THE APPLICATION OF ON-LINE ESTIMATION TO A DOUBLE EFFECT EVAPORATOR

APPENDICES

A thesis submitted for the degree of

Doctor of Philosophy

by

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August 1974

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Supporting papers are to be found in the wallet at the inside back cover of this part of the thesis.

APPENDIX 1

HEAT EXCHANGER DATA

TABLE A1

	Preheater	1st Effect	2nd Effect	Condenser
No. of Shell Passes	1	1	1	1
No. of Tube Passes	4	1	1	6
No. of Tubes	1	4	7	1
Shell I.D. (m)	0.1015	0.1015	0.152	0.152
Shell O.D. (m)	0.11	0.11	0.1605	0.1605
Tube I.D. (m)	0.0188	0.0188	0.0254	0.0205
Tube O.D. (m)	0.0221	0.0221	0.0286	0.0286
Tube Length (m)	1.37	2.59	1.065	2.13
Volume of Tubes (m^3)	0.585E-3	0.1105E-2	0.114 E-2	0.194 E-2
Tubes internal volume (m^3)	0.152E-2	0.2875E-2	0.376 E-2	0.645 E-2
Volume of Shell (m^3)	0.9E-2	0.17E-1	0.145 E-1	0.302 E-1
Tube Flow Area (m^2)	0.478E-3	0.111E-2	0.354 E-2	0.505 E-3
Shell Flow Area (m^2)	0.694 E-2	0.694 E-2	0.146 E-1	0.15E-1
Tubes Inside Area (m^2)	0.324	0.612	0.591	1.01
Tubes Outside Area (m^2)	0.38	0.72	0.672	1.15
Shell Inside Area (m^2)	0.437	0.825	0.508	1.102
Wetted perimeter (m)	0.0695	0.0695	0.0895	0.0895
Tube OD/ID	1.18	1.18	1.15	1.15

APPENDIX 2

THE H316/MDP200 INTERFACE

A2.1 Introduction

Originally, the available on-line system hardware consisted of the EAL MDP200 data logger and the PDS1020 digital computer. Although the logger and computer are produced by the same manufacturer, and thus are hardware and software compatible, the system is restricted. Firstly, the PDS1020 has only 4K core and is relatively slow in operation and secondly, as a result of the small memory size, on-line programming is limited to the use of machine code or assembler language.

Replacement of the PDS1020 by a Honeywell 316 minicomputer improves the on-line system in three ways. Firstly, the machine is faster so that data logging can be accompanied by processing and results made available to the user in real time. Secondly, the H316 has 12K core so that on-line processing is not restricted by machine size. Finally, as a result of both processing speed and core size, the programming capability is vastly improved. The development of the high level data logging software is described in Appendix 3.

One disadvantage of the acquisition of the H316 is that the computer and data logger are not hardware compatible. The objective of this Appendix is to describe in detail the hardware link between the H316 and MDP200. The new machine code instructions for the H316 are discussed together with the hardware operations they produce.

A2.2 The PDS1020 - MDP200 Link

Since the objective of the interface design is for the H316 to emulate the PDS1020, it is advantageous to discuss the operation of the data logger in its original state (ref. A2.1).

To select channels in random order under the control of the PDS1020, the computer parallel output is used. This consists of 17 parallel input/output lines representing four hexadecimal digits and a sign bit. In order to select input channels together with data amplifier ranging, computer information must be output as follows:

1000	ADC	Amplifier Range by-pass	Filter in
2000	ADC	Amplifier Range x 10	
3000	ADC	Amplifier Range x 100	
4000	ADC	Amplifier Range x 1000	
5000	ADC	Amplifier Range by-pass	Filter out
6000	ADC	Amplifier Range x 10	
7000	ADC	Amplifier Range x 100	
8000	ADC	Amplifier Range x 1000	
9000	Digital Clock Data (hours and minutes)		
L000	Scan Identification Switches		
C000	Digital Clock Data (seconds and tenths of seconds)		

where L and C are hexidecimal equivalents of decimal 10 and 11.

With regard to the channel address, the tens digit on the first eight commands is the tens digit of the channel. The units digit corresponds to the units digit of the channel. Thus the channel number is entered into the last two digits as a BCD number.

When one of the above commands is loaded into the accumulator of the

PDS1020 it is output to the MDP200 by the output data parallel (1800 +) instruction. When the MDP200 responds with the resulting data word, it is input to the accumulator by the input data parallel (0005 +) instruction. The control signals generated by the MDP200 and PDS1020 in executing input/output are as follows.

A2.2.1 Output

a) Device Ready - The logger applies a logic 1 signal to the computer whenever it has finished processing a previous channel.

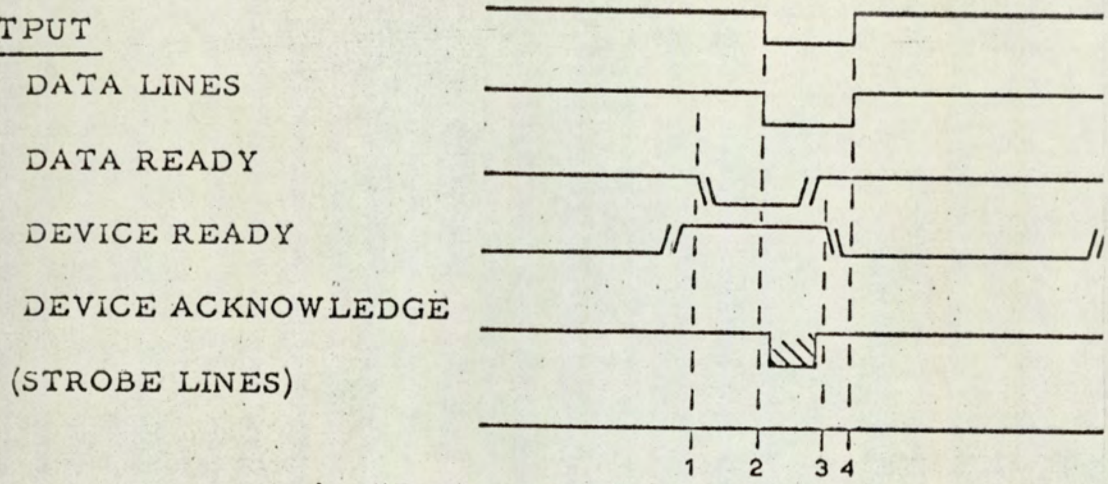
b) Data Ready - If a device ready signal is presented by the logger and an 1800 + instruction has been carried out in the computer, the data lines will assume the levels dictated by the information currently in the accumulator, and the Data Ready control line assumes a logic 1 level.

c) Device Acknowledge - On receipt of a data ready signal, the logger will transfer the command portion of the data output into a buffer store and the address portion into the scanner control unit decade counters. When this is complete the data logger will present a logic 1 level on the Device Acknowledge control line.

FIGURE A2.1

MDP200/PDS1020 CONTROL SIGNALS

OUTPUT

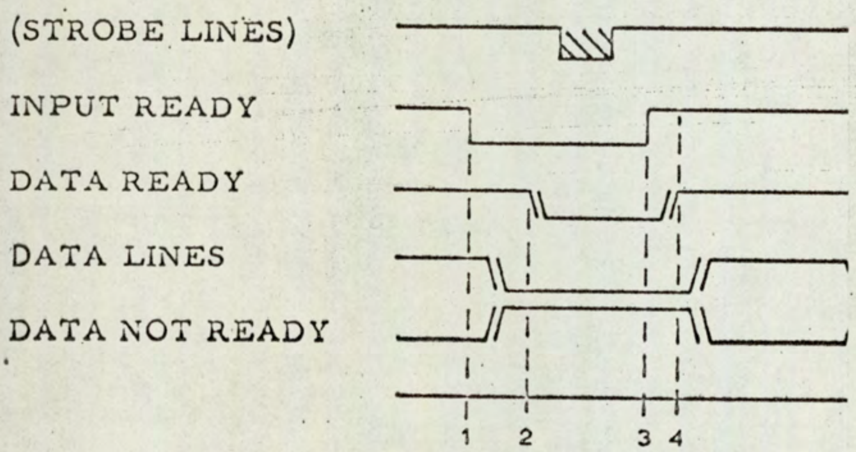


1. "Device ready" from device
2. Data and "Data ready" from computer
3. Acknowledge from device
4. Data lines released

FIGURE A2.2

MDP200/PDS1020 CONTROL SIGNALS

INPUT



1) Computer will strobe lines if DATA READY and INP instruction is created.

2) Device must release DATA READY after INPUT READY is released.

1. "Input ready" from computer
2. "Data ready" from device
3. "Input ready" released
4. "Data ready" released

The timing of the PDS1020 output control signals is shown in Figure A2.1. When the computer executes the output command, it waits for a Device Ready signal from the MDP200. When the signal is received, the computer places an instruction data word on the lines and sends a Data Ready signal to the device. When the device has sampled the data, it sends an acknowledge signal to release the computer.

A2.2.2 Input

Input Ready - The computer applies a logic 1 signal to the logger whenever a 0005 + instruction is executed.

The timing of the input control signals is shown in Figure A2.2. When the computer executes the input command, the computer sends an Input Ready signal to the logger which places the data on the parallel input lines. The computer then samples the data lines and places the result in the accumulator. As soon as the computer has accepted the data, it releases the Input Ready line, and the logger releases the Data Ready line to terminate the input command.

A2.3 The H316 - MDP200 Link

The MDP200 data logger is constructed specifically to link with the PDS1020 computer. The emulation of the operation of the PDS1020 by the H316 is not trivial since the two computers are produced by separate companies and the dates of manufacture are separated by the transition from transistor to integrated circuits. Thus the interface problems are concerned with logic level conversion and signal timing so that the H316 produces and accepts the logical control signals described previously.

A2.3.1 The Honeywell Buffer

External devices can be linked to the standard Honeywell input/output interface by the Buffered I/O Channel option (ref. A2.2). Figure A2.3 presents a simplified block diagram of the standard buffered I/O channel showing the principal control signals involved in input/output data transfers. The device permits the transfer of a 16-bit word to or from an external device (the MDP200). It is assumed that the device presents incoming signals in the correct logical state. The instructions are as follows:

Output

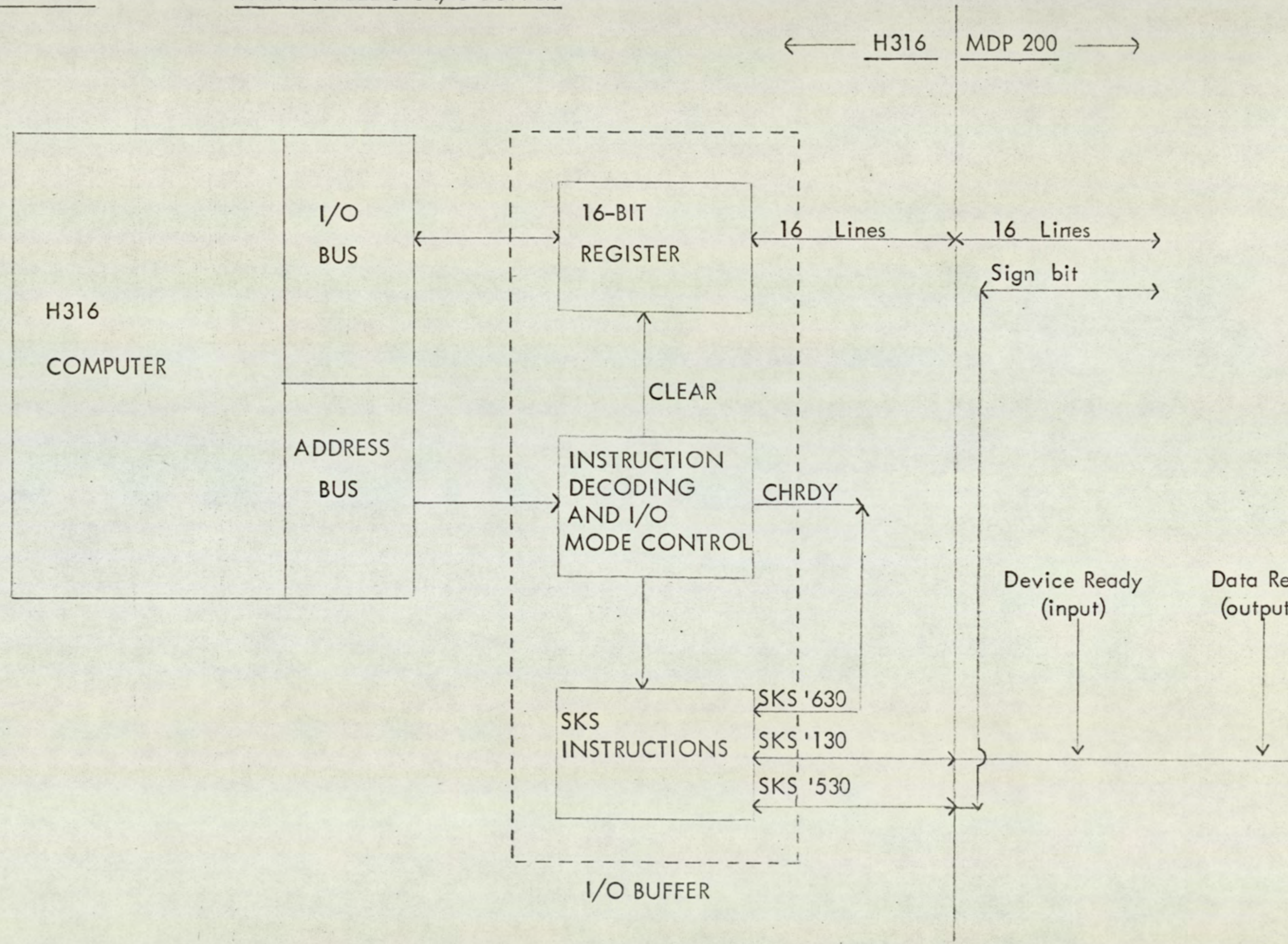
a) OCP '130 — This pulse enables the buffer in the output mode and produces CLEAR which resets the buffer register flip-flops. CHRDY (Channel ready) is inhibited.

b) SKS '130 — This tests the condition of 'Device Ready' from the MDP200. If the state is true, the next instruction is executed. If false, the next instruction is skipped.

c) OTA '1030 — Produces CHRDY in the buffer and outputs 16-bits of parallel information to the MDP200.

d) SKS '630 — Tests the condition of CHRDY. If true the next instruction is executed otherwise the next instruction is skipped.

FIGURE A2.3 HONEYWELL 316 I/O BUFFER



Input

a) OCP '030 This enables the buffer in the input mode and produces CLEAR which resets the buffer register flip-flops and enables CHRDY.

b) SKS '130 This tests the condition of 'Data Ready'.

c) INA '1030 Inputs the 16-bits of parallel data via the buffer register into the H316 A-register.

d) SKS '530 This tests the sign bit of the MDP200 ADC.

A2.3.2 Additional Features

In addition to the standard Honeywell buffer an interface between the MDP200 and the buffer is required for logic level conversion and signal conditioning. The logical states of signals generated by the H316 are logic 1 = 0 volts and logic 0 = 6 volts. At the MDP200 the signals are logic 1 = -6 volts and logic 0 = 0 volts. From logic level conversion and pulse conditioning hardware modules as supplied by Honeywell, an interface was constructed by departmental technicians.

One further addition to the buffer is the extension of the H316 sense switches in parallel with the MDP200 sense lines. This requires logic level conversion and the necessary modules were included in the interface construction described above.

A2.4 Sample Program

When a 16-bit BCD command word is passed from the A-register to the MDP200 via the buffer, a resulting 16-bit BCD data word is returned. The following DAP-16 assembler subroutine exemplifies the operation of the buffer for input/output to the MDP200.

```
   CRA      -   CLEAR SIGN FLAG
   STA   YY
   LDA   XX  - INSTRUCTION INTO A-REG
   OCP  '130- ENABLE OUTPUT MODE
   SKS  '130- TEST DEVICE READY
   JMP  *+2
   JMP  *-2
   OTA'1030- OUTPUT TO MDP 200
   JMP  *-1
   SKS  '130- DEVICE READY FALSE?
   JMP  *-1
   SKS  '630- CHRDY FALSE?
   JMP  *-1
   OCP  '030- ENABLE INPUT MODE
   SKS  '130- TEST DATA READY
   JMP  *+2
   JMP  *-2
   INA'1030- INPUT FROM MDP200
   JMP  *-1
   SKS  '130- DATA READY FALSE?
   JMP  *-1
   SKS  '530- TEST SIGN BIT
   JMP  *+3
   LDA  =1
   STA  YY
   HLT
YY BSS 1
XX BSS 1
   END
```

A2.5 References

A2.1 Electronic Associates Limited. Document 75/1120. "MDP200 - PDS 1020 Data Logging System - Aston University"

A2.2 Honeywell Information Systems. Document 130071722 "Buffered I/O Channel Option"

APPENDIX 3

THE BASELINE COMPILER

A3.1 Introduction

Originally, the available on-line system hardware consisted of the MDP200 data logger and the PDS 1020 digital computer. Although the logger and computer are produced by the same manufacturer, and thus are hardware and software compatible, the programming capability is restricted. Firstly, the PDS 1020 has only 4K core and is relatively slow in operation and secondly, as a result of the small memory size, on-line programming is limited to the use of machine code or assembler language. This means that writing and editing of on-line programs is laborious and time consuming. Furthermore, since the machine code and assembler instructions are necessarily hardware orientated, on-line usage is restricted to those programmers with a detailed knowledge of the computer system. Thus a general logging facility cannot be provided for the PDS 1020 - MDP200 system (without all users affording time to gain machine code expertise).

Replacement of the PDS 1020 by a Honeywell 316 minicomputer improves the on-line system in three ways. Firstly, the machine is faster so that data logging can be accompanied by processing and results made available to the user in real time. Secondly, the H316 has 12K core so that on-line processing is not restricted by machine size. Finally, as a result of both processing speed and core size, the computer can be programmed in either of the high-level languages BASIC and FORTRAN which are more widely known than assembler and machine code.

The most important facility of Honeywell software is the ability of the high-level languages to communicate with machine code and assembler programs. For on-line programs, the fundamental logging operations must be programmed in assembler language. If the format of these assembler programs matches the requirements of the FORTRAN CALL statement then logging operations can be controlled from FORTRAN. Furthermore, if the FORTRAN and assembler programs are compatible with the BASIC CALL statement, then the on-line operations can be linked to interactive BASIC compiler. BASELINE is such a version of the BASIC compiler with FORTRAN and assembler subroutines included in core to perform data logging operations.

In addition to the standard H316 computer, the available system includes the hardware option of a real time clock. This facility enables repetitive operations such as channel scanning, to be given priority over other programs at a fixed frequency.

One disadvantage of the acquisition of the H316 is that the computer and data logger are not hardware compatible. This requires the construction of a special purpose interface (Appendix 2) and corresponding special machine code instructions so that the H316 and interface emulate the behaviour of the PDS1020. However, this disadvantage is not common to all users since the instructions form part of the fundamental assembler routines available to the high-level programmer. One further disadvantage is the reduction in processing speed due to the interpretative nature of the BASIC compiler. This is only by comparison with the processing time in FORTRAN or assembler for the H316; BASIC programs are executed considerably faster than machine code programs for the PDS 1020.

The objective of the Appendix is to describe, in detail, the software link between BASIC and the on-line system that comprises the BASELINE compiler (A3.6). This includes detailed documentation of the programs and the method of loading the programs into the computer with the BASIC compiler to form the BASELINE system tape. When the complete program system is loaded into the computer, on-line data acquisition is available to any user with a knowledge of BASIC. All relevant computer programs are included in the Appendix and for assembler programs a summary of the Honeywell assembler program (DAP-16) operation and pseudo-operation codes is given in Tables A3.1 and A3.2 at the end of the Appendix. The details of DAP-16 (A3.4) and Honeywell FORTRAN (A3.3) are well documented.

A3.2 General Considerations

A3.2.1 The Structure of Programs

As shown in Figure A3.1, the result of any programming in DAP-16 or FORTRAN is the production of an object code tape.

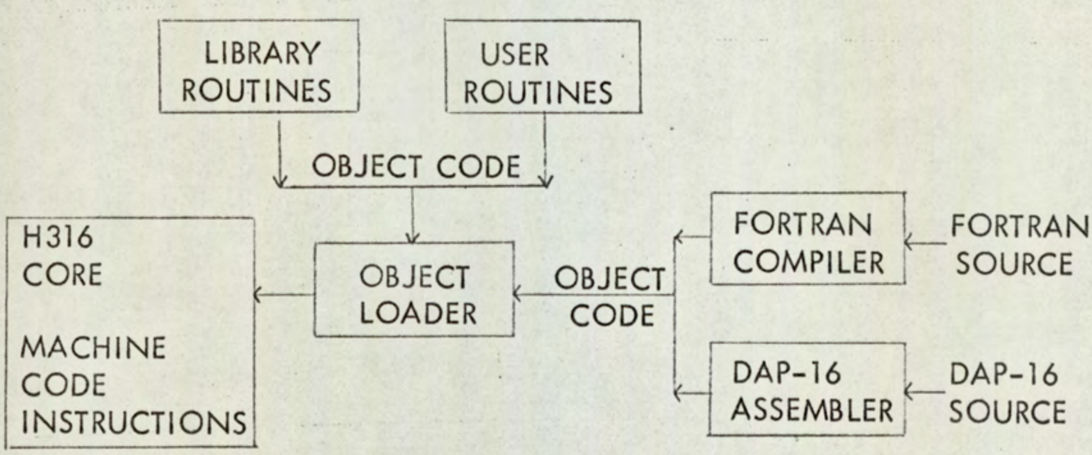


Figure A3.1

Object code information is arranged in blocks, each block containing information about the type of block (e.g. subroutine, function, etc.) and a coded form of the machine instructions that are formed when the object tape is loaded into the computer. Also in each block are the names of subroutines that are required for the execution of the instructions in that block.

The function of the object code loader is to form the machine code instructions in core from the information contained in each block. At the same time, the loader notes any external references to subroutines so that at a later time the object form of the subroutines can be loaded to satisfy the external calls. At any stage of loading, the object code loader can produce a memory map of the names of loaded programs and subroutines with their absolute memory addresses. All unsatisfied external calls are also flagged and only when no subroutine names are flagged is loading complete so that program execution can commence.

To the loader, object code blocks produced by FORTRAN and DAP-16 are the same. No knowledge is available to the loader as to whether a call to a subroutine is from DAP-16 or FORTRAN, or in which source language the subroutine is written. Subroutines are either from the Honeywell library tapes or are user-written. Since the object codes are the same to the loader, user-written and library FORTRAN and assembler subroutines can be mixed in computer core provided the rules of communication between subroutines are followed.

When a called subroutine is in core or when a subroutine is force-loaded into memory, i.e. without being explicitly called, and its external references satisfied by loading the appropriate subroutines, then it can be accessed from

BASIC by the CALL statement. This is performed by manually inserting the starting address of the subroutine into a fixed area of the BASIC compiler. According to the position within the fixed area of BASIC, the subroutine is given a reference number which is the first argument following the CALL statement. In this way it is possible to link the interactive BASIC compiler to FORTRAN and assembler routines as shown in Figure A3.2.

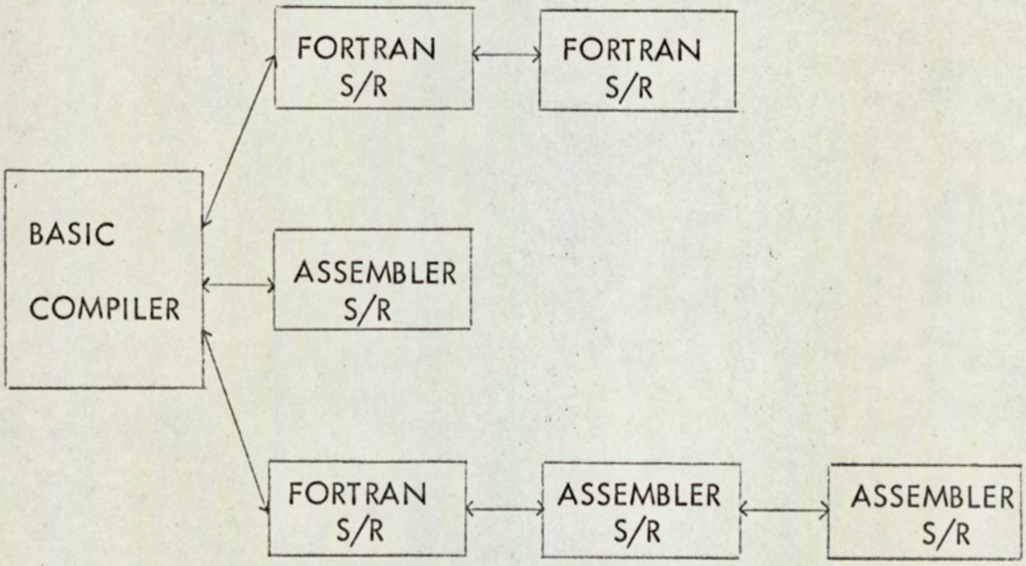


Figure A3.2

A3.2.2 FORTRAN - DAP-16 Communication

Communication between DAP and FORTRAN can be achieved by loading together subroutines in object code. Transfer of information between DAP and FORTRAN can be achieved in either of two ways. These are,

a) By reference to items in COMMON.

b) By argument transfer.

The first of these requires a knowledge of the way DAP and FORTRAN allocate COMMON storage and the second requires a knowledge of the way FORTRAN compiles CALL statements.

Common Storage Allocation

Common storage declared in FORTRAN programs is allocated in the following way:-

(a) Blank common storage is allocated first so that the variables in blank common are assigned storage, in the reverse order to which they are declared, starting at the high end of store, immediately below the initial common base and working downwards in the store.

(b) Variables in both named blocks and unnamed blocks of common storage are then assigned storage in the reverse order to which they are declared starting immediately below any variables in blank common (or, if there is no blank common, below the initial common base) and, again, working downwards in the store.

Thus the following statements

```
COMMON   A,B / BL1 / C,D / /E,F
COMMON   X,Y,Z / BL2 / R,S,T
```

will result in the following allocations.

STORE	C D	E F	R S T	A B X Y Z	High end of store →
	BLOCK / BL1	BLOCK / UNNAMED	BLOCK / BLO2	BLANK / COMMON	← Initial COMMON base

Common storage declared in DAP programs is illustrated by the following example.

```
AA    COMN  4
BC    COMN  6
CC    COMN  6
DD    COMN  8
```

The first statement allocates identifier 'AA' four words below the initial COMMON base, and the second allocates 'BC' six words below 'AA' (i.e. ten words below the initial COMMON base), and so on for the remaining statements.

Thus, if a DAP program with the above COMN statements is loaded into core in the same job as the FORTRAN COMMON statements, they will be the following association of identifiers.

AA : Y

AA+2 : Z

BC : A

BC+2 : B

BC+4 : X

CC : R

CC+2 : S

CC+4 : T

DD : C

DD+2 : D

DD+4 : E

DD+6 : F

Argument Transfer

The DAP-16 code generated by a FORTRAN CALL statement is as follows.

For 1 argument : JST routine

DAC argument

For n arguments : JST routine

DAC argument 1

"

"

DAC argument n

OCT 0

Knowing this, it is possible to write a DAP subroutine that makes a CALL on a FORTRAN subroutine.

When writing a DAP subprogram that is called by a FORTRAN program, it is possible to use the standard FORTRAN library subroutine F$AT to effect the argument transfer. This has the added advantage that all levels of indirect addressing in the argument are removed on transfer, thus possibly increasing efficiency.

An example of a call on F$AT is as follows:-

```
DAC     **      Link word of subroutine
CALL    F$AT
OCT     3       No. of arguments.
OCT     0       Locations to which
OCT     0       addresses of arguments
OCT     0       are transferred.
```

The call on F$AT must follow the link word of the called subroutine.

The form of actual arguments compiled by FORTRAN is as follows:-

Identifiers	-	the address of the identifier
Array Element	-	the address of the array element
Array Name	-	the address of the first element in the array
Hollerith constant	-	the address of the first word of the constant
Expression	-	the address of the resultant value of the expression (includes arrays with non-constant subscripts)

A3.2.3 BASIC-FORTRAN Communication

To call a FORTRAN subroutine from a BASIC program the user writes an instruction of the form

CALL (R, A, B, C)

where R is the subroutine reference number and A, B and C are the BASIC variables corresponding to the arguments of the FORTRAN subroutine. For example, if subroutine 1 was defined by the FORTRAN statement

SUBROUTINE SUBR (CONC1, CONC2, RATE)

a BASIC call to this routine would be CALL (1, C1, C2, R1). The arguments are transferred automatically by the CALL F$AT generated by the subroutine compilation..

It is important to note that (in FORTRAN terms) a BASIC program contains only real variables. Therefore, if the FORTRAN subroutine contains variables of any other type the user must arrange the conversion outside the BASIC program. For example, if a FORTRAN subroutine MATOP (N, A) in which N is an integer and A is a real array to be used, the conversion could be handled by another subroutine:

```
SUBROUTINE  CONVN   (X, A)
DIMENSION   A(1)
N  =  INT (X + 0.5)
CALL MATOP (N, A)
X  =  FLOAT (N)
RETURN
END
```

The subroutine CONVN might be subroutine 1 and MATOP would be a subroutine of CONVN. A call from the BASIC program would be

CALL (1, N, A(0))

in which N is of course a real variable. Unlike FORTRAN, arrays are subscripted in the CALL argument list. Usually, unless otherwise required, the first element of the array appears in the argument list.

A3.2.4 The Structure of BASELINE

Figure A3.3 shows a block diagram of the FORTRAN and assembler subroutines that comprise the BASELINE compiler. Programming is carried out at four district levels:

a) The BASIC level ,

b) The high level (FORTRAN) ,

c) The intermediate level (assembler) .

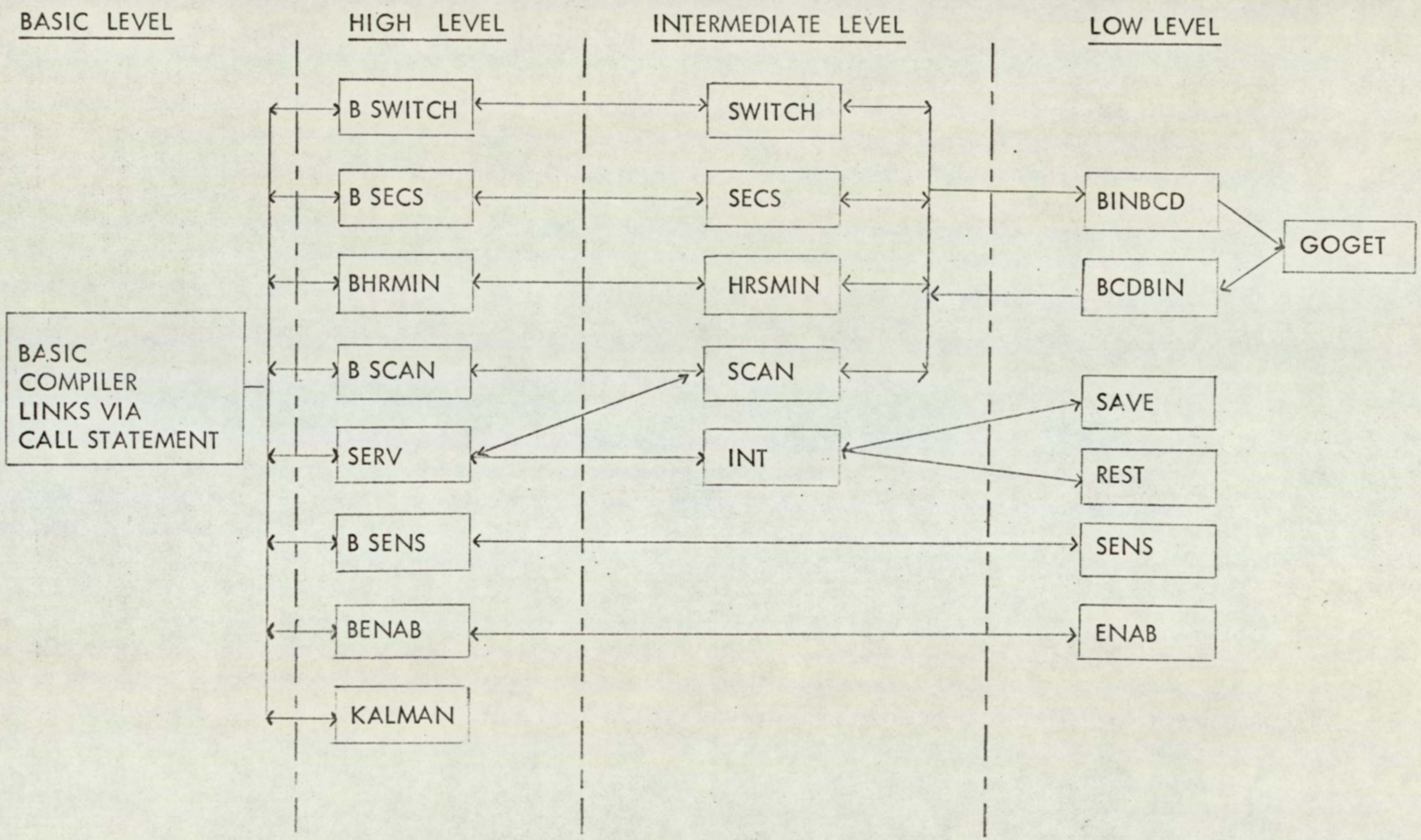
d) The low level (assembler) .

At the BASIC programmer level there are 8 distinct subroutine operations available through the CALL statement ,

1. To scan a single channel.
2. To scan the MDP200 clock in hours and minutes.
3. To scan the MDP200 clock in seconds and tenths of seconds.
4. To scan the MDP200 scan identification switches.
5. To stop the real-time clock and set interrupt masks.
6. To test the H316/MDP200 sense switches.
7. To scan repetitively a given channel range at a fixed time interval.
8. To execute the problem independent section of the Kalman filter algorithm.

Subroutine No. 8 is not an on-line subroutine and is described separately in Section A3.7. Each of the on-line operations is effected by calling the high-level FORTRAN subroutine where the BASIC arguments are transferred

FIGURE A3.3 THE STRUCTURE OF BASELINE



and integer/real conversion takes place. From the high level, the calls to the scanning and interrupt handling routines are programmed in assembler at the intermediate level. At the lowest level are the fundamental assembler soubroutines that are written specifically to control the MDP200/H316 interface and sense switches.

A3.3 The Low Level Subroutines

A3.3.1 Subroutine GOGET

The most fundamental subroutine for the on-line system is subroutine GOGET - Program A3.1, which performs the control of the interface in emulating the PDS1020. Basically, this consists of outputting BCD commands and receiving BCD results in the correct timing sequence. When the subroutine is entered, the A-register contains a 16-bit BCD command word of the following type:-

10NN	-	Scan channel NN (filter in)
50NN	-	Scan channel NN (filter out)
9000	-	Read clock (hours and minutes)
L000	-	Scan identification switches
C000	-	Real clock (seconds and tenths of seconds)

where L and C are the BCD equivalent of decimal 10 and 11.

When the logger is enabled, the command word is output to the buffer and multiplexer and the program waits for the slower MDP200 to perform the scan and return the resulting 16-bit BCD data word to the buffer. When this is complete the result of scanning is input to the A-register as a 16-bit BCD word, converted to binary by subroutine BCDBIN and if the MDP200 sign bit is negative, the two's complement is formed. Thus, when the execution of GOGET is complete the A-register contains a 16-bit binary integer equivalent of the 4 digit BCD result.

A3.3.2 Subroutines BCDBIN and BINBCD

All output from the MDP200 is in the form of four digit BCD, which must be converted to a single-word binary constant in the H316. Also, all output commands to the MDP200 must be formed in BCD from the binary equivalent of the channel number.

An algorithm for converting from binary to BCD is reported by Dean (A3.1). A digit b_x in a binary number $b_n - b_x - b_o$ has a decimal equivalent given by 2^x. Multiplication of a binary digit or a binary number by 2 can be accomplished by shifting the binary digit or word one digit in the direction of the most significant bit of the word. Repeated shifting, x times, can be utilised to multiply a digit or binary number by 2^x. The shifting technique of obtaining 2^x can be used as part of an algorithm to obtain the BCD equivalent of a binary word. Since a BCD output is desired, the result of each multiplication must be converted to the BCD format. If, for example, binary 1000 (8) is multiplied by 2, the binary word 10000 (16) is formed; however, in BCD code the 16 becomes 0001 0110. Thus 6 must be added to the binary 10000 to form the corresponding BCD output. The same result can be obtained by adding 3 to the binary 1000 before the multiplication. The shift operation then multiplies the binary 1011 by 2 to form the BCD 0001 0110. This forms the basis of the

Figure A3.4

Procedure	Hundreds Decade	Tens Decade	Units Decade	Binary Word b_7 b_6 b_5 b_4 b_3 b_2 b_1 b_0 1 1 1 1 1 1 1 1	= (255)
Step 1 Shift			1	1 1 1 1 1 1 1	
2 Shift			1 1	1 1 1 1 1 1	
3 Shift			1 1 1	1 1 1 1 1	
4 Add 3 to units			1 0 1 0	1 1 1 1 1	
Shift		1	0 1 0 1	1 1 1 1	
5 Add 3 to units		1	1 0 0 0	1 1 1 1	
Shift		1 1	0 0 0 1	1 1 1	
6 Shift		1 1 0	0 0 1 1	1 1	
7 Add 3 to tens		1 0 0 1	0 0 1 1	1 1	
Shift	1	0 0 1 0	0 1 1 1	1	
8 Add 3 to units	1	0 0 1 0	1 0 1 0	1	
Shift	1 0	0 1 0 1	0 1 0 1		
BCD	(2)	(5)	(5)		

ADD-3 algorithm; 3 must be added prior to multiplication any time the number in a BCD decade reaches 5 or more, corresponding to 10 or more after the multiplication. The steps in converting an 8-bit word are shown in Figure A3.4. In every step, each decade is incremented by 3 if the binary representation of the number in that decade equals or exceeds 5.

For a 16-bit word, the algorithm is implemented in subroutine BINBCD Program A3.2. On entry to the subroutine, the binary word is transferred to the B-register and the combined A and B registers are treated as a 32-bit shift register. Each time the number is 'long shifted' one bit into the A-register, each four bit decade (in the A-register) is rotated to test the numerical value of the most significant decade and add 3 when required. This procedure is repeated until the whole binary number is converted to BCD in the A-register.

In subroutine BCDBIN, Program A7.3, the procedure is reversed and the BCD number is shifted one bit into the B-register as the SUBTRACT-3 algorithm is executed. Before exit from the subroutine, the binary number is returned from the B-register to the A-register.

A3.3.3 Subroutines SAVE and REST

Each time the H316 real-time clock interrupts a running program to execute subroutine SERV, the address of the current instruction immediately transfers to the address given by the contents of location 61 (octal) - the H316 single hardware interrupt address. Before subroutine SERV can be executed, the essential registers of the computer must be preserved so that after interrupt is serviced, the original program execution sequence can be continued. Subroutine SAVE, Program A3.4, preserves the A, B and index registers and the computer keys following interrupt. The computer keys represent in a single word, the state of the hardware processors of the machine (e.g. hardware arithmetic unit, extended addressing, etc.). The instruction INK forms the bit pattern corresponding to the keys in the A-register. Program A3.4 also includes subroutine REST which restores the register and the keys preserved by SAVE. This takes place when subroutine SERV has been executed and control is ready to return to the interrupted program.

A3.3.4 Subroutine SENS

A useful extension to the BASIC compiler that provides remote program control, is the ability to test the state of the H316 and MDP200 sense switches. The low-level subroutine that performs this, subroutine SENS is shown in Program A3.5. The subroutine can be accessed directly from FORTRAN; there are two integer arguments. The first argument indicates the number of the switch to be tested and into the second argument is placed a constant whose value is dependent upon the state of the switch. If the switch is on the value is 2 otherwise it is unity.

The subroutine forms the test sense switch instruction by its own internal software since the instruction is related to the switch number. A shift instruction is first formed from the switch number which operates on a fixed bit pattern to form the test instruction. Before exit from the subroutine the numerical result of the test is copied to the calling program.

A3.3.5 Subroutine ENAB

In the event of a program error or a plant breakdown, it is essential to stop the real time clock. If it is not halted the interrupt service routine may continue ad infinitum since the computer is always running when BASIC is operational. Subroutine ENAB, Program A3.6 permits the interrupt mask bits (i.e. the bit pattern determining the devices permitted to interrupt at any time) to be set from FORTRAN or BASIC. The subroutine has a single integer argument defining the mask bit pattern. If the argument is zero, all interrupts are inhibited and the real time clock is stopped and reset. Non-zero arguments are described in the listing of Program A3.6.

A3.4 The intermediate level subroutines

A3.4.1 Subroutine SWITCH

Subroutine SWITCH, Program A3.7, is an assembler subroutine written in FORTRAN compatible form to read the MDP200 scan identification switches. The single integer argument is the binary equivalent of the 4 digit value set on the switches. On entry, the MDP switches code - 60000 octal (L000 BCD) is loaded into the A-register prior to calling subroutine GOGET. When the binary result is returned from GOGET in the A-register, it is forced to be positive. This is due to separation of the BCD value from the sign bit in GOGET. If the sign bit on the ADC is negative then the result from GOGET for the

MDP200 clock and the scan switches will also be negative. Prior to exit, the result of the scan is copied into the calling program.

A3.4.2 Subroutine SECS

Subroutine SECS, Program A3.8, is an assembler subroutine written in FORTRAN compatible form to read the MDP200 clock in seconds and tenths of seconds. The single integer argument is the binary equivalent of the 4 digit BCD value returned from the clock. The most significant two digits represent seconds and the least significant tenths of seconds. On entry, the seconds code - 70000 octal (C000 BCD) is loaded into the A-register prior to calling subroutine GOGET. The binary result, returned from GOGET, is forced to be positive before being copied into the calling program.

A3.4.3 Subroutine HRSMIN

Subroutine HRSMIN, Program A3.9, is an assembler subroutine written in FORTRAN compatible form to read the MDP200 clock in hours and minutes. The single integer argument is the binary equivalent of the 4 digit BCD value returned from the clock. The most significant two digits represent hours and the least significant minutes. On entry, the code - 50000 octal (9000 BCD) is loaded into the A-register prior to calling subroutine GOGET. The binary result, returned from GOGET is forced to be positive before being copied into the calling program.

A3.4.4 Subroutine SCAN

The principal operation of controlling channel scanning is performed by subroutine SCAN, Program A3.10. This is a FORTRAN compatible subroutine with 3 integer arguments. The arguments are:-

1. The channel number
2. The binary result of scanning
3. An error flag

On entry to the subroutine, the channel number is examined. If it is outside the range 0 - 40, the error flag is set to unity and the subroutine is exited. If the channel number is within the correct range, it is converted to BCD by subroutine BINBCD and formed into the MDP200 channel Scan command. The contents of the A-register are then output to subroutine GOGET where the scanning is carried out. On return from GOGET, the binary result is copied into the calling program, the error flag is set to zero and control is returned to the FORTRAN or BASIC calling program.

A3.4.5 Subroutine INT

Subroutine INT, Program A3.11, is the interrupt handling routine for the BASELINE compiler. Interrupt is derived from one source only, the H316 real time clock, and when interrupt occurs a single program is to be executed - subroutine SERV. Subroutine INT is a FORTRAN compatible subroutine with a single integer argument - the number of real time clock counts of 20 milliseconds between each interrupt.

The real time clock consists of a 16-bit counter that is incremented once every 20 milliseconds. When the counter (location 61) is full and the bit pattern changes from all ones to all zeros the hardware interrupt line is set. This means that if a fixed bit pattern is stored into the counter each time interrupt occurs, the current program execution will be interrupted at a fixed frequency. This enables repetitive operations such as scanning, to be given priority over other programs at fixed times.

When the subroutine is entered the two's complement form of the argument is stored into location 61, the real time clock is started and the address of the beginning of the interrupt service program (location AA) is stored into location 63. Control is then returned to the FORTRAN calling program.

When interrupt occurs, execution immediately transfers to location AA, Program A3.11, where the real time clock is temporarily stopped and the registers and keys are preserved by subroutine SAVE.

The program then transfers the locations of the arguments following the prior explicit call to subroutine SERV to the locations following the interrupt service call to SERV (location DD onwards). The arguments are copied in the format of FORTRAN programs described in Section A3.2.2, so that an implicit call to SERV is established. When all the arguments are copied, subroutine SERV is executed.

Following the execution of subroutine SERV, the registers and keys are restored by subroutine REST and program execution order is transferred back to the program originally interrupted. Once the arguments to subroutine SERV are established, the execution procedure, described above, is repeated each time interrupt occurs and cannot be modified from FORTRAN or BASIC programs. In order to establish the arguments it is necessary to call SERV (and hence F$AT) at least once explicitly before interrupt occurs.

A3.5 The High Level Subroutines

In order to communicate between BASIC and assembler, the high-level FORTRAN subroutines are available for each BASIC call. In all cases the subroutines provide essential conversion between real and integer format. The subroutines are presented in the order in which the starting addresses are stored in BASIC.

A3.5.1 Subroutine BSCAN

Subroutine BSCAN, Program A3.12 is a FORTRAN subroutine that scans a single channel of the MDP200. The three arguments are the real equivalent of the integer arguments of subroutine SCAN. The BASIC call to this subroutine is of the form

CALL (1, C, V, E)

A3.5.2 Subroutine BHRMIN

Subroutine BHRMIN, Program A3.13, is a FORTRAN subroutine that scans the MDP200 clock in hours and minutes. The single argument is the real equivalent of the integer argument of subroutine HRSMIN. The BASIC call to this subroutine is of the form

CALL (2, H)

A3.5.3 Subroutine BSECS

Subroutine BSECS, Program A3.14, is a FORTRAN subroutine that scans the MDP200 clock. The single argument is the real equivalent of the integer argument of subroutine SECS. The BASIC call to this subroutine is of the form,

CALL (3, S)

A3.5.4 Subroutine BSWITCH

Subroutine BSWITCH, Program A3.15, is a FORTRAN subroutine that scans the MDP200 scan identification switches. The single argument is the real equivalent of the integer argument of subroutine SWITCH. The BASIC call to this subroutine is of the form,

CALL (4, S3)

A3.5.5 Subroutine BENAB

Subroutine BENAB, Program A3.16, provides real/integer conversion between BASIC and assembler subroutine ENAB. The integer form of the real argument sets the hardware interrupt masks. If the argument is zero, all interrupt is inhibited. The BASIC call to this subroutine is of the form,

CALL (5, I)

A3.5.6 Subroutine BSENS

Subroutine BSENS, Program A3.17, provides real/integer conversion between BASIC and assembler subroutine SENS. The integer form of the first argument determines the sense switch to be tested. The numerical result of the testing (2 if on, otherwise unity) is stored in the second argument. The BASIC call to this subroutine is of the form,

CALL (6, S4, A)

A3.5.7 Subroutine SERV

During on-line experiments that require repetitive channel scanning, subroutine SERV, Program A3.18, is executed. After an initial explicit call to this subroutine, it is executed each time the H316 real time clock interrupts. There are 8 real arguments:

1. RINT - the interrupt interval in seconds.
2. LO - the lowest channel number to be scanned.
3. HI - the highest channel number to be scanned.
4. ENS - the number of repetitive scans at each interrupt that forms the ensemble average.
5. VALUE - the array into which the results are stored.
6. SCREQ - the total number of interrupts required.
7. SLDONE - the total number of interrupts up the current time.
8. ERROR - an error flag set if the channel is out of range.

At the first explicit call to this subroutine the addresses of the arguments are established for transferring to subroutine INT. If the value of NINT is zero, the real time clock and interrupt handling routines are not established. When NINT is non-zero, subroutine INT is called to start the real time clock and establish the arguments for executions of SERV on interrupt. Following conversion of the real arguments to integer, channels LO - HI are scanned consecutively (by subroutine SCAN), ENS number of times, and the average for each channel is stored in VALUE (Channel No., SCDONE). If, at any time, the channel number is out of range, the error flag (ERROR) is set and the real time clock is stopped. Subroutine SERV is executed each time interrupt occurs until either SCDONE = SCREQ or the fifth BASELINE subroutine (BENAB) is called with a zero argument.

Since the addresses of the BASIC variables that form the arguments are preserved by subroutine INT, it is important to note that the arguments must be BASIC variable names and not constants. Also, since only one-dimensional dynamic arrays are available in Honeywell FORTRAN, the first dimension of variable VALUE, at the BASIC level, must be 39 (i.e..40 possible channels). Thus, the BASIC call is of the form,

CALL (7, I, N1, N2, E3, A(0,0), S3, S4, E1)

where A is previously defined by, say,

DIM A(39,20)

A3.6 The BASELINE Package System

A3.6.1 General

When the object code form of the subroutines at all levels is available, it can be loaded into core together with the BASIC compiler. Further library subroutines (object code) are then loaded and manual patches inserted.

Loading subroutine SERV is a separate procedure to loading the other BASELINE subroutines. If a library routine is shared by another subroutine (say BSENS), in addition to SERV, and interrupt occurs during the execution of BSENS at the library subroutine, then program execution will never return to BSENS because the subroutine link address (DAC **) is corrupted by the call to the same subroutine from SERV. This means that two separate loading procedures must be carried out; the first for the six non-interrupt routines and the second for subroutine SERV. A knowledge of the behaviour of the BASELINE program when execution errors occur is important. When a BASIC program execution error occurs the computer does not stop so that the real time clock will continue interrupting. This is avoided by manually patching a 'stop real time clock' instruction into the BASIC compiler each time a question mark character is output. In particular, this character is output after a BASIC execution error is located by the compiler. When a FORTRAN execution error occurs, the computer halts. This is undesirable since the interactive facility of BASIC, and hence the remote on-line program control is immediately lost. This is avoided by manually patching a jump back into BASIC from the FORTRAN error routine, F$ER, when the question mark character will be output, and hence the real time clock stopped so that the execution error can be investigated.

Sector 0, or base sector, of the computer core provides vital link addresses for cross sector memory-reference instructions. The writers of the BASIC compiler have allocated locations 716 to 777 (octal) of base sector for link addresses for user-written subroutines. This represents a very limited number of link addresses for the BASELINE subroutines and only by judicious location of subroutine starting addresses can they be loaded. Formation of a BASELINE system tape containing the first seven subroutines is described here. For subroutine KALMAN, the available base sector storage is insufficient and the loading procedure described in Section A3.7.2 is adopted.

A3.6.2 Construction of the System Tape

The 12K baseline system tape is formed as follows. The prime refers to an octal number.

1. The computer memory is cleared
2. The standard BASIC compiler is loaded into core (Sectors 0 - 7). This a self loading system tape (SLST). The following manual patches are made to stop the real time clock each time the question mark character is output.

Location	Contents
1505	JMP '775
'774	OCT 1506
'775	OCP '220
'776	IAB
'777	JMP* '774

3. The special loader, LDR-APM (SLST), described in Section A3.6.3 that loads above itself is loaded into sectors '12 - '16. Location '15000, initial common base is set to '27777 (top of core).

4. Punch and load object tape, PAL-AP is loaded into sector '20 by LDR-APM so that the complete system tape can be prepared when loading is complete. The address to which the relocatable bookstrap of the final system tape is to be directed ('27600) is patched into location '20575.

5. The first six BASELINE subroutines are force loaded into memory from '26330 using LDRAPM. Base sector is set to '716.

6. The remaining on-line assembler tapes are loaded together with the library routines. The following memory map is obtained.

NAME	ADDRESS
*START	26327
*HIGH	27576
*NAMES	12564
*COMN	27777
*BASE	00735
AC5	00073
BSCAN	26330
BHRMIN	26376
BSECS	26414
BSWTCH	26432
BENAB	26450
BSENS	26476
HRSMIN	26534
SECS	26550
SWITCH	26564
ENAB	26600
SENS	26616
SCAN	26654
GOGET	26714
BINBCD	26744
BCDBIN	27000
FLOAT	27026
INT	27036
IDINT	27036
IFIX	27036
C$12	27046
C$21	27100
S$22	27132

```
A$22        27140
M$22        27362
REAL        27374
L$22        27374
H$22        27404
F$ER        27422
F$HT        27432
F$AT        27470
ARG$        27552
AC1         27572
AC2         27573
AC3         27574
AC5         27575
```

7. Location F$ER + '30 is modified to permit re-entry to BASIC following a FORTRAN execution error.

Location	Contents
F$ER + 30	JMP* '760
'760	'1000

(BASIC is re-entered at location '1000).

8. A separate loading procedure is initiated for subroutine SERV from location '24016. The following memory map is produced

```
NAME        ADDRESS
----        -------

*START       24015
*HIGH        26262
*NAMES       12567
*COMN        27777
*BASE        00756
AC5          00073
SERV         24016
INT          24470
SCAN         24576
ENAB         24636
SAVE         24654
REST         24670
FLOAT        24700
IDINT        24710
IFIX         24710
M$11X        24720
M$11         24720
M$22X        25000
```

M$22	25000
D$22X	25161
D$22	25161
C$12	25420
C$21	25452
S$22	25504
A$22	25512
M$22	25734
REAL	25746
L$22	25746
H$22	25756
F$ER	25774
F$HT	26004
F$AT	26042
ARG$	26124
AC1	26144
AC2	26145
AC3	26146
AC4	26147
GOGET	26150
BINBCD	26200
BCDBIN	26234

9. Location F$ER + 30 for the subroutine SERV library routines is modified as described above.

10. The starting addresses of the BASELINE subroutines are stored in the reserved area of the BASIC compiler.

Location	Contents	
'516	'26330	(BSCAN)
'517	'26376	(BHRMIN)
'520	'26414	(BSECS)
'521	'26414	(BSWTCH)
'522	'26432	(BENAB)
'523	'26476	(BSENS)
'524	'24016	(SERV)

11. PAL-AP is used to punch the contents of memory from '100 to '27575 to form the BASELINE system tape.

A3.6.3 Special LDR-APM

In order to enter object programs into the highest part of memory, it is necessary to construct a version of the loader LDR-APM which is resident in a lower section of core but loads programs above itself. This is performed as follows:

1. The computer memory is cleared
2. LDR-APM (SLST) is loaded into core .
3. LDR-APM (OBJECT) is loaded into the desired sector by means of LDR-APM (SLST) .
4. PAL-AP (OBJECT) is loaded into any available sector of memory.
5. In the new LDR-APM, relative address '2000 is set to the new initial common base, i.e. the highest location in memory.
6. Location '575 of the PAL-AP sector is set to 'NN600 where NN is the highest sector in memory.
7. The new LDR-APM (SLST) is punched out by PAL-AP.

A3.7 Subroutine KALMAN

A3.7.1 General

For experiments in on-line real time filtering, it is essential to include the Kalman filter algorithm (A3.2) as a FORTRAN subroutine, in the BASELINE compiler. This minimises the execution time of the algorithm and separates the problem independent calculations from the integration of the mathematical model carried out at the BASIC level. The principal disadvantage of including subroutine KALMAN is that there is insufficient base sector available for it to be loaded as the other BASELINE subroutines.

The base sector problem is overcome by use of the FORTRAN Translator (A3.5). This package enables FORTRAN programs to be mixed with assembler instructions to produce a single source tape containing assembler source only. Object code is produced in the usual way by assembling the translator output. This means that if the overall size of the subroutine is known, the SETB (set base) pseudo-operation can be included in the FORTRAN program so that base sector can be relocated to the sector of the loaded subroutine. This procedure avoids the use of sector zero as base sector.

One limitation of using the FORTRAN translator is that doubly subscripted arrays are not permitted in the subroutine argument list. Since the filter algorithm is conveniently programmed in two dimensional form, it is still possible to maintain the structure of the algorithm by a non-standard feature of FORTRAN available with the Honeywell FORTRAN Translator. This is the use of an integer function with arguments used as an array subscript expression.

Thus, if the maximum size of an array is stated as 10 x 10, an integer subscript function is defined by

$$L1(I, J) = I + (J-1) * 10$$

and a two-dimensional algorithm can be translated in the form A(L1 (I, J)) where A is a singly subscripted variable. The combination of the integer subscript function to overcome the translator deficiency and the translator itself to perform base sector relocation means that Kalman filter subroutine can be included in BASELINE.

A3.7.2 Subroutine Translation

Combined FORTRAN and assembler source is shown in Program A3.19. FORTRAN Translator source code is identical to standard FORTRAN code but assembler instructions have a letter A in column 1. The DAP-16 operation code and address field are separated by commas. Examples of Translator code are shown in Program A3.19.

The program translation is an iterative process. A first translation is carried out without assembler instructions included to define the overall size of the subroutine. When the size is established, sector boundaries are determined based on a fixed starting address for the subroutine. The number of link addresses for each sector is estimated and the following assembler code inserted at the start of each sector.

```
A        SETB, * + 1

A        JMP, * + NN

A        BSS, NN
```

The SETB pseudo-operation produces object code to inform the loader that base sector is to be relocated to the current address. The JMP operation transfers program execution over the NN locations estimated to be sufficient for the link addresses for this sector. There are three base sector relocations in subroutine KALMAN.

When the subroutine is translated, the resulting source tape is assembled and loaded. At this stage an indication of the number of locations in each sector used as link addresses is available by taking a memory map. If the number is insufficient the program must be retranslated with NN increased for the appropriate sector.

A call to the subroutine is of the form

```
CALL  (8, F(0, 0), Q(0,0), R(0, 0), M(0, 0), P(0, 0), X(0), Y(0),
                          E1, S(0, 0), K(0, 0) N, M)
```

where the variables are defined in Program A3.9.

A3.7.3 Loading Subroutine KALMAN

Subroutine KALMAN is added to the 7 subroutine version of BASELINE by the following procedure.

1. The 7-subroutine BASELINE system tape is loaded and a memory map output.

2. KALMAN object tape is force loaded from '21000 so that the library routines of SERV are made available. Subroutine KALMAN requires no further base sector.

3. Subroutine SUB$, required as a result of the integer subscript function in the FORTRAN translation, is loaded from '20640 with base sector set to the first available location indicated by the memory map. This uses one further base sector location. The following memory map is obtained

NAME	ADDRESS
*START	24015
*HIGH	26262
*NAMES	12545
*COMN	27777
*BASE	22033
*BASE	23014
*BASE	00757
AC5	00073
SUB$	20640
KALMAN	21745
SERV	24016
INT	24470
SCAN	24576
ENAB	24636
SAVE	24654
REST	24670
FLOAT	24700
IDINT	24710
IFIX	24710
M$11X	24720
M$11	24720
M$22X	25000
M$22	25000
D$22X	25161
D$22	25161
C$12	25420
C$21	25452
S$22	25504

A$22	25512
N$22	25734
REAL	25746
L$22	25746
H$22	25756
F$ER	25774
F$HT	26004
F$AT	26042
ARG$	26124
AC1	26144
AC2	26145
AC3	26146
AC4	26147
GOGET	26150
BINBCD	26200
BCDBIN	26234

4. To provide input/output from the paper tape reader and punch, the following BASIC I/O modification is made,

Location	Contents
'20601	SS3
'20602	JMP * + 3
'20603	CRA
'20604	STA '105
'20605	LDA '406
'20606	JMP* * + 1
'20607	OCT 4143
'20610	IRS '105
'20611	CRA
'20612	STA '106
'20613	JST* * + 2
'20614	JMP* * + 2
'20615	OCT 3065
'20616	OCT 4575
'20617	SS4
'20620	SKP
'20621	IRS '106
'20622	JST* * + 2
'20623	JMP* * + 2
'20624	OCT 3047
'20625	OCT 4217
'20626	IRS '105
'20627	CRA
'20630	STA '106
'20631	JMP* * + 1
'20632	OCT 5245

and into BASIC the following modifications,

Location	Contents
'4142	JMP* '761
'761	OCT 20601
'4574	JMP* '762
'762	OCT 20610
'4211	JMP* 763
'763	OCT 20617
'5244	JMP* 764
'764	OCT 20626

These modifications enable the PRINT and INPUT statement of BASIC to operate through the high speed paper tape punch and reader respectively. When sense switch 3 is depressed all INPUT statements are directed to the paper tape reader, and when sense switch 4 is depressed, PRINT statements are output to the paper tape punch. This provides a method of obtaining a hard copy of filtering results without speed restrictions of the teletype.

5. The starting location of the 8th subroutine is inserted into the dedicated table within BASIC.

Location	Contents
'525	'21745 (KALMAN).

