD.EQ.1)CALL FBACK
      IF(IIX.GE.50) GO TO 1500
      IF(ISC.EQ.0) GO TO 1500
      IF(IHD.EQ.1.AND.IDD.EQ.0) CALL HFBACK
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```
      IF(IIX.GE.50) GO TO 1500
      IF(IHD.EQ.1.AND.IDD.EQ.0) GO TO 1500
C
C     MONTE CARLO SIMULATION
C
 666  NETRN=2
  505 DO 2500 IPR=1,LX
      DO 2000 I=1,NELMT
      JXX=NELM(I)
      IF(IDN(JXX).EQ.1) GO TO 310
      IF(IDN(JXX).EQ.9) GO TO 320
      IF(IDN(JXX).EQ.2) GO TO 330
      IF(IDN(JXX).EQ.8) GO TO 340
      IF(IDN(JXX).EQ.3) GO TO 341
      IF(IDN(JXX).EQ.5) GO TO 342
      IF(IDN(JXX).EQ.6) GO TO 700
      IF(IDN(JXX).EQ.7) GO TO 701
      IF(IDN(JXX).EQ.4) GO TO 360
 310  CALL RANDV(JXX)
      GO TO 2000
 330  CALL RANDV(JXX)
      CALL ADDR(JXX)
      GO TO 2000
 340  CALL RANDV(JXX)
      CALL DISTL(JXX)
      GO TO 2000
 341  CALL RANDV(JXX)
      CALL DVDR(JXX)
      GO TO 2000
 342  CALL FRHR(JXX)
      IF(IERR(JXX).EQ.1) GO TO 1500
      GO TO 2000
 700  CALL HRCR(JXX)
      IF(IERR(JXX).EQ.1) GO TO 1500
      GO TO 2000
 701  CALL RCTR(JXX)
      IF(IERR(JXX).EQ.1) GO TO 1500
      GO TO 2000
 360  CALL HEX(JXX)
      IF(IERR(JXX).EQ.1) GO TO 1500
      GO TO 2000
 320  IF(IPR.GT.1) GO TO 370
      MOTPT=NF(JXX)
      DO 365 NK=1,MOTPT
      WMAX(NK)=0.000001
      WMIN(NK)=90000000.0
      TMAX(NK)=0.00001
      TMIN(NK)=100000000.0
 365  CONTINUE
 370  CALL PRINT(JXX)
2000  CONTINUE
2500  CONTINUE
C
C     CALCULATE THE MEAN AND STANDARD DEVIATION FOR EACH HEAT EXCHANGER
```

```
C     AREA
C
      MTEMP=0
      DO 400 I=1,NELMT
      JXX=NELM(I)
      IF(IDN(JXX).EQ.4) GO TO 410
      IF(IDN(JXX).EQ.6) GO TO 410
      GO TO 400
 410  IF(IREA(JXX).GE.1) CALL VAHX(JXX)
      IF(IREA(JXX).GE.1)MTEMP=1
 400  CONTINUE
      IF(MTEMP.GE.1) GO TO 1500
C
C     CALCULATE THE MEAN AND STANDARD DEVIATION FOR EXTENT OF REACTION
C     IN EACH REACTOR ELEMENT.
C
      DO 5000 I=1,NELMT
      JXX=NELM(I)
      IF(IDN(JXX).EQ.7)GO TO 5510
      GO TO 5000
 5510 CALL EXTENT(JXX)
 5000 CONTINUE
C     CALCULATE THE MEAN AND STANDARD DEVIATION FOR FIRED HEATER
C     HEAT DUTY.
C
      DO 4000 I=1,NELMT
      JXX=NELM(I)
      IF(IDN(JXX).EQ.5)GO TO 4410
      GO TO 4000
 4410 CALL EFFECT(JXX)
 4000 CONTINUE
C
C
C     CALCULATE THE MEAN AND STANDARD DEVIATION FOR EACH OUTLET STREAM.
C
C
      JXX=NELM(NELMT)
      DO 1400 IY=1,MOTPT
      IA=IFD(JXX,IY)
      IF(TMAX(IY).EQ.TMIN(IY)) GO TO 1400
      IUNIGH=LUNIT(JXX)
      MK=TMIN(IY)/10.0
      AMK=MK*10
      IF(TINC.NE.0.0) GO TO 420
      TINC=1.0
 420  BMK=AMK-TINC/2.0
      INTLT=(TMAX(IY)-BMK)/TINC+0.5
      IF(INTLT.LE.100) GO TO 423
      TINC=TINC+1.0
      GO TO 420
 423  DO 1420 NT=1,INTLT
      YAR(NT)=0.0
      XAR(NT)=0.0
 1420 LIST(NT)=0
```

```
      SUMA=0.0
      SUMT1=0.0
      SUMT2=0.0
      SUMT3=0.0
      SUMT4=0.0
      DO 1450 IS=1,LX
      LT=(TOPT(IY,IS)-BMK)/TINC+1.0
      LIST(LT)=LIST(LT)+1
      SUMA=TOPT(IY,IS)+SUMA
 1450 CONTINUE
      DO 1452 IT=1,INTLT
      IM=IT-1
      TAV(IT)=AMK+IM*TINC
 1452 CONTINUE
      LIMIT=INTLT
 1455 BLX=LX
      TPRB=0.0
      DO 1456 NX=1,LIMIT
      ALIST=LIST(NX)
      TPRB=ALIST/BLX+TPRB
      XAR(NX)=TAV(NX)
      YAR(NX)=TPRB
 1456 CONTINUE
C
C     PLOT THE CUMULATIVE PROBABILITY CURVES
C
      TMINN=AMK
      TBAR=SUMA/BLX
      TMEAN(IY)=TBAR
      DO 1440 IZ=1,LX
      T1=TOPT(IY,IZ)-TBAR
      T2=T1*T1
      T3=T1*T1*T1
      T4=T1*T1*T1*T1
      SUMT1=T1+SUMT1
      SUMT2=T2+SUMT2
      SUMT3=T3+SUMT3
      SUMT4=T4+SUMT4
 1440 CONTINUE
      TMOM1=SUMT1/BLX
      TMOM2=SUMT2/BLX
      TMOM3=SUMT3/BLX
      TMOM4=SUMT4/BLX
      BT1=TMOM3/(TMOM2)**1.5
      BT2=TMOM4/TMOM2
      STDV=SQRT(TMOM2)
      STAND(IY)=STDV
      IF(NPRB.NE.0) CALL GRAPH
 1400 CONTINUE
      IF(IHD.EQ.1.AND.IDD.EQ.1)CALL DFBACK
 999  IF(NPRB.NE.0) GO TO 1500
      WRITE(NPRNT,375)ID
 375  FORMAT('1'/5X,'PROBLEM IDENTIFICATION***',18A4,1X,'*** OUTPUT LIST
     1ING ***')
```

```
      JXX=NELM(NELMT)
      IUNIT=LUNIT(JXX)
      WRITE(NPRNT,1460)TUNIT(IUNIT),TUNIT(IUNIT)
 1460 FORMAT(////5X,'RESULTS OF TEMPERATURE CALCULATION FOR ALL OUTLET S
     1TREAMS'//5X,'STREAM NUMBER',5X,'MEAN TEMPERATURE DEG ',A2,5X,'STAN
     2DARD DEVIATION DEG ',A2//)
      DO 1430 I=1,MOTPT
      IOT=IFD(JXX,I)
      WRITE(NPRNT,1425)IOT,TMEAN(I),STAND(I)
 1425 FORMAT(10X,I3,15X,F10.3,16X,F10.3)
 1430 CONTINUE
 1500 STOP
      END
      BLOCK DATA
      COMMON/ZAK/IA,TBAR,STDV,RVAR(9),STAND(20),TMEAN(20)
      COMMON/IOUNIT/NREAD,NPRNT,NPNCH
      COMMON/PHUNIT/WUNIT(2),TUNIT(2),TMUNIT(2),EUNIT(2),ALGTH(2),KUNIT(
     $100),LUNIT(100),PUNIT(2)
      DATA RVAR/3HALL,2HT2,2HT1,2HW2,2HW1,2HHI,2HHO,3HRFI,3HRFO/
      DATA WUNIT/2HLB,2HKG/
      DATA TUNIT/1HF,1HK/
      DATA TMUNIT/2HHR,2HHR/
      DATA EUNIT/3HBTU,3H KJ/
      DATA PUNIT/3HBTU,3H  W/
      DATA ALGTH/2HFT,2H M/
      DATA NREAD,NPRNT,NPNCH/5,6,7/
      DATA TMEAN,STAND/20*0.0,20*0.0/
      END
      SUBROUTINE INPT(JXX)
C
C     SUBROUTINE INPT READS INPUT CONDITIONS OF UP TO 20 FEED STREAMS IN
C     THE ORDER THEY HAVE BEEN ARRANGED.
C
      DIMENSION F(50),E(50),CT(50),SF(50),SE(50),SCT(50)
      COMMON//ID(18)
      COMMON/KEYS/IERR(100),NELM(100),NXX,NETRN,NX,IPR,ISC,LX,JX,IBD,NFD
      COMMON/PHUNIT/WUNIT(2),TUNIT(2),TMUNIT(2),EUNIT(2),ALGTH(2),KUNIT(
     $100),LUNIT(100),PUNIT(2)
      COMMON/IOUNIT/NREAD,NPRNT,NPNCH,IIX,EPS
      COMMON/NUMA/NF(100),NP(100),IFD(100,20),IPD(100,20),IDN(100)
      COMMON/ADATA/W(200),T(200),CP(200),Q(100),UD(100),HI(100),HO(100),
     1RFI(100),RFO(100),DI(100),DO(100),TISO(100),FT(100),TP1(100),TP2(1
     200),WISO(100),HFG(100),A(100),AI(100),AO(100),KW,TDIFF(100),TIGN(1
     300),HREAC(100),CONV(100)
      COMMON/STD/SW(200),ST(200),SCP(200),SHI(100),SHO(100),SRFI(100),SR
     1FO(100),SUD(100)
      DATA F,E,CT,SF,SE,SCT/50*0.0,50*0.0,50*0.0,50*0.0,50*0.0,50*0.0/
  370 FORMAT('1'/5X,'PROBLEM IDENTIFICATION***',18A4,2X,'*** INPUT LISTI
     1NG ***')
      IF(NETRN.EQ.0)WRITE(NPRNT,370)ID
      MINPT=NP(JXX)
      DO 23 MM=1,MINPT
      READ(NREAD,24)ISTM,W(ISTM),T(ISTM),CP(ISTM),SW(ISTM),ST(ISTM),SCP(
     1ISTM)
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```
 24   FORMAT(6X,I4,2F10.2,F10.5,2F10.2,F10.5)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C
C      ISTM ..............INPUT ELEMENT PRODUCT STREAM NUMBER
C      W(ISTM) ...........INPUT ELEMENT PRODUCT STREAM FLOW RATE
C      T(ISTM) ...........INPUT ELEMENT PRODUCT STREAM TEMPERATURE
C      CP(ISTM) ..........INPUT ELEMENT PRODUCT STREAM SPECIFIC
C                         HEAT
C      SW(ISTM)...........INPUT ELEMENT PRODUCT STREAM FLOW RATE
C                         STANDARD DEVIATION
C      ST(ISTM)...........INPUT ELEMENT PRODUCT STREAM TEMPERATURE
C                         STANDARD DEVIATION
C      SCP(ISTM)..........INPUT ELEMENT PRODUCT STREAM SPECIFIC
C                         HEAT STANDARD DEVIATION
C
C
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      IPD(JXX,MM)=ISTM
      F(MM)=W(ISTM)
      E(MM)=T(ISTM)
      CT(MM)=CP(ISTM)
      SF(MM)=SW(ISTM)
      SE(MM)=ST(ISTM)
      SCT(MM)=SCP(ISTM)
  23  CONTINUE
      WRITE(NPRNT,25)JXX,NF(JXX),NP(JXX)
  25  FORMAT(////1X,'INPUT TANK'//1X,'ELEMENT NUMBER**',I3//1X,     'NUM
     1BER OF FEED STREAMS**',I3,' NUMBER OF PRODUCT STREAMS**',I3/////
     265X,'PRODUCT')
      J=1
      N=10
  27  WRITE(NPRNT,30)(IPD(JXX,MM),MM=J,N)
 30   FORMAT(//1X,'STREAM NUMBER',14X,I4,9(6X,I4))
      IUNIT=KUNIT(JXX)
      WRITE(NPRNT,31)WUNIT(IUNIT),TMUNIT(IUNIT),(F(MM),MM=J,N)
 31   FORMAT(///1X,'FLOW RATE ',A2,'/',A3,8X,10F10.2)
      WRITE(NPRNT,32)TUNIT(IUNIT),(E(MM),MM=J,N)
 32   FORMAT(1X,'TEMPERATURE DEG ',A1,7X,10F10.2)
      WRITE(NPRNT,33)EUNIT(IUNIT),WUNIT(IUNIT),TUNIT(IUNIT),(CT(MM),MM=J
     1,N)
 33   FORMAT(1X,'HEAT CAPACITY ',A3,'/',A2,' ',A1,3X,10F10.5)
      WRITE(NPRNT,34)WUNIT(IUNIT),TMUNIT(IUNIT),(SF(MM),MM=J,N)
 34   FORMAT(1X,'FLOW RATE STD ',A2,'/',A3,4X,10F10.2)
      WRITE(NPRNT,35)TUNIT(IUNIT),(SE(MM),MM=J,N)
 35   FORMAT(1X,'TEMPERATURE STD DEG ',A1,4X,10F10.2)
      WRITE(NPRNT,36)EUNIT(IUNIT),WUNIT(IUNIT),TUNIT(IUNIT),(SCT(MM),MM=
     1J,N)
 36   FORMAT(1X,'HEAT CPY STD ',A3,'/',A2,' ',A1,3X,10F10.5)
      IF(N.GT.10) GO TO 40
      IF(MINPT.LE.10) GO TO 40
      WRITE(NPRNT,38)
  38  FORMAT(//////)
```

```
      J=11
      N=MINPT
      GO TO 27
   40 RETURN
      END
      SUBROUTINE ADDR(JXX)
C
C     SUBROUTINE ADDR ADDS UP TO 4 STREAMS INTO ONE PRODUCT STREAM.
C
      REAL KW(100)
      COMMON//ID(18)
      COMMON/KEYS/IERR(100),NELM(100),NXX,NETRN,NX,IPR,ISC,LX,JX,IBD,NFD
      COMMON/PHUNIT/WUNIT(2),TUNIT(2),TMUNIT(2),EUNIT(2),ALGTH(2),KUNIT(
     $100),LUNIT(100),PUNIT(2)
      COMMON/IOUNIT/NREAD,NPRNT,NPNCH,IIX,EPS
      COMMON/NUMA/NF(100),NP(100),IFD(100,20),IPD(100,20),IDN(100)
      COMMON/ADATA/W(200),T(200),CP(200),Q(100),UD(100),HI(100),HO(100),
     1RFI(100),RFO(100),DI(100),DO(100),TISO(100),FT(100),TP1(100),TP2(1
     200),WISO(100),HFG(100),A(100),AI(100),AO(100),KW,TDIFF(100),TIGN(1
     300),HREAC(100),CONV(100)
      COMMON/STD/SW(200),ST(200),SCP(200),SHI(100),SHO(100),SRFI(100),SR
     1FO(100),SUD(100)
  370 FORMAT('1'/5X,'PROBLEM IDENTIFICATION***',18A4,2X,'***INPUT LISTIN
     1G ***')
  375 FORMAT('1'/5X,'PROBLEM IDENTIFICATION***',18A4,1X,'*** OUTPUT LIST
     1ING ***')
      IF(NETRN.EQ.0)WRITE(NPRNT,370) ID
      IF(NETRN.EQ.1.AND.NXX.EQ.2)WRITE(NPRNT,375) ID
      IF(NETRN.NE.0) GO TO 108
      READ(NREAD,105)(IFD(JXX,K),K=1,4),IPD(JXX,1)
  105 FORMAT(5(6X,I4))
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C
C       IFD(JXX,1) ..........ADDER ELEMENT FEED STREAM 1 NUMBER
C       IFD(JXX,2) ..........ADDER ELEMENT FEED STREAM 2 NUMBER
C       IFD(JXX,3) ..........ADDER ELEMENT FEED STREAM 3 NUMBER
C       IFD(JXX,4) ..........ADDER ELEMENT FEED STREAM 4 NUMBER
C       IPD(JXX,1) ..........ADDER ELEMENT PRODUCT STREAM NUMBER
C
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
  108 IFD1=IFD(JXX,1)
      IFD2=IFD(JXX,2)
      IFD3=IFD(JXX,3)
      IFD4=IFD(JXX,4)
      IPD1=IPD(JXX,1)
      W3=0.0
      SW3=0.0
      W4=0.0
      SW4=0.0
      T3=0.0
      ST3=0.0
      T4=0.0
```

```
      ST4=0.0
      CP3=0.0
      SCP3=0.0
      CP4=0.0
      SCP4=0.0
      IF(IFD3.EQ.0) GO TO 113
      W3=W(IFD3)
      SW3=SW(IFD3)
      T3=T(IFD3)
      ST3=ST(IFD3)
      CP3=CP(IFD3)
      SCP3=SCP(IFD3)
      IF(IFD4.EQ.0) GO TO 113
      W4=W(IFD4)
      SW4=SW(IFD4)
      T4=T(IFD4)
      ST4=ST(IFD4)
      CP4=CP(IFD4)
      SCP4=SCP(IFD4)
  113 W(IPD1)=W(IFD1)+W(IFD2)+W3+W4
      T(IPD1)=(T(IFD1)*W(IFD1)+T(IFD2)*W(IFD2)+T3*W3+T4*W4)/W(IPD1)
      CP(IPD1)=(W(IFD1)*CP(IFD1)+W(IFD2)*CP(IFD2)+W3*CP3+W4*CP4)/W(IPD1)
      SW(IPD1)=SQRT(SW(IFD1)**2+SW(IFD2)**2+SW3**2+SW4**2)
      ST(IPD1)=SQRT(((W(IFD1)/W(IPD1))*ST(IFD1))**2+((W(IFD2)/W(IPD1))*
     1ST(IFD2))**2+((W3/W(IPD1))*ST3)**2+((W4/W(IPD1))*ST4)**2)
      SCP(IPD1)=SQRT(((W(IFD1)/W(IPD1))*SCP(IFD1))**2+((W(IFD2)/W(IPD1))
     1*SCP(IFD2))**2+((W3/W(IPD1))*SCP3)**2+((W4/W(IPD1))*SCP4)**2)
      IF (NETRN.EQ.1.AND.NXX.EQ.1) GO TO 130
      IF (NETRN.EQ.2.AND.ISC.GE.1) GO TO 130
  115 WRITE(NPRNT,100)JXX,NF(JXX),NP(JXX)
  100 FORMAT(////5X,'STREAM ADDER'//5X,'ELEMENT NUMBER**',I3//5X,    'NU
     1MBER OF FEED STREAMS**',I3,' NUMBER OF PRODUCT STREAMS**',I3/////6
     22X,'FEED',30X,'PRODUCT')
      WRITE(NPRNT,110)(IFD(JXX,K),K=1,4),IPD(JXX,1)
  110 FORMAT(//5X,'STREAM NUMBER',22X,4(6X,I4),16X,I4)
      IF (NETRN.EQ.1.AND.NXX.EQ.2) KUNIT(JXX)=LUNIT(JXX)
      IUNIT=KUNIT(JXX)
      WRITE(NPRNT,117)WUNIT(IUNIT),TMUNIT(IUNIT),W(IFD1),W(IFD2),W3,W4,
     1W(IPD1),TUNIT(IUNIT),T(IFD1),T(IFD2),T3,T4,T(IPD1),EUNIT(IUNIT),
     2WUNIT(IUNIT),TUNIT(IUNIT),CP(IFD1),CP(IFD2),CP3,CP4,CP(IPD1)
  117 FORMAT(///5X,'FLOW RATE ',A2,'/',A2,24X,4F10.2,10X,F10.2/5X,'TEMPE
     1RATURE DEG ',A1,22X,4F10.2,10X,F10.2/5X,'HEAT CAPACITY ',A3,'/',A2
     2,' ',A1,17X,4F10.5,10X,F10.5)
      WRITE(NPRNT,120)WUNIT(IUNIT),TMUNIT(IUNIT),SW(IFD1),SW(IFD2),SW3,
     1SW4,SW(IPD1),TUNIT(IUNIT),ST(IFD1),ST(IFD2),ST3,ST4,ST(IPD1),EUNIT
     2(IUNIT),WUNIT(IUNIT),TUNIT(IUNIT),SCP(IFD1),SCP(IFD2),SCP3,SCP4,
     3SCP(IPD1)
  120 FORMAT(5X,'FLOW RATE STD ',A2,'/',A2,20X,4F10.2,10X,F10.2/5X,'TEMP
     1ERATURE STD,DEG ',A1,18X,4F10.2,10X,F10.2/5X,'HEAT CAPACITY STD ',
     2A3,'/',A2,' ',A1,13X,4F10.5,10X,F10.5)
  130 RETURN
      END
      SUBROUTINE DVDR(JXX)
C
```

```
C     SUBROUTINE DVDR DIVIDES ONE STREAMS INTO  UP TO 4 PRODUCT STREAMS
C
      REAL KW(100)
      COMMON//ID(18)
      COMMON/KEYS/IERR(100),NELM(100),NXX,NETRN,NX,IPR,ISC,LX,JX,IBD,NFD
      COMMON/PHUNIT/WUNIT(2),TUNIT(2),TMUNIT(2),EUNIT(2),ALGTH(2),KUNIT(
     $100),LUNIT(100),PUNIT(2)
      COMMON/IOUNIT/NREAD,NPRNT,NPNCH,IIX,EPS
      COMMON/NUMA/NF(100),NP(100),IFD(100,20),IPD(100,20),IDN(100)
      COMMON/ADATA/W(200),T(200),CP(200),Q(200),UD(100),HI(100),HO(100),
     1RFI(100),RFO(100),DI(100),DO(100),TISO(100),FT(100),TP1(100),TP2(1
     200),WISO(100),HFG(100),A(100),AI(100),AO(100),KW
      COMMON/STD/SW(200),ST(200),SCP(200),SHI(100),SHD(100),SRFI(100),SR
     1FO(100),SUD(100)
      COMMON//PERCT(100,4)
 370  FORMAT('1'/5X,'PROBLEM IDENTIFICATION***',18A4,2X,'***INPUT LISTIN
     1G ***')
 375  FORMAT('1'/5X,'PROBLEM IDENTIFICATION***',18A4,1X,'*** OUTPUT LIST
     1ING ***')
      IF(NETRN.EQ.0)WRITE(NPRNT,370) ID
      IF(NETRN.EQ.1.AND.NXX.EQ.2)WRITE(NPRNT,375) ID
      IF(NETRN.NE.0) GO TO 213
      READ(NREAD,212)IFD(JXX,1),(IPD(JXX,M),M=1,4),(PERCT(JXX,M),M=1,4)
 212  FORMAT(5(6X,I4)/4F10.5)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C
C     IFD(JXX,1) ..........DIVIDER ELEMENT FEED STREAM NUMBER
C     IPD(JXX,1) ..........DIVIDER ELEMENT PRODUCT STREAM 1 NUMBER
C     IPD(JXX,2) ..........DIVIDER ELEMENT PRODUCT STREAM 2 NUMBER
C     IPD(JXX,3) ..........DIVIDER ELEMENT PRODUCT STREAM 3 NUMBER
C     IPD(JXX,4) ..........DIVIDER ELEMENT PRODUCT STREAM 4 NUMBER
C     PERCT(JXX,1) ........FRACTION OF FEED STREAM GOING INTO
C                          PRODUCT STREAM 1
C     PERCT(JXX,2) ........FRACTION OF FEED STREAM GOING INTO
C                          PRODUCT STREAM 2
C     PERCT(JXX,3) ........FRACTION OF FEED STREAM GOING INTO
C                          PRODUCT STREAM 3
C     PERCT(JXX,4) ........FRACTION OF FEED STREAM GOING INTO
C                          PRODUCT STREAM 4
C
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
 213  LA=IPD(JXX,1)
      LB=IPD(JXX,2)
      LC=IPD(JXX,3)
      LD=IPD(JXX,4)
      LE=IFD(JXX,1)
      FR1=PERCT(JXX,1)
      FR2=PERCT(JXX,2)
      FR3=PERCT(JXX,3)
      FR4=PERCT(JXX,4)
      W(LA)=W(LE)*FR1
      CP(LA)=CP(LE)
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      T(LA)=T(LE)
      W(LB)=W(LE)*FR2
      CP(LB)=CP(LE)
      T(LB)=T(LE)
      SW(LA)=FR1*SW(LE)
      SW(LB)=FR2*SW(LE)
      ST(LA)=ST(LE)
      ST(LB)=ST(LE)
      SCP(LA)=SCP(LE)
      SCP(LB)=SCP(LE)
      WP3=0.0
      WP4=0.0
      TP3=0.0
      TP4=0.0
      CPP3=0.0
      CPP4=0.0
      SWP3=0.0
      SWP4=0.0
      STP3=0.0
      STP4=0.0
      SCPP3=0.0
      SCPP4=0.0
      IF(LC.EQ.0) GO TO 215
      WP3=W(LE)*FR3
      W(LC)=WP3
      TP3=T(LE)
      T(LC)=TP3
      CPP3=CP(LE)
      CP(LC)=CPP3
      SWP3=SW(LE)*FR3
      STP3=ST(LE)
      SCPP3=SCP(LE)
      SW(LC)=SWP3
      ST(LC)=STP3
      SCP(LC)=SCPP3
      IF (LD.EQ.0) GO TO 215
      WP4=W(LE)*FR4
      TP4=T(LE)
      CPP4=CP(LE)
      SWP4=SW(LE)*FR4
      STP4=ST(LE)
      SCPP4=SCP(LE)
      W(LD)=WP4
      T(LD)=TP4
      CP(LD)=CPP4
      SW(LD)=SWP4
      ST(LD)=STP4
      SCP(LD)=SCPP4
  215 IF(NETRN.EQ.1.AND.NXX.EQ.1) GO TO 250
      IF(ISC.GE.1.AND.NETRN.EQ.2) GO TO 250
      WRITE(NPRNT,200)JXX,NF(JXX),NP(JXX)
  200 FORMAT(////5X,'STREAM DIVIDER'//5X,'ELEMENT NUMBER**',I3//5X,     '
     1NUMBER OF FEED STREAMS**',I2,' NUMBER OF PRODUCT STREAMS**',I2////
     2/47X,'FEED',32X,'PRODUCT')
```

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      WRITE(NPRNT,210)IFD(JXX,1),(IPD(JXX,M),M=1,4)
 210  FORMAT(//5X,'STREAM NUMBER',29X,I3,10X,4(9X,I3))
      IF(NETRN.EQ.1.AND.NXX.EQ.2) KUNIT(JXX)=LUNIT(JXX)
      IUNIT=KUNIT(JXX)
      WRITE(NPRNT,220)WUNIT(IUNIT),TMUNIT(IUNIT),W(LE),W(LA),W(LB),WP3,W
     1P4,TUNIT(IUNIT),T(LE),T(LA),T(LB),TP3,TP4,EUNIT(IUNIT),WUNIT(IUNIT
     2),TUNIT(IUNIT),CP(LE),CP(LA),CP(LB),CPP3,CPP4
 220  FORMAT(///5X,'FLOW RATE ',A2,'/',A2,24X,F10.2,8X,4(2X,F10.2)/5X,'T
     1EMPERATURE,DEG ',A1,22X,F10.2,8X,4(2X,F10.2)/5X,'HEAT CAPACITY,',A
     23,'/',A2,' ',A1,17X,F10.5,8X,4(2X,F10.5))
      WRITE(NPRNT,230)WUNIT(IUNIT),TMUNIT(IUNIT),SW(LE),SW(LA),SW(LB),SW
     1P3,SWP4,TUNIT(IUNIT),ST(LE),ST(LA),ST(LB),STP3,STP4,EUNIT(IUNIT),W
     2UNIT(IUNIT),TUNIT(IUNIT),SCP(LE),SCP(LA),SCP(LB),SCPP3,SCPP4
 230  FORMAT(5X,'FLOW RATE STD,',A2,'/',A2,20X,F10.2,8X,4(2X,F10.2)/5X,
     1'TEMPERATURE STD,DEG ',A1,18X,F10.2,8X,4(2X,F10.2)/5X,'HEAT CAPACI
     2TY STD,',A3,'/',A2,' ',A1,13X,F10.5,8X,4(2X,F10.5))
 250  RETURN
      END
      SUBROUTINE DISTL(JXX)
C
C
      REAL KW(100)
      COMMON//ID(18)
      COMMON/KEYS/IERR(100),NELM(100),NXX,NETRN,NX,IPR,ISC,LX,JX,IBD,NFD
      COMMON/PHUNIT/WUNIT(2),TUNIT(2),TMUNIT(2),EUNIT(2),ALGTH(2),KUNIT(
     $100),LUNIT(100),PUNIT(2)
      COMMON/IOUNIT/NREAD,NPRNT,NPNCH,IIX,EPS
      COMMON/NUMA/NF(100),NP(100),IFD(100,20),IPD(100,20),IDN(100)
      COMMON/ADATA/W(200),T(200),CP(200),Q(100),UD(100),HI(100),HO(100),
     1RFI(100),RFO(100),DI(100),DO(100),TISO(100),FT(100),TP1(100),TP2(1
     200),WISO(100),HFG(100),A(100),AI(100),AO(100),KW,TDIFF(100),TIGN(1
     300),HREAC(100),CONV(100)
      COMMON/STD/SW(200),ST(200),SCP(200),SHI(100),SHO(100),SRFI(100),SR
     1FO(100),SUD(100)
      COMMON//PERCT(100,4)
 370  FORMAT('1'/5X,'PROBLEM IDENTIFICATION***',18A4,2X,'***INPUT LISTIN
     1G ***')
 375  FORMAT('1'/5X,'PROBLEM IDENTIFICATION***',18A4,1X,'*** OUTPUT LIST
     1ING ***')
      IF(NETRN.EQ.0)WRITE(NPRNT,370) ID
      IF(NETRN.EQ.1.AND.NXX.EQ.2)WRITE(NPRNT,375) ID
      IF(NETRN.NE.0) GO TO 213
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C
C       IFD(JXX,1) ....DISTILLATION ELEMENT FEED STREAM NUMBER
C       IPD(JXX,1) ....DISTILLATION ELEMENT PRODUCT STREAM 1 NUMBER
C       IPD(JXX,2) ....DISTILLATION ELEMENT PRODUCT STREAM 2 NUMBER
C       IPD(JXX,3) ....DISTILLATION ELEMENT PRODUCT STREAM 3 NUMBER
C       IPD(JXX,4) ....DISTILLATION ELEMENT PRODUCT STREAM 4 NUMBER
C       IPD(JXX,5) ....DISTILLATION ELEMENT PRODUCT STREAM 5 NUMBER
C       IPD(JXX,6) ....DISTILLATION ELEMENT PRODUCT STREAM 6 NUMBER
C       W(IFD1) .......DISTILLATION ELEMENT FEED STREAM FLOW RATE
C       W(IPD1) .......DISTILLATION ELEMENT PRODUCT STREAM 1 FLOW RATE
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C      W(IPD2) .......DISTILLATION ELEMENT PRODUCT STREAM 2 FLOW RATE
C      W(IPD3) .......DISTILLATION ELEMENT PRODUCT STREAM 3 FLOW RATE
C      W(IPD4) .......DISTILLATION ELEMENT PRODUCT STREAM 4 FLOW RATE
C      W(IPD5) .......DISTILLATION ELEMENT PRODUCT STREAM 5 FLOW RATE
C      W(IPD6) .......DISTILLATION ELEMENT PRODUCT STREAM 6 FLOW RATE
C      T(IFD1) .......DISTILLATION ELEMENT FEED STREAM TEMPERATURE
C      T(IPD1) .......DISTILLATION ELEMENT PRODUCT STREAM 1 TEMP.
C      T(IPD2)........DISTILLATION ELEMENT PRODUCT STREAM 2 TEMP.
C      T(IPD3) .......DISTILLATION ELEMENT PRODUCT STREAM 3 TEMP.
C      T(IPD4) .......DISTILLATION ELEMENT PRODUCT STREAM 4 TEMP.
C      T(IPD5) .......DISTILLATION ELEMENT PRODUCT STREAM 5 TEMP.
C      T(IPD6) .......DISTILLATION ELEMENT PRODUCT STREAM 6 TEMP.
C      CP(IFD1) ......DISTILLATION ELEMENT FEED STREAM SPEC. HEAT
C      CP(IPD1) ......DISTILLATION ELEMENT PRODUCT STREAM 1 SPEC.HEAT
C      CP(IPD2) ......DISTILLATION ELEMENT PRODUCT STREAM 2 SPEC.HEAT
C      CP(IPD3) ......DISTILLATION ELEMENT PRODUCT STREAM 3 SPEC.HEAT
C      CP(IPD4) ......DISTILLATION ELEMENT PRODUCT STREAM 4 SPEC.HEAT
C      CP(IPD5) ......DISTILLATION ELEMENT PRODUCT STREAM 5 SPEC.HEAT
C      CP(IPD6) ......DISTILLATION ELEMENT PRODUCT STREAM 6 SPEC.HEAT
C      SW(IFD1).......DISTILLATION ELEMENT FEED STREAM FLOW RATE
C                     STANDARD DEVIATION
C      SW(IPD1).......DISTILLATION ELEMENT PRODUCT STREAM 1 FLOW RATE
C                     STANDARD DEVIATION
C      SW(IPD2).......DISTILLATION ELEMENT PRODUCT STREAM 2 FLOW RATE
C                     STANDARD DEVIATION
C      SW(IPD3).......DISTILLATION ELEMENT PRODUCT STREAM 3 FLOW RATE
C                     STANDARD DEVIATION
C      SW(IPD4).......DISTILLATION ELEMENT PRODUCT STREAM 4 FLOW RATE
C                     STANDARD DEVIATION
C      SW(IPD5).......DISTILLATION ELEMENT PRODUCT STREAM 5 FLOW RATE
C                     STANDARD DEVIATION
C      SW(IPD6).......DISTILLATION ELEMENT PRODUCT STREAM 6 FLOW RATE
C                     STANDARD DEVIATION
C      ST(IFD1).......DISTILLATION ELEMENT FEED STREAM TEMPERATURE
C                     STANDARD DEVIATION
C      ST(IPD1).......DISTILLATION ELEMENT PRODUCT STREAM 1 TEMP.
C                     STANDARD DEVIATION
C      ST(IPD2).......DISTILLATION ELEMENT PRODUCT STREAM 2 TEMP.
C                     STANDARD DEVIATION
C      ST(IPD3).......DISTILLATION ELEMENT PRODUCT STREAM 3 TEMP.
C                     STANDARD DEVIATION
C      ST(IPD4).......DISTILLATION ELEMENT PRODUCT STREAM 4 TEMP.
C                     STANDARD DEVIATION
C      ST(IPD5).......DISTILLATION ELEMENT PRODUCT STREAM 5 TEMP.
C                     STANDARD DEVIATION
C      ST(IPD6).......DISTILLATION ELEMENT PRODUCT STREAM 6 TEMP.
C                     STANDARD DEVIATION
C      SCP(IFD1)......DISTILLATION ELEMENT FEED STREAM SPEC. HEAT
C                     STANDARD DEVIATION
C      SCP(IPD1)......DISTILLATION ELEMENT PRODUCT STREAM 1 SPEC.HEAT
C                     STANDARD DEVIATION
C      SCP(IPD2)......DISTILLATION ELEMENT PRODUCT STREAM 2 SPEC.HEAT
C                     STANDARD DEVIATION
C      SCP(IPD3)......DISTILLATION ELEMENT PRODUCT STREAM 3 SPEC.HEAT
```

```
C                        STANDARD DEVIATION
C       SCP(IPD4)......DISTILLATION ELEMENT PRODUCT STREAM 4 SPEC.HEAT
C                        STANDARD DEVIATION
C       SCP(IPD5)......DISTILLATION ELEMENT PRODUCT STREAM 5 SPEC.HEAT
C                        STANDARD DEVIATION
C       SCP(IPD6)......DISTILLATION ELEMENT PRODUCT STREAM 6 SPEC.HEAT
C                        STANDARD DEVIATION
C
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      READ(NREAD,212)IFD(JXX,1),(IPD(JXX,M),M=1,6)
 212  FORMAT(7(6X,I4))
      IFD1=IFD(JXX,1)
      IPD1=IPD(JXX,1)
      IPD2=IPD(JXX,2)
      IPD3=IPD(JXX,3)
      IPD4=IPD(JXX,4)
      IPD5=IPD(JXX,5)
      IPD6=IPD(JXX,6)
      READ(NREAD,400)W(IFD1),W(IPD1),W(IPD2),W(IPD3),W(IPD4),W(IPD5),
     1W(IPD6)
 400  FORMAT(7F10.2)
      READ(NREAD,401)T(IFD1),T(IPD1),T(IPD2),T(IPD3),T(IPD4),T(IPD5),
     1T(IPD6)
 401  FORMAT(7F10.2)
      READ(NREAD,402)CP(IFD1),CP(IPD1),CP(IPD2),CP(IPD3),CP(IPD4),
     1CP(IPD5),CP(IPD6)
 402  FORMAT(7F10.5)
      READ(NREAD,403)SW(IFD1),SW(IPD1),SW(IPD2),SW(IPD3),SW(IPD4),
     1SW(IPD5),SW(IPD6)
 403  FORMAT(7F10.5)
      READ(NREAD,404)ST(IFD1),ST(IPD1),ST(IPD2),ST(IPD3),ST(IPD4),
     1ST(IPD5),ST(IPD6)
 404  FORMAT(7F10.5)
      READ(NREAD,405)SCP(IFD1),SCP(IPD1),SCP(IPD2),SCP(IPD3),SCP(IPD4),
     1SCP(IPD5),SCP(IPD6)
 405  FORMAT(7F10.5)
 213  IPD1=IPD(JXX,1)
      IPD2=IPD(JXX,2)
      IFD1=IFD(JXX,1)
      IF(IPD3.EQ.0) GO TO 410
      IF(IPD3.NE.0) GO TO 411
 410  W(IPD3)=0.0
      SW(IPD3)=0.0
      T(IPD3)=0.0
      ST(IPD3)=0.0
      CP(IPD3)=0.0
      SCP(IPD3)=0.0
 411  IPD3=IPD(JXX,3)
      IF(IPD4.EQ.0) GO TO 412
      IF(IPD4.NE.0) GO TO 413
 412  W(IPD4)=0.0
      SW(IPD4)=0.0
      T(IPD4)=0.0
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      ST(IPD4)=0.0
      CP(IPD4)=0.0
      SCP(IPD4)=0.0
 413  IPD4=IPD(JXX,4)
      IF(IPD5.EQ.0) GO TO 414
      IF(IPD5.NE.0) GO TO 415
 414  W(IPD5)=0.0
      SW(IPD5)=0.0
      T(IPD5)=0.0
      ST(IPD5)=0.0
      CP(IPD5)=0.0
      SCP(IPD5)=0.0
 415  IPD5=IPD(JXX,6)
      IF(IPD6.EQ.0) GO TO 416
      IF(IPD6.NE.0) GO TO 417
 416  W(IPD6)=0.0
      SW(IPD6)=0.0
      T(IPD6)=0.0
      ST(IPD6)=0.0
      CP(IPD6)=0.0
      SCP(IPD6)=0.0
 417  IPD6=IPD(JXX,6)
 215  IF(NETRN.EQ.1.AND.NXX.EQ.1) GO TO 250
      IF(ISC.GE.1.AND.NETRN.EQ.2) GO TO 250
      WRITE(NPRNT,200)JXX,NF(JXX),NP(JXX)
 200  FORMAT(////5X,'DISTILLATION UNIT'//5X,'ELEMENT NUMBER**',I3//5X,
     1  'NUMBER OF FEED STREAMS**',I2,' NUMBER OF PRODUCT STREAMS**',I2/
     2////47X,'FEED',32X,'PRODUCT')
      WRITE(NPRNT,210)IFD(JXX,1),(IPD(JXX,M),M=1,4)
 210  FORMAT(//5X,'STREAM NUMBER',29X,I3,10X,4(9X,I3))
      IF(NETRN.EQ.1.AND.NXX.EQ.2) KUNIT(JXX)=LUNIT(JXX)
      IUNIT=KUNIT(JXX)
      WRITE(NPRNT,220)WUNIT(IUNIT),TMUNIT(IUNIT),W(IFD1),W(IPD1),W(IPD2)
     1,W(IPD3),W(IPD4),TUNIT(IUNIT),T(IFD1),T(IPD1),T(IPD2),T(IPD3),T(IP
     2D4),EUNIT(IUNIT),WUNIT(IUNIT),TUNIT(IUNIT),CP(IFD1),CP(IPD1),CP(IP
     3D2),CP(IPD3),CP(IPD4)
 220  FORMAT(///5X,'FLOW RATE ',A2,'/',A2,24X,F10.2,8X,4(2X,F10.2)/5X,'T
     1EMPERATURE,DEG ',A1,22X,F10.2,8X,4(2X,F10.2)/5X,'HEAT CAPACITY,',A
     23,'/',A2,' ',A1,17X,F10.5,8X,4(2X,F10.5))
      WRITE(NPRNT,230)WUNIT(IUNIT),TMUNIT(IUNIT),SW(IFD1),SW(IPD1),SW(IP
     1D2),SW(IPD3),SW(IPD4),TUNIT(IUNIT),ST(IFD1),ST(IPD1),ST(IPD2),ST(I
     2PD3),ST(IPD4),EUNIT(IUNIT),WUNIT(IUNIT),TUNIT(IUNIT),SCP(IFD1),SCP
     3(IPD1),SCP(IPD2),SCP(IPD3),SCP(IPD4)
 230  FORMAT(5X,'FLOW RATE STD,',A2,'/',A2,20X,F10.2,8X,4(2X,F10.2)/5X,
     1'TEMPERATURE STD,DEG ',A1,18X,F10.2,8X,4(2X,F10.2)/5X,'HEAT CAPACI
     2TY STD ',A3,'/',A2,' ',A1,13X,F10.5,8X,4(2X,F10.5))
 250  RETURN
      END
      SUBROUTINE HEX00(JXX)
C
C     SUBROUTINE HEXOO READS AND PRINTS INPUT CONDITIONS AND RESULTS OF
C     CALCULATIONS FOR HEAT EXCHANGERS AND HEATERS AND COOLERS ELEMENTS.
C
      DIMENSION ARRGT(6),TBUNIT(2)
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```
      REAL KW(100)
      COMMON//ID(18)
      COMMON/KEYS/IERR(100),NELM(100),NXX,NETRN,NX,IPR,ISC,LX,JX,IBD,NFD
      COMMON/PHUNIT/WUNIT(2),TUNIT(2),TMUNIT(2),EUNIT(2),ALGTH(2),KUNIT(
     $100),LUNIT(100),PUNIT(2)
      COMMON/IOUNIT/NREAD,NPRNT,NPNCH,IIX,EPS
      COMMON/NUMA/NF(100),NP(100),IFD(100,20),IPD(100,20),IDN(100)
      COMMON/ADATA/W(200),T(200),CP(200),Q(100),UD(100),HI(100),HO(100),
     1RFI(100),RFO(100),DI(100),DO(100),TISO(100),FT(100),TP1(100),TP2(1
     200),WISO(100),HFG(100),A(100),AI(100),AO(100),KW,TDIFF(100),TIGN(1
     300),HREAC(100),CONV(100),NTEMP(100)
      COMMON/STD/SW(200),ST(200),SCP(200),SHI(100),SHO(100),SRFI(100),SR
     1FO(100),SUD(100)
      COMMON/VAMXN/WMAX(20),WMIN(20),TMAX(20),TMIN(20),WOPT(20,500),TOPT
     $(20,500)
      COMMON/ADAP/CPC(200),CPH(200),SCPC(200),SCPH(200),NFA(200),NSP(200
     1),EEF(500)
      DATA TBUNIT/' ',' '/
      DATA ARRGT/'PARA','LLEL','COUN','TER ','PAR-','CNTR'/
 300  FORMAT(////5X,'HEATER OR CONDSR'//5X,'ELEMENT NUMBER**',I3//5X
     1,'NUMBER OF FEED STREAMS**',I2,' NUMBER OF PRODUCT STREAMS**',I2//
     2///52X,'FEED',26X,'PRODUCT')
 370  FORMAT('1'/5X,'PROBLEM IDENTIFICATION***',18A4,2X,'*** INPUT LISTI
     1NG ***')
 375  FORMAT('1'/5X,'PROBLEM IDENTIFICATION***',18A4,1X,'*** OUTPUT LIST
     1ING ***')
      IF(NETRN.EQ.0)WRITE(NPRNT,370)ID
      IF(NETRN.EQ.1.AND.NXX.EQ.2)WRITE(NPRNT,375)ID
      WNF2=0.0
      TNF2=0.0
      CPNF2=0.0
      SWNF2=0.0
      STNF2=0.0
      SCPNF2=0.0
      WNP2=0.0
      TNP2=0.0
      CPNP2=0.0
      SWNP2=0.0
      STNP2=0.0
      SCPNP2=0.0
      IF(NETRN.NE.0) GO TO 297
C
C     READ INPUT
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C
C       IFD(JXX,1) ......FEED STREAM 1 NUMBER
C       IFD(JXX,2) ......FEED STREAM 2 NUMBER
C       IPD(JXX,1) ......PRODUCT STREAM 1 NUMBER
C       IPD(JXX,2) ......PRODUCT STREAM 2 NUMBER
C       Q(JXX) ..........HEAT DUTY
C       A(JXX) ..........OUTSIDE SURFACE AREA
C       UD(JXX) .........OVERALL HEAT TRANSFER COEFFICIENT
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C      HI(JXX) .........TUBE INSIDE HEAT TRANSFER COEFFICIENT
C      HO(JXX) .........SHELL SIDE HEAT TRANSFER COEFFICIENT
C      RFI(JXX) ........TUBE INSIDE FOULING RESISTANCE
C      RFO(JXX) ........SHELL SIDE FOULING RESISTANCE
C      AI(JXX) .........TUBE INSIDE EFFECTIVE AREA
C      AO(JXX) .........TUBE OUTSIDE EFFECTIVE AREA
C      TISO(JXX) .......ISOTHERMAL STREAM TEMPERATURE
C      WISO(JXX) .......ISOTHERMAL STREAM FLOW RATE
C      HFG(JXX) ........ISOTHERMAL STREAM LATENT HEAT OF
C                       CONDENSATION
C      TP1(JXX) ........PRODUCT STREAM 1 TEMPERATURE
C      TP2(JXX) ........PRODUCT STREAM 2 TEMPERATURE
C      CPC(JXX) ........FEED STREAM 1 SPECIFIC HEAT
C      CPH(JXX) ........FEED STREAM 2 SPECIFIC HEAT
C      DI(JXX) .........TUBE INSIDE DIAMETER
C      DO(JXX) .........TUBE OUTSIDE DIAMETER
C      KW(JXX) .........TUBE WALL THERMAL CONDUCTIVITY
C      NFA(JXX).........NUMBER OF TUBE PASSES
C      NSP(JXX).........NUMBER OF SHELL PASSES
C      SUD(JXX).........OVERALL HEAT TRANSFER COEFFICIENT
C                       STANDARD DEVIATION
C      SHI(JXX).........TUBE INSIDE HEAT TRANSFER COEFFICIENT
C                       STANDARD DEVIATION
C      SHO(JXX).........SHELL SIDE  HEAT TRANSFER COEFFICIENT
C                       STANDARD DEVIATION
C      SRFI(JXX)........TUBE INSIDE FOULING RESISTANCE
C                       STANDARD DEVIATION
C      SRFO(JXX)........SHELL SIDE  FOULING RESISTANCE
C                       STANDARD DEVIATION
C      SCPC(JXX)........FEED STREAM 1 SPECIFIC HEAT
C                       STANDARD DEVIATION
C      SCPH(JXX)........FEED STREAM 2 SPECIFIC HEAT
C                       STANDARD DEVIATION
C
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      READ(NREAD,290)IFD(JXX,1),IFD(JXX,2),IPD(JXX,1),IPD(JXX,2),Q(JXX),
     1A(JXX),UD(JXX),HI(JXX),HO(JXX),RFI(JXX),RFO(JXX),AI(JXX),AO(JXX),
     2TISO(JXX),WISO(JXX),HFG(JXX),TP1(JXX),TP2(JXX),CPC(JXX),CPH(JXX),
     3DI(JXX),DO(JXX),KW(JXX),NFA(JXX),NSP(JXX)
 290  FORMAT(4(6X,I4)/E10.3,4F10.2,2F10.5/2F10.5,F10.2,F10.2,E10.3,F10.2
     1,F10.2/2F10.5,2F10.5,F10.3,2(6X,I4))
      READ(NREAD,295)SUD(JXX),SHI(JXX),SHO(JXX),SRFI(JXX),SRFO(JXX),SCPC
     1(JXX),SCPH(JXX)
 295  FORMAT(3F10.2,4F10.5)
 297  NF1=IFD(JXX,1)
      NF2=IFD(JXX,2)
      NP1=IPD(JXX,1)
      NP2=IPD(JXX,2)
      IF(TP1(JXX).NE.0.0)T(NP1)=TP1(JXX)
      IF(CPC(JXX).NE.0.0)CP(NF1)=CPC(JXX)
      IF(SCPC(JXX).NE.0.0)SCP(NF1)=SCPC(JXX)
      IF(NETRN.EQ.1.AND.NXX.EQ.2) KUNIT(JXX)=LUNIT(JXX)
      W(NP1)=W(NF1)
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      CP(NP1)=CP(NF1)
      SCP(NP1)=SCP(NF1)
      IF(IDN(JXX).EQ.7) GO TO 550
      IF(TP2(JXX).NE.0.0)T(NP2)=TP2(JXX)
      IF(CPH(JXX).NE.0.0)CP(NF2)=CPH(JXX)
      IF(SCPH(JXX).NE.0.0)SCP(NF2)=SCPH(JXX)
      W(NP2)=W(NF2)
      CP(NP2)=CP(NF2)
      SCP(NP2)=SCP(NF2)
      WNF2=W(NF2)
      TNF2=T(NF2)
      CPNF2=CP(NF2)
      SWNF2=SW(NF2)
      STNF2=ST(NF2)
      SCPNF2=SCP(NF2)
      WNP2=W(NP2)
      TNP2=T(NP2)
      CPNP2=CP(NP2)
      SWNP2=SW(NP2)
      STNP2=ST(NP2)
      SCPNP2=SCP(NP2)
      IF(IDN(JXX).EQ.6) GO TO 450
C
C     PRINT OUTPUT
C
      WRITE(NPRNT,305)JXX,NF(JXX),NP(JXX)
  305 FORMAT(////5X,'HEAT EXCHANGER '//5X,'ELEMENT NUMBER**',I3//5X
     1,'NUMBER OF FEED STREAMS**',I2,' NUMBER OF PRODUCT STREAMS**',I2//
     2///52X,'FEED',26X,'PRODUCT')
  450 IF(IDN(JXX).EQ.6) WRITE(NPRNT,300)JXX,NF(JXX),NP(JXX)
      WRITE(NPRNT,310)IFD(JXX,1),IFD(JXX,2),IPD(JXX,1),IPD(JXX,2)
  310 FORMAT(//5X,'STREAM NUMBER',29X,I3,9X,I3,17X,I3,8X,I3)
      IUNIT=KUNIT(JXX)
      WRITE(NPRNT,320)WUNIT(IUNIT),TMUNIT(IUNIT),W(NF1),WNF2,W(NP1),WNP2
     1,TUNIT(IUNIT),T(NF1),TNF2,T(NP1),TNP2,EUNIT(IUNIT),WUNIT(IUNIT),TU
     2NIT(IUNIT),CP(NF1),CPNF2,CP(NP1),CPNP2
  320 FORMAT(///5X,'FLOW RATE,',A2,'/',A2,22X,2(2X,F10.2),8X,2(2X,F10.2)
     1/5X,'TEMPERATURE,DEG ',A1,20X,2(2X,F10.2),8X,2(2X,F10.2)/5X,'HEAT
     2CAPACITY,',A3,'/',A2,' ',A1,15X,2(2X,F10.5),8X,2(2X,F10.5))
      WRITE(NPRNT,330)WUNIT(IUNIT),TMUNIT(IUNIT),SW(NF1),SWNF2,SW(NP1),S
     1WNP2,TUNIT(IUNIT),ST(NF1),STNF2,ST(NP1),STNP2,EUNIT(IUNIT),WUNIT(I
     2UNIT),TUNIT(IUNIT),SCP(NF1),SCPNF2,SCP(NP1),SCPNP2
  330 FORMAT(5X,'FLOW RATE STD,',A2,'/',A2,18X,2(2X,F10.2),8X,2(2X,F10.2
     1)/5X,'TEMPERATURE STD,DEG ',A1,16X,2(2X,F10.2),8X,2(2X,F10.2)/5X,
     2'HEAT CAPACITY STD,',A3,'/',A2,' ',A1,11X,2(2X,F10.5),8X,2(2X,F10.
     35))
      IF(IUNIT.NE.2) GO TO 335
      IF(NETRN.EQ.0) GO TO 333
      Q(JXX)=Q(JXX)/3.6
      UD(JXX)=UD(JXX)/3.6
      HI(JXX)=HI(JXX)/3.6
      HO(JXX)=HO(JXX)/3.6
      SUD(JXX)=SUD(JXX)/3.6
      SHI(JXX)=SHI(JXX)/3.6
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      SHO(JXX)=SHO(JXX)/3.6
      RFI(JXX)=RFI(JXX)*3.6
      SRFI(JXX)=SRFI(JXX)*3.6
      RFO(JXX)=RFO(JXX)*3.6
      SRFO(JXX)=SRFO(JXX)*3.6
      KW(JXX)=KW(JXX)/3.6
  333 WRITE(NPRNT,340)PUNIT(IUNIT),ALGTH(IUNIT),TBUNIT(IUNIT),TUNIT(IUNI
     1T),HI(JXX),SHI(JXX),PUNIT(IUNIT),ALGTH(IUNIT),TBUNIT(IUNIT),TUNIT(
     2IUNIT),HO(JXX),SHO(JXX),ALGTH(IUNIT),TBUNIT(IUNIT),TUNIT(IUNIT),PU
     3NIT(IUNIT),RFI(JXX),SRFI(JXX),ALGTH(IUNIT),TBUNIT(IUNIT),TUNIT(IUN
     4IT),PUNIT(IUNIT),RFO(JXX),SRFO(JXX),PUNIT(IUNIT),ALGTH(IUNIT),TBUN
     5IT(IUNIT),TUNIT(IUNIT),UD(JXX),SUD(JXX)
      WRITE(NPRNT,342)PUNIT(IUNIT),ALGTH(IUNIT),TBUNIT(IUNIT),TUNIT(IUNI
     1T),KW(JXX)
      GO TO 345
  335 WRITE(NPRNT,340)EUNIT(IUNIT),ALGTH(IUNIT),TMUNIT(IUNIT),TUNIT(IUNI
     1T),HI(JXX),SHI(JXX),EUNIT(IUNIT),ALGTH(IUNIT),TMUNIT(IUNIT),TUNIT(
     2IUNIT),HO(JXX),SHO(JXX),ALGTH(IUNIT),TMUNIT(IUNIT),TUNIT(IUNIT),EU
     3NIT(IUNIT),RFI(JXX),SRFI(JXX),ALGTH(IUNIT),TMUNIT(IUNIT),TUNIT(IUN
     4IT),EUNIT(IUNIT),RFO(JXX),SRFO(JXX),EUNIT(IUNIT),ALGTH(IUNIT),TMUN
     5IT(IUNIT),TUNIT(IUNIT),UD(JXX),SUD(JXX)
  340 FORMAT(/////5X,'HEAT EXCHANGER DATA'//44X,'NOMINAL VALUE',13X,'STD
     1'//5X,'INSIDE COEFF.,',A3,'/','SQR ',A2,' ',A2,' DEG ',A1,8X,F10.2
     2,12X,F10.2/5X,'OUTSIDE COEFF.,',A3,'/','SQR ',A2,' ',A2,' DEG ',A1
     3,7X,F10.2,12X,F10.2/5X,'INSIDE FOULING FACTR,SQR ',A2,' ',A2,' DEG
     4',A1,'/',A3,2X,F10.5,12X,F10.5/5X,'OUTSIDE FOULING FACTR,SQR ',A2,
     5' ',A2,' DEG ',A1,'/',A3,F10.5,12X,F10.5/5X,'OVERALL COEFF.,',A
     63,'/','SQR ',A2,' ',A2,' DEG ',A1,7X,F10.5,12X,F10.5)
      WRITE(NPRNT,342)EUNIT(IUNIT),ALGTH(IUNIT),TMUNIT(IUNIT),TUNIT(IUNI
     1T),KW(JXX)
  342 FORMAT(5X,'TUBE WALL THERMAL CONDTY,',A3,'/',A2,' ',A2,' DEG ',A1,
     111X,F10.5)
  345 WRITE(NPRNT,360)ALGTH(IUNIT),ALGTH(IUNIT),AI(JXX),ALGTH(IUNIT),ALG
     1TH(IUNIT),AO(JXX)
  360 FORMAT(5X,'TUBE INSIDE WALL AREA SQR',A2,'/',A2,11X,F10.5/5X,'TUBE
     1 OUTSIDE WALL AREA SQR',A2,'/',A2,10X,F10.5)
      NTF=NFA(JXX)
      GO TO (351,352,353),NTF
  351 N=1
      M=2
      GO TO 354
  352 N=3
      M=4
      GO TO 354
  353 N=5
      M=6
  354 WRITE(NPRNT,355)(ARRGT(I),I=N,M),NSP(JXX)
  355 FORMAT(///5X,'FLOW ARRANGEMENT',10X,2A4//5X,'NUMBER OF SHELL-PASSE
     1S',I8)
      IF(IUNIT.NE.2) GO TO 357
      WRITE(NPRNT,366)WISO(JXX),WUNIT(IUNIT),TMUNIT(IUNIT),HFG(JXX),EUNI
     1T(IUNIT),WUNIT(IUNIT),Q(JXX),PUNIT(IUNIT),A(JXX),ALGTH(IUNIT)
  366 FORMAT(/5X,'ISOTHERMAL STREAM FLOW RATE',F10.2,' ',A2,'/',A2//5X
     1,'ISOTHERMAL STREAM ENTHALPY',E11.4,' ',A3,'/',A2//5X,'HEAT TRANSF
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     2ERED',E11.4,A3           //5X,'AREA REQUIRED',F10.2,' SQR ',A2)
      IF(NETRN.EQ.0) GO TO 380
      Q(JXX)=Q(JXX)*3.6
      UD(JXX)=UD(JXX)*3.6
      HI(JXX)=HI(JXX)*3.6
      HO(JXX)=HO(JXX)*3.6
      SUD(JXX)=SUD(JXX)*3.6
      SHI(JXX)=SHI(JXX)*3.6
      SHO(JXX)=SHO(JXX)*3.6
      RFI(JXX)=RFI(JXX)/3.6
      SRFI(JXX)=SRFI(JXX)/3.6
      RFO(JXX)=RFO(JXX)/3.6
      SRFO(JXX)=SRFO(JXX)/3.6
      KW(JXX)=KW(JXX)*3.6
      GO TO 380
 357  WRITE(NPRNT,365)WISO(JXX),WUNIT(IUNIT),TMUNIT(IUNIT),HFG(JXX),EUNI
     1T(IUNIT),WUNIT(IUNIT),Q(JXX),EUNIT(IUNIT),TMUNIT(IUNIT),A(JXX),ALG
     2TH(IUNIT)
 365  FORMAT(/5X,'ISOTHERMAL STREAM FLOW RATE',F10.2,' ',A2,'/',A2//5X
     1,'ISOTHERMAL STREAM ENTHALPY',E11.4,' ',A3,'/',A2//5X,'HEAT TRANSF
     2ERED',E11.4,' ',A3,'/',A2//5X,'AREA REQUIRED',F10.2,' SQR ',A2)
 380  RETURN
      END
      SUBROUTINE HEX(JXX)
C
C     SUBROUTINE HEX CALCULATES THE AREA OR TEMPERATURES FOR HEAT
C     EXCHANGER ELEMENT.