PROGRAM A3.1

```
* SUBROUTINE     GOGET
*
* PURPOSE -      TO PERFORM CONTROL OF MDP200/H316 INTERFACE
*                FOR CHANNEL, CLOCK AND SWITCH SCANNING.
*
* DESCRIPTION -  THE BCD COMMAND CODE IN THE A-REGISTER IS
*                OUTPUT TO THE MDP200 BUFFER AND
*                MULTIPLEXOR.  THE RESULTING DATA ARE
*                CONVERTED TO BINARY, COMPLEMENTED IF
*                NEGATIVE AND RETURNED IN THE A-REGISTER.
*
* CALLING -      CALL   GOGET
*
*
*
*
*
      SUBR   GOGET
      REL
GOGE  DAC    **             ENTRY FOR GOGET
      OCP    '130           ENABLE CHANNEL IN O/P MODE.
      SKS    '130           READY TO CONTINUE?
      JMP    *+2            YES.
      JMP    *-2            NO.
      OTA    '1030          OUTPUT TO MDP200
      JMP    *-1
      SKS    '130           READY TO CONTINUE?
      JMP    *-1            NO.
      SKS    '630           YES - PAUSE FOR LOGGER TO
      JMP    *-1            WAIT.                  [RESPOND.
      OCP    '30            ENABLE CHANNEL IN I/P MODE.
      SKS    '130           READY TO CONTINUE?
      JMP    *+2            YES.
      JMP    *-2            NO.
      INA    '1030          INPUT FROM MDP200.
      JMP    *-1
      SKS    '130           READY TO CONTINUE?
      JMP    *-1            NO.
      CALL   BCDBIN         YES - CONVERT TO BINARY.
      SKS    '530           TEST SIGN BIT
      SKP                   POSITIVE.
      TCA                   NEGATIVE.
      JMP*   GOGE           EXIT.
      FIN
      END
```

PROGRAM A3.2

```
* SUBROUTINE      BINBCD
*
* PURPOSE -       TO CONVERT BINARY CONSTANTS TO BINARY
*                 CODED DECIMAL.
*
* DESCRIPTION -   WHEN CALLED, THE BINARY NUMBER IN THE
*                 A-REGISTER IS CONVERTED TO BCD BY THE ADD-3
*                 ALGORITHM.  THE RESULT IS RETURNED IN THE
*                 A-REGISTER BUT B IS NOT PRESERVED.
*
* CALLING -       CALL    BINBCD
*
*
*
*
*
      SUBR    BINBCD
      REL
BINB  DAC     **                    ENTRY FOR BINBCD.
      STA     ZZ                    PRESERVE BINARY CONSTANT.
      CRA
      IAB                           CLEAR B.
      LDA     XY                    SET UP SHIFT COUNTER.
      STA     XX
      LDA     ZZ
      IAB                           PUT BINARY IN B-REG.
L2    LDX     YZ                    ROTATE COUNTER.
L1    SMI                           TEST BIT 16.
      CAS     ='50000
      JMP     L3                    CONVERT LEFT MOST-
      JMP     L3                    FOUR BITS IF > = 5.
      JMP     L3+1
L3    ADD     ='30000
      ALR     4                     ROTATE-
      IRS     0                     FOUR TIMES.
      JMP     L1
      LLL     1                     LOGICAL SHIFT FROM B-REG.
      IRS     XX                    SIXTEEN TIMES
      JMP     L2
      JMP*    BINB                  EXIT.
      FIN

ZZ    BSS     1
XX    BSS     1
XY    DEC     -16
YZ    DEC     -4
      END
```

PROGRAM A3.3

```
* SUBROUTINE     BCDBIN
* PURPOSE -      TO CONVERT BINARY CODED DECIMAL CONSTANTS
*                TO BINARY
*
* DESCRIPTION -  WHEN CALLED THE BCD NUMBER IN THE A-REGISTER
*                IS CONVERTED TO BINARY BY THE SUBTRACT - 3
*                ALGORITHM.  THE RESULT IS RETURNED IN THE
*                A-REGISTER BUT B IS NOT PRESERVED.
*
* CALLING -      CALL   BCDBIN
*
*
*
*
*
     SUBR   BCDBIN
     REL
BCDB DAC    **                   ENTRY FOR BCDBIN.
     STA    ZZ                   PRESERVE BCD CONSTANT.
     LDA    XY                   SET UP SHIFT COUNTER.
     STA    XX
     LDA    ZZ
L2   LDX    YZ                   SET UP ROTATE COUNTER.
     LRL    1                    LONG SHIFT INTO B-REG.
L1   SPL                         TEST BIT 16.
     SUB    ='30000
     ALR    4                    ROTATE-
     IRS    0                    FOUR TIMES.
     JMP    L1
     IRS    XX                   LOGICAL SHIFT - 16 TIMES.
     JMP    L2
     IAB                         BRING BINARY BACK.
     JMP*   BCDB                 EXIT.
     FIN

ZZ   BSS    1
XX   BSS    1
XY   DEC    -16
YZ   DEC    -4
     END
```

PROGRAM A3.4

```
*  SUBROUTINE     SAVE AND SUBROUTINE REST
*
*  PURPOSE -      TO PRESERVE OR RESTORE THE ESSENTIAL COMPUTER
*                 REGISTERS WHEN INTERRUPT OCCURS.
*
*  DESCRIPTION -  THE INDEX, A AND B REGISTERS ARE HELD
*                 TEMPORARILY IN BUFFER AA TOGETHER WITH THE
*                 REGISTER KEYS.
*
*  CALLING -      CALL   SAVE
*                 CALL   REST
*
*
*
*
*
     SUBR    SAVE
     SUBR    REST
     REL
SAVE DAC     **                    ENTRY FOR SAVE.
     STA     AA                    PRESERVE A-REGISTER.
     IAB
     STA     AA+1                  PRESERVE B-REGISTER.
     INK
     STA     AA+2                  PRESERVE KEYS.
     STX     AA+3                  PRESERVE INDEX REGISTER.
     JMP*    SAVE                  EXIT.
AA   BSS     4
REST DAC     **                    ENTRY FOR REST.
     LDX     AA+3                  RESTORE INDEX REGISTER.
     LDA     AA+2                  RESTORE KEYS.
     OTK
     LDA     AA+1                  RESTORE B-REGISTER.
     IAB
     LDA     AA                    RESTORE A-REGISTER.
     JMP*    REST                  EXIT.
     END
```

PROGRAM A3.5

```
*   SUBROUTINE SENS
*
*   PURPOSE -        TO PERMIT TESTING OF SENSE SWITCHES
*                    FROM FORTRAN HENCE BASIC PROGRAMS
*
*   DESCRIPTION -    THE REQUIRED SENSE SWITCH NUMBER IS
*                    TRANSFERRED BY F$AT AND A TEST SENSE
*                    SWITCH INSTRUCTION IS FORMED BY LOGICAL
*                    SHIFTING.  IF ON, THE SECOND ARGUMENT IS
*                    2, ELSE 1
*
*   CALLING -        CALL SENS (N SWITCH, N VALUE)
*
*
*
*
*
*
*
       SUBR   SENS
       REL
SENS   DAC    **                    ENTRY POINT.
       CALL   F$AT                  TRANSFER ARGUMENTS.
       OCT    2                     NO. OF ARGUMENTS.
       OCT    0                     ARG  1.
       OCT    0                     ARG  2.
       LDA*   SENS + 3              LOAD SWITCH NO.
       CAS    =0                    OUT OF RANGE?
       CAS    =5
       JMP    TEST + 4              YES - EXIT.
       JMP    TEST + 4              YES - EXIT.
       TCA                          NO - 2'S COMP.
       ANA    = '77                 FORM RIGHT SHIFT -
       ADD    = '40400              INSTRUCTION.
       STA    * +2
       LDA    = '40                 SET BIT PATTERN.
       ***                          SHIFT.
       SSM                          SET BIT 1 TO FORM -
       STA    * +2                  SENSE TEST INSTRUCTION.
       CRA
TEST   ***                          TEST SENSE SWITCH .
       AOA                          IT IS ON.
       AOA                          IT IS OFF.
       STA*   SENS+4                STORE IN ARG  2.
       JMP*   SENS                  EXIT.
       FIN
       END
```

PROGRAM A3.6

```
* SUBROUTINE    ENAB
*
* PURPOSE -     TO PERMIT RESETTING OF INTERRUPT FROM
*               FORTRAN PROGRAMS.
*
* DESCRIPTION - THE BIT PATTERN RECEIVED BY ARGUMENT TRANSFER
*               IS OUTPUT TO THE I/O BUS TO SET THE
*               APPROPRIATE MASK FLIP-FLOPS.
*
* CALLING -     CALL   ENAB (NBIT)
*
*     BIT PATTERN                   DEVICE
*       '40                           ASR
*       '200                          PTR
*       '100                          PTP
*       '1                            RTC
*       '0                            INHIBIT INTERRUPT
*
*
*
*
*
      SUBR   ENAB
      REL
ENAB  DAC    **                     ENTRY FOR ENAB.
      CALL   F$AT
      OCT    1                      ONE ARGUMENT.
      OCT    0
      LDA*   ENAB+3                 SET BIT PATTERN IN A-REG.
      SNZ                           ZERO?
      JMP    E1                     YES.
      SMK    '20                    NO - RESET MASKS.
      ENB                           ENABLE INTERRUPT.
      JMP*   ENAB                   EXIT.
E1    OCP    '220                   STOP REAL TIME CLOCK.
      INH                           INHIBIT INTERRUPT.
      JMP*   ENAB                   EXIT.
      FIN
      END
```

PROGRAM A3.7

```
*  SUBROUTINE     SWITCH
*
*  PURPOSE -      TO SCAN THE MDP200 SCAN IDENTIFICATION
*                 SWITCHES FROM FORTRAN.
*
*  DESCRIPTION -  THE BINARY EQUIVALENT OF THE SCAN SWITCHES
*                 CODE IS OUTPUT TO THE MDP200.  THE RESULT IS
*                 TRANSFERRED BACK TO THE CALLING PROGRAM
*                 AS A FOUR DIGIT INTEGER ARGUMENT.
*
*  CALLING -      CALL   SWITCH (NVALUE)
*
*
*
*
*
         SUBR   SWITCH
         REL
SWIT     DAC    **                       ENTRY FOR SWITCH .
         CALL   F$AT
         OCT    1                        ONE ARGUMENT.
         OCT    0
         LDA    ='-60000                 MDP CODE.
         CALL   GOGET                    PERFORM SCAN.
         SPL                             IS NUMBER POSITIVE?
         TCA                             NO - COMPLEMENT.
         STA*   SWIT+3                   YES - STORE BACK.
         JMP*   SWIT                     EXIT.
         FIN
         END
```

PROGRAM A3.8

```
*  SUBROUTINE      SECS
*
*  PURPOSE -       TO SCAN THE MDP200 CLOCK TO READ SECONDS
*                  AND TENTHS OF SECONDS FROM FORTRAN
*
*  DESCRIPTION -   THE BINARY EQUIVALENT OF THE CLOCK READING
*                  CODE IS OUTPUT TO THE MDP200.  THE RESULT IS
*                  TRANSFERRED BACK TO THE CALLING PROGRAM AS
*                  A FOUR DIGIT INTEGER ARGUMENT
*
*  CALLING -       CALL    SECS (N VALUE)
*
*
*
*
*
       SUBR   SECS
       REL
SECS   DAC    **                     ENTRY FOR SECS.
       CALL   F$AT
       OCT    1                      ONE ARGUMENT.
       OCT    0
       LDA    ='-70000               MDP CODE.
       CALL   GOGET                  PERFORM SCAN.
       SPL                           IS NUMBER POSITIVE?
       TCA                           NO - COMPLEMENT
       STA*   SECS+3                 YES - STORE BACK.
       JMP*   SECS                   EXIT.
       FIN
       END
```

PROGRAM A3.9

```
*  SUBROUTINE     HRSMIN
*
*  PURPOSE -      TO SCAN THE MDP200 CLOCK TO READ HOURS
*                 AND MINUTES FROM FORTRAN.
*
*  DESCRIPTION -  THE BINARY EQUIVALENT OF THE CLOCK READING
*                 CODE IS OUTPUT TO THE MDP200.  THE RESULT IS
*                 TRANSFERRED BACK TO THE CALLING PROGRAM AS
*                 A FOUR DIGIT INTEGER ARGUMENT.
*
*  CALLING -      CALL   HRSMIN (N VALUE)
*
*
*
*
*
      SUBR   HRSMIN
      REL
HRSM  DAC    **                    ENTRY FOR HRSMIN .
      CALL   F$AT
      OCT    1                     ONE ARGUMENT .
      OCT    0
      LDA    ='-50000              MDP CODE.
      CALL   GOGET                 PERFORM SCAN.
      SPL                          IS NUMBER POSITIVE?
      TCA                          NO - COMPLEMENT .
      STA*   HRSM+3                YES - STORE BACK.
      JMP*   HRSM                  EXIT.
      FIN
      END
```

PROGRAM A3.10

```
* SUBROUTINE    SCAN
*
* PURPOSE -     TO SCAN A SINGLE CHANNEL FROM FORTRAN
*               HENCE BASIC PROGRAMS.
*
* DESCRIPTION - THE APPROPRIATE CHANNEL NUMBER TRANSFERRED
*               AS AN INTEGER ARGUMENT IS CONVERTED TO
*               BCD AND OUTPUT TO THE MDP200 FOR SCANNING.
*               THE RESULT IS TRANSFERRED TO THE CALLING
*               PROGRAM IN BINARY.  IF THE CHANNEL NUMBER
*               IS OUT OF RANGE THE ERROR FLAG IS SET TO 1
*               ELSE 0.
*
* CALLING       CALL   SCAN (NCHANNEL, NRESULT, NERROR)
*
*
*
*
*
        SUBR   SCAN
        REL
SCAN    DAC    **                  ENTRY FOR SCAN.
        CALL   F$AT                TRANSFER 3 ARGUMENTS.
        OCT    3
        OCT    0                   ARG 1.
        OCT    0                   ARG 2.
        OCT    0                   ARG 3.
        CRA                        CLEAR ERROR FLAG.
        STA    TS1
        LDA*   SCAN+3              GET CHANNEL NUMBER.
        CAS    =0                  TOO SMALL?
        JMP    SC2                 NO.
        JMP    SC2                 NO.
        JMP    SC4                 YES.
SC2     CAS    =40                 TOO LARGE?
        JMP    SC4                 YES.
        JMP    SC4                 YES.
        CALL   BINBCD              CONVERT TO BCD.
        ADD    ='10000             SET UP MDP CODE.
        CALL   GOGET               PERFORM SCAN.
        STA*   SCAN+4              STORE RESULT BACK.
        LDA    TS1                 ZERO ERROR FLAG.
        STA*   SCAN+5
        JMP*   SCAN                EXIT.
SC4     CRA                        SET ERROR FLAG.
        AOA
        STA*   SCAN+5              STORE BACK.
        JMP*   SCAN                EXIT.
TS1     BSS    1
        FIN
        END
```

PROGRAM A3.11

```
*  SUBROUTINE      INT
*
*  PURPOSE -       TO HANDLE INTERRUPT FROM THE REAL TIME
*                  CLOCK AND INITIATE EXECUTION OF
*                  SUBROUTINE SERV.
*
*  DESCRIPTION-    THIS SUBROUTINE SETS UP THE INTERRUPT
*                  FREQUENCY OF THE REAL TIME CLOCK AND
*                  ENTERS THE STARTING ADDRESS OF THE INTERRUPT
*                  SERVICE PROGRAM INTO LOCATION 63.  WHEN
*                  INTERRUPT OCCURS, EXECUTION COMMENCES
*                  FROM THE ADDRESS GIVEN BY LOCATION 63.  THE
*                  SINGLE INTEGER ARGUMENT IS THE NUMBER OF
*                  20 MILLISECOND COUNTS PERFORMED BY THE REAL
*                  TIME CLOCK BETWEEN INTERRUPT (LOCATION 61).
*
*  CALLING-        CALL   INT(N INT)
*
*
*
*
*
       SUBR   INT
       REL
INT    DAC    **                    ENTRY FOR INT.
       CALL   F$AT
       OCT    1                     ONE ARGUMENT.
       OCT    0
       LDA*   INT+3                 LOAD N INT.
       TCA                          INVERT.
       STA    '61                   STORE IN RTC ADDRESS.
       LDA    BB                    INTERRUPT SERVICE ADDRESS.
       STA    '63
       ENB                          ENABLE INTERRUPT.
       LDA    ='1                   SET RTC MASK.
       SMK    '20
       OCP    '20                   START CLOCK.
       JMP*   INT                   EXIT.
BB     DAC    AA
*
*
*
*
*  SUBROUTINE (CONTINUED)
```

```
* SUBROUTINE INT (CONTINUED)
*
*
*
*                   FOLLOWING SUBROUTINE INT, EXECUTION
*                   RETURNS TO THE CALLING PROGRAM UNTIL
*                   INTERRUPT OCCURS.
*                   ON INTERRUPT THE EXECUTION SEQUENCE GOES
*                   TO LOCATION AA AS FOLLOWS. THIS PROGRAM
*                   REQUIRES A PRIOR EXPLICIT CALL TO SERV
*                   BEFORE IT CAN BE EXECUTED.
*
*
*
AA    DAC    **          HERE WHEN INTERRUPT OCCURS
      OCP    '220        STOP RTC.
      CALL   SAVE        SAVE REGISTERS & KEYS.
      LDA    CC          FIND THE NUMBER OF -
      ADD    ='2         ARGUMENTS FOR SUBROUTINE-
      STA    TS1         SERV FROM PRIOR EXPLICIT CALL.
      LDA*   TS1
      TCA                TWO'S COMPLEMENT.
      STA    TS2         STORE IT FOR LATER.
      IMA    0           STORE IT IN INDEX REGISTER.
      LDA    EE          DEFINE LOCATION FOR -
      STA    TS3         POSITIONING OF ARGUMENTS -
      IRS    TS1         FOR NEW CALL SERV.
      LDA*   TS1         LOAD FROM EXPLICIT CALL.
      STA*   TS3         STORE IN NEW CALL.
      IRS    TS3
      IRS    0           FOR ALL ARGUMENTS.
      JMP    *-5
      CRA
      STA*   TS3         EXTRA ZERO REQUIRED FOR -
      IRS    TS3         FORTRAN.
      LDA    =-10        HAVE WE FILLED ALL NEW -
      SUB    TS2         ARGUMENT BUFFER - LOCATION DD
      SNZ                ONWARDS?
      JMP    *+7         YES.
      IMA    0           NO - ENTER REDUNDANT -
      LDA    NOP         OPERATIONS FOR REMAINING -
      STA*   TS3         LOCATIONS.
      IRS    TS3
      IRS    0
      JMP    *-3         ALL COMPLETE NOW.
      CALL   SERV        EXECUTE NEW SERV AND ALL -
DD    BSZ    1           SUBSEQUENT EXECUTIONS FROM -
      BSZ    1           HERE
```

PROGRAM A3.11 (continued)

```
*  SUBROUTINE INT (CONTINUED)
*
         BSZ    1                   ARGUMENT LIST
         BSZ    1
         BSZ    1
         BSZ    1
         BSZ    1
         BSZ    1
         BSZ    1
         BSZ    1
         BSZ    1
         CALL   REST                RESTORE REGISTERS AND KEYS
         JMP*   AA                  RETURN TO PRE INTERRUPT -
CC       XAC    SERV                EXECUTION.
TS1      BSS    1
TS2      BSS    1
TS3      BSS    1
EE       DAC    DD
NOP      OCT    101000
         FIN
         END
```

PROGRAM A3.12

```
C   SUBROUTINE BSCAN
C
C   THE FIRST BASELINE ROUTINE
C
C   PURPOSE -        TO SCAN A SINGLE CHANNEL OF THE MDP200
C                    AND RETURN THE RESULT TO BASIC.
C
C   DESCRIPTION -  THIS SUBROUTINE PROVIDES INTEGER/REAL
C                    CONVERSION FOR ASSEMBLER SUBROUTINE SCAN.
C                    THE REAL ARGUMENTS ARE :-
C                        1. CHANNO - CHANNEL NUMBER
C                        2. VARBLE - RESULT OF SCANNING CHANNO
C                        3. ERROR -  A FLAG SET TO 1.0 IF CHANNO
C                                    IS OUT OF RANGE, ELSE 0.0
C
C   BASIC CALL -     CALL(1,C,V,E)
C
C
C
      SUBROUTINE BSCAN(CHANNO,VARBLE,ERROR)
      NCHAN = IFIX(CHANNO+.5)
      CALL SCAN(NCHAN,NVAR,NERR)
      VARBLE = FLOAT(NVAR)
      ERROR = FLOAT(NERR)
      RETURN
      END
```

PROGRAM A3.13

```
C   SUBROUTINE BHRMIN
C
C   THE SECOND BASELINE ROUTINE
C
C   PURPOSE -        TO SCAN THE CURRENT VALUE OF THE MDP200
C                    CLOCK IN HOURS AND MINUTES.
C
C   DESCRIPTION -  INTO THE REAL ARGUMENT IS STORED THE FOUR
C                    DIGIT CLOCK READING. THE LEFTMOST TWO DIGITS
C                    REPRESENT HOURS AND THE RIGHTMOST MINUTES.
C                    THIS SUBROUTINE PROVIDES REAL/INTEGER
C                    CONVERSION FOR ASSEMBLER SUBROUTINE HRSMIN.
C
C   BASIC CALL -     CALL(2,H)
C
C
C
      SUBROUTINE BHRMIN(ANS)
      CALL HRSMIN(NANS)
      ANS = FLOAT(NANS)
      RETURN
      END
```

PROGRAM A3.14

```
C   SUBROUTINE  BSECS
C
C   THE THIRD BASELINE ROUTINE
C
C   PURPOSE -        TO SCAN THE CURRENT VALUE OF THE MDP200
C                    CLOCK IN SECONDS AND TENTHS OF SECONDS.
C
C   DESCRIPTION - INTO THE REAL ARGUMENT IS STORED THE FOUR
C                    DIGIT CLOCK READING. THE LEFTMOST TWO DIGITS
C                    REPRESENT SECONDS AND THE RIGHTMOST TENTHS.
C                    THIS SUBROUTINE PROVIDES REAL/INTEGER
C                    CONVERSION FOR ASSEMBLER SUBROUTINE SECS.
C
C   BASIC CALL -    CALL(3, S)
C
C
C
      SUBROUTINE BSECS(ANS)
      CALL SECS(NANS)
      ANS = FLOAT(NANS)
      RETURN
      END
```

PROGRAM A3.15

```
C   SUBROUTINE BSWTCH
C
C   THE FOURTH BASELINE ROUTINE
C
C   PURPOSE -        TO SCAN THE FOUR DIGIT CONSTANT SET
C                    MANUALLY ON THE MDP200 SCAN IDENTIFICATION
C                    SWITCHES
C
C   DESCRIPTION - INTO THE REAL ARGUMENT IS STORED THE
C                    FOUR DIGIT VALUE. THIS SUBROUTINE PROVIDES

C                    REAL/INTEGER CONVERSION FOR ASSEMBLER
C                    SUBROUTINE SWITCH.
C
C   BASIC CALL -    CALL(4, S3)
C
C
C
      SUBROUTINE BSWTCH(ANS)
      CALL SWITCH(NANS)
      ANS = FLOAT(NANS)
      RETURN
      END
```

PROGRAM A3.16

```
C   SUBROUTINE BENAB
C
C   THE FIFTH BASELINE SUBROUTINE
C
C   PURPOSE -         TO SET THE H316 INTERRUPT MASK FLIP-FLOPS
C
C   DESCRIPTION -     THE INTEGER VALUE OF THE REAL ARGUMENT
C                     IS TRANSFERRED TO ASSEMBLER SUBROUTINE
C                     ENAB TO SET THE MASKS .IF THE ARGUMENT IS
C                     ZERO, INTERRUPT IS INHIBITED AND THE H316
C                     REAL TIME CLOCK IS STOPPED AND RESET. SEE
C                     SUBROUTINE ENAB FOR OTHER ARGUMENTS.
C
C   BASIC CALL -      CALL(5,I)
C
C
C
      SUBROUTINE BENAB(ASK)
      MASK = IFIX(ASK+.5)
      CALL ENAB(MASK)
      RETURN
      END
```

PROGRAM A3.17

```
C   SUBROUTINE BSENS
C
C   THE SIXTH BASELINE ROUTINE
C
C   PURPOSE -       TO TEST THE H316 SENSE SWITCHES FROM BASIC
C
C   DESCRIPTION -THE SENSE SWITCH NUMBER GIVEN BY SWNO IS TESTED.
C                IF ON, ANS = 2.Ø ELSE ANS = 1.Ø .THIS SUBROUTINE
C                PROVIDES INTEGER/REAL CONVERSION FOR ASSEMBLER
C                SUBROUTINE SENS. NOTE THAT SWITCH 1 IS ALREADY
C                DEDICATED TO BASIC PROGRAM BREAK.
C
C   BASIC CALL - CALL(6,S4,A)
C
C
C
      SUBROUTINE BSENS(SWNO,ANS)
      NOSW = IFIX(SWNO+.5)
      CALL SENS(NOSW,NANS)
      ANS = FLOAT(NANS)
      RETURN
      END
```

PROGRAM A3.18

```
C   SUBROUTINE SERV
C
C   THE SEVENTH BASELINE ROUTINE
C
C   PURPOSE -        TO SERVICE INTERRUPT FROM THE H316
C                    REAL TIME CLOCK.
C
C   DESCRIPTION -  DUMMY ARGUMENTS :-
C                     1. RINT -INTERRUPT INTERVAL (SECS)
C                     2. LO   -LOWEST CHANNEL NO.
C                     3. HI   -HIGHEST CHANNEL NO.
C                     4. ENS  -ENSEMBLE SIZE
C                     5. VALUE-RESULTS STORAGE ARRAY
C                     6. SCREQ-TOTAL INTERRUPTS REQUIRED
C                     7. SCDON-NO. OF INTERRUPTS TO DATE
C                     8. ERROR-ERROR FLAG IF CHANNEL OUT
C                              OF RANGE.
C
C                   ON INTERRUPT THE H316 REAL TIME CLOCK
C                   IS RESTARTED AND CHANNELS LO - HI ARE
C                   SCANNED AND AN ENSEMBLE AVERAGE STORED
C                   AS VALUE(CH. NO., SCDONE). ARRAY VALUE
C                   MUST BE DIMENSIONED (39,N) IN BASIC.
C                   WHEN SCDONE = SCREQ INTERRUPT IS HALTED.
C                   THE NORMAL EXIT FROM THIS SUBROUTINE
C                   IS THROUGH ASSEMBLER SUBROUTINE INT
C                   TO THE BASIC PROGRAM INTERRUPTED.
C
C  BASIC CALL - CALL(7,I,N1,N2,E3,A(Ø,Ø),S3,S4,E1)
C
C
C
```

PROGRAM A3.18 (cont/..)

```
C  SUBROUTINE SERV (CONTINUED)


      SUBROUTINE SERV(RINT,LO,HI,ENS,VALUE,SCREQ,SCDONE,ERROR)
      REAL LO
      DIMENSION VALUE(40,1)
      DIMENSION SUM(40)
      NINT=IFIX(RINT*50.0+.5)
C
C  IF NINT = 0 ,JUST SCAN AND RETURN.
C
      IF (NINT) 19,30,40
   40 CALL INT(NINT)
C
C  FORM INTEGERS
C
   30 NLO=IFIX(LO+.5)
      NHI=IFIX(HI+.5)
      SCDONE=SCDONE+1.0
      NENS=IFIX(ENS+.5)
      NSCD=IFIX(SCDONE+.5)
      NS=NHI-NLO+1
C
C  CLEAR SUMMATIONS
C
      DO 50 I=NLO,NHI
      SUM(I)=0.
   50 CONTINUE
C
C  PERFORM SCANS
C
      DO 60 I=1,NENS
      DO 10 J=1,NS
      NC= NLO+J-1
      CALL SCAN(NC,NANS,NERR)
      IF(NERR.EQ.1) GOTO 19
      SUM(NC)=SUM(NC)+ FLOAT(NANS)
   10 CONTINUE
   60 CONTINUE
C
C  ENSEMBLE AVERAGE AND STORE BACK
C
      DO 70 I=NLO,NHI
      VALUE(I+1,NSCD+1)=SUM(I)/ENS
   70 CONTINUE
      IF (SCDONE.GE.SCREQ) GOTO 20
      ERROR=0.
      RETURN
C
C  HERE IF CHANNEL OUT OF RANGE OR NINT -VE
C
   19 ERROR=1.0
   20 CALL ENAB(0)
      RETURN
      END
```

PROGRAM A3.19

```
C     SUBROUTINE KALMAN
C
C     THE EIGHTH BASELINE ROUTINE
C
C     PURPOSE :-       TO EXECUTE THE PROBLEM INDEPENDENT SECTION
C                      OF THE KALMAN FILTER ALGORITHM.
C
C     DESCRIPTION :-DUMMY ARGUMENTS:
C                          PHI - TRANSITION MATRIX (INPUT)
C                          Q   - PROCESS NOISE CVM (INPUT)
C                          R   - MEASUREMENT NOISE CVM (INPUT)
C                          M   - MEASUREMENT MATRIX (INPUT)
C                          P   - ESTIMATION ERROR CVM (INPUT/OUTPUT)
C                          X   - STATE VECTOR (INPUT/OUTPUT)
C                          Y   - MEASUREMENT VECTOR (INPUT)
C                          EPS - CONVERGENCE FACTOR
C                          S   - PREDICTION ERROR CVM (OUTPUT)
C                          K   - FILTER GAIN MATRIX (OUTPUT)
C                          VAR - NO. OF STATE VARIABLES
C                          MEAS- NO. OF MEASUREMENTS
C
C                      THIS SUBROUTINE IS WRITTEN SPECIFICALLY FOR
C                      INCORPORATION INTO THE BASELINE PACKAGE. THE
C                      USE OF BASE SECTOR IS MINIMISED BY MIXING
C                      ASSEMBLER AND FORTRAN INSTRUCTIONS, AND
C                      TRANSLATING INTO ASSEMBLER BY THE FORTRAN
C                      TRANSLATOR. THIS REQUIRES AN ARRAY SUBSCRIPT
C                      FUNCTION.
C
C                      ALL ARRAYS MUST BE DIMENSIONED 9*9 IN BASIC,
C                      THUS THE PROGRAM WILL PROCESS A MAXIMUM OF
C                      10 STATE VARIABLES AND 10 MEASUREMENTS
C
C
C     BASIC CALL  :-   CALL(8,F(Ø,Ø),Q(Ø,Ø),R(Ø,Ø),M(Ø,Ø),P(Ø,Ø),
C                                  X(Ø),Y(Ø),E1,S(Ø,Ø),K(Ø,Ø),N,M)

C
C
C

C     CONTINUED
```

PROGRAM A3.19 (cont/..)

```
      SUBROUTINE KALMAN(PHI,Q,R,M,P,X,Y,EPS,S,K1,VAR,MEAS)
C
C FIRST BASE SECTOR RELOCATION
C
A      SETB
A      BSS ,39
C
      REAL K1,M,MEAS
      DIMENSION PHI(1),Q(1),R(1),X(1),Y(1),P(1),S(1),K1(1)
     1,T(10,10),T1(10,10),M(1)
C
C ARRAY SUBSCRIPT FUNCTION
C
      L1(I,J)=I+(J-1)*10
C
C SECOND BASE SECTOR RELOCATION
C
A     SETB,*+1
A     JMP ,*+44
A     BSS ,43
C
C SET UP INTEGERS
C
      NVAR = IFIX(VAR+.5)
      NMEAS = IFIX(MEAS+.5)
C
C UPDATE PREVIOUS ERROR CVM (WEIGHTED)
C
      DO 10 I=1,NVAR
      DO 10 J=1,NVAR
      T(I,J)=0.0
      DO 10 K=1,NVAR
      T(I,J)=T(I,J) + P(L1(I,K))*PHI(L1(J,K))
   10 CONTINUE
      DO 30 I=1,NVAR
      DO 30 J=1,NVAR
      P(L1(I,J))=0.0
      DO 20 K=1,NVAR
      P(L1(I,J))=P(L1(I,J)) + PHI(L1(I,K))*T(K,J)
   20 CONTINUE
      P(L1(I,J))=(P(L1(I,J))+Q(L1(I,J)))/EPS
   30 CONTINUE
C
C COMPUTE PREDICTION ERROR CVM
C
      DO 25 I=1,NVAR
      DO 25 J=1,NMEAS
      T(I,J)=0.0
      DO 25 K=1,NVAR
      T(I,J)=T(I,J)+P(L1(I,K))*M(L1(J,K))
   25 CONTINUE
      DO 27 I=1,NMEAS
      DO 23 J=1,NMEAS
      S(L1(I,J))=0.0
      DO 23 K=1,NVAR
```

PROGRAM A3.19 (cont/..)

```
      S(L1(I,J))=S(L1(I,J))+M(L1(I,K))*T(K,J)
   23 CONTINUE
      S(L1(I,I))=S(L1(I,I))+R(L1(I,I))
   27 CONTINUE
C
C SET UP MEASUREMENT COUNTER
C
      DO 40 L=1,NMEAS
C
C COMPUTE FILTER GAIN VECTOR
C
      DO 50 I=1,NVAR
      T(I,1)=0.0
      DO 50 J=1,NVAR
      T(I,1)=T(I,1)+P(L1(I,J))*M(L1(L,J))
   50 CONTINUE
      TEMP =0.0
      DO 60 J=1,NVAR
      TEMP=TEMP+M(L1(L,J))*T(J,1)
   60 CONTINUE
C
C  THIRD BASE SECTOR RELOCATION
C
A      SETB,*+1
A      JMP ,*+45
A      BSS ,44
C
      TEMP=TEMP+R(L1(L,L))
      DO 70 I=1,NVAR
      K1(L1(I,L))=T(I,1)/TEMP
   70 CONTINUE
C
C PROCESS OBSERVATION VECTOR AND ESTIMATE
C
      TEMP=0.0
      DO 80 I=1,NVAR
      TEMP=TEMP+M(L1(L,I))*X(I)
   80 CONTINUE
      TEMP=Y(L)-TEMP
      DO 90 I=1,NVAR
      X(I)=X(I)+K1(L1(I,L))*TEMP
   90 CONTINUE
C
C COMPUTE ESTIMATION ERROR CVM
C
      DO 100 I=1,NVAR
      DO 105 J=1,NVAR
      T(I,J)=-K1(L1(I,L))*M(L1(L,J))
  105 CONTINUE
      T(I,I)=1.+T(I,I)
  100 CONTINUE
      DO 110 I=1,NVAR
      DO 110 J=1,NVAR
      T1(I,J)=0.0
      DO 110 K=1,NVAR
      T1(I,J)=T1(I,J)+P(L1(I,K))*T(J,K)
  110 CONTINUE
```

PROGRAM A3.19 (cont/..)

```
      DO 120 I=1,NVAR
      DO 120 J=1,NVAR
      P(L1(I,J))=0.0
      DO 120 K=1,NVAR
      P(L1(I,J))=P(L1(I,J))+T(I,K)*T1(K,J)
  120 CONTINUE
      DO 130 I=1,NVAR
      DO 130 J=1,NVAR
      P(L1(I,J))=P(L1(I,J))+K1(L1(I,L))*K1(L1(L,J))*R(L1(L,L))
  130 CONTINUE
   40 CONTINUE
      RETURN
      END
```

TABLE A3.1 DAP-16 OPERATION CODES

Mnemonic	Meaning
ADD	Binary add to A-reg
ALR	Logical left rotate A
ALS	Arithmetic left shift A
ANA	Logical AND to A
AOA	Add one to A
ARR	Logical right rotate A
ARS	Arithmetic right shift
CAS	Compare and skip
CRA	Clear A
ENB	Enable program interrupt
IAB	Interchange A and B
IMA	Interchange memory and A
INA	Input to A from peripheral
INH	Inhibit program interrupt
INK	Input keys
IRS	Increment, replace and skip
JMP	Unconditional jump
JST	Jump and store current location
LDA	Load A
LDX	Load index register
LLL	Long left shift of A and B
LRL	Long right shift of A and B
NOP	No operation
OCP	Output peripheral control pulse
OTA	Output from A to peripheral
OTK	Output keys
SKP	Unconditional skip
SKS	Skip if peripheral ready line is set
SMI	Skip if A negative

Table A3.1 (cont/..)

SMK	Set interrupt mask
SNZ	Skip if A not zero
SPL	Skip if A plus
SSM	Set sign minus
STA	Store A
STX	Store index register
SUB	Subtract
SZE	Skip if A zero
TCA	Two's complement A
**	Zero address code
*	Indirect operation (when in op. code)
*	The address of this instruction (when in address code)
'220	Octal constant
=	Literal string

TABLE A3.2 DAP-16 PSEUDO-OPERATION CODES

Mnemonic	Meaning
BSS	Defines storage area
BSZ	Storage for block of zeros
CALL	Call subroutine
COMN	Define common variables
DAC	Define address constant
DEC	Define decimal constant
END	End of assembly pass
FIN	Finish assembly and output literals
OCT	Define octal constant
REL	Program relocatable
SETB	Specify new base sector
SUBR	Define subroutine name
XAC	External address constant
***	Zero code for special use

A3.8 References

A3.1 Dean, K. J., 'Conversion Between Binary Code and Some Binary-decimal Codes'. The Radio and Electronic Engineer, 1968, 34(1), 49

A3.2 Goldman, S. F. and Sargent, R. W. H., 'Applications of Linear Estimation Theory to Chemical Processes: A Feasibility Study', Chem. Engng. Sci., 1971, 26(10), 1535

A3.3 Honeywell Information Systems Ltd., Document 130071364, 'FORTRAN IV Manual for DDP Computers'. August 1967

A3.4 Honeywell Information Systems Ltd., Document 130071629, 'DAP-16 Manual for DDP Computers'. August 1967

A3.5 Honeywell Information Systems Ltd., Document 41286103126 'FORTRAN Translator Software Manual'. April 1972

A3.6 Payne, S. G. and Gay, B., 'Development and Use of a high-level language compiler for interactive data acquisition and processing'. The Institution of Chemical Engineers, 1st Annual Research Meeting, April 1974.

APPENDIX 4

THE ASP COMPILER

The development of the Aston Simulation Program, including listings has been published. A copy of the paper is to be found in the wallet inside the back cover of the thesis.

APPENDIX 5

THE DYNAMIC MODEL OF THE DOUBLE EFFECT EVAPORATOR

A5.1 General

The objective of this modelling exercise is to produce a set of ordinary differential equations describing the thermal behaviour of the double effect evaporator and suitable for use in the real time implementation of the Kalman filter algorithm. Figure A5.1 shows the evaporator, stream numbers and mass flows.

In deriving the model, the following assumptions are made

1. The heat exchanger shells are well mixed regions so that the exit and shell temperatures are equal. Where vapour and liquid mixtures exist, the temperature is that of the saturated vapour at the operating pressure.

2. In the majority of the heat exchanger tubes, liquid is in the plug flow regime. A lumped liquid temperature is approximated by the arithmetic mean of liquid inlet and outlet temperatures.

3. In the tubes of the climbing film first effect, the liquid and vapour are assumed to be well mixed.

4. The exchanger tubes have zero thermal resistance.

5. The temperature driving force is given by the arithmetic mean of the inlet and outlet temperature differences.

6. There are no heat losses.

The volume fraction of vapour (where vapour and condensate exist together) is denoted by Y, the shell and tube volume by W_s and W_t, the overall heat transfer coefficients by U, the heat transfer area by A, liquid density by ρ_L, vapour density and latent heat by ρ_N and λ_N where N refers to the stream number and hence temperature at which the vapour density or latent heat is calculated. The subscripts c, e, f and g refer to the condenser, first effect, second effect and preheater respectively.

A5.2 Preheater

A5.2.1 Tubeside

At the preheater tubes, there is no change of phase and under the above assumptions, the dynamic energy balance is given by,

$$M_1 Cp T_1 - M_2 Cp T_2 + Ug Ag\left(T_4 - \frac{(T_1 + T_2)}{2}\right) = W_{tg} \rho_L \frac{d}{dt} \frac{(T_1 + T_2)}{2} \qquad \text{A5.1}$$

A5.2.2 Shellside

At the preheater shell, the vapour from the cyclone separator is partially condensed. An unsteady state mass balance is given by,

$$V_3 - M_4 - V_4 = W_{sg} \frac{d}{dt}\left((1 - Y_g) \qquad + Y_g \rho_4 \right) \qquad \text{A5.2}$$

and an unsteady state energy balance by,

$$V_3(T_3 Cp + \lambda_3) - V_4(T_4 Cp + \lambda_4) - M_4 Cp T_4 - U_g A_g\left(T_4 - \frac{(T_1 + T_2)}{2}\right)$$

$$= W_{sg} \frac{d}{dt}\left((1 - Y_g)\rho_L Cp T_4 + Y_g \rho_4 (Cp T_4 + \lambda_4) \right) \qquad \text{A5.3}$$

Expanding the right hand side (RHS) of equation A5.3,

$$RHS = W_{sg}\left((1 - Y_g)\rho_L C_p \cdot \frac{dT_4}{dt} - T_4 \rho_L C_p \cdot \frac{dY_g}{dt} + \rho_4 (C_p T_4 + \lambda_4) \cdot \frac{dY_g}{dt}\right.$$

$$\left. + \rho_4 Y_g C_p \cdot \frac{dT_4}{dt} + (C_p T_4 + \lambda_4) Y_g \cdot \frac{d\rho_4}{dt}\right) \qquad A5.4$$

and rearranging A5.2

$$\frac{dY_g}{dt} = \frac{V_3 - M_4 - V_4 - W_{sg} Y_g \cdot \frac{d\rho_4}{dt}}{W_{sg}(\rho_4 - \rho_L)} \qquad A5.5$$

Substituting equation A5.5 into A5.4 gives

$$RHS = W_{sg}\left(((1 - Y_g) + Y_g \rho_4) C_p \frac{dT_4}{dt} + (C_p T_4 + \lambda_4) Y_g \frac{d\rho_4}{dt}\right)$$

$$+ \left(C_p T_4 + \frac{\rho_4 \lambda_4}{(\rho_4 - \rho_L)}\right) \left(V_3 - M_4 - V_4 - W_{sg} Y_g \cdot \frac{d\rho_4}{dt}\right) \qquad A5.6$$

which when combined with LHS of A5.3 gives

$$V_3 C_p (T_3 - T_4) + V_3 \lambda_3 - V_4 \lambda_4 - U_g A_g \left(T_4 - \frac{(T_1 + T_2)}{2}\right) - \frac{\rho_4 \lambda_4}{(\rho_4 - \rho_L)} (V_3 - M_4 - V_4)$$

$$= W_{sg}\left(C_p (\rho_L + Y_g (\rho_4 - \rho_L)) \cdot \frac{dT_4}{dt} + \lambda_4 Y_g \left(1 - \frac{\rho_4}{(\rho_4 - \rho_L)}\right) \frac{d\rho_4}{dt}\right) \qquad A5.7$$

Equation A5.7 is further simplified by assuming $\rho_4 << \rho_L$, hence

$$V_3 C_p (T_3 - T_4) + V_3 \lambda_3 - V_4 \lambda_4 - U_g A_g \left(T_4 - \frac{(T_1 + T_2)}{2}\right)$$

$$= W_{sg}\left(C_p (1 - Y_g) \rho_L \cdot \frac{dT_4}{dt} + Y_g \lambda_4 \cdot \frac{d\rho_4}{dt}\right) \qquad A5.8$$

The thermodynamic relationship between vapour density and temperature is assumed to be known

$$\rho_4 = \alpha(T_4) \qquad \text{A5.9}$$

and hence by the chain rule

$$\frac{d\rho_4}{dt} = \frac{d\alpha(T_4)}{dT_4} \cdot \frac{dT_4}{dt} \qquad \text{A5.10}$$

Equations A5.5, A5.8 and A5.10 represent 3 differential equations in five unknowns - Y_g, T_4, ρ_4, M_4, V_4. As discussed in section 5.3.7, the pressure dynamics are uncertain so that variations in vapour temperature must be considered. Consequently, the derivative of equations for M_4 and V_4, the exit mass flow rates, is based upon the approximate method of steady state perturbations. If the preheater is operating at steady state, the shellside energy balance is given by

$$V_3(C_pT_3 + \lambda_3) - V_4(C_pT_4 + \lambda_4) - M_4C_pT_4 - A_gU_g\left(T_4 - \frac{(T_1 + T_2)}{2}\right) = 0 \qquad \text{A5.11}$$

and the mass balance by

$$V_3 = V_4 + M_4 \qquad \text{A5.12}$$

Differentiation of the steady state energy equation gives

$$dV_3(C_pT_3 + \lambda_3) + V_3C_pT_3 - dV_4(C_pT_4 + \lambda_4) - V_4C_p dT_4$$
$$- M_4C\, dT_4 - T_4C\, dM_4 - A_gU_g\left(dT_4 - \frac{dT_2}{2}\right) = 0 \qquad \text{A5.13}$$

and the mass balance gives

$$dV_3 = dV_4 + dM_4 \qquad \text{A5.14}$$

Substitution of A5.14 into A5.12 yields

$$dV_3C_p(T_3 - T_4) + V_3C_p(dT_3 - dT_4) + \lambda_4 dM_4 - A_gU_gdT_4 + A_gU_g\frac{dT_2}{2} = 0 \qquad \text{A5.15}$$

Since $(T_3 - T_4)$ is small, the resulting differential equations are

$$\frac{dM_4}{dt} = \frac{A_gU_g + V_3C_p}{4} \cdot \frac{dT_4}{dt} - \frac{A_gU_g}{2\lambda_4} \cdot \frac{dT_2}{dt} - \frac{V_3C_p}{\lambda_4} \cdot \frac{dT_3}{dt} \qquad \text{A5.16}$$

$$\frac{dV_4}{dt} = \frac{dV_3}{dt} - \frac{dM_4}{dt} \qquad \text{A5.17}$$

A5.3 First Effect

A5.3.1 Tubeside

In the tubes of the climbing film type first effect, the liquid is partially vaporised by the shellside steam. The resulting two-phase mixture is assumed to be well mixed. Zuber (A5.1) has developed the distributed-parameter dynamic equations based upon two-phase flow theory. The unsteady state mass balance is given by

$$M_2 - M_7 - V_7 = W_{te}\frac{d}{dt}\Big((1 - Y_e)\rho_L + Y_e\rho_7\Big) \qquad \text{A5.18}$$

where Ye refers to the vapour volume fraction in the evaporator tubes.

The unsteady state energy balance is

$$M_2C_pT_2 - M_7C_pT_7 - V_7(C_pT_7 + \lambda_7) + A_gU_g(T_5 - T_7)$$

$$= W_{et}\frac{d}{dt}\Big((1 - Y_e)\rho_L C_pT_7 + Y_e\rho_7(C_pT_7 + \lambda_7)\Big) \qquad \text{A5.19}$$

Rearranging equation A5.18 gives

$$\frac{dYe}{dt} = \frac{M_2 - M_7 - V_7 - W_{te} Ye \frac{d\rho_7}{dt}}{W_{te}(\rho_7 - \rho_L)} \qquad \text{A5.20}$$

substitution of equation A5.20 into A5.19, rearrangement as shown in the preheater dynamic equations, and assuming $\rho_7 \ll \rho_L$, gives,

$$M_2 Cp(T_2 - T_7) - V_7\lambda_7 + AeUe(T_5 - T_7)$$

$$= W_{te} \quad Cp(1 - Ye)\rho_L \frac{dT_7}{dt} + \lambda_7 Ye \cdot \frac{d\rho_7}{dt} \qquad \text{A5.21}$$

$$\frac{d\rho_7}{dt} = \frac{d\alpha(T_7)}{dT_7} \cdot \frac{dT_7}{dt} \qquad \text{A5.22}$$

and the steady state operating equations are

$$\frac{dV_7}{dt} = - \frac{(AeUe + M_2Cp)}{\lambda_7} \cdot \frac{dT_7}{dt} + \frac{M_2Cp}{\lambda_7} \cdot \frac{dT_2}{dt} \qquad \text{A5.23}$$

$$\frac{dM_7}{dt} = \frac{dM_2}{dt} - \frac{dV_7}{dt} \qquad \text{A5.24}$$

A5.3.2 Shellside

The operating pressure of the steam supply to the first effect is maintained constant by a pressure regulator. It is assumed that the steam loses heat by condensation only so that the shellside of the evaporator is isothermal. Thus, for the purpose of describing the evaporator dynamics the shellside is represented by stating that T_5 is constant and that there is no accumulation of condensate. It should be noted, however, that the overall heat transfer coefficient, Ue, is a non-linear function of steam flow rate and temperature.

A5.4 Cyclone Separator

It is assumed that the liquid hold up in the cyclone separator is negligible (confirmed by observation) and that the unit operates isothermally. Thus,

$$T_7 = T_3 = T_8 \quad \text{A5.25}$$

$$\frac{dT_7}{dt} = \frac{dT_3}{dt} = \frac{dT_8}{dt} \quad \text{A5.26}$$

$$M_7 = M_8 \quad \text{A5.27}$$

$$\frac{dM_7}{dt} = \frac{dM_8}{dt} \quad \text{A5.28}$$

$$V_7 = V_3 \quad \text{A5.29}$$

$$\frac{dV_7}{dt} = \frac{dV_3}{dt} \quad \text{A5.30}$$

A5.5 Second Effect

A5.5.1 Tubeside

At the forced circulation second effect tubes there is no change of phase so that in a similar manner to the preheater the dynamic energy balance is given by

$$M_{15}CpT_{15} - M_{14}CpT_{14} + U_f A_f \left(T_{10} - \frac{(T_{14} + T_{15})}{2} \right)$$

$$= W_{tf}\, Cp \rho_L \frac{d}{dt} \frac{(T_{14} + T_{15})}{2} \quad \text{A5.31}$$

A5.5.2 Shellside

At the second effect shell, the vapour and liquid from the preheater shell is further condensed. An unsteady state mass balance is given by

$$V_4 + M_4 - V_{10} - M_{10} = W_{sf}\frac{d}{dt}\left((1 - Y_f)\rho_L + Y_f\rho_{10}\right) \qquad \text{A5.32}$$

and an unsteady state energy balance by

$$Y_4(T_4 Cp + \lambda_4) + M_4 CpT_4 - V_{10}(T_{10}Cp + \lambda_{10}) - M_{10}CpT_{10} - U_f A_f\left(T_{10} - \frac{(T_{14} - T_{15})}{2}\right)$$

$$= W_{sf}\frac{d}{dt}\left((1 - Y_f)\rho_L CpT_{10} + Y_f\rho_{10}(CpT_{10} + \lambda_{10})\right) \qquad \text{A5.33}$$

Rearranging equation A5.33 gives

$$\frac{dYf}{dt} = \frac{V_4 + M_4 - M_{10} - V_{10} - W_{sf}Y_f\frac{d\rho_{10}}{dt}}{W_{sf}(\rho_{10} - \rho_L)} \qquad \text{A5.34}$$

substitution of equation A5.34 into A5.33, rearrangement as shown in the preheater dynamic equations and assuming $\rho_{10} \ll \rho_L$, gives,

$$(V_4 + M_4)\,Cp\,(T_4 - T_{10}) + \lambda_4 V_4 - \lambda_{10}V_{10} - U_f A_f\left(T_{10} - \frac{(T_{14} + T_{15})}{2}\right)$$

$$= W_{sf}\left((1 - Y_f)Cp\rho_L\frac{dT_{10}}{dt} + Y_f\lambda_{10}\frac{d\rho_{10}}{dt}\right) \qquad \text{A5.35}$$

$$\frac{d\rho_{10}}{dt} = \frac{d\alpha(T_{10})}{dT_{10}}\cdot\frac{dT_{10}}{dt} \qquad \text{A5.36}$$

and the steady state operating equations are

$$\frac{dM_{10}}{dt} = \frac{A_f U_f + M_4 + V_4}{\lambda_{10}}\cdot\frac{dT_{10}}{dt} - \frac{A_f U_f}{2\lambda_{10}}\left(\frac{dT_{14}}{dt} + \frac{dT_{15}}{dt}\right)$$

$$- \frac{M_4 + V_4}{\lambda_{10}}\cdot\frac{dT_4}{dt} \qquad \text{A5.37}$$

$$\frac{dV_{10}}{dt} = \frac{dV_4}{dt} + \frac{dM_4}{dt} - \frac{dM_{10}}{dt} \qquad \text{A5.38}$$

A5.6 Second Effect Separator

The second effect separator is assumed to be a well mixed tank at temperature T_{15}, into which hot liquor is fed from the cyclone separator and from the second effect tubes. Vapour flashes off instantaneously so that as boiling takes place, the liquid level in the separator changes. An unsteady state mass balance on the separator gives,

$$M_{14} + M_8 - M_{15} - V_9 = A_s \rho_L \frac{dH_s}{dt} \qquad \text{A5.39}$$

where A_s and H_s are the cross sectional area and liquid level in the separator. An unsteady state energy balance gives,

$$M_{14}CpT_{14} - M_{15}CpT_{15} + M_8CpT_8 - V_9(CpT_9 + \lambda_9)$$

$$= A_s \rho_L \, Cp \, \frac{dH_s T_{15}}{dt} \qquad \text{A5.40}$$

Substitution of equation A5.39 into A5.40 and utilising the constant pump circulation rate ($M_{14} = M_{15}$) and isothermal boiling ($T_9 = T_{15}$) gives,

$$M_{14}C_p(T_{14} - T_{15}) + M_8C_p(T_8 - T_{15}) - V_9\lambda_{15} =$$

$$A_s \rho_L \, C_p H_s \frac{dT_{15}}{dt} \qquad \text{A5.41}$$

The rate of change of vapour rate V_9 is determined from the steady state energy equation

$$M_{14}C_pT_{14} - M_{15}C_pT_{15} + M_8C_pT_8 - V_9(C_pT_{15} + \lambda_{15}) = 0 \qquad \text{A5.42}$$

Differentiating and assuming constant circulation rate gives

$$\frac{dV_9}{dt} = \frac{1}{\lambda_{15}}\left((T_8 - T_{15})C_p\frac{dM_8}{dt} + M_8C_p\frac{dT_8}{dt} - (M_{14} + M_8)C_p\frac{dT_{15}}{dt} + M_{14}C_p\frac{dT_{14}}{dt}\right) \qquad \text{A5.43}$$

A5.7 Condenser

A5.7.1 Tubeside

At the condenser tubes there is no change of phase, so that in a similar manner to the preheater and second effect, the dynamic energy balance is given by,

$$M_{12}C_pT_{12} - M_{13}C_pT_{13} + U_cA_c\left(T_{vac} - \frac{(T_{12} + T_{13})}{2}\right) = W_{tc}\rho_L C_p \frac{d}{dt}\frac{(T_{12} + T_{13})}{2} \qquad \text{A5.44}$$

A5.7.2 Shellside

At the condenser shell, the vapour from the second effect separator and vapour/liquid mixture from the second effect shell are condensed. The vapour pressure is maintained constant by the vacuum pump at temperature T_{vac} and the condensate pump does not permit any accumulation of condensate in the condenser shell. Thus, the steady state mass balance is

$$M_{11} = V_9 + M_{10} + V_{10} \qquad \text{A5.45}$$

and steady state energy balance is

$$T_{11} = \frac{V_9(C_p T_{15} + \lambda_{15}) + M_{10} C_p T_{10} + V_{10}(C_p T_{10} + \lambda_{10}) - U_c A_c \left(T_{vac} - \frac{T_{12} + T_{13}}{2}\right)}{M_{11} C_p} \qquad \text{A5.46}$$

A5.8 Summary of Dynamic Equations

A5.8.1 Preheater

$$\frac{W_{tg}\rho_L}{2} \frac{dT_2}{dt} = M_1 C_p T_1 - M_2 C_p T_2 + U_g A_g \left(T_4 - \frac{(T_1 + T_2)}{2}\right) \qquad \text{A5.47}$$

$$W_{sg}\left(C_p(1 - Y_g)\rho_L \frac{dT_4}{dt} + Y_g \lambda_4 \frac{d\rho_4}{dt}\right) \qquad \text{A5.48}$$

$$= V_3 C_p(T_3 - T_4) + V_3 \lambda_3 - V_4 \lambda_4 - U_g A_g \left(T_4 - \frac{(T_1 + T_2)}{2}\right)$$

$$\frac{dY_g}{dt} = \frac{V_3 - M_4 - V_4 - W_{sg} Y_g \frac{d\rho_4}{dt}}{W_{sg}(\rho_4 - \rho_L)} \qquad \text{A5.49}$$

$$\frac{d\rho_4}{dt} = \frac{d\alpha(T_4)}{dT_4} \frac{dT_4}{dt} \qquad \text{A5.50}$$

$$\frac{dM_4}{dt} = \frac{A_gU_g + V_3C_p}{\lambda_4} \cdot \frac{dT_4}{dt} - \frac{A_gU_g}{2\lambda_4} \cdot \frac{dT_2}{dt} - \frac{V_3C_p}{\lambda_4} \cdot \frac{dT_3}{dt} \qquad \text{A5.51}$$

$$\frac{dV_4}{dt} = \frac{dV_3}{dt} - \frac{dM_4}{dt} \qquad \text{A5.52}$$

A5.8.2 First Effect

$$W_{te}\left(C_p(1 - Y_e)\rho_L\frac{dT_7}{dt} + \lambda_7 Y_e \frac{d\rho_7}{dt} \right) \qquad \text{A5.53}$$

$$= M_2C_p(T_2 - T_7) - V_7\lambda_7 + A_eU_e(T_5 - T_7)$$

$$\frac{dY_e}{dt} = \frac{M_2 - M_7 - V_7 - W_{te}Y_e \cdot \frac{d\rho_7}{dt}}{W_{te}(\rho_7 - \rho_L)} \qquad \text{A5.54}$$

$$\frac{d\rho_7}{dt} = \frac{d\alpha}{dT_7}(T_7) \cdot \frac{dT_7}{dt} \qquad \text{A5.55}$$

$$\frac{dV_7}{dt} = -\frac{(A_eU_e + M_2C_p)}{\lambda_7} \cdot \frac{dT_7}{dt} + \frac{M_2C_p}{\lambda_7}\frac{dT_2}{dt} \qquad \text{A5.56}$$

$$\frac{dM_7}{dt} = \frac{dM_2}{dt} - \frac{dV_7}{dt} \qquad \text{A5.57}$$

$$T_5 = \text{constant} \qquad \text{A5.58}$$

A5.8.3 Cyclone Separator

$$T_7 = T_3 = T_8 \quad \text{A5.59}$$

$$\frac{dT_7}{dt} = \frac{dT_3}{dt} = \frac{dT_8}{dt} \quad \text{A5.60}$$

$$M_7 = M_8 \quad \text{A5.61}$$

$$\frac{dM_7}{dt} = \frac{dM_8}{dt} \quad \text{A5.62}$$

$$V_7 = V_3 \quad \text{A5.63}$$

$$\frac{dV_7}{dt} = \frac{dV_3}{dt} \quad \text{A5.64}$$

A5.8.4 Second Effect

$$W_{tf} C_p \rho_L \frac{d}{dt} \frac{(T_{14} + T_{15})}{2} = M_{15} C_p T_{15} - M_{14} C_p T_{14} + U_f A_f \left(T_{10} - \frac{(T_{14} + T_{15})}{2} \right) \quad \text{A5.65}$$

$$W_{sf}\left(C_p(1 - Y_f)\rho_L \frac{dT_{10}}{dt} + Y_f \lambda_{10} \frac{d\rho_{10}}{dt}\right)$$

A5.66

$$= (V_4 + M_4)C_p(T_4 - T_{10}) + \lambda_4 V_4 - \lambda_{10} V_{10} - U_f A_f\left(T_{10} - \frac{(T_{14} + T_{15})}{2}\right)$$

$$\frac{dY_f}{dt} = \frac{V_4 + M_4 - M_{10} - Y_{10} - W_{sf} Y_f \dfrac{d\rho_{10}}{dt}}{W_{sf}(\rho_{10} - \rho_L)} \qquad \text{A5.67}$$

$$\frac{d\rho_{10}}{dt} = \frac{d\alpha(T_{10})}{dT_{10}} \cdot \frac{dT_{10}}{dt} \qquad \text{A5.68}$$

$$\frac{dM_{10}}{dt} = \frac{A_f U_f + (M_4 + V_4)}{\lambda_{10}} C_p \cdot \frac{dT_{10}}{dt} - \frac{A_f U_f}{2\lambda_{10}}\left(\frac{dT_{14}}{dt} + \frac{dT_{15}}{dt}\right) \qquad \text{A5.69}$$

$$- \frac{M_4 + V_4}{\lambda_{10}} \cdot \frac{dT_4}{dt}$$

$$\frac{dV_{10}}{dt} = \frac{dV_4}{dt} + \frac{dM_4}{dt} - \frac{dM_{10}}{dt} \qquad \text{A5.70}$$

A5.8.5 Second Effect

$$A_s \rho_L C_p H_s \frac{dT_{15}}{dt} = M_{14} C_p (T_{14} - T_{15}) + M_8 C_p (T_8 - T_{15}) - V_9 \lambda_{15} \qquad \text{A5.71}$$

$$A_s \rho_L \frac{dH_s}{dt} = M_{14} + M_8 - M_{15} - V_9 \qquad \text{A5.72}$$

$$\frac{dV_9}{dt} = \frac{1}{\lambda_{15}} \left((T_8 - T_{15}) C_p \frac{dM_8}{dt} + M_8 C_p \frac{dT_8}{dt} - (M_{14} + M_8) C_p \frac{dT_{15}}{dt} + M_{14} C_p \frac{dT_{14}}{dt} \right) \qquad \text{A5.73}$$

A5.8.6 Condenser

$$\frac{W_{tc}}{2} L C_p \frac{dT_{13}}{dt} = M_{12} C_p T_{12} - M_{13} C_p T_{13} + U_c A_c \left(T_{vac} - \frac{(T_{12} + T_{13})}{2} \right) \qquad \text{A5.74}$$

$$T_{11} = \frac{V_9 (C_p T_{15} + \lambda_{15}) + M_{10} C_p T_{10} + V_{10} (C_p T_{10} + \lambda_{10}) - U_c A_c \left(T_{vac} - \frac{(T_{12} + T_{13})}{2} \right)}{M_{11} C_p} \qquad \text{A5.75}$$

$$M_{11} = V_9 + M_{10} + V_{10} \qquad \text{A5.76}$$

A5.8.7 Notation

Equation A5.47 to A5.76 represent the mathematical model of the double effect evaporator and are referred to in Section 5.3 as equations 5.3.1 to 5.3.30.

A5.9 Reference

A5.1 Zuber, N., and Staub, F.W., "An Analytical Investigation of the Transient Response of the Volumetric Concentration in a Boiling Forced-Flow System".
Nuclear Science and Engineering 30, 268-278 (1967).

APPENDIX 6 - COMPUTER PROGRAMS

PROGRAM 1

```
10   REM
15   REM
20   REM   PROGRAM 1
25   REM
30   REM   EVALUATION OF STEAM TEMPERATURE FROM PRESSURE
35   REM
40   E=.1E-03
42   PRINT " PRESSURE"," TEMPERATURE","CALCULATED"
43   PRINT " "," TABLES","   TEMP"
44   PRINT "  KN/M2","    C","    C": PRINT
45   FOR I=1,12
50   READ T,P
55   GOSUB 100
60   PRINT P,T,T0
65   NEXT I
70   STOP
95   REM
100  REM   BASIC SUBROUTINE TO DETERMINE
105  REM   T FROM P ITERATIVELY.
110  REM
115  Z1=LOG(P/101.325)/13.3185
120  Z3=Z1
125  Z2=Z1+((.1299*Z3+.6445)*Z3+1.976)*Z3↑2/13.3185
130  IF ABS(Z3-Z2)>E THEN Z3=Z2: GOTO 125
135  T0=373.15/(1-Z2)-273.15
140  RETURN
143  REM
145  REM   DATA FOR TEST RUN
150  REM
160  DATA 10,1.227,15,1.704,20,2.337,25,3.166,30,4.242
170  DATA 36,5.94,42,8.198,50,12.33,60,19.92,70,31.16
180  DATA 80,47.36,90,70.11,100,101.325
190  END

?RUN

 PRESSURE        TEMPERATURE  CALCULATED
                  TABLES          TEMP
  KN/M2             C              C

    1.227          10              9.99396
    1.704          15             14.9979
    2.337          20             19.9993
    3.166          25             24.9959
    4.242          30             29.9979
    5.94           36             35.996
    8.198          42             41.9953
   12.33           50             49.9885
   19.92           60             59.9968
   31.16           70             69.9964
   47.36           80             79.9984
   70.11           90             89.9991

70 EXIT
?
```

PROGRAM 2

```
10  REM  PROGRAM 2
20  REM
30  REM  ON-LINE INSTRUMENT CALIBRATION
40  REM
50  INPUT N: REM  CHANNEL NUMBER
60  CALL (6,2,F1)
65  REM  HERE TO WAIT TO START
70  IF F1=1 THEN 60
74  K=0
75  S=0
80  CALL (1,N,V,F)
90  IF F=2 THEN  STOP
95  S=S+V
100  K=K+1
110  CALL (6,2,F1)
120  IF F1=1 THEN  GOTO 80
130  PRINT N,S/K,K
140  REM  CHANGE OF CHANNEL?
150  CALL (6,3,F2)
160  IF F2=1 THEN  GOTO 60
170  GOTO 50
180  END

?RUN

! 12

   12          1234.21          71
   12          1227.72          18
   12          1243.81         321
! 15

   15          1763.41          55
   15          1802.59         231
   15          1799.24          92
```

PROGRAM 3

```
10  REM  PROGRAM  3
12  REM
14  REM  ON-LINE STEADY STATE PROGRAM
15  REM
16  REM  INITIALISATION
17  REM
20  PRINT "STEADY STATE LOGGING PROGRAM"
30  CALL (2,T9): PRINT "START TIME ";T9;"HRS": PRINT
40  PRINT "SAMPLING INTERVAL";: INPUT T8: PRINT
45  PRINT "SAMPLES REQUIRED ";: INPUT S8: PRINT
50  PRINT "ENSEMBLE         ";: INPUT E8: PRINT
60  PRINT "STEAM VALVE POSITION ";: INPUT V8: PRINT
70  PRINT "WATER FLOW RATE ";: INPUT W8: PRINT
80  CALL (4,01):01=01/10
104  S9=0
105  D3=0:N1=12:N2=29
106  REM
120  DIM A(39,2),S(39),D(39),M(39),C(39)
125  REM
126  REM  WAIT TO START
127  REM
130  CALL (6,2,L9): IF L9=1 THEN 130
131  GOSUB 3000
132  T9=F2
133  P3=0: FOR I=1,200: CALL (1,18,V,F):P3=P3+V
134  NEXT I:P3=P3/200
135  REM
136  REM  FIRST EXPLICIT CALL TO SERV
137  REM
140  CALL (7,T8,N1,N2,E8,A(0,0),S8,S9,E9)
150  IF E9=2 THEN  PRINT "SCAN ERROR": STOP
160  FOR I=N1,N2:S(I)=S(I)+A(I,1): NEXT I
170  FOR I=N1,N2:D(I)=D(I)+A(I,1)↑2: NEXT I
175  D3=D3+1
179  IF S9=2 THEN  CALL (1,12,V,F)
180  IF S9=2 THEN  FOR I=N1,N2:A(I,1)=A(I,2): NEXT I
181  S9=1: GOTO 150
185  REM
186  REM  WAIT FOR INTERRUPT
187  REM
190  IF D3<S8 THEN 180
195  CALL (5,0): GOTO 2000
200  REM
201  REM  SCAN COMPLETE START CONVERSION AND OUTPUT
202  REM
220  FOR I=12,19: READ M(I),C(I): NEXT I
230  DATA .26368E-01,103.993
232  DATA .518311E-01,100.221
234  DATA .24498E-01,97.6864
236  DATA .522646E-01,99.9977
238  DATA -.835852E-02,-26.4328
240  DATA -.520776E-02,-13.642
242  DATA -.475E-03,.30933
244  DATA 1,0
```

PROGRAM 3 (Cont.)

```
250  FOR I=N1,N2:S(I)=S(I)/S8: NEXT I
260  FOR I=20,29:S(I)=S(I)*(-.25E-01): NEXT I
270  FOR I=12,19:S(I)=S(I)*M(I)+C(I): NEXT I
325  DIM H(20)
330  P3=((P8-P3)*M(18)*3.147*.408*.408*.1E07)/(4*(T2-T9)*60)
340  H(1)=S(16)*4.1868*S(22)
345  H(2)=S(16)*4.1868*S(23)
350  T0=S(29)
370  H(4)=(S(16)-S(17))*(1.67472*T0+2500.8)
380  H(5)=S(17)*4.1868*S(26)
390  T0=S(15)
400  GOSUB 1000
412  Z9=T0
420  T0=S(14)
430  GOSUB 1000
440  H(8)=(S(17)-P3)*(1.67472*T0+2500.8)
450  H(9)=(S(16)-P3)*4.1868*S(27)
460  T0=100
480  H(12)=W8*S(20)*4.1868
490  H(13)=W8*S(21)*4.1868
500  H(16)=P3*4.1868*S(24)
510  H(3)=H(4)+H(5)
520  H(6)=(S(16)-S(17))*(1.67472*S(28)+2500.8)
530  S5=(H(3)-H(2))/(1.67472*01+2500.8-4.1868*T0)
540  H(10)=S5*(1.67472*01+2500.8)
550  H(11)=S5*4.1868*T0
560  W(1)=(H(2)-H(1)+H(4)-H(6))/(2501.63-2.4069*S(28))
561  H(7)=(S(16)-S(17)-W(1))*(1.67472*Z9+2500.8)
562  H(6)=(S(16)-S(17)-W(1))*(1.67472*S(28)+2500.8)
564  W(3)=W(1)*4.1868*S(28)
566  H(17)=(H(5)-H(8)-H(16))/(4.1868*(S(24)-S(25)))
568  H(14)=H(17)*4.1868*S(24):H(15)=H(17)*4.1868*S(25)
570  W(4)=(H(15)-H(14)-H(6)+H(7)-W81)*4.2*(S(28)-Z9)
571  W(4)=W(4)/(2501.6-2.41*Z9)
572  H(7)=(S(16)-S(17)-W(1)-W(4))*(1.67472*Z9+2500.8)
573  W(5)=(W(1)+W(4))*4.1868*Z9
574  W9=(H(9)-H(8)-H(7)-W(5))/(4.1868*(S(20)-S(21)))
576  H(19)=S(28)
577  Q=(S(16)-S(17))*(1.67472)+S(17)*4.1868
578  H(20)=(H(3)-(S(16)-S(17))*2500.8)/Q
630  PRINT : PRINT : PRINT : PRINT "CONVERTED OUTPUT"
640  PRINT "  TEMP C","FLOW G/S","ENTHALPY J/S"
649  PRINT
650  PRINT TAB(0),"*"
660  PRINT "PREHEATER"
670  PRINT "         TUBESIDE  L IN",TAB(28),S(22),S(16),H(1)
680  PRINT "                   L OUT",TAB(28),S(23),S(16),H(2)
685  T0=S(29)
690  PRINT "        SHELLSIDE  V IN",TAB(28),T0,S(16)-S(17),H(4)
695  T7=T0
700  PRINT "                   V OUT",TAB(28),H(19)
```

PROGRAM 3 (Cont.)

```
701  PRINT S(16-S(17(-W(1),H(6)
705  PRINT "                    L OUT",TAB(28),S(28),W(1),W(3)
710  PRINT TAB(0),"*"
720  PRINT "1ST EFFECT"
730  PRINT "        TUBESIDE  L IN",TAB(28),S(23),S(16),H(2)
740  PRINT "                L/V OUT",TAB(28),H(20),S(16),H(3)
745  T0=100
750  PRINT "       SHELLSIDE  S IN",TAB(28),01,S5,H(10)
760  PRINT "                 SC OUT",TAB(28),T0,S5,H(11)
770  PRINT TAB(0),"*"
780  PRINT "CYCLONE SEPARATOR"
790  PRINT "                L/V IN",TAB(28),H(20),S(16),H(3)
800  PRINT "                 L OUT",TAB(28),S(26),S(17),H(5)
810  PRINT "                 V OUT",TAB(28),T7,S(16)-S(17),H(4)
820  PRINT TAB(0),"*"
830  PRINT "2ND EFFECT"
840  PRINT "        TUBESIDE  L IN",TAB(28),S(24),H(17),H(14)
850  PRINT "                 L OUT",TAB(28),S(25),H(17),H(15)
860  PRINT "      SHELLSIDE  V IN",TAB(28),H(19),
861  PRINT S(16)-S(17)-W(1),H(6)
862  PRINT "                 L IN",TAB(28),S(28),W(1),W(3)
865  T0=S(15): GOSUB 1000
870  PRINT "                 V OUT",TAB(28),T0,
871  PRINT S(16)-S(17)-W(1)-W(4),H(7)
872  PRINT "                 L OUT",TAB(28),Z9,W(1)+W(4),W(5)
875  T7=T0
880  PRINT TAB(0),"*"
890  PRINT "2ND EFFECT SEPARATOR"
900  PRINT "          L IN FROM CS",TAB(28),S(26),S(17),H(5)
910  PRINT "          L IN FROM E2",TAB(28),S(25),H(17),H(15)
920  PRINT "                 L OUT",TAB(28),S(24),H(17),H(14)
925  T0=S(14): GOSUB 1000
930  PRINT "                 V OUT",TAB(28),T0,S(17)-P3,H(8)
935  PRINT "          ACCUMULATION",TAB(28)," ",P3,H(16)
940  PRINT TAB(0),"*"
945  PRINT "CONDENSER"
950  PRINT "        TUBESIDE  L IN",TAB(28),S(20),W8,H(12)
955  PRINT "                 L OUT",TAB(28),S(21),W8,H(13)
960  PRINT "    SHELLSIDE V IN (E2S)",TAB(28),T0,S(17)-P3,H(8)
965  PRINT "               V IN (E2)",TAB(28),T7,
966  PRINT S(16)-S(17)-W(1)-W(4),H(7)
967  PRINT "                 L IN",TAB(28),Z9,W(1)+W(4),W(5)
970  PRINT "              L OUT",TAB(28),S(27),S(16)-P3,H(9)
975  PRINT : PRINT : PRINT
980  PRINT "PUMP CIRCULATION RATE IN E2  ";H(17);"G/S"
982  PRINT "CONDENSER LIQUID RATE (DATA) ";W8;"G/S"
984  PRINT "  ''   ''   ''   '' (COMPUTED)  ";W9;"G/S"
986  PRINT "ACCUMULATION IN E2S(MEASURED)";P3;"G/S"
990  PRINT "STEAM RATE TO 1ST EFFECT     ";S5;"G/S"
992  PRINT "VALVE STEM POSITION          ";V8;"TURN OPEN"
993  GOTO 4000
995  REM
996  PRESSURE-TEMPERATUREC ON VERSI ON ROUTINE
997  REM
998  GOTO 4000
1000  Z1=LOG(T0/101.325)/13.3185
1005  Z3=Z1
1010  Z2=Z1+((.1299*Z3+.6445)*Z3+1.976)*Z3↑2/13.3185
1020  IF ABS(Z3-Z2)>.1E-03 THEN Z3=Z2: GOTO 1010
1030  T0=373.15/(1-Z2)-273.15
1040  RETURN
```

PROGRAM 3 (Cont.)

```
1950  REM
1955  REM  ANALOGUE OUTPUT SECTION
1960  REM
2000  PRINT : GOSUB 3000
2001  CALL (1, 18, V, F): CALL (1, 18, V, F)
2002  P8=0
2004  FOR I=1, 200: CALL (1, 18, V, F):P8=P8+V: NEXT I:P8=P8/200
2010  PRINT : CALL (2, T2): PRINT "FINISH TIME";T2;"HRS"
2012  T2=F2
2015  PRINT : PRINT : PRINT S8;"SCANS DONE"
2020  PRINT : PRINT "ANALOGUE OUTPUT": PRINT
2030  PRINT "CHANNEL NO","    MEAN"," ST DEV"
2035  PRINT
2040  FOR I=N1,N2
2050  PRINT I, S(I)/S8, SQR(ABS(D(I)/S8-(S(I)/S8)↑2))
2060  NEXT I
2070  PRINT : PRINT
2080  GOTO 200
2090  END
3000  CALL (2, Q3): CALL (3, Q4):F1=INT(Q3/100)
3005  F2=Q3-F1*100: IF F2<0 THEN  GOTO 3000
3010  F2=F2+60*F1:F2=F2+Q4/6000
3020  RETURN
3950  REM
3960  REM  DYNAMIC LOGGING PROGRAM
3970  REM
4000  DIM B(39, 30)
4005  S9=0
4010  PRINT : PRINT : PRINT : PRINT
4020  PRINT "DYNAMIC STATE LOG"
4030  E8=26:T8=60:N1=12:N2=29:S8=30
4040  PRINT : PRINT : PRINT "VARIABLE CODE ";: INPUT V
4050  CALL (6, 4, V4): IF V4=1 THEN  GOTO 4050
4060  CALL (2, Q3): CALL (3, Q4):F1=INT(Q3/100)
4070  F2=Q3-F1*100: IF F2<0 THEN  GOTO 4060
4075  F2=F2+60*F1:F2=F2+Q4/6000
4080  CALL (7, T8, N1, N2, E8, B(0, 0), S8, S9, E9)
4085  S7=S9
4090  IF E9=2 THEN  PRINT "SCAN ERROR": STOP
4095  CALL (1, 12, G, F): CALL (1, 12, G, F)
4100  CALL (6, 3, V4): IF V4=2 THEN  CALL (5, 0): GOTO 4140
4110  IF S9>=S8 THEN  GOTO 4140
4120  IF S9>S7 THEN  GOTO 4085
4130  GOTO 4100
4140  PRINT : PRINT "START TIME";F2;"MINS"
4150  PRINT : PRINT S9;"SCANS DONE"
4160  PRINT : PRINT "CHANGE IN ";
4170  IF V>1 THEN  IF V<3 THEN  PRINT "FEED RATE": GOTO 4200
4180  IF V=1 THEN  PRINT "STEAM FLOW": GOTO 4200
4190  PRINT "OPERATING VACUUM"
4195  RESTORE
4200  FOR I=12, 29: READ M(I), C(I): NEXT I
4210  FOR J=12, 29: PRINT J: FOR I=1, S9
4220  B(J, I)=B(J, I)*M(J)+C(J): PRINT B(J, I),
4230  NEXT I: NEXT J
4235  END
```