C
      DIMENSION XLMTD(100)
      REAL KW(100)
      COMMON/KEYS/IERR(100),NELM(100),NXX,NETRN,NX,IPR,ISC,LX,JX,IBD,NFD
      COMMON/ARAV/AREA(100,500),ANL(100),IREA(100),NUD(100),NQ(100),INFN
     1A(100),IZERA(100)
      COMMON/IOUNIT/NREAD,NPRNT,NPNCH,IIX,EPS
      COMMON/NUMA/NF(100),NP(100),IFD(100,20),IPD(100,20),IDN(100)
      COMMON/ADATA/W(200),T(200),CP(200),Q(100),UD(100),HI(100),HO(100),
     1RFI(100),RFO(100),DI(100),DO(100),TISO(100),FT(100),TP1(100),TP2(1
     200),WISO(100),HFG(100),A(100),AI(100),AO(100),KW,TDIFF(100),TIGN(1
     300),HREAC(100),CONV(100)
      COMMON/STD/SW(200),ST(200),SCP(200),SHI(100),SHO(100),SRFI(100),SR
     1FO(100),SUD(100)
      COMMON/ADAP/CPC(200),CPH(200),SCPC(200),SCPH(200),NFA(200),NSP(200
     1),EEF(500)
      NF1=IFD(JXX,1)
      NF2=IFD(JXX,2)
      NP1=IPD(JXX,1)
      NP2=IPD(JXX,2)
      IF(CPC(JXX).NE.0.0)CP(NF1)=CPC(JXX)
      IF(CPH(JXX).NE.0.0)CP(NF2)=CPH(JXX)
      IF(ISC.EQ.1.AND.NETRN.EQ.2) CALL RANDV(JXX)
      T(NP1)=TP1(JXX)
      T(NP2)=TP2(JXX)
      IF(UD(JXX).EQ.0.0)NUD(JXX)=1
      IF(Q(JXX).EQ.0.0)NQ(JXX)=1
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      IF(NUD(JXX).NE.1) GO TO 30
      IF(HI(JXX).EQ.0.0.OR.HO(JXX).EQ.0.0) GO TO 625
      RW=0.0
      IF(KW(JXX).NE.0.0)RW=ALOG(DO(JXX)/DI(JXX))/(2.0*3.1416*KW(JXX))
      UD(JXX)=1.0/(1.0/HO(JXX)+RFI(JXX)*(AO(JXX)/AI(JXX))+(1.0/HI(JXX))*
     $AO(JXX)/AI(JXX)+RFO(JXX)+RW*AO(JXX))
 30   IF(A(JXX).EQ.0.0) IREA(JXX)=1
      IF(IREA(JXX).NE.1) GO TO 100
C
C     CALCULATE AREA
C
      IF(T(NP1).EQ.0.0.AND.T(NP2).EQ.0.0) GO TO 76
      IF(T(NP1).NE.0.0.AND.T(NP2).NE.0.0) GO TO 40
      IF(T(NP1).EQ.0.0.AND.T(NP2).NE.0.0) GO TO 35
      IF(T(NP2).EQ.0.0.AND.T(NP1).NE.0.0) GO TO 38
 35   IF(NQ(JXX).NE.0)Q(JXX)=W(NF2)*CP(NF2)*(T(NF2)-T(NP2))
      T(NP1)=T(NF1)+Q(JXX)/(W(NF1)*CP(NF1))
      GO TO 40
 38   IF(NQ(JXX).NE.0)Q(JXX)=W(NF1)*CP(NF1)*(T(NP1)-T(NF1))
      T(NP2)=T(NF2)-Q(JXX)/(W(NF2)*CP(NF2))
      GO TO 40
 40   IF(NQ(JXX).NE.0)Q(JXX)=W(NF1)*CP(NF1)*(T(NP1)-T(NF1))
      IF(T(NF1).GE.T(NP1).AND.TP1(JXX).NE.0.0) GO TO 25
      IF(T(NF2).LE.T(NP2).AND.TP2(JXX).NE.0.0) GO TO 25
      IF(T(NP2).LE.T(NF1)) GO TO 27
      IF(T(NP1).GE.T(NF2)) GO TO 27
      IF (NFA(JXX).EQ.1.AND.T(NP2).LE.T(NP1)) GO TO 27
      GO TO 42
 25   IZERA(JXX)=IZERA(JXX)+1
      GO TO  950
 27   INFNA(JXX)=INFNA(JXX)+1
      GO TO 950
 42   NTB=NFA(JXX)
      GO TO (61,62,63),NTB
 61   FT(JXX)=1.0
      XLMTD(JXX)=((T(NF2)-T(NF1))-(T(NP2)-T(NP1)))/(ALOG((T(NF2)-T(NF1))
     1/(T(NP2)-T(NP1))))
      GO TO 50
 62   FT(JXX)=1.0
      GO TO 45
 63   P=(T(NF2)-T(NP2))/(T(NP1)-T(NF1))
      S=(T(NP1)-T(NF1))/(T(NF2)-T(NF1))
      DEL1=SQRT(P**2+1.0)
      DEL2=(1.0-S)/(1.0-P*S)
      DEL3=2.0-S*(P+1.0+DEL1)
      DEL4=2.0-S*(P+1.0-DEL1)
      DEL5=(1.0-S)*(1.0-P*S)
      DEL6=DEL4/DEL3
      IF(DEL3.LE.0.0) GO TO 29
      IF(NSP(JXX).GE.2) GO TO 47
      FT(JXX)=DEL1*ALOG(DEL2)/((P-1.0)*ALOG(DEL4/DEL3))
      GO TO 45
 47   DEL7=(2.0/S-1.0-P+(2.0/S)*SQRT(DEL5)+DEL1)/(2.0/S-1.0-P+(2.0/S)*
     1SQRT(DEL5)-DEL1)
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      IF(DEL7.LE.0.0) GO TO 29
      FT(JXX)=(DEL1/(2.0*(P-1.0)))*ALOG(DEL2)/ALOG(DEL7)
 45   DELTA1=T(NF2)-T(NP1)
      DELTA2=T(NP2)-T(NF1)
      XLMTD(JXX)=(DELTA1-DELTA2)/ALOG(DELTA1/DELTA2)
 50   A(JXX)=Q(JXX)/(UD(JXX)*FT(JXX)*XLMTD(JXX))
      IF(NETRN.EQ.1) ANL(JXX)=A(JXX)
      IF(ISC.GE.1.AND.NETRN.EQ.2)AREA(JXX,IPR)=A(JXX)
      GO TO 950
 29   INFNA(JXX)=INFNA(JXX)+1
      GO TO 950
 100  IF(T(NP1).NE.0.0.AND.T(NP2).NE.0.0) GO TO 950
      IF(T(NP1).EQ.0.0.AND.T(NP2).NE.0.0) GO TO 103
      IF(T(NP2).EQ.0.0.AND.T(NP1).NE.0.0) GO TO 104
      GO TO 135
 103  IF(NQ(JXX).NE.0)Q(JXX)=W(NF2)*CP(NF2)*(T(NF2)-T(NP2))
      T(NP1)=T(NF1)+Q(JXX)/(W(NF1)*CP(NF1))
      GO TO 150
 104  IF (NQ(JXX).NE.0)Q(JXX)=W(NF1)*CP(NF1)*(T(NP1)-T(NF1))
      T(NP2)=T(NF2)-Q(JXX)/(W(NF2)*CP(NF2))
      GO TO 150
 150  IF(Q(JXX).EQ.0.0)Q(JXX)=W(NF1)*CP(NF1)*(T(NP1)-T(NF1))
C
C  CALCULATE TEMPERATURES
C
 135  C1=W(NF1)*CP(NF1)
      C2=W(NF2)*CP(NF2)
      IF(C1.EQ.0.0.OR.C2.EQ.0.0) GO TO 140
      IF(C1-C2)870,871,872
 870  CMIN=C1
      CMAX=C2
      GO TO 875
 871  CMIN=C1
      CMAX=CMIN
      GO TO 875
 872  CMIN=C2
      CMAX=C1
 875  ANTU=A(JXX)*UD(JXX)/CMIN
      NTB=NFA(JXX)
      GO TO (876,877,878),NTB
 876  EFF=(1.0-EXP(-ANTU*(1.0+CMIN/CMAX)))/(1.0+CMIN/CMAX)
      IF(NSP(JXX).GT.1) GO TO 880
      GO TO 881
 877  EFF=(1.0-EXP(-ANTU*(1.0-CMIN/CMAX)))/(1.0-(CMIN/CMAX)*EXP(-ANTU*(1
     $.0-CMIN/CMAX)))
      IF(NSP(JXX).GT.1) GO TO 880
      GO TO 881
 878  GAMMA=ANTU*SQRT(1.0+(CMIN/CMAX)**2)
      EFF=2.0/(1.0+CMIN/CMAX+SQRT(1.0+(CMIN/CMAX)**2)*(1.0+EXP(-GAMMA))
     $/(1.0-EXP(-GAMMA)))
      IF(NSP(JXX).LE.1) GO TO 881
 880  NSH=NSP(JXX)
      EFF=(((1.0-EFF*CMIN/CMAX)/(1.0-EFF))**NSH-1.0)/(((1.0-EFF*CMIN/CMA
     $X)/(1.0-EFF))**NSH-CMIN/CMAX)
```

```
 881  T(NP2)=T(NF2)-(EFF*CMIN*(T(NF2)-T(NF1)))/C2
      T(NP1)=T(NF1)+(EFF*CMIN*(T(NF2)-T(NF1)))/C1
      Q(JXX)=W(NF2)*CP(NF2)*(T(NF2)-T(NP2))
      GO TO 950
 865  IF(T(NP2).NE.0.0) GO TO 950
      Q(JXX)=W(NF1)*CP(NF1)*ABS(T(NP1)-T(NF1))
      T(NP2)=T(NF2)-Q(JXX)/(W(NF2)*CP(NF2))
      GO TO 950
 866  Q(JXX)=W(NF2)*CP(NF2)*ABS(T(NP2)-T(NF2))
      T(NP1)=T(NF1)+Q(JXX)/(W(NF1)*CP(NF1))
 950  W(NP2)=W(NF2)
      W(NP1)=W(NF1)
      CP(NP2)=CP(NF2)
      CP(NP1)=CP(NF1)
      IERR(JXX)=0
      GO TO 910
 900  IERR(JXX)=1
 76   WRITE(NPRNT,80)
 80   FORMAT('1','BOTH OF THE OUTLET TEMPERATURES ARE NOT SPECIFIED')
      GO TO 910
 140  WRITE(NPRNT,141)
 141  FORMAT('1','THE FLOW RATE OR THE HEAT CAPACITY IS ZERO')
      IERR(JXX)=1
      GO TO 910
 625  WRITE(NPRNT,626)
 626  FORMAT('1'/////5X,'HEAT EXCHANGER NUMBER**',I3//5X,'HEAT TRANSFER
     1COEFF. IS ZERO')
      IERR(JXX)=1
 910  RETURN
      END
      SUBROUTINE HRCR(JXX)
C
C     HEATER OR CONDENSER
C
      DIMENSION XLMTD(100)
      REAL KW(100)
      COMMON/KEYS/IERR(100),NELM(100),NXX,NETRN,NX,IPR,ISC,LX,JX,IBD,NFD
      COMMON/IOUNIT/NREAD,NPRNT,NPNCH,IIX,EPS
      COMMON/ARAV/AREA(100,500),ANL(100),IREA(100),NUD(100),NQ(100),INFN
     1A(100),IZERA(100)
      COMMON/NUMA/NF(100),NP(100),IFD(100,20),IPD(100,20),IDN(100)
      COMMON/ADATA/W(200),T(200),CP(200),Q(100),UD(100),HI(100),HO(100),
     1RFI(100),RFO(100),DI(100),DO(100),TISO(100),FT(100),TP1(100),TP2(1
     200),WISO(100),HFG(100),A(100),AI(100),AO(100),KW,TDIFF(100),TIGN(1
     300),HREAC(100),CONV(100),NTEMP(100)
      COMMON/STD/SW(200),ST(200),SCP(200),SHI(100),SHO(100),SRFI(100),SR
     1FO(100),SUD(100)
      COMMON/ADAP/CPC(200),CPH(200),SCPC(200),SCPH(200),NFA(200),NSP(200
     1),EEF(500)
      IF=IFD(JXX,1)
      IP=IPD(JXX,1)
      IF2=IFD(JXX,2)
      IP2=IPD(JXX,2)
      T(IF2)=TISO(JXX)
```

```
      T(IP2)=TISO(JXX)
      W(IF2)=WISO(JXX)
      W(IP2)=WISO(JXX)
      IF(CPC(JXX).NE.0.0)CP(IF)=CPC(JXX)
      IF(ISC.EQ.1.AND.NETRN.EQ.2) CALL RANDV(JXX)
      IF(Q(JXX).EQ.0.0) NQ(JXX)=1
      T(IP)=TP1(JXX)
  999 IF(UD(JXX).EQ.0.0) NUD(JXX)=1
      IF(NUD(JXX).NE.1) GO TO 660
      IF(HI(JXX).EQ.0.0.OR.HO(JXX).EQ.0.0) GO TO 625
      RW=0.0
      IF(KW(JXX).NE.0.0)RW=ALOG(DO(JXX)/DI(JXX))/(2.0*3.1416*KW(JXX))
      UD(JXX)=1.0/(1.0/HO(JXX)+RFI(JXX)*(AO(JXX)/AI(JXX))+(1.0/HI(JXX))*
     $AO(JXX)/AI(JXX)+RFO(JXX)+RW*AO(JXX))
  660 IF(A(JXX).EQ.0.0) IREA(JXX)=1
      IF(TISO(JXX).NE.0.0) GO TO 601
      IF(IREA(JXX).NE.1.AND.T(IP).NE.0.0) GO TO 600
C
C     CALCULATE AREA
C
      IF(TISO(JXX).EQ.0.0) GO TO 617
      IF(NQ(JXX).NE.1) GO TO 560
      IF(T(IP).EQ.0.0) GO TO 616
      IF(T(IF).GE.T(IP)) GO TO 550
      IF(T(IP).GE.TISO(JXX)) GO TO 570
      Q(JXX)=W(IF)*CP(IF)*(T(IP)-T(IF))
      IF(Q(JXX).EQ.0.0) GO TO 615
      GO TO 666
  560 IF(TP1(JXX).NE.0.0.AND.W(IF).EQ.0.0)W(IF)=Q(JXX)/(CP(IF)*(T(IP)-T(
     1IF)))
      IF(TP1(JXX).EQ.0.0.AND.W(IF).NE.0.0)T(IP)=T(IF)+Q(JXX)/(W(IF)*CP(I
     1F))
      IF(T(IP).GE.TISO(JXX)) GO TO 570
  666 IF(HFG(JXX).EQ.0.0.AND.WISO(JXX).NE.0.0)HFG(JXX)=ABS(Q(JXX)/WISO(J
     1XX))
      IF(WISO(JXX).EQ.0.0.AND.HFG(JXX).NE.0.0)WISO(JXX)=ABS(Q(JXX)/HFG(J
     1XX))
      DELTA1=TISO(JXX)-T(IP)
      DELTA2=TISO(JXX)-T(IF)
      XLMTD(JXX)=(DELTA1-DELTA2)/ALOG(DELTA1/DELTA2)
      A(JXX)=ABS(Q(JXX)/(UD(JXX)*XLMTD(JXX)))
      IF(NETRN.EQ.1) ANL(JXX)=A(JXX)
      IF(ISC.GE.1.AND.NETRN.EQ.2)AREA(JXX,IPR)=A(JXX)
      GO TO 650
  550 IZERA(JXX)=IZERA(JXX)+1
      GO TO 650
  570 INFNA(JXX)=INFNA(JXX)+1
      GO TO 650
C
C     CALCULATE TEMPERATURES
C
  600  IF(NQ(JXX).EQ.1)Q(JXX)=W(IF)*CP(IF)*(T(IP)-T(IF))
      X=(T(IP)-T(IF))*UD(JXX)*A(JXX)/Q(JXX)
      T(IP2)=(T(IF)-T(IP)*EXP(X))/(1.0-EXP(X))
```

```
      IF(T(IP2).NE.0.0) GO TO 650
      IF(TISO(JXX).EQ.0.0.OR.W(IF).EQ.0.0) GO TO 617
 601  X=UD(JXX)*A(JXX)/(W(IF)*CP(IF))
      T(IP)=TISO(JXX)-(TISO(JXX)-T(IF))*EXP(-X)
      IF(Q(JXX).EQ.0.0)Q(JXX)=W(IF)*CP(IF)*(T(IP)-T(IF))
      GO TO 650
 615  WRITE(NPRNT,620)JXX
 620  FORMAT('1'/////5X,'HEAT EXCHANGER NUMBER**',I3//5X,'EXCHANGER DUTY
     1 WAS NOT SPECIFIED'/5X,'******************************************
     2****************************')
      IERR(JXX)=1
      GO TO 700
 616  WRITE(NPRNT,630)JXX
 630  FORMAT('1'/////5X,'HEAT EXCHANGER NUMBER**',I3/////5X,'ONE OF THE
     1TWO STREAMS TEMPERATURES IS ZERO AND CAN NOT BE CALCULATED')
      IERR(JXX)=1
      GO TO 700
 617  WRITE(NPRNT,640)JXX
 640  FORMAT('1'/////5X,'EITHER THE ISOTHERMAL STREAM TEMPERATURE OR THE
     1FLOW RATE OF THE COLD STREAM WAS NOT SPECIFIED'/5X,'**************
     2******************************************************************
     3************')
      IERR(JXX)=1
      GO TO 700
 625  WRITE(NPRNT,626)JXX
 626  FORMAT('1'/////5X,'HEAT EXCHANGER NUMBER**',I3//5X,'HEAT TRANSFER
     1COEFF. IS ZERO')
      IERR(JXX)=1
 650  W(IP)=W(IF)
      CP(IP)=CP(IF)
      IERR(JXX)=0
 700  RETURN
      END
      SUBROUTINE RANDV(JXX)
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C
C     THIS SUBROUTINE GENERATES RANDOM NUMBERS FOR THE FOLLOWING
C     INPUT VARIABLES:
C                   1) INPUT STREAM FLOW RATES
C                   2) INPUT STREAM TEMPERATURES
C                   3) TUBE INSIDE HEAT TRANSFER COEFFICIENT
C                   4) SHELL SIDE  HEAT TRANSFER COEFFICIENT
C                   5) TUBE INSIDE FOULING RESISTANCE
C                   6) SHELL SIDE  FOULING RESISTANCE
C                   7) OVERALL HEAT TRANSFER COEFFICIENT
C                   8) FEED STREAM 1 SPECIFIC HEAT
C                   9) FEED STREAM 2 SPECIFIC HEAT
C
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
      REAL KW(100)
```

```
      COMMON/KEYS/IERR(100),NELM(100),NXX,NETRN,NX,IPR,ISC,LX,JX,IBD,NFD
      COMMON/IOUNIT/NREAD,NPRNT,NPNCH,IIX,EPS
      COMMON/NUMA/NF(100),NP(100),IFD(100,20),IPD(100,20),IDN(100)
      COMMON/ADATA/W(200),T(200),CP(200),Q(100),UD(100),HI(100),HO(100),
     1RFI(100),RFO(100),DI(100),DO(100),TISO(100),FT(100),TP1(100),TP2(1
     200),WISO(100),HFG(100),A(100),AI(100),AO(100),KW,TDIFF(100),TIGN(1
     300),HREAC(100),CONV(100)
      COMMON/STD/SW(200),ST(200),SCP(200),SHI(100),SHO(100),SRFI(100),SR
     1FO(100),SUD(100)
      COMMON/MEAN/HIM(100),HOM(100),RFIM(100),RFOM(100),WM(200),TM(200)
     1,CPM(200),UMD(100)
      COMMON/ADAP/CPC(200),CPH(200),SCPC(200),SCPH(200),NFA(200),NSP(200
     1),EEF(500)
      COMMON//IXX
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C
C      JX ...........SEED INTEGER
C      SW1...........INPUT STREAM FLOW RATE STANDARD DEVIATION
C      WM1...........INPUT STREAM FLOW RATE NOMINAL VALUE
C      V1............GENERATED RANDOM NUMBER FOR INPUT STREAM
C                    FLOW RATE
C
C      ST1 ..........INPUT STREAM TEMPERATURE STANDARD DEVIATION
C      TM1 ..........INPUT STREAM TEMPERATURE NOMINAL VALUE
C      V2............GENERATED RANDOM NUMBER FOR INPUT STREAM
C                    TEMPERATURE
C
C      SIH ..........TUBE INSIDE HEAT TRANSFER COEFFICIENT
C                    STANDARD DEVIATION
C      HMI ..........TUBE INSIDE HEAT TRANSFER COEFFICIENT
C                    NOMINAL VALUE
C      V1............GENERATED RANDOM NUMBER FOR TUBE INSIDE
C                    HEAT TRANSFER COEFFICIENT
C
C      SOH ..........SHELL SIDE  HEAT TRANSFER COEFFICIENT
C                    STANDARD DEVIATION
C      HMO ..........SHELL SIDE  HEAT TRANSFER COEFFICIENT
C                    NOMINAL VALUE
C      V2............GENERATED RANDOM NUMBER FOR SHELL SIDE
C                    HEAT TRANSFER COEFFICIENT
C
C      SIRF..........TUBE INSIDE FOULING RESISTANCE
C                    STANDARD DEVIATION
C      RFMI..........TUBE INSIDE FOULING RESISTANCE
C                    NOMINAL VALUE
C      V3............GENERATED RANDOM NUMBER FOR TUBE INSIDE
C                    FOULING RESISTANCE
C
C      SORF..........SHELL SIDE  FOULING RESISTANCE
C                    STANDARD DEVIATION
C      RFMO..........SHELL SIDE  FOULING RESISTANCE
C                    NOMINAL VALUE
C      V4............GENERATED RANDOM NUMBER FOR SHELL SIDE
```

```
C                    FOULING RESISTANCE
C
C      SCP1..........FEED STREAM 1 SPECIFIC HEAT
C                    STANDARD DEVIATION
C      CPM1..........FEED STREAM 1 SPECIFIC HEAT
C                    NOMINAL VALUE
C      V6............GENERATED RANDOM NUMBER FOR FEED STREAM 1
C                    SPECIFIC HEAT
C
C      SCP2..........FEED STREAM 2 SPECIFIC HEAT
C                    STANDARD DEVIATION
C      CPM2..........FEED STREAM 2 SPECIFIC HEAT
C                    NOMINAL VALUE
C      V7............GENERATED RANDOM NUMBER FOR FEED STREAM 2
C                    SPECIFIC HEAT
C
C      UDS ..........OVERALL HEAT TRANSFER COEFFICIENT
C                    STANDARD DEVIATION
C      UDM ..........OVERALL HEAT TRANSFER COEFFICIENT
C                    NOMINAL VALUE
C      V9............GENERATED RANDOM NUMBER FOR OVERALL
C                    HEAT TRANSFER COEFFICIENT
C
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      IF(NF(JXX).EQ.2.AND.NP(JXX).EQ.2)GO TO 50
      IF(IPR.GT.1) GO TO 806
      MINPT=NP(JXX)
      DO 5 N=1,MINPT
      IPT=IPD(JXX,N)
      WM(IPT)=W(IPT)
      TM(IPT)=T(IPT)
      CPM(IPT)=CP(IPT)
    5 CONTINUE
  806 MINPT=NP(JXX)
      DO 10 N=1,MINPT
      IPT=IPD(JXX,N)
      IF(SW(IPT).EQ.0.0) GO TO 20
      SW1=SW(IPT)
      WM1=WM(IPT)
      CALL GAUSS(JX,SW1,WM1,V1)
      W(IPT)=V1
      IF(IXX.NE.0) JX=IXX
   20 IF(ST(IPT).EQ.0.0) GO TO 10
      ST1=ST(IPT)
      TM1=TM(IPT)
      CALL GAUSS(JX,ST1,TM1,V2)
      T(IPT)=V2
      IF(IXX.NE.0) JX=IXX
   10 CONTINUE
      GO TO 905
   50 NF1=IFD(JXX,1)
      NF2=IFD(JXX,2)
      NP1=IPD(JXX,1)
```

```
      NP2=IPD(JXX,2)
      IF(IPR.GT.1) GO TO 807
      HIM(JXX)=HI(JXX)
      HOM(JXX)=HO(JXX)
      RFIM(JXX)=RFI(JXX)
      RFOM(JXX)=RFO(JXX)
      UMD(JXX)=UD(JXX)
      CPM(NF1)=CP(NF1)
      CPM(NF2)=CP(NF2)
807   UDM=UMD(JXX)
      HMI=HIM(JXX)
      HMO=HOM(JXX)
      RFMI=RFIM(JXX)
      RFMO=RFOM(JXX)
      CPM1=CPM(NF1)
      CPM2=CPM(NF2)
      SIH=SHI(JXX)
      SOH=SHO(JXX)
      SIRF=SRFI(JXX)
      SORF=SRFO(JXX)
      UDS=SUD(JXX)
      SCP1=SCP(NF1)
      SCP2=SCP(NF2)
770   IF(SCP1.EQ.0.0) GO TO 780
      CALL GAUSS(JX,SCP1,CPM1,V6)
      CP(NF1)=V6
      IF(IXX.NE.0) JX=IXX
780   IF(SCP2.EQ.0.0) GO TO 790
      CALL GAUSS(JX,SCP2,CPM2,V7)
      CP(NF2)=V7
      IF(IXX.NE.0) JX=IXX
790   IF(UDS.EQ.0.0) GO TO 808
      CALL GAUSS(JX,UDS,UDM,V9)
      UD(JXX)=V9
      IF(IXX.NE.0) JX=IXX
808   IF(SIH.EQ.0.0) GO TO 809
      CALL GAUSS(JX,SIH,HMI,V1)
      HI(JXX)=V1
      IF(IXX.NE.0) JX=IXX
 809  IF(SOH.EQ.0.0) GO TO 810
      CALL GAUSS(JX,SOH,HMO,V2)
      HO(JXX)=V2
      IF(IXX.NE.0) JX=IXX
 810  IF(SIRF.EQ.0.0)GO TO 813
      CALL GAUSS(JX,SIRF,RFMI,V3)
      RFI(JXX)=V3
      IF(IXX.NE.0) JX=IXX
813   IF(SORF.EQ.0.0) GO TO 905
      CALL GAUSS(JX,SORF,RFMO,V4)
      RFO(JXX)=V4
      IF(IXX.NE.0) JX=IXX
      IERR(JXX)=0
905   RETURN
      END
```

```
      SUBROUTINE VAHX(JXX)
C
C     THIS SUBROUTINE CALCULATES THE MEAN AND STANDARD DEVIATION FOR THE
C     AREA OF EACH HEAT EXCHANGER AND HEATER OR CONDENSER
C
      COMMON//ID(18)
      COMMON/KEYS/IERR(100),NELM(100),NXX,NETRN,NX,IPR,ISC,LX,JX,IBD,NFD
      COMMON/ARAV/AREA(100,500),ANL(100),IREA(100),NUD(100),NQ(100),INFN
     1A(100),IZERA(100)
      COMMON/PHUNIT/WUNIT(2),TUNIT(2),TMUNIT(2),EUNIT(2),ALGTH(2),KUNIT(
     $100),LUNIT(100),PUNIT(2)
      COMMON/IOUNIT/NREAD,NPRNT,NPNCH,IIX,EPS
      DATA NTLE/0/
 375  FORMAT('1'/5X,'PROBLEM IDENTIFICATION***',18A4,1X,'*** OUTPUT LIST
     1ING ***')
      IF(NTLE.NE.0) GO TO 410
      WRITE(NPRNT,375)ID
      NTLE=1
 410  SUMA=0.0
      LM=0
      DO 420 K=1,LX
      IF(AREA(JXX,K).EQ.0.0) LM=LM+1
 420  SUMA=SUMA+AREA(JXX,K)
      ALX=LX-LM
      LXR=ALX
      ABAR=SUMA/ALX
      IUNIT=LUNIT(JXX)
      DO 430 K=1,LX
      IF(AREA(JXX,K).EQ.0.0) GO TO 430
      A1=AREA(JXX,K)-ABAR
      A2=A1*A1
      SUMA2=SUMA2+A2
 430  CONTINUE
      STDA=SQRT(SUMA2/(ALX-1.0))
      WRITE(NPRNT,450)JXX,LX,IZERA(JXX),INFNA(JXX),ABAR,ALGTH(IUNIT),
     1STDA,ALGTH(IUNIT)
 450  FORMAT(////5X,'ELEMENT NUMBER**',I3//5X,'TOTAL NUMBER OF SIMULATIO
     1NS**',I3/5X,'NUMBER OF SIMULATIONS WHERE HEAT EXCHANGER IS NOT NEE
     2DED**',I3/5X,'NUMBER OF SIMULATIONS WHERE THE SPECIFIED CONDITIONS
     3 CAN NOT BE MET**',I3/5X,'MEAN AREA FOR THE REMAINING SIMULATIONS*
     4*',F10.3,' SQR ',A2/5X,'STANDARD DEVIATION FOR THE REMAINING SIMUL
     5ATIONS**',F10.3,' SQR ',A2)
      RETURN
      END
      SUBROUTINE PRINT(JXX)
C
C     SUBROUTINE PRINT CALCULATES THE MAXIMUM AND MINIMUM TEMPERATURES
C     FOR EACH OUTLET STREAM
C
      COMMON/KEYS/IERR(100),NELM(100),NXX,NETRN,NX,IPR,ISC,LX,JX,IBD,NFD
      COMMON/NUMA/NF(100),NP(100),IFD(100,20),IPD(100,20),IDN(100)
      COMMON/ADATA/W(200),T(200),CP(200),Q(100),UD(100),HI(100),HO(100),
     1RFI(100),RFO(100),DI(100),DO(100),TISO(100),FT(100),TP1(100),TP2(1
     200),WISO(100),HFG(100),A(100),AI(100),AO(100),KW,TDIFF(100),TIGN(1
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     300),HREAC(100),CONV(100)
      COMMON/VAMXN/WMAX(20),WMIN(20),TMAX(20),TMIN(20),WOPT(20,500),TOPT
     $(20,500)
      MOPT=NF(JXX)
      DO 115 II=1,MOPT
      IN=IFD(JXX,II)
      TMAX(II)=AMAX1(TMAX(II),T(IN))
      TMIN(II)=AMIN1(TMIN(II),T(IN))
      TOPT(II,IPR)=T(IN)
  115 CONTINUE
      RETURN
      END
      SUBROUTINE OTPT(JXX)
C
C     SUBROUTINE OTPT READS OUTPUT STREAM NUMBERS AND PRINT THEIR
C     CONDITIONS.