PROGRAM 4

```
10  REM  PROGRAM 4
11  REM
12  REM  SIMULATION OF COMPREHENSIVE MODEL
20  REM
30  REM                      INITIALISATION
40  REM
45  DIM T(16),M(16),V(16),D(18)
50  K1=.72:K2=.152E-02:K3=.9E-02:K4=.2875E-02
60  C1=4.1868:C2=.1E07:C3=.13
70  K5=.376E-02:K6=.145E-01:K7=.645E-02:K8=.672
80  K9=1.15:K0=.38
85  F9=1
86  S2=15.4
90  DEF FND(T)=EXP(1.93059*LOG(T)-3.1487)
100  DEF FNE(T)=1.93059*FND(T)/T
110  DEF FNF(T)=2501.6-2.4068*T
120  CALL (1,Z)
130  REM
140  REM                      INITIAL CONDITIONS INPUT
150  REM
160  INPUT S9,I9,P9,E9
162  REM                      INPUT SYSTEM INPUTS
165  INPUT T(1),M(1),M(14),M(12),T(12),T(16)
170  REM                      INPUT INITIAL CONDITIONS
175  INPUT T(2),T(4),M(4),V(4),T(7),V(7),M(7)
177  INPUT T(14),T(10),M(10),V(10),T(15),H,V(9),T(13)
180  Y(0)=(V(4)/FND(T(4)))/(V(4)/FND(T(4))+M(4)/C2)
185  Y(1)=(V(7)/FND(T(7)))/(V(7)/FND(T(7))+M(7)/C2)
190  Y(2)=(V(10)/FND(T(10)))/(V(10)/FND(T(10))+M(10)/C2)
200  REM
210  REM                      DERIVATIVE SECTION
220  REM
222  REM                      T(1) INLET TEMP
223  REM                      M(1) INLET RATE
224  REM                      M(14) CIRC RATE
225  REM                      M(12) COOLANT RATE
226  REM                      T(12) COOLANT TEMP IN
227  REM                     T(16) T VACUUM
228  REM
229  REM          HEAT TRANSFER COEFFICIENT CORRELATIONS
230  U1=682-27.55*(T(4)-(T(1)+T(2))/2)+13.44*M(1)+5.27*V(4)
240  U2=623.66-11.3405*(100-T(7))-1.039*M(1)+58.026*S2
250  U3=3900-161.6*(T(10)-(T(14)+T(15))/2)+85.8*V(10)
255  U4=-1151.92-63.01*(T(16)-(T(12)+T(13))/2)+.6634*M(12)
260  U4=U4+61*(V(9)+V(10))
261  IF F9=1 THEN  GOSUB 2000
262  T(5)=100
263  M(2)=M(1)
265  T(3)=T(7):V(3)=V(7)
266  T(8)=T(3):M(8)=M(7)
267  REM
268  REM          EVALUATE DERIVATIVES
269  REM
270  T=U1*K0*(T(4)-(T(1)+T(2))/2)
280  D(1)=(M(1)*C1*(T(1)-T(2))+T+L1)/(.5*K2*C2*C1)
290  T1=K3*(C1*(1-Y(0))*C2+FNE(T(4))*Y(0)*FNF(T(4)))
300  D(2)=(V(3)*C1*(T(3)-T(4))+FNF(T(4))*(V(3)-V(4))-T+L2)/T1
310  D(3)=(V(3)-M(4)-V(4)-K3*Y(0)*FNE(T(4))*D(2))
315  D(3)=D(3)/(K3*(FND(T(4))-C2))
```

PROGRAM 4(Cont.)

```
320  T=K1*U2*(T(7)-T(2))/(LOG((T(5)-T(2))/(T(5)-T(7))))
330  T1=K4*(C1*(1-Y(1))*C2+FNE(T(7))*Y(1)*FNF(T(7)))
340  D(6)=(M(1)*C1*(T(2)-T(7))-FNF(T(7))*V(7)+T+L3)/T1
350  D(7)=(M(2)-M(7)-V(7)-K4*Y(1)*FNE(T(7))*D(6))
355  D(7)=D(7)/(K4*(FND(T(7))-C2))
360  D(8)=(M(2)*C1*D(1)-(C1*(M(2))+K1*U2)*D(6))/FNF(T(7))
370  D(9)=-D(8)
380  D(5)=-D(2)*C1*(V(3))-K0*U1*(D(2)-D(1)/2)+V(7)*C1*D(6)
381  D(5)=-D(5)/FNF(T(4))
382  D(4)=D(9)-D(5)
400  T=U3*K8*(T(10)-(T(14)+T(15))/2)
410  T1=K6*((1-Y(2))*C1*C2+FNF(T(10))*Y(2)*FNE(T(10)))
420  D(11)=((V(4)+M(4))*(T(4)-T(10))*C1
422  D(11)=D(11)+FNF(T(10))*(V(4)-V(10))-T
425  D(11)=(D(11)+L5)/T1
430  D(12)=(V(4)+M(4))-(V(10)+M(10))-K6*Y(2)*FNE(T(10))*D(11)
435  D(12)=D(12)/((FND(T(10))-C2)*K6)
440  D(15)=M(14)*C1*(T(14)-T(15))+M(8)*C1*(T(8)-T(15))
445  D(15)=D(15)-V(9)*FNF(T(15))
450  D(15)=(D(15)+L6)/(C3*C2*C1*H)
460  D(16)=(M(8)-V(9))/(C3*C2*.5)
470  D(10)=(M(14)*C1*(T(15)-T(14))+T-K5*C1*C2*D(15)/2
475  D(10)=(D(10)+L4)/(K5*C1*C2*.5)
480  D(14)=U3*K8*(D(11)-(D(10)+D(15))/2)
482  D(14)=(D(14)+(M(4)+V(4))*C1*(D(11)-D(2)))/FNF(T(10))
484  D(13)=D(4)+D(5)-D(14)
500  D(17)=((T(8)-T(15))*C1*D(8)+M(8)*C1*D(6)
505  D(17)=D(17)-(M(14)+M(8))*C1*D(15)
510  D(17)=(D(17)+M(14)*C1*D(10))/FNF(T(15))
520  T=K9*U4*(T(16)-(T(12)+T(13))/2)
530  D(18)=(M(12)*C1*(T(12)-T(13))+T+L7)/(.5*K7*C2*C1)
550  CALL (2,P9,E9,F1,F2)
560  IF F1=2 THEN  STOP
570  IF F2=2 THEN  PRINT : PRINT : GOTO 1000
575  REM
576  REM                     INTEGRATION SECTION
577  REM
580  CALL (3,Z,S9,I9)
600  CALL (4,T(2),D(1))
610  CALL (4,T(4),D(2))
620  CALL (4,Y(0),D(3))
625  CALL (4,V(4),D(4))
630  CALL (4,M(4),D(5))
650  CALL (4,T(7),D(6))
660  CALL (4,Y(1),D(7))
670  CALL (4,M(7),D(8))
675  CALL (4,V(7),D(9))
690  CALL (4,T(14),D(10))
700  CALL (4,T(10),D(11))
710  CALL (4,Y(2),D(12))
715  CALL (4,V(10),D(13))
720  CALL (4,M(10),D(14))
730  CALL (4,T(15),D(15))
740  CALL (4,H,D(16))
750  CALL (4,V(9),D(17))
760  CALL (4,T(13),D(18))
770  GOTO 230
995  REM
996  REM                     OUTPUT SECTION
997  REM
1000  PRINT : PRINT : PRINT : PRINT
1005  PRINT " ","TIME    ";Z;"SECS"
```

PROGRAM 4 (Cont.)

```
1008  PRINT
1010  PRINT " ","                                              DERIVATIVE"
1012  PRINT
1015  PRINT " ","PREHEATER"
1018  PRINT " "," TEMPS"
1020  PRINT " ","   L TUBES";T(2),D(1)
1025  PRINT " ","  LV SHELL";T(4),D(2)
1030  PRINT " "," FLOWS"
1035  PRINT " ","   L SHELL";M(4),D(5)
1040  PRINT " ","   V SHELL";V(4),D(4)
1045  PRINT " ","   V FRAC ";Y(0),D(3)
1047  PRINT " "," HTC       ";U1
1050  PRINT
1055  PRINT " ","FIRST EFFECT"
1060  PRINT " "," TEMPS"
1070  PRINT " ","  LV TUBES";T(7),D(6)
1075  PRINT " "," FLOWS"
1080  PRINT " ","   L TUBES";M(7),D(8)
1085  PRINT " ","   V TUBES";V(7),D(9)
1090  PRINT " ","   V FRAC ";Y(1),D(7)
1092  PRINT " "," HTC       ";U2
1095  PRINT
1100  PRINT " ","2ND EFFECT"
1105  PRINT " "," TEMPS"
1110  PRINT " ","   L TUBES";T(14),D(10)
1115  PRINT " ","  LV SHELL";T(10),D(11)
1120  PRINT " "," FLOWS"
1125  PRINT " ","   L SHELL";M(10),D(14)
1130  PRINT " ","   V SHELL";V(10),D(13)
1135  PRINT " ","   V FRAC ";Y(2),D(12)
1137  PRINT " "," HTC       ";U3
1140  PRINT
1150  PRINT " ","2ND SEPARATOR"
1155  PRINT "  ","      HEAD ";H,D(16)
1160  PRINT " ","      TEMP ";T(15),D(15)
1165  PRINT " ","   V RATE ";V(9),D(17)
1170  PRINT
1175  PRINT " ","CONDENSER"
1180  PRINT " ","   L TEMP ";T(13),D(18)
1182  PRINT " "," HTC       ";U4
1185  M(1)=M(1)+.1
1190  GOTO 580
1195  REM
1200  REM          LOSS TERMS
1205  REM
2000  T(5)=100:M(2)=M(1):T(3)=T(7):V(3)=V(7)
2002  T(8)=T(3):M(8)=M(7)
2005  T=U1*K0*(T(4)-(T(1)+T(2))/2)
2010  L1=M(1)*C1*(T(2)-T(1))-T
2020  L2=(V(3)*C1*(T(4)-T(3))-FNF(T(4))*(V(3)-V(4))+T)
2025  T=K1*U2*(T(7)-T(2))/(LOG((T(5)-T(2))/(T(5)-T(7))))
2030  L3=M(1)*C1*(T(7)-T(2))+FNF(T(7))*V(7)-T
2040  L4=M(14)*C1*(T(14)-T(15))
2045  L4=L4-U3*K8*(T(10)-(T(14)+T(15))/2)
2050  T=U3*K8*(T(10)-(T(14)+T(15))/2)
2060  L5=(V(4)+M(4))*(T(10)-T(4))*C1
2065  L5=L5-FNF(T(10))*(V(4)-V(10))+T
2070  L6=M(14)*C1*(T(15)-T(14))+M(8)*C1*(T(15)-T(8))
2075  L6=L6+V(9)*FNF(T(15))
2080  L7=M(12)*C1*(T(13)-T(12))
2085  L7=L7-K9*U4*(T(16)-T(12)+T(13))/2)
2090  F9=2: RETURN
2091  END
```

PROGRAM 5

```
10  REM    PROGRAM  5
14  REM
15  REM  SIMULATION OF REDUCED MODEL
20  REM
30  REM                  INITIALISATION
40  REM
42  DIM A(30),B(30),C(30),E(30),F(30),G(30),H(30)
45  DIM T(16),M(16),V(16),D(10)
50  K1=.72:K2=.152E-02:K3=.9E-02:K5=.376E-02
55  K7=.645E-02:K8=.672
60  K9=1.15:C1=4.1868:C2=.1E07:C3=.13
62  K0=.38
63  T(5)=100
64  S2=15.4
65  DEF FNF(Q)=2501.6-2.4068*Q
70  CALL (1,T)
80  REM
90  REM                  INPUT DATA SECTION
99  GOTO 110
100  REM
102  FOR I=0,30: READ A(I): NEXT I
103  FOR I=0,30: READ B(I): NEXT I
104  FOR I=0,30: READ C(I): NEXT I
105  FOR I=0,30: READ E(I): NEXT I
106  FOR I=0,30: READ F(I): NEXT I
107  FOR I=0,30: READ G(I): NEXT I
108  FOR I=0,30: READ H(I): NEXT I
109  GOTO 190
110  INPUT S9,I9,P9,E9
165  READ T(1),M(1),M(14),M(12),T(12)
175  READ T(2),M(4),V(4),V(7),M(7)
180  READ T(14),M(10),V(10),T(15),H,V(9),T(13)
185  M(4)=V(7)-V(4)
186  M(10)=V(4)+M(4)-V(10)
187  GOTO 100
190  REM
200  REM                  DERIVATIVE SECTION
210  REM
216  GOSUB 3000
218  GOSUB 2000
219  PRINT U1,U2,U3,U4
220  L1=M(1)*C1*(T(2)-T(1))-U1*K0*(T(4)-(T(1)+T(2))/2)
223  L6=V(4)*FNF(T(4))+U1*K0*(T(4)-(T(1)+T(2))/2)
224  L6=L6-V(7)*(C1*(T(7)-T(4))+FNF(T(7)))
225  T6=K1*U2*(T(7)-T(2))/(LOG((T(5)-T(2))/(T(5)-T(7))))
230  L2=V(7)*FNF(T(7))-M(1)*C1*(T(2)-T(7))-T6
240  L3=M(14)*C1*(T(14)-T(15))-U3*K8*(T(10)-(T(14)+T(15))/2)
245  L7=V(10)*FNF(T(10))+U3*K8*(T(10)-(T(14)+T(15))/2)
246  L7=L7-(V(4)+M(4))*C1*(T(4)-T(10))-V(4)*FNF(T(4))
250  L4=M(12)*C1*(T(13)-T(12))-K9*U4*(T(16)-(T(12)+T(13))/2)
255  L5=M(14)*C1*(T(15)-T(14))+M(7)*C1*(T(15)-T(7))
257  L5=L5+V(9)*FNF(T(15))
```

PROGRAM 5 (Cont.)

```
260  PRINT "HEAT LOSSES"
270  PRINT " PT ";L1
275  PRINT " PS ";L6
280  PRINT " E ";L2
290  PRINT " FT ";L3
292  PRINT " FS ";L7
295  PRINT "FSEP";L5
300  PRINT " C ";L4
305  GOTO 359
350  REM
352  GOSUB 3000
355  GOSUB 2000
359  M(1)=41.1
360  D(1)=M(1)*C1*(T(1)-T(2))+U1*K0*(T(4)-(T(1)+T(2))/2)
370  D(1)=(D(1)+L1)/(.5*K2*C2*C1)
375  T(3)=T(7)
380  V(4)=(L1-U1*K0*(T(4)-(T(1)+T(2))/2)
385  V(4)=V(4)+V(7)*(C1*(T(3)-T(4))+FNF(T(7)))
390  V(4)=(V(4)-L1+L6)/FNF(T(4))
395  M(4)=V(7)-V(4)
396  T9=K1*U2*(T(7)-T(2))/(LOG((T(5)-T(2))/(T(5)-T(7))))
397  V(7)=(M(1)*C1*(T(2)-T(7))+T9+L2)/(FNF(T(7)))
399  M(7)=M(1)-V(7)
410  T(11)=(V(9)*(C1*(T(15))+T1)+M(10)*C1*T(10)
420  D(3)=(M(14)*C1*(T(15)-T(14))+M(7)*C1*(T(15)-T(7))
421  D(3)=(D(3)+M(7)*FNF(T(15)))/(C3*C2*(FNF(T(15))))
430  T9=U3*K8*(T(10)-(T(14)+T(15))/2)
440  D(4)=(M(14)*C1*(T(15)-T(14))+T9+L3)/(.5*C1*C2*K5)-D(2)
445  D(4)=D(4)+D(2)
450  V(10)=(L7-T9+(V(4)+M(4))*C1*(T(4)-T(10))
452  V(10)=(V(10)+V(4)*FNF(T(4))/FNF(T(10))
455  M(10)=V(4)+M(4)-V(10)
470  T9=K9*U4*(T(16)-(T(12)+T(13))/2)
480  D(6)=(M(12)*C1*(T(12)-T(13))+T9+L4)/(.5*K7*C1*C2)
485  V(9)=M(14)*C1*(T(14-T(15))+M(7)*C1*(T(7)-T(15))
486  V(9)=(V(9)+L5)/FNF(T(15))
490  M(11)=V(9)+M(10)+V(10)
500  T1=FNF(T(15)):T2=FNF(T(10))
510  T(11)=(V(9)*(C1*(T(15))+T1)+M810)*C1*T(10)
515  T(11)=T(11)+V(10)*(C1*(T(10)+T2)-T9)
520  T(11)=(T(11)-L4)/(M(11)*C1)
530  CALL (2,P9,E9,F1,F2)
540  IF F1=2 THEN  STOP
545  IF F2=2 THEN  GOTO 1000
```

PROGRAM 5 (Cont.)

```
550  REM .
553  REM              INTEGRATION SECTION
555  REM
560  CALL (3,T,S9,I9)
570  CALL (4,T(2),D(1))
590  CALL (4,H,D(3))
600  CALL (4,T(14),D(4))
620  CALL (4,T(13),D(6))
630  GOTO 352
1000  PRINT T: PRINT : FOR I=1,6: PRINT D(I);: NEXT I: PRINT
1010  PRINT T(1),T(2),M(1),M(4),V(4)
1012  PRINT T(4),T(7),V(7),M(7)
1014  PRINT T(10),M(10),V(10),T(14)
1016  PRINT T(15),H,V(9)
1017  PRINT U1,U2,U3,U4
1018  PRINT T(13),M(11),T(11)
1019  PRINT : PRINT : PRINT
1020  GOTO 560
2000  REM
2010  REM          H.T.C. SECTION
2020  REM
2030  U1=682-27.55*(T(4)-(T(1)+T(2))/2)+13.44*M(1)+5.27*M(4)
2040  U2=623.66-11.3405*(100-T(7))-1.039*M(1)+58.026*S2
2050  U3=.218076E-06-161.6*(T(10)-(T(14)+T(15))/2)
2052  U3=U3-66.93*M(14)+85.5*M(10)
2060  U4=1151.92-63.01*(T(16)-(T(12)+T813))/2)+.663*M(12)
2062  U4=U4+61*(V(9)+V(10))
2070  RETURN
2995  REM
2996  REM  FUNCTION GENERATION
2999  REM
3000  CALL (5,T,S2,31,A(0),B(0))
3010  S2=-S2
3012  S2=-11.381-.53255E-02*S2-.234755E-06*S2↑2
3020  CALL (5,T,T(4),31,A(0),C(0))
3025  CALL (5,T,T(1),31,A(0),H(0))
3030  CALL (5,T,T(7),31,A(0),E(0))
3040  CALL (5,T,T(15),31,A(0),F(0))
3050  CALL (5,T,T(10),31,A(0),G(0))
3060  T(16)=36
3070  RETURN
3999  REM
4000  REM  FUNCTION GENERATION DATA IS STORED FROM HERE
4010  REM
4020  REM  AN EXAMPLE IS SHOWN IN FIGURE A7.49
4030  REM
4040  END
```

PROGRAM 6

```
5  REM  PROGRAM 6
6  REM
7  REM  FILTER TIMING EXPERIMENTS
8  REM
10  DIM P(9,9),Q(9,9),R(9,9),M(9,9)F(9,9)
20  DIM X(9),Y(9),S(9,9),K(9,9)
30  FOR =0,9: FOR J=0,9
40  P(I,J),Q(I,J),R(I,J),M(I,J),F(I,J)=.1
50  NEXT J
60  X(I),Y(I)=2
70  NEXT I
80  FOR M=1,10
90  FOR N=1,10
100  CALL (2,K): CALL (3,S): CALL (2,M1)
110  IF M1>K THEN  GOTO 100
120  T=M1*60+S/100
130  CALL (8,P(0,0),Q(0,0),R(0,0),M(0,0),F(0,0),0
                             X(0),Y(0),1,S(0,0),K(0,0),N,M)
140  CALL (2,K1): CALL (3,S): CALL (2,M1)
150  IF M1>K1 THEN  GOTO 100
160  T1=M1*60+S/100
170  PRINT N,M,T1-T
180  NEXT N: NEXT M
190  END

?
```

PROGRAM 7

```
1   REM  PROGRAM 7
2   REM
3   REM  ON - LINE KALMAN FILTER
4   REM
5   X6=0
10  DIM A(39,1),C(18),D(18),E(29)
20  DIM P(9,9),Q(9,9),R(9,9),M(9,9),F(9,9),X(9),Y(9)
21  DIM S(9,9),K(9,9)
25  DEF FNF(Q)=2501.6-2.4068*Q
30  FOR I=14,18: READ D(I),C(I): NEXT I
35  C1=4.1868
40  DATA .235843E-01,97.36,.518311E-01,100.221
45  DATA -.958402E-02,-.911227
50  DATA -.576235E-02,-14.8723
60  DATA -.475E-03,.30933
70  PRINT : PRINT "ON-LINE KALMAN FILTER"
80  CALL (2,T9): PRINT "START TIME";T9;"HRS"
85  PRINT
90  PRINT "SAMPLING INTERVAL";: INPUT T8: PRINT
100  PRINT "ENSEMBLE   ";: INPUT E8: PRINT
101  REM
102  REM  INPUT FILTER STATISTICS
103  REM
110  P1=1000:P2=1000
115  FOR I=0,3:F(I,I)=P1: NEXT I: FOR I=4,7:F(I,I)=P2: NEXT I
120  Q1=1:Q2=100
125  FOR I=0,3:Q(I,I)=Q1: NEXT I: FOR I=4,7:Q(I,I)=Q2: NEXT I
130  R1=.1:R2=.15
135  FOR I=0,2:R(I,I)=R1: NEXT I:R(3,3)=R2
140  FOR I=0,7:M(I,I)=1: NEXT I
142  E2=1
143  CALL (4,W8)
145  GOSUB 300
160  S8=100: CALL (4,W8):S9=0:N1=14:N2=29
170  CALL (7,T8,N1,N2,E8,A(0,0),S8,S9,Q7)
180  IF Q7=1 THEN  PRINT "SCAN ERROR": STOP
190  GOSUB 5000
230  GOSUB 1110
235  REM
240  REM  HERE FOR MINIMAL ON - LINE OUTPUT
241  REM
243  PRINT : FOR I=0,7: PRINT X(I);: NEXT I: PRINT
244  FOR I=0,3: PRINT Y(I);: NEXT I: PRINT : PRINT
245  FOR I=0,7: PRINT SQR(F(I,I)): NEXT I
247  GOSUB 1000
250  GOSUB 5999
252  S9=0
255  IF S9=1 THEN 180
260  GOTO 255
270  STOP
300  FOR I=16,29: INPUT A(I,1): NEXT I
310  GOSUB 5000
315  GOSUB 4000
```

PROGRAM 7 (Cont.)

```
316   REM
317   REM  LOSS TERMS
318   REM
320   L1=E(16)*C1*(E(22)-E(23))+U1*.38*(E(29)-(E(22)+E(23))/2)
330   L2=3200*C1*(E(24)-E(25))+U3*.762*(E(28)-(E(24)+E(25))/2)
335   X(4)=U1:X(5)=U3:X(6)=U4:X(7)=U2
340   L3=W3*C1*(E(20)-E(21))+U4*1.15*(E(24)-(E(20)+E(21))/2)
350   X(0)=E(23):X(1)=E(25):X(2)=E(21):X(3)=E(18)
355   GOSUB 1000
360   RETURN
995   REM
996   REM  TRANSITION MATRIX
997   REM
1000  U1=X(4):U2=X(7):U3=X(5):U4=X(6)
1020  P(0,0)=1-((E(16)*C1+U1*.38/2)/3182)*T8
1030  P(1,1)=1-((3200*C1+U3*.762/2)/8732)*T8
1060  P(2,2)=1-((W3*C1+U4*1.15/2)/.135024E05)*T8
1070  P(3,0)=-T8*E(16)*C1*(C1*E(24)+FNF(E(24))-C1*E(26))
1075  P(3,0)=P(3,0)/(FNF(E(26))↑2*.13E06)
1080  P(3,1)=3200*C1*T8/(FNF(E(24))*.13E06)
1090  P(3,3)=1
1092  P(0,4)=.38*(E(28)-(E(22)+X(0))/2)*T8/3182
1094  P(1,5)=.762*(E(28)-(E(24)+X(1))/2)*T8/8732
1096  P(2,6)=1.15*(E(24)-(E(20)+X(2))/2)*T8/.135024E05
1098  P(3,7)=T8*(C1*E(24)+FNF(E(24))-C1*E(26))*.72
1099  P(3,7)=P(3,7)*(100-E(29))/(FNF(E(26))↑2*.13E06)
1100  P(4,4)=1:P(5,5)=1:P(6,6)=1:P(7,7)=1
1105  RETURN
1107  REM
1108  REM  EXECUTE FILTER ALGORITHM
1109  REM
1110  N=8:M=4
1115  Y(0)=E(23):Y(1)=E(25):Y(2)=E(21):Y(3)=E(18)
1120  CALL (8,P(0,0),Q(0,0),R(0,0),M(0,0),F(0,0),X(0),
                  Y(0),E2,S(0,0),K(0,0),N,M)
1200  RETURN
1950  REM
1960  REM  OPTIONAL PRINTOUT SUBROUTINE
1970  REM
2000  FOR I=0,M-1: FOR J=0,N-1: PRINT P(I,J)8 NEXT J: NEXT I
2010  FOR I=0,N-1: FOR J=0,N-1: PRINT F(I,J): NEXT J: NEXT I
2020  FOR I=0,N-1: PRINT X(I): NEXT I
2030  FOR I=0,M-1: PRINT Y(I): NEXT I
2040  FOR I=0,M-1: FOR J=0,M-1: PRINT S(I,J): NEXT J: NEXT I
2050  FOR I=0,N-1: FOR J=0,M-1: PRINT K(I,J): NEXT J: NEXT I
2060  FOR I=16,29: PRINT E(I): NEXT I
2100  RETURN
3950  REM
3960  REM  HEAT TRANSFER COEFFICIENT CORRELATIONS
3970  REM
4000  U1=632-27.55*(E(29)-(E(22)+E(23))/2)+13.44*E(16)
4010  U2=623.66-11.3405*(100-E(29))-1.039*E(16)+53.026(E(19)
4020  U3=.21307E06-161.6*(E(28)-(E(24)+E(25))/2)-66.93*3200
4030  U4=1151.92-63.01*(E(24)-(E(20)+E(21))/2)+.6634*W3
4035  U4=U4+61*E(17)
4040  RETURN
```

PROGRAM 7 (Cont.)

```
4950  REM
4960  REM  RAW DATA CONVERSION
4970  REM
5000  FOR I=16,29:E(I)=A(I,1): NEXT I: RETURN
5020  L9=A(19,1)
5030  E(19)=-11.381-.53255E-02*L9-.234755E-06*L9↑2
5040  RETURN
5950  REM
5960  REM  STATE PREDICTION BY EULER
5970  REM
5999  T8=T8/135: FOR Z=1,135
6000  D1=E(16)*C1*(E(21)-X(0))+X(4)*.38*(E(29)-(E(22)+X(0))/2)
6010  D1=(D1-L1)/3182
6020  D2=3200*C1*(E(24)-X(1))+X(5)*.762*(E(23)-(E(24)+X(1))/2)
6030  D2=(D2-L2)/3782
6040  D3=W8*C1*(E(20)-X(2))+X(6)*1.15*(E(24)-(E(20)+X(2))/2)
6050  D3=(D3-L3)/.135024E05
6055  J7=E(16)-(E(16)*C1*(X(0)-E(26))+.72*X(7)*(100-E(29)))
6056  J7=J7/FNF(E(26))
6060  D4=3200*C1*(E(24)-X(1))+((C1*E(24)+FNF(E(24))-C1*E(26)))
6062  D4=D4*J7
6065  D4=D4/(.13E06*FNF(E(24)))
6066  E(23)=X(0):E(25)=X(1):E(21)=X(2):E(18)=X(3): GOSUB 4000
6070  X(0)=X(0)+D1*T8
6080  X(1)=X(1)+D2*T8
6090  X(2)=X(2)+D3*T8
6100  X(3)=X(3)+D4*T8
6101  REM
6102  REM  REMOVE NEXT LINE FOR STRATEGY 2
6103  REM
6105  GOTO 6145
6110  X(4)=U1
6120  X(5)=U3
6130  X(6)=U4
6140  X(7)=U2
6145  NEXT Z
6147  T8=T8*135
6148  X6=X6+1
6150  PRINT : PRINT : PRINT X6: FOR I=0,7: PRINT X(I);: NEXT I
6200  RETURN
```

?

PROGRAM 8

```
10  REM
20  REM  PROGRAM 8
30  REM
40  REM  OFF LINE ANALYSIS OF STEADY STATE RESULTS
50  REM
90  REM
95  REM  INPUT GLOBAL DATA FOR THIS RUN
99  REM
100  DIM G(20)
110  FOR I=1,13
120  INPUT G(I)
125  NEXT I
130  PRINT : PRINT "RUN NO  ";G(1): PRINT "------"
131  PRINT : PRINT
140  T7=G(4)+G(6)+G(2)*(1.67472*G(3)+2500.8)
150  PRINT "TOTAL RATE HEAT IN",T7;"  J/S"
160  T8=G(5)+G(7)+G(2)*(4.1868*100)
170  PRINT "TOTAL RATE HEAT OUT",T8;"  J/S"
180  PRINT "ACCUMULATION"," ",G(8),"J/S"
190  PRINT "ACTUAL HEAT LOSS",(T7-T8-G(8))*100/T7;" %"
200  PRINT "COMPUTED HEAT LOSS",
201  PRINT (G(9)-G(13))*4.1868*(G(11)-G(10))*100/T7;"%"
210  PRINT "STEAM RATE"," ",G(2),"G/S"
220  PRINT "ANALOGUE READING",G(12)
230  PRINT : PRINT : PRINT "PREHEATER": PRINT "---------"
235  PRINT : PRINT
240  GOSUB 980
250  PRINT : PRINT "IST EFFECT": PRINT "----------"
253  INPUT T(1),T(2),T(3),F(1),F(2)
254  READ N(1),N(2),N(3),N(4),N(5),O3,I3
255  Q=G(2)*(1.67472*G(3)+2500.8-4.1868*100): GOSUB 1001
260  PRINT "2ND EFFECT": PRINT "----------"
265  GOSUB 980
270  PRINT "CONDENSER": PRINT "-----------"
275  GOSUB 980
290  PRINT "2ND EFFECT SEPARATOR": PRINT "-----------------"
300  PRINT : PRINT
310  INPUT A
320  PRINT "MEAN LEVEL",-.475E-03*A+.30933;"  M"
340  PRINT "OVERALL DATA": PRINT
342  FOR I=1,6: PRINT G(I);: NEXT I
343  FOR I=7,13: PRINT G(I);: NEXT I
345  RESTORE : GOTO 100
350  STOP
```

PROGRAM 8 (Cont.)

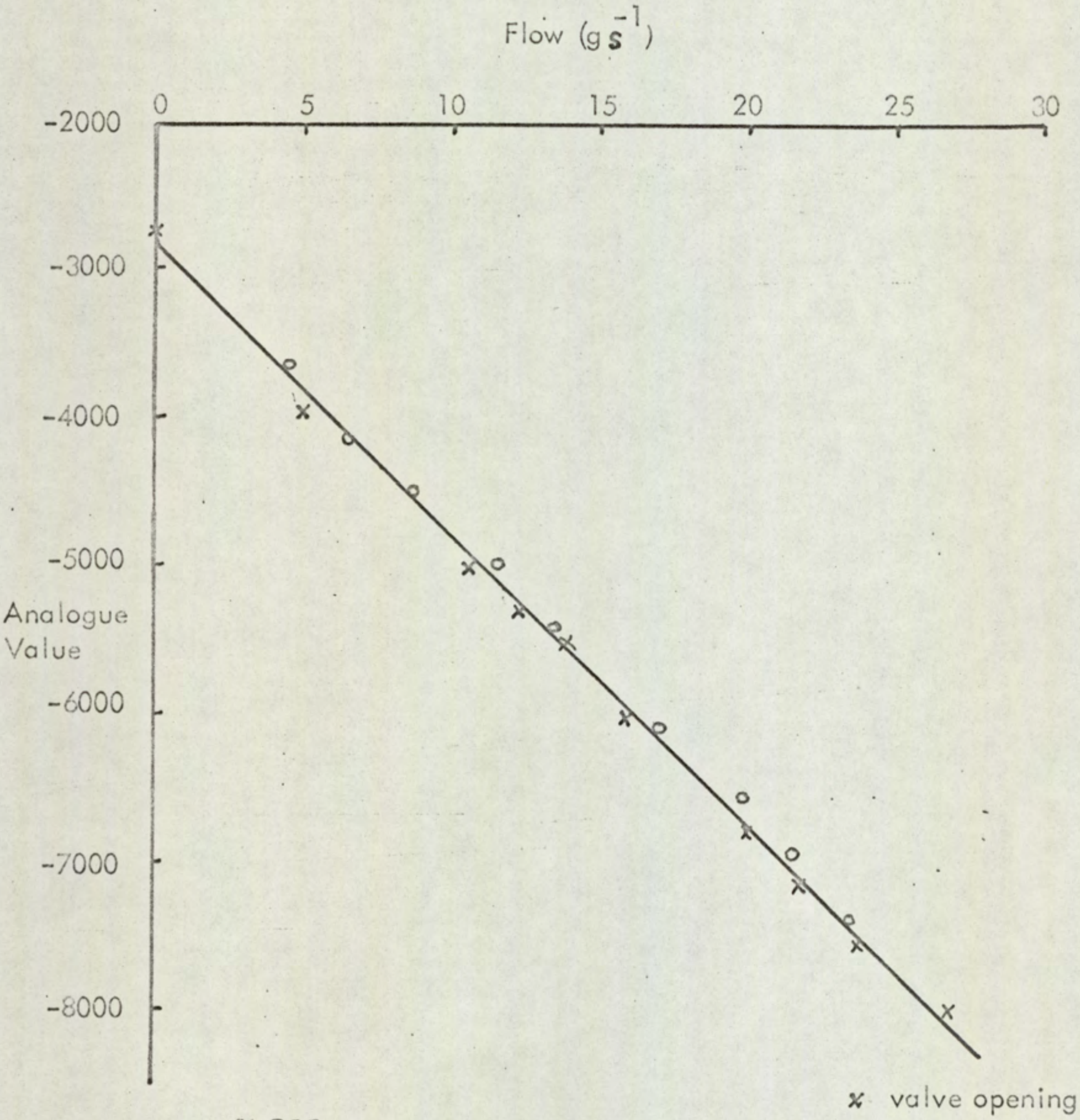
```
950  REM
960  REM  THEORETICAL HTC SUBROUTINE
970  REM
980  INPUT T(1),T(2),T(3),F(1),F(2)
990  READ N(1),N(2),N(3),N(4),N(5),O3,I3
1ØØØ  Q=F(1)*4.1868*(T(3)-T(2))
1ØØ1  PRINT "HEAT TRANSFER",Q;"  J/S"
1ØØ2  PRINT "HEAT FLUX",Q/N(5);"  J/SM↑2"
1ØØ3  L1=(T(3)-T(2))/(LOG((T(1)-T(2))/(T(1)-T(3))))
1ØØ4  PRINT "L M T D  ",L1;"  C"
1ØØ5  PRINT "OVERALL HTC",Q/(N(5)*L1)," W/M↑2C"
1ØØ6  PRINT : PRINT "TUBESIDE"
1ØØ7  PRINT :T(4)=(T(2)+T(3))/2
1ØØ8  PRINT "MEAN LIQUID TEMP";T(4);"C"
1Ø2Ø  M=EXP(-3.438+475.45/(T(4)+118))
1Ø3Ø  K=EXP(2.241-62.58/(T(4)+118))
1Ø4Ø  R=(F(1)/N(4))*I3/(M*.1E-Ø2*1ØØØ)
1Ø45  PRINT "REYNOLDS NO",R
1Ø6Ø  P=41.85*M/K: PRINT "PRANDTL NO",P
1Ø7Ø  IF R>=21ØØ THEN  GOTO 1Ø9Ø
1Ø8Ø  H1=1.86*(4*F(1)*4.1868/(3.141*K*.1*N(2)))↑.333*K*.1/I3
1Ø9Ø  H1=H1*I3/O3
11ØØ  PRINT "COEFFICIENT",H1;" W/M↑2C"
111Ø  PRINT : PRINT "SHELLSIDE"
1112  PRINT
112Ø  G=F(2)/(3.147*N(1)*O3)
113Ø  H2=4ØØØ
114Ø  T(5)=T(4)+H2/(H1+H2)*(T(1)-T(4))
115Ø  T(6)=(T(5)+T(1))/2
116Ø  K=EXP(2.241-62.58/(T(6)+118))*.1: REM          W/MC
117Ø  M=EXP(-3.438+475.45/(T(6)+118))*.1E-Ø2: REM          NS/M↑2
118Ø  H3=.925*(K↑3*1ØØØ↑3*9.8Ø7/(M*G))↑(1/3)
119Ø  IF ABS(H3-H2)>1 THEN H2=H3: GOTO 114Ø
12ØØ  PRINT "COEFFICIENT",H3;" W/M↑2C"
12Ø5  PRINT
12Ø6  PRINT : PRINT
121Ø  PRINT "CLEAN OVERALL COEFF";H1*H3/(H1+H3);"W/M↑2C"
1215  H4=Q/(N(5)*L1)
122Ø  H5=H1*H3/(H1+H3)
123Ø  PRINT "DIRT FACTOR          ";(H5-H4)/(H5(H4);" M↑2C/W"
1232  PRINT : PRINT "DATA"
1235  PRINT T(1),T(2),T(3),F(1),F(2)
125Ø  RETURN
127Ø  REM
128Ø  REM  PHYSICAL CONSTANTS OF EVAPORATOR
129Ø  REM
13ØØ  DATA 1,1.37,.694E-Ø2,.278E-Ø3,.38,.221E-Ø1,.188E-Ø1
131Ø  DATA 4,2.59,.694E-Ø2,.1112E-Ø2,.72,.221E-Ø1,.188E-Ø1
132Ø  DATA 7,1.Ø65,.146E-Ø1,.3535E-Ø2,.672,.286E-Ø1,.254E-Ø1
133Ø  DATA 1,2.13,.15E-Ø1,.5Ø5E-Ø3,1.15,.286E-Ø1,.254E-Ø1

?
```

APPENDIX 7 - GRAPHS, FIGURES AND TABLES OF RESULTS

The symbols on the graphs of Figures A7.50 to A7.65 and A7.70 to A7.102 do not represent actual data points. The graphs are contructed through the experimental points and the symbols are employed to differentiate between curves.

FIGURE A7.1

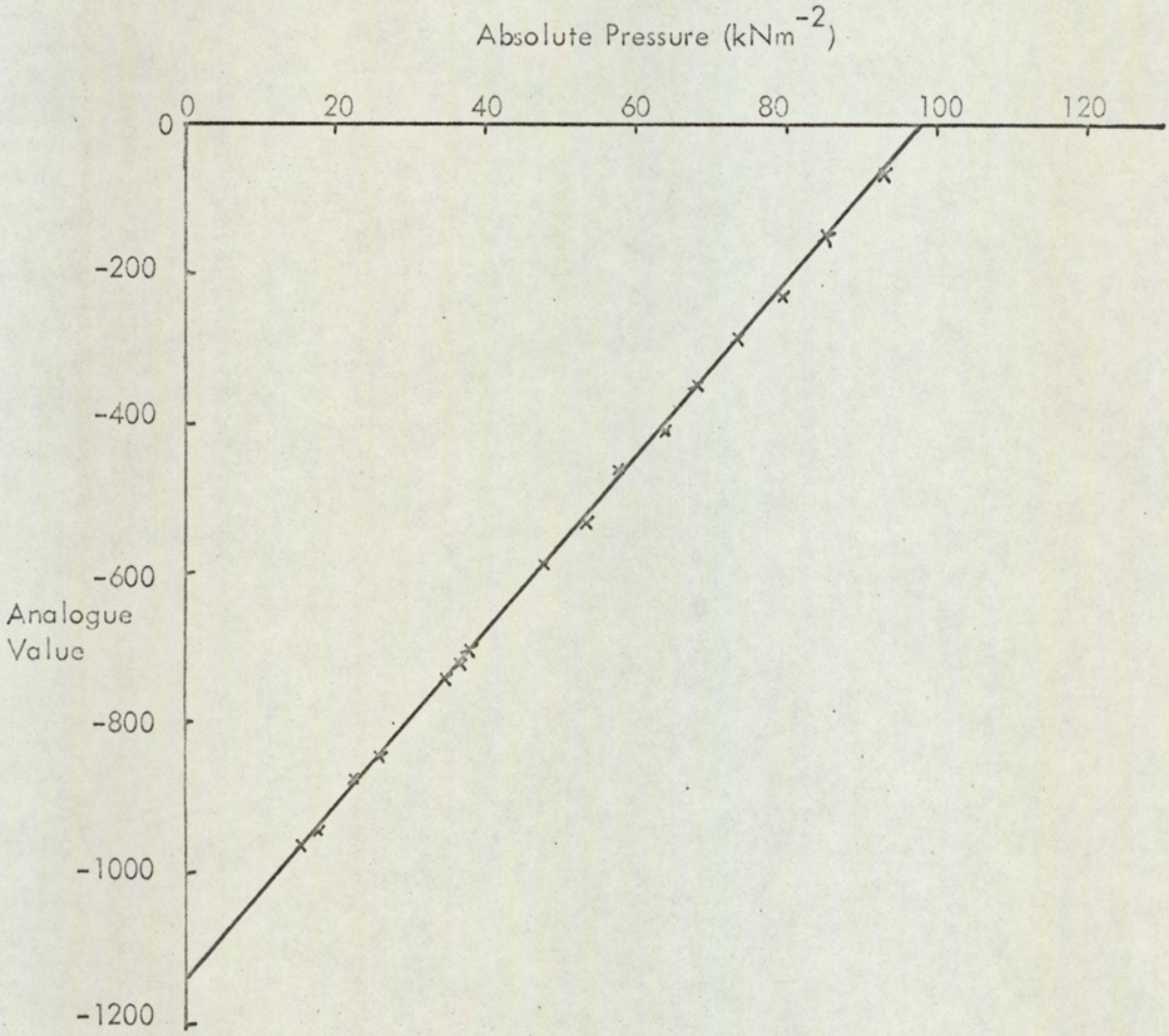
Calibration of Flowmeter to Second Effect Separator



SLOPE: -0.0052077
INTERCEPT: -15.04203
CORRELATION
COEFFICIENT : 0.9977854

FIGURE A7.2

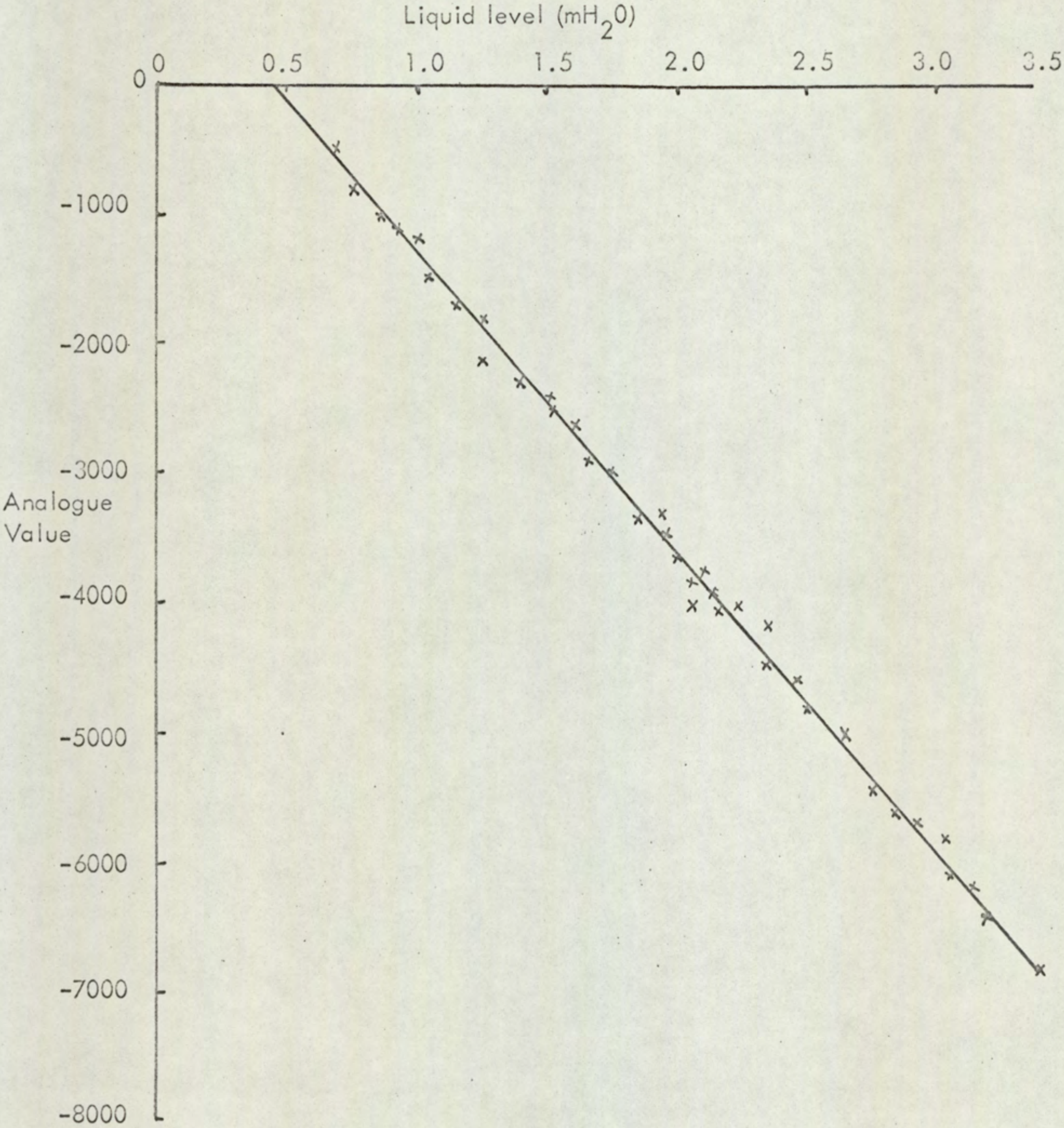
Calibration of 2nd Effect Shellside Pressure Transducer



SLOPE : 0.08627
INTERCEPT : 99.08
CORRELATION COEFFICIENT : 0.99987

FIGURE A7.3

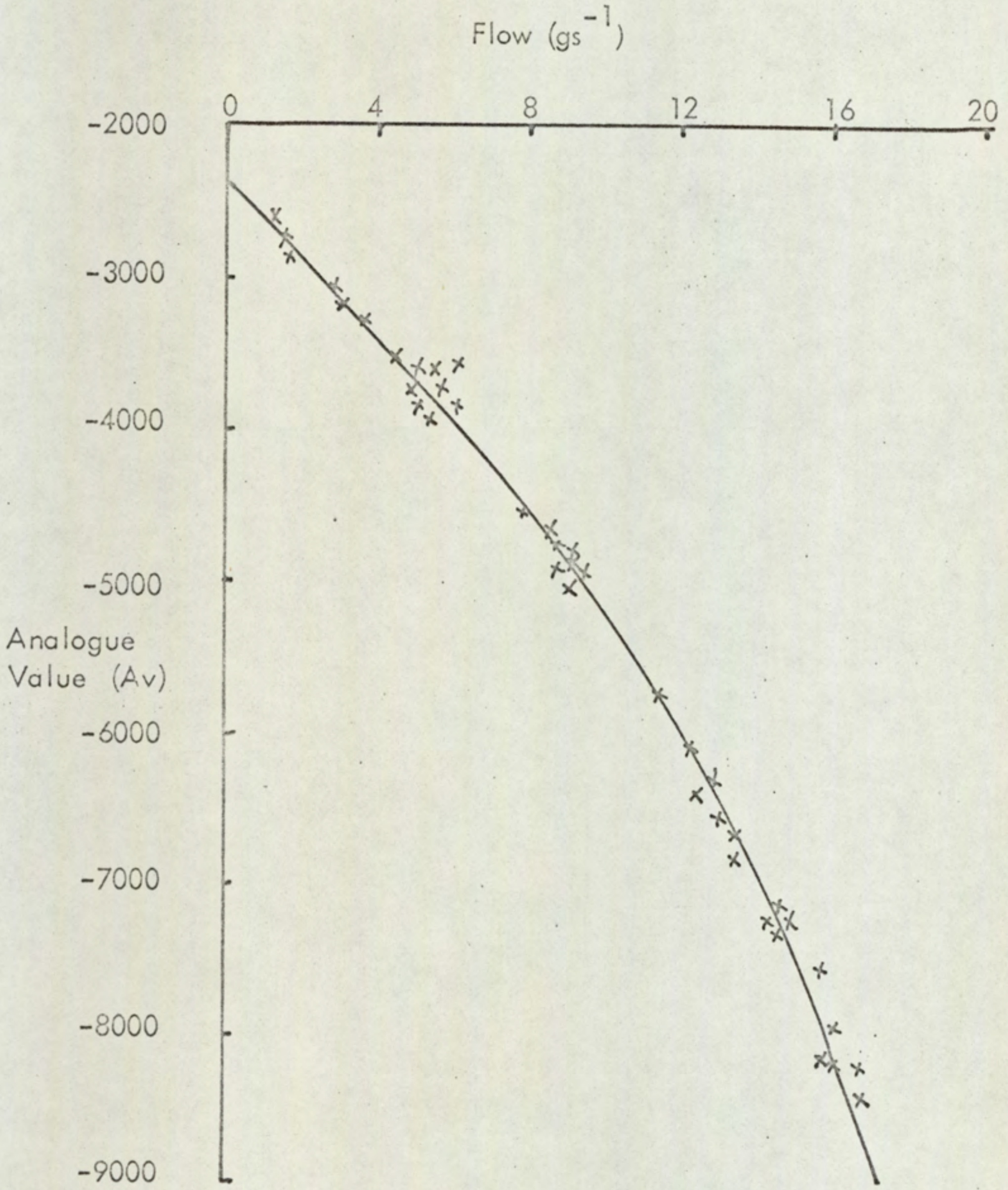
Calibration of Liquid level in 2nd Effect Separator



SLOPE : -0.0004307
INTERCEPT : 0.03093
CORRELATION COEFFICIENT : 0.99977

FIGURE A7.4

Calibration of Steam flow through orifice plate

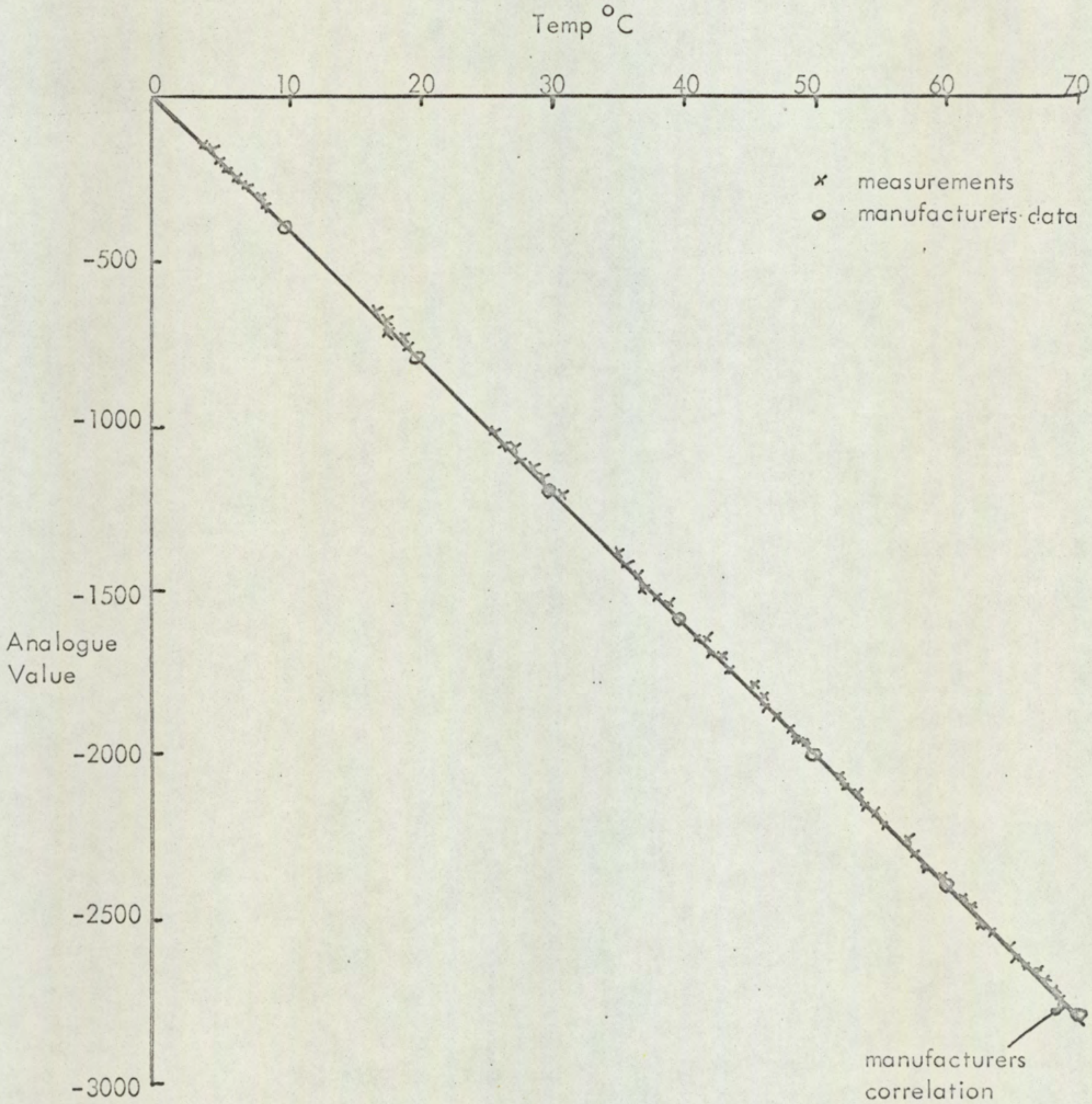


POLYNOMIAL EXPRESSION : $V_6 = -11.381 - 0.53255 \times 10^{-2} Av - 0.234755 \times 10^{-6} Av^2$

CORRELATION COEFFICIENT : 0.995661

FIGURE A7.5

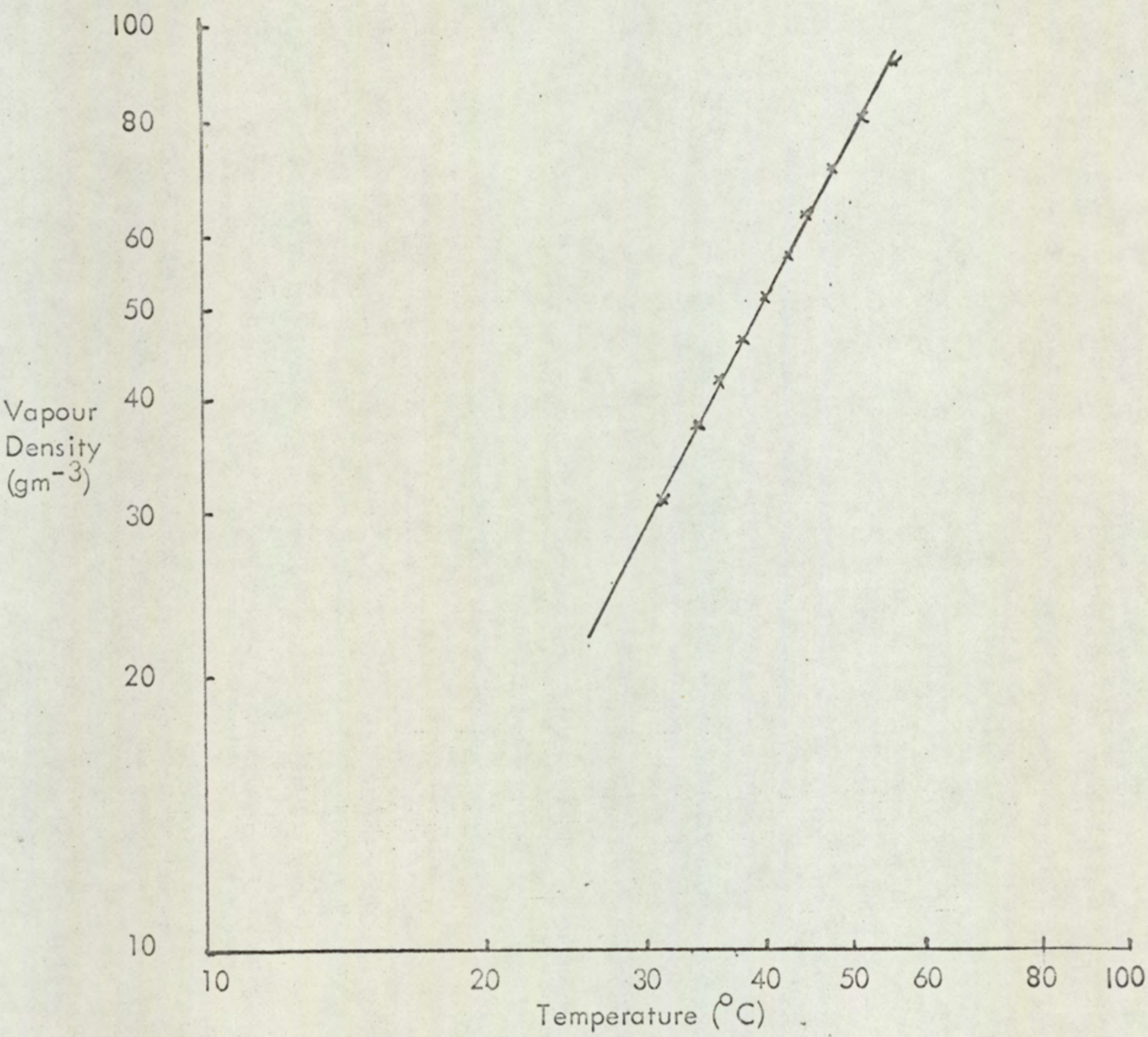
Calibration of Thermocouples



SLOPE : -0.025
INTERCEPT : 0.0
CORRELATION COEFFICIENT : 0.999997

FIGURE A7.6

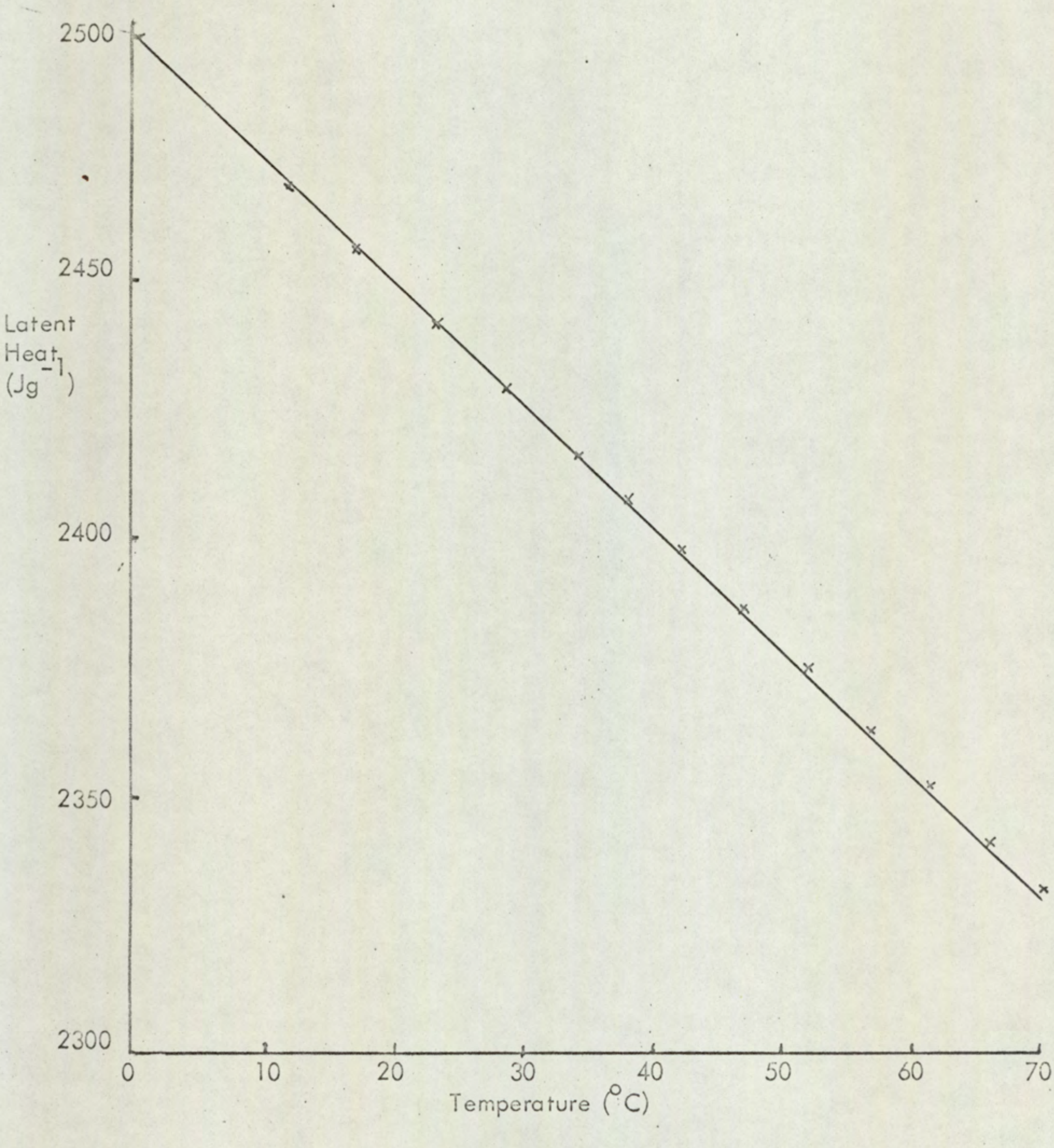
Vapour Density/Temperature Correlation for Saturated Steam



SLOPE : 1.93053
INTERCEPT : -3.18488
CORRELATION COEFFICIENT : 0.99935

FIGURE A7.7

Latent Heat/Temperature Correlation for Saturated Steam



SLOPE : -2.407
INTERCEPT : 2501.637
CORRELATION
COEFFICIENT : 0.99957

Figure A7.8

CONVERTED OUTPUT
--------- ------

	TEMP C	FLOW G/S	ENTHALPY J/S
*			
PREHEATER			
TUBESIDE L IN	15.9742	31.2967	2093.14
L OUT	43.3875	31.2967	5635.2
SHELLSIDE V IN	51.3004	16.16	.418014E 05
V OUT	48.5878	14.6229	.377539E 05
L OUT	48.5878	1.53709	312.636
*			
1ST EFFECT			
TUBESIDE L IN	43.3875	31.2967	5635.2
L/V OUT	51.5442	31.2967	.450745E 05
SHELLSIDE S IN	99.1251	17.4925	.408413E 05
SC OUT	99.1251	17.4925	7259.67
*			
CYCLONE SEPARATOR			
L/V IN	51.5442	31.2967	.450745E 05
L OUT	51.6432	15.1367	3273.17
V OUT	51.3004	16.16	.418014E 05
*			
2ND EFFECT			
TUBESIDE L IN	35.8825	3509.67	.527267E 06
L OUT	37.7073	3509.67	.554081E 06
SHELLSIDE V IN	48.5878	14.6229	.377539E 05
L IN	48.5878	1.53709	312.636
V OUT	47.0695	3.41474	8808.75
L OUT	47.0695	12.7453	2511.72
*			
2ND EFFECT SEPARATOR			
L IN FROM CS	51.6482	15.1367	3273.17
L IN FROM E2	37.7073	3509.67	.554081E 06
L OUT	35.8825	3509.67	.527267E 06
V OUT	34.1684	11.5513	.295435E 05
ACCUMULATION		3.53538	538.642
*			
CONDENSER			
TUBESIDE L IN	13.8291	800	.463196E 05
L OUT	22.4594	800	.752263E 05
SHELLSIDE V IN (E2S)	34.1684	11.5513	.295435E 05
V IN (E2)	47.0695	3.41474	8808.75
L IN	47.0695	12.7453	2511.72
L OUT	25.17	27.7113	2920.27

PUMP CIRCULATION RATE IN E2	3509.67 G/S
CONDENSER LIQUID RATE (DATA)	800 G/S
.. .. (COMPUTED)	1058.24 G/S
ACCUMULATION IN E2S(MEASURED)	3.53538 G/S
STEAM RATE TO 1ST EFFECT	17.4925 G/S
VALVE STEM POSITION	.5 TURN OPEN

Figure A7.9

CONVERTED OUTPUT
--------- ------

	TEMP C	FLOW G/S	ENTHALPY J/S
*			
PREHEATER			
TUBESIDE L IN	16.0621	32.2496	2163.74
L OUT	32.2079	32.2496	4343.79
SHELLSIDE V IN	39.4391	11.2436	.238615E 05
V OUT	34.4075	10.3027	.263537E 05
L OUT	34.4075	.940349	135.536
*			
1ST EFFECT			
TUBESIDE L IN	32.2079	32.2496	4348.79
L/V OUT	39.2095	32.2496	.323346E 05
SHELLSIDE S IN	98.9733	12.4128	.239346E 05
SC OUT	98.9733	12.4128	5143.65
*			
CYCLONE SEPARATOR			
L/V IN	39.2095	32.2496	.323346E 05
L OUT	39.1496	21.006	3443.12
V OUT	39.4391	11.2436	.238615E 05
*			
2ND EFFECT			
TUBESIDE L IN	29.7125	3023.77	.376153E 06
L OUT	30.7942	3023.77	.339352E 06
SHELLSIDE V IN	34.4075	10.3027	.263537E 05
L IN	34.4075	.940349	135.536
V OUT	34.5775	4.63357	.118633E 05
L OUT	34.5775	6.60499	956.199
*			
2ND EFFECT SEPARATOR			
L IN FROM CS	39.1496	21.006	3443.12
L IN FROM E2	30.7942	3023.77	.339352E 06
L OUT	29.7125	3023.77	.376153E 06
V OUT	31.2374	5.98004	.152677E 05
ACCUMULATION		15.026	1869.23
*			
CONDENSER			
TUBESIDE L IN	13.0723	800	.437843E 05
L OUT	18.2375	800	.612529E 05
SHELLSIDE V IN (E2S)	31.2374	5.98004	.152677E 05
V IN (E2)	34.5775	4.63357	.118633E 05
L IN	34.5775	6.60499	956.199
L OUT	17.7054	17.2236	1276.77

PUMP CIRCULATION RATE IN E2 3023.77 G/S
CONDENSER LIQUID RATE (DATA) 833 G/S
'' '' '' '' (COMPUTED) 1228.11 G/S
ACCUMULATION IN E2S(MEASURED) 15.026 G/S
STEAM RATE TO 1ST EFFECT 12.4128 G/S
VALVE STEM POSITION .25 TURN OPEN

Figure A7.10

CONVERTED OUTPUT

	TEMP C	FLOW G/S	ENTHALPY J/S
*			
PREHEATER			
TUBESIDE L IN	15.9227	16.1956	1079.69
L OUT	35.5762	16.1956	2412.35
SHELLSIDE V IN	39.9625	11.6353	.298776E 05
V OUT	35.6819	11.0496	.232933E 05
L OUT	35.6819	.586185	87.5718
*			
1ST EFFECT			
TUBESIDE L IN	35.5762	16.1956	2412.35
L/V OUT	39.375	16.1956	.306179E 05
SHELLSIDE S IN	98.9757	12.5237	.292435E 05
SC OUT	98.9757	12.5237	5189.73
*			
CYCLONE SEPARATOR			
L/V IN	39.375	16.1956	.306179E 05
L OUT	38.7754	4.55981	748.262
V OUT	39.9625	11.6353	.298776E 05
*			
2ND EFFECT			
TUBESIDE L IN	27.9383	3246.23	.379317E 06
L OUT	28.9421	3246.23	.393367E 06
SHELLSIDE V IN	35.6319	11.0496	.232933E 05
L IN	35.6319	.586185	87.5718
V OUT	37.5294	5.28639	.133474E 05
L OUT	37.5294	6.42944	1018.25
*			
2ND EFFECT SEPARATOR			
L IN FROM CS	38.7754	4.55981	748.262
L IN FROM E2	28.9421	3246.23	.393367E 06
L OUT	27.9383	3246.23	.379317E 06
V OUT	35.1191	5.8367	.149397E 05
ACCUMULATION		-1.27683	-149.199
*			
CONDENSER			
TUBESIDE L IN	11.4306	633.33	.304423E 05
L OUT	17.9721	633.33	.476552E 05
SHELLSIDE V IN (E2S)	35.1191	5.8367	.149397E 05
V IN (E2)	37.5294	5.28639	.133474E 05
L IN	37.5294	6.42944	1018.25
L OUT	19.1158	17.4725	1393.4

PUMP CIRCULATION RATE IN E2 3246.23 G/S
CONDENSER LIQUID RATE (DATA) 633.33 G/S
" " " " (COMPUTED) 1026.51 G/S
ACCUMULATION IN E2S(MEASURED) -1.27683 G/S
STEAM RATE TO 1ST EFFECT 12.5237 G/S
VALVE STEM POSITION .25 TURN OPEN

Figure A7.11

CONVERTED OUTPUT

	TEMP C	FLOW G/S	ENTHALPY J/S
*			
PREHEATER			
TUBESIDE L IN	14.6121	16.1956	990.315
L OUT	35.4637	16.1956	2404.72
SHELLSIDE V IN	40.2117	10.8745	.279272E 05
V OUT	35.4204	10.2532	.262494E 05
L OUT	35.4204	.621244	92.1294
*			
1ST EFFECT			
TUBESIDE L IN	35.4637	16.1956	2404.72
L/V OUT	39.214	16.1956	.287326E 05
SHELLSIDE S IN	98.9767	11.7123	.273436E 05
SC OUT	98.9767	11.7123	4353.51
*			
CYCLONE SEPARATOR			
L/V IN	39.214	16.1956	.287326E 05
L OUT	38.3985	5.32119	855.472
V OUT	40.2117	10.8745	.279272E 05
*			
2ND EFFECT			
TUBESIDE L IN	27.8948	3487.99	.437361E 06
L OUT	28.9308	3487.99	.422491E 06
SHELLSIDE V IN	35.4204	10.2532	.262494E 05
L IN	35.4204	.621244	92.1294
V OUT	37.4504	3.96216	.101571E 05
L OUT	37.4504	6.9123	1083.83
*			
2ND EFFECT SEPARATOR			
L IN FROM CS	38.3985	5.32119	855.472
L IN FROM E2	23.9303	3437.99	.422491E 06
L OUT	27.8943	3487.99	.437361E 06
V OUT	34.6302	6.29122	.163935E 05
ACCUMULATION		-.970032	-113.29
*			
CONDENSER			
TUBESIDE L IN	11.5846	633.333	.307131E 05
L OUT	17.7421	633.333	.470456E 05
SHELLSIDE V IN (E2S)	34.6802	6.29122	.163935E 05
V IN (E2)	37.4504	3.96216	.101571E 05
L IN	37.4504	6.9123	1083.33
L OUT	17.6467	17.1657	1263.25

PUMP CIRCULATION RATE IN E2 3487.99 G/S
CONDENSER LIQUID RATE (DATA) 633.333 G/S
" " " " (COMPUTED) 1011.23 G/S
ACCUMULATION IN E2S(MEASURED) -.970032 G/S
STEAM RATE TO 1ST EFFECT 11.7123 G/S
VALVE STEM POSITION .25 TURN OPEN

Figure A7.12

CONVERTED OUTPUT
--------- ------

		TEMP C	FLOW G/S	ENTHALPY J/S
*				
PREHEATER				
TUBESIDE	L IN	6.59041	46.0955	1271.9
	L OUT	34.4325	46.0955	6645.21
SHELLSIDE	V IN	41.8279	16.5104	.424457E 05
	V OUT	40.9656	14.2644	.36651E 05
	L OUT	40.9656	2.24598	385.219
*				
1ST EFFECT				
TUBESIDE	L IN	34.4325	46.0955	6645.21
	L/V OUT	43.6654	46.0955	.479052E 05
SHELLSIDE	S IN	99.1632	18.324	.427815E 05
	SC OUT	99.1632	18.324	7607.63
*				
CYCLONE SEPARATOR				
	L/V IN	43.6654	46.0955	.479052E 05
	L OUT	44.0756	29.5351	5459.51
	V OUT	41.8279	16.5104	.424457E 05
*				
2ND EFFECT				
TUBESIDE	L IN	30.015	3833.21	.481707E 06
	L OUT	31.7287	3833.21	.509211E 06
SHELLSIDE	V IN	40.9656	14.2644	.36651E 05
	L IN	40.9656	2.24598	385.219
	V OUT	49.3083	2.60497	6729.63
	L OUT	49.3083	13.9054	2370.69
*				
2ND EFFECT SEPARATOR				
	L IN FROM CS	44.0756	29.5351	5459.51
	L IN FROM E2	31.7287	3833.21	.509211E 06
	L OUT	30.015	3833.21	.481707E 06
	V OUT	41.1848	11.9657	.30749E 05
	ACCUMULATION		17.6194	2214.13
*				
CONDENSER				
TUBESIDE	L IN	4.61312	433.333	9335.2
	L OUT	17.8571	433.333	.361359E 05
SHELLSIDE	V IN (E2S)	41.1848	11.9657	.30749E 05
	V IN (E2)	49.3083	2.60497	6729.63
	L IN	49.3083	13.9054	2370.69
	L OUT	22.5779	28.476	2691.82

PUMP CIRCULATION RATE IN E2	3833.21 G/S
CONDENSER LIQUID RATE (DATA)	433.333 G/S
'' '' '' '' (COMPUTED)	679.129 G/S
ACCUMULATION IN E2S(MEASURED)	17.6194 G/S
STEAM RATE TO 1ST EFFECT	18.324 G/S
VALVE STEM POSITION	.5 TURN OPEN

Figure A7.13

```
CONVERTED OUTPUT
--------- ------


                                 TEMP C        FLOW G/S     ENTHALPY J/S

*
PREHEATER
      TUBESIDE  L IN             15.4539        39.4311      2555.34
                L OUT            43.4303        39.4311      6633.19
     SHELLSIDE  V IN             43.5346        15.4436      .393773E 05
                V OUT            46.3533        13.6396      .352903E 05
                L OUT            46.3533         1.75395      333.193
*
1ST EFFECT
      TUBESIDE  L IN             43.4303        39.4311      6633.19
              L/V OUT            43.7921        39.4311      .447937E 05
     SHELLSIDE  S IN             93.9633        16.9215      .395127E 05
               SC OUT            93.9633        16.9215      7311.23
*
CYCLONE SEPARATOR
              L/V IN             43.7921        39.4311      .447937E 05
                L OUT            43.3454        24.0375      4915.32
                V OUT            43.5346        15.4436      .393773E 05
*
2ND EFFECT
      TUBESIDE  L IN             37.0973      2937.35        .456303E 06
                L OUT            33.6216      2937.35        .475954E 06
     SHELLSIDE  V IN             46.3533        13.6396      .352903E 05
                L IN             46.3533         1.75395      333.193
                V OUT            47.3672         5.30932     .149929E 05
                L OUT            47.3672         9.63454     1933.36
*
2ND EFFECT SEPARATOR
           L IN FROM CS          43.3454        24.0375      4915.32
           L IN FROM E2          33.6216      2937.35        .475354E 06
                L OUT            37.3973      2937.35        .456373E 06
                V OUT            40.4632         3.25954     .212152E 05
           ACCUMULATION                         15.773       2450.62
*
CONDENSER
      TUBESIDE  L IN             14.0733       479           .232246E 05
                L OUT            26.2423       479           .526233E 05
   SHELLSIDE V IN (E2S)          40.4632         3.25954     .212152E 05
             V IN (E2)           47.3672         5.30932     .149929E 05
                L IN             47.3672         9.63454     1933.36
            L OUT                27.0721        23.7331      2636.64


PUMP CIRCULATION RATE IN E2    2937.35 G/S
CONDENSER LIQUID RATE (DATA)    479  G/S
  ''   ''   ''   '' (COMPUTED)  695.363 G/S
ACCUMULATION IN E2S(MEASURED)   15.773 G/S
STEAM RATE TO 1ST EFFECT        16.9215 G/S
VALVE STEM POSITION              .5 TURN OPEN

??? EXIT
```

Figure A7.14

```
CONVERTED OUTPUT
--------- ------

                                       TEMP C         FLOW G/S     ENTHALPY J/S

*
PREHEATER
      TUBESIDE  L IN                   14.5166         23.6946      1443.11
                L OUT                  43.3464         23.6946      4349.77
     SHELLSIDE  V IN                   43.9431         15.6332      .403397E 05
                V OUT                  46.0519         14.3395      .370949E 05
                L OUT                  46.0519          1.2437       240.763
*
1ST EFFECT
      TUBESIDE  L IN                   43.3464         23.6946      4349.77
              L/V OUT                  43.3372         23.6946      .400372E 05
     SHELLSIDE  S IN                   99.3711         16.7413      .390335E 05
               SC OUT                  99.3711         16.7413      6965.15
*
CYCLONE SEPARATOR
              L/V IN                   43.3372         23.6946      .400372E 05
                L OUT                  43.3433          3.05643     1647.55
                V OUT                  43.9431         15.6332      .403397E 05
*
2ND EFFECT
      TUBESIDE  L IN                   36.207        3175.34        .431355E 06
                L OUT                  37.3525       3175.34        .503231E 06
     SHELLSIDE  V IN                   46.0519         14.3395      .370949E 05
                L IN                   46.0519          1.2437       248.763
                V OUT                  52.437           5.10035     .132029E 05
                L OUT                  52.437          10.5373      2313.5
*
2ND EFFECT SEPARATOR
         L IN FROM CS                  43.3433          3.05643     1647.55
         L IN FROM E2                  37.3525       3175.34        .503231E 06
                L OUT                  36.207        3175.34        .431355E 06
                V OUT                  43.7077          9.2069      .236933E 05
         ACCUMULATION                                  -1.15032     -174.373
*
CONDENSER
      TUBESIDE  L IN                   13.6312        504           .237639E 05
                L OUT                  25.2352        504           .533555E 05
   SHELLSIDE V IN (E2S)                43.7077          9.2063      .236933E 05
             V IN (E2)                 52.437           5.10035     .132029E 05
                L IN                   52.437          10.5373      2313.5
             L OUT                     26.3235         24.345       2790.73


PUMP CIRCULATION RATE IN E2    3175.34 G/S
CONDENSER LIQUID RATE (DATA)    504  G/S
  ''   ''   ''   '' (COMPUTED)  746.542 G/S
ACCUMULATION IN E2S(MEASURED)   -1.15032 G/S
STEAM RATE TO 1ST EFFECT        16.7413 G/S
VALVE STEM POSITION               .5 TURN OPEN

993 EXIT
```

Figure A7.15

CONVERTED OUTPUT
--------- ------

	TEMP C	FLOW G/S	ENTHALPY J/S
*			
PREHEATER			
TUBESIDE L IN	14.4579	23.0379	1708.23
L OUT	41.7376	23.0379	4914.16
SHELLSIDE V IN	43.6431	12.2095	.31523E 05
V OUT	46.356	10.8452	.279636E 05
L OUT	46.356	1.36427	264.733
*			
1ST EFFECT			
TUBESIDE L IN	41.7376	23.0379	4914.16
L/V OUT	43.6329	23.0379	.347639E 05
SHELLSIDE S IN	93.974	13.2525	.339451E 05
SC OUT	93.974	13.2525	5491.61
*			
CYCLONE SEPARATOR			
L/V IN	43.6329	23.0379	.347639E 05
L OUT	43.6293	15.3735	3232.9
V OUT	43.6431	12.2095	.31523E 05
*			
2ND EFFECT			
TUBESIDE L IN	35.9343	3535.04	.523373E 06
L OUT	37.675	3535.04	.552377E 06
SHELLSIDE V IN	46.356	10.8452	.279636E 05
L IN	46.356	1.36427	264.733
V OUT	51.5295	.360109	931.633
L OUT	51.5295	11.3493	2556.42
*			
2ND EFFECT SEPARATOR			
L IN FROM CS	43.6293	15.3735	3232.9
L IN FROM E2	37.675	3535.04	.552377E 06
L OUT	35.9343	3535.04	.523373E 06
V OUT	43.774	10.5313	.272337E 05
ACCUMULATION		5.29667	793.332
*			
CONDENSER			
TUBESIDE L IN	13.7634	504	.290423E 05
L OUT	24.7541	504	.522347E 05
SHELLSIDE V IN (E2S)	43.774	10.5313	.272337E 05
V IN (E2)	51.5295	.360109	931.633
L IN	51.5295	11.3493	2556.42
L OUT	26.0343	22.7912	2434.25

PUMP CIRCULATION RATE IN E2 3535.04 G/S
CONDENSER LIQUID RATE (DATA) 504 G/S
'' '' '' '' (COMPUTED) 613.757 G/S
ACCUMULATION IN E2S(MEASURED) 5.29667 G/S
STEAM RATE TO 1ST EFFECT 13.2525 G/S
VALVE STEM POSITION .5 TURN OPEN

993 EXIT

FIGURE A7.16

Off Line Steady State Analysis

RUN NO 3

TOTAL RATE HEAT IN	.850995E 05	J/S
TOTAL RATE HEAT OUT	.777157E 05	J/S
ACCUMULATION	-80.5947	J/S
ACTUAL HEAT LOSS	8.77133	%
COMPUTED HEAT LOSS	13.1721	%
STEAM RATE	16	G/S
ANALOGUE READING	-8723.42	

PREHEATER

HEAT TRANSFER	2890.29	J/S
HEAT FLUX	7606.04	J/SM↑2
L M T D	15.0316	C
OVERALL HTC	506.002	W/M↑2C

TUBESIDE

MEAN LIQUID TEMP	30.405	C
REYNOLDS NO	2336.97	
PRANDTL NO	5.36829	
COEFFICIENT	653.53	W/M↑2C

SHELLSIDE

COEFFICIENT 5931.41 W/M↑2C

CLEAN OVERALL COEFF 588.67 W/M↑2C
DIRT FACTOR .277531E-03 M↑2C/W

DATA

48.8154	17.78	43.03	27.34	1.229

FIGURE A7.16 cont/...

1ST EFFECT

```
HEAT TRANSFER   .365294E 05    J/S
HEAT FLUX       .507352E 05    J/SM↑2
L M T D           53.618    C
OVERALL HTC      946.236         W/M↑2C

TUBESIDE

MEAN LIQUID TEMP      46.315  C
REYNOLDS NO        796.733
PRANDTL NO           3.77905
COEFFICIENT        239.79  W/M↑2C

SHELLSIDE

COEFFICIENT     5474.35    W/M↑2C


CLEAN OVERALL COEFF   229.728 W/M↑2C
DIRT FACTOR             -.329616E-02  M↑2C/W

DATA
  100            43.03           49.6          27.34          16
```

2ND EFFECT

```
HEAT TRANSFER   .395535E 05    J/S
HEAT FLUX       .588594E 05    J/SM↑2
L M T D           15.4393    C
OVERALL HTC     3812.32         W/M↑2C

TUBESIDE

MEAN LIQUID TEMP       35.98   C
REYNOLDS NO      .491595E 05
PRANDTL NO          4.70793
COEFFICIENT      5614.18   W/M↑2C

SHELLSIDE

COEFFICIENT      5934     W/M↑2C


CLEAN OVERALL COEFF 2884.83 W/M↑2C
DIRT FACTOR             -.84333E-04  M↑2C/W

DATA
   51.44          35            36.96         4820           11.0599
```

FIGURE A7.16 cont/...

CONDENSER

```
HEAT TRANSFER   .290648E 05   J/S
HEAT FLUX       .252737E 05   J/SM↑2
L M T D           20.4279   C
OVERALL HTC     1237.22         W/M↑2C

TUBESIDE

MEAN LIQUID TEMP      16.65  C
REYNOLDS NO     .357474E 05
PRANDTL NO          7.77458
COEFFICIENT     4851.4  W/M↑2C

SHELLSIDE

COEFFICIENT     2074.98   W/M↑2C


CLEAN OVERALL COEFF 1453.36 W/M↑2C
DIRT FACTOR            .120208E-03  M↑2C/W

DATA
   37.4            12.2            21.1            780             23
```

2ND EFFECT SEPARATOR

```
MEAN LEVEL          3.13978   M
OVERALL DATA

    3      16      120    .398361E 05  .68921E 05  2035.13  2095.85
 -80.5947  1080.61     12.1983     21.1046 -8723.42   780
```

FIGURE A7.17

DYNAMIC LOG I

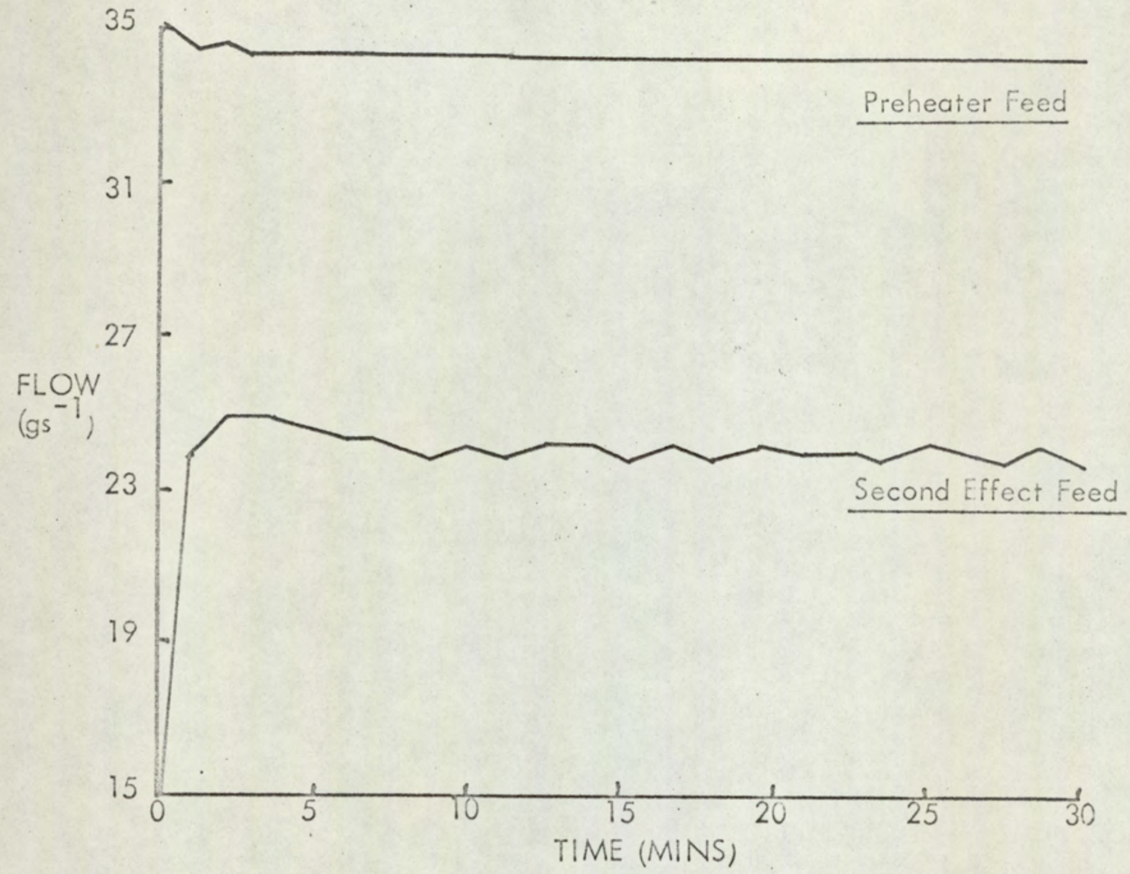
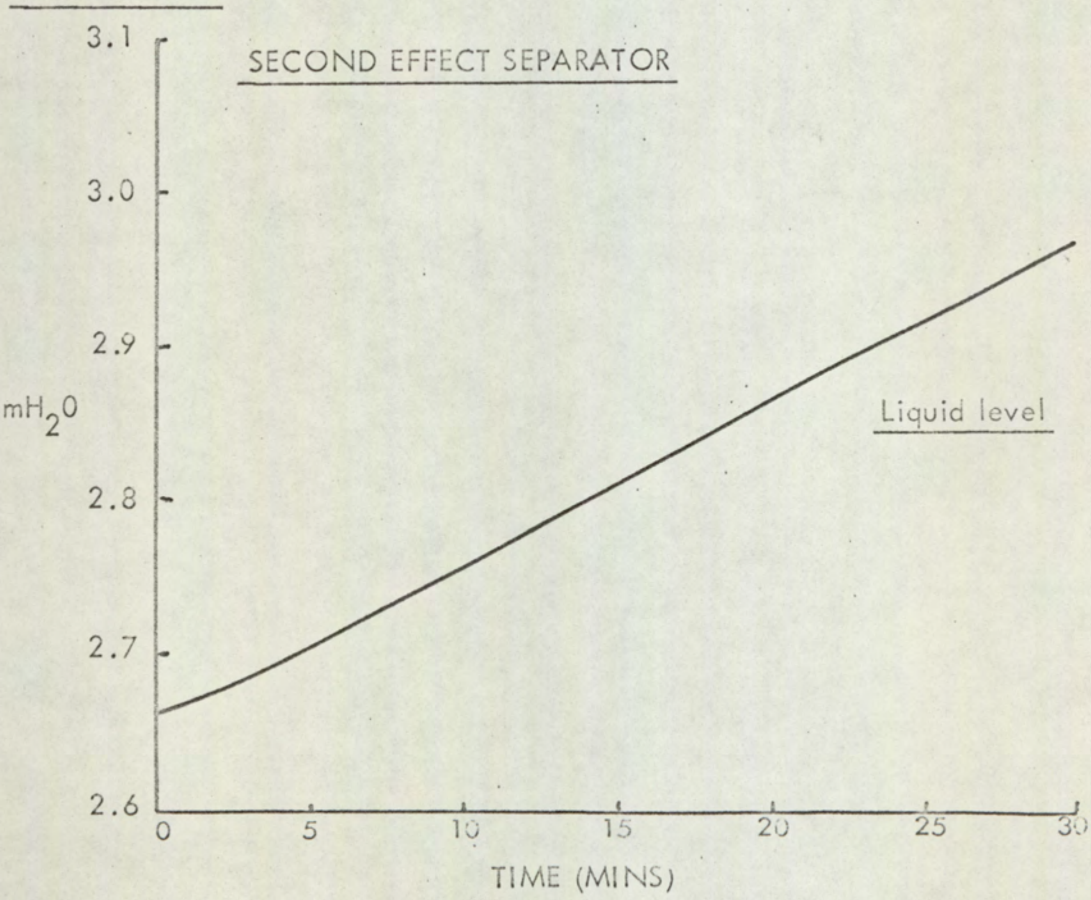


FIGURE A7.18



DYNAMIC LOG I

FIGURE A7.19

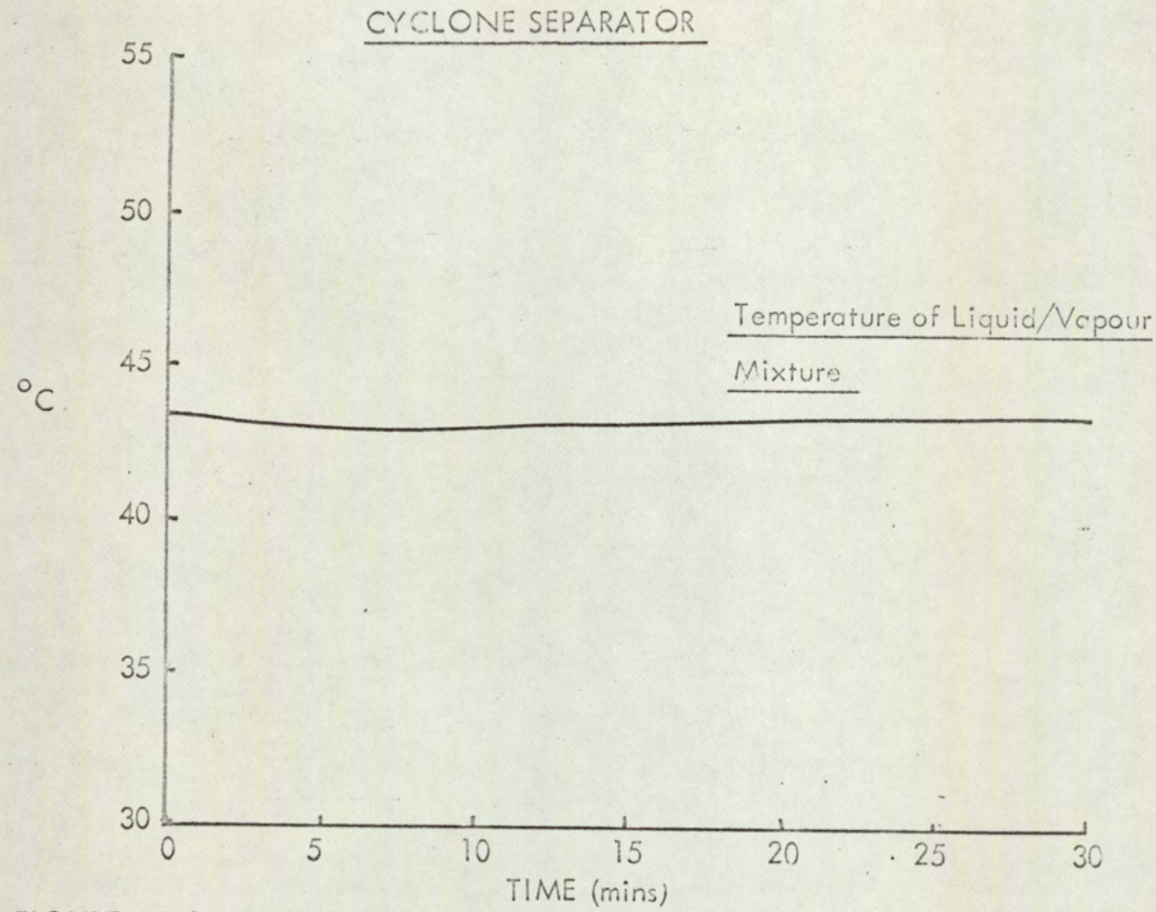
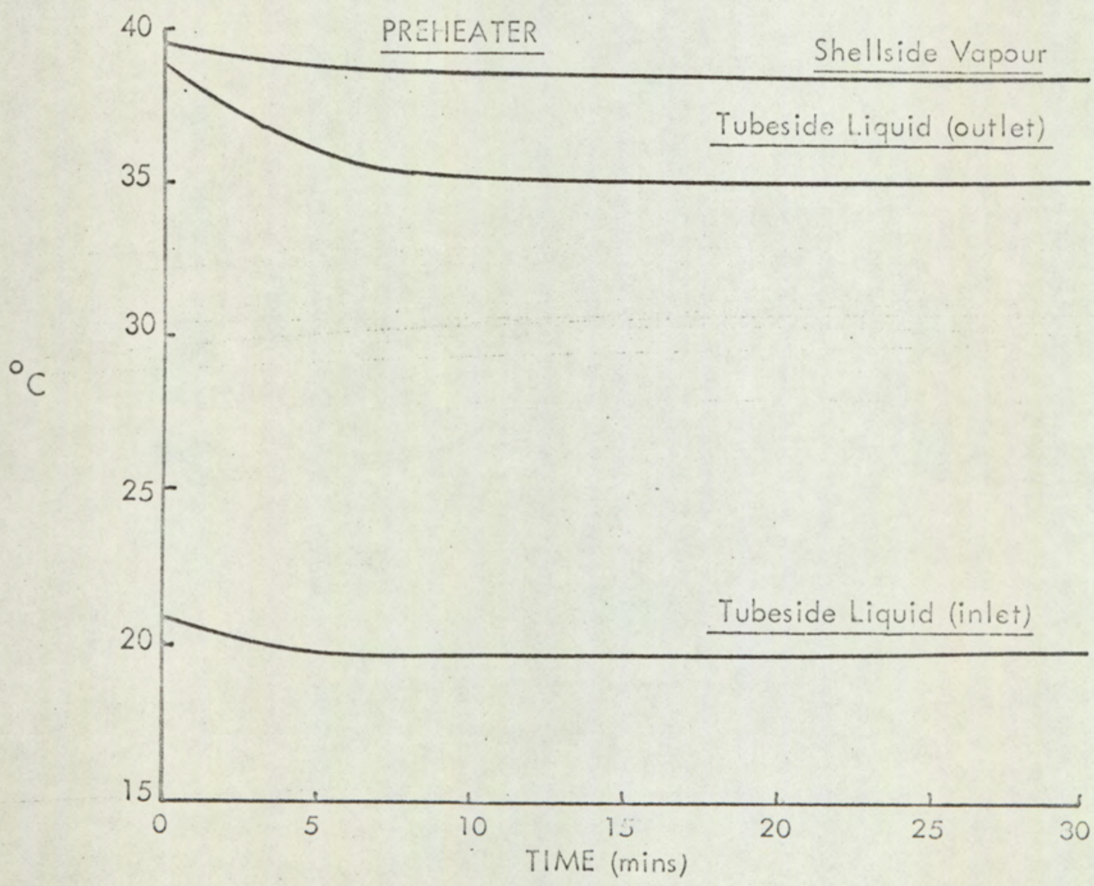


FIGURE A7.20



DYNAMIC LOG I

FIGURE A7.21

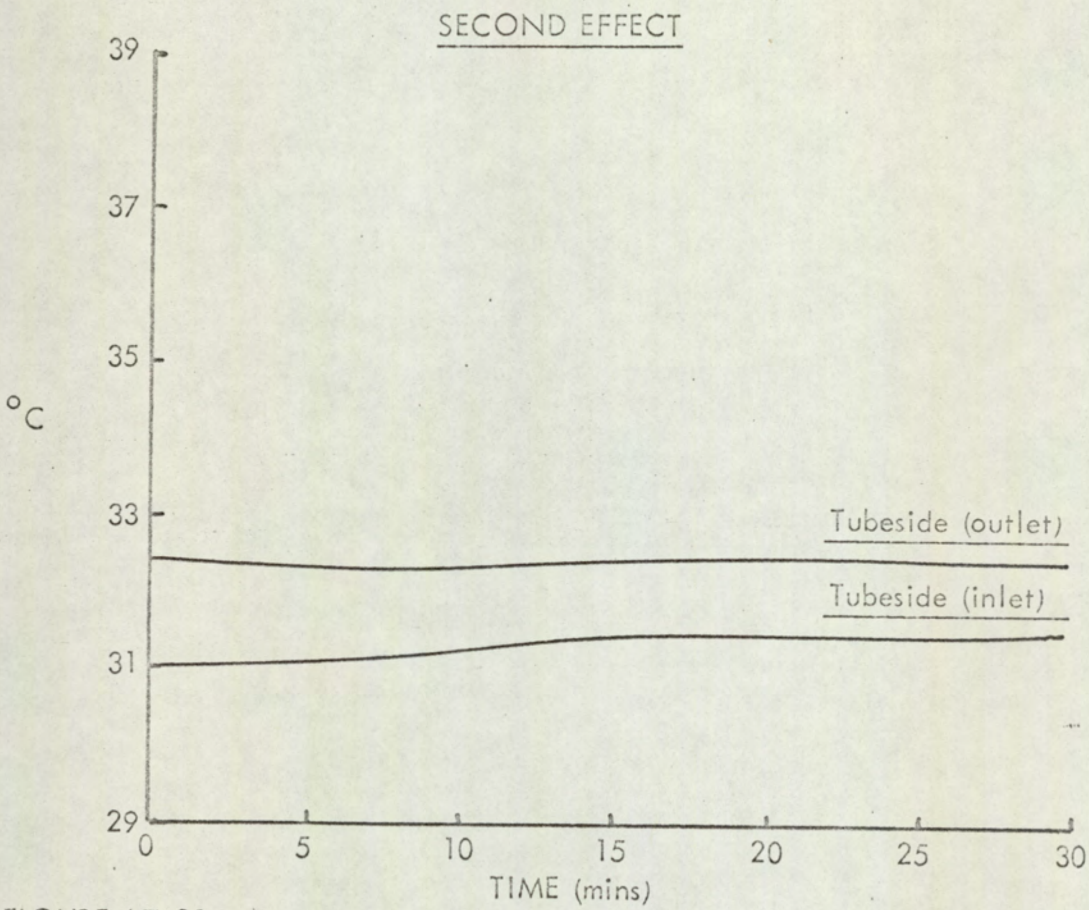
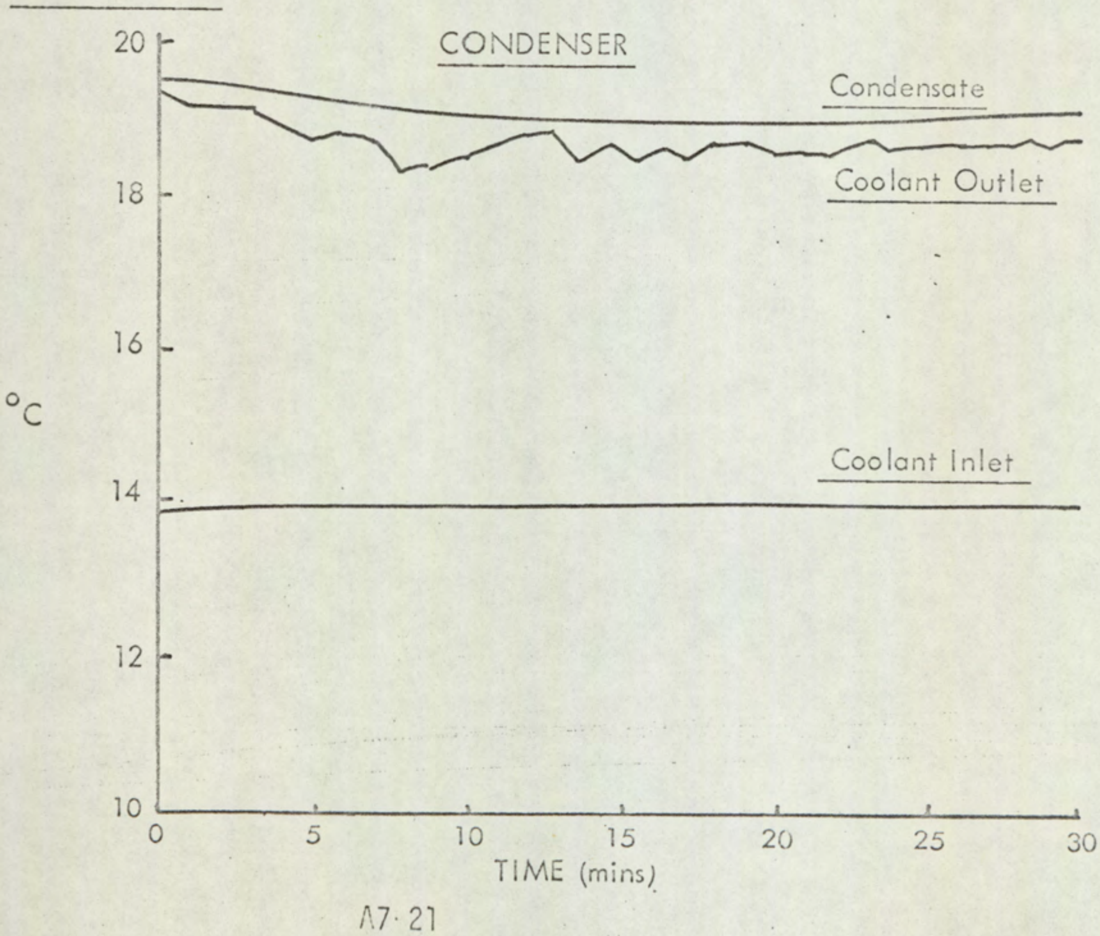


FIGURE A7.22



DYNAMIC LOG II

FIGURE A7.23

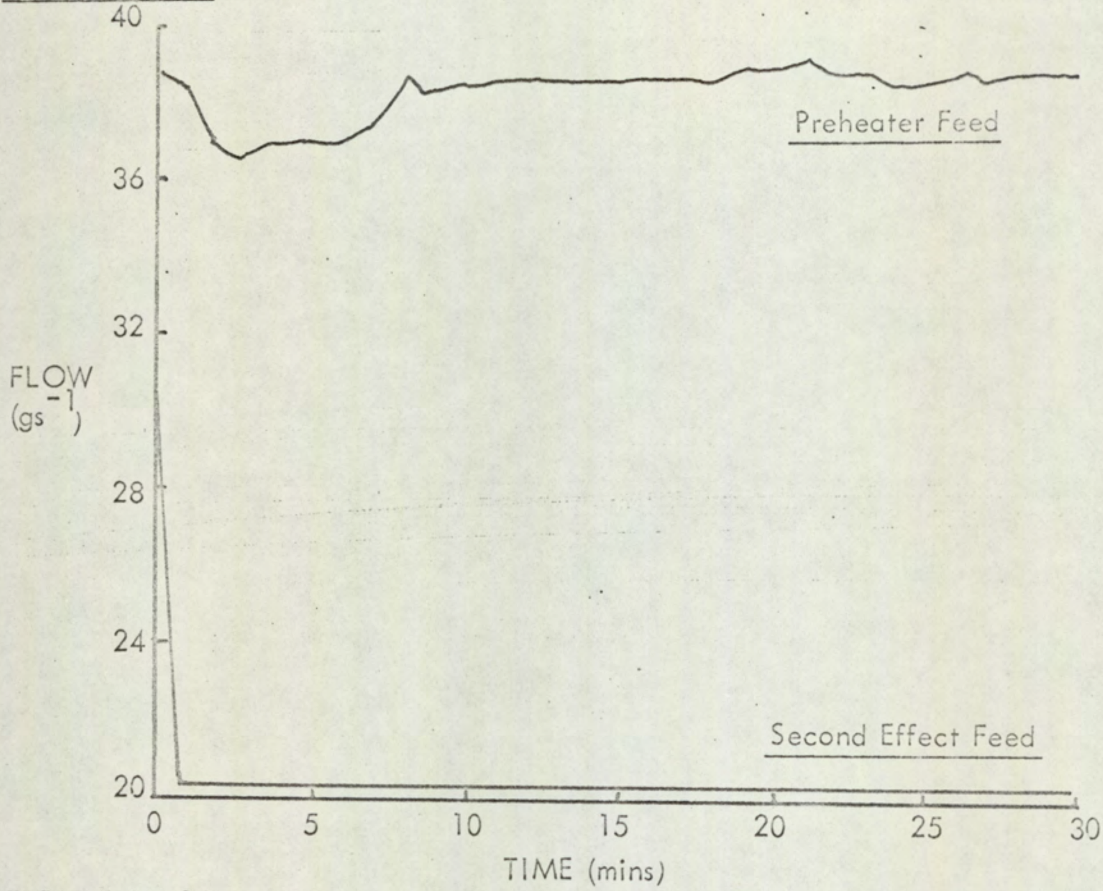
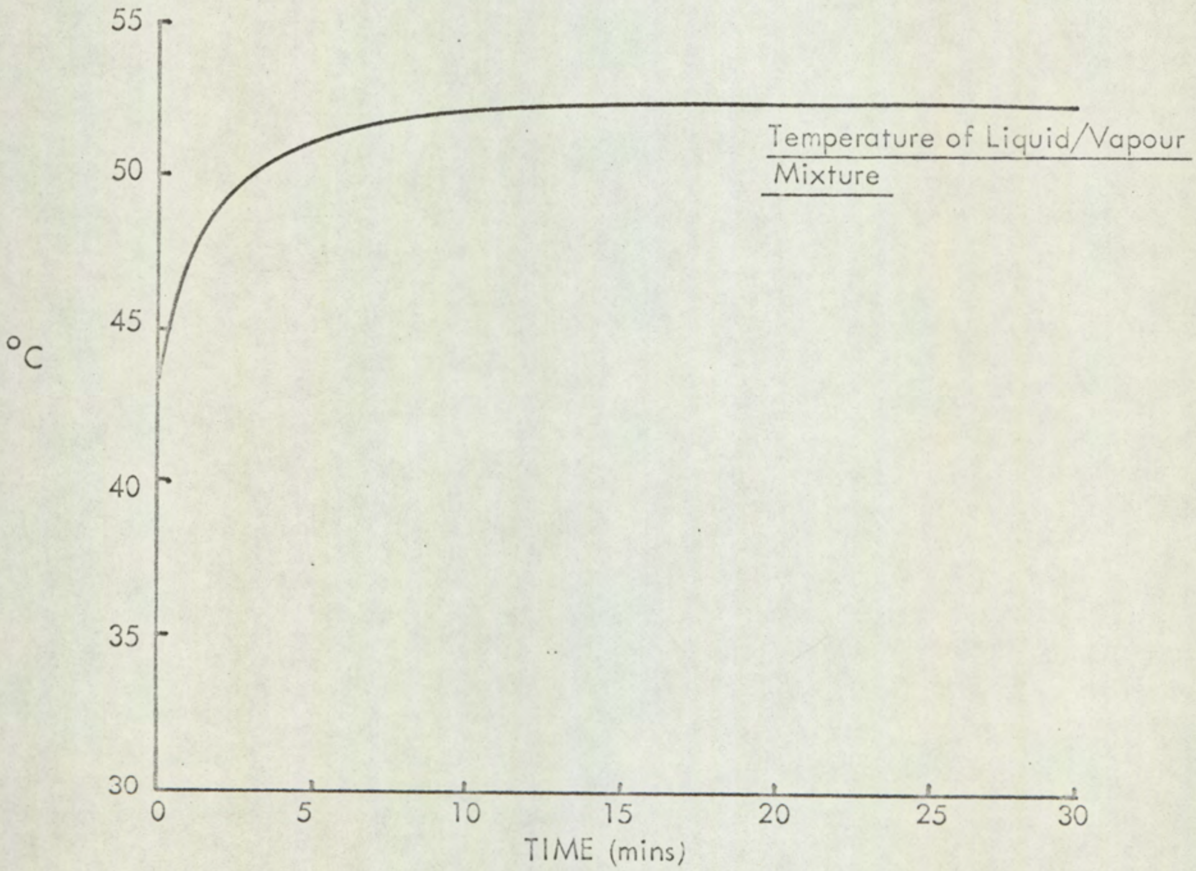


FIGURE A7.24

CYCLONE SEPARATOR



DYNAMIC LOG II

FIGURE A7.25

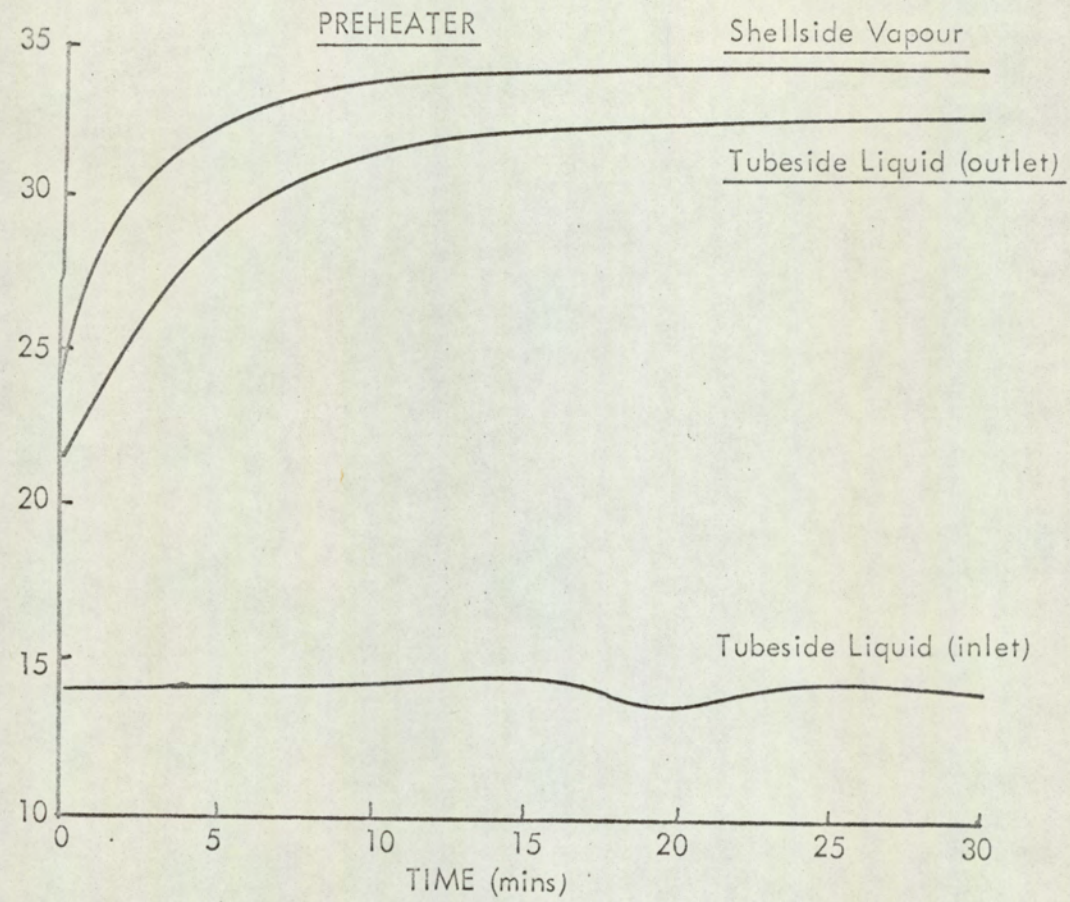
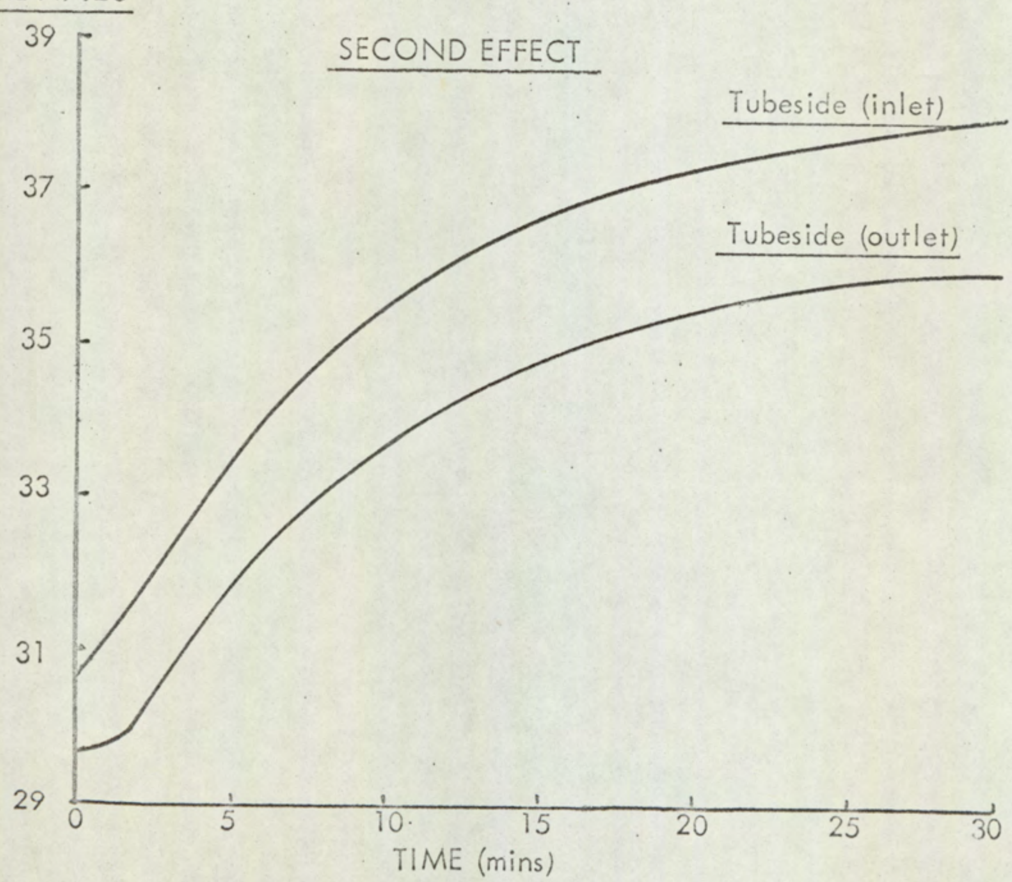


FIGURE A7.26



DYNAMIC LOG II

FIGURE A7.27

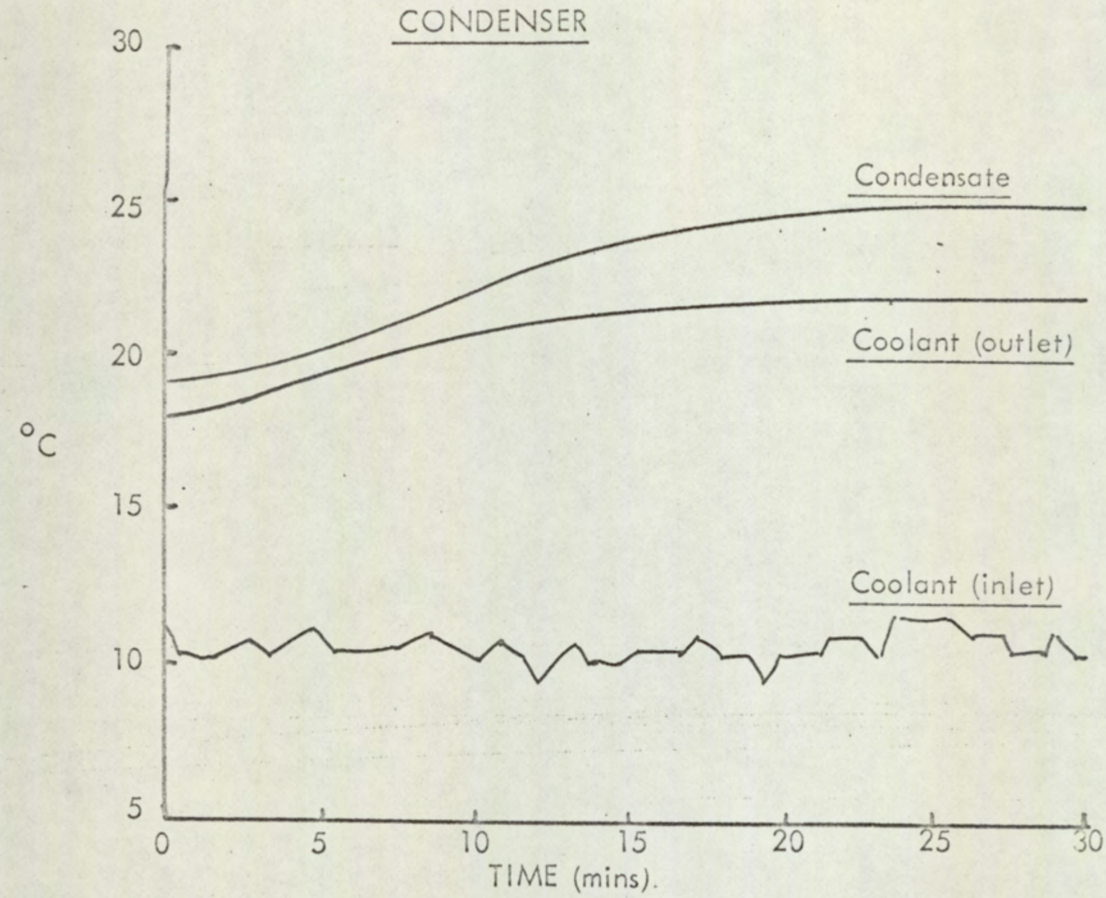


FIGURE A7.28

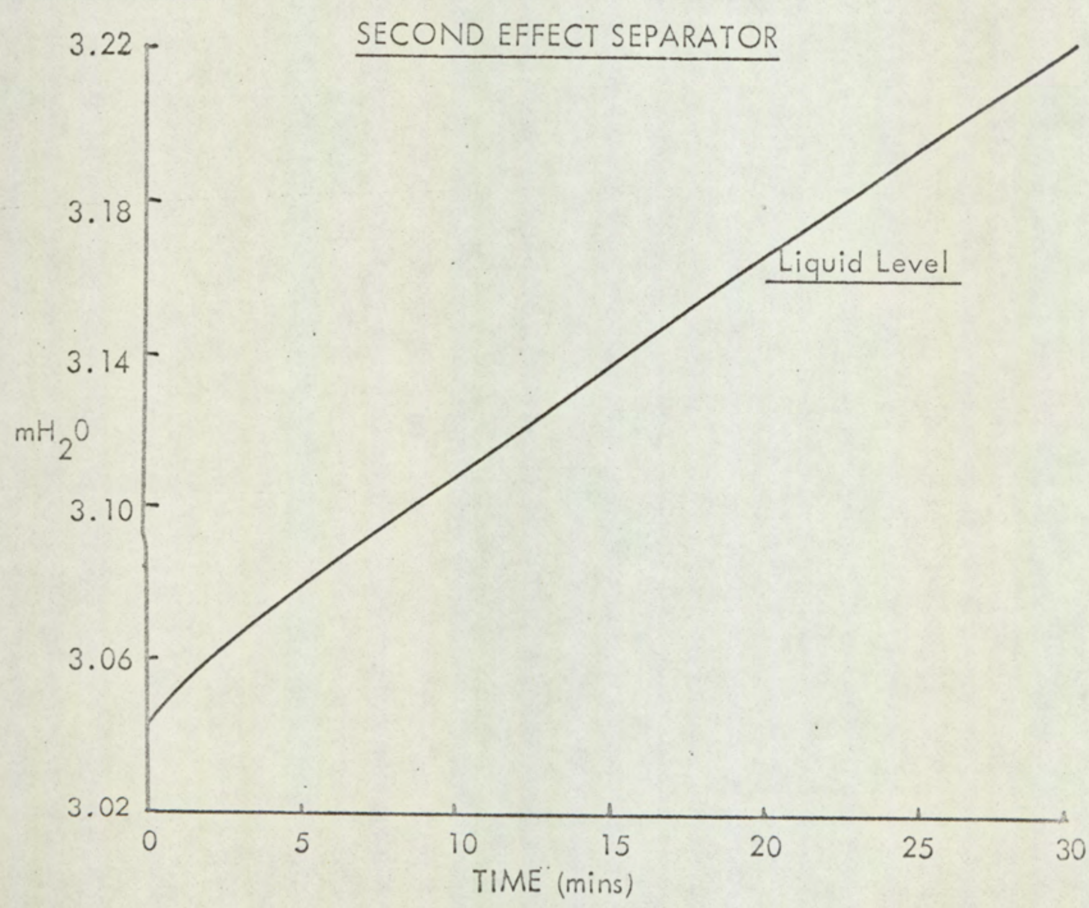


Figure A7.29

TIME 0 SECS

		DERIVATIVE
PREHEATER		
TEMPS		
L TUBES	40.65	0
LV SHELL	45.75	0
FLOWS		
L SHELL	1.267	-22.7116
V SHELL	12.73	455.916
V FRAC	.999993	0
HTC	607.367	
FIRST EFFECT		
TEMPS		
LV TUBES	47.9	923.523
FLOWS		
L TUBES	13.01	-433.204
V TUBES	14.047	433.204
V FRAC	.99993	.230145E-02
HTC	1397.33	
2ND EFFECT		
TEMPS		
L TUBES	36.12	0
LV SHELL	46.97	0
FLOWS		
L SHELL	12.647	0
V SHELL	1.4	433.204
V FRAC	.999346	0
HTC	2122.13	
2ND SEPARATOR		
HEAD	2.7	.224616E-04
TEMP	34.33	0
V RATE	11.55	10.6212
CONDENSER		
L TEMP	20.6	0
HTC	1231.03	

Figure A7.30

```
TIME     .999999E-01 SECS

                                          DERIVATIVE

PREHEATER
 TEMPS
   L TUBES    40.6571              .352076E-01
  LV SHELL    45.7207             -.592363E-01
 FLOWS
   L SHELL      .330513           -.393665E-01
   V SHELL    20.2346               1.17691
   V FRAC       .999992           -.172503E-06
 HTC         643.059

FIRST EFFECT
 TEMPS
  LV TUBES    62.0303               2.07971
 FLOWS
   L TUBES     5.99132             -1.03755
   V TUBES    21.0651               1.03755
   V FRAC       .999973            .301719E-05
 HTC        1557.53

2ND EFFECT
 TEMPS
   L TUBES    36.1609                .254375
  LV SHELL    43.0904             -71.2273
 FLOWS
   L SHELL     9.06633            -75.3404
   V SHELL    11.9933              76.923
   V FRAC       .999334           -.195631E-03
 HTC        3661.71

2ND SEPARATOR
     HEAD      2.69999            -.337343E-04
     TEMP     34.33               -.136599E-05
   V RATE     11.7596               1.33109

CONDENSER
   L TEMP     20.6677               1.00971
 HTC        1942.44
```

Figure A7.31

TIME .2 SECS

		DERIVATIVE
PREHEATER		
TEMPS		
L TUBES	40.6656	.349442E-01
LV SHELL	45.7137	-.353055E-01
FLOWS		
L SHELL	.32736	-.16073E-01
V SHELL	20.2546	.763137E-02
V FRAC	.999991	-.249643E-06
HTC	643.472	
FIRST EFFECT		
TEMPS		
LV TUBES	62.0642	-.329593E-02
FLOWS		
L TUBES	5.97444	.344661E-02
V TUBES	21.0325	-.344661E-02
V FRAC	.999978	-.479523E-07
HTC	1557.96	
2ND EFFECT		
TEMPS		
L TUBES	36.0504	-3.53564
LV SHELL	32.4375	-124.067
FLOWS		
L SHELL	-6.44571	-231.904
V SHELL	27.5232	231.395
V FRAC	.999303	-.261675E-03
HTC	6706.76	
2ND SEPARATOR		
HEAD	2.69993	-.79579E-04
TEMP	34.33	-.21637E-05
V RATE	11.1471	-19.3592
CONDENSER		
L TEMP	20.8257	2.37752
HTC	2357.33	

Figure A7.32

```
TIME          0  SECS

                                        DERIVATIVE

PREHEATER
 TEMPS
   L TUBES     40.65                    0
  LV SHELL     45.75                    0
 FLOWS
   L SHELL      1.267                   0
   V SHELL     12.73                    0
   V FRAC        .999993                0
 HTC          607.367

FIRST EFFECT
 TEMPS
  LV TUBES     47.9                     0
 FLOWS
   L TUBES     13.01                    0
   V TUBES     14.047                   0
   V FRAC        .99993                 0
 HTC          393.303

2ND EFFECT
 TEMPS
   L TUBES     36.12                    0
  LV SHELL     46.97                    0
 FLOWS
   L SHELL     12.647                   0
   V SHELL      1.4                     0
   V FRAC        .999346                0
 HTC         2122.13

2ND SEPARATOR
      HEAD      2.7                    .224616E-04
       TEMP    34.33                    0
    V RATE     11.55                    0

CONDENSER
   L TEMP      20.6                     0
 HTC         1231.03
```

Figure A7.33

TIME .999999E-01 SECS

		DERIVATIVE
PREHEATER		
TEMPS		
L TUBES	40.6501	.117545E-02
LV SHELL	45.7461	-.535445E-01
FLOWS		
L SHELL	1.25397	-.167156E-01
V SHELL	12.8362	.140532
V FRAC	.999992	-.17053E-06
HTC	603.535	
FIRST EFFECT		
TEMPS		
LV TUBES	43.206	.335563
FLOWS		
L TUBES	12.9118	-.123367
V TUBES	14.1452	.123367
V FRAC	.999931	.116939E-05
HTC	907.532	
2ND EFFECT		
TEMPS		
L TUBES	36.1206	.880314E-02
LV SHELL	46.929	-.316315
FLOWS		
L SHELL	12.6213	-.512766
V SHELL	1.52337	.636633
V FRAC	.999345	-.242805E-05
HTC	2139.43	
2ND SEPARATOR		
HEAD	2.7	.203233E-04
TEMP	34.33	-.234416E-06
V RATE	11.553	.544231E-01
CONDENSER		
L TEMP	20.6008	.123525E-01
HTC	1289.1	

Figure A7.34

```
TIME          .2 SECS

                                         DERIVATIVE

PREHEATER
 TEMPS
   L TUBES    40.6502              .230332E-02
  LV SHELL    45.7354                -.137363
 FLOWS
   L SHELL     1.24992             -.263162E-01
   V SHELL    12.9961                 .149443
   V FRAC       .999991            -.399801E-06
 HTC         609.41

FIRST EFFECT
 TEMPS
  LV TUBES    48.5176                 .379991
 FLOWS
   L TUBES    12.8109                -.123132
   V TUBES    14.246                  .123132
   V FRAC      .999931             .115323E-05
 HTC         916.917

2ND EFFECT
 TEMPS
   L TUBES    36.1222              .204222E-01
  LV SHELL    46.733                 -3.43417
 FLOWS
   L SHELL    12.4967                -2.20457
   V SHELL     1.74935                2.3277
   V FRAC       .999344            -.10175E-04
 HTC        2190.57

2ND SEPARATOR
     HEAD      2.7                 .190693E-04
     TEMP     34.33               -.653392E-06
   V RATE     11.5714                 .118516

CONDENSER
   L TEMP     20.6032              .344964E-01
 HTC        1303.75
```

Figure A7.35

```
TIME          .3 SECS

                                             DERIVATIVE

PREHEATER
 TEMPS
   L TUBES     40.6505                   .331105E-02
  LV SHELL     45.7157                     -.241317
 FLOWS
   L SHELL      1.23985                 -.337694E-01
   V SHELL     13.1061                       .157675
   V FRAC        .99999                 -.702E-06
 HTC          610.538

FIRST EFFECT
 TEMPS
  LV TUBES     43.8236                       .363355
 FLOWS
   L TUBES     12.7109                     -.113906
   V TUBES     14.346                        .113906
   V FRAC        .999932                 .110362E-05
 HTC          926.191

2ND EFFECT
 TEMPS
   L TUBES     36.1251                   .335922E-01
  LV SHELL     46.0437                   -11.5345
 FLOWS
   L SHELL     12.0418                     -7.94432
   V SHELL      2.30414                     8.06373
   V FRAC        .999341                -.333549E-04
 HTC         2349

2ND SEPARATOR
     HEAD       2.7                      .172151E-04
     TEMP      34.33                    -.10021E-05
   V RATE      11.592                        .191032

CONDENSER
   L TEMP      20.6091                   .377932E-01
 HTC         1339.03
```

Figure A7.36

TIME .4 SECS

		DERIVATIVE
PREHEATER		
TEMPS		
L TUBES	40.6509	.415979E-02
LV SHELL	45.634	-.379334
FLOWS		
L SHELL	1.22338	-.555022E-01
V SHELL	13.2166	.170339
V FRAC	.999939	-.110275E-05
HTC	611.997	
FIRST EFFECT		
TEMPS		
LV TUBES	49.124	.343625
FLOWS		
L TUBES	12.6119	-.114336
V TUBES	14.445	.114336
V FRAC	.999932	.105612E-05
HTC	935.4	
2ND EFFECT		
TEMPS		
L TUBES	36.127	-.339326E-01
LV SHELL	43.9054	-34.3459
FLOWS		
L SHELL	10.4254	-23.6394
V SHELL	4.01952	23.7542
V FRAC	.999334	-.974155E-04
HTC	2342.69	
2ND SEPARATOR		
HEAD	2.7	.15461E-04
TEMP	34.33	-.149651E-05
V RATE	11.607	-.13354
CONDENSER		
L TEMP	20.6245	.243514
HTC	1445.07	

Figure A7.37

TIME .5 SECS

		DERIVATIVE
PREHEATER		
TEMPS		
L TUBES	40.6513	.479309E-02
LV SHELL	45.6364	-.56337
FLOWS		
L SHELL	1.21503	-.730733E-01
V SHELL	13.323	.138922
V FRAC	.999933	-.163646E-05
HTC	613.903	
FIRST EFFECT		
TEMPS		
LV TUBES	49.419	.333577
FLOWS		
L TUBES	12.5139	-.110344
V TUBES	14.543	.110344
V FRAC	.999933	.100354E-05
HTC	944.547	
2ND EFFECT		
TEMPS		
L TUBES	36.0923	-.976593
LV SHELL	33.2523	-79.392
FLOWS		
L SHELL	4.71475	-96.1596
V SHELL	9.32323	96.2704
V FRAC	.999319	-.196456E-03
HTC	4251.73	
2ND SEPARATOR		
HEAD	2.7	.1635E-04
TEMP	34.33	-.179421E-05
V RATE	11.4137	-5.40463
CONDENSER		
L TEMP	20.6709	.770593
HTC	1739.37	

Figure A7.38

```
TIME          .599999 SECS

                                        DERIVATIVE

PREHEATER
 TEMPS
   L TUBES    40.6518              .512593E-02
  LV SHELL    45.5674                 -.310616
 FLOWS
   L SHELL     1.1991                 -.103531
   V SHELL    13.441                   .215431
   V FRAC       .999936           -.234391E-05
 HTC         616.405

FIRST EFFECT
 TEMPS
  LV TUBES    49.7037                  .319054
 FLOWS
   L TUBES    12.4163                  -.1069
   V TUBES    14.6401                   .1069
   V FRAC       .999933            .961939E-06
 HTC         953.635

2ND EFFECT
 TEMPS
   L TUBES    35.327                  -4.73163
  LV SHELL    29.6352                -72.0257
 FLOWS
   L SHELL    -3.27616              -131.534
   V SHELL    22.9162                131.691
   V FRAC       .999299           -.139331E-03
 HTC        6737.77

2ND SEPARATOR
      HEAD     2.7                 .373966E-04
      TEMP    34.33               -.217964E-05
   V RATE      9.9535                -26.2026

CONDENSER
   L TEMP     20.8001                 1.33632
 HTC        2502.44
```

Figure A7.39

```
TIME        Ø  SECS

                                DERIVATIVE

PREHEATER
 TEMPS
   L TUBES    40.65               -.624936
  LV SHELL    45.75               Ø
 FLOWS
   L SHELL     1.267               .648872
   V SHELL    12.78              -3.63228
   V FRAC       .999993           Ø
 HTC         607.367

FIRST EFFECT
 TEMPS
  LV TUBES    47.9               -25.158
 FLOWS
   L TUBES    13.01               7.98341
   V TUBES    14.047             -7.98341
   V FRAC       .99993          -.763148E-04
 HTC         398.308

2ND EFFECT
 TEMPS
   L TUBES    36.12               Ø
  LV SHELL    46.97               Ø
 FLOWS
   L SHELL    12.647              Ø
   V SHELL     1.4               -7.98341
   V FRAC       .999346           Ø
 HTC        2122.13

2ND SEPARATOR
     HEAD      2.7              .224616E-04
     TEMP     34.33               Ø
   V RATE     11.55              -.378999

CONDENSER
   L TEMP     20.6                Ø
 HTC        1281.03
```

Figure A7.40

```
TIME     .999999E-01 SECS

                                          DERIVATIVE

PREHEATER
 TEMPS
   L TUBES     40.6324                    -.255303
  LV SHELL     42.6239                   -37.4193
 FLOWS
   L SHELL       .783493                  -6.36646
   V SHELL     12.7529                     5.33337
   V FRAC        .999984                 -.101842E-03
 HTC          934.622

FIRST EFFECT
 TEMPS
  LV TUBES     46.4125                    -1.63401
 FLOWS
   L TUBES     13.5156                     .533333
   V TUBES     13.5414                    -.533333
   V FRAC        .999312                 -.62463E-02
 HTC          862.797

2ND EFFECT
 TEMPS
   L TUBES     36.1155                   -.852904E-01
  LV SHELL     47.8163                    20.6993
 FLOWS
   L SHELL     13.2163                    12.4353
   V SHELL       .324605                 -12.9637
   V FRAC        .999343                 .62651E-04
 HTC         1392.73

2ND SEPARATOR
      HEAD      2.7                      .309714E-04
      TEMP     34.33                     -.26531E-06
    V RATE     11.5025                    -.499459

CONDENSER
    L TEMP     20.5944                    -.105453
 HTC         1212.35
```