C
      DIMENSION R(50),D(50),CY(50),SR(50),SD(50),SCY(50)
      REAL KW(100)
      COMMON//ID(18)
      COMMON/KEYS/IERR(100),NELM(100),NXX,NETRN,NX,IPR,ISC,LX,JX,IBD,NFD
      COMMON/PHUNIT/WUNIT(2),TUNIT(2),TMUNIT(2),EUNIT(2),ALGTH(2),KUNIT(
     $100),LUNIT(100),PUNIT(2)
      COMMON/IOUNIT/NREAD,NPRNT,NPNCH,IIX,EPS
      COMMON/NUMA/NF(100),NP(100),IFD(100,20),IPD(100,20),IDN(100)
      COMMON/ADATA/W(200),T(200),CP(200),Q(100),UD(100),HI(100),HO(100),
     1RFI(100),RFO(100),DI(100),DO(100),TISO(100),FT(100),TP1(100),TP2(1
     200),WISO(100),HFG(100),A(100),AI(100),AO(100),KW,TDIFF(100),TIGN(1
     300),HREAC(100),CONV(100)
      COMMON/STD/SW(200),ST(200),SCP(200),SHI(100),SHO(100),SRFI(100),SR
     1FO(100),SUD(100)
      DATA R,D,CY,SR,SD,SCY/50*0.0,50*0.0,50*0.0,50*0.0,50*0.0,50*0.0/
 370  FORMAT('1'/5X,'PROBLEM IDENTIFICATION***',18A4,2X,'*** INPUT LISTI
     1NG ***')
 375  FORMAT('1'/5X,'PROBLEM IDENTIFICATION***',18A4,1X,'*** OUTPUT LIST
     1ING ***')
      IF(NETRN.EQ.0)WRITE(NPRNT,370)ID
      IF(NETRN.EQ.1.AND.NXX.EQ.2)WRITE(NPRNT,375)ID
      MOTPT=NF(JXX)
      IF(NETRN.NE.0) GO TO 20
      READ(NREAD,10)(IFD(JXX,MN),MN=1,20)
  10  FORMAT(14I5/6I5)
  20  DO 50 MM=1,MOTPT
      IPT=IFD(JXX,MM)
      R(MM)=W(IPT)
      D(MM)=T(IPT)
      CY(MM)=CP(IPT)
      SR(MM)=SW(IPT)
      SD(MM)=ST(IPT)
      SCY(MM)=SCP(IPT)
  50  CONTINUE
      WRITE(NPRNT,25)JXX,NF(JXX),NP(JXX)
  25  FORMAT(////1X,'OUTPUT TANK'//1X,'ELEMENT NUMBER**',I3//1X,    'NUM
     1BER OF FEED STREAMS**',I3,' NUMBER OF PRODUCT STREAMS**',I3/////
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     266X,'FEED')
      K=1
      L=10
  27  WRITE(NPRNT,30)(IFD(JXX,MM),MM=K,L)
 30   FORMAT(//1X,'STREAM NUMBER',14X,I4,9(6X,I4))
      IF(NETRN.EQ.1.AND.NXX.EQ.2)KUNIT(JXX)=LUNIT(JXX)
      IUNIT=KUNIT(JXX)
      WRITE(NPRNT,31)WUNIT(IUNIT),TMUNIT(IUNIT),(R(MM),MM=K,L)
 31   FORMAT(///1X,'FLOW RATE ',A2,'/',A3,8X,10F10.2)
      WRITE(NPRNT,32)TUNIT(IUNIT),(D(MM),MM=K,L)
 32   FORMAT(1X,'TEMPERATURE DEG ',A1,7X,10F10.2)
      WRITE(NPRNT,33)EUNIT(IUNIT),WUNIT(IUNIT),TUNIT(IUNIT),(CY(MM),MM=K
     1,L)
 33   FORMAT(1X,'HEAT CAPACITY ',A3,'/',A2,' ',A1,3X,10F10.5)
      WRITE(NPRNT,34)WUNIT(IUNIT),TMUNIT(IUNIT),(SR(MM),MM=K,L)
 34   FORMAT(1X,'FLOW RATE STD ',A2,'/',A3,4X,10F10.2)
      WRITE(NPRNT,35)TUNIT(IUNIT),(SD(MM),MM=K,L)
 35   FORMAT(1X,'TEMPERATURE STD DEG ',A1,4X,10F10.2)
      WRITE(NPRNT,36)EUNIT(IUNIT),WUNIT(IUNIT),TUNIT(IUNIT),(SCY(MM),MM=
     1K,L)
 36   FORMAT(1X,'HEAT CPY STD ',A3,'/',A2,' ',A1,3X,10F10.5)
      IF(L.GT.10) GO TO 40
      IF(MOTPT.LE.10) GO TO 40
      K=11
      L=MOTPT
      WRITE(NPRNT,38)
  38  FORMAT(//////)
      GO TO 27
  40  RETURN
      END
      SUBROUTINE GRAPH
C
C     SUBROUTINE GRAPH PLOTS THE CUMULATIVE PROBABILITY FOR EACH OUTLET
C     TEMPERATURE.
C
      DIMENSION IZAR(100),X(20)
      COMMON/GUNIT/IUNIGH,NCASE,NYORD
      COMMON/PHUNIT/WUNIT(2),TUNIT(2),TMUNIT(2),EUNIT(2),ALGTH(2),KUNIT(
     $100),LUNIT(100),PUNIT(2)
      COMMON/IOUNIT/NREAD,NPRNT,NPNCH,IIX,EPS
      COMMON/TCPP/XAR(100),YAR(100),LIMIT,TMINN,IY,TINC
      COMMON/ZAK/IA,TBAR,STDV,RVAR(9)
      DATA IB,IG/' ','*'/
  23  FORMAT(4X,'CUMULATIVE',6X,'*',100A1)
  24  FORMAT(4X,'PROBABILITY',5X,'*',100A1)
      N=LIMIT
      AJJ=TMINN
      WRITE(NPRNT,10)
  10  FORMAT('1'/)
      I=NYORD
      IF(NYORD.EQ.0)I=50
      PINC=1.0/I
      M=I
   5  DO 2 K=1,100
```

```
  2   IZAR(K)=IB
      DO 3 J=1,N
      IV=YAR(J)/PINC+.5
      IF(IV.NE.I) GO TO 3
      IX=(XAR(J)-AJJ)/TINC+0.5
      IZAR(IX)=IG
  3   CONTINUE
      IF(I.EQ.(M/2+10)) GO TO 35
      IF((I/10)*10.EQ.I) GO TO 4
      IF(I.NE.(M/2+11)) GO TO 19
      WRITE(NPRNT,25)(IZAR(L),L=1,70),IA
 25   FORMAT(20X,'*',70A1,'EFFLUENT STREAM NO',I8)
      GO TO 6
 35   YP=PINC*I
      WRITE(NPRNT,36)YP,(IZAR(L),L=1,70),TBAR
 36   FORMAT(10X,F8.4,2X,'+',70A1,'STREAM TEMP. MEAN ',F10.3)
      GO TO 6
 19   IF(I.NE.(M/2+10)) GO TO 26
      WRITE(NPRNT,27)(IZAR(L),L=1,70),TBAR
 27   FORMAT(20X,'*',70A1,'STREAM TEMP. MEAN ',F10.3)
      GO TO 6
 26   IF(I.NE.(M/2+9)) GO TO 32
      WRITE(NPRNT,33)(IZAR(L),L=1,70),STDV
 33   FORMAT(20X,'*',70A1,'STANDARD DEVIATION',F10.3)
      GO TO 6
 32   IF(I.NE.(M/2+1)) GO TO 28
      WRITE(NPRNT,23)IZAR
      GO TO 6
 28   IF(I.NE.M/2) GO TO 29
      WRITE(NPRNT,24)IZAR
      GO TO 6
 29   WRITE(NPRNT,20)IZAR
 20   FORMAT(20X,'*',100A1)
      GO TO 6
  4   IF(I.NE.M/2) GO TO 8
      YP=PINC*I
      WRITE(NPRNT,30)YP,IZAR
 30   FORMAT(4X,'PROB.',1X,F8.4,2X,'+',100A1)
      GO TO 6
  8   YP=PINC*I
      WRITE(NPRNT,21)YP,IZAR
 21   FORMAT(10X,F8.4,2X,'+',100A1)
  6   I=I-1
      IF(I.GT.0) GO TO 5
      YP=0.
      WRITE(NPRNT,22)YP
 22   FORMAT(10X,F8.4,2X,'+',10('*********+'))
      DO 9 I=1,11
  9   X(I)=AJJ+(I-1)*10.0*TINC
      WRITE(6,12)(X(I),I=1,11)
 12   FORMAT(13X,11F10.1)
      WRITE(NPRNT,14)TUNIT(IUNIGH)
 14   FORMAT(/45X,'TEMPERATURE DEG ',A1)
      RETURN
```

```
      END
      SUBROUTINE EFFECT(JXX)
C
C     THIS SUBROUTINE CALCULATES THE MEAN AND STANDARD DEVIATION
C     FOR THE HEAT DUTY OF EACH FIRED HEATER.
C
C
      COMMON//ID(18)
      COMMON/KEYS/IERR(100),NELM(100),NXX,NETRN,NX,IPR,ISC,LX,JX,IBD,NFD
      COMMON/ARAV/AREA(100,500),ANL(100),IREA(100),NUD(100),NQ(100),INFN
     1A(100),IZERA(100)
      COMMON/PHUNIT/WUNIT(2),TUNIT(2),TMUNIT(2),EUNIT(2),ALGTH(2),KUNIT(
     $100),LUNIT(100),PUNIT(2)
      COMMON/ZAK/IA,TBAR,STDV,RVAR(9)
      COMMON/IOUNIT/NREAD,NPRNT,NPNCH,IIX,EPS
      DATA NTLE/0/
 375  FORMAT('1'/5X,'PROBLEM IDENTIFICATION***',18A4,1X,'*** OUTPUT LIST
     1ING ***')
      IF(NTLE.NE.0) GO TO 410
      WRITE(NPRNT,375)ID
      NTLE=1
 410  SUMA=0.0
      SUMA2=0.0
      LM=0
      DO 420 K=1,LX
      IF(AREA(JXX,K).EQ.0.0) LM=LM+1
 420  SUMA=SUMA+AREA(JXX,K)
      ALX=LX-LM
      LXR=ALX
      ABAR=SUMA/ALX
      TBAR=ABAR
      IUNIT=LUNIT(JXX)
      DO 430 K=1,LX
      IF(AREA(JXX,K).EQ.0.0) GO TO 430
      A1=AREA(JXX,K)-ABAR
      A2=A1*A1
      SUMA2=SUMA2+A2
 430  CONTINUE
      STDA=SQRT(SUMA2/(ALX-1.0))
      STDV=STDA
      IF(IUNIT.EQ.2)ABAR=ABAR/3.6
      IF(IUNIT.EQ.2)STDA=STDA/3.6
      WRITE(NPRNT,450)JXX,LX,ABAR,PUNIT(IUNIT),STDA,PUNIT(IUNIT)
 450  FORMAT(////5X,'ELEMENT NUMBER**',I5//5X,'TOTAL NUMBER OF SIMULATIO
     1NS**',I8/5X,'REQUIRED MEAN HEAT TRANSFER**',E11.4,A3/5X,'REQUIRED
     2 HEAT TRANSFER STANDARD DEVIATION**',E11.4,A3)
      RETURN
      END
      SUBROUTINE FBACK(JXX)
C
C
C     THIS SUBROUTINE PERFORMS THE DETERMINISTIC CALCULATION
C     FOR NOMINAL VALUES OF THE FEED BACK STREAM VARIABLES
C     WHEN THEY ARE UNKNOWN AND NEEDS TO BE CONVERGED
```

```
C
      DIMENSION TMEAN(20),STAND(20),TAV(100),LIST(100),WAV(100),
     $ITER(100)
      REAL KW(100)
      COMMON//ID(18)
      COMMON/PHUNIT/WUNIT(2),TUNIT(2),TMUNIT(2),EUNIT(2),ALGTH(2),KUNIT(
     $100),LUNIT(100),PUNIT(2)
      COMMON/ARAV/AREA(100,500),ANL(100),IREA(100),NUD(100),NQ(100),INFN
     1A(100),IZERA(100)
      COMMON/ZAK/IA,TBAR,STDV,RVAR(9)
      COMMON/ADAP/CPC(200),CPH(200),SCPC(200),SCPH(200),NFA(200),NSP(200
     1),EEF(500)
      COMMON/ADATA/W(200),T(200),CP(200),Q(100),UD(100),HI(100),HO(100),
     1RFI(100),RFO(100),DI(100),DO(100),TISO(100),FT(100),TP1(100),TP2(1
     200),WISO(100),HFG(100),A(100),AI(100),AO(100),KW,TDIFF(100),TIGN(1
     300),HREAC(100),CONV(100)
      COMMON/STD/SW(200),ST(200),SCP(200),SHI(100),SHO(100),SRFI(100),SR
     1FO(100),SUD(100)
      COMMON/KEYS/IERR(100),NELM(100),NXX,NETRN,NX,IPR,ISC,LX,JX,IBD,NFD
      COMMON/NUMA/NF(100),NP(100),IFD(100,20),IPD(100,20),IDN(100)
      COMMON/IOUNIT/NREAD,NPRNT,NPNCH,IIX,EPS
      COMMON/TCPP/XAR(100),YAR(100),LIMIT,TMINN,IY,TINC,NELMT
      COMMON/VAMXN/WMAX(20),WMIN(20),TMAX(20),TMIN(20),WOPT(20,500),TOPT
     $(20,500)
      COMMON/MEAN/HIM(100),HOM(100),RFIM(100),RFOM(100),WM(200),TM(200)
     1,CPM(200),UMD(100)
      COMMON//PERCT(100,4)
      COMMON//IXX
      COMMON/GUNIT/IUNIGH,NCASE,NYORD
      READ(NREAD,5)EPS,NFD
 5    FORMAT(F10.5,6X,I4)
      READ(NREAD,7)ICN1,ICN2,ICN3,ICN4,ICN5,ICN6,ICN7,ICN8,ICN9,ICN10,
     1ICN11,ICN12,ICN13,ICN14,ICN15,ICN16,ICN17,ICN18,ICN19,ICN20
 7    FORMAT(20I3)
      IIX=1
10    IF(ABS(T(ICN1)-T(ICN2)).LE.EPS) GO TO 11
      GO TO 50
 11   IF(NFD.EQ.1) GO TO 1000
      IF(ABS(T(ICN3)-T(ICN4)).LE.EPS) GO TO 12
      GO TO 50
 12   IF(NFD.EQ.2) GO TO 1000
      IF(ABS(T(ICN5)-T(ICN6)).LE.EPS) GO TO 13
      GO TO 50
 13   IF(NFD.EQ.3) GO TO 1000
      IF(ABS(T(ICN7)-T(ICN8)).LE.EPS) GO TO 14
      GO TO 50
 14   IF(NFD.EQ.4) GO TO 1000
      IF(ABS(T(ICN9)-T(ICN10)).LE.EPS) GO TO 15
 15   IF(NFD.EQ.5) GO TO 1000
      IF(ABS(T(ICN11)-T(ICN12)).LE.EPS) GO TO 16
      GO TO 50
 16   IF(NFD.EQ.6) GO TO 1000
      IF(ABS(T(ICN13)-T(ICN14)).LE.EPS) GO TO 17
      GO TO 50
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17    IF(NFD.EQ.7) GO TO 1000
      IF(ABS(T(ICN15)-T(ICN16)).LE.EPS) GO TO 18
      GO TO 50
18    IF(NFD.EQ.8) GO TO 1000
      IF(ABS(T(ICN17)-T(ICN18)).LE.EPS) GO TO 19
      GO TO 50
19    IF(NFD.EQ.9) GO TO 1000
      IF(ABS(T(ICN19)-T(ICN20)).LE.EPS) GO TO 1000
50    T(ICN1)=T(ICN2)
      W(ICN1)=W(ICN2)
      CP(ICN1)=CP(ICN2)
      IF(NFD.EQ.1) GO TO 200
      T(ICN3)=T(ICN4)
      W(ICN3)=W(ICN4)
      CP(ICN3)=CP(ICN4)
      IF(NFD.EQ.2) GO TO 200
      T(ICN5)=T(ICN6)
      W(ICN5)=W(ICN6)
      CP(ICN5)=CP(ICN6)
      IF(NFD.EQ.3) GO TO 200
      T(ICN7)=T(ICN8)
      W(ICN7)=W(ICN8)
      CP(ICN7)=CP(ICN8)
      IF(NFD.EQ.4) GO TO 200
      T(ICN9)=T(ICN10)
      W(ICN9)=W(ICN10)
      CP(ICN9)=CP(ICN10)
      IF(NFD.EQ.5) GO TO 200
      T(ICN11)=T(ICN12)
      W(ICN11)=W(ICN12)
      CP(ICN11)=CP(ICN12)
      IF(NFD.EQ.6) GO TO 200
      T(ICN13)=T(ICN14)
      W(ICN13)=W(ICN14)
      CP(ICN13)=CP(ICN14)
      IF(NFD.EQ.7) GO TO 200
      T(ICN15)=T(ICN16)
      W(ICN15)=W(ICN16)
      CP(ICN15)=CP(ICN16)
      IF(NFD.EQ.8) GO TO 200
      T(ICN17)=T(ICN18)
      W(ICN17)=W(ICN18)
      CP(ICN17)=CP(ICN18)
      IF(NFD.EQ.9) GO TO 200
      T(ICN19)=T(ICN20)
      W(ICN19)=W(ICN20)
      CP(ICN19)=CP(ICN20)
200   DO 290 NX=1,NELMT
      JXX=NELM(NX)
      IF(IDN(JXX).EQ.1) GO TO 212
      IF(IDN(JXX).EQ.6) GO TO 222
      IF(IDN(JXX).EQ.7) GO TO 333
      IF(IDN(JXX).EQ.4) GO TO 203
      IF(IDN(JXX).EQ.8) GO TO 204
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      IF(IDN(JXX).EQ.3) GO TO 207
      IF(IDN(JXX).EQ.2) GO TO 206
      IF(IDN(JXX).EQ.5) GO TO 209
      IF(IDN(JXX).EQ.9) GO TO 205
      GO TO 290
 212  GO TO 290
 222  CALL HEX00(JXX)
      CALL HRCR(JXX)
      GO TO 290
 333  CALL RCTR(JXX)
      GO TO 290
 203  CALL HEX(JXX)
      CALL HEX00(JXX)
      GO TO 290
 204  CALL DISTL(JXX)
      GO TO 290
 206  CALL ADDR(JXX)
      GO TO 290
 207  CALL DVDR(JXX)
      GO TO 290
 209  CALL FRHR(JXX)
      GO TO 290
 205  CALL OTPT(JXX)
 290  CONTINUE
      IF(IIX.GE.50) WRITE(NPRNT,500)
 500  F0RMAT('1','SYSTEM IS UNSTABLE. SYSTEM DID NOT CONVERGED
     1AFTER 50 ITERATIONS. )
      IF(IIX.GE.50) GO TO 1000
      IIX=IIX+1
      GO TO 10
 1000 RETURN
      END
      SUBROUTINE HFBACK
C
C
C     THIS SUBROUTINE PERFORMS THE MONTECARLO SIMULATION FOR THE
C     FEED BACK STREAM VARIABLES WHEN THEY ARE UNKNOWN AND NEEDS
C     TO BE CONVERGED.
C
C

      DIMENSION TAV(100),LIST(100),WAV(100),ITER(100)
      REAL KW(100)
      COMMON//ID(18)
      COMMON/PHUNIT/WUNIT(2),TUNIT(2),TMUNIT(2),EUNIT(2),ALGTH(2),KUNIT(
     $100),LUNIT(100),PUNIT(2)
      COMMON/ARAV/AREA(100,500),ANL(100),IREA(100),NUD(100),NQ(100),INFN
     1A(100),IZERA(100)
      COMMON/ZAK/IA,TBAR,STDV,RVAR(9),STAND(20),TMEAN(20)
      COMMON/ADAP/CPC(200),CPH(200),SCPC(200),SCPH(200),NFA(200),NSP(200
     1),EEF(500)
      COMMON/ADATA/W(200),T(200),CP(200),Q(100),UD(100),HI(100),HO(100),
     1RFI(100),RFO(100),DI(100),DO(100),TISO(100),FT(100),TP1(100),TP2(1
     200),WISO(100),HFG(100),A(100),AI(100),AO(100),KW,TDIFF(100),TIGN(1
     300),HREAC(100),CONV(100)
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      COMMON/STD/SW(200),ST(200),SCP(200),SHI(100),SHO(100),SRFI(100),SR
     1FO(100),SUD(100)
      COMMON/KEYS/IERR(100),NELM(100),NXX,NETRN,NX,IPR,ISC,LX,JX,IBD,NFD
      COMMON/NUMA/NF(100),NP(100),IFD(100,20),IPD(100,20),IDN(100)
      COMMON/IOUNIT/NREAD,NPRNT,NPNCH,IIX,EPS
      COMMON/TCPP/XAR(100),YAR(100),LIMIT,TMINN,IY,TINC,NELMT
      COMMON/VAMXN/WMAX(20),WMIN(20),TMAX(20),TMIN(20),WOPT(20,500),TOPT
     $(20,500)
      COMMON/MEAN/HIM(100),HOM(100),RFIM(100),RFOM(100),WM(200),TM(200)
     1,CPM(200),UMD(100)
      COMMON//PERCT(100,4)
      COMMON//IXX
      COMMON/GUNIT/IUNIGH,NCASE,NYORD
      DATA IBK/'    '/
C
C
C
C
      IF(NFD.NE.0.AND.EPS.NE.0.0) GO TO 6
      READ(NREAD,5)EPS,NFD
 5    FORMAT(F10.5,6X,I4)
 6    READ(NREAD,7)ICN1,ICN2,ICN3,ICN4,ICN5,ICN6,ICN7,ICN8,ICN9,ICN10,
     1ICN11,ICN12,ICN13,ICN14,ICN15,ICN16,ICN17,ICN18,ICN19,ICN20
 7    FORMAT(20I3)
 200  NETRN=2
      DO 2500 IPR=1,LX
      DO 2000 I=1,NELMT
      JXX=NELM(I)
      IF(IDN(JXX).EQ.1) GO TO 310
      IF(IDN(JXX).EQ.9) GO TO 320
      IF(IDN(JXX).EQ.2) GO TO 330
      IF(IDN(JXX).EQ.8) GO TO 340
      IF(IDN(JXX).EQ.3) GO TO 341
      IF(IDN(JXX).EQ.5) GO TO 342
      IF(IDN(JXX).EQ.6) GO TO 700
      IF(IDN(JXX).EQ.7) GO TO 701
      IF(IDN(JXX).EQ.4) GO TO 360
 310  CALL RANDV(JXX)
      GO TO 2000
 330  CALL RANDV(JXX)
      CALL ADDR(JXX)
      GO TO 2000
 340  CALL RANDV(JXX)
      CALL DISTL(JXX)
      GO TO 2000
 341  CALL RANDV(JXX)
      CALL DVDR(JXX)
      GO TO 2000
 342  CALL FRHR(JXX)
      IF(IERR(JXX).EQ.1) GO TO 1500
      GO TO 2000
 700  CALL HRCR(JXX)
      IF(IERR(JXX).EQ.1) GO TO 1500
      GO TO 2000
```

```
 701  CALL RCTR(JXX)
      IF(IERR(JXX).EQ.1) GO TO 1500
      GO TO 2000
 360  CALL HEX(JXX)
      IF(IERR(JXX).EQ.1) GO TO 1500
      GO TO 2000
 320  IF(IPR.GT.1) GO TO 370
      MOTPT=NF(JXX)
      DO 365 NK=1,MOTPT
      WMAX(NK)=0.000001
      WMIN(NK)=90000000.0
      TMAX(NK)=0.00001
      TMIN(NK)=100000000.0
 365  CONTINUE
 370  CALL PRINT(JXX)
2000  CONTINUE
      IIX=1
10    IF(ABS(T(ICN1)-T(ICN2)).LE.EPS) GO TO 11
      GO TO 50
 11   IF(NFD.EQ.1) GO TO 2500
      IF(ABS(T(ICN3)-T(ICN4)).LE.EPS) GO TO 12
      GO TO 50
 12   IF(NFD.EQ.2) GO TO 2500
      IF(ABS(T(ICN5)-T(ICN6)).LE.EPS) GO TO 13
      GO TO 50
 13   IF(NFD.EQ.3) GO TO 2500
      IF(ABS(T(ICN7)-T(ICN8)).LE.EPS) GO TO 14
      GO TO 50
 14   IF(NFD.EQ.4) GO TO 2500
      IF(ABS(T(ICN9)-T(ICN10)).LE.EPS) GO TO 15
      GO TO 50
 15   IF(NFD.EQ.5) GO TO 2500
      IF(ABS(T(ICN11)-T(ICN12)).LE.EPS) GO TO 16
      GO TO 50
 16   IF(NFD.EQ.6) GO TO 2500
      IF(ABS(T(ICN13)-T(ICN14)).LE.EPS) GO TO 17
      GO TO 50
 17   IF(NFD.EQ.7) GO TO 2500
      IF(ABS(T(ICN15)-T(ICN16)).LE.EPS) GO TO 18
      GO TO 50
 18   IF(NFD.EQ.8) GO TO 2500
      IF(ABS(T(ICN17)-T(ICN18)).LE.EPS) GO TO 19
      GO TO 50
 19   IF(NFD.EQ.9) GO TO 2500
      IF(ABS(T(ICN19)-T(ICN20)).LE.EPS) GO TO 2500
 50   T(ICN1)=T(ICN2)
      W(ICN1)=W(ICN2)
      CP(ICN1)=CP(ICN2)
      IF(NFD.EQ.1) GO TO 100
      T(ICN3)=T(ICN4)
      W(ICN3)=W(ICN4)
      CP(ICN3)=CP(ICN4)
      IF(NFD.EQ.2) GO TO 100
      T(ICN5)=T(ICN6)
```

```
      W(ICN5)=W(ICN6)
      CP(ICN5)=CP(ICN6)
      IF(NFD.EQ.3) GO TO 100
      T(ICN7)=T(ICN8)
      W(ICN7)=W(ICN8)
      CP(ICN7)=CP(ICN8)
      IF(NFD.EQ.4) GO TO 100
      T(ICN9)=T(ICN10)
      W(ICN9)=W(ICN10)
      CP(ICN9)=CP(ICN10)
      IF(NFD.EQ.5) GO TO 100
      T(ICN11)=T(ICN12)
      W(ICN11)=W(ICN12)
      CP(ICN11)=CP(ICN12)
      IF(NFD.EQ.6) GO TO 100
      T(ICN13)=T(ICN14)
      W(ICN13)=W(ICN14)
      CP(ICN13)=CP(ICN14)
      IF(NFD.EQ.7) GO TO 100
      T(ICN15)=T(ICN16)
      W(ICN15)=W(ICN16)
      CP(ICN15)=CP(ICN16)
      IF(NFD.EQ.8) GO TO 100
      T(ICN17)=T(ICN18)
      W(ICN17)=W(ICN18)
      CP(ICN17)=CP(ICN18)
      IF(NFD.EQ.9) GO TO 100
      T(ICN19)=T(ICN20)
      W(ICN19)=W(ICN20)
      CP(ICN19)=CP(ICN20)
100   DO 290 NX=1,NELMT
      JXX=NELM(NX)
      IF(IDN(JXX).EQ.1) GO TO 212
      IF(IDN(JXX).EQ.6) GO TO 222
      IF(IDN(JXX).EQ.7) GO TO 333
      IF(IDN(JXX).EQ.4) GO TO 203
      IF(IDN(JXX).EQ.8) GO TO 204
      IF(IDN(JXX).EQ.3) GO TO 207
      IF(IDN(JXX).EQ.2) GO TO 206
      IF(IDN(JXX).EQ.5) GO TO 209
      IF(IDN(JXX).EQ.9) GO TO 290
      GO TO 290
212   GO TO 290
222   CALL HRCR(JXX)
      GO TO 290
333   CALL RCTR(JXX)
      GO TO 290
203   CALL HEX(JXX)
      GO TO 290
204   CALL DISTL(JXX)
      GO TO 290
206   CALL ADDR(JXX)
      GO TO 290
207   CALL DVDR(JXX)
```

```
      GO TO 290
 209  CALL FRHR(JXX)
      GO TO 290
 290  CONTINUE
      IF(IIX.GE.50) WRITE(NPRNT,500)
 500  FORMAT('1','SYSTEM IS UNSTABLE. SYSTEM DID NOT CONVERGED
     1AFTER 50 ITERATIONS. )
      IF(IIX.GE.50) GO TO 1000
      IIX=IIX+1
      GO TO 10
2500  CONTINUE
C
C     CALCULATE THE MEAN AND STANDARD DEVIATION FOR EACH OUTLET STREAM.