Figure A7.41

```
TIME          .2 SECS

                                        DERIVATIVE

PREHEATER
 TEMPS
   L TUBES     40.5923                     -.585323
  LV SHELL     38.1778                  -52.2964
 FLOWS
   L SHELL-.137413E-01                   -9.92552
   V SHELL     13.5399                    9.92538
   V FRAC         .999972              -.128447E-03
 HTC         1060.84

FIRST EFFECT
 TEMPS
  LV TUBES     46.3583                     -.136717
 FLOWS
   L TUBES     13.5308                  .145889E-03
   V TUBES     13.5261                 -.145889E-03
   V FRAC         .998637              -.62419E-02
 HTC          862.181

2ND EFFECT
 TEMPS
   L TUBES     36.0875                     -.737137
  LV SHELL     52.8537                   97.467
 FLOWS
   L SHELL     15.4089                   23.1111
   V SHELL     -1.88279                 -28.1113
   V FRAC         .999364              .323863E-03
 HTC          886.224

2ND SEPARATOR
      HEAD      2.7                    .336073E-04
      TEMP     34.33                  -.588731E-06
    V RATE     11.3463                   -4.08591

CONDENSER
   L TEMP      20.5744                    -.325631
 HTC         1067.55
```

Figure A7.42

TIME 0 SECS

		DERIVATIVE
PREHEATER		
TEMPS		
L TUBES	40.65	0
LV SHELL	45.75	0
FLOWS		
L SHELL	1.267	0
V SHELL	12.78	0
V FRAC	.999993	0
HTC	607.867	
FIRST EFFECT		
TEMPS		
LV TUBES	47.9	0
FLOWS		
L TUBES	13.01	0
V TUBES	14.047	0
V FRAC	.99993	0
HTC	898.303	
2ND EFFECT		
TEMPS		
L TUBES	36.12	0
LV SHELL	46.97	0
FLOWS		
L SHELL	12.647	0
V SHELL	1.4	0
V FRAC	.999346	0
HTC	2122.13	
2ND SEPARATOR		
HEAD	2.7	.224616E-04
TEMP	34.33	0
V RATE	11.55	0
CONDENSER		
L TEMP	20.6	0
HTC	1281.03	

Figure A7.43

```
TIME     .999999E-Ø1 SECS

                                         DERIVATIVE

PREHEATER
 TEMPS
   L TUBES     4Ø.6499             -.76312E-Ø3
  LV SHELL     45.733                 -.199735
 FLOWS
   L SHELL      1.26517            -.233952E-Ø1
   V SHELL     12.7738              .19635E-Ø1
   V FRAC        .999992           -.53Ø364E-Ø6
 HTC          6Ø9.673

FIRST EFFECT
 TEMPS
  LV TUBES     47.89Ø4             -.13323E-Ø1
 FLOWS
   L TUBES     13.Ø13               .421Ø17E-Ø2
   V TUBES     14.Ø44              -.421Ø17E-Ø2
   V FRAC        .999927           -.343317E-Ø4
 HTC          898.Ø96

2ND EFFECT
 TEMPS
   L TUBES     36.1199             -.298733E-Ø3
  LV SHELL     46.9738              .917969E-Ø1
 FLOWS
   L SHELL     12.6498              .62Ø44E-Ø1
   V SHELL      1.39416            -.662542E-Ø1
   V FRAC        .999346            .273415E-Ø6
 HTC         2121.Ø1

2ND SEPARATOR
     HEAD       2.7                 .225119E-Ø4
     TEMP      34.33               -.515671E-Ø6
   V RATE      11.5497             -.13531E-Ø2

CONDENSER
  L TEMP       2Ø.5999             -.566449E-Ø3
 HTC         128Ø.66
```

Figure A7.44

TIME .2 SECS

		DERIVATIVE
PREHEATER		
TEMPS		
L TUBES	40.6497	-.179362E-02
LV SHELL	45.6926	-.470696
FLOWS		
L SHELL	1.26051	-.569537E-01
V SHELL	12.7803	.530366E-01
V FRAC	.999991	-.136677E-05
HTC	612.135	
FIRST EFFECT		
TEMPS		
LV TUBES	47.8305	-.1256E-01
FLOWS		
L TUBES	13.0162	.391716E-02
V TUBES	14.0408	-.391716E-02
V FRAC	.99992	-.696207E-04
HTC	897.879	
2ND EFFECT		
TEMPS		
L TUBES	36.1198	-.133157E-02
LV SHELL	46.9987	.431506
FLOWS		
L SHELL	12.6663	.310394
V SHELL	1.37452	-.314311
V FRAC	.999346	.143457E-05
HTC	2115.29	
2ND SEPARATOR		
HEAD	2.7	.225692E-04
TEMP	34.33	-.337301E-06
V RATE	11.5492	-.756147E-02
CONDENSER		
L TEMP	20.5998	-.24521E-02
HTC	1279.42	

Figure A7.45

TIME .3 SECS

		DERIVATIVE
PREHEATER		
TEMPS		
L TUBES	40.6494	-.323509E-02
LV SHELL	45.6206	-.333229
FLOWS		
L SHELL	1.25197	-.102117
V SHELL	12.7357	.935135E-01
V FRAC	.99999	-.243067E-05
HTC	615.437	
FIRST EFFECT		
TEMPS		
LV TUBES	47.8706	-.117746E-01
FLOWS		
L TUBES	13.0193	.359384E-02
V TUBES	14.0377	-.359384E-02
V FRAC	.999909	-.10441E-03
HTC	897.663	
2ND EFFECT		
TEMPS		
L TUBES	36.1195	-.505377E-02
LV SHELL	47.1027	1.36739
FLOWS		
L SHELL	12.7323	1.16739
V SHELL	1.3054	-1.17149
V FRAC	.999346	.557526E-05
HTC	2092.53	
2ND SEPARATOR		
HEAD	2.7	.226439E-04
TEMP	34.33	-.114032E-05
V RATE	11.5474	-.281932E-01
CONDENSER		
L TEMP	20.5992	-.906376E-02
HTC	1275.03	

Figure A7.46

TIME	.4 SECS	
		DERIVATIVE
PREHEATER		
TEMPS		
L TUBES	40.6439	-.527392E-02
LV SHELL	45.5056	-1.33653
FLOWS		
L SHELL	1.23311	-.163956
V SHELL	12.7964	.160709
V FRAC	.999933	-.336631E-05
HTC	620.049	
FIRST EFFECT		
TEMPS		
LV TUBES	47.3607	-.109767E-01
FLOWS		
L TUBES	13.0224	.324661E-02
V TUBES	14.0346	-.324661E-02
V FRAC	.999395	-.139199E-03
HTC	897.447	
2ND EFFECT		
TEMPS		
L TUBES	36.1134	-.203937E-01
LV SHELL	47.4735	6.57135
FLOWS		
L SHELL	12.9617	3.92193
V SHELL	1.07233	-3.92513
V FRAC	.999346	.19761E-04
HTC	2011.75	
2ND SEPARATOR		
HEAD	2.7	.227372E-04
TEMP	34.33	-.153372E-05
V RATE	11.5412	-.113116
CONDENSER		
L TEMP	20.5974	-.313372E-01
HTC	1263.45	

Figure A7.47

```
TIME          .5 SECS

                                   DERIVATIVE

PREHEATER
 TEMPS
   L TUBES    40.6482          -.326419E-02
  LV SHELL    45.3324            -2.01135
 FLOWS
   L SHELL     1.21693            -.243705
   V SHELL    12.3145              .24474
   V FRAC       .999987        -.579707E-05
 HTC         626.243

FIRST EFFECT
 TEMPS
  LV TUBES    47.3509          -.136785E-01
 FLOWS
   L TUBES    13.0254           .396454E-02
   V TUBES    14.0315          -.396454E-02
   V FRAC       .999377        -.173998E-03
 HTC         897.232

2ND EFFECT
 TEMPS
   L TUBES    36.1133             -.10409
  LV SHELL    43.7804            22.7731
 FLOWS
   L SHELL    13.6367            11.7951
   V SHELL      .344793         -11.7991
   V FRAC       .99935          .70221E-04
 HTC        1733.49

2ND SEPARATOR
      HEAD     2.7              .232636E-04
      TEMP    34.33            -.13394E-05
   V RATE     11.5133             -.576719

CONDENSER
   L TEMP     20.5914             -.101305
 HTC        1214.15

25 BREAK
```

FIGURE A7.48

Dynamic Log Output for Simulation of Reduced Model

12

97.5126	97.8158	97.7266	97.7803	97.8868
97.6708	97.7367	97.7844	97.8391	97.7701
97.4943	97.7691	97.618	97.545	97.6961
97.7103	97.8929	97.8827	97.7701	97.8483
97.8878	97.8401	97.6992	97.7752	97.757
97.8249	97.8259	97.9324	97.6657	97.9628

13

99.7705	99.8223	99.7944	99.7665	99.8103
99.8103	99.7904	99.8064	99.7944	99.8263
99.7904	99.7744	99.7744	99.8462	99.7545
99.7984	99.8382	99.7665	99.8422	99.8303
99.8103	99.7585	99.8223	99.7864	99.7784
99.7904	99.8303	99.8183	99.7824	99.8064

14

7.42129	7.45666	7.42401	7.41313	7.34871
7.34691	7.44034	7.41313	7.52107	7.42763
7.45395	7.53467	7.44669	7.41766	7.45485
7.50655	7.39679	7.4857	7.48207	7.35779
7.42129	7.36142	7.52742	7.40042	7.43762
7.41856	7.46664	7.45848	7.44669	7.48207

15

12.0563	12.1919	12.2158	15.6127	15.6526
12.2756	12.3274	12.3793	12.3992	12.4231
12.4789	12.4949	12.4949	12.5268	12.5587
12.6025	22.6976	15.9676	12.6185	12.6344
12.6743	12.6823	12.774	12.8298	12.8936
12.7979	12.8457	12.8138	12.8497	16.2347

16

41.3658	41.1344	41.0315	41.0122	41.0122
41.0315	41.0315	41.0315	41.0315	41.0315
41.0315	41.0315	41.0315	41.0315	41.0315
41.0315	40.9383	41.0026	41.0315	41.0315
41.0315	40.9929	40.9801	40.9415	40.8515
40.7936	40.7679	40.7132	40.6586	40.6007

17

9.71921	9.7096	9.69357	9.40434	9.16438
6.24483	6.27248	6.26967	6.27288	3.32603
2.58618	2.32499	2.23446	2.15153	2.12469
2.10546	2.08303	2.03055	2.01413	1.9935
1.98048	1.96486	1.95244	1.93481	1.93
1.91598	1.90116	1.89996	1.88474	1.87392

FIGURE A7.48 cont/...

18

3.01354	3.01323	3.00897	3.00669	3.01088
3.0021	2.99759	2.99573	2.98835	2.99016
2.98378	2.97863	2.98278	2.97538	2.97085
2.9673	2.96865	2.95935	2.95621	2.95755
2.95165	2.95075	2.94247	2.94317	2.93875
2.9373	2.93073	2.92735	2.92654	2.92125

19

-6941.69	-6946.92	-6931.31	-6928.77	-6928.61
-6922.23	-6924.92	-6928.69	-6929.61	-6935.77
-6945.08	-6956.23	-6957.92	-6961.61	-6981.77
-6986.54	-6992.08	-6986.31	-6986.46	-6992.61
-6997.46	-7006.54	-7063.85	-7096.85	-7101.46
-7035.08	-7037.69	-7027.08	-7046.54	-7046.61

20

11.0808	11.075	11.074	11.0731	11.0846
11.0885	11.1125	11.1394	11.1452	11.1461
10.2865	10.2875	11.1154	11.1337	9.85481
10.7202	11.1587	11.1615	11.1577	11.1471
11.1442	11.1269	11.124	11.1471	11.1423
11.1327	11.1394	11.1404	11.1452	11.1538

21

19.8327	19.8654	19.7846	19.7692	19.8635
19.4346	19.5558	19.4692	19.7096	19.8731
20.0211	20.0173	20.1692	19.9096	20.0327
20.1615	20.1635	20.0673	20.1827	20.0346
20.0904	20.1096	20.1404	20.225	20.2615
20.1711	20.0731	20.2346	20.3423	20.1596

22

14.4923	14.5808	14.6298	14.6894	14.774
14.8413	14.9154	14.9625	14.9894	15.0188
15.0644	15.074	15.0981	15.099	15.1058
15.1423	15.1346	15.1596	15.1798	15.1962
15.2202	15.2317	15.2288	15.225	15.2327
15.2317	15.2423	15.2788	15.2913	15.2913

23

41.3154	41.5077	41.8423	42.1654	42.4384
42.6673	42.8538	42.9961	43.1423	43.2615
43.3808	43.4942	43.6288	43.7077	43.75
43.8057	43.8288	43.8827	43.9288	43.9731
44.0135	44.1	44.1865	44.2481	44.3134
44.3962	44.45	44.4731	44.5154	44.5404

FIGURE A7.48 cont/...

24

34.1663	34.1808	34.2048	34.2731	34.3077
34.4173	34.5606	34.6548	34.7586	34.7971
34.8298	34.8692	34.8577	34.8788	34.9404
34.975	34.9529	34.9933	35.0154	35.0058
35.0654	35.1058	35.1529	35.1538	35.1817
35.2106	35.2769	35.3317	35.3183	35.3317

25

35.8942	35.9327	35.9635	36.0385	36.0808
36.175	36.3269	36.4346	36.5365	36.5827
36.6385	36.6654	36.6577	36.6769	36.7596
36.8154	36.7981	36.8365	36.8738	36.875
36.9173	36.9404	37.0019	37.0192	37.0692
37.0961	37.1442	37.1981	37.1885	37.1923

26

47.2481	47.1567	47.0644	46.9433	46.8211
46.6423	46.4865	46.3327	46.2125	46.1635
46.1269	46.0413	45.9885	45.9202	45.8923
45.8346	45.8115	45.8115	45.7586	45.7067
45.6913	45.6817	45.6856	45.6644	45.6029
45.5865	45.5471	45.5144	45.4567	45.4125

27

21.4519	21.45	21.4615	21.45	21.4558
21.4423	21.3711	21.3558	21.3288	21.4096
21.5058	21.5481	21.6461	21.6923	21.7058
21.7692	21.9058	21.9365	21.9769	22.0423
22.0442	22.0481	22.0269	22.0711	22.1154
22.1538	22.1538	22.1961	22.2423	22.2788

28

44.3509	44.4894	44.6433	44.7029	44.7663
44.8442	44.9135	44.9606	45.0365	45.0711
45.1634	45.2519	45.2673	45.3096	45.451
45.5423	45.5769	45.6144	45.7106	45.7683
45.8298	45.8875	45.925	46.1106	46.2673
46.251	46.176	46.2596	46.2692	46.3308

29

45.6211	45.7519	45.8308	45.9461	46.0115
46.1173	46.1365	46.1884	46.2538	46.2904
46.3461	46.4461	46.6231	46.7923	46.9038
46.9154	46.9538	46.9538	46.9654	46.9827
47.0884	47.1558	47.2904	47.4769	47.5731
47.5058	47.4365	47.5154	47.5519	47.6615

FIGURE A7.49

Simulation of Reduced Model
Control Input Data

```
4ØØØ  REM  SIMULATION OF REDUCED MODEL.
4ØØ5  REM DATA FOR FUNCTION GENERATORS
4Ø1Ø  REM
4Ø15  REM  SAMPLE TIMES - ARRAY A
4Ø2Ø  REM
4Ø25  DATA Ø,3Ø,9Ø,15Ø,18Ø,21Ø,27Ø,33Ø,39Ø,45Ø,51Ø,57Ø,63Ø
4Ø3Ø  DATA 69Ø,75Ø,81Ø,87Ø,93Ø,99Ø,1Ø5Ø,111Ø,117Ø,123Ø
4Ø35  DATA 129Ø,135Ø,141Ø,147Ø,153Ø,159Ø,165Ø,171Ø,177Ø
4Ø4Ø  REM
4Ø45  REM  STEAM RATE ANALOGUE VALUE - ARRAY B
4Ø5Ø  REM
4Ø55  DATA 693Ø,6942,6947,6931,6924,6923,6922,6924,6923,6929
4Ø6Ø  DATA 6935,6945,6956,6957,6961,6931,6986,6992,6986,6986
4Ø65  DATA 6996,6997,7ØØ6,7Ø63,7Ø96,71Ø7,7Ø35,7Ø37,7Ø27,7Ø46
4Ø7Ø  DATA 7Ø64,
4Ø75  REM
4Ø8Ø  REM  PREHEATER SHELLSIDE VAPOUR TEMP -ARRAY C
4Ø85  REM
4Ø9Ø  DATA 44.41,44.35,44.43,44.64,44.7,44.76,44.84,44.91,44.96
4Ø95  DATA 44.Ø3,45.Ø7,45.16,45.25,45.26,45.31,45.45,45.54
41ØØ  DATA 45.57,45.61,45.71,45.77,45.83,45.9,45.93,46.11
41Ø5  DATA 46.26,46.25,46.17,46.26,46.27,46.33
411Ø  REM
4115  REM  FIRST EFFECT VAPOUR TEMP - ARRAY E
412Ø  REM
4125  DATA 46.68,45.62,45.75,45.83,45.94,46.Ø1,46.12,46.14,46.19
413Ø  DATA 46.25,46.29,46.34,46.45,46.62,46.8,46.9,46.91,46.95
4135  DATA 46.95,46.97,46.98,47.Ø4,47.16,47.29,47.48,47.57,47.51
414Ø  DATA 47.44,47.51,47.55,47.66
4145  REM
415Ø  REM  VACUUM TEMPERATURE - ARRAY F
4155  REM
416Ø  DATA 33.98,34.17,34.18,34.2,34.27,34.31,34.42,34.56,34.65
4165  DATA 34.76,34.8,34.83,34.87,34.86,34.88,34.94,34.975,34.95
417Ø  DATA 35,35.Ø2,35,35.Ø7,35.11,35.15,35.15,35.18,35.21
4175  DATA 35.28,35.33,35.32,35.33
418Ø  REM
4185  REM  2ND EFFECT SHELLSIDE VAPOUR TEMP - ARRAY G
419Ø  REM
42ØØ  DATA 49.49,49.54,49.76,49.8,54.83,54.88,49.899,49.98,5Ø.Ø6
42Ø5  DATA 5Ø.1,5Ø.14,5Ø.23,5Ø.26,5Ø.26,5Ø.31,5Ø.36,5Ø.43,5Ø.43
421Ø  DATA 5Ø.44,5Ø.45,5Ø.48,5Ø.54,5Ø.56,5Ø.7,5Ø.79,5Ø.99,5Ø.74
4215  DATA 5Ø.82,5Ø.76,5Ø.82,5Ø.82
422Ø  REM
4225  REM  LIQUID FEED TEMP - ARRAY H
423Ø  REM
4235  DATA 14.4,14.49,14.48,14.629,14.69,14.77,14.84,14.9,14.96
424Ø  DATA 14.99,15.Ø2,15.Ø6,15.Ø7,15.1,15.11,15.14,15.13,15.16
4245  DATA 15.16,15.18,15.2,15.55,15.23,15.23,15.22,15.23,15.23
425Ø  DATA 15.24,15.28,15.29,15.3
```

SIMULATION OF REDUCED MODEL

RESPONSE TO INCREASE IN STEAM FLOW RATE

FIGURE A7.50 - Preheater tubeside liquid temperatures

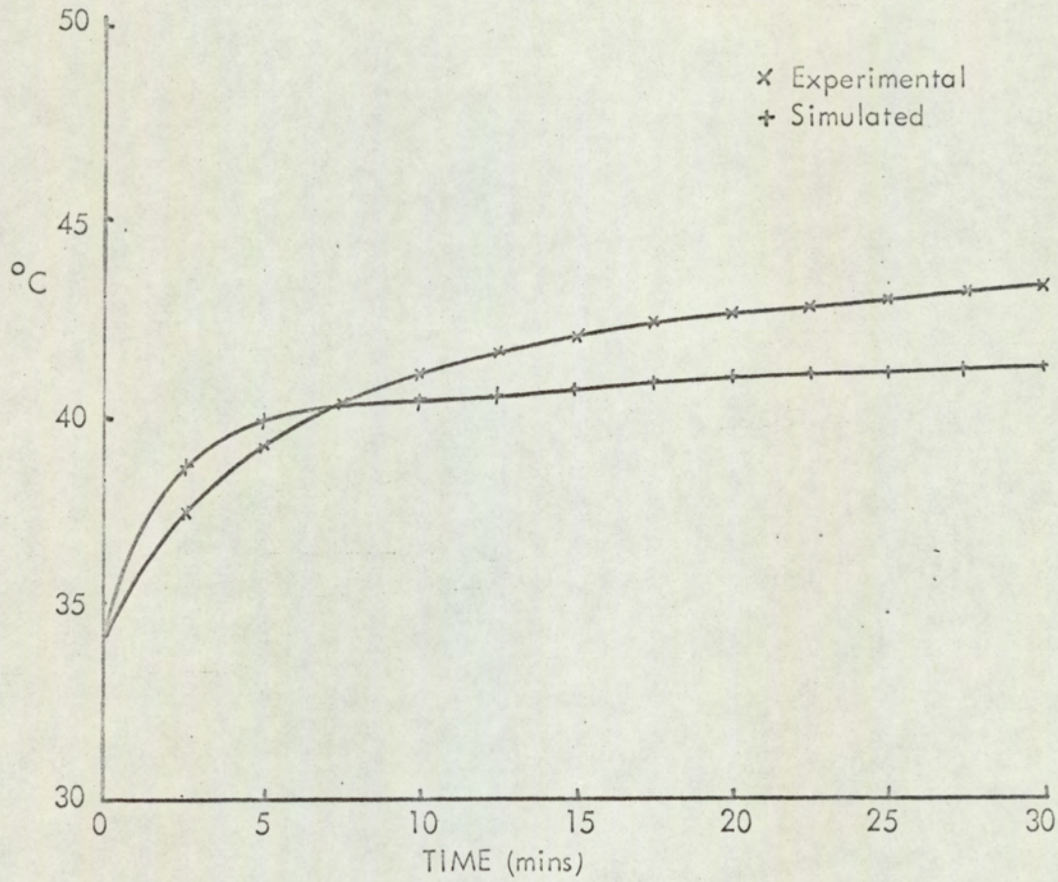
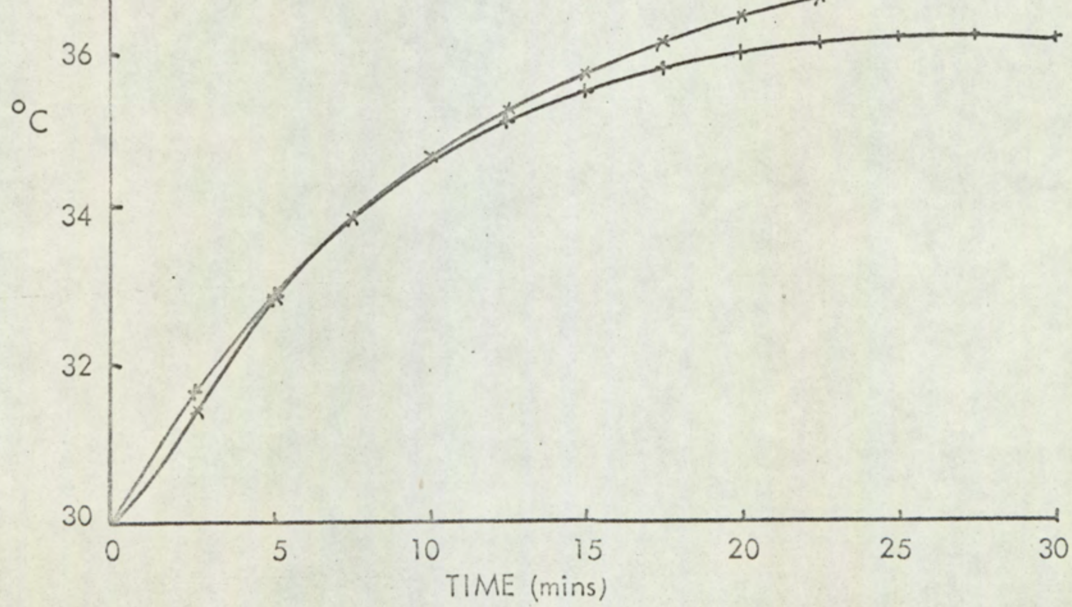
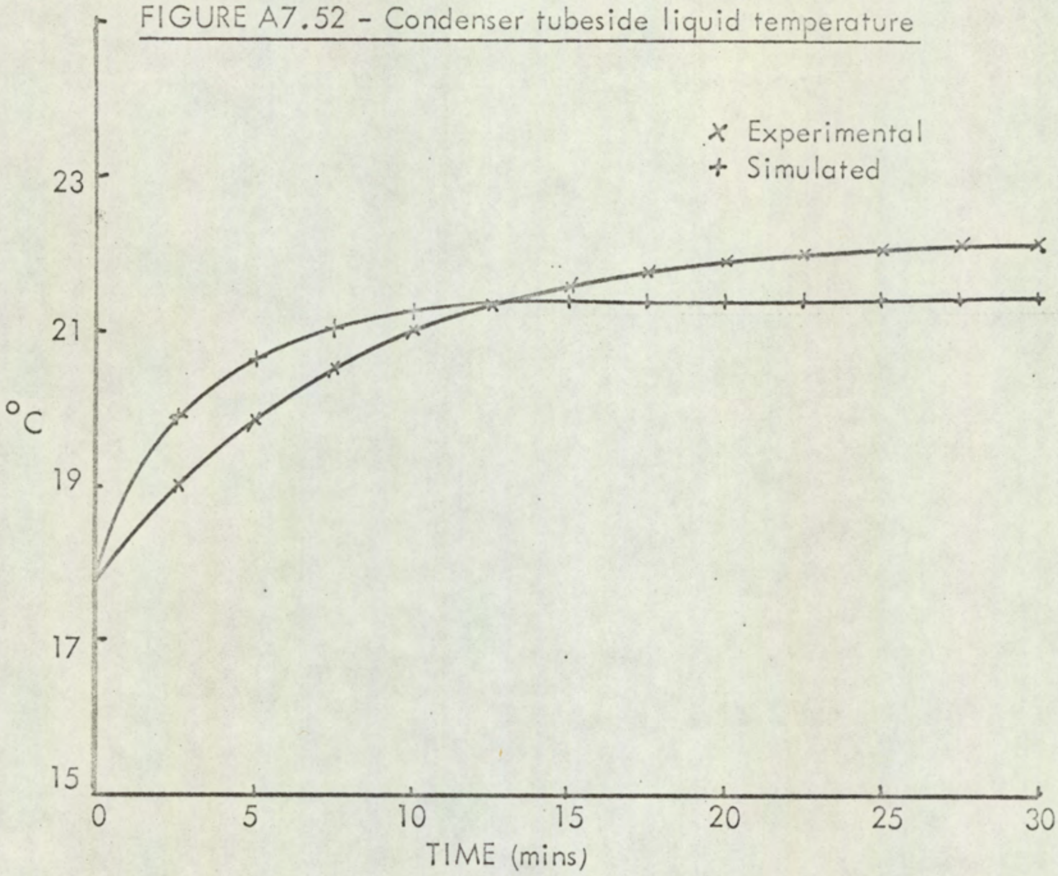


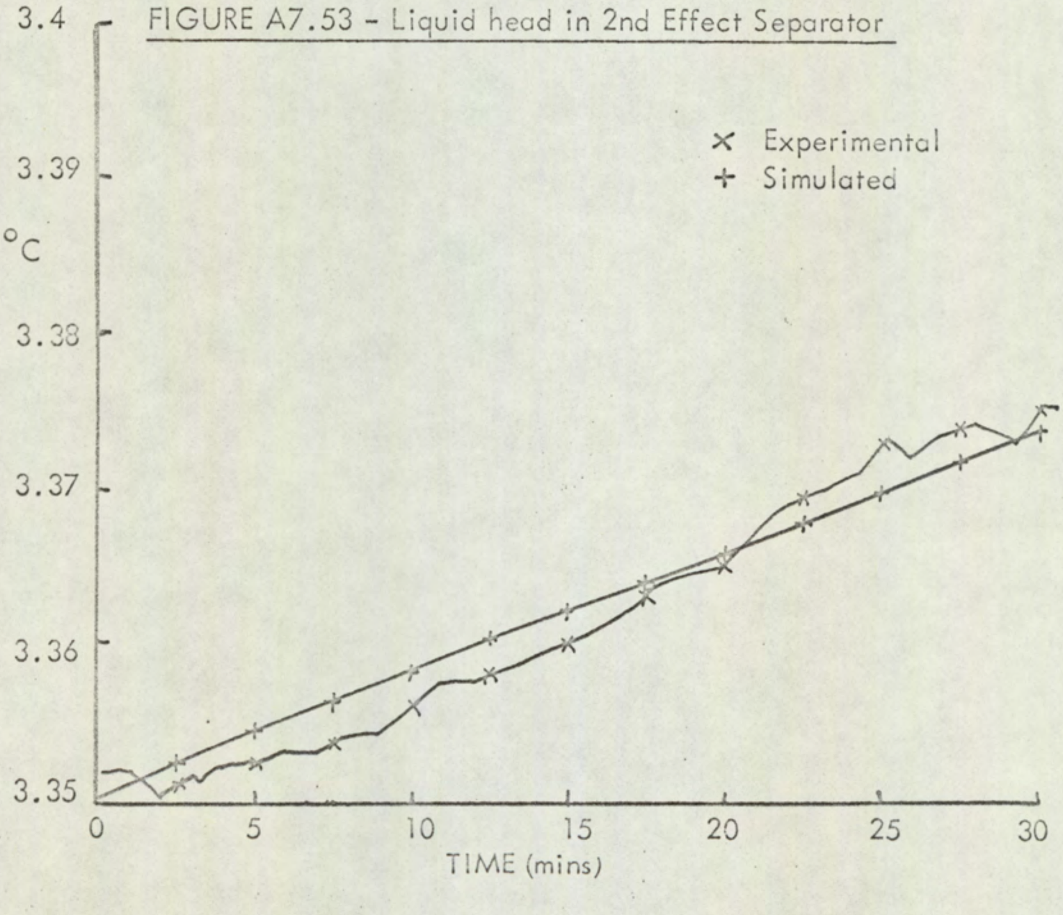
FIGURE A7.51 - Second Effect tubeside liquid temperature



SIMULATION OF REDUCED MODEL

RESPONSE TO INCREASE IN STEAM FLOW RATE





SIMULATION OF REDUCED MODEL

RESPONSE TO DECREASE IN STEAM FLOW RATE

FIGURE A7.54 - Preheater tubeside liquid temperature

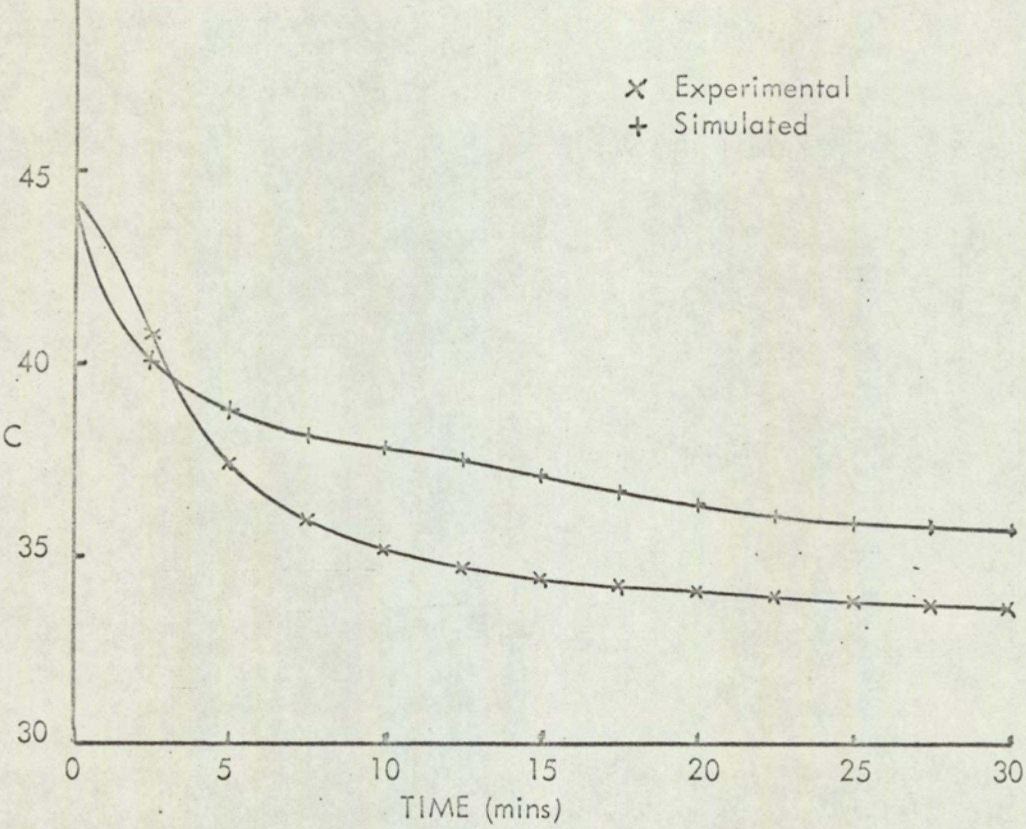
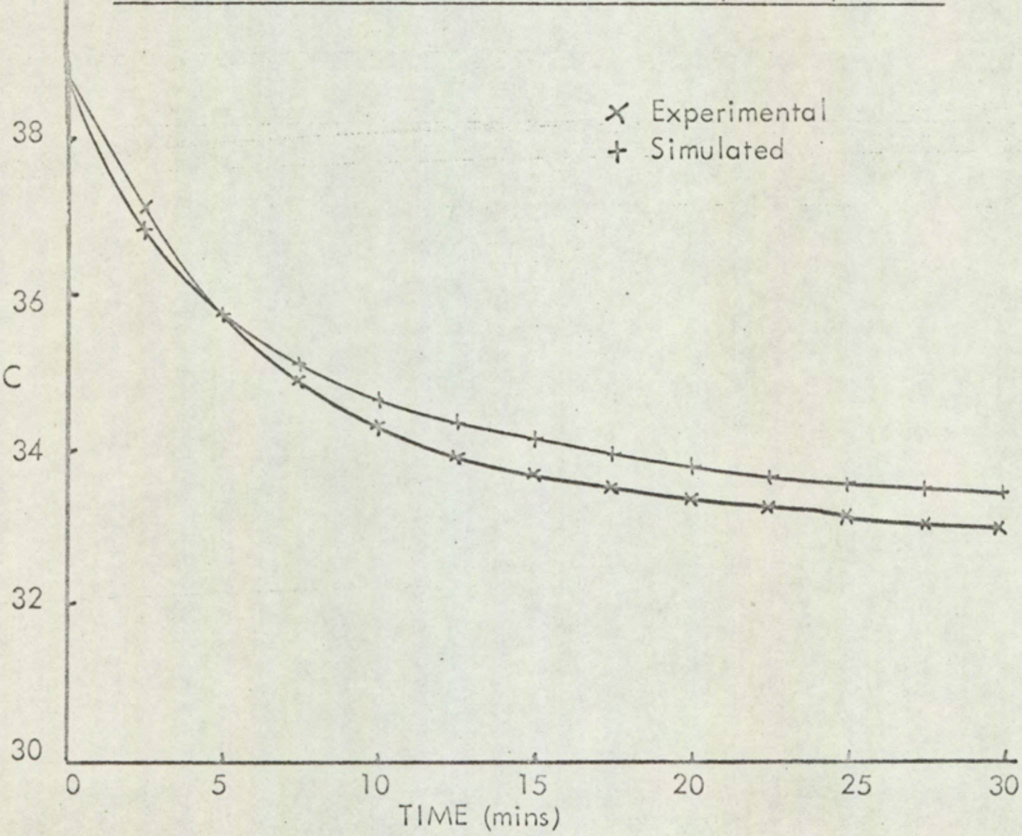


FIGURE A7.55 - Second Effect tubeside liquid temperature



SIMULATION OF REDUCED MODEL

RESPONSE TO DECREASE IN STEAM RATE

FIGURE A7.56 - Condenser tubeside liquid temperature

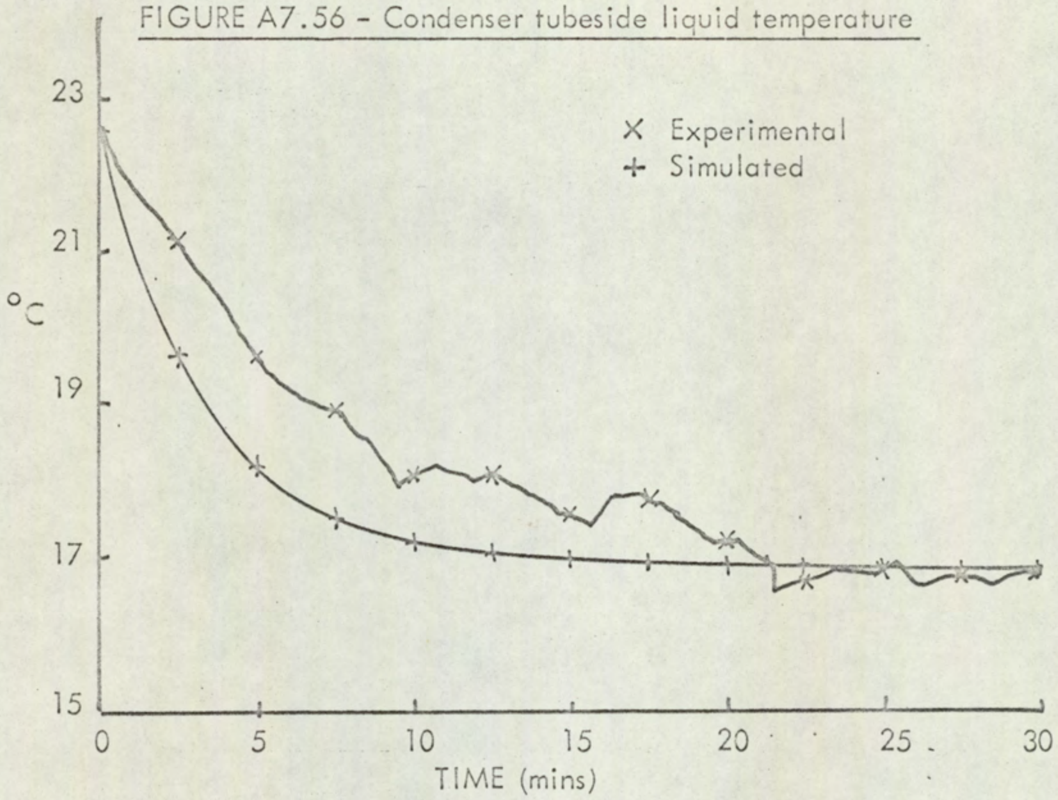
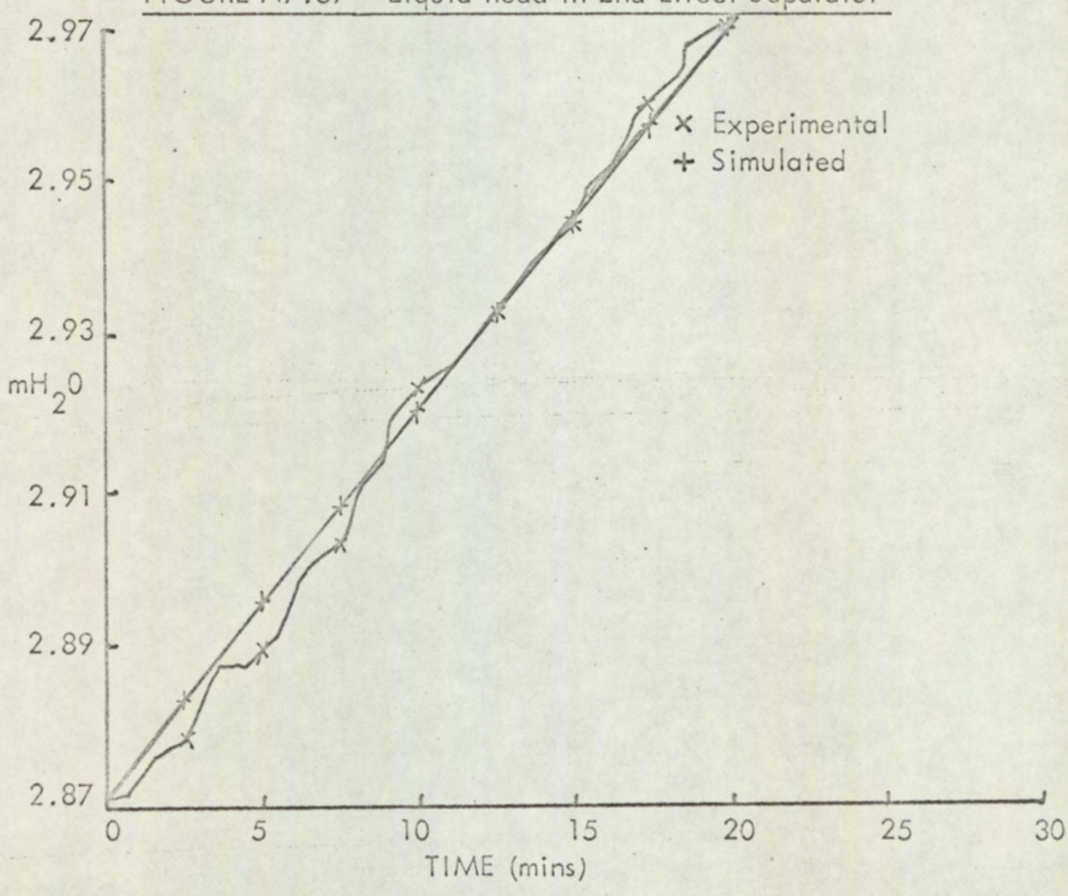


FIGURE A7.57 - Liquid head in 2nd Effect Separator



SIMULATION OF REDUCED MODEL

RESPONSE TO INCREASE IN FEED RATE

FIGURE A7.58 Preheater tubeside liquid temperature

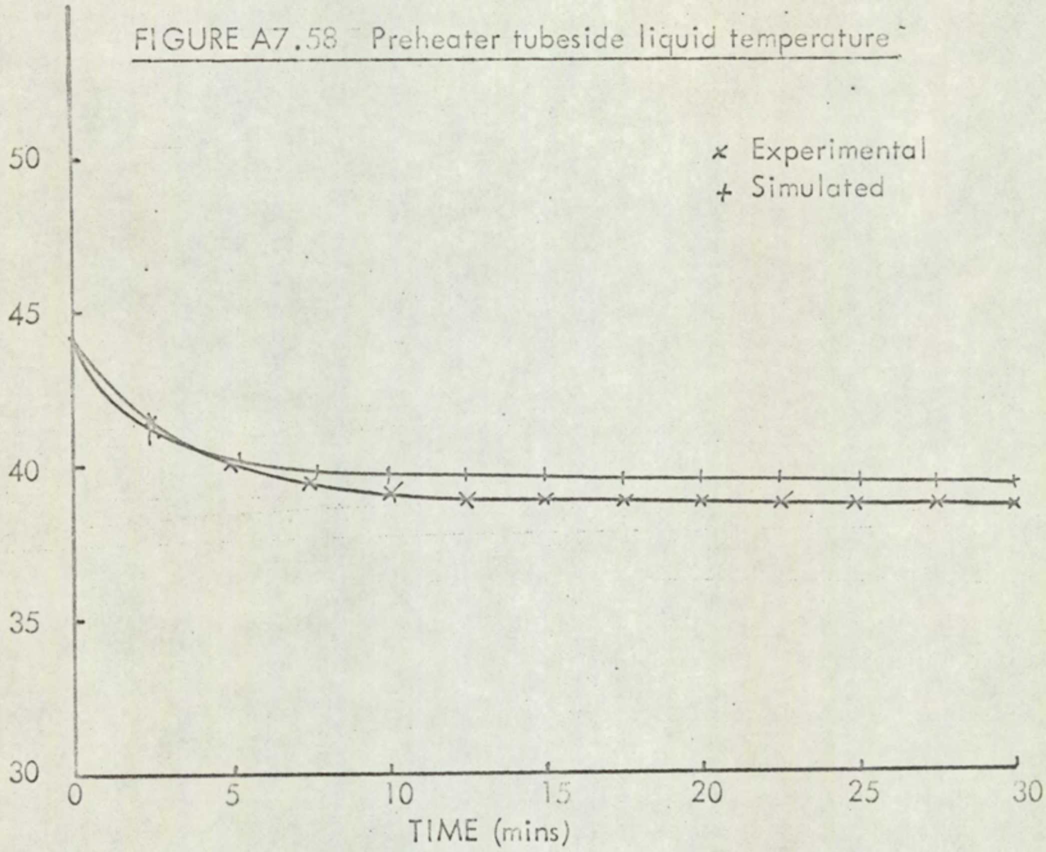
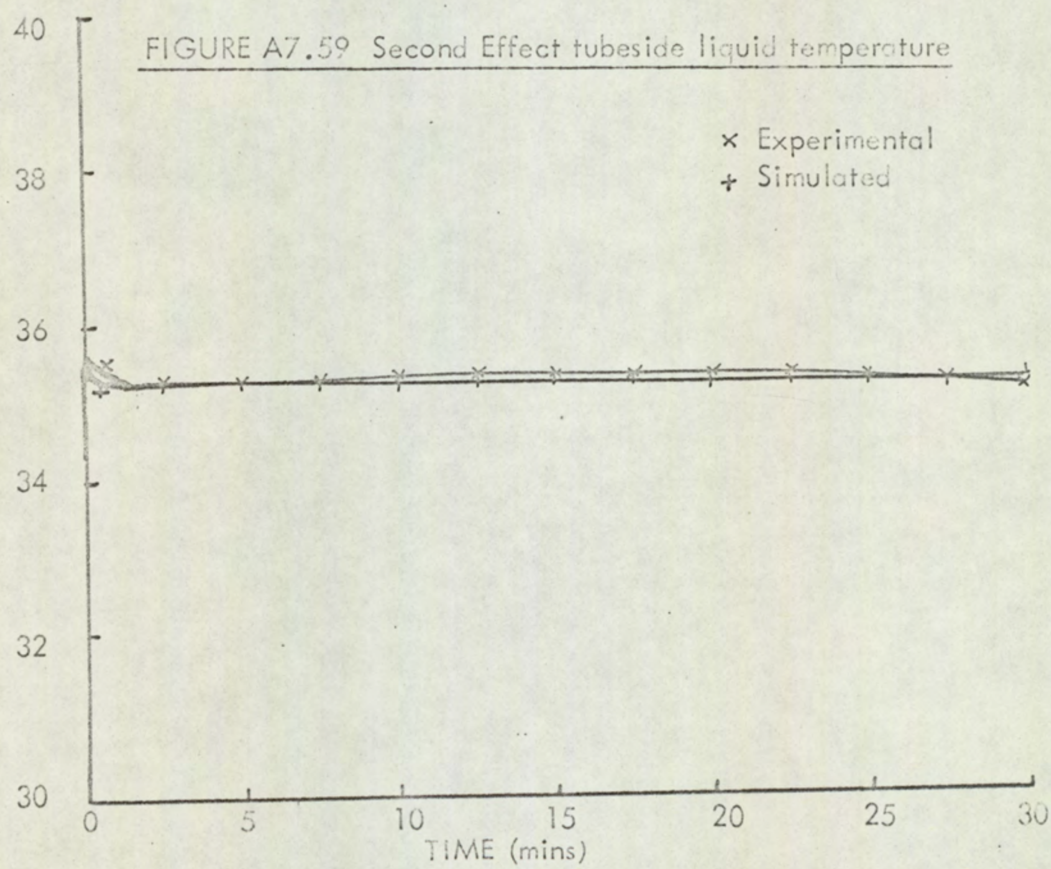
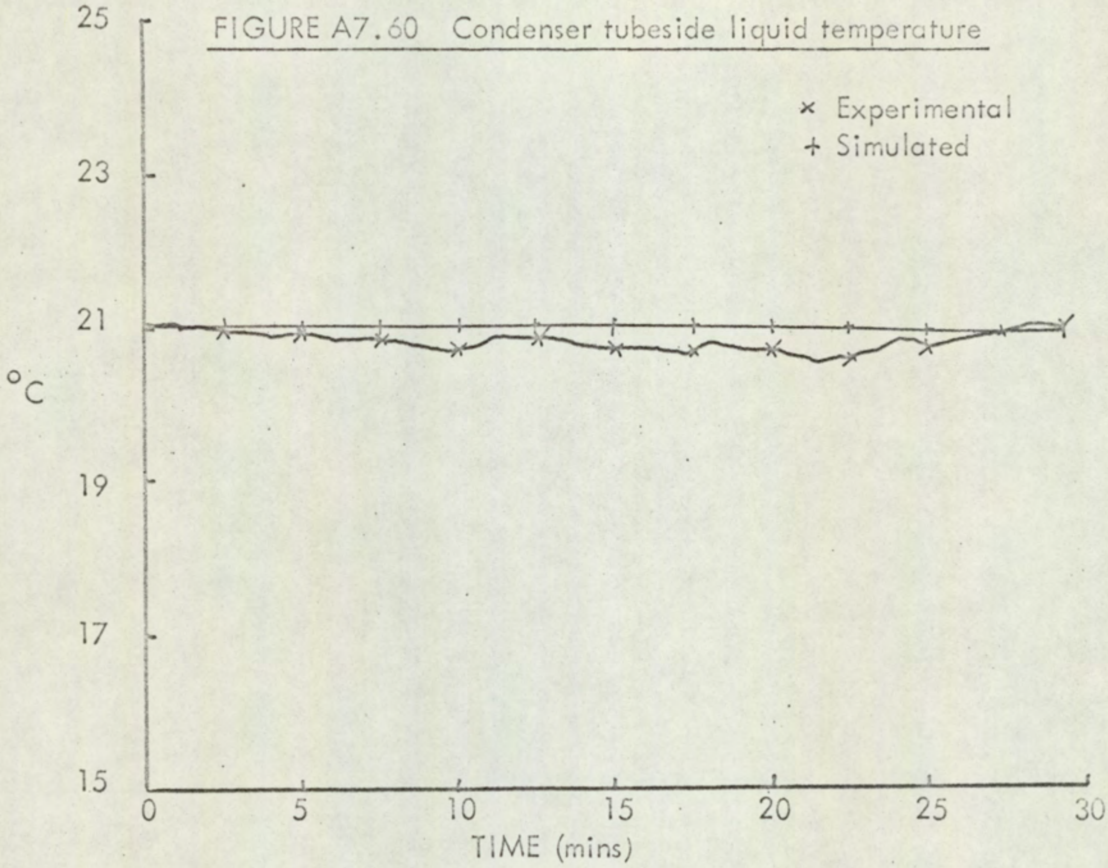


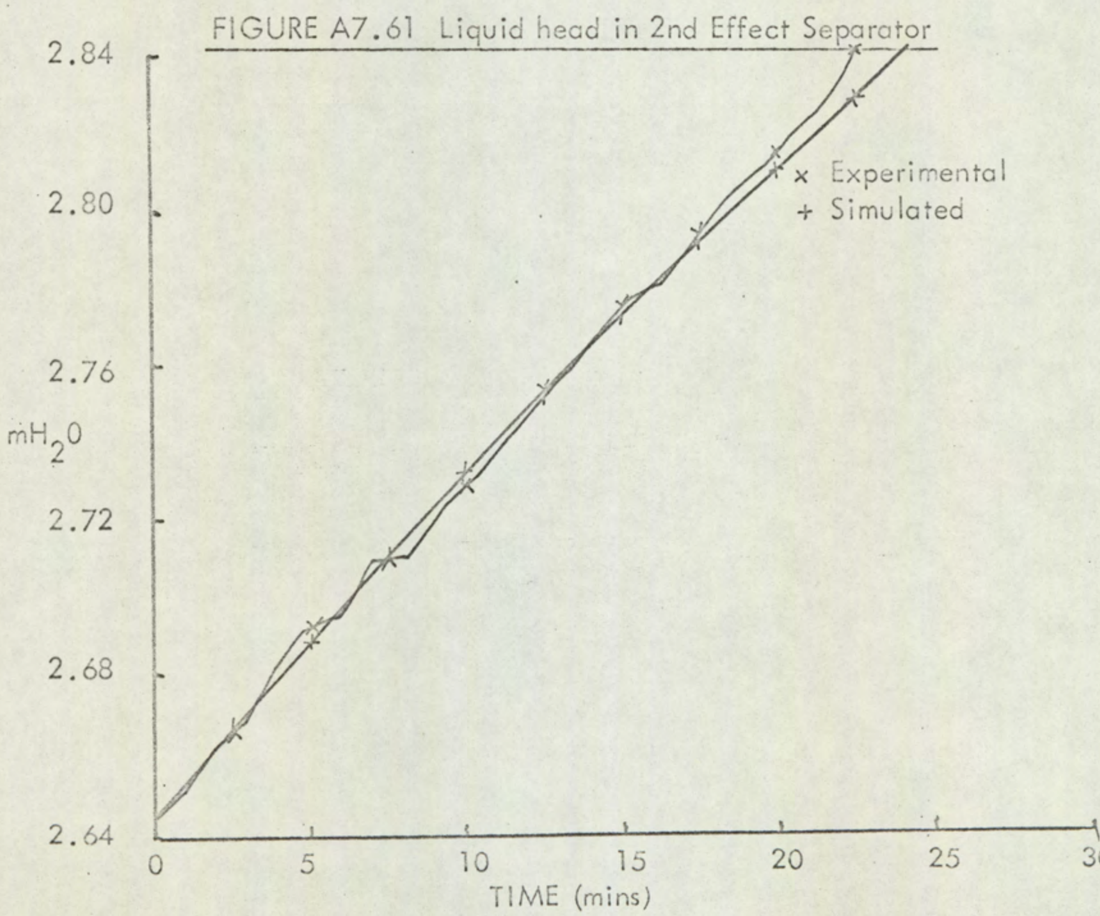
FIGURE A7.59 Second Effect tubeside liquid temperature



SIMULATION OF REDUCED MODEL

RESPONSE TO INCREASE IN FEED RATE





SIMULATION OF REDUCED MODEL

RESPONSE TO DECREASE IN FEED RATE

FIGURE A7.62 Preheater tubeside liquid temperature

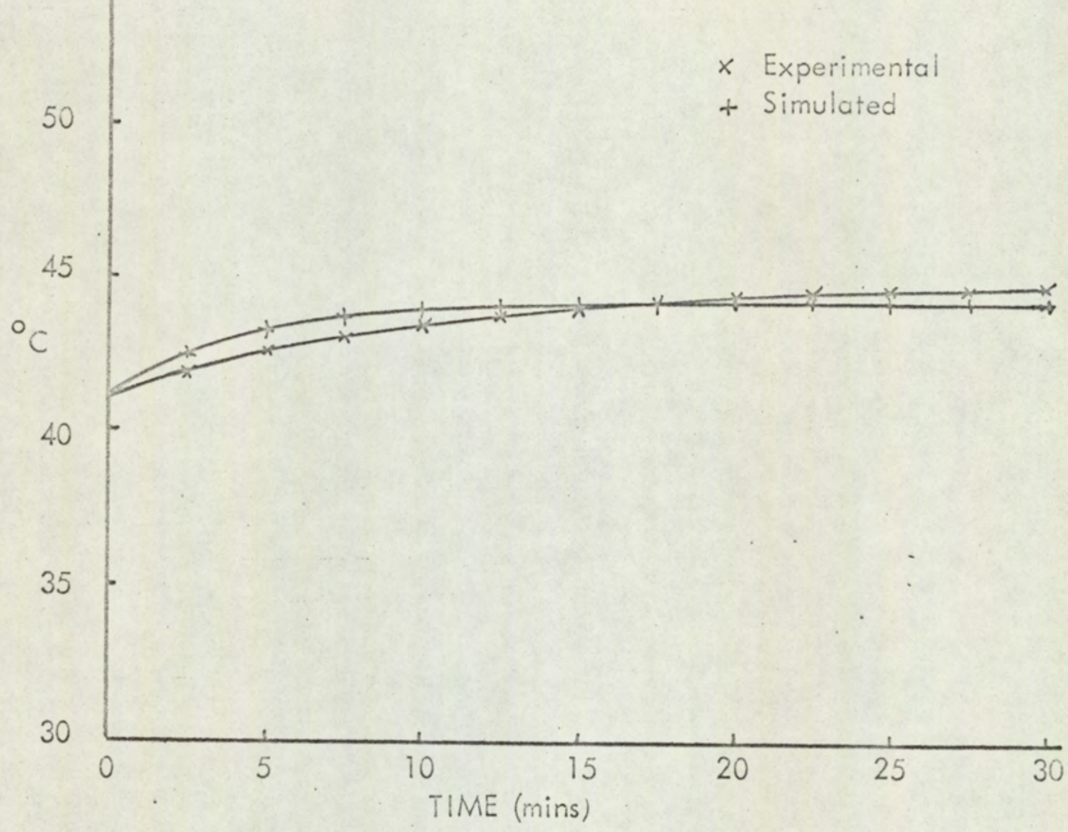
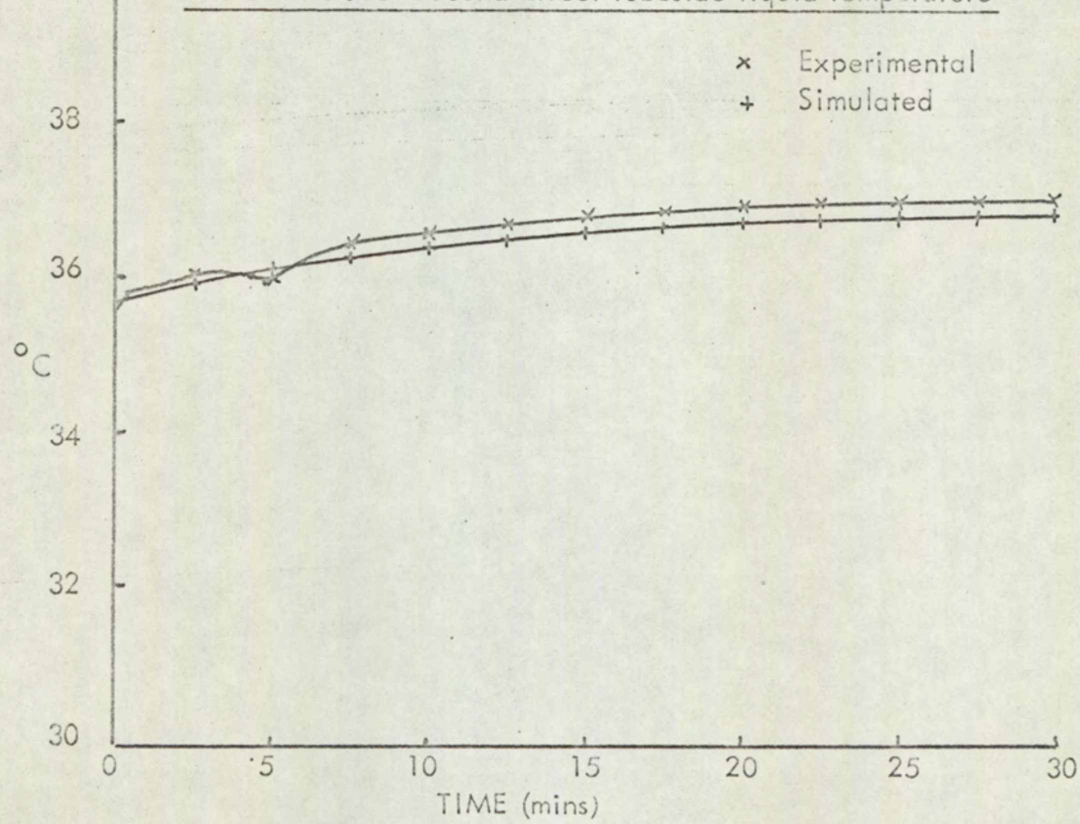


FIGURE A7.63 Second Effect tubeside liquid temperature



SIMULATION OF REDUCED MODEL

RESPONSE TO DECREASE IN FEED RATE

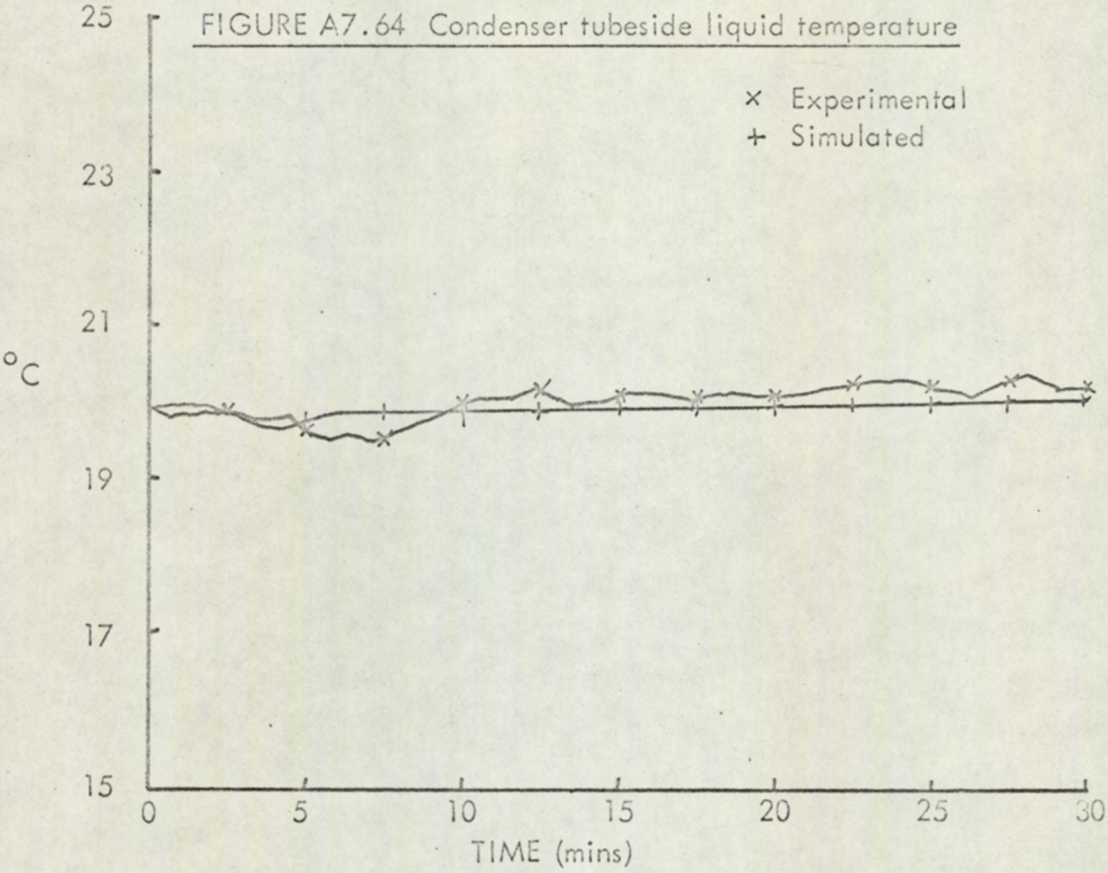


FIGURE A7.64 Condenser tubeside liquid temperature

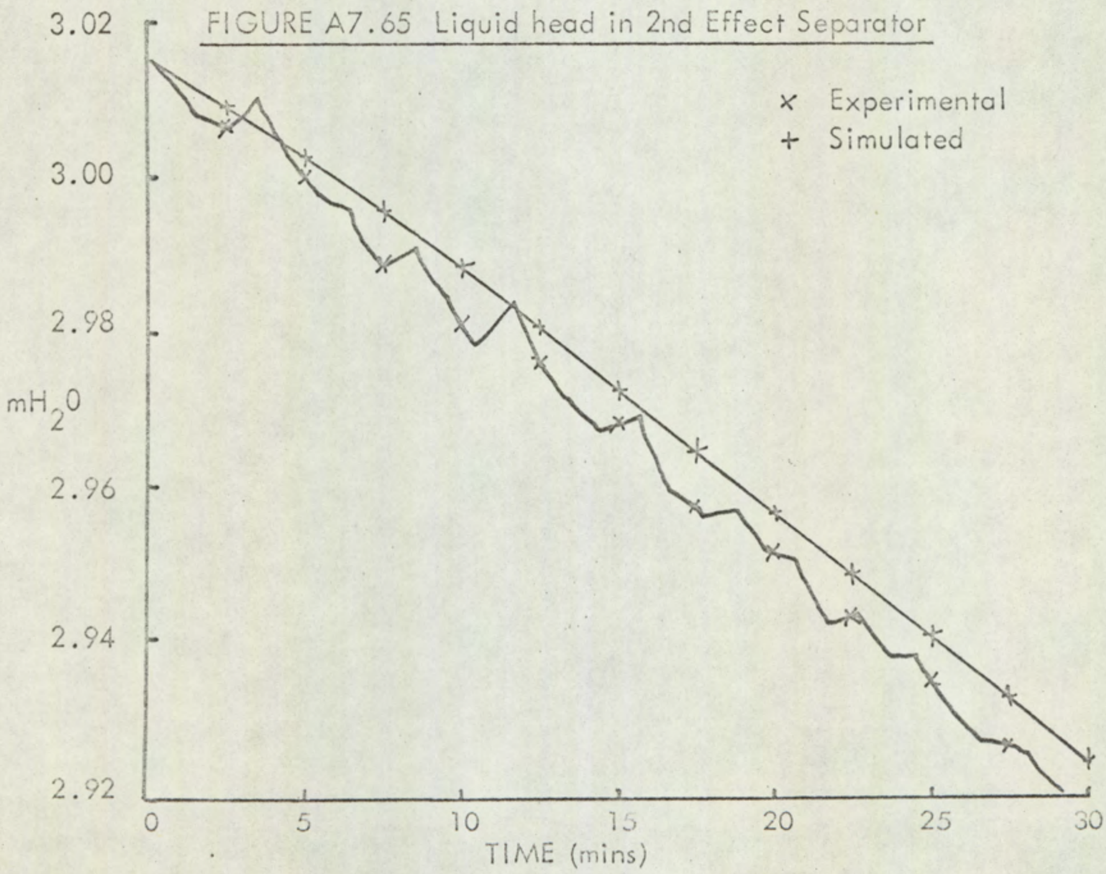


FIGURE A7.65 Liquid head in 2nd Effect Separator

FIGURE A7.66

KALMAN FILTER - CYCLE EXECUTION TIME

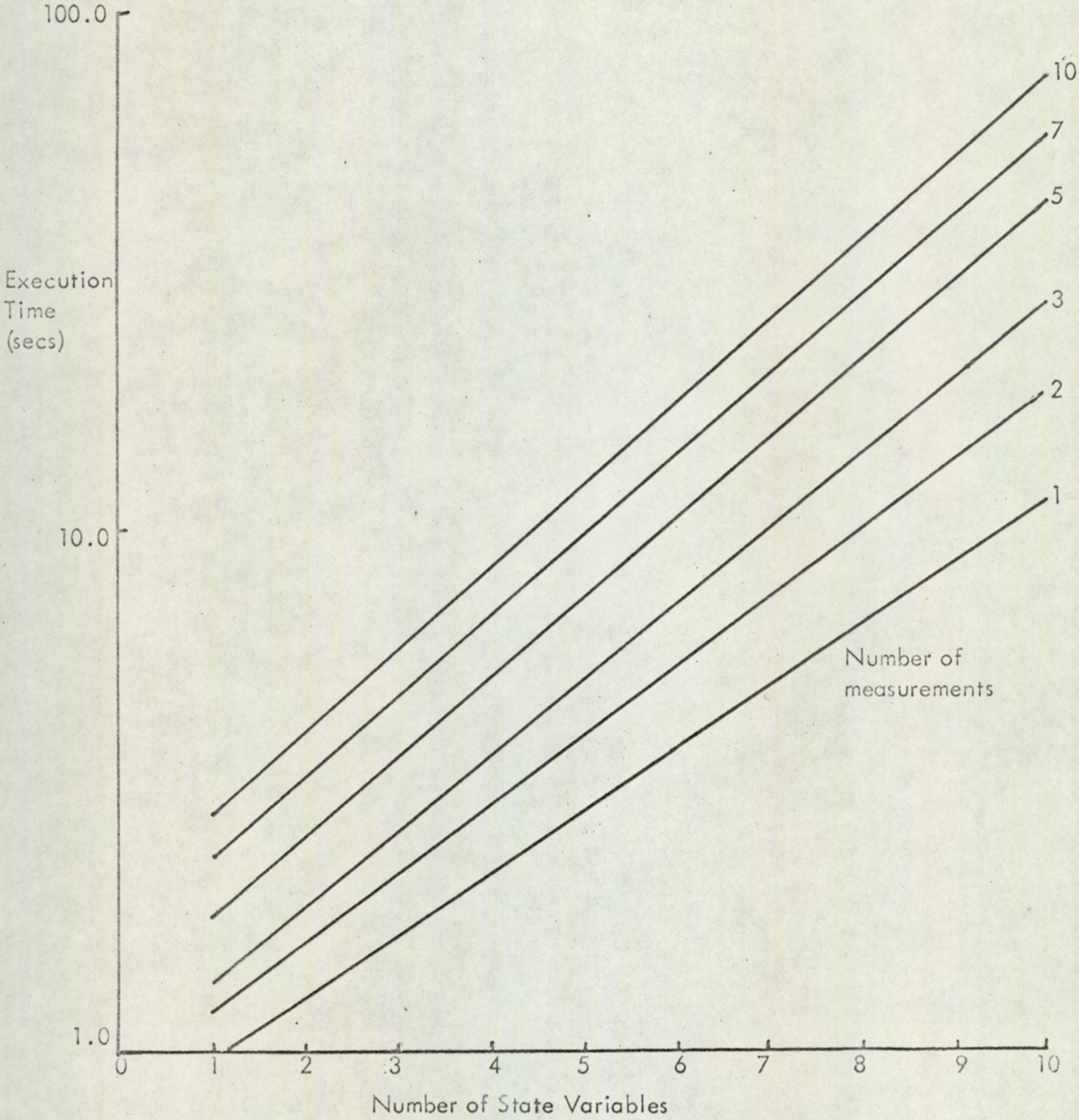


Figure A7.67

```
ON - LINE KALMAN FILTER

START TIME 1937 HRS
SAMPLING INTERVAL! 120

ENSEMBLE !5

E    45.775        40.675        29.1375       2.62364
     690.775       1443.25       2033.67       1035.61

M    45.775        40.675        29.1375       2.62364

       .316212
       .316212
       .316212
       .337269
     31.5341
     31.5997
     31.6022
     31.6244


     1
P    43.6241       40.7022       25.613        2.63341
     726.473       1431.34       1769.33       1040.66

E    45.3099       40.6764       23.9543       2.63133
     690.692       1431.27       1833.37       1040.66

M    45.7625       40.675        29.1125       2.63039

       .3136
       .307674
       .30901
       .306181
      7.03323
     12.6476
     11.632
     31.6259


     2
P    51.0295       40.6605       29.1334       2.63659
     753.999       1420.41       2037.02       1042.23

E    46.4536       40.673        29.1153       2.63433
     724.995       1420.53       2036.73       1042.23

M    45.775        40.675        29.1125       2.63256

       .295101
       .293343
       .290232
       .290766
      4.14013
      7.72053
      7.54204
     31.6275
```

Figure A7.68

3

P	43.7203	40.6605	25.5943	2.63904
	726.773	1420.41	1763.03	1063.25
E	46.3936	40.6719	23.3343	2.63207
	714.977	1420.51	1793.77	1063.25
M	45.7375	40.675	29.1	2.62633

.231365
.230963
.232134
.237653
3.07333
5.74914
5.52363
31.6291

4

P	51.1623	40.6745	29.1544	2.63635
	755.467	1407.33	2037.61	1037.17
E	47.1314	40.6749	29.0774	2.63059
	740.329	1407.33	2037.09	1037.17
M	45.325	40.675	29.05	2.62543

.273105
.272925
.271567
.23702
2.53263
4.71061
4.59566
31.6307

5

P	51.2314	40.6734	29.1536	2.63541
	757.64	1421.41	2036.36	1025.33
E	47.3706	40.6656	29.0972	2.63255
	745.371	1421.36	2036.57	1025.33
M	45.3125	40.6625	29.075	2.63013

.267413
.267536
.265329
.236391
2.21109
4.0765
4.04043
31.6322

Figure A7.69

6

P	51.2432	40.7033	29.1466	2.63732
	762.664	1467.16	2033.95	1032.14
E	47.4324	40.659	29.0972	2.63002
	753.167	1466.93	2033.73	1032.14
M	45.7625	40.6375	29.075	2.62401

.263636
.263736
.262577
.236365
2.00034
3.65352
3.65724
31.6333

7

P	51.223	40.6939	29.156	2.63475
	765.274	1476.5	2036.66	1041.3
E	47.4603	40.6435	29.0926	2.62933
	757.203	1476.3	2036.41	1041.3
M	45.7125	40.625	29.0625	2.62579

.261292
.261222
.260421
.236359
1.35152
3.34707
3.37217
31.6354

3

P	51.2333	40.6661	29.1407	2.63457
	763.633	1453.66	2037.71	1042.37
E	47.5273	40.6334	29.0967	2.63023
	756.626	1453.56	2037.56	1042.37
M	45.7375	40.625	29.075	2.62674

.259742
.25953
.253877
.236353
1.73349
3.10954
3.14935
31.637

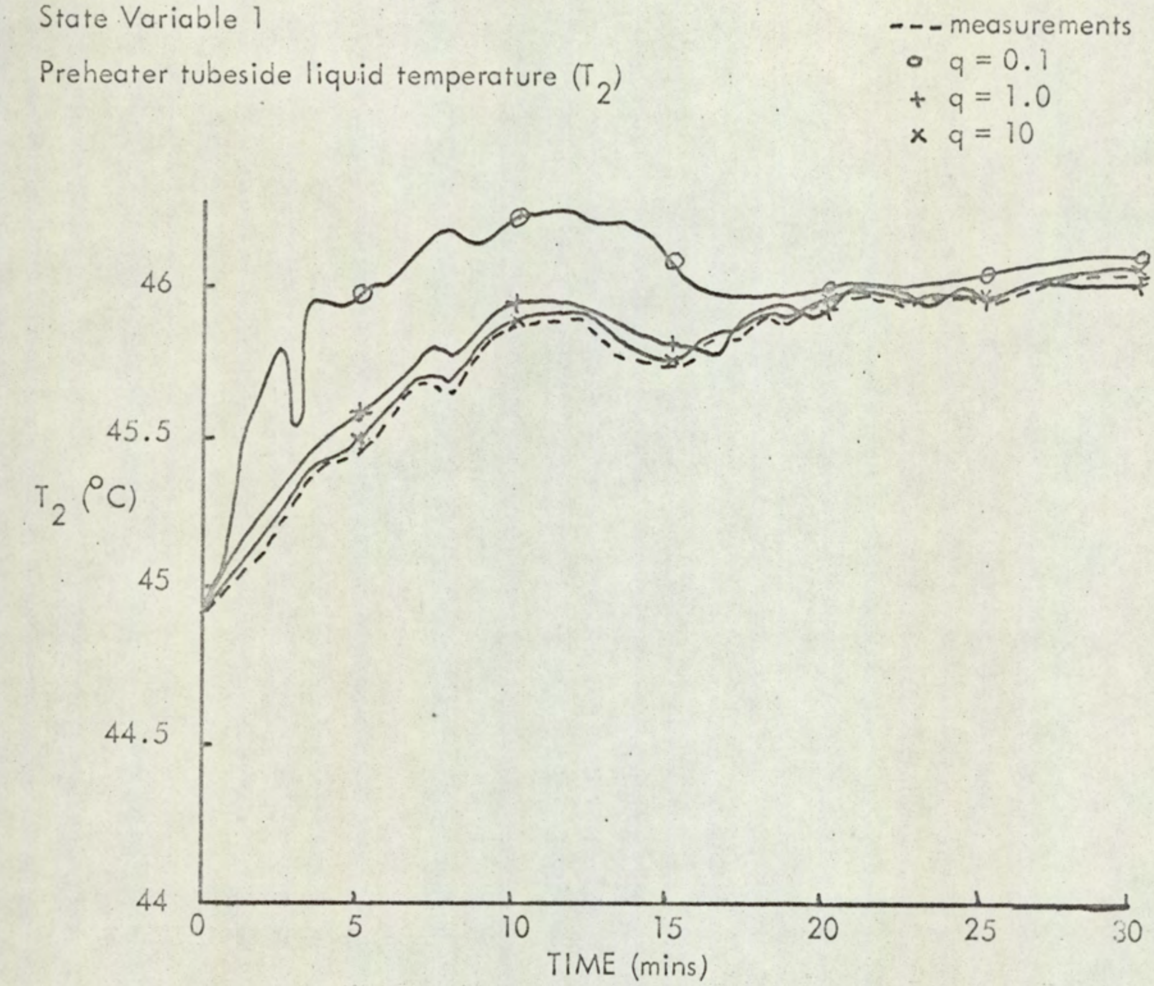
FIGURE A7.70

OFF-LINE KALMAN FILTER

DATA 1 PREDICTION 1

State Variable 1

Preheater tubeside liquid temperature (T_2)



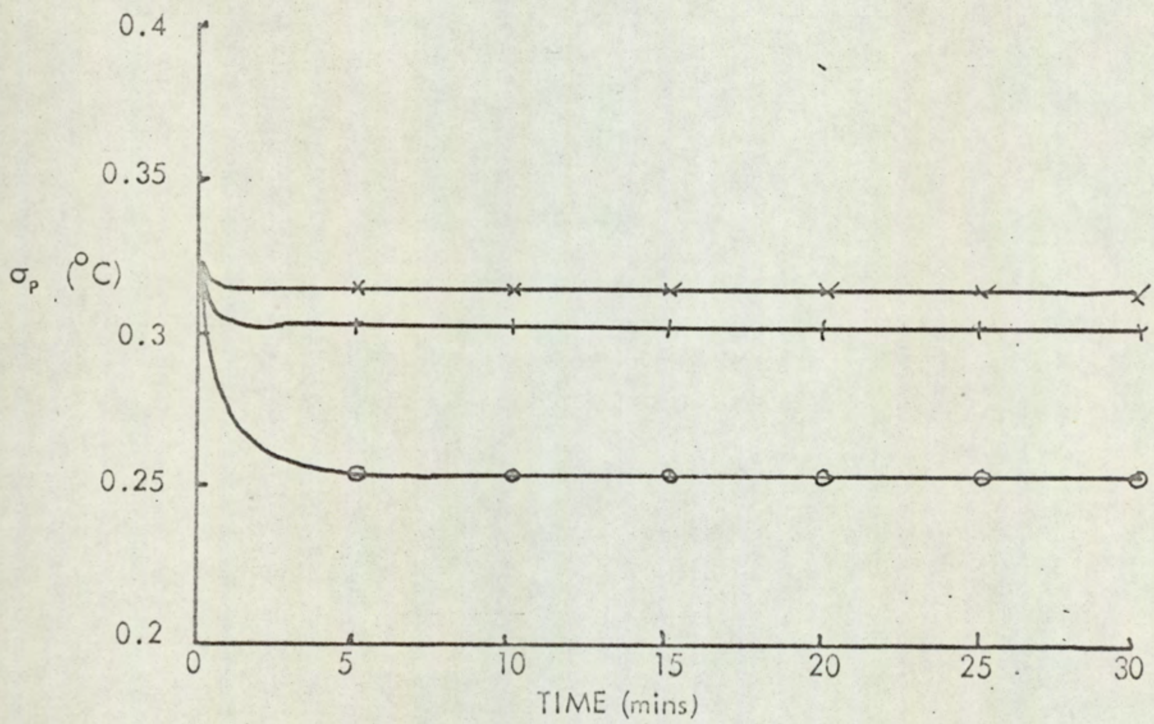


FIGURE A7.71

OFF-LINE KALMAN FILTER

DATA 1 PREDICTION 1

State Variable 2

2nd Effect tubeside liquid temperature (T_{14})

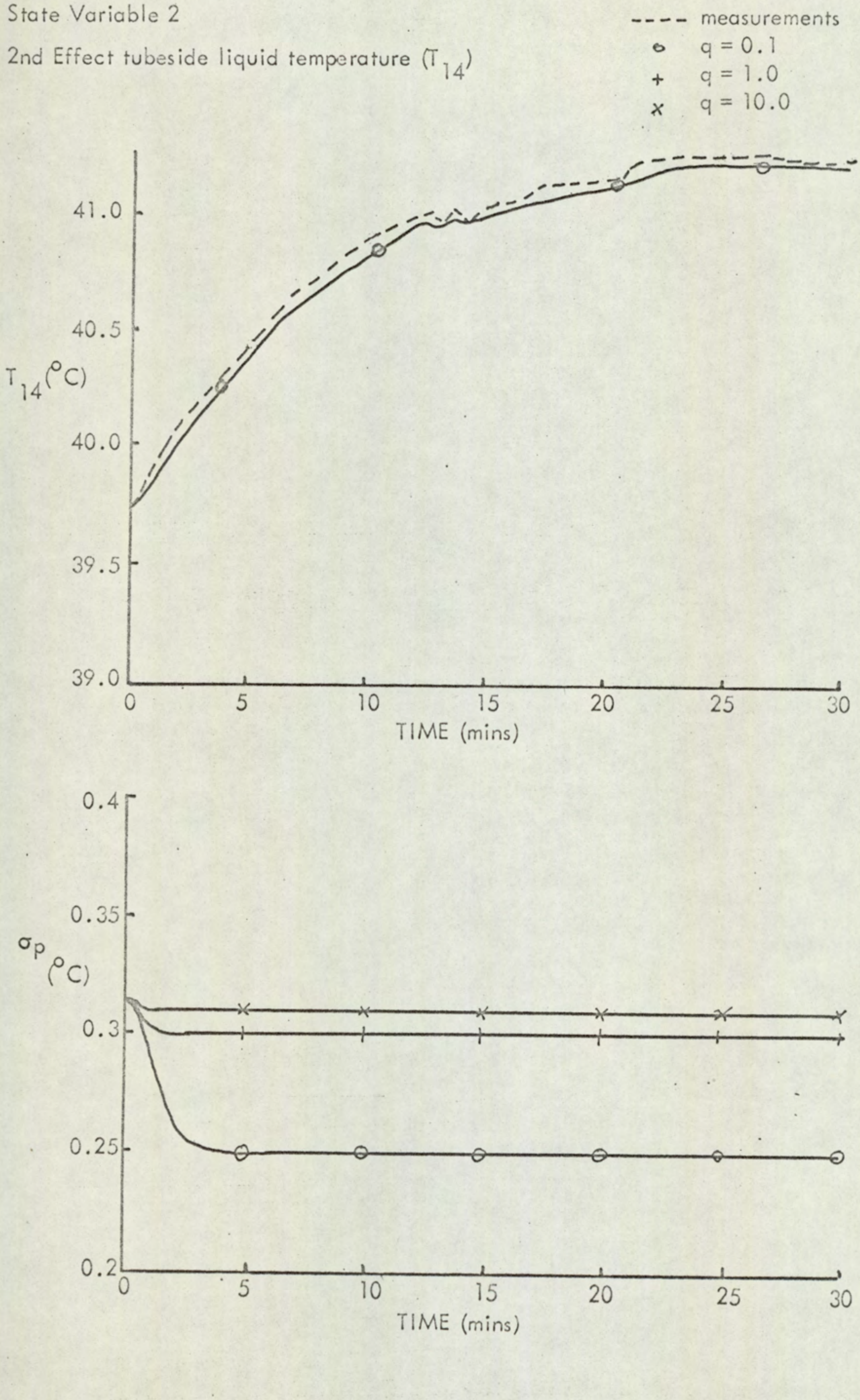


FIGURE A7.72

OFF-LINE KALMAN FILTER

DATA 1 PREDICTION 1

State Variable 3

Condenser tubeside liquid temperature (T_{13})

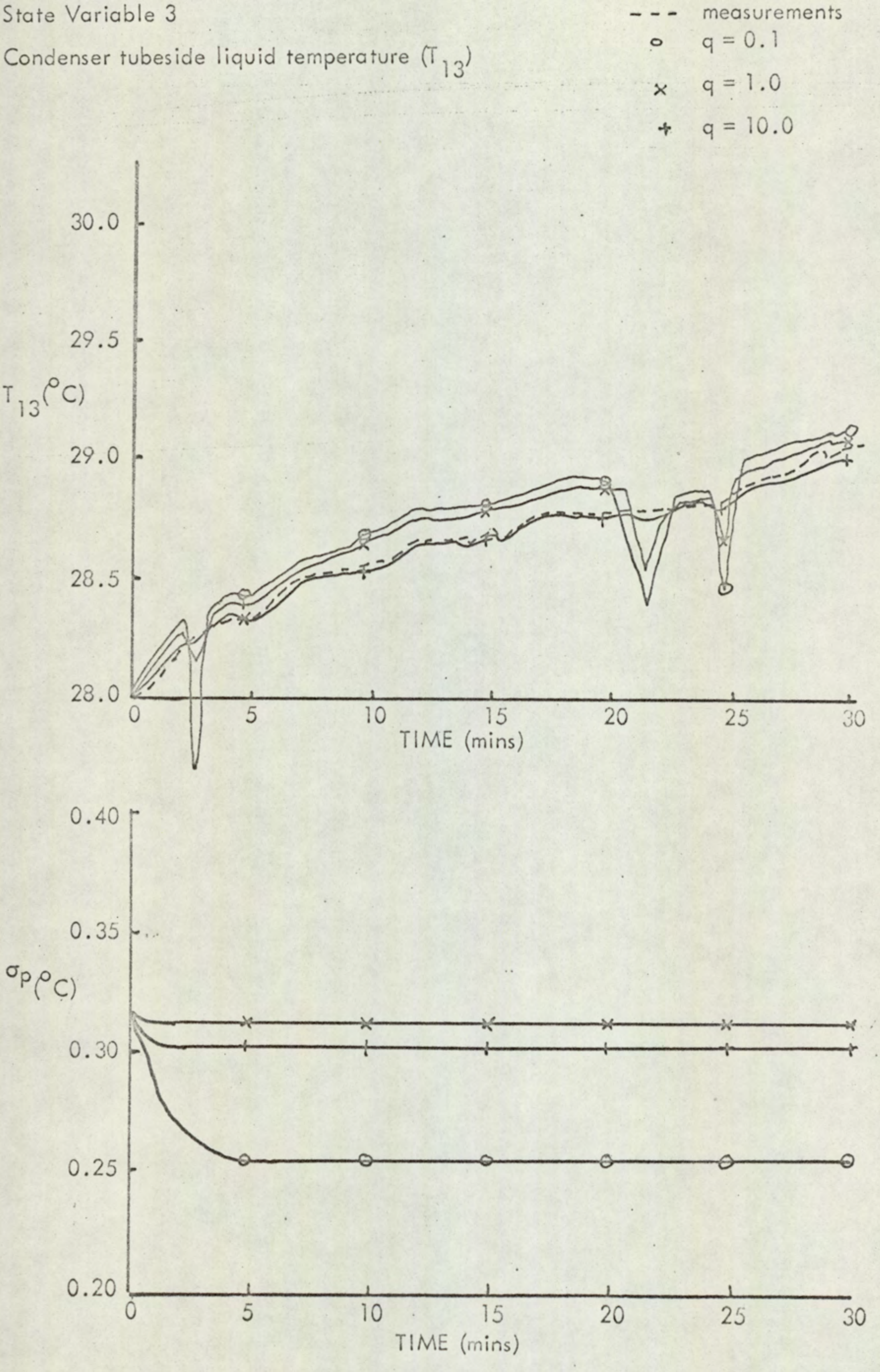


FIGURE A7.73

OFF-LINE KALMAN FILTER

State Variable 4

Liquid head in 2nd Separator(H_s)

DATA 1 PREDICTION 1

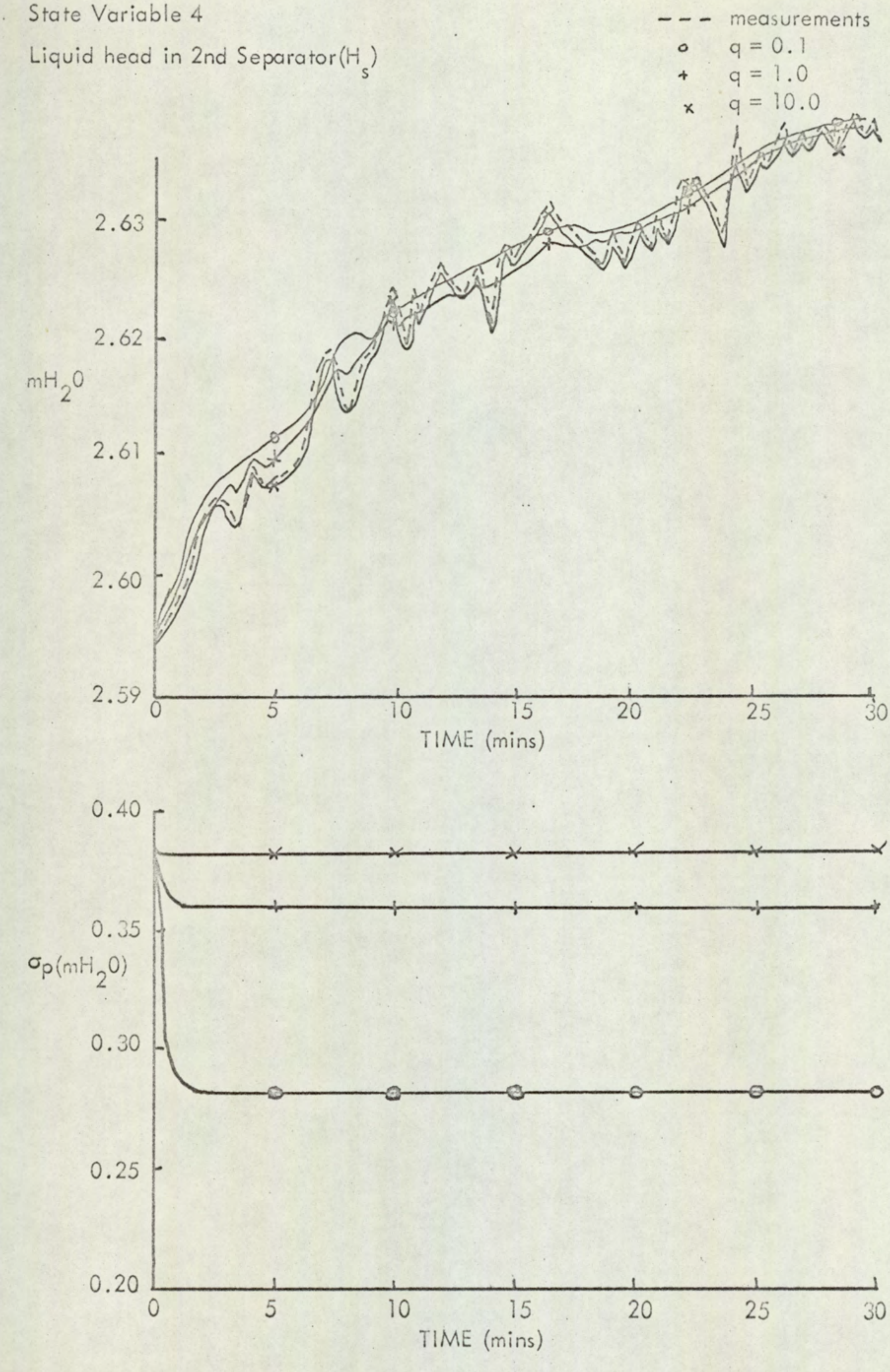


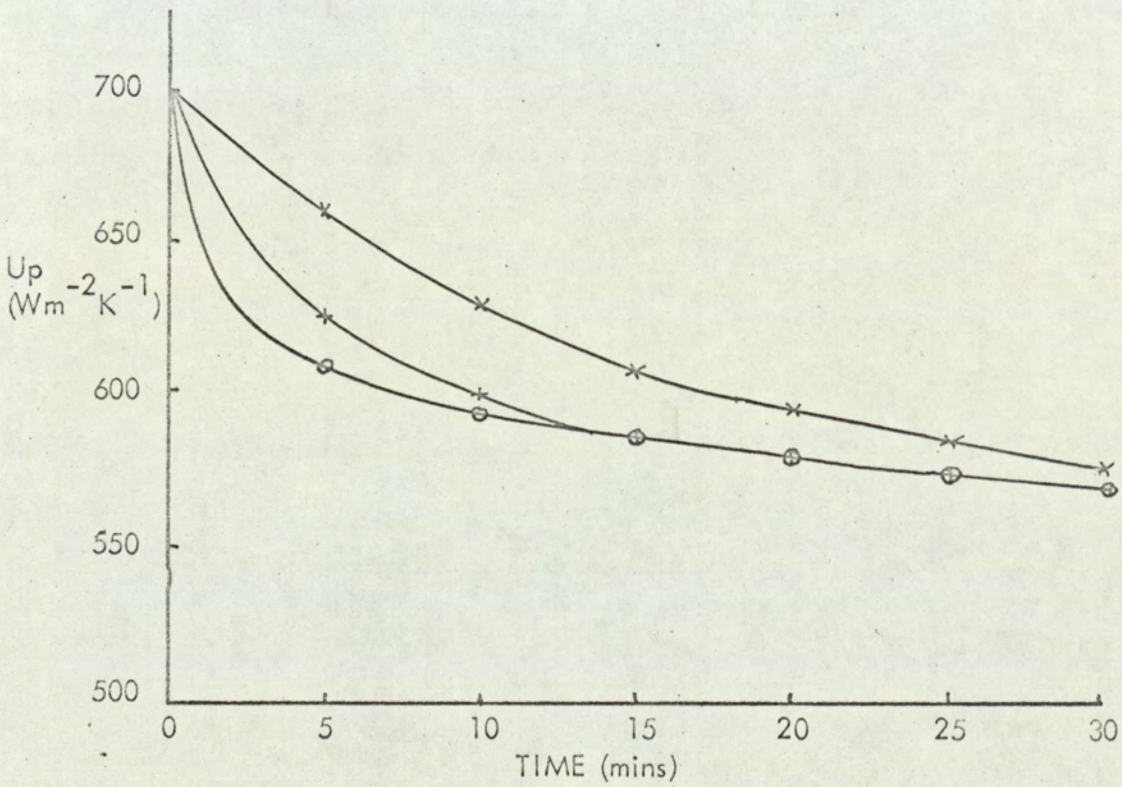
FIGURE A7.74

OFF-LINE KALMAN FILTER

DATA 1 PREDICTION 1

State Variable 5

Preheater overall heat transfer coefficient (Up)



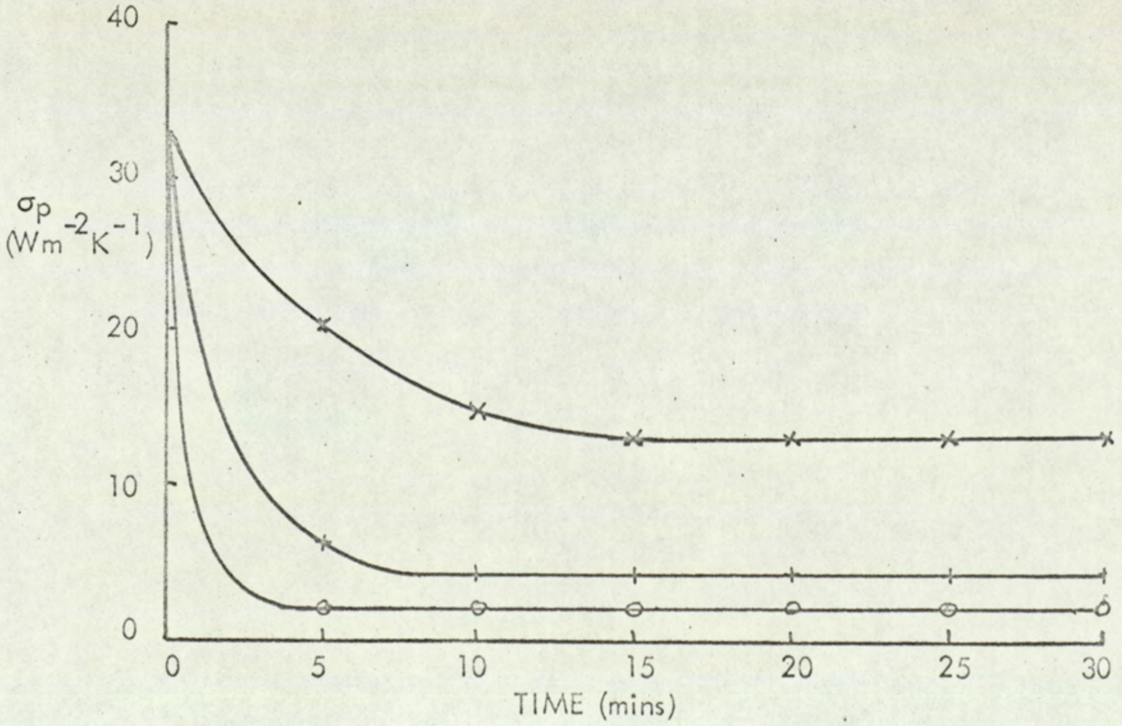


FIGURE A7.75

OFF-LINE KALMAN FILTER

State Variable 6

2nd Effect overall heat transfer coefficient (Uf)

DATA 1 PREDICTION 1

o q = 0.1
+ q = 1.0
× q = 10.0

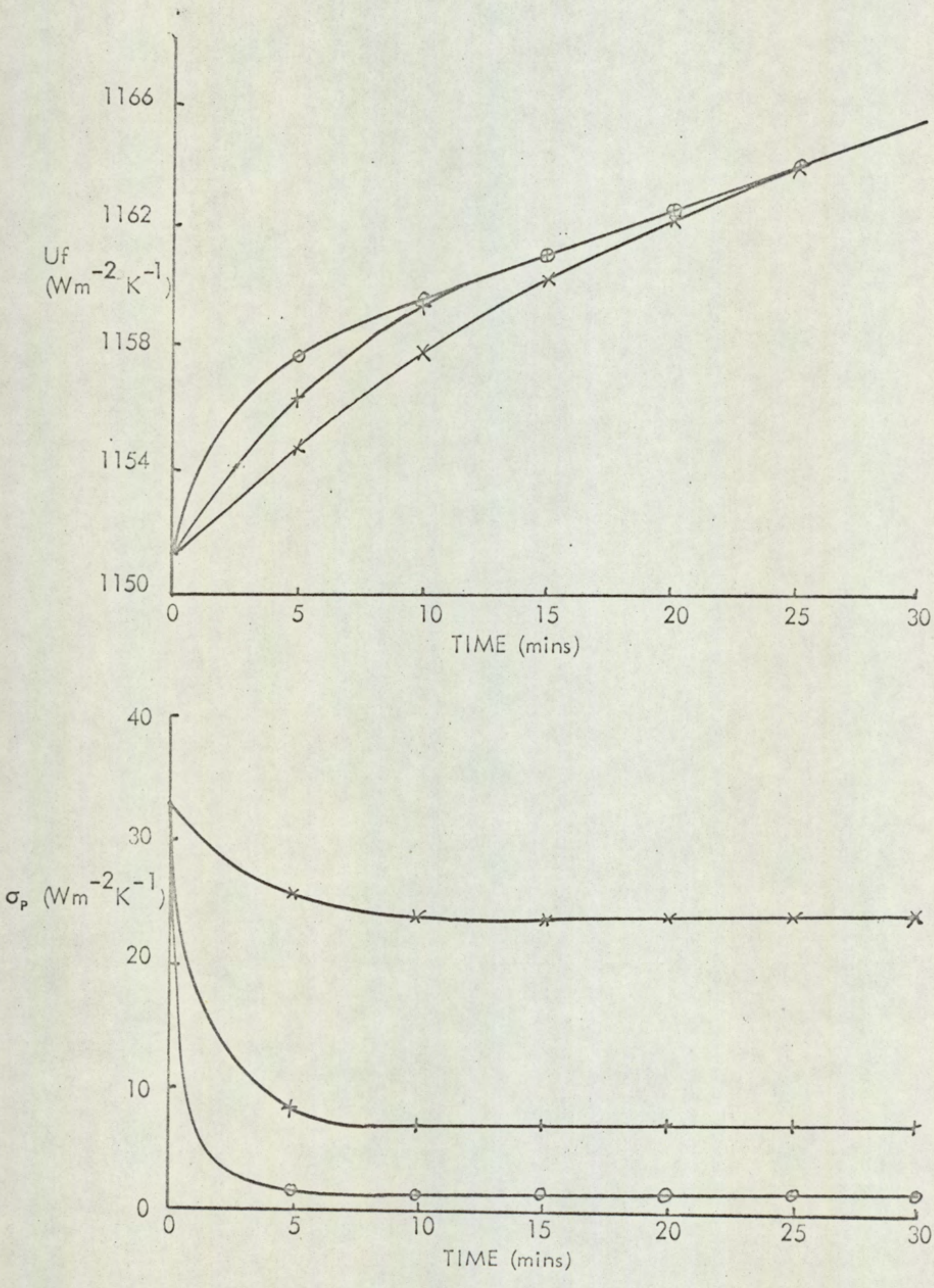


FIGURE A7.76

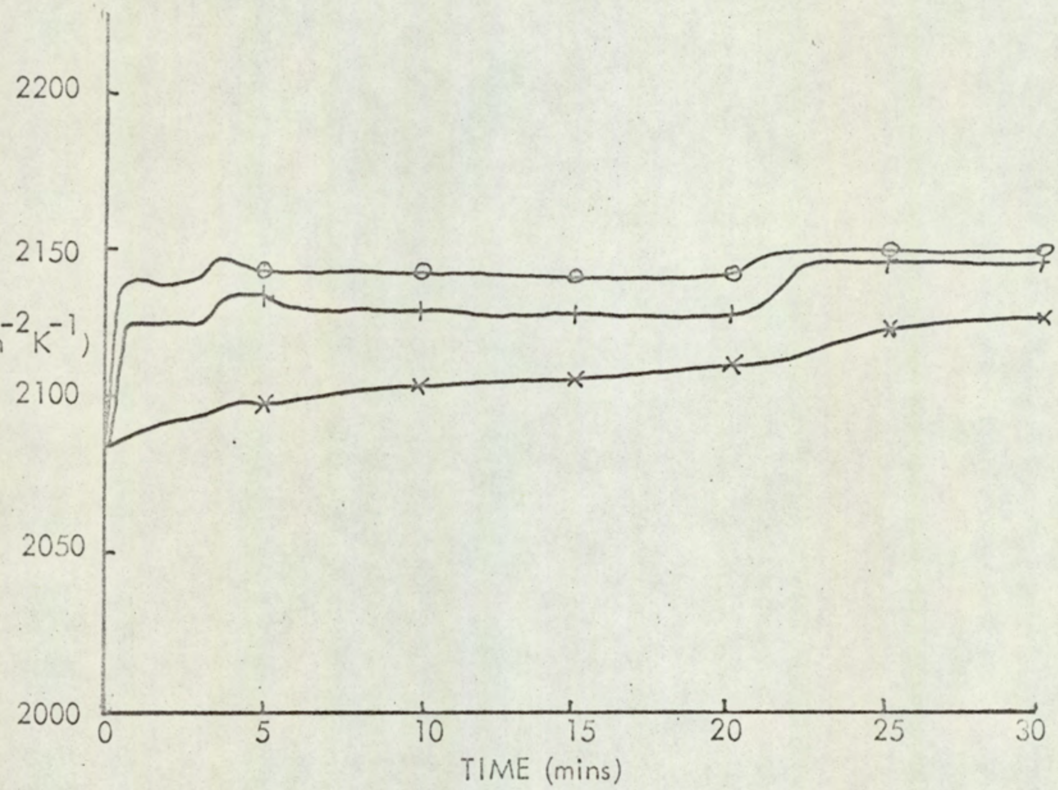
OFF-LINE KALMAN FILTER

DATA 1 PREDICTION 1

State Variable 7

Condenser overall heat transfer coefficient

o q = 0.1
+ q = 1.0
× q = 10.0



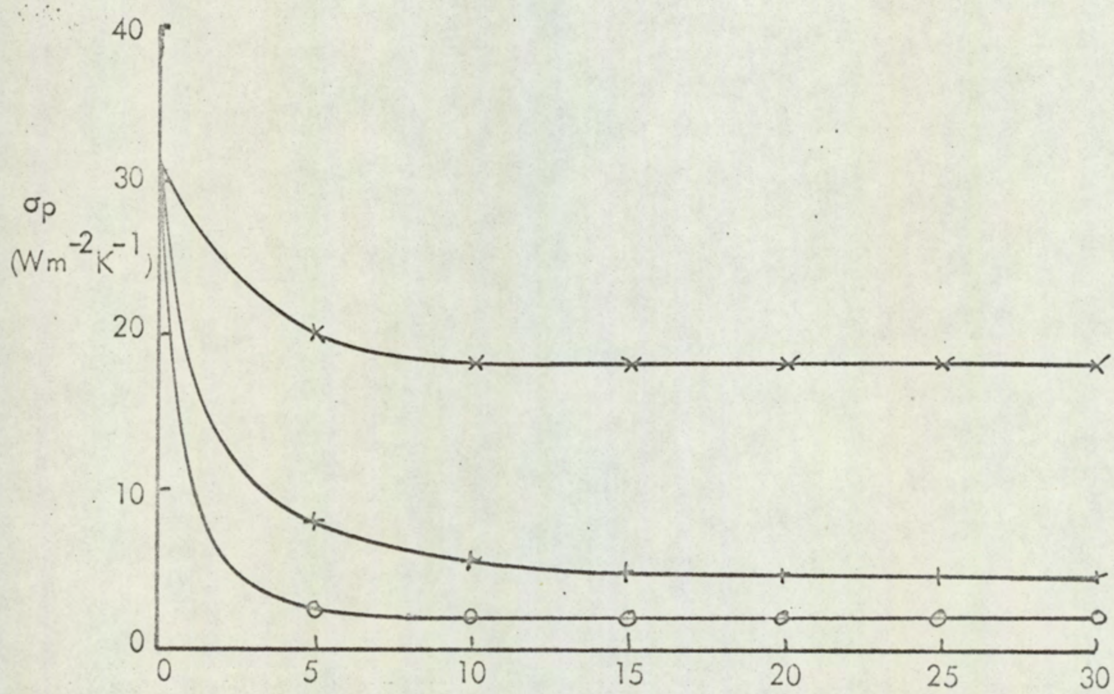


FIGURE A7.77

OFF-LINE KALMAN FILTER

DATA 1 PREDICTION 1

State Variable 8

1st Effect overall heat transfer coefficient (Ue)

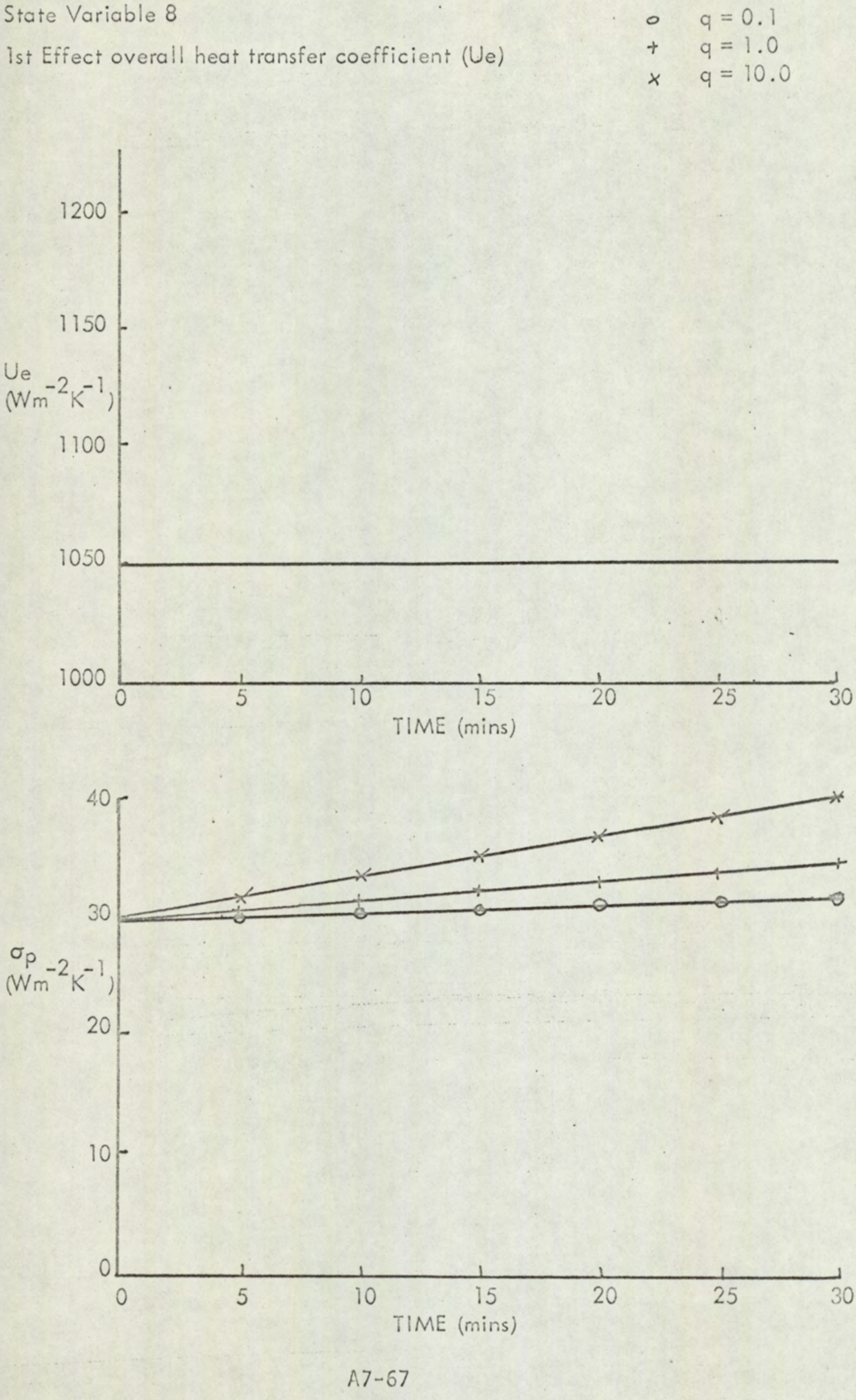


FIGURE A7.78

OFF-LINE KALMAN FILTER

DATA 2 PREDICTION 1

State Variable 1

Preheater tubeside liquid temperature (T_2)

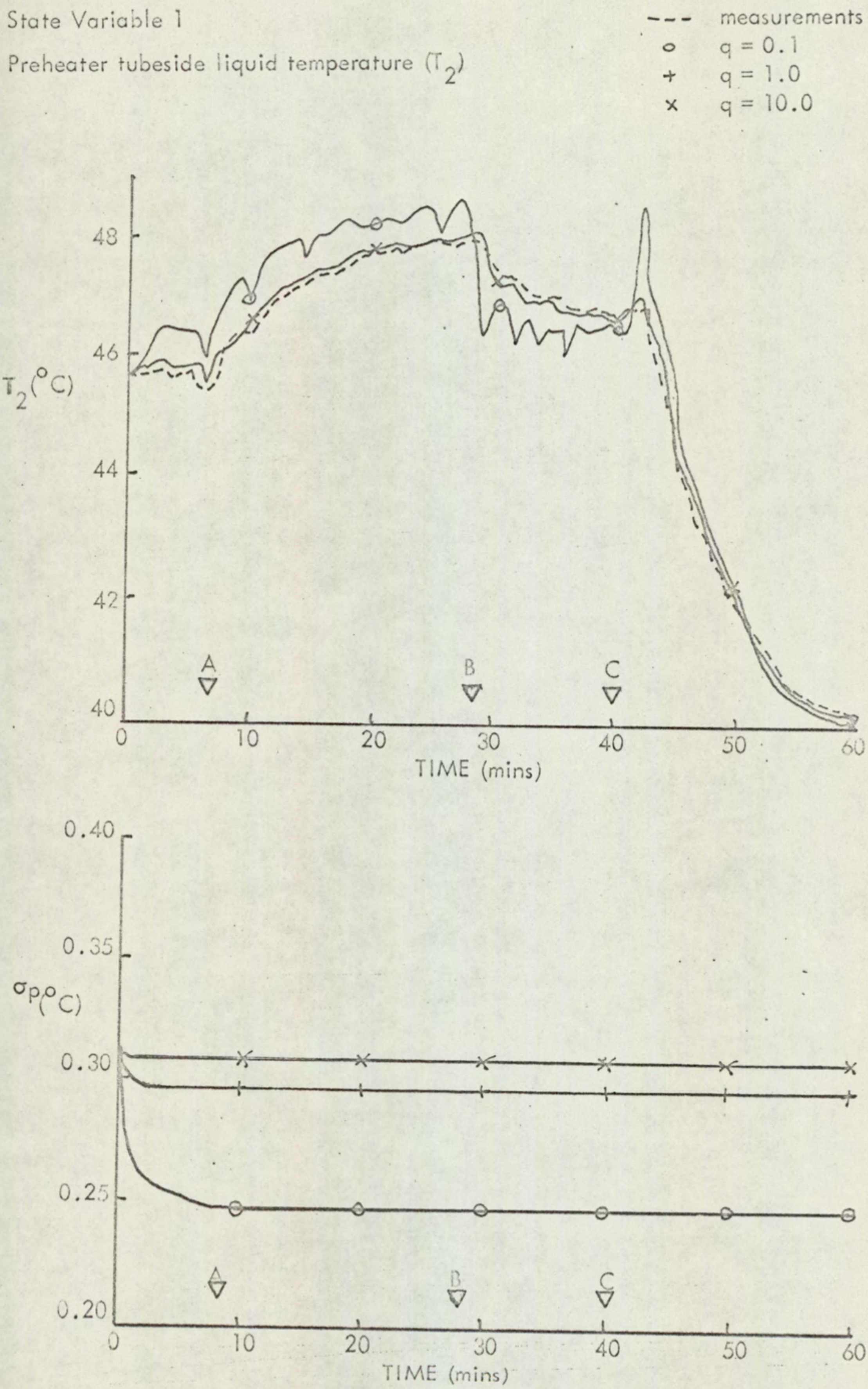


FIGURE A7.79

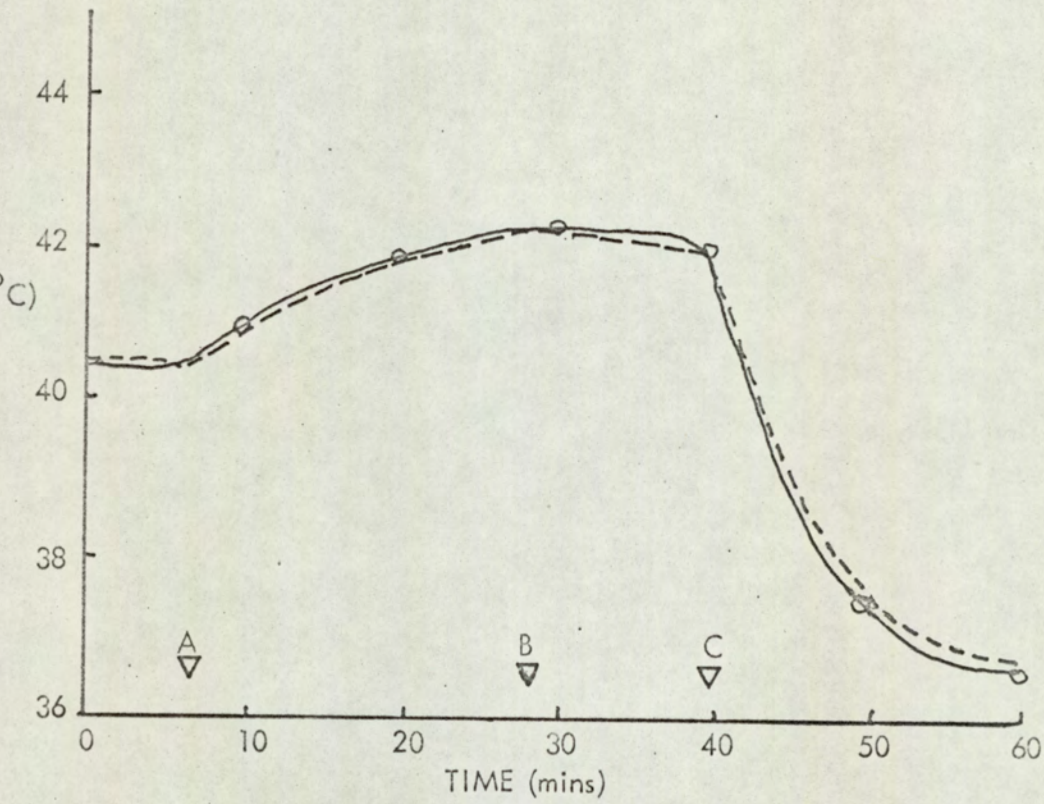
OFF-LINE KALMAN FILTER

DATA 2 PREDICTION 1

State Variable 2

2nd Effect tubeside liquid temperature (T_{14})

--- measurements
o q = 0.1
+ q = 1.0
x q = 10.0



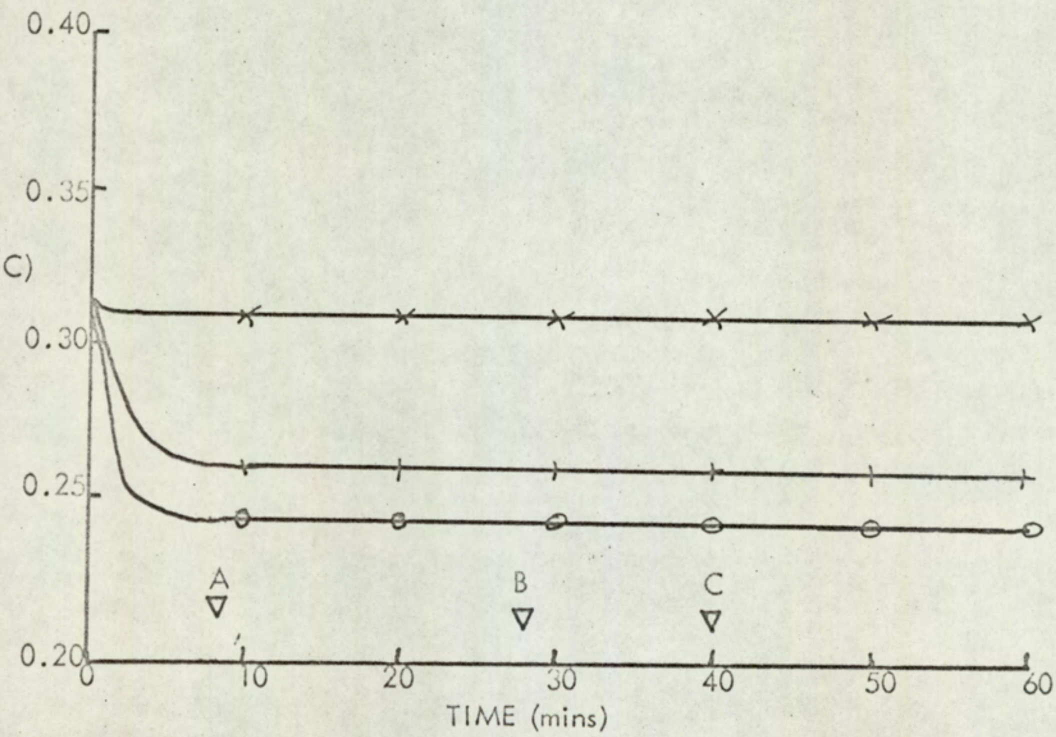


FIGURE A7.80

OFF-LINE KALMAN FILTER

DATA 2 PREDICTION 1

State Variable 3

Condenser tubeside liquid temperature (T_{13})

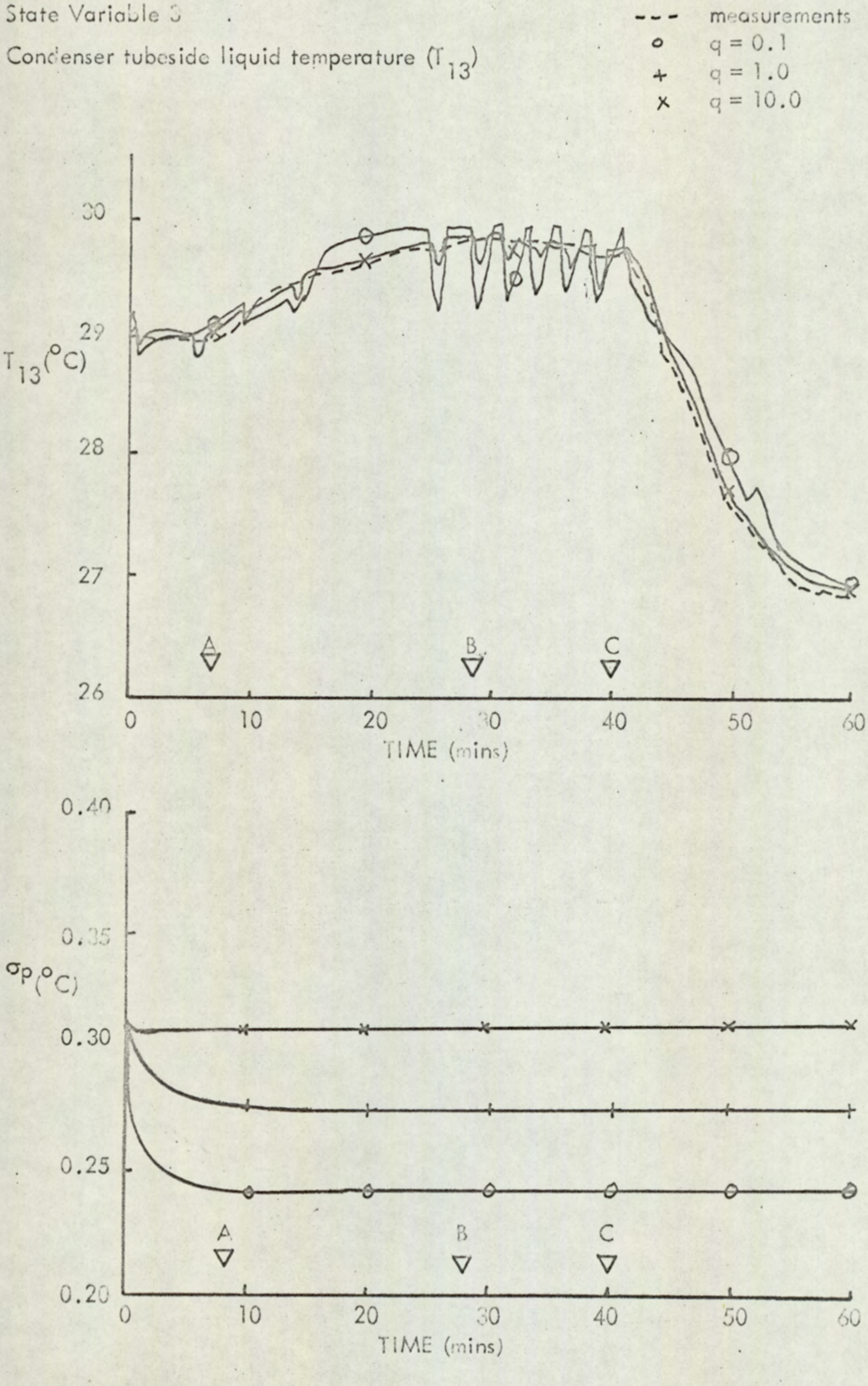


FIGURE A7.81

OFF-LINE KALMAN FILTER

State Variable 4

Liquid head in 2nd Separator H_s

DATA 2 PREDICTION 1

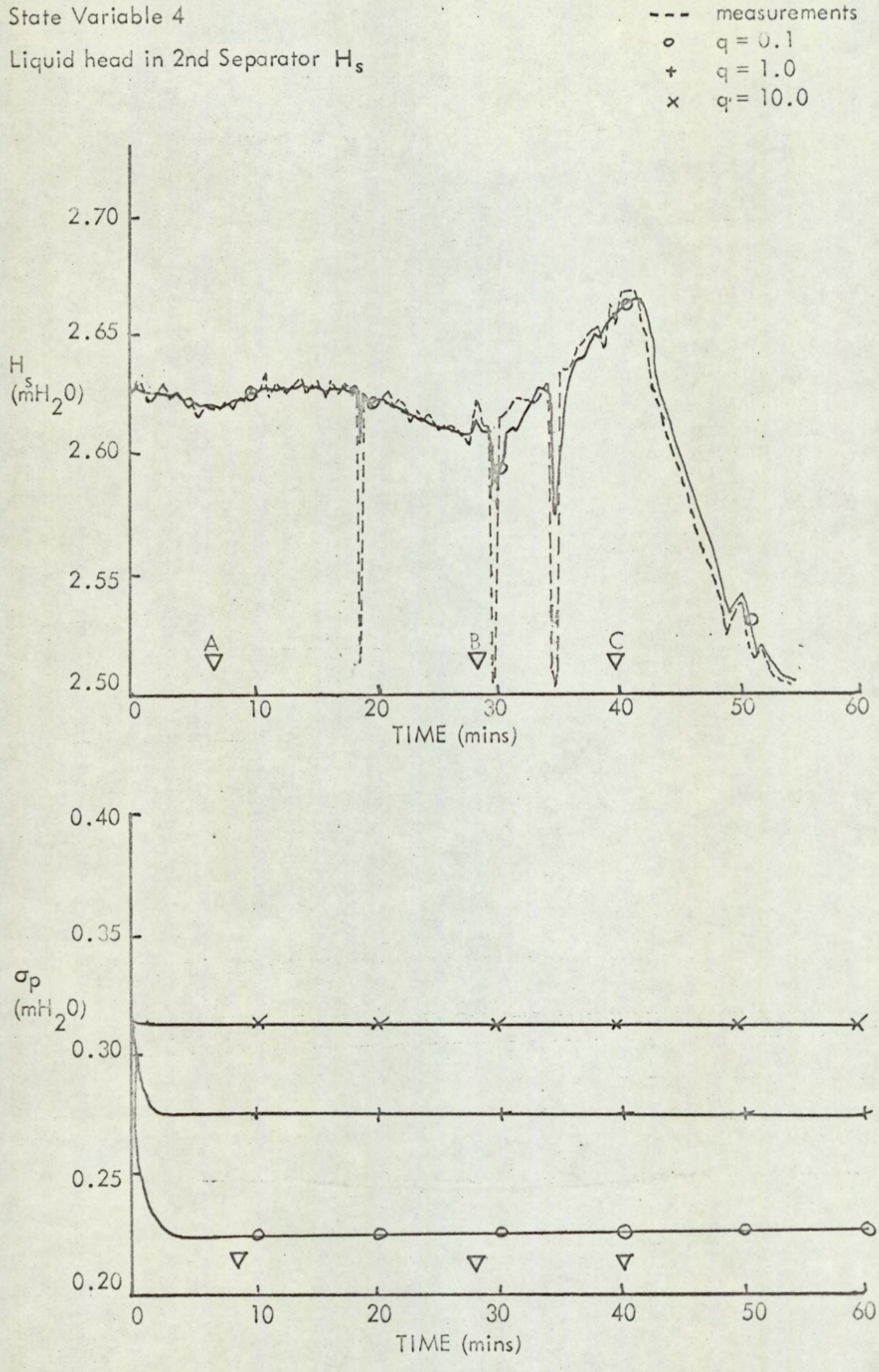


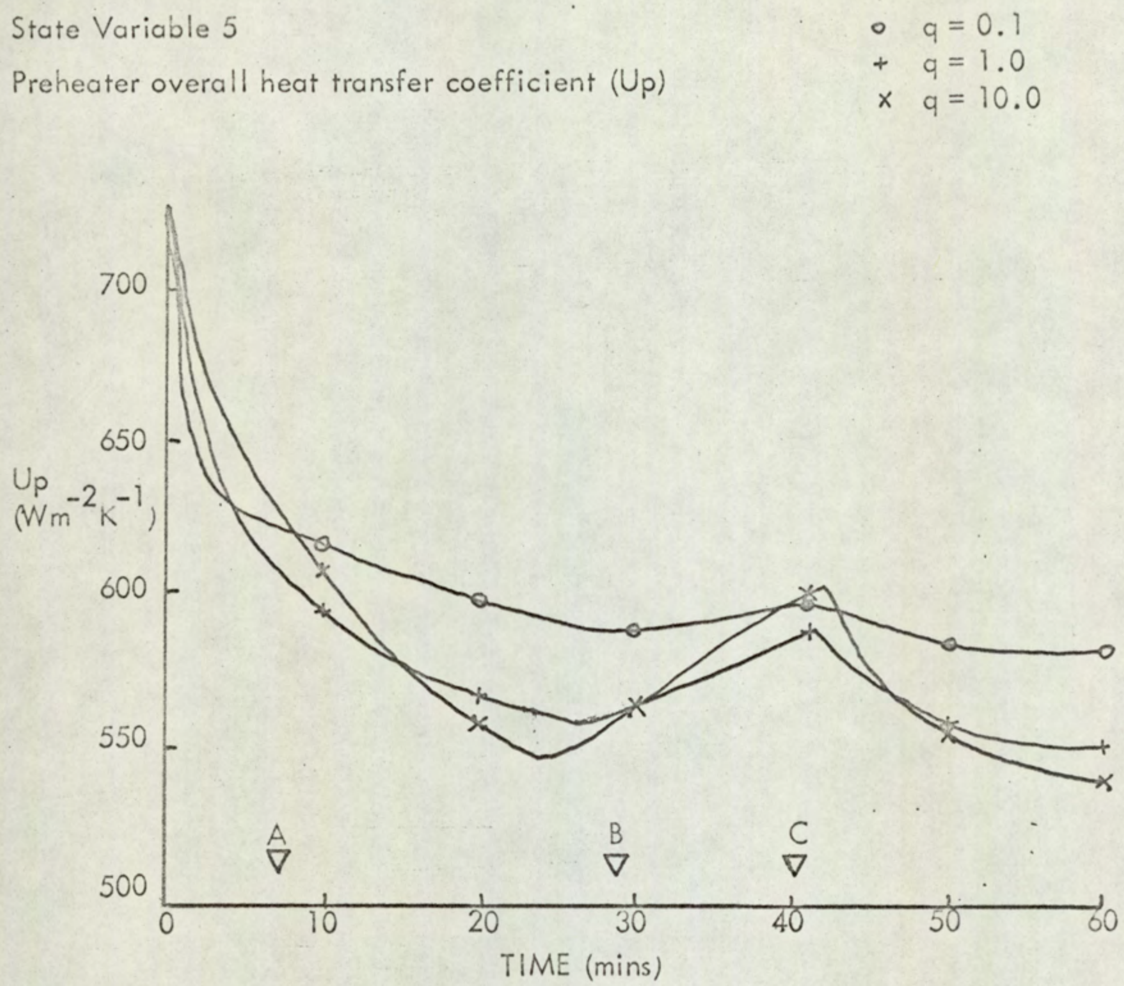
FIGURE A7.82

OFF-LINE KALMAN FILTER

DATA 2 PREDICTION 1

State Variable 5

Preheater overall heat transfer coefficient (Up)



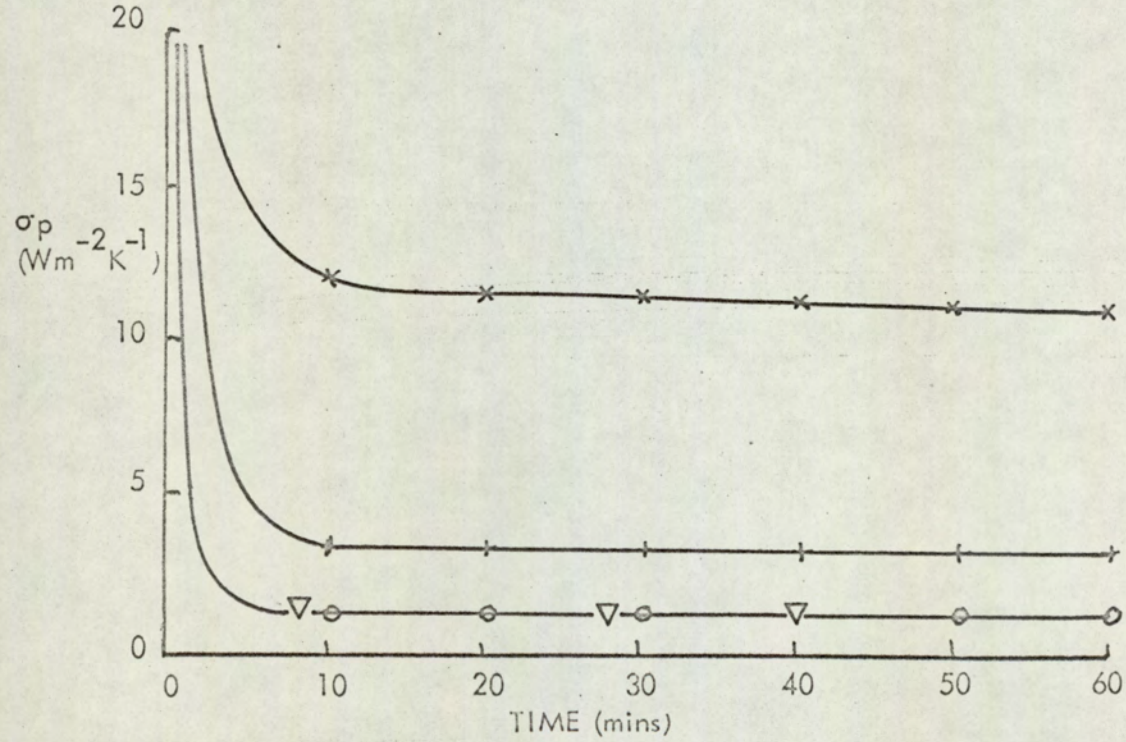


FIGURE A7.83

OFF-LINE KALMAN FILTER

DATA 2 PREDICTION 1

State Variable 6

2nd Effect overall heat transfer coefficient (U_f)