C
      JXX=NELM(NELMT)
      DO 1400 IY=1,MOTPT
      IA=IFD(JXX,IY)
      IF(TMAX(IY).EQ.TMIN(IY)) GO TO 1400
      IUNIGH=LUNIT(JXX)
      MK=TMIN(IY)/10.0
      AMK=MK*10
      IF(TINC.NE.0.0) GO TO 420
      TINC=1.0
 420  BMK=AMK-TINC/2.0
      INTLT=(TMAX(IY)-BMK)/TINC+0.5
      IF(INTLT.LE.100) GO TO 423
      TINC=TINC+1.0
      GO TO 420
 423  DO 1420 NT=1,INTLT
      YAR(NT)=0.0
      XAR(NT)=0.0
 1420 LIST(NT)=0
      SUMA=0.0
      SUMT1=0.0
      SUMT2=0.0
      SUMT3=0.0
      SUMT4=0.0
      DO 1450 IS=1,LX
      LT=(TOPT(IY,IS)-BMK)/TINC+1.0
      LIST(LT)=LIST(LT)+1
      SUMA=TOPT(IY,IS)+SUMA
 1450 CONTINUE
      DO 1452 IT=1,INTLT
      IM=IT-1
      TAV(IT)=AMK+IM*TINC
 1452 CONTINUE
      LIMIT=INTLT
 1455 BLX=LX
      TPRB=0.0
      DO 1456 NX=1,LIMIT
      ALIST=LIST(NX)
      TPRB=ALIST/BLX+TPRB
      XAR(NX)=TAV(NX)
      YAR(NX)=TPRB
```

```
 1456 CONTINUE
C
C     PLOT THE CUMULATIVE PROBABILITY CURVES
C
      TMINN=AMK
      TBAR=SUMA/BLX
      TMEAN(IY)=TBAR
      DO 1440 IZ=1,LX
      T1=TOPT(IY,IZ)-TBAR
      T2=T1*T1
      T3=T1*T1*T1
      T4=T1*T1*T1*T1
      SUMT1=T1+SUMT1
      SUMT2=T2+SUMT2
      SUMT3=T3+SUMT3
      SUMT4=T4+SUMT4
 1440 CONTINUE
      TMOM1=SUMT1/BLX
      TMOM2=SUMT2/BLX
      TMOM3=SUMT3/BLX
      TMOM4=SUMT4/BLX
      BT1=TMOM3/(TMOM2)**1.5
      BT2=TMOM4/TMOM2
      STDV=SQRT(TMOM2)
      STAND(IY)=STDV
      CALL GRAPH
 1400 CONTINUE
 1500 GO TO 1000
 1000 RETURN
      END
      SUBROUTINE DFBACK
C
C
C     THIS SUBROUTINE PERFORMS THE MONTE CARLO SIMULATION
C     AND GENERATES THE UNCERTAINTIES IN THE DISTILLATION
C     ELEMENT PRODUCT STREAM VARIABLES AS A FUNCTION OF
C     THE UNCERTAINTIES IN THE FEED STREAM VARIABLES.
C
C
      DIMENSION TAV(100),LIST(100),WAV(100),ITER(100)
      REAL KW(100)
      REAL K1,K2,K3,K4,K5,K6,K7,K8,K9,K10
      COMMON//ID(18)
      COMMON/PHUNIT/WUNIT(2),TUNIT(2),TMUNIT(2),EUNIT(2),ALGTH(2),KUNIT(
     $100),LUNIT(100),PUNIT(2)
      COMMON/ARAV/AREA(100,500),ANL(100),IREA(100),NUD(100),NQ(100),INFN
     1A(100),IZERA(100)
      COMMON/ZAK/IA,TBAR,STDV,RVAR(9),STAND(20),TMEAN(20)
      COMMON/ADAP/CPC(200),CPH(200),SCPC(200),SCPH(200),NFA(200),NSP(200
     1),EEF(500)
      COMMON/ADATA/W(200),T(200),CP(200),Q(100),UD(100),HI(100),HO(100),
     1RFI(100),RFO(100),DI(100),DO(100),TISO(100),FT(100),TP1(100),TP2(1
     200),WISO(100),HFG(100),A(100),AI(100),AO(100),KW,TDIFF(100),TIGN(1
     300),HREAC(100),CONV(100)
```

```
      COMMON/STD/SW(200),ST(200),SCP(200),SHI(100),SHO(100),SRFI(100),SR
     1FO(100),SUD(100)
      COMMON/KEYS/IERR(100),NELM(100),NXX,NETRN,NX,IPR,ISC,LX,JX,IBD,NFD
      COMMON/NUMA/NF(100),NP(100),IFD(100,20),IPD(100,20),IDN(100)
      COMMON/IOUNIT/NREAD,NPRNT,NPNCH ,IIX,EPS
      COMMON/TCPP/XAR(100),YAR(100),LIMIT,TMINN,IY,TINC,NELMT
      COMMON/VAMXN/WMAX(20),WMIN(20),TMAX(20),TMIN(20),WOPT(20,500),TOPT
     $(20,500)
      COMMON/MEAN/HIM(100),HOM(100),RFIM(100),RFOM(100),WM(200),TM(200)
     1,CPM(200),UMD(100)
      COMMON//PERCT(100,4)
      COMMON//IXX
      COMMON/GUNIT/IUNIGH,NCASE,NYORD
      DATA IBK/'    '/
C
C
      READ(NREAD,5)EPS,NFD
 5    FORMAT(F10.5,6X,I4)
      READ(NREAD,6)K1,K2,K3,K4,K5,K6
 6    FORMAT(6F10.5)
      READ(NREAD,7)L1,L2,L3,L4,L5,L6
 7    FORMAT(6I5)
      MCN1=1
 10   PST1=(1.0/K1)*ST(L1)
      IF(NFD.EQ.1) GO TO 9
      PST2=(1.0/K2)*ST(L2)
      IF(NFD.EQ.2) GO TO 9
      PST3=(1.0/K3)*ST(L3)
      IF(NFD.EQ.3) GO TO 9
      PST4=(1.0/K4)*ST(L4)
      IF(NFD.EQ.4) GO TO 9
      PST5=(1.0/K5)*ST(L5)
      IF(NFD.EQ.5) GO TO 9
      PST6=(1.0/K6)*ST(L6)
 9    IF(ABS(STAND(MCN1)-PST1).LE.EPS) GO TO 11
      GO TO 50
 11   IF(NFD.EQ.1) GO TO 1000
      IF(ABS(STAND(MCN1)-PST2).LE.EPS) GO TO 12
      GO TO 50
 12   IF(NFD.EQ.2) GO TO 1000
      IF(ABS(STAND(MCN1)-PST3).LE.EPS) GO TO 13
      GO TO 50
 13   IF(NFD.EQ.3) GO TO 1000
      IF(ABS(STAND(MCN1)-PST4).LE.EPS) GO TO 14
      GO TO 50
 14   IF(NFD.EQ.4) GO TO 1000
      IF(ABS(STAND(MCN1)-PST5).LE.EPS) GO TO 15
      GO TO 50
 15   IF(NFD.EQ.5) GO TO 1000
      IF(ABS(STAND(MCN1)-PST6).LE.EPS) GO TO 1000
 50   ST(L1)=K1*STAND(MCN1)
      IF(NFD.EQ.1) GO TO 200
      ST(L2)=K2*STAND(MCN1)
      IF(NFD.EQ.2) GO TO 200
```

```
      ST(L3)=K3*STAND(MCN1)
      IF(NFD.EQ.3) GO TO 200
      ST(L4)=K4*STAND(MCN1)
      IF(NFD.EQ.4) GO TO 200
      ST(L5)=K5*STAND(MCN1)
      IF(NFD.EQ.5) GO TO 200
      ST(L6)=K6*STAND(MCN1)
      GO TO 200
 200  NETRN=2
      DO 2500 IPR=1,LX
      DO 2000 I=1,NELMT
      JXX=NELM(I)
      IF(IDN(JXX).EQ.1) GO TO 310
      IF(IDN(JXX).EQ.9) GO TO 320
      IF(IDN(JXX).EQ.2) GO TO 330
      IF(IDN(JXX).EQ.8) GO TO 340
      IF(IDN(JXX).EQ.3) GO TO 341
      IF(IDN(JXX).EQ.5) GO TO 342
      IF(IDN(JXX).EQ.6) GO TO 700
      IF(IDN(JXX).EQ.7) GO TO 701
      IF(IDN(JXX).EQ.4) GO TO 360
 310  CALL RANDV(JXX)
      GO TO 2000
 330  CALL RANDV(JXX)
      CALL ADDR(JXX)
      GO TO 2000
 340  CALL RANDV(JXX)
      CALL DISTL(JXX)
      GO TO 2000
 341  CALL RANDV(JXX)
      CALL DVDR(JXX)
      GO TO 2000
 342  CALL FRHR(JXX)
      IF(IERR(JXX).EQ.1) GO TO 1500
      GO TO 2000
 700  CALL HRCR(JXX)
      IF(IERR(JXX).EQ.1) GO TO 1500
      GO TO 2000
 701  CALL RCTR(JXX)
      IF(IERR(JXX).EQ.1) GO TO 1500
      GO TO 2000
 360  CALL HEX(JXX)
      IF(IERR(JXX).EQ.1) GO TO 1500
      GO TO 2000
 320  IF(IPR.GT.1) GO TO 370
      MOTPT=NF(JXX)
      DO 365 NK=1,MOTPT
      WMAX(NK)=0.000001
      WMIN(NK)=90000000.0
      TMAX(NK)=0.00001
      TMIN(NK)=100000000.0
 365  CONTINUE
 370  CALL PRINT(JXX)
2000  CONTINUE
```

```
2500  CONTINUE
C
C     CALCULATE THE MEAN AND STANDARD DEVIATION FOR EACH OUTLET STREAM.
      JXX=NELM(NELMT)
      DO 1400 IY=1,MOTPT
      IA=IFD(JXX,IY)
      IF(TMAX(IY).EQ.TMIN(IY)) GO TO 1400
      IUNIGH=LUNIT(JXX)
      MK=TMIN(IY)/10.0
      AMK=MK*10
      IF(TINC.NE.0.0) GO TO 420
      TINC=1.0
 420  BMK=AMK-TINC/2.0
      INTLT=(TMAX(IY)-BMK)/TINC+0.5
      IF(INTLT.LE.100) GO TO 423
      TINC=TINC+1.0
      GO TO 420
 423  DO 1420 NT=1,INTLT
      YAR(NT)=0.0
      XAR(NT)=0.0
 1420 LIST(NT)=0
      SUMA=0.0
      SUMT1=0.0
      SUMT2=0.0
      SUMT3=0.0
      SUMT4=0.0
      DO 1450 IS=1,LX
      LT=(TOPT(IY,IS)-BMK)/TINC+1.0
      LIST(LT)=LIST(LT)+1
      SUMA=TOPT(IY,IS)+SUMA
 1450 CONTINUE
      DO 1452 IT=1,INTLT
      IM=IT-1
      TAV(IT)=AMK+IM*TINC
 1452 CONTINUE
      LIMIT=INTLT
 1455 BLX=LX
      TPRB=0.0
      DO 1456 NX=1,LIMIT
      ALIST=LIST(NX)
      TPRB=ALIST/BLX+TPRB
      XAR(NX)=TAV(NX)
      YAR(NX)=TPRB
 1456 CONTINUE
C
C     PLOT THE CUMULATIVE PROBABILITY CURVES
C
      TMINN=AMK
      TBAR=SUMA/BLX
      TMEAN(IY)=TBAR
      DO 1440 IZ=1,LX
      T1=TOPT(IY,IZ)-TBAR
      T2=T1*T1
      T3=T1*T1*T1
```

```
      T4=T1*T1*T1*T1
      SUMT1=T1+SUMT1
      SUMT2=T2+SUMT2
      SUMT3=T3+SUMT3
      SUMT4=T4+SUMT4
 1440 CONTINUE
      TMOM1=SUMT1/BLX
      TMOM2=SUMT2/BLX
      TMOM3=SUMT3/BLX
      TMOM4=SUMT4/BLX
      BT1=TMOM3/(TMOM2)**1.5
      BT2=TMOM4/TMOM2
      STDV=SQRT(TMOM2)
      STAND(IY)=STDV
      CALL GRAPH
 1400 CONTINUE
      GO TO 10
 1500 GO TO 1000
 1000 RETURN
      END
      SUBROUTINE UNITS(JXX)
C
C     SUBROUTINE UNITS CONVERTS UNITS FROM USA SYSTEM TO SI SYSTEM AND
C     VISE VERSA.
C
      REAL KW(100)
      COMMON/PHUNIT/WUNIT(2),TUNIT(2),TMUNIT(2),EUNIT(2),ALGTH(2),KUNIT(
     $100),LUNIT(100),PUNIT(2)
      COMMON/ADAP/CPC(200),CPH(200),SCPC(200),SCPH(200),NFA(200),NSP(200
     1),EEF(500)
      COMMON/ADATA/W(200),T(200),CP(200),Q(100),UD(100),HI(100),HO(100),
     1RFI(100),RFO(100),DI(100),DO(100),TISO(100),FT(100),TP1(100),TP2(1
     200),WISO(100),HFG(100),A(100),AI(100),AO(100),KW,TDIFF(100),TIGN(1
     300),HREAC(100),CONV(100)
      COMMON/STD/SW(200),ST(200),SCP(200),SHI(100),SHO(100),SRFI(100),SR
     1FO(100),SUD(100)
      COMMON/KEYS/IERR(100),NELM(100),NXX,NETRN,NX,IPR,ISC,LX,JX,IBD,NFD
      COMMON/NUMA/NF(100),NP(100),IFD(100,20),IPD(100,20),IDN(100)
      IF(LUNIT(JXX).EQ.KUNIT(JXX)) GO TO 55
      IF(LUNIT(JXX).EQ.1.AND.KUNIT(JXX).EQ.2) GO TO 40
C
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C
C     VARIABLE              BRITISH UNITS               SI UNITS
C
C     HEAT TRANSFER
C     COEFFICIENT            BTU/HR.SQ.FT. F              W/SQ.M. K
C     THERMAL
C     CONDUCTIVITY           BTU/HR.FT. F                 W/M. K
C     SPECIFIC
C     HEAT                   BTU/LB.F                    J/KG. K
C     POWER                  BTU/HR                         W
```

```
C      TEMPERATURE                   F                        K
C      LENGTH                        FT                       M
C      MASS                          LB                       KG
C
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C      CONVERT TO SI UNITS
C
       IF(IDN(JXX).EQ.8)GO TO 10
       IF(NF(JXX).NE.0.AND.NP(JXX).NE.0) GO TO 30
 10    MINPT=NP(JXX)
       DO 20 M=1,MINPT
       NSTM=IPD(JXX,M)
       W(NSTM)=W(NSTM)/2.205
       T(NSTM)=(1.0/1.8)*(T(NSTM)-32.0)+273.16
       CP(NSTM)=CP(NSTM)*4.1868
       SW(NSTM)=SW(NSTM)/2.205
       ST(NSTM)=0.5556*ST(NSTM)
       SCP(NSTM)=SCP(NSTM)*4.1868
  20   CONTINUE
       GO TO 55
  30   Q(JXX)=Q(JXX)*1.055
       A(JXX)=A(JXX)/(3.281)**2
       UD(JXX)=UD(JXX)*20.4418
       HI(JXX)=HI(JXX)*20.4418
       HO(JXX)=HO(JXX)*20.4418
       RFI(JXX)=RFI(JXX)/20.4418
       RFO(JXX)=RFO(JXX)/20.4418
       KW(JXX)=KW(JXX)*6.2306
       AI(JXX)=AI(JXX)/3.281
       AO(JXX)=AO(JXX)/3.281
       IF(TISO(JXX).EQ.0.0)TISO(JXX)=0.0
       IF(TISO(JXX).NE.0.0)TISO(JXX)=(1.0/1.8)*(TISO(JXX)-32.0)+273.16
       WISO(JXX)=WISO(JXX)/2.205
       HFG(JXX)=HFG(JXX)*2.326
       IF(TP1(JXX).EQ.0.0) GO TO 35
       TP1(JXX)=(1.0/1.8)*(TP1(JXX)-32.0)+273.16
  35   IF(TP2(JXX).EQ.0.0) GO TO 36
       TP2(JXX)=(1.0/1.8)*(TP2(JXX)-32.0)+273.16
  36   CPC(JXX)=CPC(JXX)*4.1868
       CPH(JXX)=CPH(JXX)*4.1868
       SUD(JXX)=SUD(JXX)*20.4418
       SHI(JXX)=SHI(JXX)*20.4418
       SHO(JXX)=SHO(JXX)*20.4418
       SRFI(JXX)=SRFI(JXX)/20.4418
       SRFO(JXX)=SRFO(JXX)/20.4418
       SCPC(JXX)=SCPC(JXX)*4.1868
       SCPH(JXX)=SCPH(JXX)*4.1868
       GO TO 55
C
C      CONVERT TO USA UNITS
C
  40   IF(NF(JXX).NE.0.AND.NP(JXX).NE.0) GO TO 45
       MINPT=NP(JXX)
```

```
      DO 42 M=1,MINPT
      NSTM=IPD(JXX,M)
      W(NSTM)=W(NSTM)*2.205
      T(NSTM)=(T(NSTM)-273.16)*1.8+32.0
      CP(NSTM)=CP(NSTM)*0.23885
      SW(NSTM)=SW(NSTM)*2.205
      ST(NSTM)=1.8*ST(NSTM)
      SCP(NSTM)=SCP(NSTM)*0.23885
   42 CONTINUE
      GO TO 55
   45 Q(JXX)=Q(JXX)*3.412
      A(JXX)=A(JXX)*(3.281)**2
      UD(JXX)=UD(JXX)/5.6783
      HI(JXX)=HI(JXX)/5.6783
      HO(JXX)=HO(JXX)/5.6783
      RFI(JXX)=RFI(JXX)*5.6783
      RFO(JXX)=RFO(JXX)*5.6783
      AI(JXX)=AI(JXX)*3.281
      AO(JXX)=AO(JXX)*3.281
      TISO(JXX)=(TISO(JXX)-273.16)*1.8+32.0
      WISO(JXX)=WISO(JXX)*2.205
      HFG(JXX)=HFG(JXX)/2.326
      TP1(JXX)=(TP1(JXX)-273.16)*1.8+32.0
      TP2(JXX)=(TP2(JXX)-273.16)*1.8+32.0
      CPC(JXX)=CPC(JXX)*0.23885
      CPH(JXX)=CPH(JXX)*0.23885
      SUD(JXX)=SUD(JXX)/5.6783
      SHI(JXX)=SHI(JXX)/5.6783
      SHO(JXX)=SHO(JXX)/5.6783
      SRFI(JXX)=SRFI(JXX)*5.6783
      SRFO(JXX)=SRFO(JXX)*5.6783
      SCPC(JXX)=SCPC(JXX)*0.23885
      SCPH(JXX)=SCPH(JXX)*0.23885
      GO TO 55
   55 RETURN
      END
      SUBROUTINE GAUSS(IX,S,AM,V)
C
C     THIS SUBROUTINE GENERATES NORMAL RANDOM DEVIATES( WITH MEAN
C     0 AND VARIANCE 1.0 ) FROM THE UNIFORM RANDOM DEVIATES. THE
C     GENERATED RANDOM VARIABLE IS THEN ADJUSTED TO THE GIVEN
C     NOMINAL VALUES AND STANDARD DEVIATION.
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C
C      IX ............SEED INTEGER
C      S  ............VARIABLE STANDARD DEVIATION
C      AM ............VARIABLE NOMINAL VALUE
C      V  ............GENERATED RANDOM NUMBER
C                     FOR THE VARIABLE
C
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
```

```
      COMMON//IXX
      A=0.0
      DO 50 I=1,12
      CALL RANDU(IX,IY,Y)
      IX=IY
   50 A=A+Y
      V=(A-6.0)*S+AM
      IXX=IX
      RETURN
      END
      SUBROUTINE RANDU(IX,IY,YFL)
C
C     THIS SUBROUTINE GENERATES UNIFORM RANDOM NUMBERS
C     WITH MEAN 0 AND VARIANCE 1/12
C
      IY=IX*65539
      IF(IY)5,6,6
    5 IY=IY+2147483647+1
    6 YFL=IY
      YFL=YFL*.4656613E-9
      RETURN
      END
      SUBROUTINE RCTR(JXX)
C
C     THIS SUBROUTINE CALCULATES THE TEMPERATURES AND THE
C     EXTENT OF REACTION FOR THE REACTOR ELEMENT.
C
C
      DIMENSION ARRGT(6),TBUNIT(2)
      REAL KW(100)
      COMMON//ID(18)
      COMMON/KEYS/IERR(100),NELM(100),NXX,NETRN,NX,IPR,ISC,LX,JX,IBD,NFD
      COMMON/PHUNIT/WUNIT(2),TUNIT(2),TMUNIT(2),EUNIT(2),ALGTH(2),KUNIT(
     $100),LUNIT(100),PUNIT(2)
      COMMON/IOUNIT/NREAD,NPRNT,NPNCH,IIX,EPS
      COMMON/NUMA/NF(100),NP(100),IFD(100,20),IPD(100,20),IDN(100)
      COMMON/ADATA/W(200),T(200),CP(200),Q(100),UD(100),HI(100),HO(100),
     1RFI(100),RFO(100),DI(100),DO(100),TISO(100),FT(100),TP1(100),TP2(1
     200),WISO(100),HFG(100),A(100),AI(100),AO(100),KW,TDIFF(100),TIGN(1
     300),HREAC(100),CONV(100),NTEMP(100),MODEL(100)
      COMMON/STD/SW(200),ST(200),SCP(200),SHI(100),SHO(100),SRFI(100),SR
     1FO(100),SUD(100)
      COMMON/VAMXN/WMAX(20),WMIN(20),TMAX(20),TMIN(20),WOPT(20,500),TOPT
     $(20,500)
      COMMON/ADAP/CPC(200),CPH(200),SCPC(200),SCPH(200),NFA(200),NSP(200
     1),EEF(500)
      DATA TBUNIT/' ',' '/
  500 FORMAT(////5X,'REACTOR         '//5X,'ELEMENT NUMBER**',I3//5X
     1,'NUMBER OF FEED STREAMS**',I2,' NUMBER OF PRODUCT STREAMS**',I2//
     2///52X,'FEED',26X,'PRODUCT')
  370 FORMAT('1'/5X,'PROBLEM IDENTIFICATION***',18A4,2X,'*** INPUT LISTI
     1NG ***')
  375 FORMAT('1'/5X,'PROBLEM IDENTIFICATION***',18A4,1X,'*** OUTPUT LIST
     1ING ***')
```

```
      IF(NETRN.EQ.0)WRITE(NPRNT,370)ID
      IF(NETRN.EQ.1.AND.NXX.EQ.2)WRITE(NPRNT,375)ID
      WNF2=0.0
      TNF2=0.0
      CPNF2=0.0
      SWNF2=0.0
      STNF2=0.0
      SCPNF2=0.0
      WNP2=0.0
      TNP2=0.0
      CPNP2=0.0
      SWNP2=0.0
      STNP2=0.0
      SCPNP2=0.0
      IF(NETRN.NE.0) GO TO 297
C
C     READ INPUT
C
      READ(NREAD,290)IFD(JXX,1),IPD(JXX,1)
 290  FORMAT(2(6X,I4))
      READ(NREAD,295)MODEL(JXX),TDIFF(JXX)
 295  FORMAT(6X,I4,F10.5)
 297  NF1=IFD(JXX,1)
      NP1=IPD(JXX,1)
      IF(TP1(JXX).NE.0.0)T(NP1)=TP1(JXX)
      IF(CPC(JXX).NE.0.0)CP(NF1)=CPC(JXX)
      IF(SCPC(JXX).NE.0.0)SCP(NF1)=SCPC(JXX)
      IF(NETRN.EQ.1.AND.NXX.EQ.2) KUNIT(JXX)=LUNIT(JXX)
      W(NP1)=W(NF1)
      CP(NP1)=CP(NF1)
      SCP(NP1)=SCP(NF1)
      IF=IFD(JXX,1)
      IP=IPD(JXX,1)
      IF(CPC(JXX).NE.0.0)CP(IF)=CPC(JXX)
      IF(ISC.EQ.1.AND.NETRN.EQ.2) CALL RANDV(JXX)
      IF(MODEL(JXX).EQ.2)GO TO 299
C     CALCULATE TEMPERATURES
C
C
C     IF THE REACTOR MODEL 1 IS TO BE EXECUTED, THE FOLLOWING
C     COMMENT CARDS MUST BE REMOVED BY THE USER AND SHOULD BE
C     REPLACED BY THE USER'S OWN MODEL( THE FUNCTIONAL FORM OF
C     THE RELATIONSHIP AMONG THE REACTOR OUTLET TEMPERATURE,
C     EXTENT OF REACTION AND THE REACTOR INLET TEMPERATURE.)
C     FOR EXAMPLE:
C
C
C     CONV(JXX)=EXP(K1/(K2-T(IF))-K3)/(1+EXP(K1/(K2-T(IF))-K3)
C     T(IP)=TDIFF(JXX)*CONV(JXX)
C
C
C
C
C
```

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C
C
C     CONV(JXX).......EXTENTENT OF REACTION
C     T(IP)...........REACTOR OUTLET TEMPERATURE
C     T(IF)...........REACTOR INLET TEMPERATURE
C     TDIFF(JXX)......TEMPERATURE DIFFERENCE BETWEEN THE REACTOR
C                     OUTLET AND INLET STREAM
C
C     K1,K2,K3 .......CONSTANTS
C
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C
C
      IF(NETRN.EQ.1)ENL(JXX)=CONV(JXX)
      IF(ISC.GE.1.AND.NETRN.EQ.2)EXTN(JXX,IPR)=CONV(JXX)
      GO TO 301
299   T(IP)=T(IF)-TDIFF(JXX)
      IF(T(IP).LT.0)T(IP)=0.0
 301  T(NF1)=T(IF)
      T(NP1)=T(IP)
      IF(NETRN.EQ.1.AND.NXX.EQ.1) GO TO 650
      IF(ISC.GE.1.AND.NETRN.EQ.2) GO TO 650
C
C     PRINT OUTPUT
C
      IF(IDN(JXX).EQ.7) WRITE(NPRNT,500)JXX,NF(JXX),NP(JXX)
      WRITE(NPRNT,310)IFD(JXX,1),IFD(JXX,2),IPD(JXX,1),IPD(JXX,2)
 310  FORMAT(//5X,'STREAM NUMBER',29X,I3,9X,I3,17X,I3,8X,I3)
      IUNIT=KUNIT(JXX)
      WRITE(NPRNT,320)WUNIT(IUNIT),TMUNIT(IUNIT),W(NF1),WNF2,W(NP1),WNP2
     1,TUNIT(IUNIT),T(NF1),TNF2,T(NP1),TNP2,EUNIT(IUNIT),WUNIT(IUNIT),TU
     2NIT(IUNIT),CP(NF1),CPNF2,CP(NP1),CPNP2
 320  FORMAT(///5X,'FLOW RATE,',A2,'/',A2,22X,2(2X,F10.2),8X,2(2X,F10.2)
     1/5X,'TEMPERATURE,DEG ',A1,20X,2(2X,F10.2),8X,2(2X,F10.2)/5X,'HEAT
     2CAPACITY,',A3,'/',A2,' ',A1,15X,2(2X,F10.5),8X,2(2X,F10.5))
      WRITE(NPRNT,330)WUNIT(IUNIT),TMUNIT(IUNIT),SW(NF1),SWNF2,SW(NP1),S
     1WNP2,TUNIT(IUNIT),ST(NF1),STNF2,ST(NP1),STNP2,EUNIT(IUNIT),WUNIT(I
     2UNIT),TUNIT(IUNIT),SCP(NF1),SCPNF2,SCP(NP1),SCPNP2
 330  FORMAT(5X,'FLOW RATE STD,',A2,'/',A2,18X,2(2X,F10.2),8X,2(2X,F10.2
     1)/5X,'TEMPERATURE STD,DEG ',A1,16X,2(2X,F10.2),8X,2(2X,F10.2)/5X,
     2'HEAT CAPACITY STD,',A3,'/',A2,' ',A1,11X,2(2X,F10.5),8X,2(2X,F10.