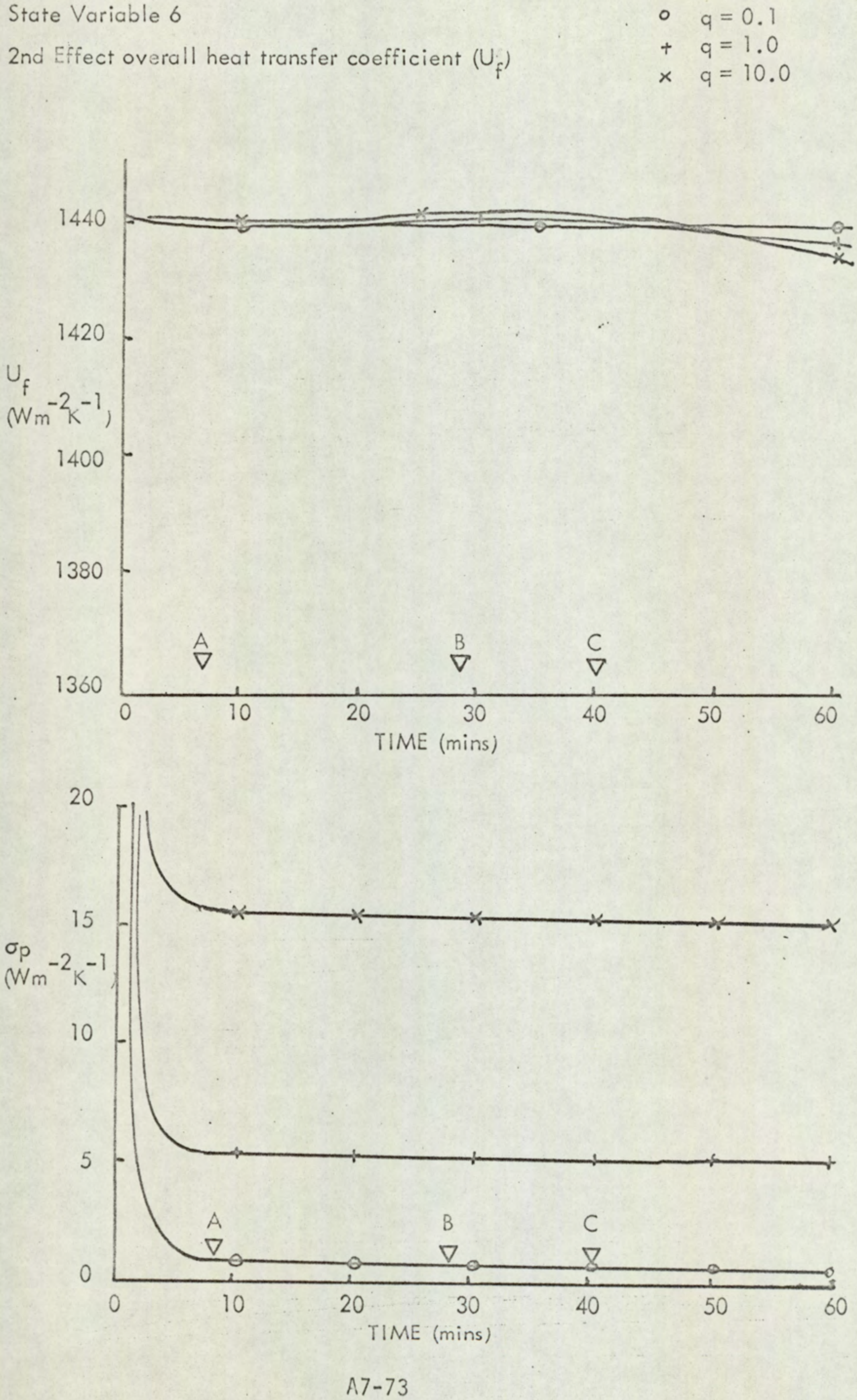


FIGURE A7.84

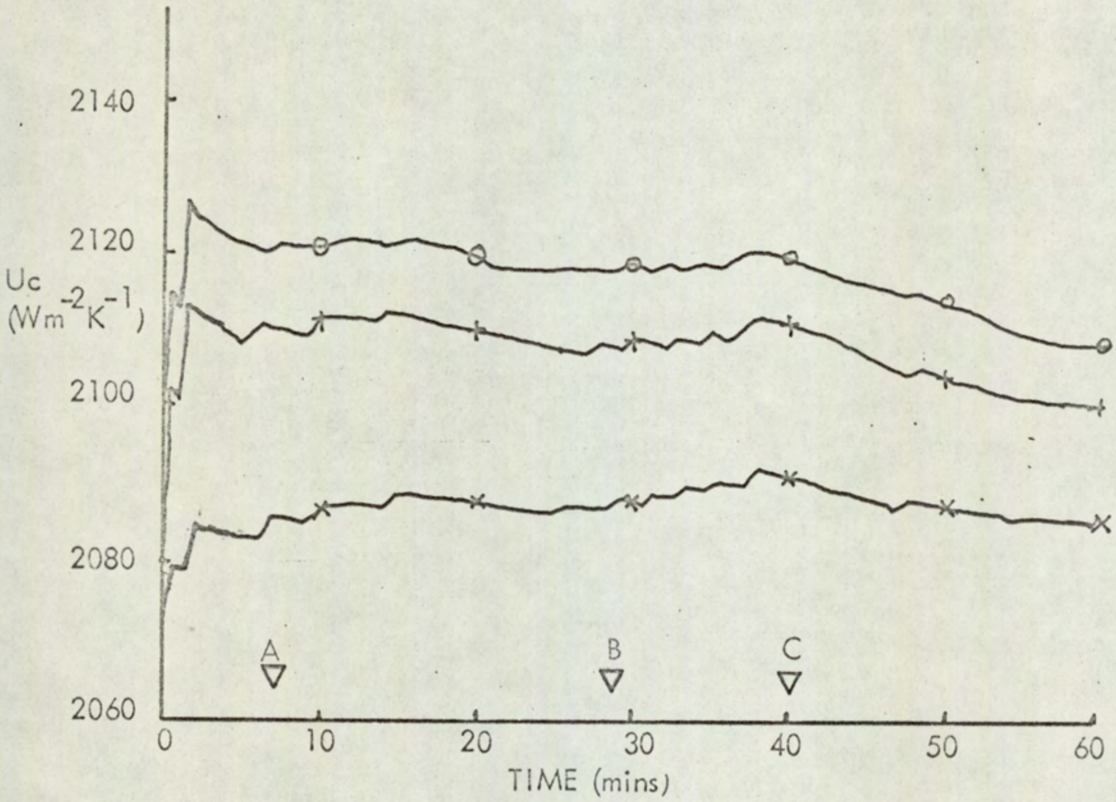
OFF-LINE KALMAN FILTER

DATA 2 PREDICTION 1

State Variable 7

Condenser overall heat transfer coefficient (Uc)

o q = 0.1
+ q = 1.0
x q = 10.0



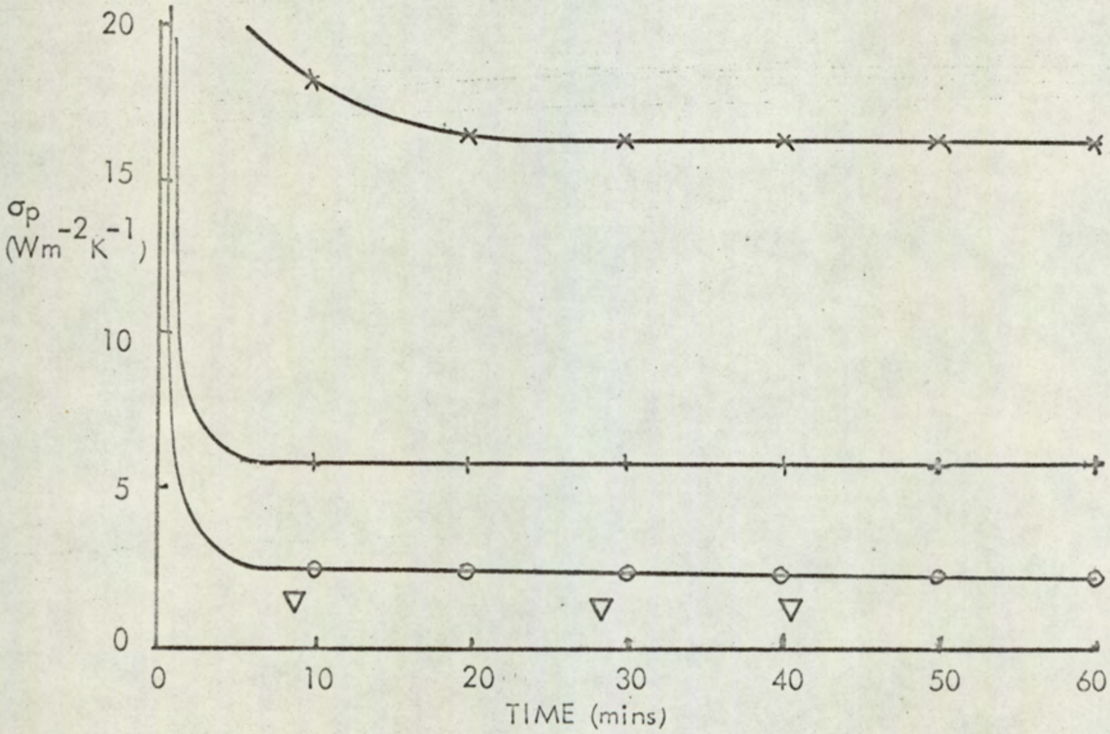


FIGURE A7.85

OFF-LINE KALMAN FILTER

State Variable 5

Preheater overall heat transfer coefficient

DATA 2 PREDICTION 1

o $q_1 = 0.1$ $q_2 = 10.0$

× $q_1 = 1.0$ $q_2 = 100$

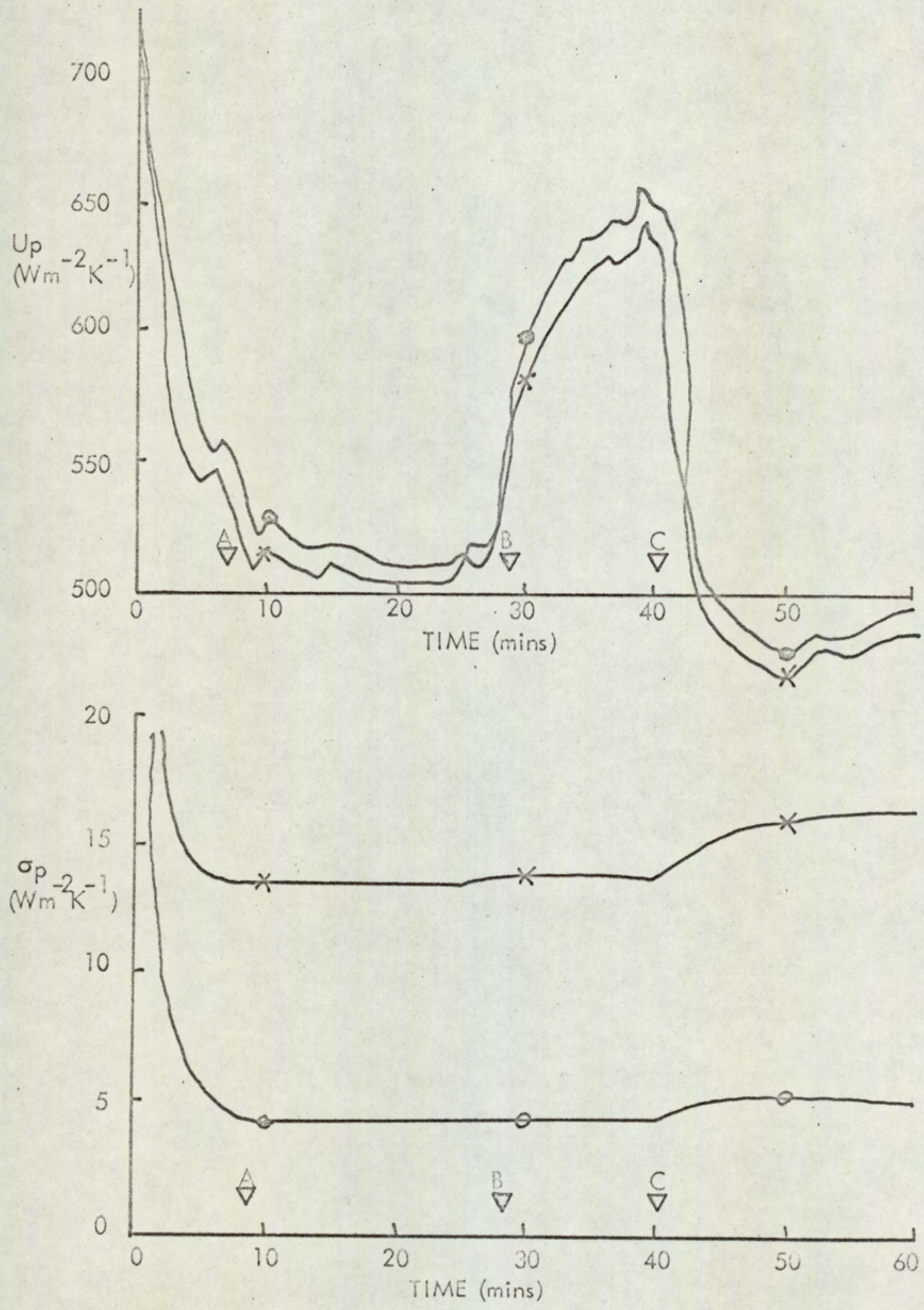


FIGURE A7.86

OFF-LINE KALMAN FILTER

State Variable 6

2nd Effect overall heat transfer coefficient

DATA 2 PREDICTION 1

o $q_1 = 0.1$ $q_2 = 10.0$

× $q_1 = 1.0$ $q_2 = 100$

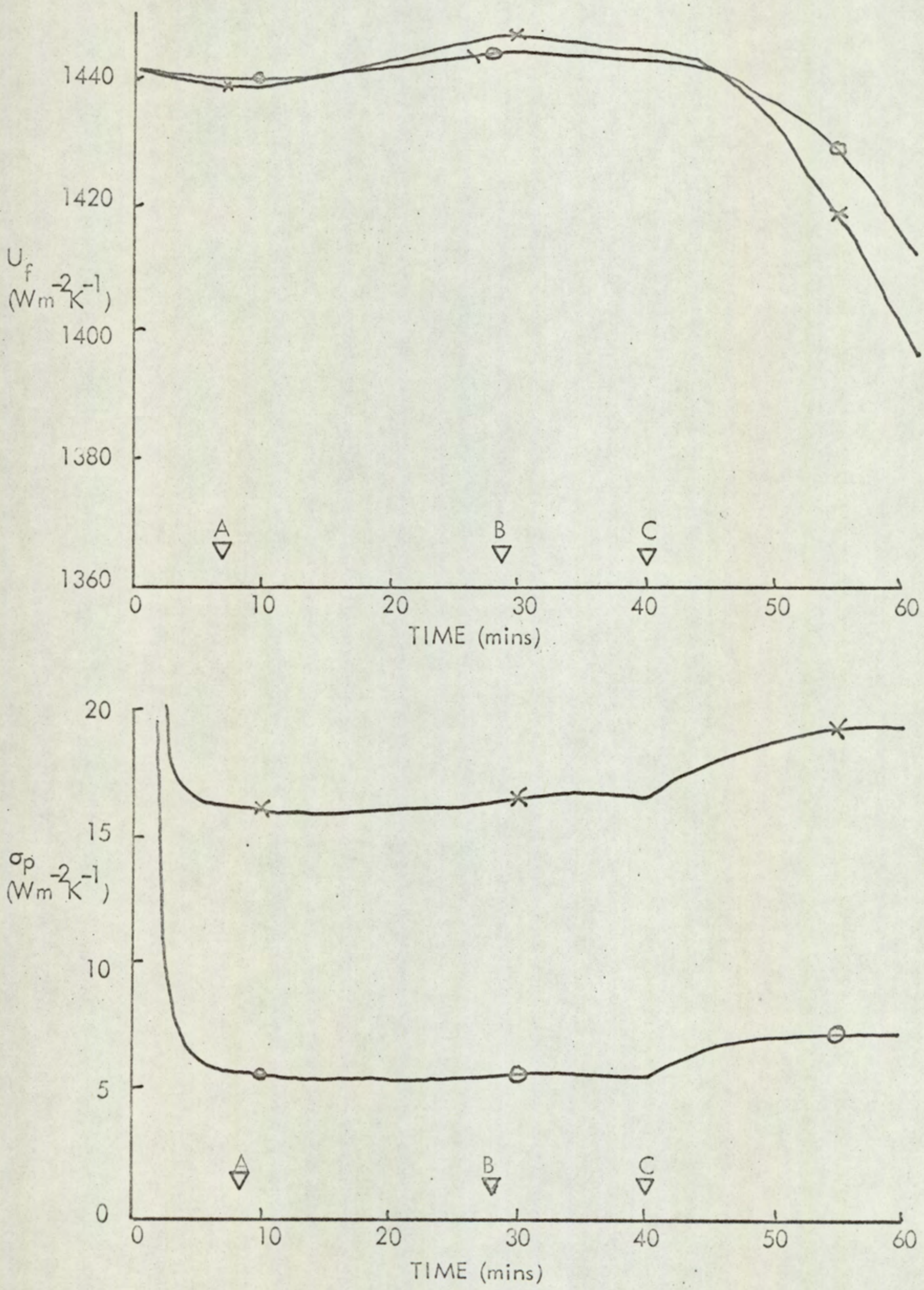


FIGURE A7.87

OFF-LINE KALMAN FILTER

DATA 2 PREDICTION 1

State Variable 7

Condenser overall heat transfer coefficient

o $q_1 = 0.1$ $q_2 = 10.0$

× $q_1 = 1.0$ $q_2 = 100$

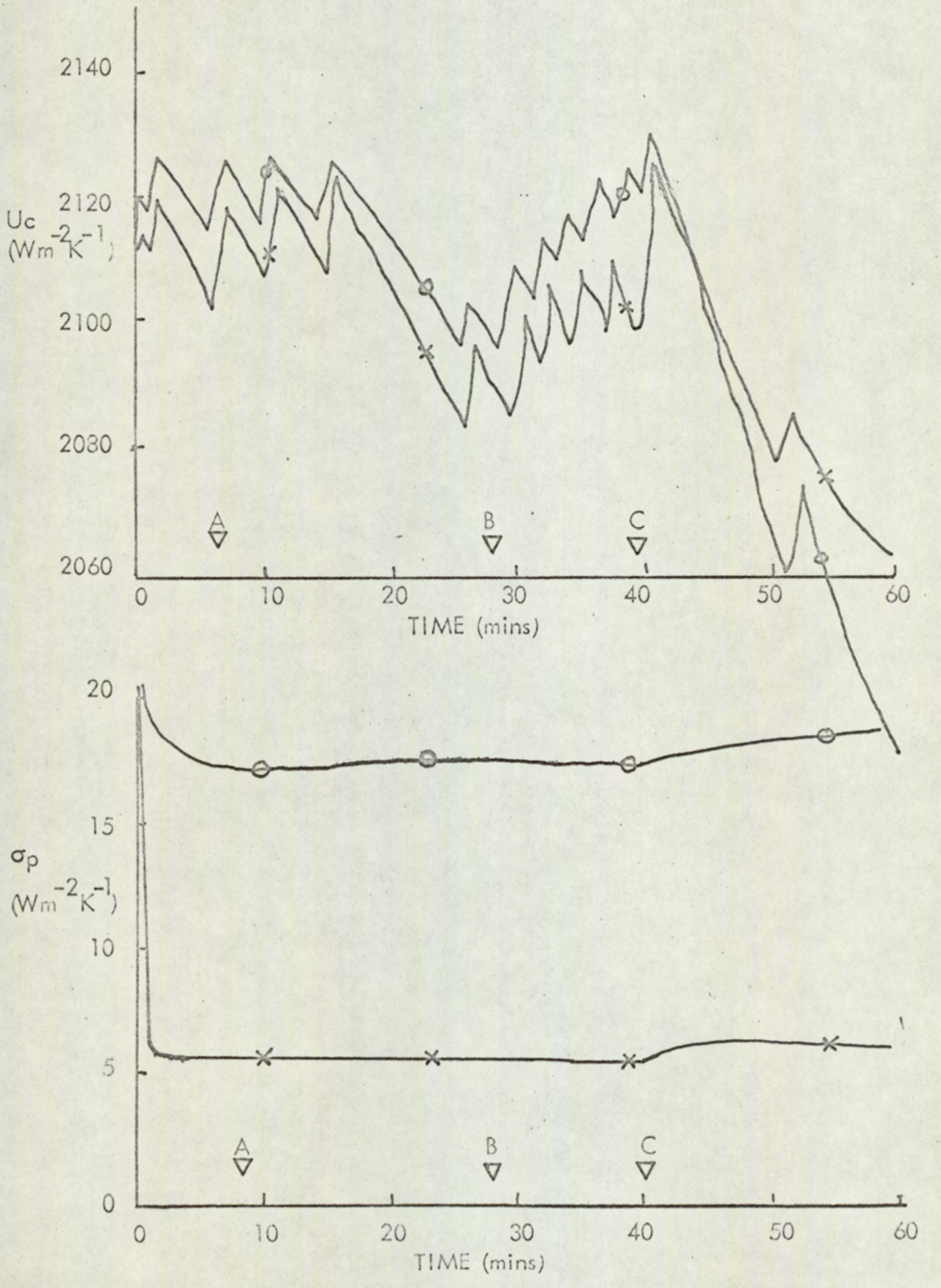


FIGURE A7.88

OFF-LINE KALMAN FILTER

DATA 1 PREDICTION 2

State Variable 1

Preheater tubeside liquid temperature

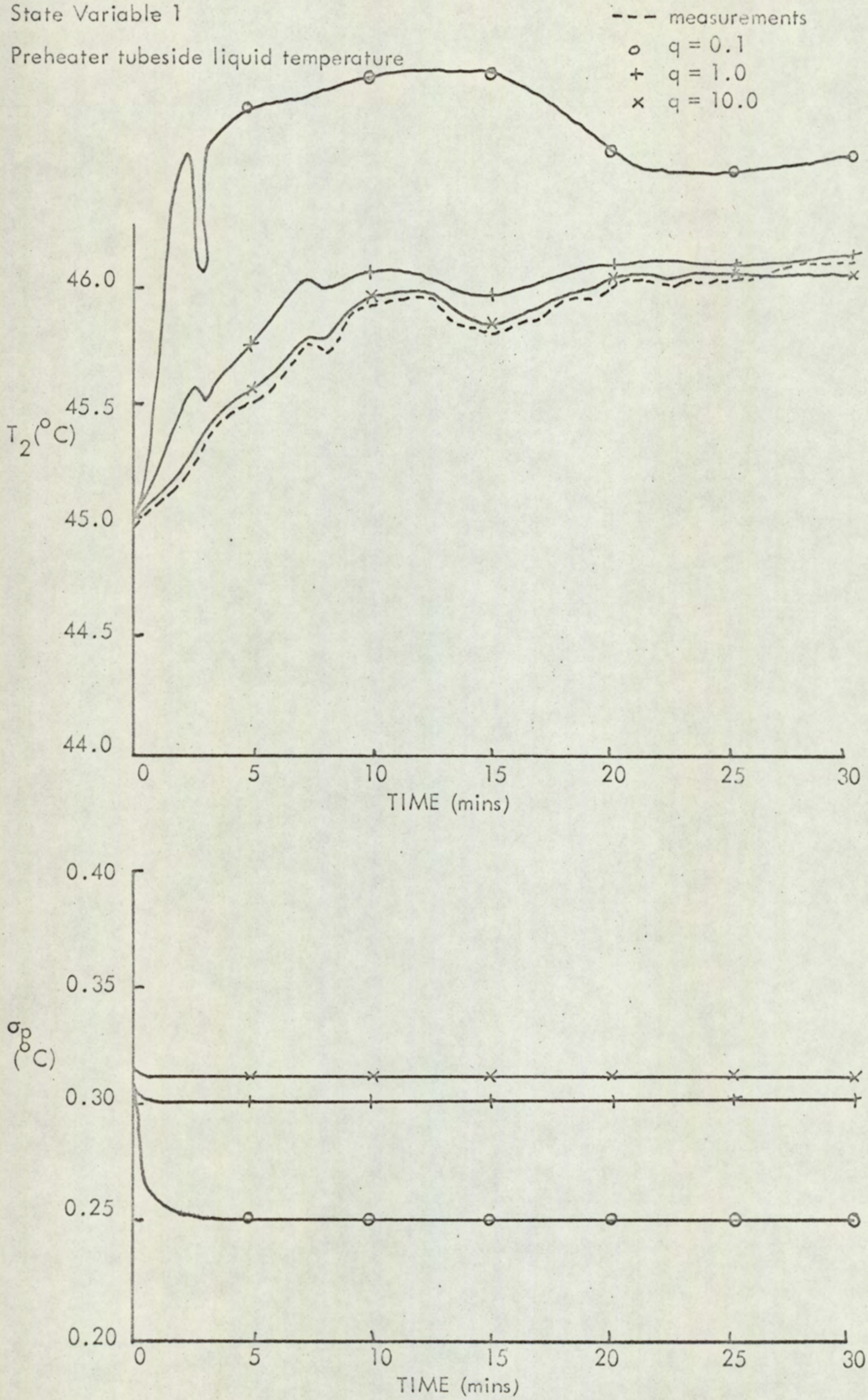


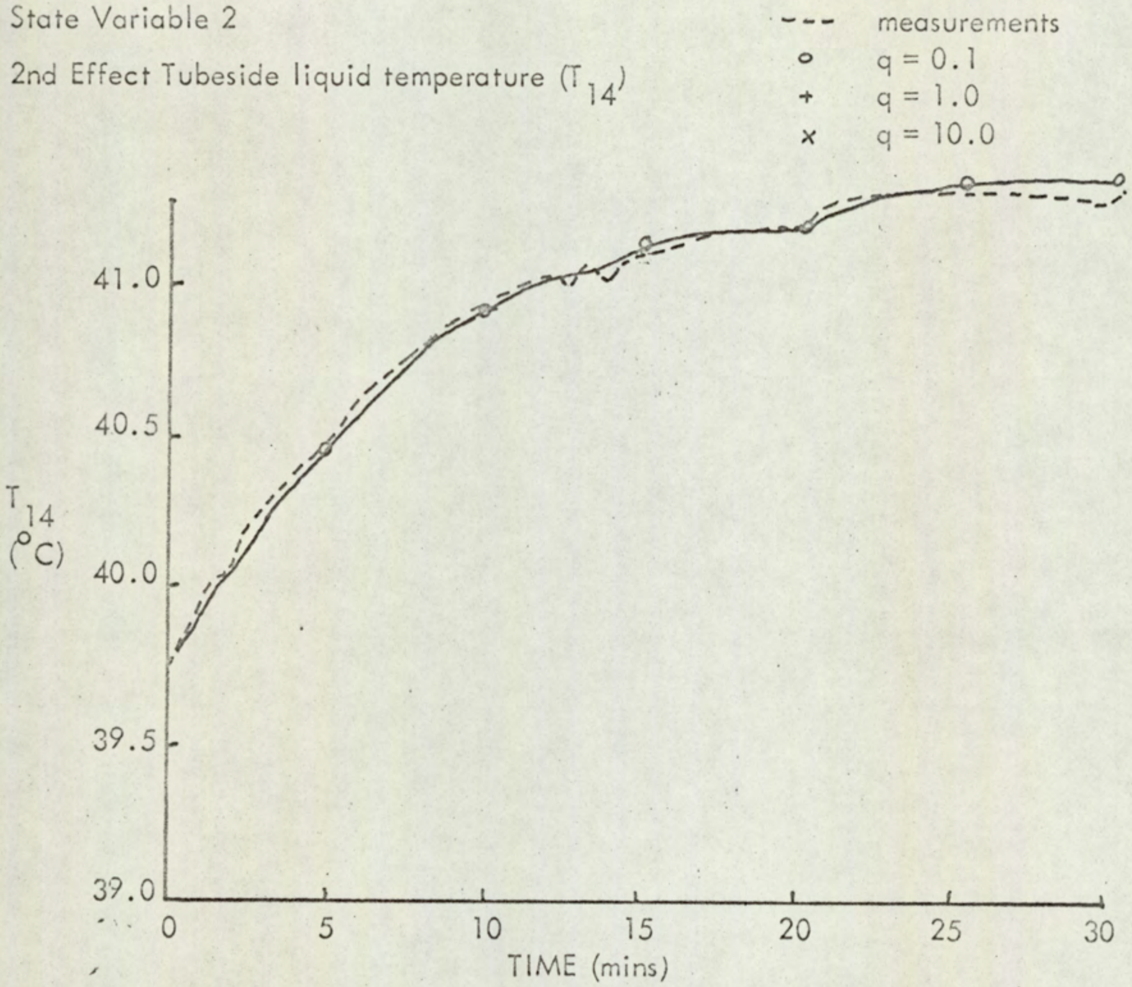
FIGURE A7.89

OFF-LINE KALMAN FILTER

DATA 1 PREDICTION 2

State Variable 2

2nd Effect Tubeside liquid temperature (T_{14})



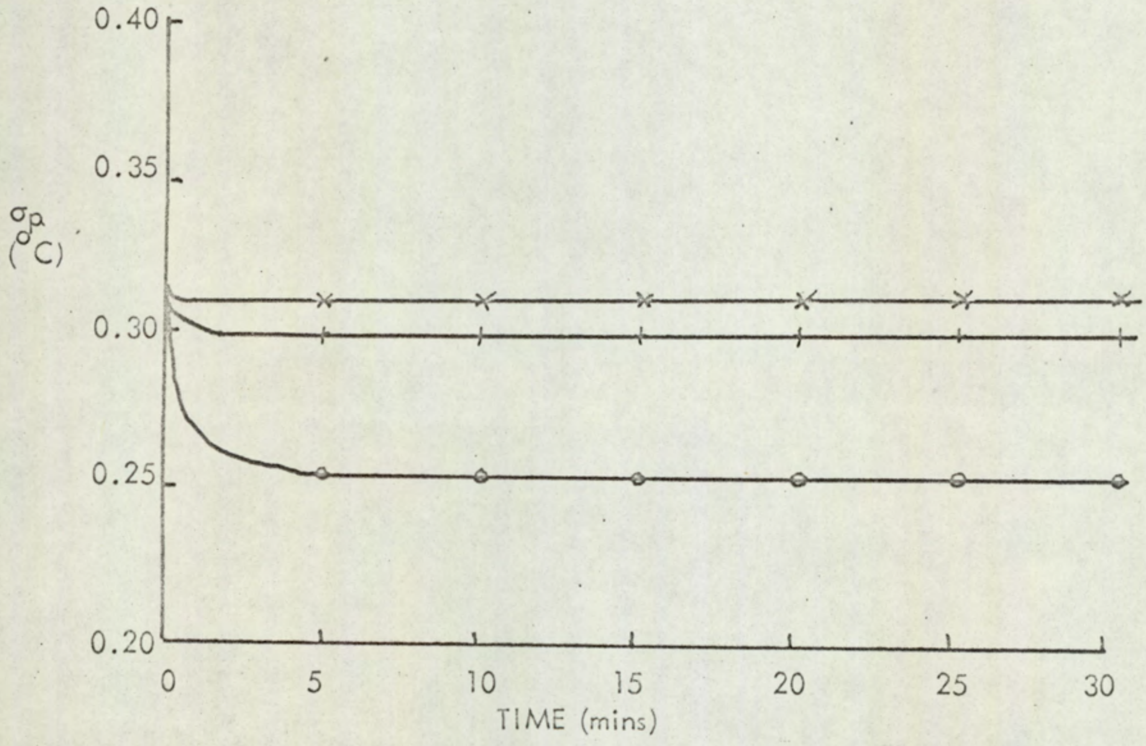


FIGURE A7.90

OFF-LINE KALMAN FILTER

DATA 1 PREDICTION 2

State Variable 3

Condenser tubeside liquid temperature (T_{13})

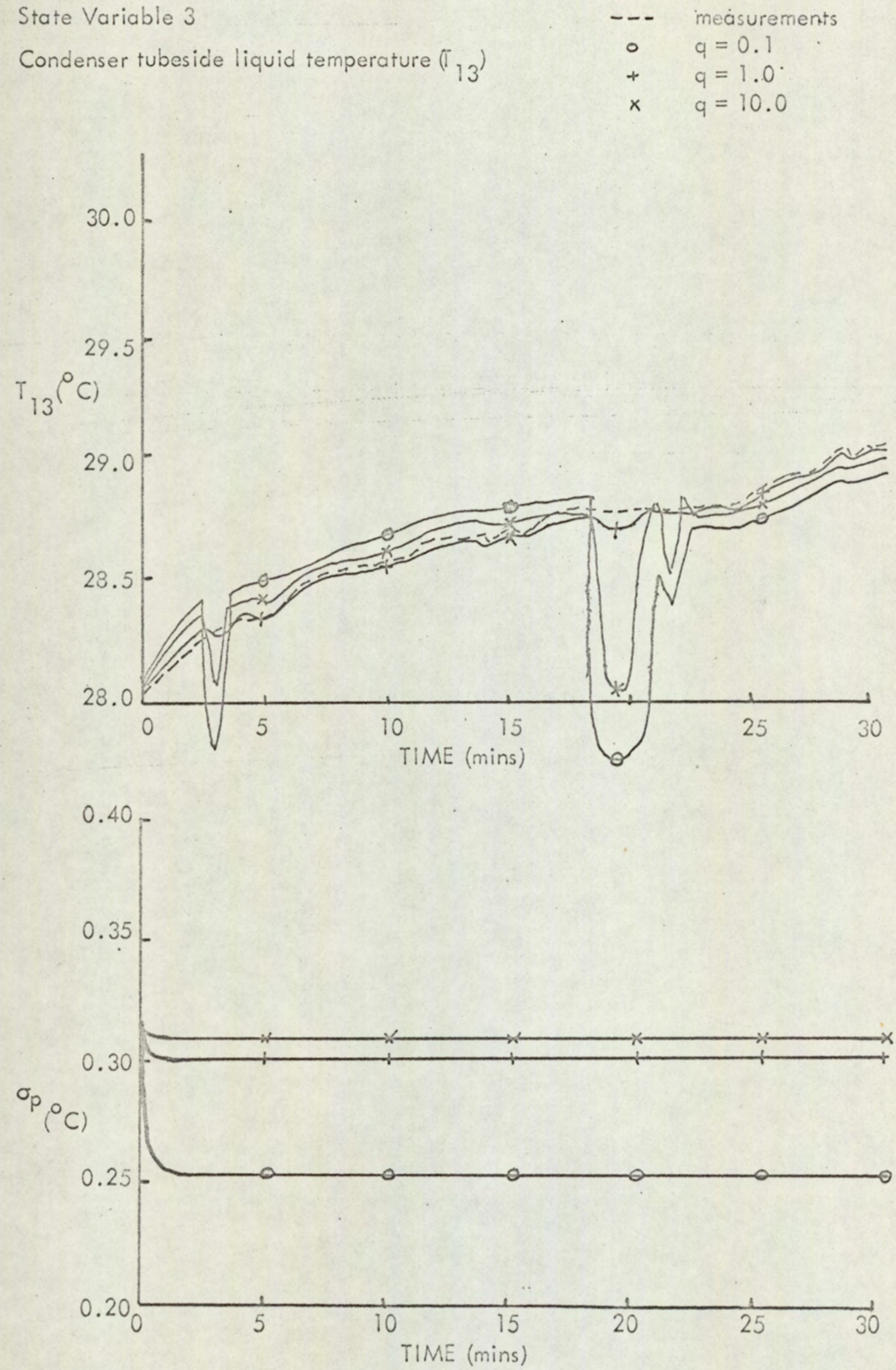


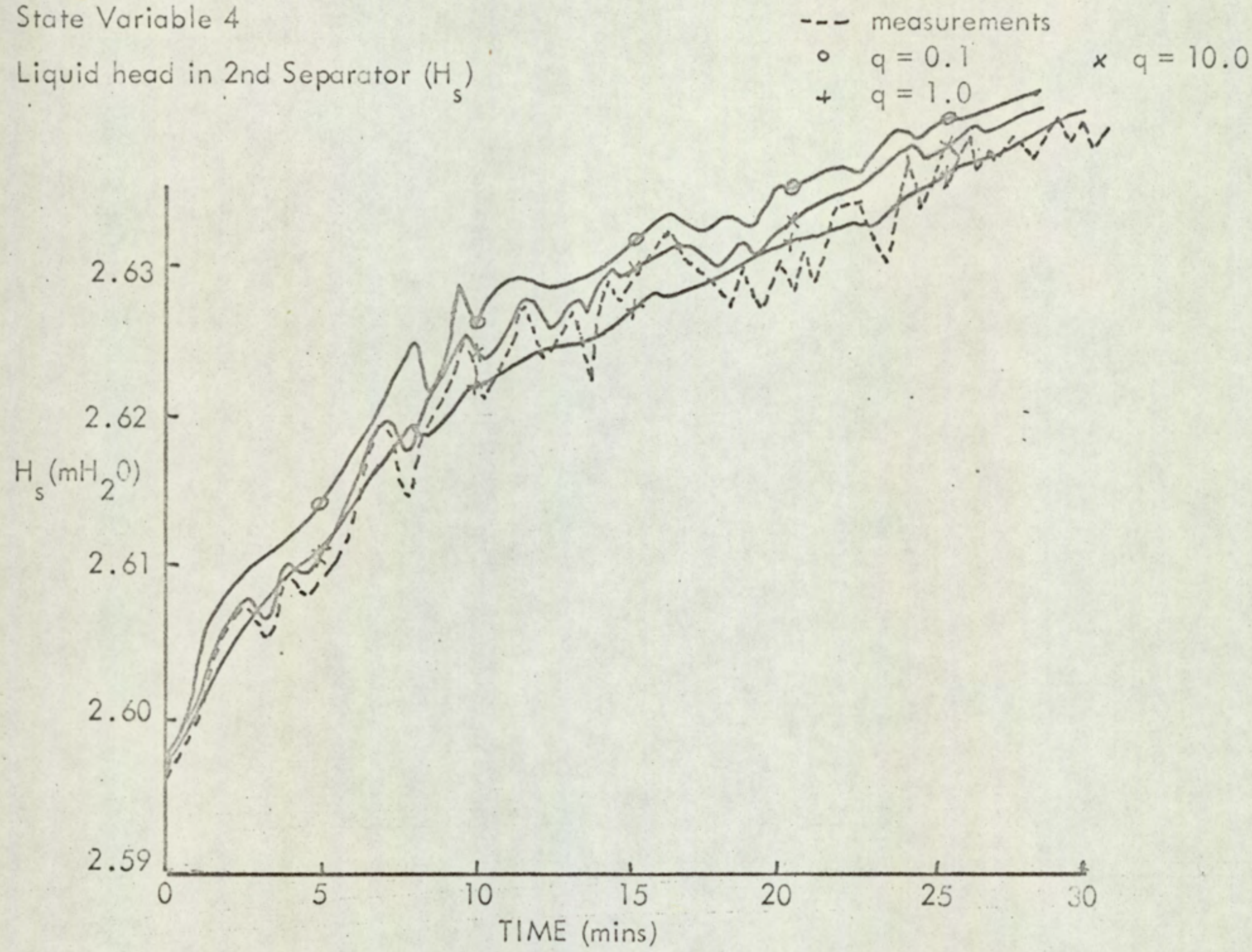
FIGURE A7.91

OFF-LINE KALMAN FILTER

DATA 1 PREDICTION 2

State Variable 4

Liquid head in 2nd Separator (H_s)



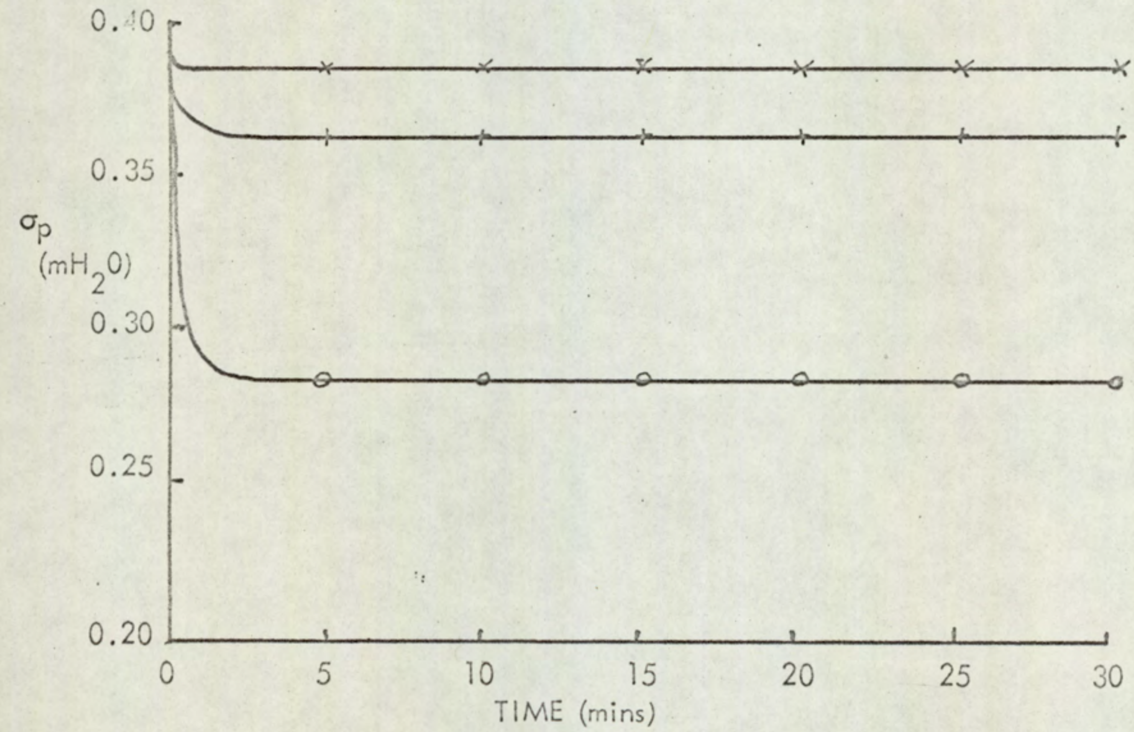


FIGURE A7.92

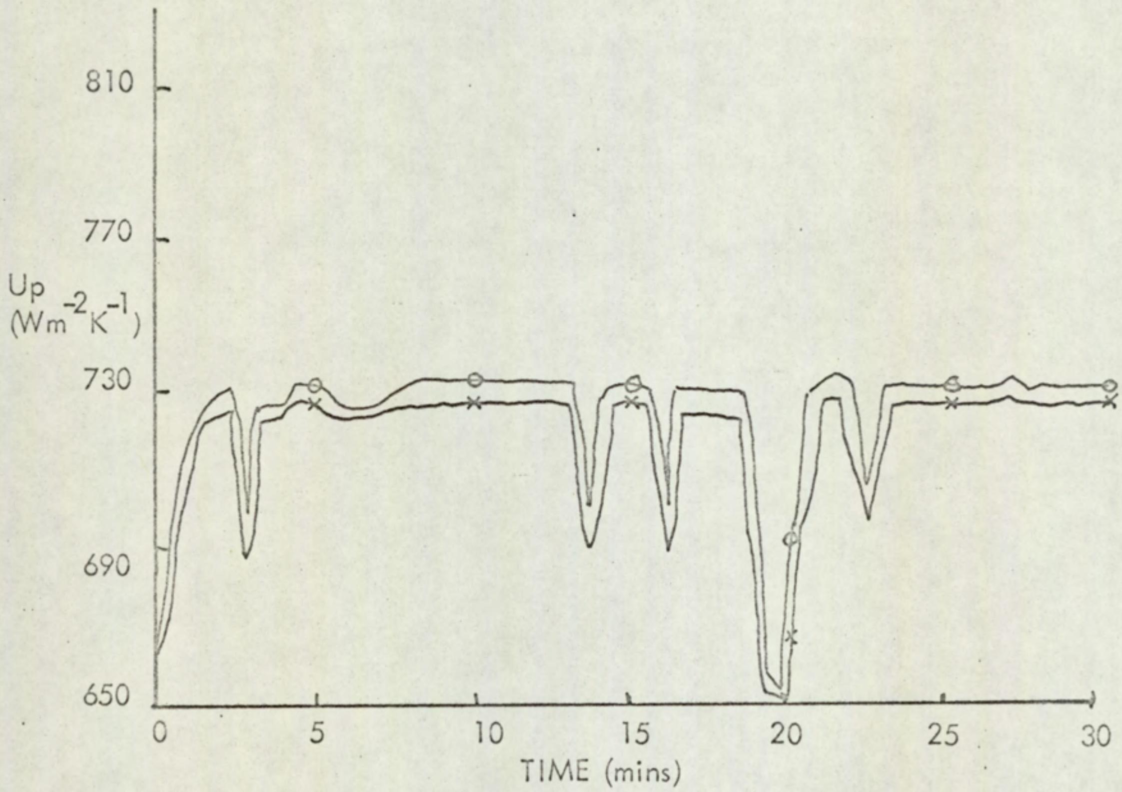
OFF-LINE KALMAN FILTER

DATA 1 PREDICTION 2

State Variable 5

Preheater overall heat transfer coefficient (Up)

o q = 0.1
+ q = 1.0
x q = 10.0



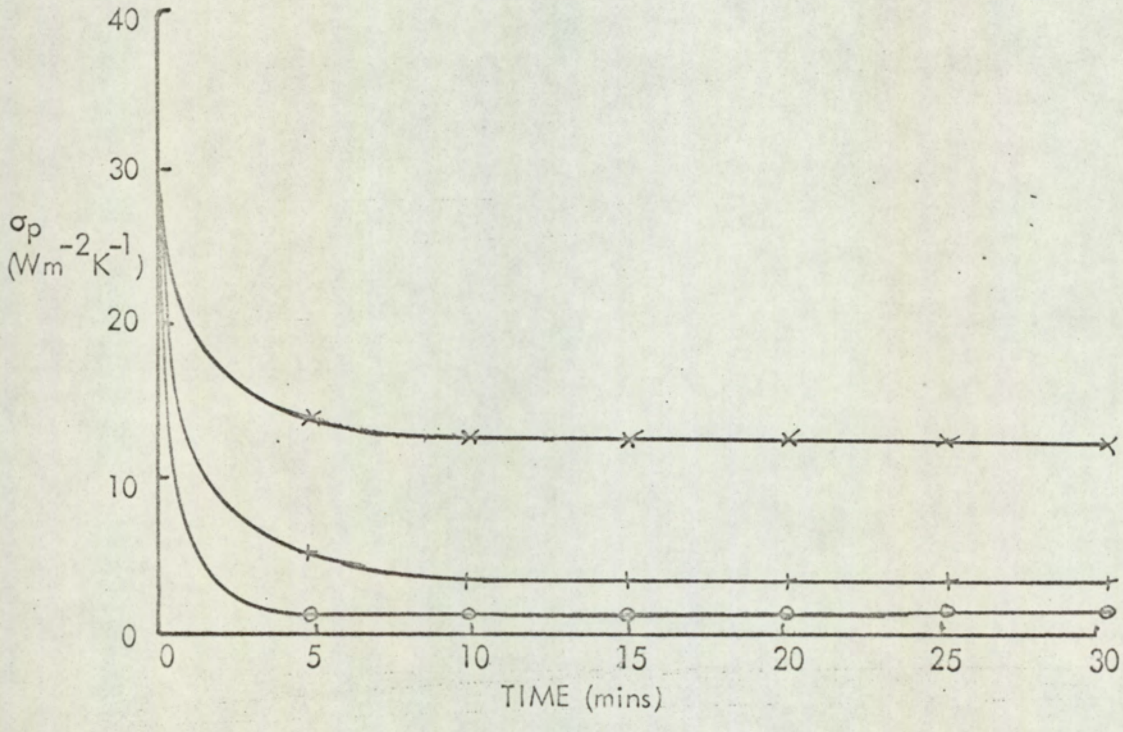


FIGURE A7.93

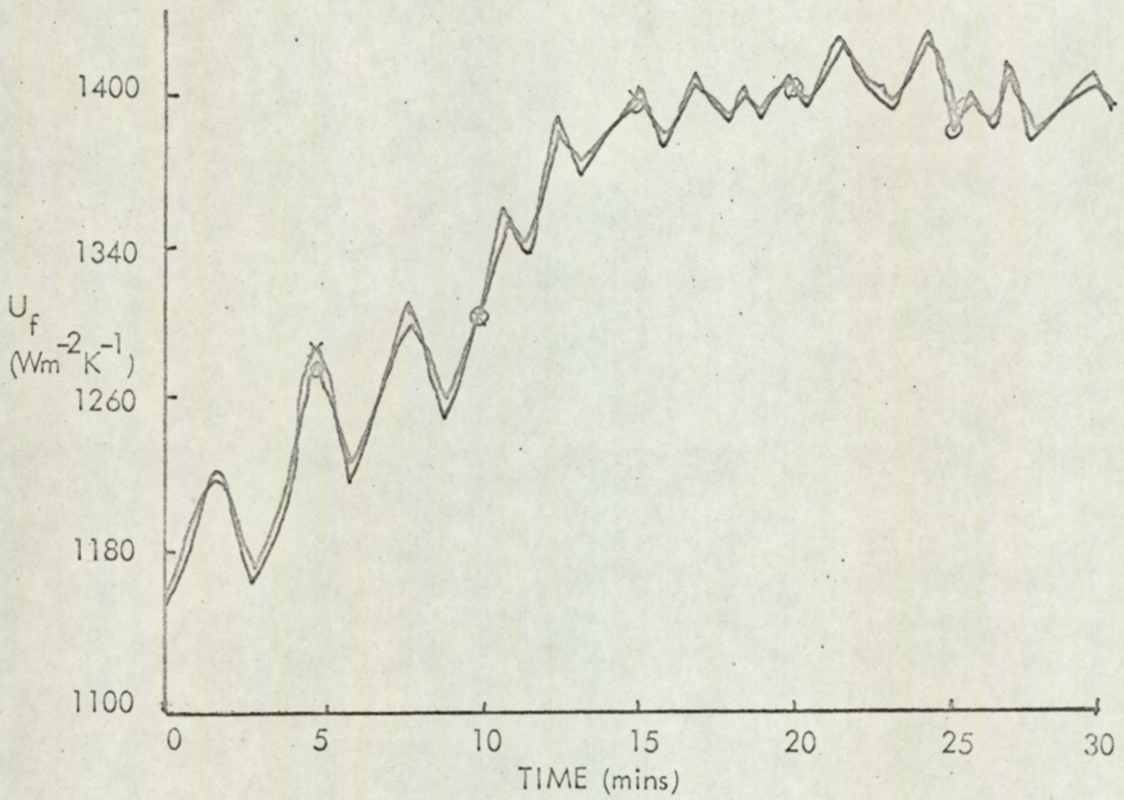
OFF-LINE KALMAN FILTER

DATA 1 PREDICTION 2

State Variable 6

2nd Effect overall heat transfer coefficient (Uf)

o q = 0.1
+ q = 1.0
x q = 10.0



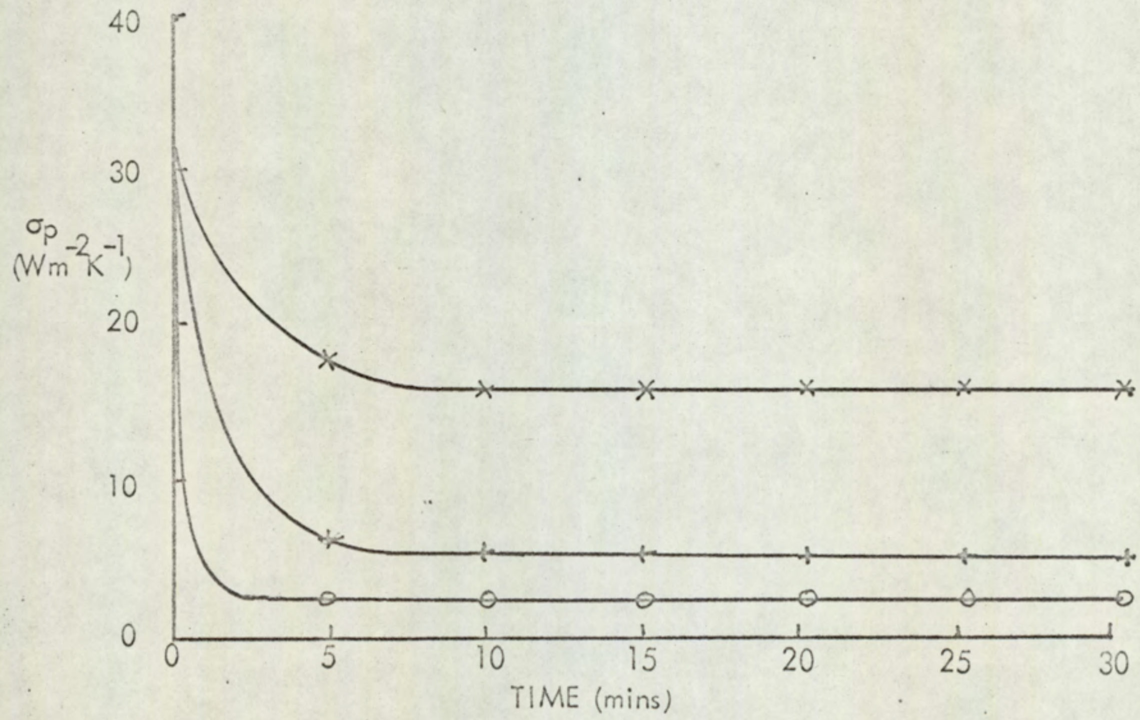


FIGURE A7.94

OFF-LINE KALMAN FILTER

DATA 1 PREDICTION 2

State Variable 7

Condenser overall heat transfer coefficient (Uc)

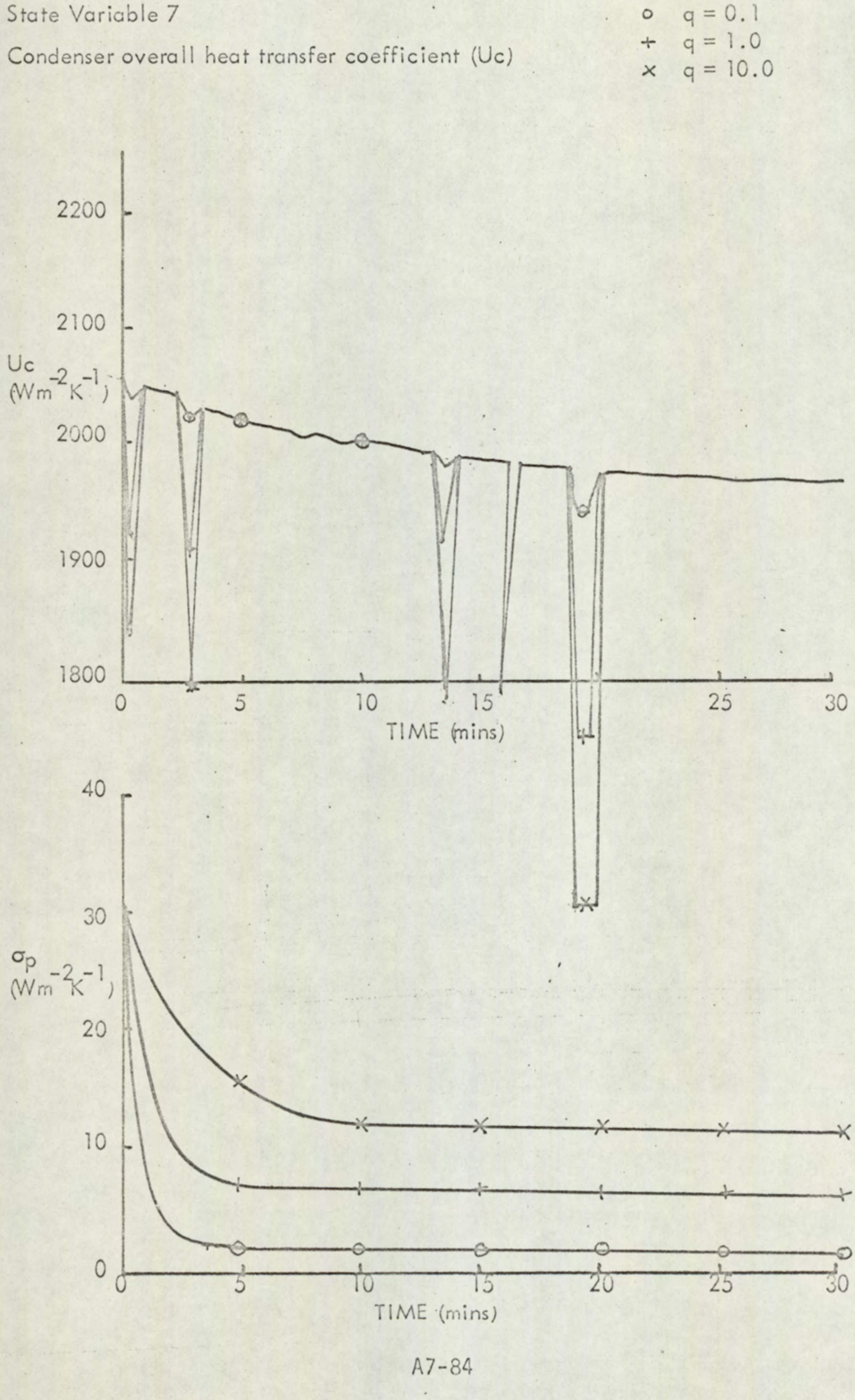


FIGURE A7.95

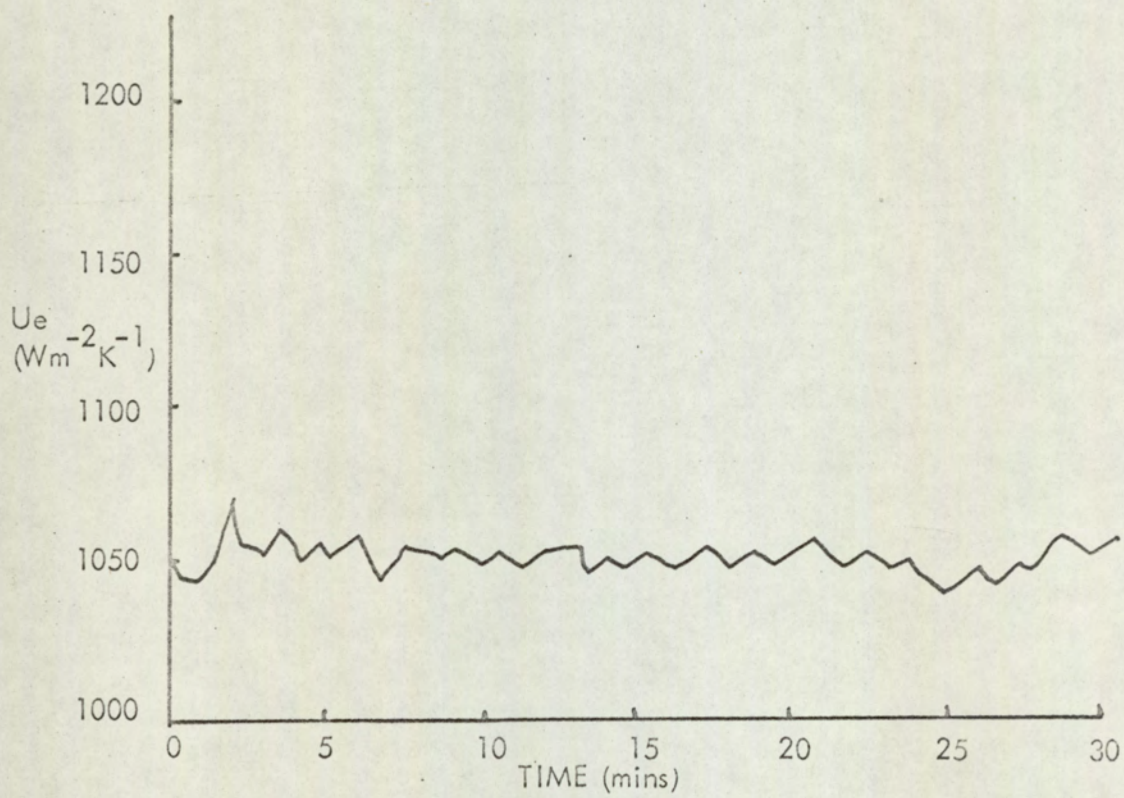
OFF-LINE KALMAN FILTER

State Variable 8

1st Effect overall heat transfer coefficient (Ue)

DATA 1 PREDICTION 2

o q = 0.1
+ q = 1.0
× q = 10.0



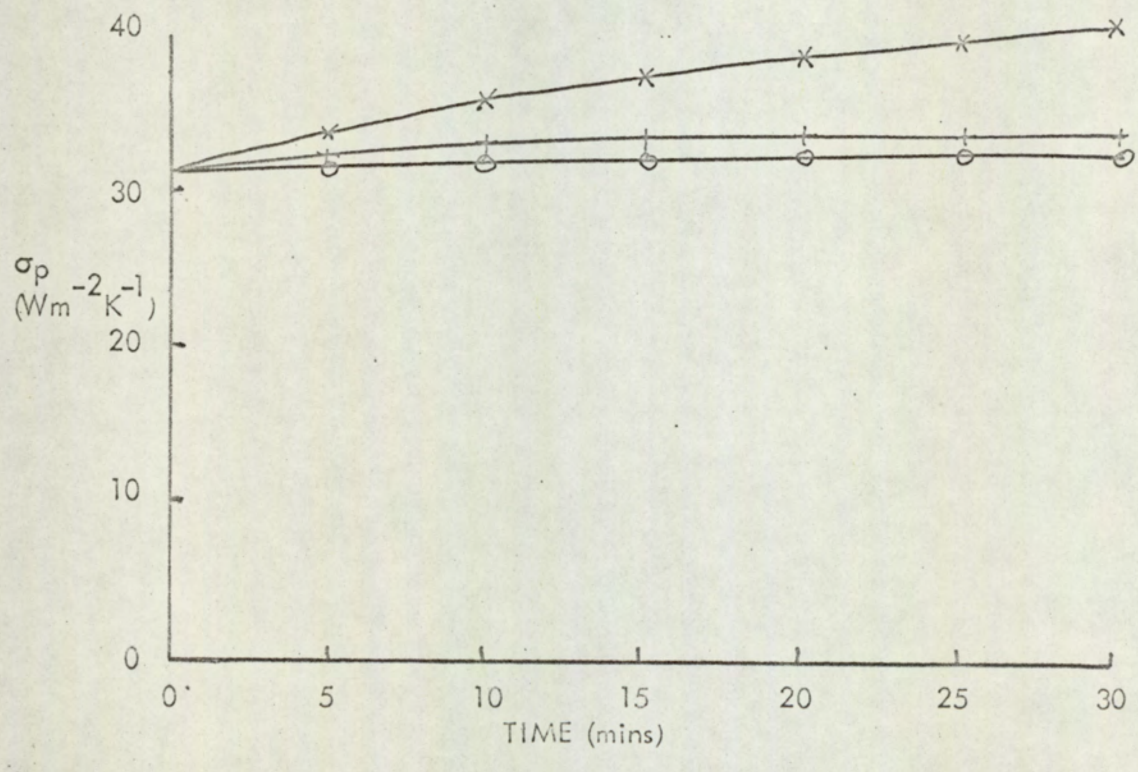


FIGURE A7.96

OFF-LINE KALMAN FILTER

State Variable 1

Preheater tubeside liquid temperature (T_2)

DATA 2 PREDICTION 2

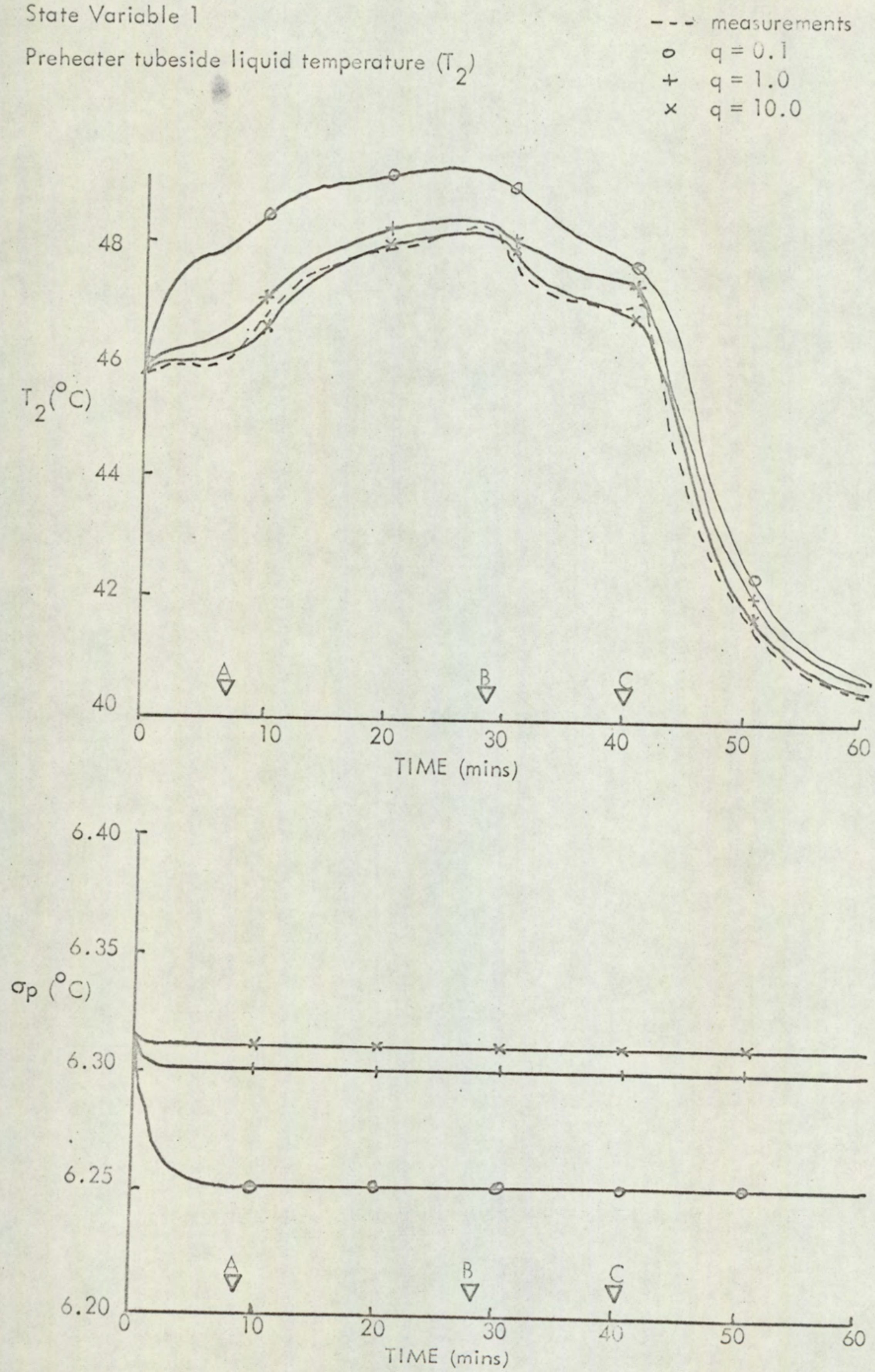


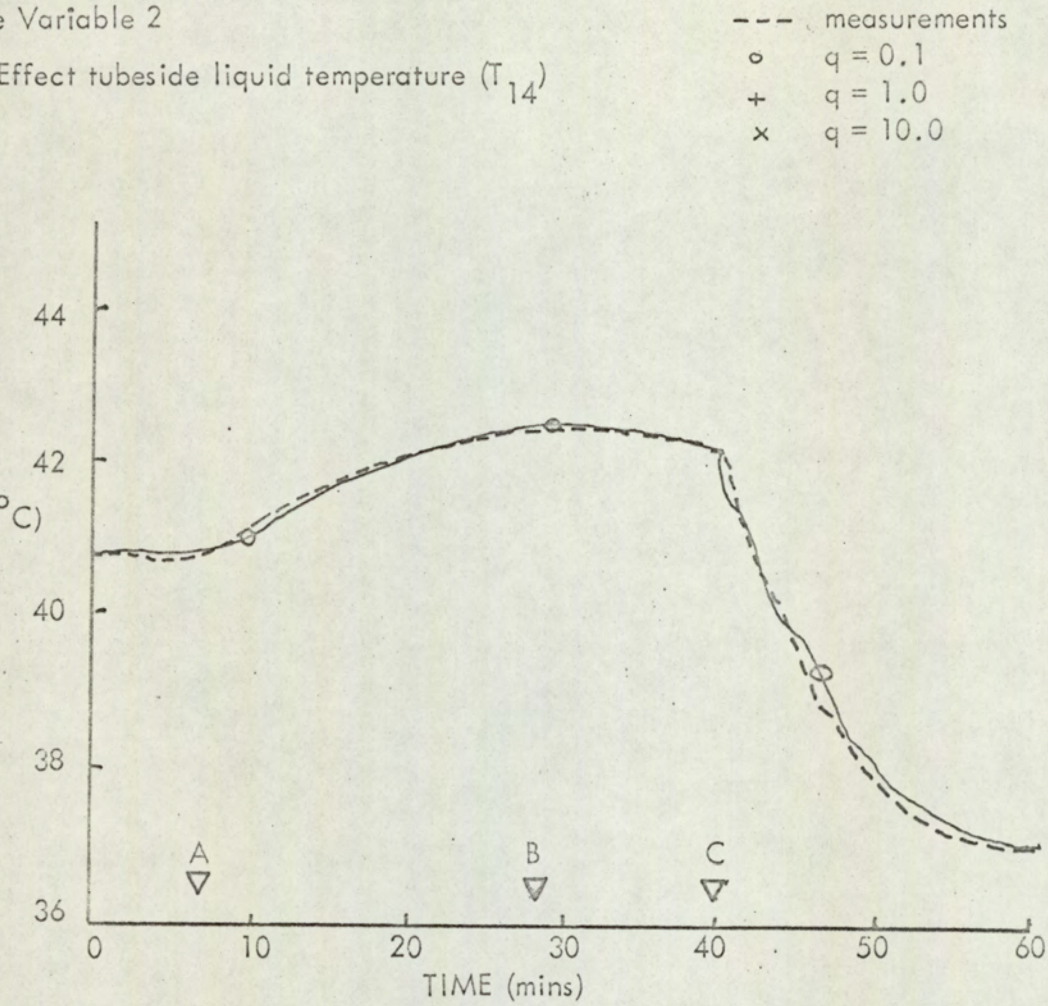
FIGURE A7.97

OFF-LINE KALMAN FILTER

DATA 2 PREDICTION 2

State Variable 2

2nd Effect tubeside liquid temperature (T_{14})