     35))
  650 W(IP)=W(IF)
      CP(IP)=CP(IF)
      IERR(JXX)=0
 700  RETURN
      END
      SUBROUTINE FRHR(JXX)
C     THIS SUBROUTINE CALCULATES THE HEAT DUTY OR THE OUTPUT
C     TEMPERATURE OF THE FIRED HEATER ELEMENT.
```

```
C
C
C
      DIMENSION ARRGT(6),TBUNIT(2)
      REAL KW(100)
      COMMON//ID(18)
      COMMON/KEYS/IERR(100),NELM(100),NXX,NETRN,NX,IPR,ISC,LX,JX,IBD,NFD
      COMMON/PHUNIT/WUNIT(2),TUNIT(2),TMUNIT(2),EUNIT(2),ALGTH(2),KUNIT(
     $100),LUNIT(100),PUNIT(2)
      COMMON/IOUNIT/NREAD,NPRNT,NPNCH
      COMMON/NUMA/NF(100),NP(100),IFD(100,20),IPD(100,20),IDN(100)
      COMMON/ADATA/W(200),T(200),CP(200),Q(100),UD(100),HI(100),HO(100),
     1RFI(100),RFO(100),DI(100),DO(100),TISO(100),FT(100),TP1(100),TP2(1
     200),WISO(100),HFG(100),A(100),AI(100),AO(100),KW,TDIFF(100),TIGN(1
     300),HREAC(100),CONV(100)
      COMMON/STD/SW(200),ST(200),SCP(200),SHI(100),SHO(100),SRFI(100),SR
     1FO(100),SUD(100)
      COMMON/VAMXN/WMAX(20),WMIN(20),TMAX(20),TMIN(20),WOPT(20,500),TOPT
     $(20,500)
      COMMON/ADAP/CPC(200),CPH(200),SCPC(200),SCPH(200),NFA(200),NSP(200
     1),EEF(500)
      DATA TBUNIT/' ',' '/
  500 FORMAT(////5X,'FIRED HEATER     '//5X,'ELEMENT NUMBER**',I3//5X
     1,'NUMBER OF FEED STREAMS**',I2,' NUMBER OF PRODUCT STREAMS**',I2//
     2///52X,'FEED',26X,'PRODUCT')
  370 FORMAT('1'/5X,'PROBLEM IDENTIFICATION***',18A4,2X,'*** INPUT LISTI
     1NG ***')
  375 FORMAT('1'/5X,'PROBLEM IDENTIFICATION***',18A4,1X,'*** OUTPUT LIST
     1ING ***')
      IF(NETRN.EQ.0)WRITE(NPRNT,370)ID
      IF(NETRN.EQ.1.AND.NXX.EQ.2)WRITE(NPRNT,375)ID
      WNF2=0.0
      TNF2=0.0
      CPNF2=0.0
      SWNF2=0.0
      STNF2=0.0
      SCPNF2=0.0
      WNP2=0.0
      TNP2=0.0
      CPNP2=0.0
      SWNP2=0.0
      STNP2=0.0
      SCPNP2=0.0
      IF(NETRN.NE.0) GO TO 297
C
C     READ INPUT
C
      READ(NREAD,290)IFD(JXX,1),IPD(JXX,1)
  290 FORMAT(2(6X,I4))
      READ(NREAD,295)Q(JXX),TP1(JXX)
  295 FORMAT(E10.3,F10.5)
  297 NF1=IFD(JXX,1)
      NP1=IPD(JXX,1)
      IF(TP1(JXX).NE.0.0)T(NP1)=TP1(JXX)
```

```
      IF(CPC(JXX).NE.0.0)CP(NF1)=CPC(JXX)
      IF(SCPC(JXX).NE.0.0)SCP(NF1)=SCPC(JXX)
      IF(NETRN.EQ.1.AND.NXX.EQ.2) KUNIT(JXX)=LUNIT(JXX)
      W(NP1)=W(NF1)
      CP(NP1)=CP(NF1)
      SCP(NP1)=SCP(NF1)
      IF=IFD(JXX,1)
      IP=IPD(JXX,1)
      IF(CPC(JXX).NE.0.0)CP(IF)=CPC(JXX)
      IF(ISC.EQ.1.AND.NETRN.EQ.2) CALL RANDV(JXX)
C     CALCULATE TEMPERATURES
C
C
 602  IF(T(IP).EQ.0.0)GO TO 701
      IF(T(IP).NE.0.0)Q(JXX)=(T(IP)-T(IF))*W(IF)*CP(IF)
      EEF(JXX)=Q(JXX)
      IF(NTERN.EQ.1)ANL(JXX)=EEF(JXX)
      IF(ISC.GE.1.AND.NETRN.EQ.2)AREA(JXX,IPR)=EEF(JXX)
      GO TO 650
 701  T(IP)=T(IF)+Q(JXX)/(W(IF)*CP(IF))
      EEF(JXX)=Q(JXX)
      IF(NTERN.EQ.1)ANL(JXX)=EEF(JXX)
      IF(ISC.GE.1.AND.NETRN.EQ.2)AREA(JXX,IPR)=EEF(JXX)
      GO TO 650
      T(NF1)=T(IF)
      T(NP1)=T(IP)
      IF(NETRN.EQ.1.AND.NXX.EQ.1) GO TO 650
      IF(ISC.GE.1.AND.NETRN.EQ.2) GO TO 650
C
C     PRINT OUTPUT
C
      IF(IDN(JXX).EQ.5) WRITE(NPRNT,500)JXX,NF(JXX),NP(JXX)
      WRITE(NPRNT,310)IFD(JXX,1),IPD(JXX,1)
 310  FORMAT(//5X,'STREAM NUMBER',29X,I3,9X,I3)
      IUNIT=KUNIT(JXX)
      WRITE(NPRNT,320)WUNIT(IUNIT),TMUNIT(IUNIT),W(NF1),W(NP1),
     1,TUNIT(IUNIT),T(NF1),T(NP1),EUNIT(IUNIT),WUNIT(IUNIT),TUNIT(IUNIT)
     2,CP(NF1),CP(NP1)
 320  FORMAT(///5X,'FLOW RATE,',A2,'/',A2,22X,F10.2,8X,F10.2,/5X,'TEMPER
     1ATURE,DEG ',A1,20X,F10.2,8X,F10.2/5X,'HEAT CAPACITY,',A3,'/',A2,
     2' ',A1,15X,F10.5,8X,F10.5)
      WRITE(NPRNT,330)WUNIT(IUNIT),TMUNIT(IUNIT),SW(NF1),SW(NP1),TUNIT(I
     1UNIT),ST(NF1),ST(NP1),EUNIT(IUNIT),WUNIT(IUNIT),TUNIT(IUNIT),SCP(N
     2F1),SCP(NP1)
 330  FORMAT(5X,'FLOW RATE STD,',A2,'/',A2,18X,F10.2,8X,F10.2/5X,'TEMPER
     1ATURE STD,DEG ',A1,16X,F10.2,8X,F10.2/5X,'HEAT CAPACITY STD,',A3,
     2'/',A2,' ',A1,11X,F10.5,8X,F10.5)
      IF(IUNIT.NE.2) GO TO 360
 340  WRITE(NPRNT,350)Q(JXX),PUNIT(IUNIT)
 350  FORMAT(/5X,'HEAT DUTY',E11.4,A3)
      IF(NETRN.EQ.0)GO TO 650
      Q(JXX)=Q(JXX)*3.6
 360  WRITE(NPRNT,370)Q(JXX),EUNIT(IUNIT),TMUNIT(IUNIT)
 370  FORMAT(/5X,'HEAT DUTY',E11.4,' ',A3)
```

```
  650 W(IP)=W(IF)
      CP(IP)=CP(IF)
      IERR(JXX)=0
 700  RETURN
      END
C
C
C
      SUBROUTINE EXTENT(JXX)
C
C     THIS SUBROUTINE CALCULATES THE MEAN AND STANDARD DEVIATION
C     FOR THE EXTENT OF REACTION IN EACH REACTOR.
C
C
      COMMON//ID(18)
      COMMON/KEYS/IERR(100),NELM(100),NXX,NETRN,NX,IPR,ISC,LX,JX,IBD,NFD
      COMMON/ARAV/AREA(100,500),ANL(100),IREA(100),NUD(100),NQ(100),INFN
     1A(100),IZERA(100),EXTN(100,500),ENL(100)
      COMMON/PHUNIT/WUNIT(2),TUNIT(2),TMUNIT(2),EUNIT(2),ALGTH(2),KUNIT(
     $100),LUNIT(100),PUNIT(2)
      COMMON/ZAK/IA,TBAR,STDV,RVAR(9)
      COMMON/IOUNIT/NREAD,NPRNT,NPNCH
      DATA NTLE/0/
 375  FORMAT('1'/5X,'PROBLEM IDENTIFICATION***',18A4,1X,'*** OUTPUT LIST
     1ING ***')
      IF(NTLE.NE.0) GO TO 410
      WRITE(NPRNT,375)ID
      NTLE=1
 410  SUMA=0.0
      SUMA2=0.0
      LM=0
      DO 420 K=1,LX
      IF(EXTN(JXX,K).EQ.0.0) LM=LM+1
 420  SUMA=SUMA+EXTN(JXX,K)
      ALX=LX-LM
      LXR=ALX
      ABAR=SUMA/ALX
      TBAR=ABAR
      IUNIT=LUNIT(JXX)
      DO 430 K=1,LX
      IF(EXTN(JXX,K).EQ.0.0) GO TO 430
      A1=EXTN(JXX,K)-ABAR
      A2=A1*A1
      SUMA2=SUMA2+A2
 430  CONTINUE
      STDA=SQRT(SUMA2/(ALX-1.0))
      STDV=STDA
      WRITE(NPRNT,450)JXX,LX,ABAR,STDA
 450  FORMAT(////5X,'ELEMENT NUMBER**',I5//5X,'TOTAL NUMBER OF SIMULATIO
     1NS**',I8/5X,'MEAN EXTENT OF REACTION    **',F10.8/5X,'STANDARD DE
     2VIATION**',F10.8)
      RETURN
      END
```

APPENDIX B

PREPARATION OF INPUT DATA AND CARD BY CARD INSTRUCTION

PREPARATION OF INPUT DATA

In preparation of the input data, some specific instructions should be followed regarding the control data cards, format for all input cards, the sequence of elements order and identification of the feedback streams. The following suggestions will help to avoid problem failure due to mislocating an element in the system:

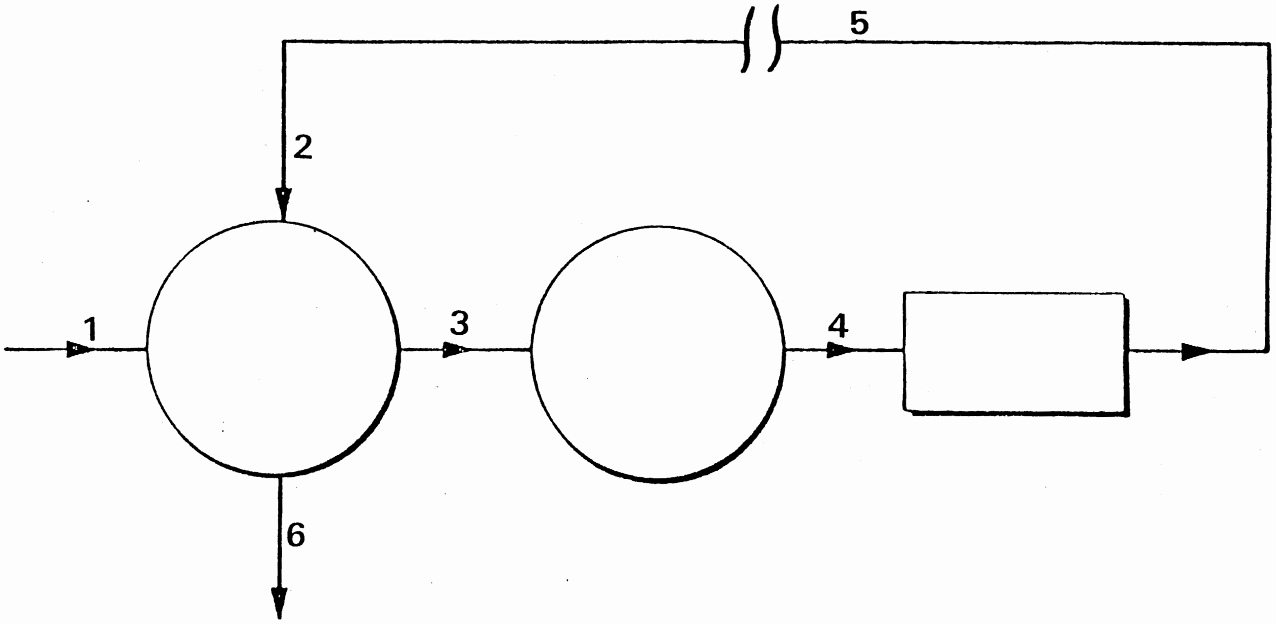
1. Draw a schematic flow diagram for the system.

2. Number all the elements in the system from 1 to 100 including the input and output tanks. It is preferred that the numbering is in the same order that the calculation is to be carried out but it is not necessary.

3. Number the streams in and out of each element between 1 and 200.

4. Pay special attention in numbering the feedback streams. An example is given in Figure B.1. Note that in the feedback stream is numbered twice. Stream 2 serves as input stream for element 1 and stream 5 serves as the output stream for element 3. But they are equivalent when the system converges. The initial guess value of the unknown parameter of the feedback stream should be supplied with the stream 2 input data specifications. The program output will provide the converged values of the feedback stream parameters.

5. Order elements (cards) in the order the calculations are to be carried out, paying attention to the continuation of flow of information from one element to the one next in line.



2 - FEED BACK STREAM INITIAL NUMBER

5 - FEED BACK STREAM FINAL NUMBER

Figure B.1. Numbering of the Feed Back Stream

6. All the output streams for which the statistics of the output stream temperature are required should be specified in the output element.

7. Number of feed streams in the output element is equal to the total number of output streams for which the statistics of the output stream temperature are required.

Card By Card Instruction

Problem Indentification

This is the first card in the data set cards and 1 to 70 alphanumeric characters can be assigned. If none is assigned, no identification is printed but a blank card should be included instead (Figure B.2).

Control Data Card 1

There are three data spaces in this card (Figure B.2). They are:

1. Deterministic Calculation for Feedback Option. If the nominal values of the feedback stream variables are unknown and need to be converged, an integer 1 should be entered here. If the nominal values of the feedback stream variables are fixed then this space should be left blank.

2. Monte Carlo Simulation for Feedback Option. If the heat exchanger system includes feedback streams and the Monte Carlo simulation is required, an integer 1 should be entered here; otherwise the space is left blank.

3. Distillation Column Option. If the feed-effluent heat exchanger system includes a Distillation Column, an integer 1 should be entered here, otherwise the space should be left blank.

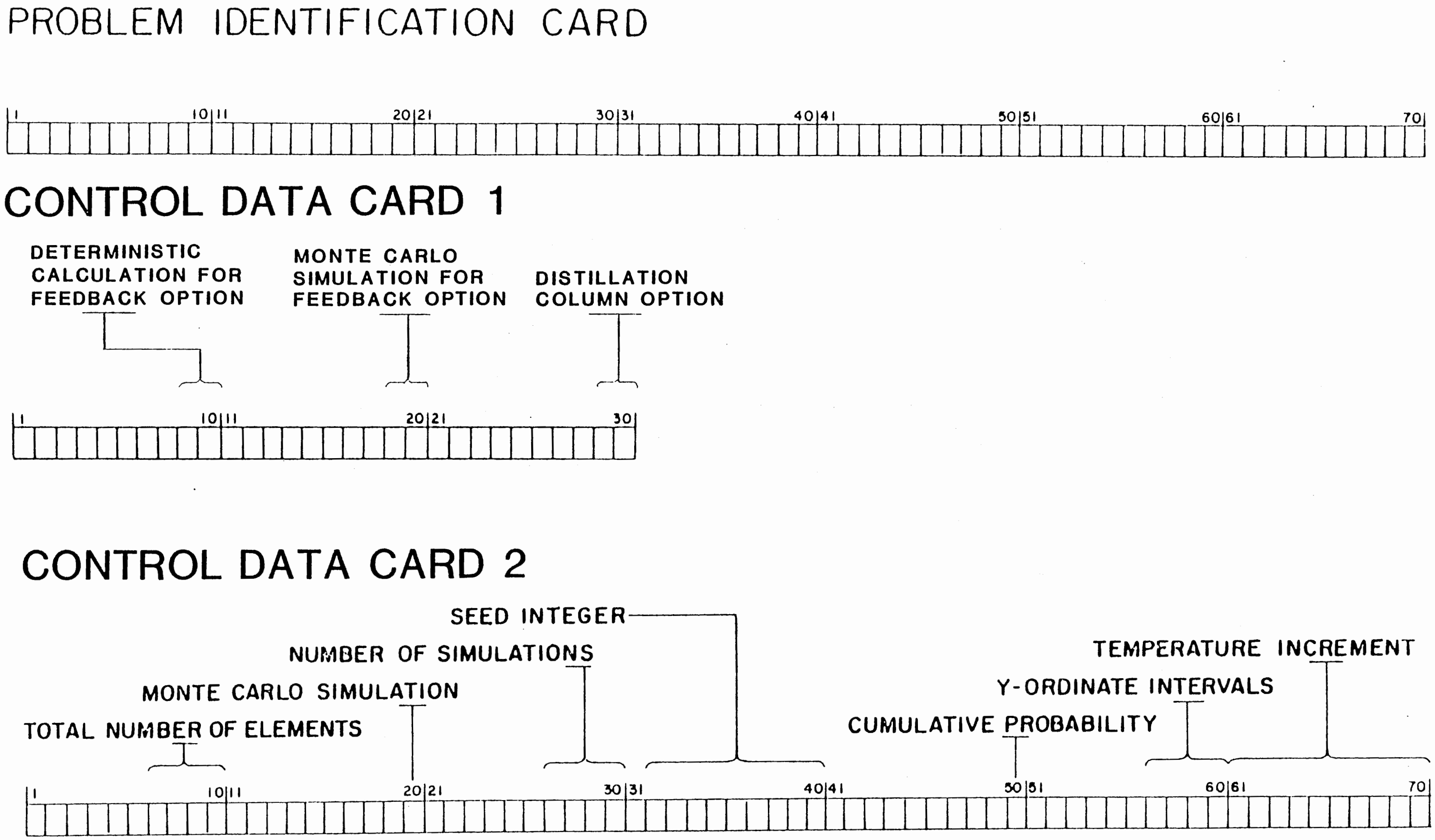


Figure B.2. Control Cards Input Data Form

If the heat exchanger system does not include any feedback stream, Control Data Card 1 should be left blank but should be included in the data set.

Control Data Card 2

This data card consists of seven data spaces (Figure B.2). They are as follows:

1. Total Number of Elements. This number indicates the total Number of elements in the system including input and output elments. An integer between 3 and 100 should be entered here.

2. Monte Carlo Simulation. An integer value 1 will cause the program to execute the Monte Carlo simulation. An integer of 0 will cause the program to perform only the deterministic simulation part. If no value is entered, the program will set the value to 0.

3. Number of Iterations. An integer between 1 to 500 should be entered here if the Monte Carlo Simulation is specified. The integer indicates the required number of simulations. If Monte Carlo simulation is not required, then this space hsould be left blank.

4. The Seed Integer. An odd integer number with nine digits should be entered here to start the random number generation process. If the Monte Carlo simulation is not specified, the space should be left blank.

5. Cumulative Probability Curves. An integer value of 1 should be entered here in order to calculate and plot the cumulative probability curve for each effluent stream temperature. If the Monte Carlo simulation is not specified, this space should be left blank.

6. Y-ordinate Scale. If the cumulative probability curves are specified, an integer number 1 to 60 (representing the number of intervals the total probability consists of) is entered here. The total probability is 1.0 and for an increment of 0.02, the number of intervals will be 50. If this data spa-e is left blank an integer number of 50 is assumed.

7. Temperature Increment. In order to calculate the cumulative probability for a certain temperature, the difference between the maximum and minimum value for the temperature is divided into intervals. The total number of intervals resulting is dependent on the temperature movement specified here. If cumulative probability curves are needed and this space is left blank, an increment of 1.0 degree is assumed for a total number of intervals 100 or less. If the temperature difference between maximum and minimum temperature is more than 100 degrees, an increment of 2.0 degrees is assumed. The temperature increment used will be evident in the X-ordinate for the plot.

Process Element Card

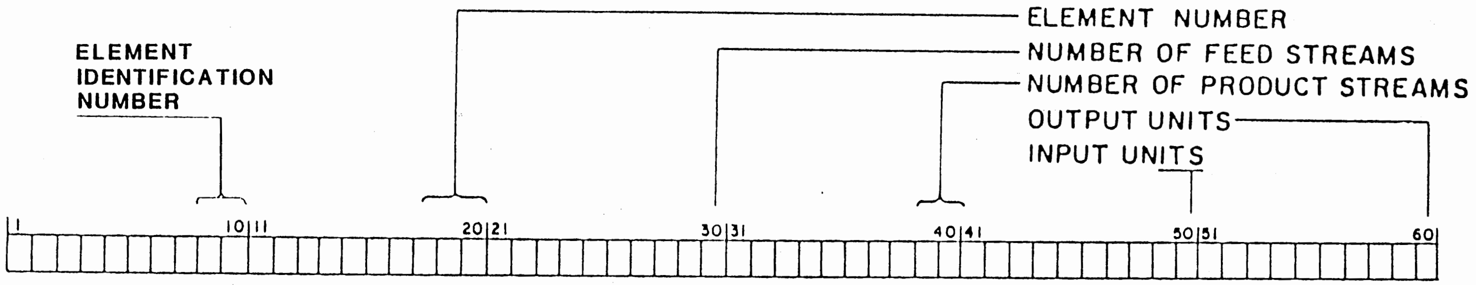
Each element must have a Process Element Card (Figure B.3). This card has six data spaces:

1. Element Identification Number. Each element has its own identification number (an integer number). They are listed in Table III.1 (and also in the main program). Identification number corresponding to each element should be entered here.

2. Element Number. An integer in the range of 1 to 100 should be assigned to each element and the specific number is entered here.

3. Number of Feed Streams to the Element. An integer in the

PROCESS ELEMENT INPUT



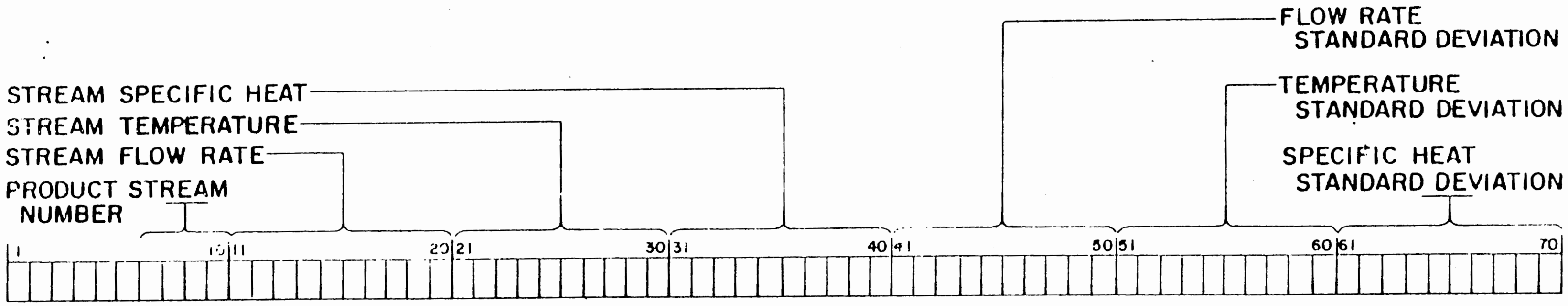


Figure B.3. Process Element Input Data Cards Form range of 0 to 20 is entered here. The integer is dependent on the type of element under consideration.

4. Number of Product Streams from the Element. An integer in the range of 0 to 20 is entered.

5. Input Units for the Element. The program is capable of handling two different types of unit: U.S. Customary and SI units. Table B.1 shows the types of units corresponding to the variables used in this program. If the input variables are in U.S. Customary units, an integer 1 should be entered here. If they are given in the International System an integer 2 should be entered here.

6. Output Units for the Element. An integer 1 or 2 is entered here depending on the desired system of units. Integer 1 for U.S. Customary units and integer 2 for SI units.

Process Element Input

Process Data Card

For each product stream of the Input Element one process data card must be included in the data set. This card has seven data spaces (Figure B.3).

1. Stream Number. An integer between 1 and 200 is assigned to each stream should be entered here.

2. Flow rate. The stream flow rate in the input units specified should be entered here.

3. Temperature. The stream temperature in the specified input units should be entered here.

4. Specific Heat. The stream fluid specific heat in the specified input units should be entered here. In the case where the

TABLE B.1

TYPES OF UNITS USED IN THE PROGRAM

Variable	U.S. Customary Units	SI Units
Heat Transfer Coefficient	Btu/hrft^2°F	W/m^{2}K
Thermal Conductivity	Btu/hrft°F	W/mK
Specific Heat	Btu/lbF	KJ/kgK
Power	Btu/hr	W
Temperature	F	K
Length	ft	m
Mass	lb	kg

fluid is a mixture of components and partial condensation is occurring inside the heat exchanger, an approximate procedure is used where a pseudo-specific heat for mixture is calculated by dividing the enthalpy difference between inlet and outlet temperatures by the temperature difference.

$$C_p(\text{pseudo}) = \frac{H_{T_1} - H_{T_2}}{T_1 - T_2}$$

where H_{T_1} and H_{T_2} are the enthalpy at temperature T_1 and T_2 respectively.

5. Flow Rate Standard Deviation. If Monte Carlo simulation is specified and there is uncertainty in the stream flow rate, a value for the flow rate standard deviation (in the same units as the specified flow rate) should be entered here. If it is assumed that there is no uncertainty in the stream flow rate, then this space should be left blank.

6. Temperature Standard Deviation. If Monte Carlo simulation is specified and there is variation in the stream temperature, a value for the stream temperature standard deviation (in the same units as the specified stream temperature) should be entered here. Otherwise this space is left blank.

7. Specific Heat Standard Deviation. If Monte Carlo simulation is specified and there is uncertainty in the specific heat of the stream fluid, a value for the specific heat standard deviation (in the same unit as specified specific heat) should be entered here. Otherwise this space is left blank.

Process Element Adder

Process Data Card

This card contains five data spaces (Figure B.4). The first four spaces should be filled by the corresponding feed stream numbers and the fifth should be filled by the product stream number. If the element has less than four feed streams, a data space is left blank for each missing stream.

Process Element Divider

Process Data Card 1

This card contains five data spaces (Figure B.5). The first space should be filled by the feed stream number and the rest of the four spaces should be filled by the corresponding product streams numbers. For elements with less than four product streams, a data space is left blank for each missing stream.

Process Data Card 2

This card contains four data spaces (Figure B.5). A space for each fraction of the feed stream going into the corresponding product stream. All fractions are positive numbers ranging in value from 0.0 to 1.0 and the sum should always be 1.0. For each product stream missing, a corresponding data space is left blank.

Process Element Heat Exchanger

Process Data Card 1

This card consists of four data spaces (Figure B.6):

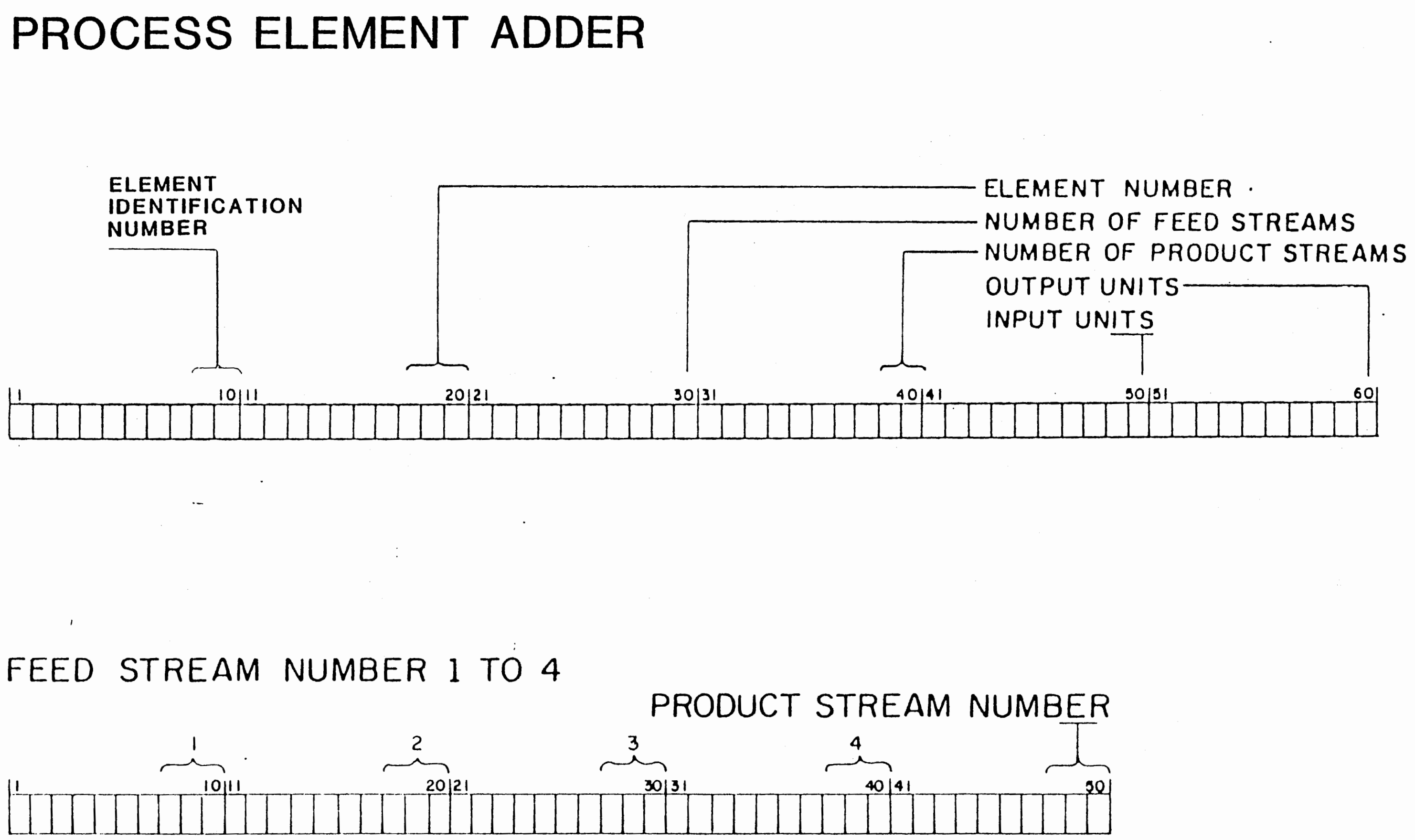


Figure B.4. Process Element Adder Input Data Card Form

PROCESS ELEMENT DIVIDER

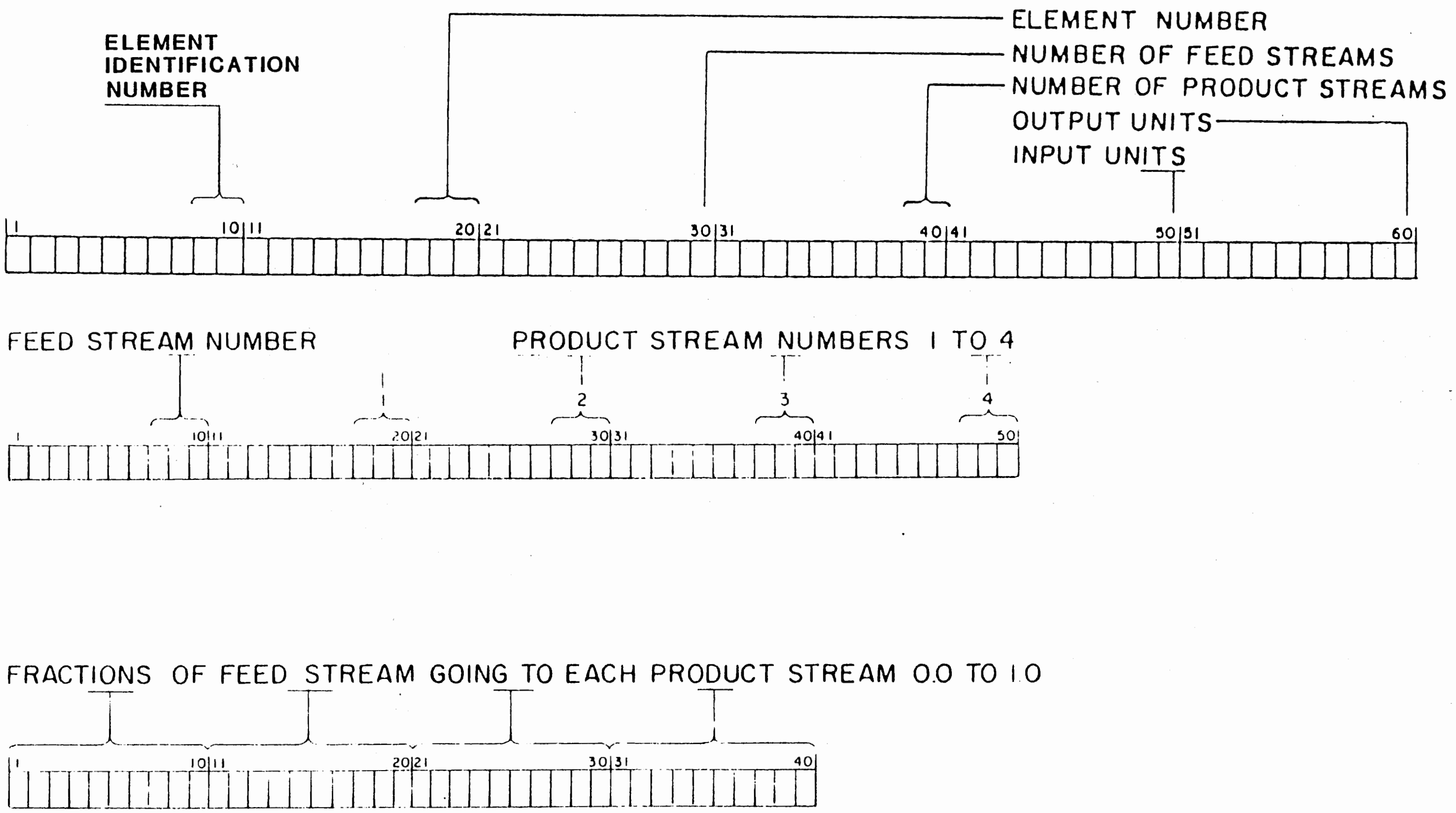


Figure B.5. Process Element Divider Input Data Cards Form

PROCESS ELEMENT HEAT EXCHANGER

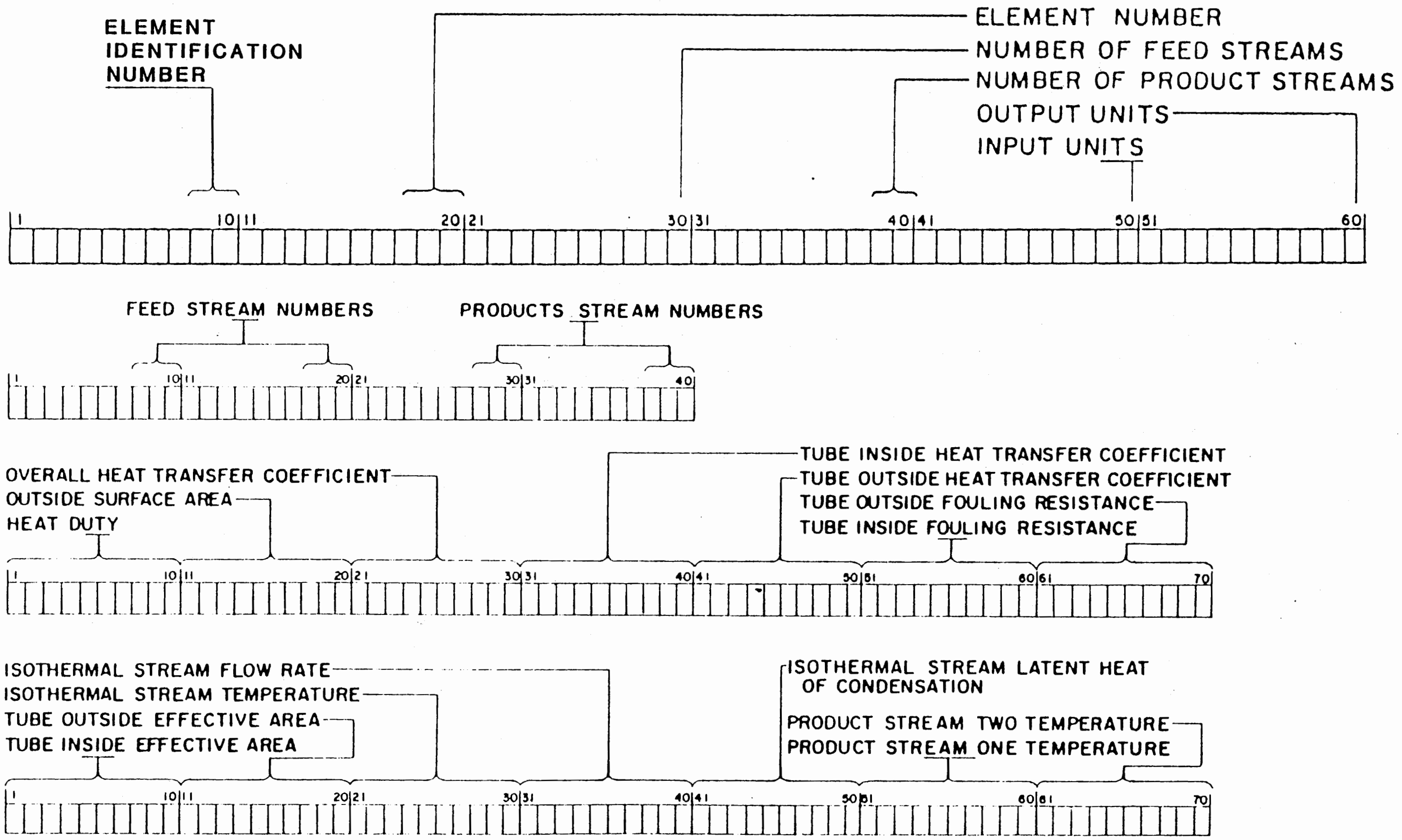


Figure B.6. Process Element Heat Exchanger Input Data Card Form

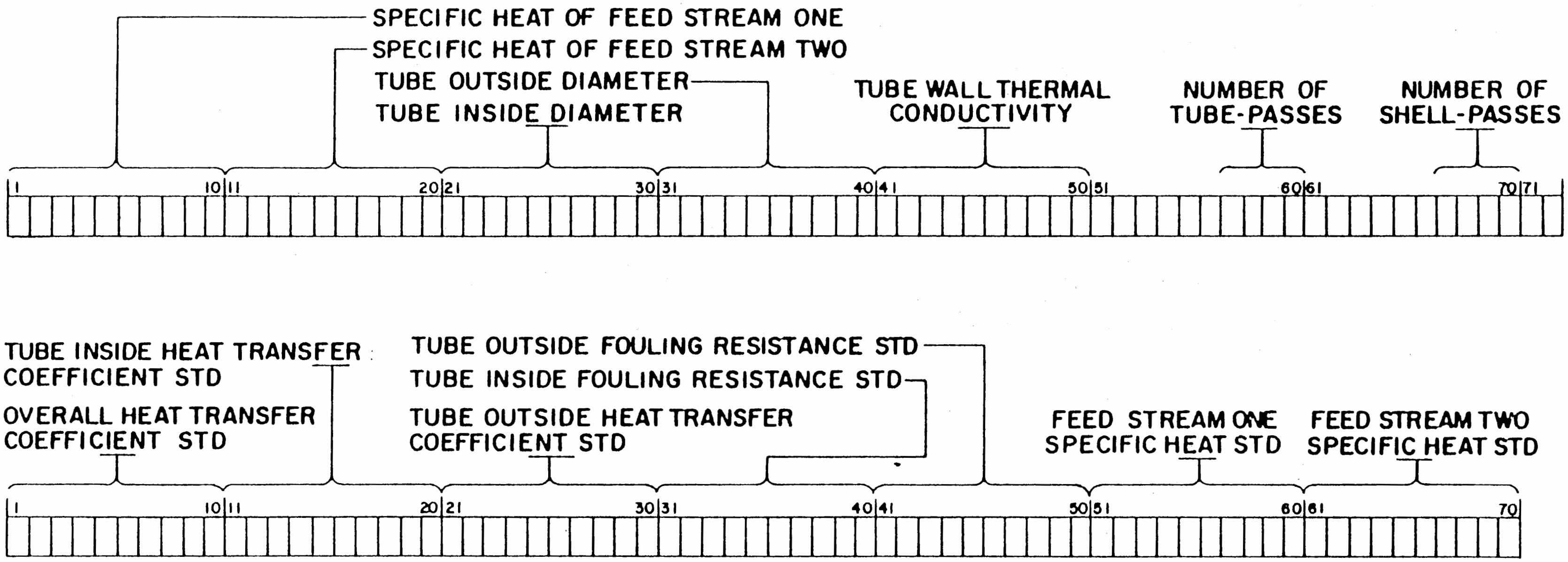


Figure B.6. (Continued)

1. First Feed Stream Number. The colder stream of the two feed streams is the first feed stream. The assigned number of the colder stream should be entered here.

2. Second Feed Stream Number. The hotter stream of the two feed streams is the second feed stream. The integer number assigned for the hotter stream should be entered here.

3. First Product Stream Number. Product stream number which corresponds to first feed stream is entered here.

4. Second Product Stream Number. Product stream number which corresponds to the second feed stream is entered here.

Process Data Card 2

There are seven data spaces in this card (Figure B.6). They are:

1. Heat Duty. The total heat flow rate (in the specified input units) is entered here. In the E-format. If the heat duty is to be calculated this space is left blank.

2. Heat Exchanger Area. If the heat duty is not specified and the outlet stream temperatures are to be calculated, then the heat exchanger total surface area (in the specified input units) should be specified here.

3. The Overall Heat Transfer Coefficient. If the overall heat transfer coefficient (based on outside area) is known, its value is entered here (in the specified input units). If it needs to be calculated, then this space is left blank.

4. The Tube Inside Heat Transfer Coefficient. If the overall heat transfer coefficient (based on outside area) is to be calculated, a value for the tube inside heat transfer coefficient should be entered here.

5. The Shell Side Heat Transfer Coefficient. If the overall heat transfer coefficient (based on the outside area) is not specified, a value for the Shell Side Heat Transfer Coefficient should be entered here.

6. Tube Inside Fouling Resistance. If the overall heat transfer coefficient is not specified, and if the tube side fouling is known, the value of the tube inside fouling resistance is entered here. Otherwise this space is left blank.

7. Shell Side Fouling Resistance. If the overall heat transfer coefficient is not specified, and if the shell side fouling is known, the value of the shell side fouling resistance is entered here. Otherwise this space is left blank.

Process Data Card 3

There are seven data spaces on this card (Figure B.6). They are:

1. Tube Inside Effective Area. A value for the tube inside effective area per unit length is entered here.

2. Tube Outside Effective Area. A value for the tube outside effective are per unit length is entered here.

3. Isothermal Stream Temperature. For Heat Exchanger Element this space is left blank.

4. Isothermal Stream Flow Rate. For Heat Exchanger Element this space is left blank.

5. The Fluid Latent Heat of Condensation. For Heat Exchanger Element this space is left Blank.

6. First Product STream Temperature. If the outlet temperature of the colder stream is specified, its value is entered here.

Otherwise this space is left blank.

7. Second Product Stream Temperature. If the outlet temperature of the hotter stream is specified, its value is to be entered here. Otherwise this space is left blank.

If the statistics of the heat exchanger surface area are to be calculated, then both the product stream temperature should be specified.

Process Data Card 4

There are seven data spaces in this card (Figure B.6). They are:

1. Cold Stream Specific Heat. If a pseudo specific heat of the cold fluid, or an average value calcualted for the inlet and outlet specific heats of the stream is needed, its value is entered here. A specific heat value entered here overrides the value designated for the stream fluid from a previous calculation on the basis of a constant specific heat assumption. If the specific heat is constant, this space is left blank.

2. Hot Stream Specific Heat. The pseudo or average specific heat for the hotter stream is entered here. If the specific heat is constant, this space is left blank.

3. Tube Inside Diameter. If the overall heat transfer coefficient is not specified, and if the tube wall resistance is to be calculated, a value for the tube inside diameter is entered here. Otherwise, this space is left blank.

4. Tube Outside Diameter. If the overall heat transfer coefficient is not specified, and if the tube wall resistance is to be considered, a value for the tube outside diameter is entered here. Otherwise this space is left blank.

5. Tube Wall Thermal Conductivity. If the overall heat transfer coefficient is not specified, and if the tube wall resistance is to be considered, a value for the tube wall thermal conductivity is entered here. Otherwise, this space is left blank.

6. Flow Arrangement. An integer 1, 2, or 3 is entered here for the type of flow arrangement specified. An integer number 1 indicates cocurrent flow and an integer number 2 indicates countercurrent flow arrangements. An integer number 3 indicates 1-n, 2-2n, etc. (n = 2, 4, 6, ...; where n is the number of tube passes) types of flow arrangement.

7. Number of Shell Passes. An integer number indicating the number of shell passes on separate shells in series is entered here.

Process Data Card 5

This data card consists of seven data spaces (Figure B.6). These data spaces are filled by the standard deviations of the overall heat transfer coefficients, tube inside heat transfer coefficients, shell side heat transfer coefficient, tube inside fouling resistance, shell side fouling resistance, cold fluid specific heat and the hot fluid specific heat respectively. If the standard deviation of the overall heat transfer coefficient is specified, then the spaces designated for the standard deviations of the tube inside and shell side heat transfer coefficients and fouling resistances are left blank. If Monte Carlo simulation is not specified this card is included as a blank card.

Process Element Heater or Condenser

Process Data Card 1

This card consists of four data spaces (Figure B.7):

1. Feed Stream Number. The nonisothermal feed stream number is entered here.

2. Isothermal Feed Stream Number. The isothermal feed stream number is entered here.

3. Product Stream Number. The nonisothermal product stream number is entered here.

4. Isothermal Product Stream Number. The isothermal product stream number is entered here.

Process Data Card 2

This data card consists of seven data spaces (Figure B.7). The entries of these data spaces are exactly the same as the Process Data Card 2 of the Process Element Heat Exchanger.

Process Data Card 3

This data card consists of seven data spaces (Figure B.7):

1. Tube Inside Effective Area. A value for the tube inside effective area per unit length is entered here.

2. Tube Outside Effective Area. A value for the tube outside effective area per unit length is entered here.

3. Isothermal Stream Temperature. If the heat duty is not specified and if the nonisothermal product stream temperature is to be calculated, the isothermal stream temperature should be specified here. Otherwise this space is left blank.

PROCESS ELEMENT HEATER OR CONDENSER

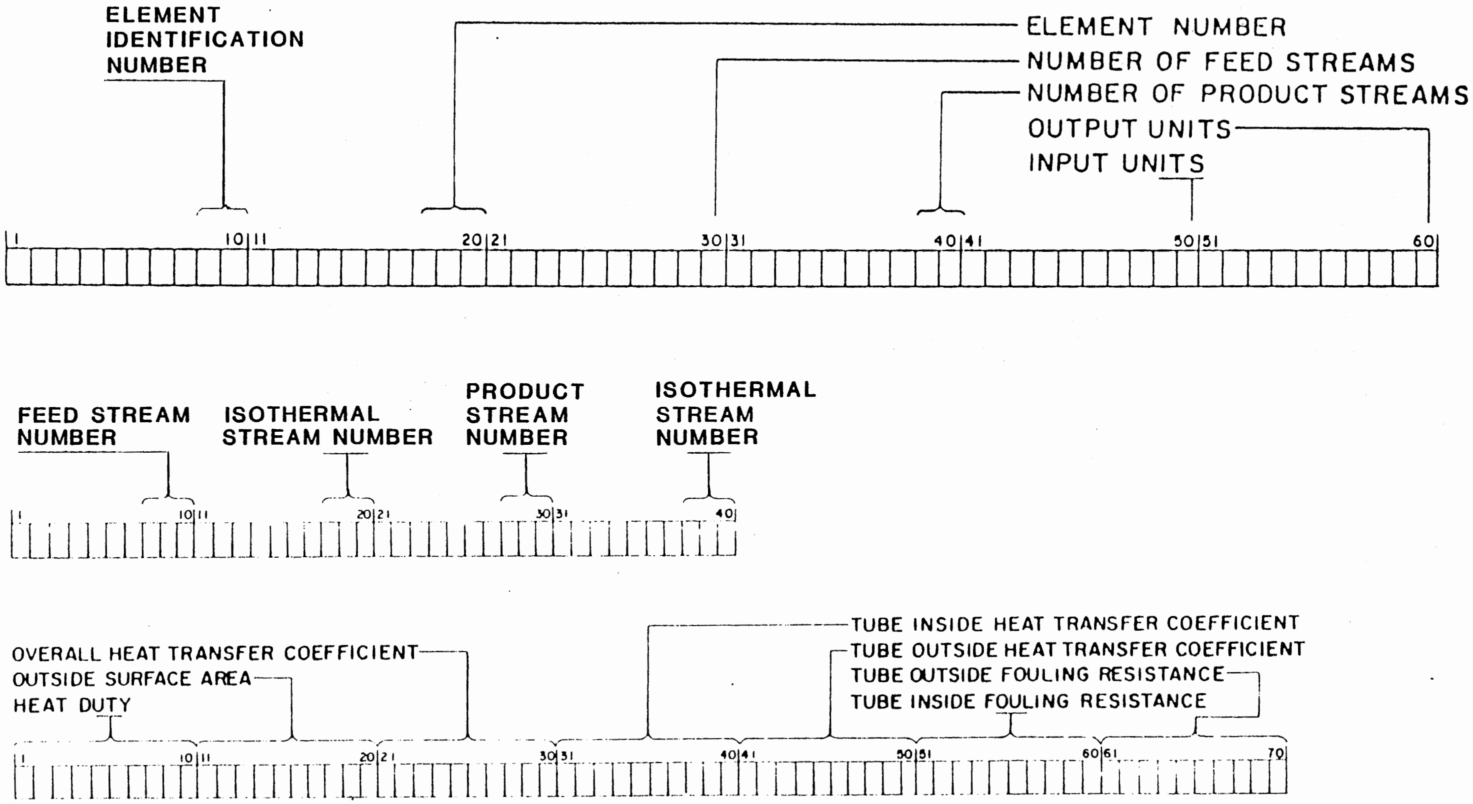


Figure B.7. Process Element Heater or Condenser Input Data Cards Form

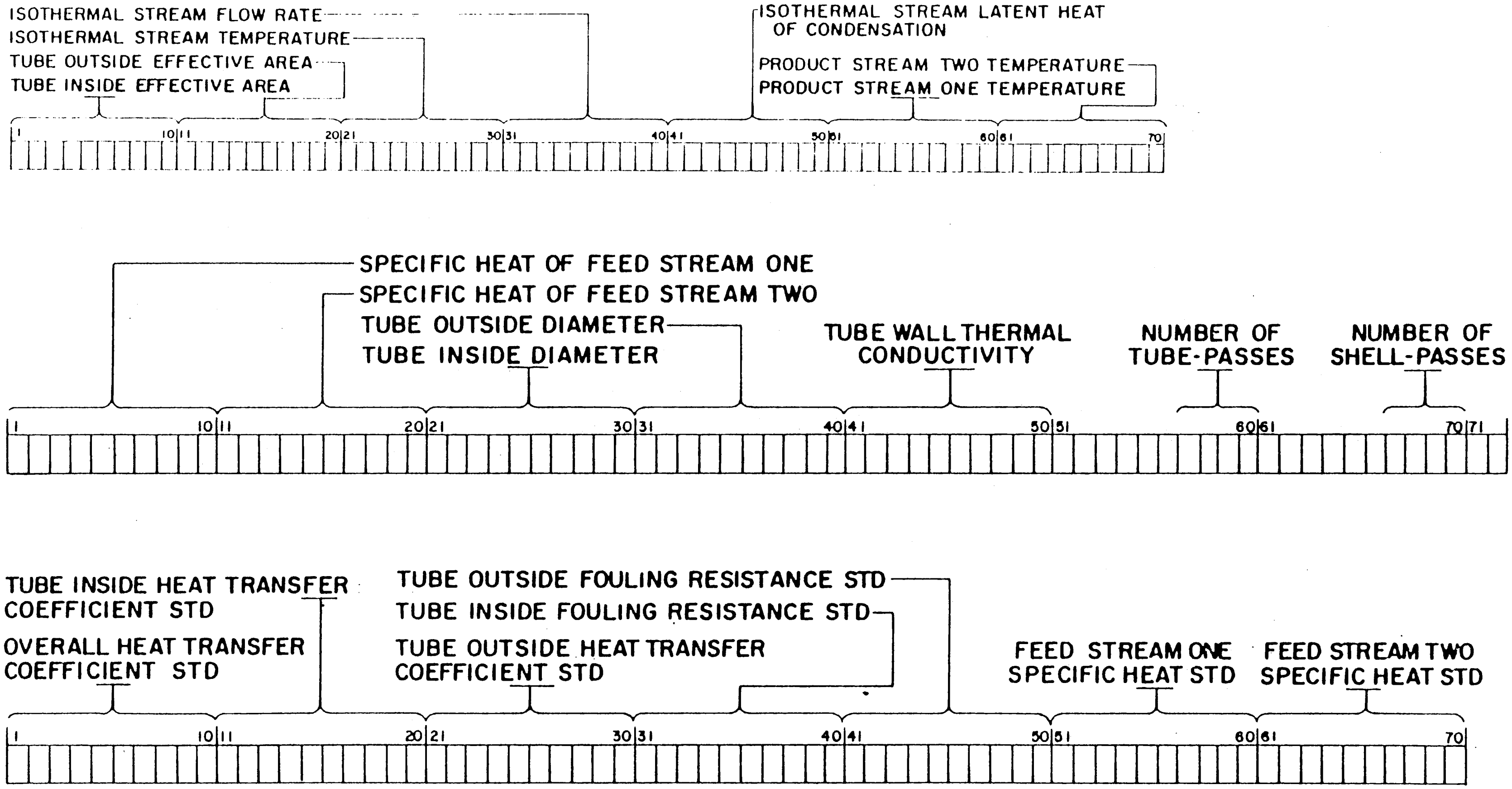


Figure B.7. (Continued)

4. Isothermal Stream Flow Rate. If the heat duty of the exchanger is not specified and needs to be calculated from the flow rate and the latent heat of the condensing vapor, the flow rate is entered here. Otherwise this space is left blank.

5. The Fluid Latent Heat of Condensation. If the latent heat of condensation is required, it is entered here. Otherwise this space is left blank.

6. First Product Stream Temperature. This is the nonisothermal product stream temperature. If the statistics of the condensing stream temperature is to be calculated, the first product stream temperature should be specified here. Otherwise this space is left blank.

7. Second Product Stream Temperature. This space is left blank.

Process Data Card 4

This card consists of seven data spaces (Figure B.7). Entries of all the data spaces except the 2nd data space, are the same as the entries of the Process Data Card 4 of the Process Element Heat Exchanger. The 2nd data space in this card which is designated for the Hot Stream Specific Heat is left blank.

Process Data Card 5

There are seven data spaces in this card (Figure B.7). The entries of these data spaces are exactly the same as the entries of the Process Data Card 5 of the Process Element Heat Exchanger.

Process Element Distillation

Process Data Card 1

This card contains seven data spaces (Figure B.8). The first space should be filled by the distillation element feed stream number and the rest of the six spaces should be filled by the distillation element product stream numbers. For an element with less than six product streams, a data space is left blank for each missing stream.

Process Data Card 2

This card consists of seven data spaces (Figure B.8). The first space should be filled by the element feed stream flow rate in the specified input units. If the flow rate to be calculated then this space should be left blank. The rest of the six data spaces should be filled by the distillation element product stream flow rates in the specified input units. If there is less than six product streams, a data space is left blank for each missing stream.

Process Data Card 3

This card consists of seven data spaces (Figure B.8). In the first data space the feed stream temperature should be entered in the specified input units. If the feed stream temperature to be calculated then this space should be left blank. In the remaining six data spaces stream temperature for each of the product streams should be entered. If there are fewer than six product streams, a data space is left blank for each missing stream.