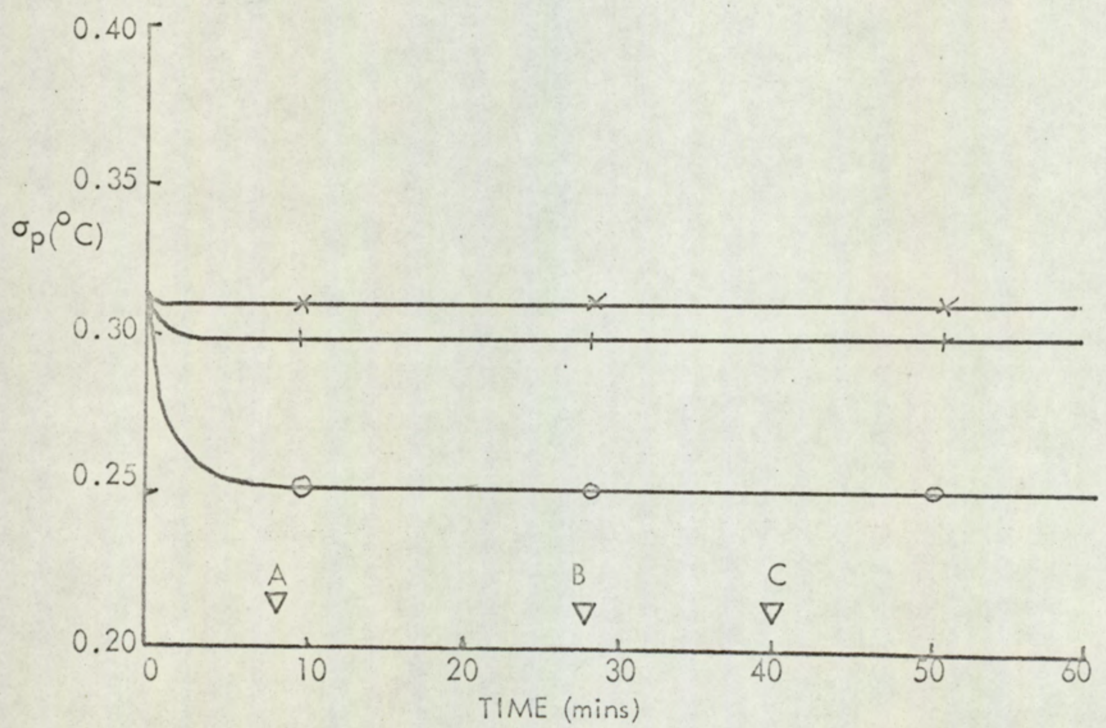


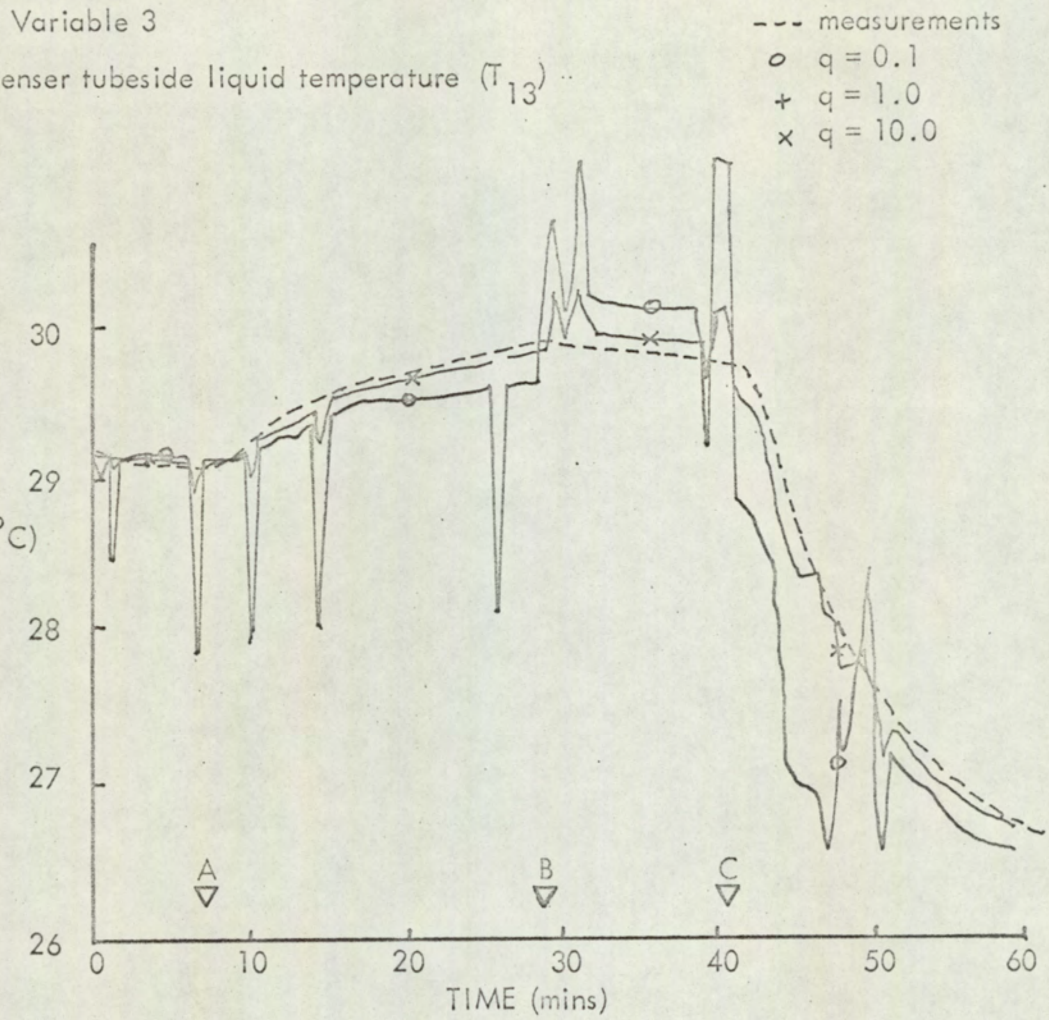
FIGURE A7.98

OFF-LINE KALMAN FILTER

DATA 2 PREDICTION 2

State Variable 3

Condenser tubeside liquid temperature (T_{13})



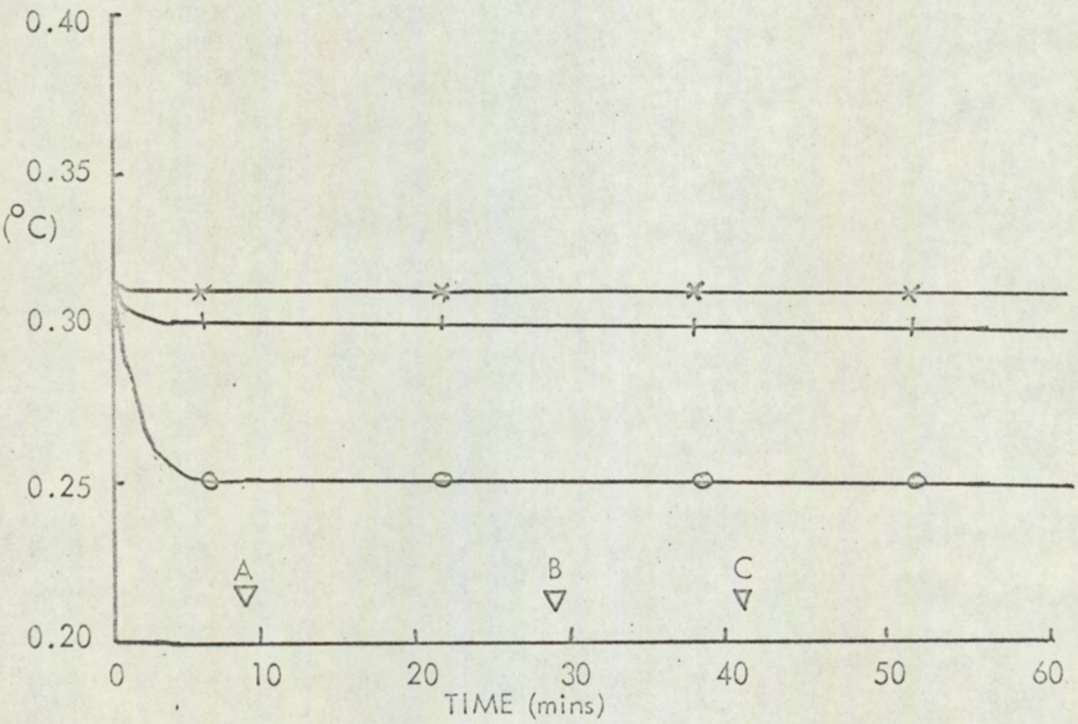


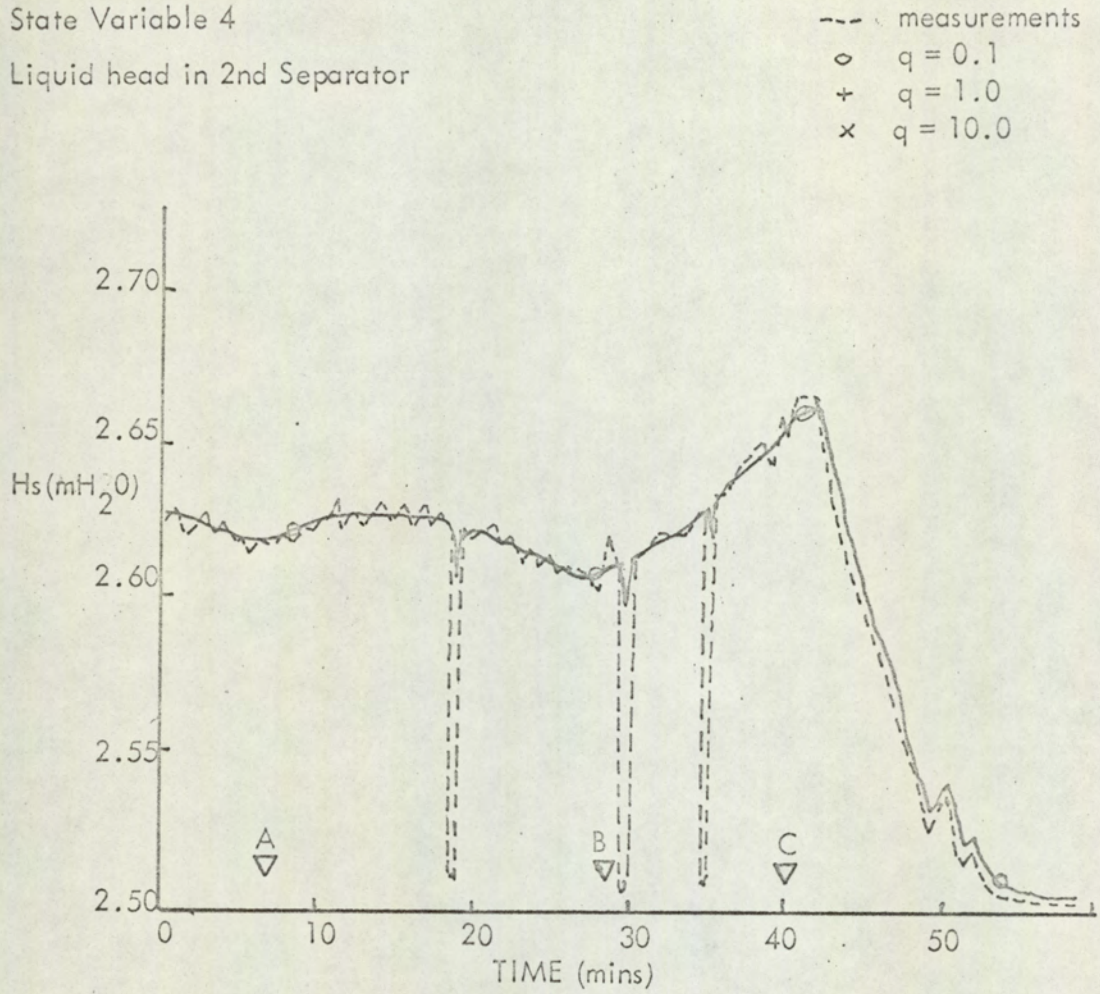
FIGURE A7.99

OFF-LINE KALMAN FILTER

State Variable 4

Liquid head in 2nd Separator

DATA 2 PREDICTION 2



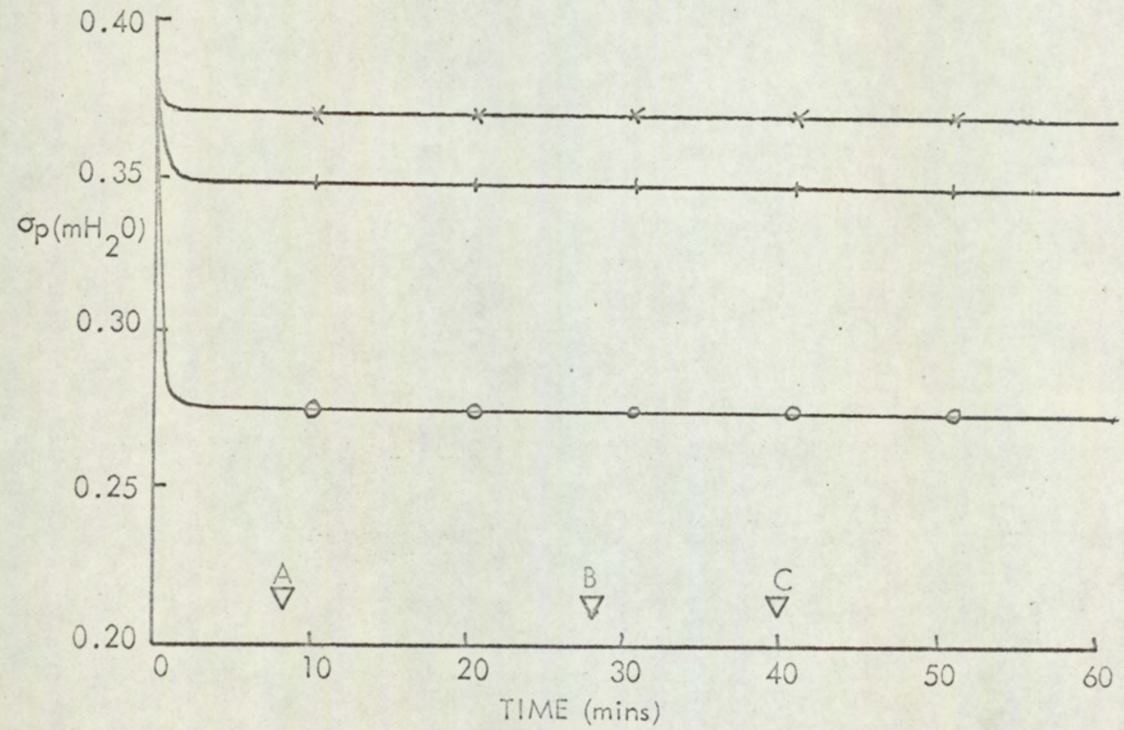


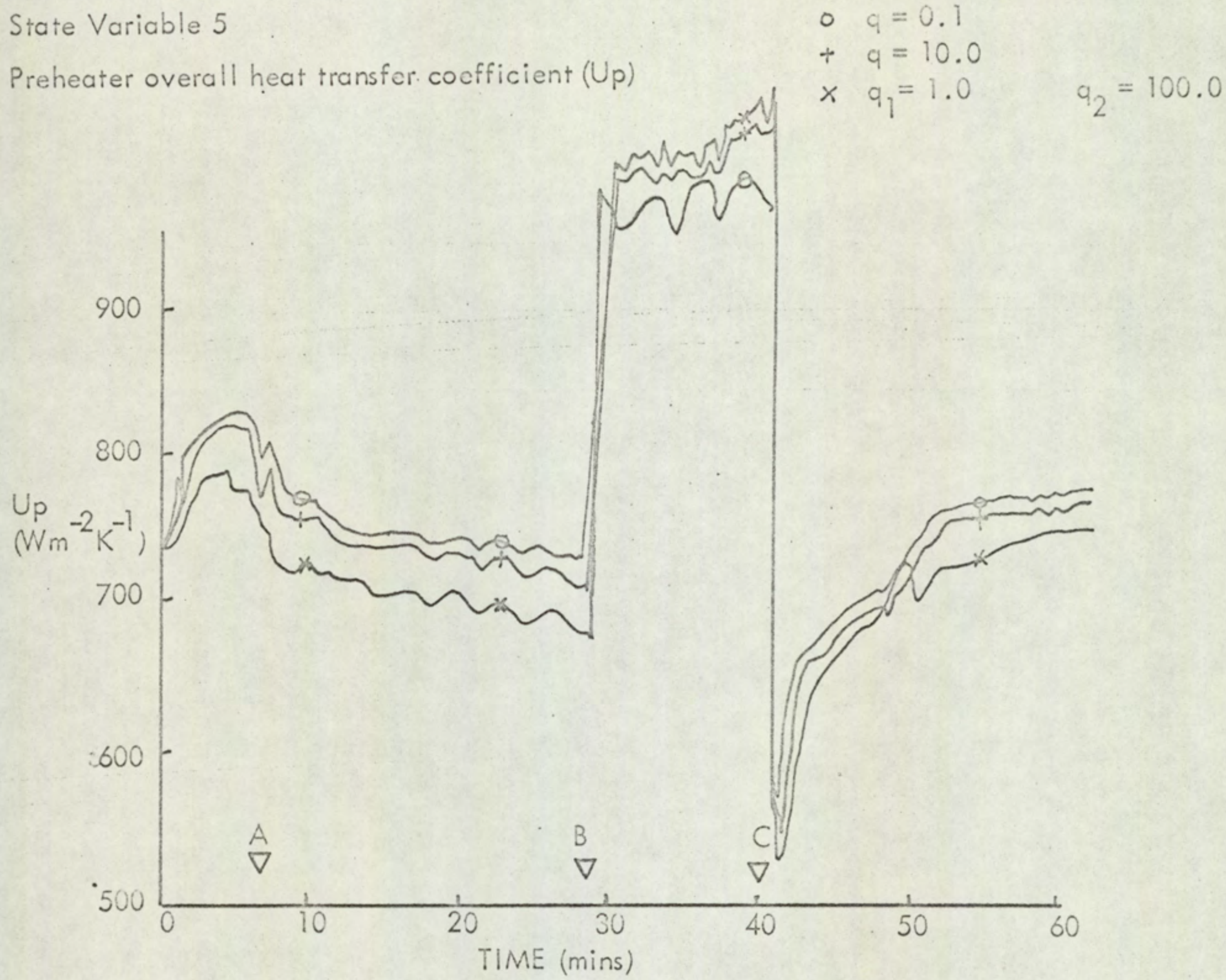
FIGURE A7.100

OFF-LINE KALMAN FILTER

DATA 2 PREDICTION 2

State Variable 5

Preheater overall heat transfer coefficient (Up)



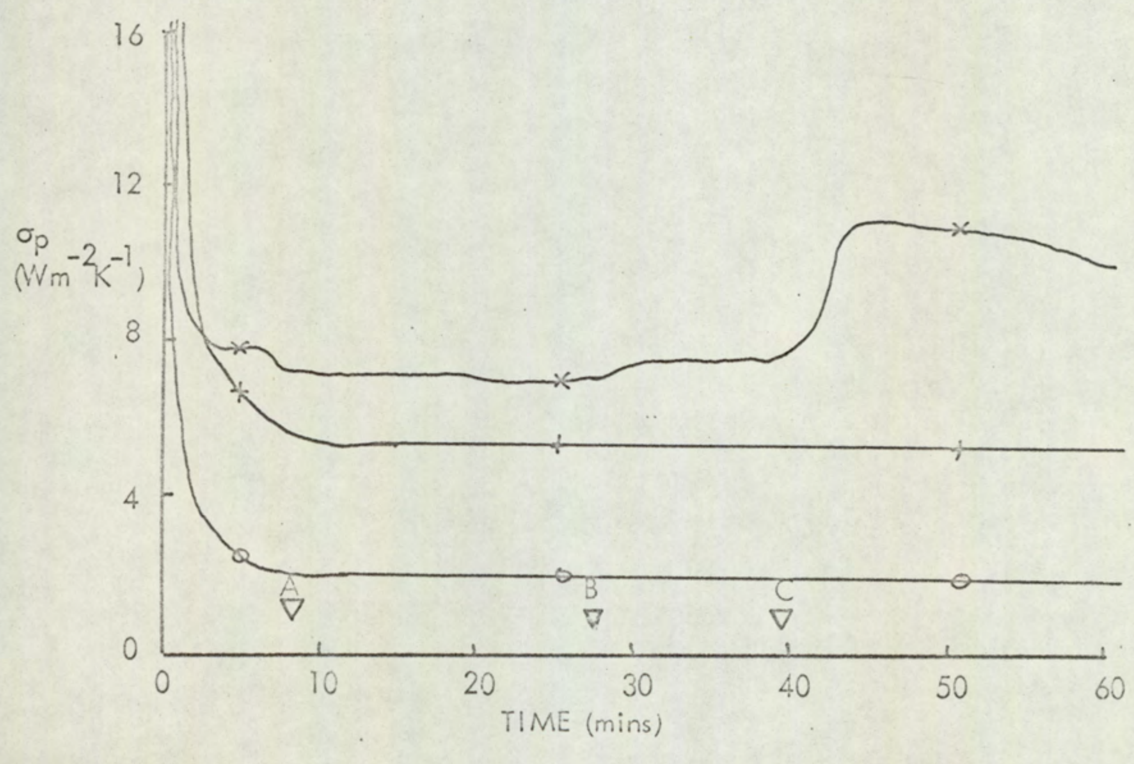


FIGURE A7.101

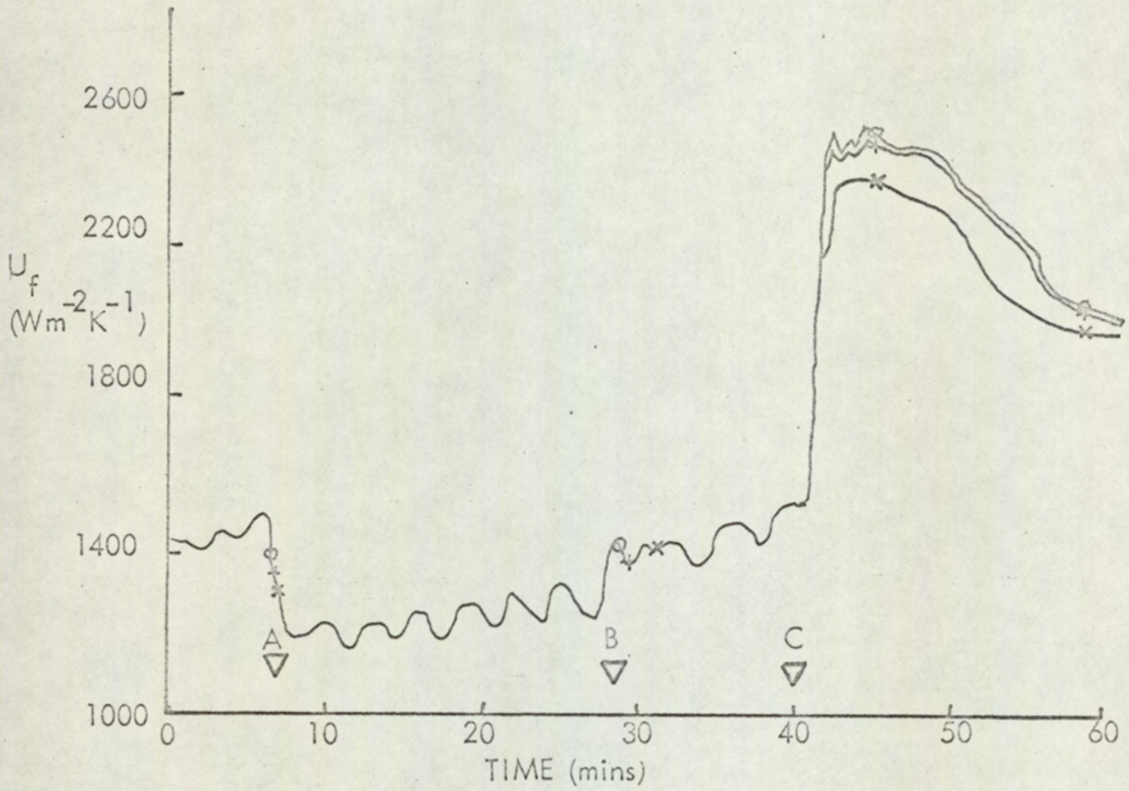
OFF-LINE KALMAN FILTER

DATA 2 PREDICTION 2

State Variable 6

2nd Effect overall heat transfer coefficient (U_f)

o $q = 0.1$
+ $q = 10.0$
× $q_1 = 1.0$ $q_2 = 100.0$



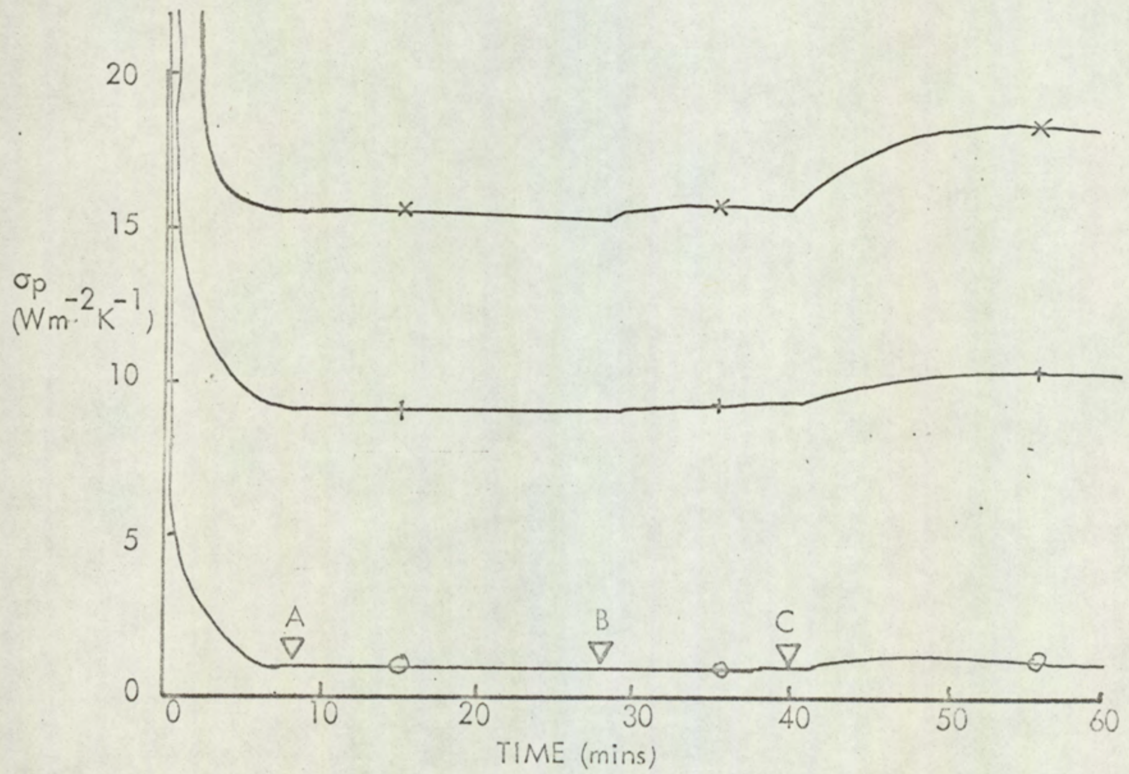


FIGURE A7.102

OFF-LINE KALMAN FILTER

DATA 2 PREDICTION 2

State Variable 7

Condenser overall heat transfer coefficient (Uc)

o q = 0.1
+ q = 10.0
× q_1 = 1.0 q_2 = 100.0

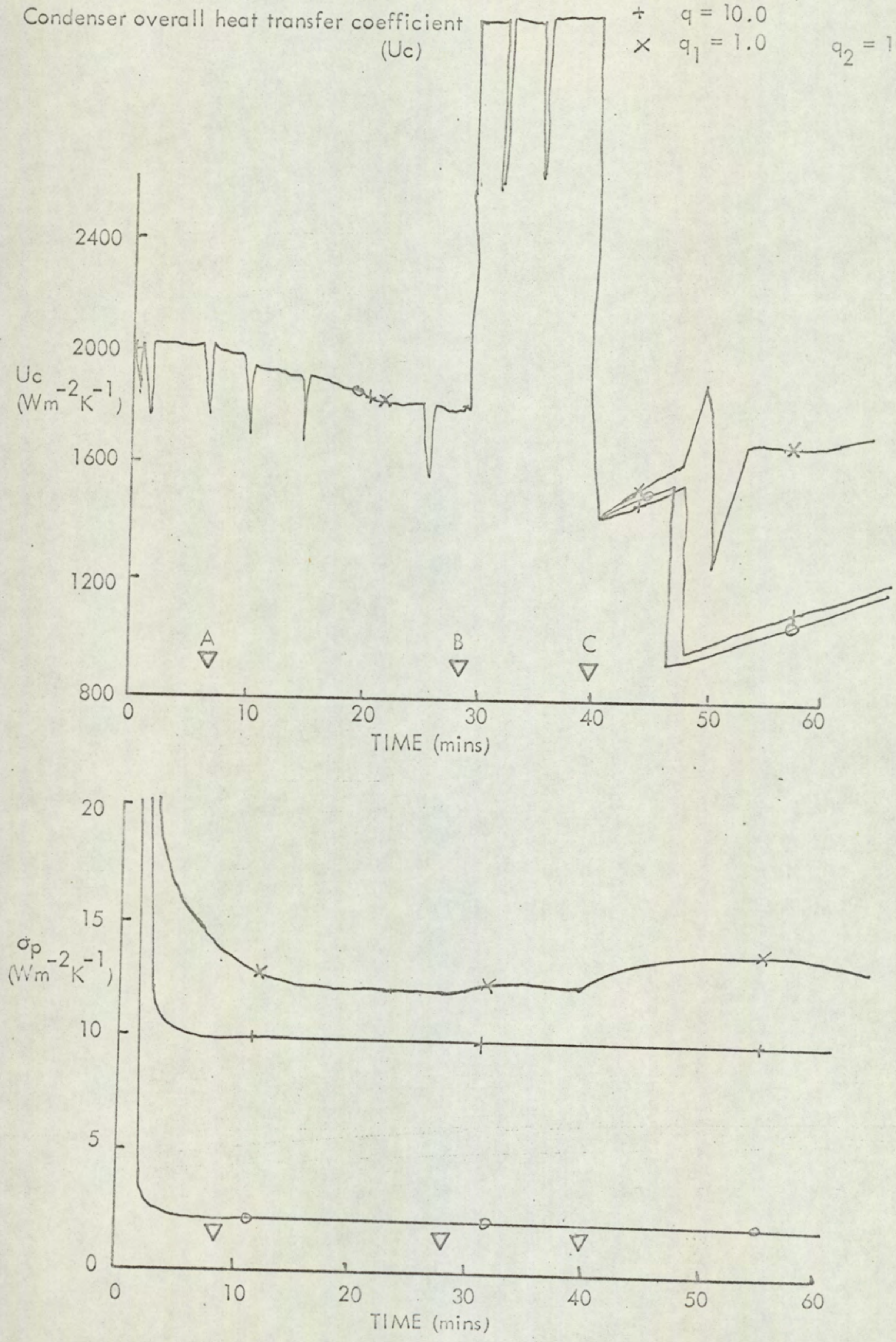


TABLE A7.1

Summary of Steady State Results for Preheater

RUN NO.	VAPOUR		LIQUID		
			IN	OUT	
	TEMP °C	FLOW gs^{-1}	TEMP °C	TEMP °C	FLOW gs^{-1}
1	48.35	2.73	16.50	42.05	30.02
2	40.87	7.77	16.14	38.21	29.51
3	48.81	1.22	17.78	43.03	27.34
4	47.08	1.31	14.94	41.26	28.19
5	46.36	1.37	14.46	41.78	28.09
6	44.63	1.70	14.07	39.47	36.68
7	46.05	1.24	14.52	43.85	23.69
8	46.2	1.20	14.4	43.89	22.82
9	45.53	1.54	14.43	41.41	32.24
10	45.56	1.52	14.43	41.05	32.21
11	47.45	1.15	15.96	38.57	28.89
12	48.04	1.31	15.8	41.57	28.74
13	46.05	1.75	15.46	40.43	39.48
14	45.31	1.69	15.37	39.88	38.76
15	34.00	0.85	15.45	33.47	26.29
16	38.84	0.83	15.22	32.9	26.26
17	48.27	0.96	15.08	45.44	17.87
18	45.66	0.90	15.54	43.86	17.72
19	43.61	1.42	15.19	38.24	34.92
20	44.38	1.44	15.07	38.7	34.69
21	45.76	1.26	14.18	40.66	27.06
22	45.91	1.22	15.14	40.66	27.06
23	46.65	1.08	15.25	42.28	22.72
24	46.02	1.07	15.33	42.35	22.24
25	43.88	1.56	14.72	37.54	38.89

TABLE A7.1 cont/..

RUN NO.	VAPOUR		LIQUID		
			IN	OUT	
	TEMP °C	FLOW gs^{-1}	TEMP °C	TEMP °C	FLOW gs^{-1}
26	39.45	0.48	19.96	38.65	13.69
27	37.29	1.04	16.86	34.34	33.73
28	48.59	1.54	15.97	43.39	31.3
29	34.41	0.94	16.06	32.21	32.25
30	49.74	14.48	16.71	43.99	30.74
31	48.86	1.47	15.34	42.51	30.39
32	47.35	1.47	13.03	42.36	28.53
33	44.76	1.51	10.12	39.64	29.23
34	40.97	2.24	6.59	34.43	46.09
35	46.14	2.19	12.77	40.02	45.61
36	50.09	1.09	13.82	47.74	17.04
37	42.34	0.70	18.6	41.84	17.03
38	40.86	1.46	16.88	38.00	39.1
39	41.42	1.17	15.31	38.48	28.46
40	41.9	1.00	15.62	40.18	22.83
41	35.68	0.58	15.92	35.51	16.2
42	40.2	0.62	14.6	35.46	16.19
43	39.5	0.96	15.37	35.15	27.51
44	49.5	1.55	14.57	44.17	29.6
45	34.53	0.88	14.95	31.88	29.38
46	44.6	1.28	14.19	38.99	29.43
47	44.42	1.07	13.87	41.01	22.39
48	43.69	1.44	17.09	38.29	38.74
49	43.49	1.46	16.12	37.63	38.65
50	42.44	1.15	15.37	36.91	30.4
51	51.6	1.90	18.59	42.59	44.97
52	52.66	1.59	17.08	43.2	34.57
53	53.28	1.24	17.51	45.61	24.91
54	43.57	1.26	16.61	36.32	40.00

Table A7.1 cont/..

RUN NO.	VAPOUR		LIQUID		
			IN	OUT	
	TEMP °C	FLOW gs^{-1}	TEMP °C	TEMP °C	FLOW gs^{-1}
55	43.3	1.32	15.12	35.64	40.31
56	51.00	1.42	14.6	49.65	26.63
57	48.77	1.97	14.18	45.64	39.47
58	40.77	0.95	14.33	37.99	23.74
59	43.00	0.48	15.69	40.32	12.22
60	38.00	1.51	14.56	37.33	38.73
61	51.66	1.85	15.79	45.25	36.35
62	49.67	2.02	14.2	45.6	40.43
63	43.97	1.46	18.03	40.7	37.11
64	44.03	1.28	15.62	42.5	27.34
65	53.98	1.18	20.94	48.4	24.19
66	52.11	2.2	18.6	44.37	48.79
67	48.47	1.1	18.47	41.67	27.31
68	48.47	1.18	16.69	41.41	27.25
69	48.93	1.15	17.82	41.97	27.05
70	49.45	1.08	19.8	43.96	25.39
71	43.19	0.83	20.99	35.69	32.89
72	41.44	0.79	19.79	34.32	31.34
73	54.08	1.26	19.12	43.88	29.6
74	53.9	1.37	19.05	45.23	29.57
75	41.77	0.41	19.98	34.4	39.55
76	54.62	1.82	17.5	44.3	38.23
77	54.23	1.78	17.62	43.9	38.15
78	47.92	12.13	19.37	41.48	22.05
79	43.53	10.18	17.26	37.67	21.38
80	41.82	10.06	17.26	34.86	39.1
81	43.35	8.36	16.17	36.38	38.18
82	41.94	10.51	16.51	35.25	38.67
83	53.87	15.58	19.75	48.4	35.64

Table A7.1 cont/..

RUN NO.	VAPOUR		LIQUID		
			IN	OUT	
	TEMP °C	FLOW gs^{-1}	TEMP °C	TEMP. °C	FLOW gs^{-1}
84	50 85	14.81	18.22	46.44	35.52
85	49.39	12.35	18.7	46.14	27.21
86	48.09	17.13	44.69	27.06	12.58
87	54.43	15.93	17.93	50.72	29.21
88	40.11	5.41	17.11	37.78	33.23
89	52.73	14.22	16.77	46.33	33.03
90	53.43	16.00	15.39	47.61	32.87
91	48.76	13.78	16.17	44.63	37.93
92	48.31	14.04	15.22	44.04	37.7
93	52.46	15.06	17.9	49.02	25.13
94	53.1	14.58	17.87	49.84	24.17
95	41.61	7.78	17.42	38.66	25.27
96	41.05	7.56	17.44	38.42	24.98

TABLE A7.2

RUN NO.	VAPOUR		LIQUID		
			IN	OUT	
	TEMP °C	FLOW gs^{-1}	TEMP °C	TEMP °C	FLOW gs^{-1}
1	100	14.2	42.05	49.55	30.02
2	100	10.9	38.21	45.19	29.51
3	100	16.00	43.03	49.6	27.34
4	100	14.00	41.26	48.14	28.19
5	100	13.95	41.78	48.63	28.09
6	100	14.00	39.47	48.01	37.68
7	100	14.05	43.85	48.88	23.69
8	100	14.15	43.89	49.04	22.8
9	100	14.13	41.41	48.96	32.24
10	100	14.2	41.65	48.74	32.21
11	100	13.85	38.57	45.95	28.89
12	100	14.00	41.57	48.8	28.74
13	100	14.00	40.43	48.79	39.48
14	100	14.00	39.88	48.24	38.76
15	100	7.5	33.47	39.3	26.29
16	100	7.9	32.9	38.45	26.26
17	100	14.5	45.44	49.38	17.87
18	100	14.45	43.86	47.7	17.72
19	100	14.3	38.24	46.48	34.92
20	100	14.3	38.7	46.96	34.69
21	100	14.4	40.66	47.85	27.06
22	100	14.4	40.66	47.88	27.06
23	100	14.45	42.28	48.72	22.72
24	100	14.4	42.35	47.87	22.24
25	100	14.4	37.54	46.7	38.89

Table A7.2 cont/...

RUN NO.	VAPOUR		LIQUID		
			IN	OUT	
	TEMP °C	FLOW gs^{-1}	TEMP °C	TEMP °C	FLOW gs^{-1}
26	100	9.67	38.65	43.19	13.69
27	100	9.4	34.34	40.95	33.73
28	100	16.00	43.39	51.54	31.3
29	100	9.00	32.21	39.21	32.25
30	100	16.8	43.99	51.72	30.73
31	100	17.00	42.51	50.19	30.39
32	100	17.00	42.36	49.32	28.53
33	100	16.55	39.64	46.91	29.23
34	100	16.8	34.43	43.67	46.09
35	100	16.8	40.02	48.8	45.61
36	100	16.75	47.73	57.01	17.04
37	100	13.00	41.84	43.82	17.03
38	100	13.3	38.00	45.6	39.1
39	100	13.2	38.48	45.76	28.46
40	100	13.1	40.18	45.75	22.83
41	100	8.95	35.57	39.38	16.2
42	100	8.95	35.4	39.21	16.19
43	100	9.00	35.15	40.2	27.51
44	100	17.00	44.17	51.56	29.6
45	100	9.00	31.88	38.45	29.38
46	100	13.55	38.99	46.71	29.43
47	100	13.33	41.01	46.69	22.39
48	100	12.9	38.29	46.34	38.74
49	100	13.1	37.63	46.02	38.65
50	100	13.2	36.91	44.65	30.4
51	100	18.00	42.6	51.5	44.97
52	100	17.9	43.2	52.22	34.57
53	100	17.8	45.61	52.98	24.91
54	100	12.4	36.32	43.57	40.00

Table A7.2 cont/...

RUN NO.	VAPOUR		LIQUID		
			IN	OUT	
	TEMP °C	FLOW gs^{-1}	TEMP °C	TEMP °C	FLOW gs^{-1}
55	100	12.5	35.64	43.3	40.31
56	100	18.00	49.65	51.86	26.63
57	100	18.00	45.64	48.77	39.47
58	100	10.8	37.99	40.77	23.74
59	100	10.7	40.32	45.15	12.22
60	100	10.5	37.33	40.82	38.73
61	100	20.1	45.25	53.63	36.35
62	100	18.00	45.6	48.67	40.43
63	100	14.5	40.7	46.98	37.11
64	100	14.7	42.5	46.3	27.34
65	100	18.00	48.4	53.5	24.19
66	100	18.00	44.37	53.49	48.79
67	100	15.4	41.67	49.3	27.31
68	100	14.9	41.41	49.49	27.25
69	100	14.6	41.97	49.36	27.05
70	100	15.4	43.96	50.21	25.39
71	100	8.8	35.69	42.45	32.89
72	100	9.6	34.32	41.12	31.34
73	100	18.92	43.38	52.85	29.6
74	100	18.6	45.23	53.54	29.57
75	100	10.5	34.4	41.49	39.55
76	100	18.00	44.3	54.21	38.23
77	100	18.2	43.9	53.72	38.15
78	100	10.7	41.48	46.73	22.05
79	100	10.7	37.67	42.73	21.38
80	100	10.5	34.86	41.09	39.1
81	100	10.4	36.38	42.73	38.18
82	100	10.5	35.25	41.32	38.76
83	100	17.2	48.4	53.42	35.65
84	100	16.00	46.44	50.77	35.52
85	100	14.2	46.14	49.26	27.21

Table A7.2 cont/...

RUN NO.	VAPOUR		LIQUID		
			IN	OUT	
	TEMP °C	FLOW gs^{-1}	TEMP °C	TEMP °C	FLOW gs^{-1}
86	100	14.00	44.69	47.83	27.06
87	100	17.8	50.72	54.15	29.21
88	100	7.1	37.78	39.41	33.23
89	100	16.6	46.33	52.05	33.03
90	100	16.6	47.61	52.75	32.87
91	100	13.75	44.63	48.68	37.93
92	100	13.9	44.04	48.11	37.7
93	100	16.1	49.02	51.77	25.13
94	100	16.1	49.84	52 43	24.17
95	100	8.4	38.66	41.22	25.27
96	100	8.3	38.42	40.77	24.98

TABLE A7.3

RUN NO.	VAPOUR		LIQUID		
			IN	OUT	
	TEMP °C	FLOW gs^{-1}	TEMP °C	TEMP °C	FLOW gs^{-1}
1	48.97	12.73	35.77	37.01	3000
2	42.08	7.77	35.19	36.05	3000
3	51.44	11.05	35.00	36.96	4820
4	51.03	10.37	35.26	36.93	3525
5	51.53	10.5	35.98	37.67	3505
6	50.71	10.5	35.78	37.32	3000
7	52.43	9.5	36.2	37.85	3175
8	51.76	12.3	36.36	38.00	3910
9	53.3	6.5	36.6	38.16	2304
10	51.05	7.4	36.71	38.23	2734
11	46.63	8.0	32.57	34.11	2961
12	48.2	9.5	36.25	37.88	3308
13	47.86	7.89	37.09	38.62	2937
14	47.21	6.1	36.63	38.07	2403
15	38.43	4.0	31.79	32.69	2149
16	37.6	8.0	30.97	31.88	3000
17	50.53	9.1	34.29	36.41	2419
18	48.52	6.7	33.29	35.26	1910
19	45.46	6.9	32.94	34.68	2263
20	48.67	8.0	33.36	35.1	2609
21	46.97	11.4	34.33	36.12	3616
22	47.74	9.4	34.68	36.47	3003
23	48.95	9.1	34.99	36.79	2876
24	46.91	8.7	34.33	36.15	2717
25	45.15	9.8	33.65	35.22	3554

Table A7.3 cont/...

RUN NO.	VAPOUR		LIQUID		
			IN	OUT	
	TEMP °C	FLOW gs^{-1}	TEMP °C	TEMP °C	FLOW gs^{-1}
26	37.79	4.0	31.00	32.37	1691
27	35.58	6.2	28.84	29.91	3360
28	47.07	11.2	35.88	37.7	3509
29	34.58	5.5	29.71	30.79	3023
30	51.51	8.0	38.09	40.03	3000
31	48.61	8.5	34.03	35.98	2463
32	52.05	11.6	35.42	37.4	3306
33	51.9	9.7	33.1	35.06	2833
34	49.3	11.6	30.01	31.72	3833
35	49.36	5.0	35.17	36.93	1885
36	51.32	12.4	37.62	39.54	3657
37	46.00	7.9	32.46	34.22	2530
38	44.11	6.4	32.96	34.4	2521
39	43.94	6.9	32.1	33.62	2580
40	45.88	8.1	32.21	33.72	3064
41	37.53	5.8	27.9	28.94	3246
42	37.45	6.3	27.89	28.93	3487
43	42.61	6.2	28.16	29.17	4852
44	54.31	9.3	36.81	38.97	2434
45	42.02	7.8	28.88	29.91	4312
46	48.91	10.2	34.07	35.73	3492
47	49.49	11.0	33.98	35.68	3678
48	44.18	9.5	34.6	36.03	4311
49	45.14	5.7	34.27	35.67	2352
50	44.38	12.3	33.57	34.89	3000
51	48.35	12.4	35.39	37.12	4097
52	48.88	14.4	35.76	37.54	4427
53	49.5	13.5	35.7	37.57	4114
54	44.78	9.5	31.6	32.9	3928
55	44.8	7.3	31.95	33.09	3079
56	53.95	12.7	36.37	38.53	3298

Table A7.3 cont/...

RUN NO.	VAPOUR		LIQUID		
			IN	OUT	
	TEMP °C	FLOW gs^{-1}	TEMP °C	TEMP °C	FLOW gs^{-1}
57	49.6	10.4	33.72	35.46	3320
58	43.94	6.6	30.00	31.22	3048
59	43.08	6.3	30.32	31.59	2805
60	43.82	7.4	29.98	31.13	3730
61	54.3	11.7	37.34	39.54	2984
62	49.6	10.3	33.83	35.56	3331
63	45.77	8.4	32.57	34.07	3653
64	45.34	8.7.	32.07	33.58	3314
65	53.37	16.0	36.77	39.1	3994
66	50.64	10.0	36.97	38.92	2868
67	46.03	10.0	34.2	35.9	3269
68	47.82	10.0	35.22	36.84	3505
69	48.22	9.3	35.65	37.28	3265
70	48.14	12.4	35.52	37.41	3732
71	40.59	7.4	27.33	28.44	3859
72	39.28	7.2	30.03	31.1	3453
73	50.23	12.6	33.42	35.56	3370
74	51.64	12.2	35.44	37.58	3272
75	34.84	6.6	29.69	30.78	3530
76	48.91	12.4	36.06	38.16	3381
77	49.94	10.6	35.85	37.89	2986
78	39.38	7.0	32.63	33.97	3039
79	36.49	6.8	29.43	30.64	3282
80	34.13	5.7	28.5	29.55	3190
81	35.39	11.5	29.37	30.48	4083
82	39.41	6.5	28.82	29.87	3572
83	51.42	0.1	36.5	38.48	3535
84	48.24	10.3	35.95	37.69	3393
85	46,95	9.0	35.07	36.66	3258
86	46.29	8.7	34.14	35.63	3359
87	51.45	11.4	37.1	39.07	3294

Table A7.3 cont/...

RUN NO.	VAPOUR		LIQUID		
			IN	OUT	
	TEMP °C	FLOW gs^{-1}	TEMP °C	TEMP °C	FLOW gs^{-1}
88	37.5	5.2	28.5	29.31	3857
89	49.69	10.5	36.17	38.11	3090
90	50.57	10.4	37.44	39.34	3131
91	46.01	9.7	35.6	37.15	3576
92	44.99	9.0	34.76	36.26	3421
93	49.5	11.8	36.36	38.32	3422
94	50.25	11.2	37.17	39.17	3204
95	37.33	5.8	32.63	33.53	3753
96	37.00	6.2	32.15	33.09	3814

TABLE A7.4

RUN NO.	VAPOUR		LIQUID		
			IN	OUT	
	TEMP °C	FLOW gs^{-1}	TEMP °C	TEMP °C	FLOW gs^{-1}
1	37.02	22.80	12.65	24.29	550
2	36.18	20.67	12.57	22.65	550
3	37.4	23.00	12.2	21.1	780
4	43,76	10.79	13.74	24.36	504
5	43.77	10.8	13.77	24.75	504
6	43.58	12.8	13.63	24.92	504
7	43.70	14.3	13.63	25.28	504
8	43.72	12.95	13.83	25.45	504
9	43.72	11.6	13.87	25.58	504
10	43.9	12.55	13.9	24.95	504
11	38.87	13.01	13.79	23.51	479
12	39.85	13.2	13.98	25.32	479
13	40.46	14.05	14.07	26.24	479
14	40.36	13.00	13.86	25.9	479
15	36.72	8.5	13.88	20.73	479
16	36.27	8.54	13.87	20.96	479
17	38.48	16.47	13.34	22.39	742
18	37.87	17.00	13.21	21.74	742
19	37.2	14.62	13.09	20.87	742
20	37.03	14.32	13.04	20.85	742
21	36.92	12.9	12.81	20.6	742
22	37.13	13.17	12.95	20.77	742
23	37.28	12.56	12.96	20.7	742
24	37.54	16.75	12.93	21.21	742
25	36.8	13.23	12.9	20.4	742
26	32.64	13.02	14.00	19.2	800
27	30.23	9.08	13.62	18.51	800

Table A7.4 cont/...

RUN NO.	VAPOUR		LIQUID		
			IN	OUT	
	TEMP °C	FLOW gs^{-1}	TEMP °C	TEMP °C	FLOW gs^{-1}
28	34.17	14.96	13.83	22.46	800
29	31.23	10.6	13.07	18.29	800
30	43.09	14.9	12.47	25.68	483
31	37.76	16.98	11.75	20.95	800
32	41.19	15.00	8.88	22.85	483
33	41.27	15.38	6.73	20.55	483
34	41.18	14.57	4.61	17.86	483
35	41.29	15.45	10.11	23.03	483
36	41.72	16.2	11.99	25.45	483
37	38.92	16.34	12.46	20.56	633
38	37.5	12.2	12.65	20.83	633
39	37.00	12.95	12.55	20.95	633
40	36.94	12.8	12.59	20.95	633
41	35.11	11.04	11.48	17.97	633
42	34.68	10.2	11.6	17.7	633
43	34.66	6.51	11.65	17.05	633
44	43.12	16.3	11.65	22.61	633
45	39.44	8.67	11.39	17.59	633
46	40.63	11.82	11.28	20.24	633
47	40.43	11.48	11.04	19.9	633
48	40.78	10.00	12.3	23.16	483
49	40.76	9.96	12.29	22.99	483
50	39.27	16.00	11.76	21.62	483
51	30.9	14.45	14.06	22.52	845
52	30.72	14.34	13.86	22.49	845
53	30.44	15.34	13.06	22.36	845
54	42.3	10.1	12.14	19.31	733
55	40.59	11.26	11.94	18.69	733
56	41.67	15.1	11.82	21.98	733
57	40.93	14.4	11.4	20.67	733
58	40.6	10.4	12.56	18.6	725
59	40.57	11.3	12.49	18.64	725

Table A7.4 cont/...

RUN NO.	VAPOUR		LIQUID		
			IN	OUT	
	TEMP °C	FLOW gs^{-1}	TEMP °C	TEMP °C	FLOW gs^{-1}
60	39.3	8.99	12.16	18.34	725
61	42.54	15.55	11.61	23.34	725
62	40.88	14.45	11.14	20.46	733
63	30.6	12.95	12.00	19.36	800
64	29.51	13.97	11.82	19.16	800
65	30.22	17.1	12.1	22.4	866
66	28.9	15.04	13.74	22.27	866
67	30.00	13.6	13.42	20.1	867
68	29.00	12.48	13.44	19.74	867
69	29.00	13.00	13.15	19.77	867
70	25.86	13.85	13.14	20.45	835
71	29.00	8.5	13.89	18.28	833
72	29.00	8.76	12.98	17.5	833
73	32.00	15.48	12.82	20.92	833
74	33.00	15.5	12.54	21.49	833
75	30.00	9.7	11.88	16.55	900
76	30.00	16.00	11.64	20.8	900
77	30.00	16.79	10.58	20.03	900
78	30.00	11.52	12.7	19.8	833
79	28.00	10.39	12.41	17.54	833
80	28.00	10.64	12.4	17.2	833
81	28.00	9.99	12.16	17.73	833
82	28.00	9.77	11.89	16.64	833
83	32.00	14.18	0.38	23.66	771
84	32.00	13.47	14.49	23.33	771
85	32.00	12.6	14.45	22.68	771
86	32.00	12.6	14.46	22.05	771
87	32.00	16.14	14.41	23.83	771
88	26.00	5.83	12.97	16.63	736
89	32.00	14.5	12.37	22.18	736
90	32.00	14.45	12.26	22.04	736
91	32.00	12.35	12.7	21.31	736

Table A7.4 cont/...

RUN NO.	VAPOUR		LIQUID		
			IN	OUT	
	TEMP °C	FLOW gs^{-1}	TEMP °C	TEMP °C	FLOW gs^{-1}
92	32.00	12.6	12.72	20.84	736
93	32.00	13.79	12.07	20.78	825
94	32.00	13.34	12.44	20.78	825
95	30.00	7.09	12.47	16.54	825
96	30.00	6.89	12.42	17.02	825

TABLE A7.5

EXPERIMENTAL AND COMPUTED HEAT LOSSES

RUN NO.	EXPERIMENTAL LOSS (%)	COMPUTED LOSS (%)	RUN NO.	EXPERIMENTAL LOSS (%)	COMPUTED LOSS (%)
1	6.74	9.62	28	6.82	9.85
2	8.76	6.17	29	3.05	3.30
3	8.77	13.17	30	12.97	10.00
4	11.84	8.04	31	7.73	13.99
5	10.36	7.38	32	13.53	15.35
6	7.82	12.34	33	13.29	18.99
7	9.28	7.34	34	14.14	19.39
8	9.78	12.72	35	6.89	8.42
9	7.93	6.88	36	14.49	19.35
10	10.14	12.33	37	11.82	8.41
11	17.07	18.84	38	9.30	12.84
12	11.66	16.02	39	9.20	14.55
13	7.28	6.03	40	9.72	14.42
14	9.41	12.37	41	5.55	9.13
15	4.37	5.53	42	7.12	7.24
16	4.94	3.94	43	9.80	5.10
17	5.75	6.78	44	10.54	15.85
18	7.66	10.07	45	5.87	11.28
19	8.52	15.70	46	8.66	10.03
20	8.40	14.98	47	9.51	9.62
21	9.65	11.27	48	8.89	5.64
22	9.47	11.65	49	9.58	5.62
23	10.26	6.98	50	15.19	20.07
24	8.25	10.65	51	9.04	6.70
25	9.57	9.94	52	8.73	12.51
26	6.68	10.55	53	7.35	6.60
27	5.71	9.11	54	6.57	5.69

TABLE A7.5 cont/...

RUN NO.	EXPERIMENTAL LOSS (%)	COMPUTED LOSS (%)	RUN NO.	EXPERIMENTAL LOSS (%)	COMPUTED LOSS (%)
55	8.13	11.22	76	5.34	6.52
56	10.11	9.06	77	4.96	6.76
57	12.20	10.02	78	8.62	9.58
58	8.01	12.14	79	9.51	10.37
59	8.52	14.80	80	4.37	6.84
60	5.29	6.66	81	7.85	9.02
61	8.89	4.66	82	6.29	8.37
62	11.98	9.95	83	12.41	11.27
63	8.78	10.13	84	7.36	8.32
64	10.09	13.46	85	14.27	11.27
65	3.98	6.89	86	6.01	8.45
66	7.56	7.09	87	3.92	7.29
67	10.99	10.74	88	5.77	4.31
68	11.31	10.11	89	8.24	7.16
69	9.56	10.26	90	10.37	8.18
70	10.48	10.93	91	4.72	6.72
71	5.90	8.76	92	9.13	8.93
72	7.54	8.78	93	6.29	7.24
73	13.73	12.08	94	5.78	6.52
74	11.04	8.83	95	4.76	8.30
75	7.60	9.54	96	13.42	12.06

TABLE A7.6

EXPERIMENTAL AND THEORETICAL

OVERALL HEAT TRANSFER

COEFFICIENTS

PREHEATER

RUN NO.	Experimental Coefficient $Wm^{-2}K^{-1}$	Theoretical Coefficient $Wm^{-2}K^{-1}$	RUN NO.	Experimental Coefficient $Wm^{-2}K^{-1}$	Theoretical Coefficient $Wm^{-2}K^{-1}$
1	536.4	552.0	28	633.2	637.9
2	725.2	545.9	29	753.7	615.5
3	506.0	588.6	30	592.1	562.2
4	530.4	584.6	31	557.0	620.8
5	600.6	582.0	32	606.1	584.7
6	719.1	685.0	33	615.7	574.3
7	694.9	261.9	34	842.7	732.2
8	659.3	259.0	35	852.3	782.7
9	718.0	637.1	36	513.7	237.2
10	685.5	635.7	37	724.3	237.6
11	402,9	592.2	38	916.0	723.2
12	508.5	597.1	39	684.8	580.1
13	737.0	730.0	40	685.8	258.7
14	729.2	719.1	41	848.8	231.9
15	1029.8	268.6	42	300.8	231.7
16	399.3	268.9	43	519.2	273.0
17	484.7	240.9	44	613.1	611.4
18	550.2	240.0	45	647.3	572.2
19	641.0	666.0	46	548.0	592.0
20	627.1	664.2	47	540.9	256.8
21	543.6	563.4	48	680.5	723.2
22	526.9	567.3	49	656.3	715.1
23	493.5	258.8	50	531.7	603.9
24	520.3	257.1	51	643.9	821.4
25	653.8	710.4	52	504.5	689.0
26	481.6	221.9	53	422.5	558.8
27	719.1	645.6	54	578.8	733.9

TABLE A7.6 cont/...

RUN NO.	Experimental Coefficient $Wm^{-2}K^{-1}$	Theoretical Coefficient $Wm^{-2}K^{-1}$	RUN NO.	Experimental Coefficient $Wm^{-2}K^{-1}$	Theoretical Coefficient $Wm^{-2}K^{-1}$
55	578.5	727.2	76	539.1	741.8
56	966.6	586.3	77	531.8	740.1
57	1044.7	743.1	78	361.7	244.6
58	589.1	261.1	79	353.4	241.5
59	312.5	213.5	80	543.2	634.6
60	1516.9	703.3	81	572.4	637.1
61	689.7	710.9	82	568.9	627.2
62	964.4	755.1	83	718.8	637.7
63	846.7	714.4	84	783.2	625.9
64	879.9	577.1	85	673.1	536.4
65	474.0	566.3	86	658.5	525.2
66	787.7	868.5	87	735.8	565.2
67	446.6	588.0	88	838.2	604.1
68	451.6	579.2	89	628.1	598.2
69	446.2	582.2	90	679.8	591.4
70	471.7	569.5	91	863.2	641.3
71	393.2	662.8	92	850.5	632.9
72	384.0	631.4	93	638.8	510.2
73	386.1	630.8	94	633.8	500.9
74	453.2	634.4	95	585.8	256.0
75	472.3	763.8	96	604.0	255.2

TABLE A7.7

EXPERIMENTAL AND THEORETICAL OVERALL HEAT TRANSFER COEFFICIENTS

FIRST EFFECT

RUN NO.	Experimental Coefficient $Wm^{-2}K^{-1}$	Theoretical Coefficient $Wm^{-2}K^{-1}$	RUN NO.	Experimental Coefficient $Wm^{-2}K^{-1}$	Theoretical Coefficient $Wm^{-2}K^{-1}$
1	832.1	236.9	28	967.6	240.2
2	594.4	234.9	29	445.3	239.9
3	946.2	229.7	30	1023.4	238.8
4	804.4	231.8	31	1006.5	237.4
5	808.9	231.7	32	996.6	232.5
6	791.2	253.9	33	926.4	233.4
7	831.8	219.8	34	875.7	267.9
8	839.3	217.1	35	960.3	269.3
9	823.3	242.1	36	1118.7	199.0
10	823.3	242.0	37	722.1	196.8
11	762.4	232.8	38	726.7	256.3
12	811.6	233.4	39	724.1	231.8
13	803.5	258.0	40	728.8	216.3
14	795.6	256.3	41	455.0	192.7
15	374.9	225.4	42	453.8	192.7
16	390.5	224.9	43	459.1	228.7
17	875.9	201.0	44	1035.7	235.9
18	847.2	200.0	45	441.5	232.6
19	789.7	247.2	46	752.9	234.4
20	795.7	246.9	47	754.5	215.2
21	822.0	228.5	48	711.3	255.9
22	822.2	228.6	49	716.3	255.5
23	843.5	216.5	50	709.3	236.2
24	834.4	214.9	51	1080.4	268.8
25	792.2	255.7	52	1088.1	247.6
26	520.8	183.4	53	1115.1	223.6
27	479.5	244.0	54	656.9	257.7

TABLE A7.7 cont/...

RUN NO.	Experimental Coefficient $Wm^{-2}K^{-1}$	Theoretical Coefficient $Wm^{-2}K^{-1}$	RUN NO.	Experimental Coefficient $Wm^{-2}K^{-1}$	Theoretical Coefficient $Wm^{-2}K^{-1}$
55	657.1	258.1	76	1128.3	256.1
56	1159.2	228.8	77	1130.8	255.8
57	1083.8	258.0	78	608.3	214.8
58	566.2	218.3	79	568.5	211.3
59	594.5	177.2	80	538.0	255.6
60	547.8	255.3	81	546.8	254.4
61	1263.5	251.7	82	540.7	255.0
62	1079.9	259.9	83	1113.6	251.3
63	819.5	252.6	84	989.1	250.5
64	838.6	229.3	85	862.4	230.2
65	1164.7	222.0	86	827.5	229.3
66	1120.6	276.6	87	1188.9	236.3
67	898.5	229.4	88	367.2	244.1
68	868.9	229.4	89	1038.5	244.8
69	854.6	229.0	90	1059.0	244.8
70	925.2	224.7	91	818.9	255.6
71	459.4	242.8	92	818.9	254.9
72	490.3	238.3	93	1030.9	224.9
73	1121.5	235.6	94	1046.5	222.3
74	1167.8	236.0	95	444.2	223.5
75	537.1	256.5	96	436.4	222.6

TABLE A7.8

EXPERIMENTAL AND THEORETICAL OVERALL HEAT TRANSFER COEFFICIENTS SECOND EFFECT

RUN NO.	Experimental Coefficient $Wm^{-2}K^{-1}$	Theoretical Coefficient $Wm^{-2}K^{-1}$	RUN NO.	Experimental Coefficient $Wm^{-2}K^{-1}$	Theoretical Coefficient $Wm^{-2}K^{-1}$
1	1841.6	2285.3	28	3880.7	2495.1
2	2491.9	2380.8	29	4722.5	2340.8
3	3812.3	2884.8	30	2908.6	2492.8
4	2456.7	2543.7	31	2203.2	2154.2
5	2520.3	2549.0	32	2611.1	2442.7
6	2034.7	2358.9	33	1943.3	2280.7
7	2119.8	2476.0	34	2222.3	2488.8
8	2743.0	2622.3	35	1555.2	1974.1
9	1407.7	2201.7	36	3440.2	2564.8
10	1908.5	2369.7	37	2200.2	2160.8
11	2140.1	2343.7	38	2170.3	2204.0
12	3022.4	2497.9	39	2208.6	2197.3
13	2804.5	2427.5	40	2234.5	2366.8
14	2190.4	2238.6	41	2311.2	2394.2
15	1950.1	2059.2	42	2490.7	2456.4
16	2785.3	2267.9	43	2190.4	2921.5
17	2106.1	2132.6	44	1997.7	2193.8
18	1648.3	1906.1	45	2193.0	2693.3
19	2109.7	2070.1	46	2580.8	2502.3
20	1961.0	2222.5	47	2660.2	2537.5
21	3440.2	2494.1	48	4342.0	2747.4
22	2758.0	2359.1	49	2020.4	2175.9
23	2465.8	2331.1	50	2434.2	2231.9
24	2645.3	2255.4	51	3657.3	2628.3
25	3250.2	2501.9	52	4021.4	2656.7
26	2374.2	1772.9	53	3732.8	2613.5
27	3618.8	2422.7	54	2541.1	2585.3

TABLE A7.8 cont/...

RUN NO.	Experimental Coefficient $Wm^{-2}K^{-1}$	Theoretical Coefficient $Wm^{-2}K^{-1}$	RUN NO.	Experimental Coefficient $Wm^{-2}K^{-1}$	Theoretical Coefficient $Wm^{-2}K^{-1}$
55	1782.1	2388.7	76	3758.7	2435.6
56	2693.7	2438.8	77	2909.6	2350.0
57	2400.5	2436.6	78	4190.0	2365.2
58	1745.2	2365.7	79	3844.8	2383.7
59	1832.1	2279.4	80	4103.1	2365.5
60	2015.9	2572.4	81	5185.6	2436.3
61	2583.0	2372.3	82	2324.1	2505.8
62	2411.5	2445.5	83	3135.8	3749.8
63	2745.4	2572.7	84	3227.1	2493.1
64	2494.2	2432.2	85	2916.5	2464.9
65	3763.5	2562.4	86	2738.7	2490.6
66	2750.1	2345.6	87	3030.5	2469.6
67	3159.7	2416.5	88	2266.3	2656.7
68	3005.2	2526.5	89	2981.9	2396.5
69	2825.2	2479.1	90	3049.1	2439.7
70	3772.3	2527.8	91	3591.9	2553.4
71	2101.9	2535.0	92	3379.9	2506.0
72	2644.6	2457.9	93	3444.5	2474.8
73	2859.0	2389.3	94	3312.5	2435.9
74	2888.1	2413.0	95	4970.2	2665.4
75	5230.2	2473.4	96	5119.4	2653.5

TABLE A7.9

EXPERIMENTAL AND THEORETICAL

OVERALL HEAT TRANSFER

COEFFICIENTS

CONDENSER

RUN NO.	Experimental Coefficient $Wm^{-2}K^{-1}$	Theoretical Coefficient $Wm^{-2}K^{-1}$	RUN NO.	Experimental Coefficient $Wm^{-2}K^{-1}$	Theoretical Coefficient $Wm^{-2}K^{-1}$
1	1300.8	1348.4	28	1608.1	1609.3
2	1113.9	1364.0	29	987.0	1686.7
3	1237.2	1453.3	30	993.5	1459.3
4	801.1	1579.1	31	1271.3	1569.8
5	835.6	1581.4	32	996.4	1412.1
6	868.1	1529.5	33	899.0	1381.5
7	899.0	1499.2	34	791.7	1368.4
8	903.2	1530.9	35	941.5	1412.1
9	913.6	1565.0	36	1060.7	1423.9
10	842.9	1539.0	37	842.6	1499.5
11	855.0	1464.6	38	920.5	1588.7
12	1006.0	1477.2	39	970.5	1565.6
13	1078.3	1468.3	40	969.7	1569.2
14	1056.3	1487.1	41	740.3	1581.2
15	621.7	1556.3	42	707.7	1603.2
16	663.6	1553.6	43	616.7	1747.9
17	1205.5	1572.9	44	987.1	1534.2
18	1146.7	1553.2	45	576.5	1688.4
19	1052.3	1596.9	46	839.8	1609.1
20	1063.9	1602.7	47	827.2	1614.0
21	1054.1	1636.9	48	844.9	1544.9
22	1054.9	1632.8	49	829.3	1544.9
23	1034.9	1650.7	50	780.9	1392.1
24	1107.9	1551.8	51	2147.4	1620.0
25	1017.3	1626.2	52	2212.1	1620.1
26	952.6	1632.0	53	2356.7	1587.6
27	1015.1	1741.9	54	723.9	1748.6

TABLE A7.9 cont/...

RUN NO.	Experimental Coefficient $Wm^{-2}K^{-1}$	Theoretical Coefficient $Wm^{-2}K^{-1}$	RUN NO.	Experimental Coefficient $Wm^{-2}K^{-1}$	Theoretical Coefficient $Wm^{-2}K^{-1}$
55	717.2	1691.3	76	2264.0	1574.9
56	1110.8	1611.2	77	2184.6	1547.0
57	1005.8	1613.4	78	1602.8	1670.0
58	640.3	1718.0	79	1210.7	1677.3
59	652.4	1687.4	80	1115.6	1666.1
60	682.0	1757.4	81	1314.5	1691.7
61	1258.5	1608.2	82	1059.8	1691.6
62	1003.8	1609.2	83	3740.1	1529.4
63	1467.0	1607.5	84	1973.0	1625.3
64	1561.1	1569.4	85	1776.5	1646.1
65	2651.4	1549.5	86	1591.3	1642.6
66	2609.5	1595.3	87	2152.5	1561.3
67	1627.6	1628.8	88	884.4	1811.8
68	1638.2	1651.6	89	1857.7	1562.0
69	1706.7	1634.5	90	1833.0	1561.5
70	2600.2	1574.8	91	1583.0	1615.7
71	1041.3	1776.9	92	1466.3	1606.3
72	1005.7	1754.2	93	1725.6	1616.1
73	1664.1	1581.7	94	1669.3	1630.6
74	1744.5	1590.5	95	793.5	1830.1
75	976.5	1745.2	96	911.1	1844.3