PROCESS ELEMENT DISTILLATION

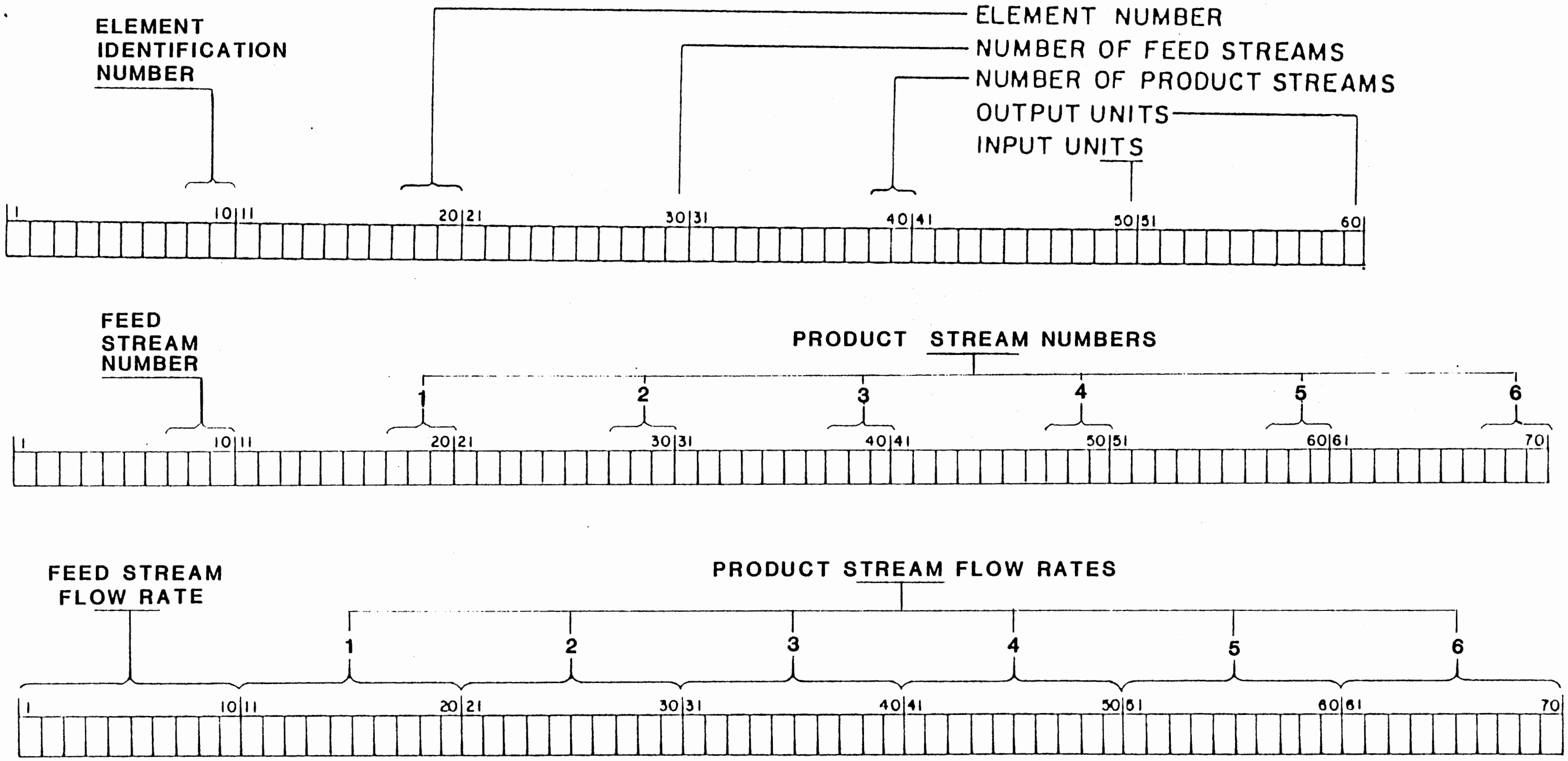


Figure B.8. Process Element Distillation Input Data Cards Form

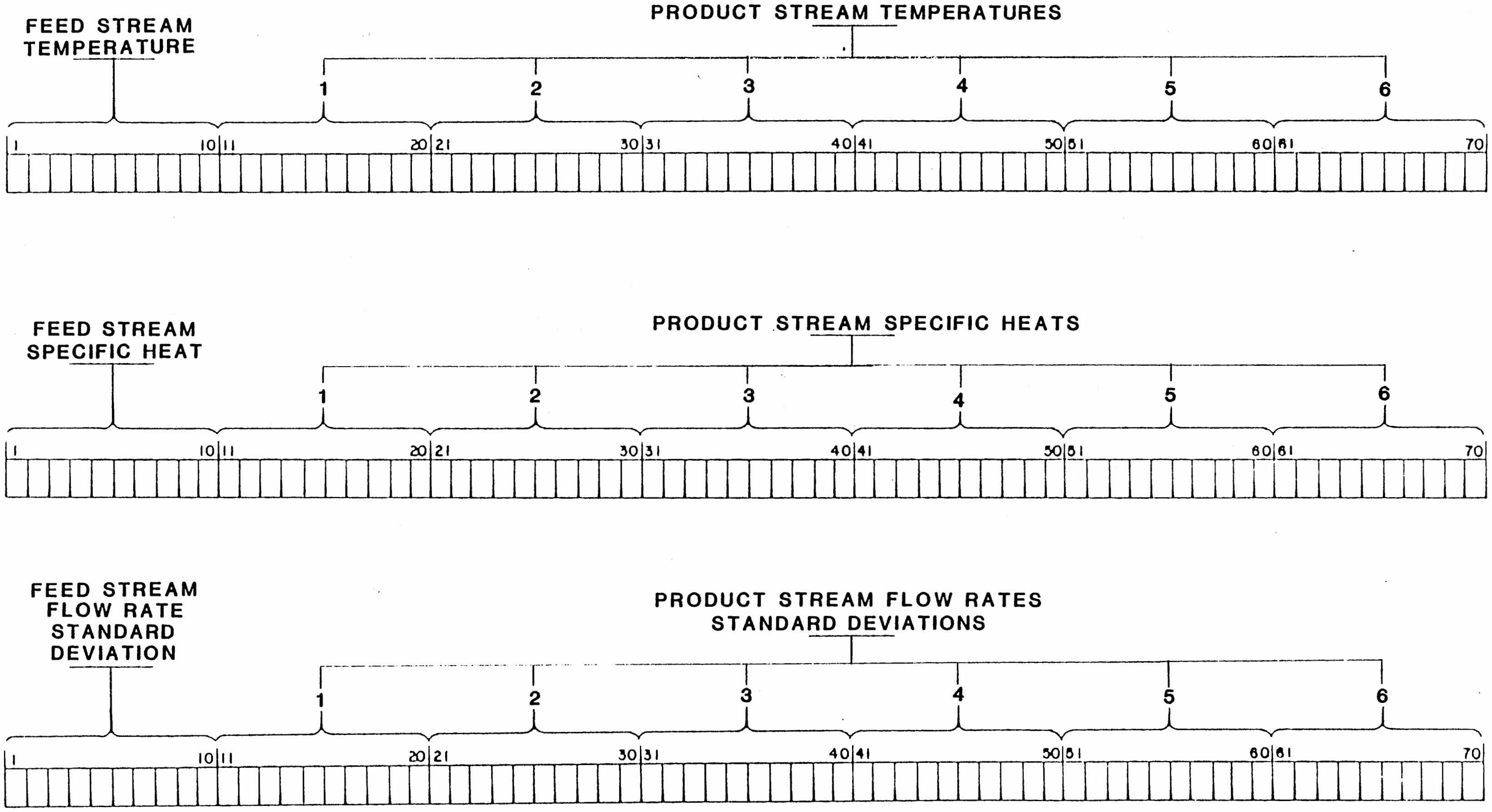


Figure B.8. (Continued)

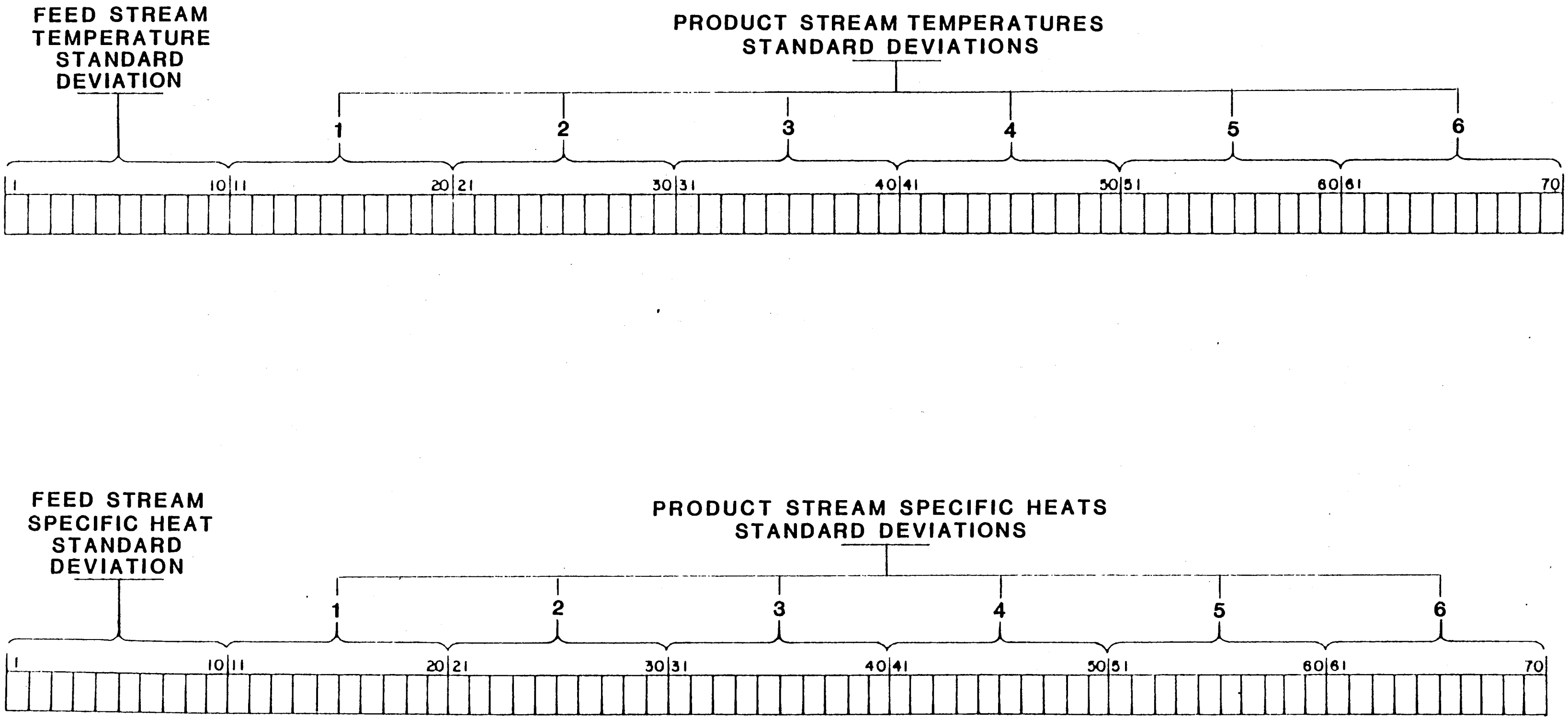


Figure B.8. (Continued)

Process Data Card 4

This card consists of seven data spaces (Figure B.8). The first data space should be filled by the feed stream specific heat in the specified input unit. If the feed stream specific heat is to be calculated, this space is left blank. The next six data spaces should be filled by the product stream specific heats in the specified input units. If there are fewer than six product streams a data space is left blank for each missing stream.

Process Data Card 5

This card consists of seven data spaces (Figure B.8). If there is uncertainty in the feed stream flow rate then a value of the flow rate standard deviation should be entered in the first data space. If there is no variation in the feed stream flow rate, then this space is left blank. Similarly the next six data spaces should be filled by the product stream flow rate standard deviations. If it is assumed that there is no uncertainty in the product stream flow rates, these spaces should be left blank.

Process Data Card 6

This card consists of seven data spaces (Figure B.8). In the first data space the feed stream temperature standard deviation should be entered. But if the feed stream temperature standard deviation is to be calculated, this space should be left blank. The next six data spaces should be filled by the product streams temperature standard deviations if they are available, if not, these spaces should be left blank. If there are fewer than six product streams a data space is left blank for each missing stream.

Process Data Card 7

This card consists of seven data spaces (Figure B.8). If there is uncertainty in the feed stream specific heat, the first data space should be filled by the standard deviation of the feed stream specific heat, otherwise this space is left blank. Similarly, the next six data spaces should be filled by the product stream specific heat standard deviations. If it is assumed that there is no uncertainty in the product stream specific heats, then these spaces should be left blank.

Process Element Reactor

Process Data Card 1

There are two data spaces in this card (Figure B.9). The first space should be filled by the reactor element feed stream number and the second space should be filled by the corresponding product stream number.

Process Data Card 2

There are two data spaces in this card (Figure B.9). The are:

1. Reactor Model. An integer value 1 will cause the program to execute the reactor model in which the reactor outlet temperature is a function of the reactor inlet temperature and the extent of the reaction. An integer value 2 will cause the program to execute the reactor model in which the change of stream temperature is constant.

2. Constant Temperature Change. If reactor model 2 is to be executed the value of the constant temperature change should be entered

PROCESS ELEMENT REACTOR

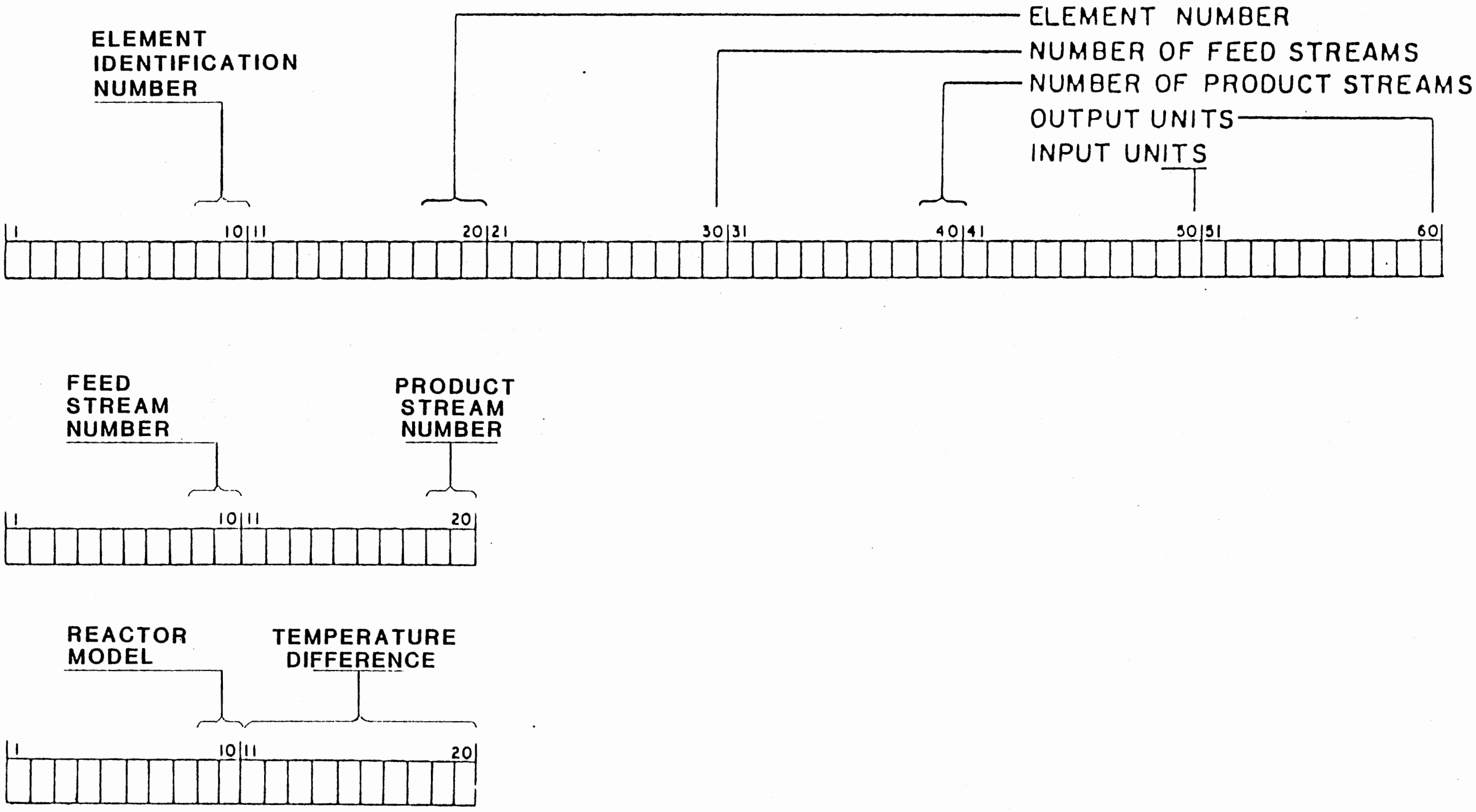


Figure B.9. Process Element Reactor Input Data Cards Form here, otherwise this space is left blank. (Note: the functional form of the relationship among the reactor inlet temperature, extent of the reaction and the reactor outlet temperature must be supplied by the user in the computer program.)

Process Element Fired Heater

Process Data Card 1

There are two data spaces in this card (Figure B.10). The first space should be filled by the fired heater element feed stream number and the second space should be filled by the corresponding product stream number.

Process Data Card 2

There are two data spaces in this card (Figure B.10). They are:

1. Heat duty. Fired heater heat duty in the specified input units should be specified here if the product stream temperature is to be calculated. If the statistics of the fired heater heat duty are to be calculated then this space should be left blank. Heat duty should be entered in E-format.

2. Product Stream Temperature. If the product stream temperature is to be calculated, this space should be left blank. But if the statistics of the fired heater heat duty to be calculated, the product stream temperature should be specified here.

Process Element Output

Process Data Card 1

This card consists of 14 data spaces (Figure B.11). Each space

PROCESS ELEMENT FIRED HEATER

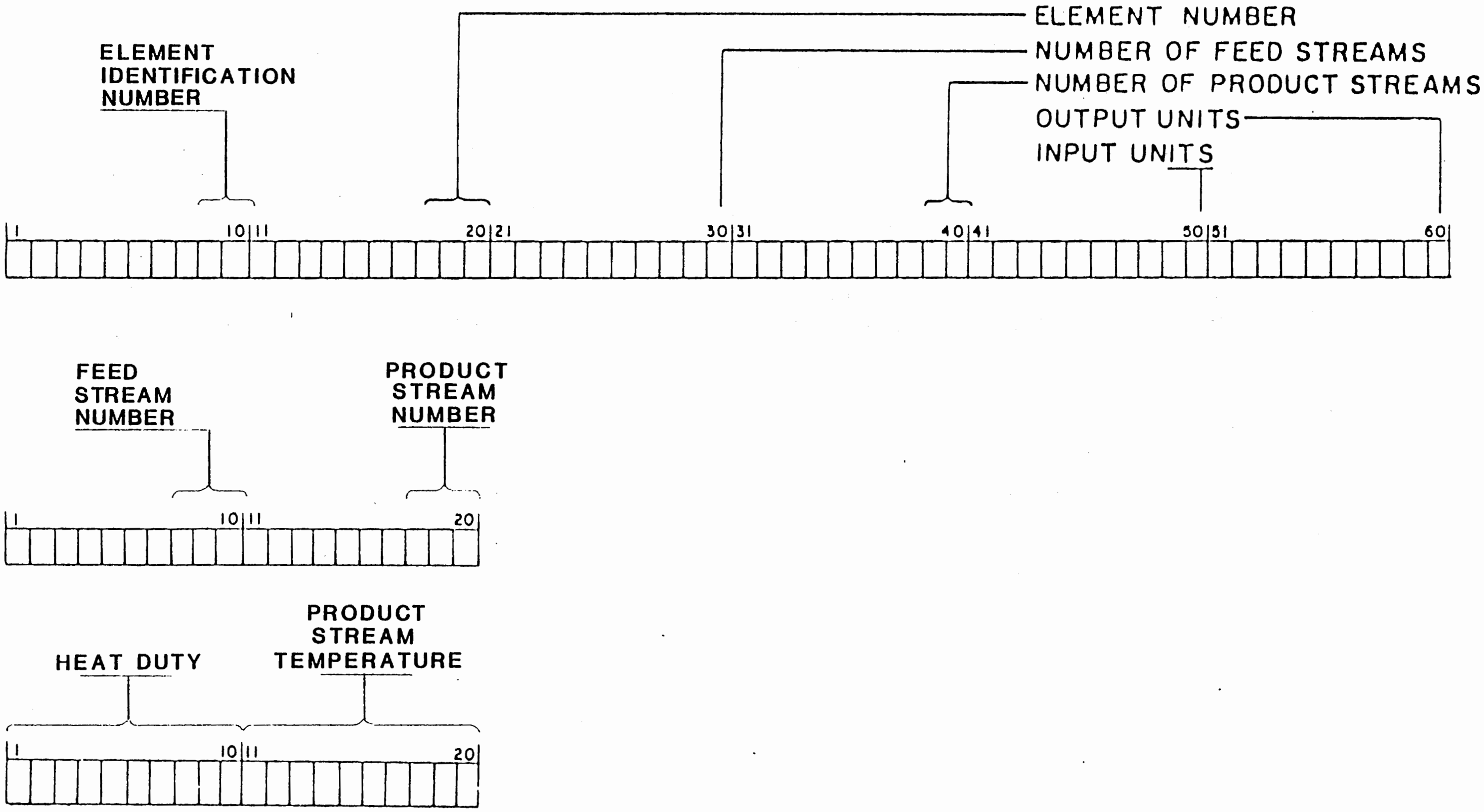


Figure B.10. Process Element Fired Heater Input Data Cards From is filled with a output stream number for which the statistics of the output stream temperature is required (each stream is considered as a feed stream to the output element). If the system includes Distillation Element, the first data space of this card should be filled by the distillation column feed stream number. If there are fewer than 14 feed streams, the remaining data spaces are left blank.

Process Data Card 2

This card contains six data spaces (Figure B.11). Each space is filled with a output stream number for which the statistics of the output stream temperature are required. If there are 14 or less feed streams, this card should be included in the data set but left blank.

Process Data Card 3

This card contains two data spaces (Figure B.11). The first space should be filled with a value for the convergence tolerance. The next space should be filled with the total number of feedback streams included in the system.

Process Data Card 4

This card (Figure B.11) should be included if any of the nominal values of the feedback stream variables are unknown and the Monte Carlo simulations for the feedback stream are specified. This card should not be included if the program executes distillation column option. This card contains 10 pair of data spaces (20 data spaces). Each pair of data spaces should be filled with the pair of feedback stream numbers specified for each feedback stream (Figure B.1), the initial number being the first number to be filled. If there are fewer than 10 feedback streams, each pair of data spaces should be left blank for each missing feedback stream.

Process Data Card 5

There are six data spaces in this card (Figure B.11). If the feedback system includes distillation element, the uncertainty coefficient for each product stream should be entered in these spaces. Otherwise this card should not be included in the data set.

Process Data Card 6

There are six data spaces in this card (Figure B.11). If the feedback system includes distillation element, each space is filled with a distillation element output stream number. If there are fewer than 6 product streams, the remaining data spaces are left blank.

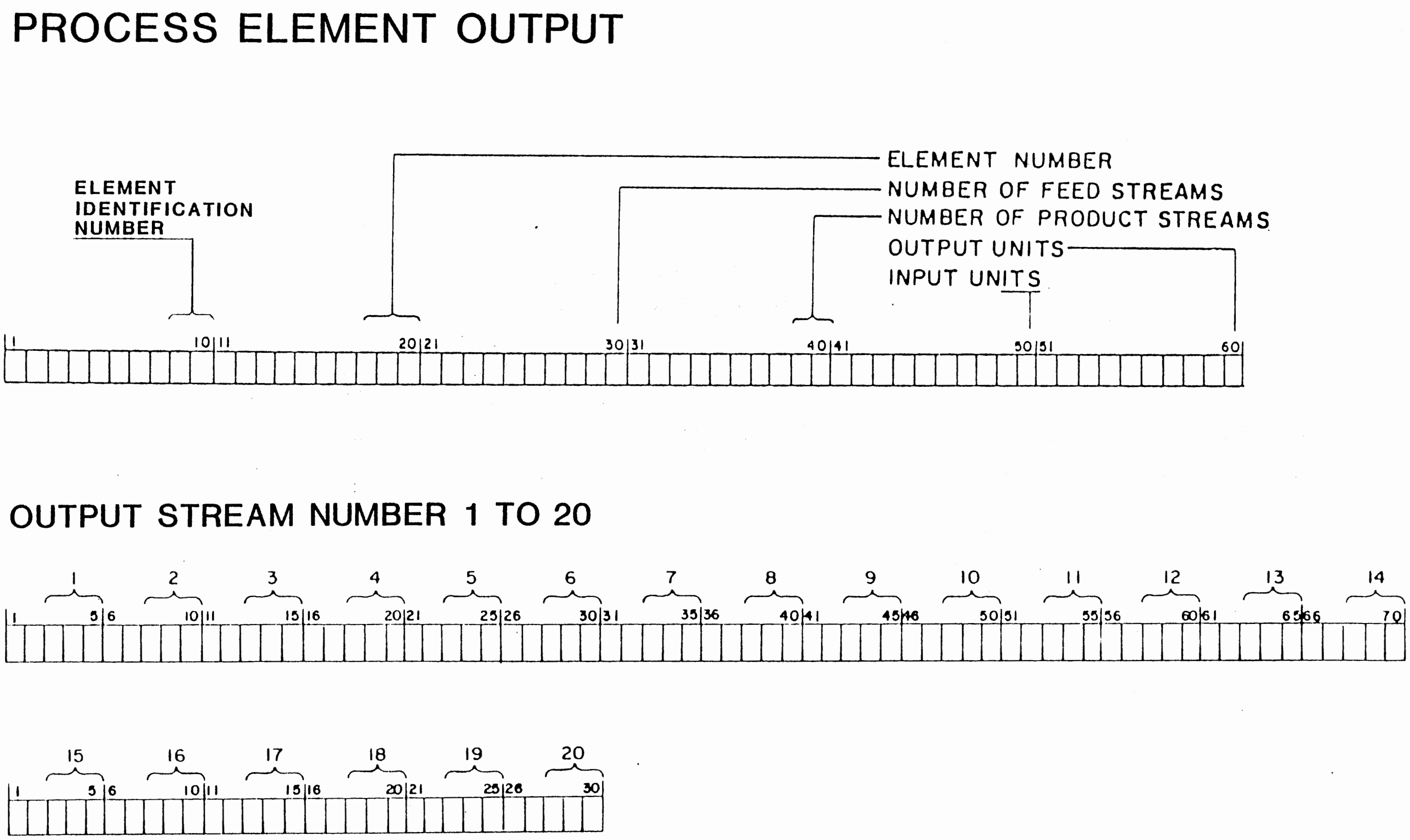


Figure B.11. Process Element Output Data Cards Form

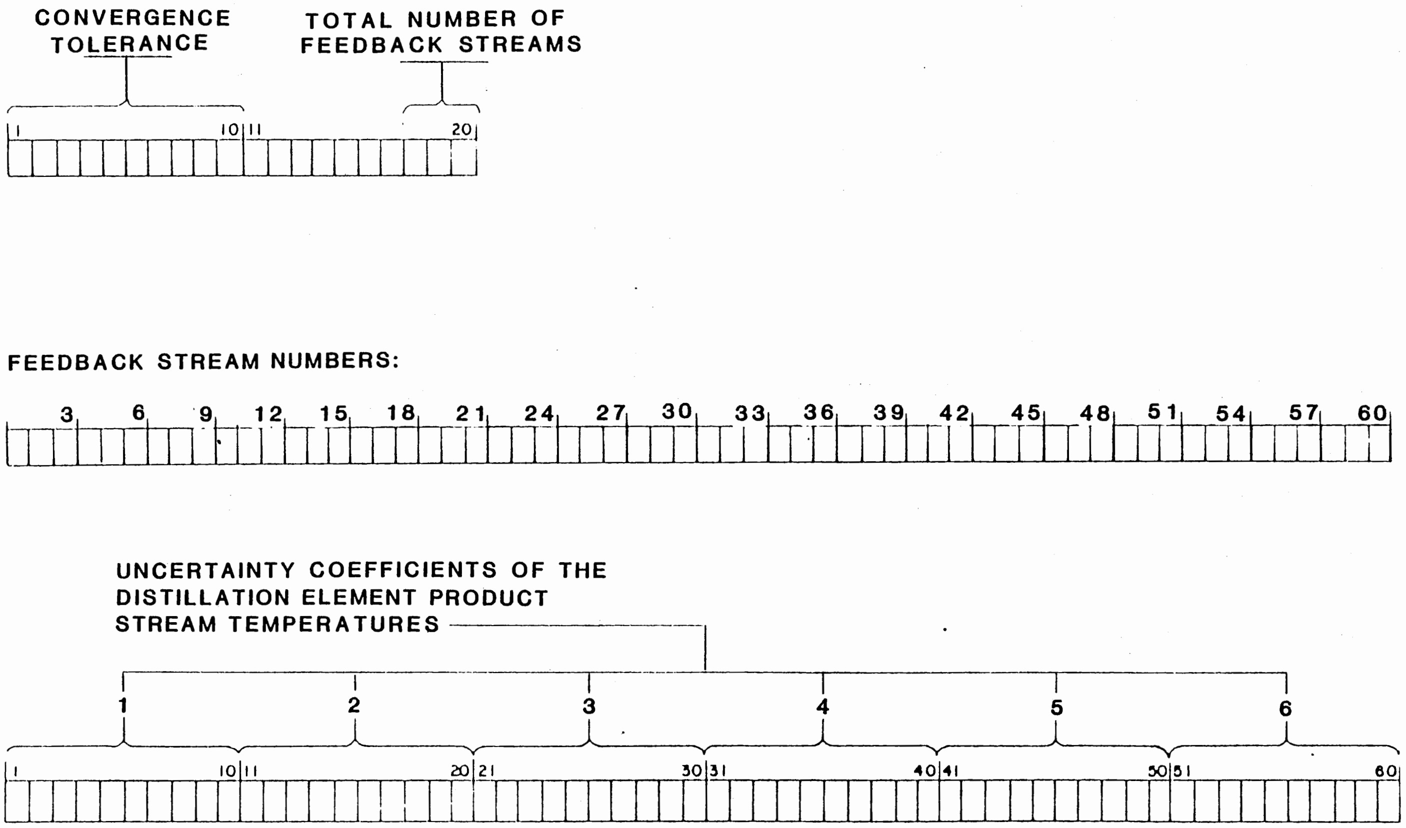


Figure B.11. (Continued)

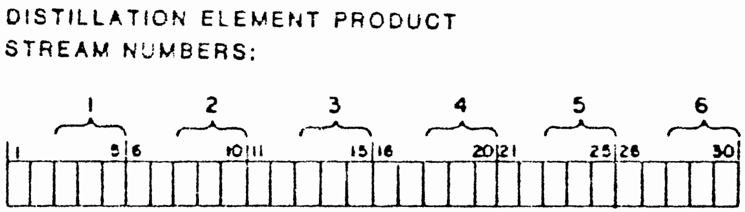


Figure B.11. (Continued)

VITA

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