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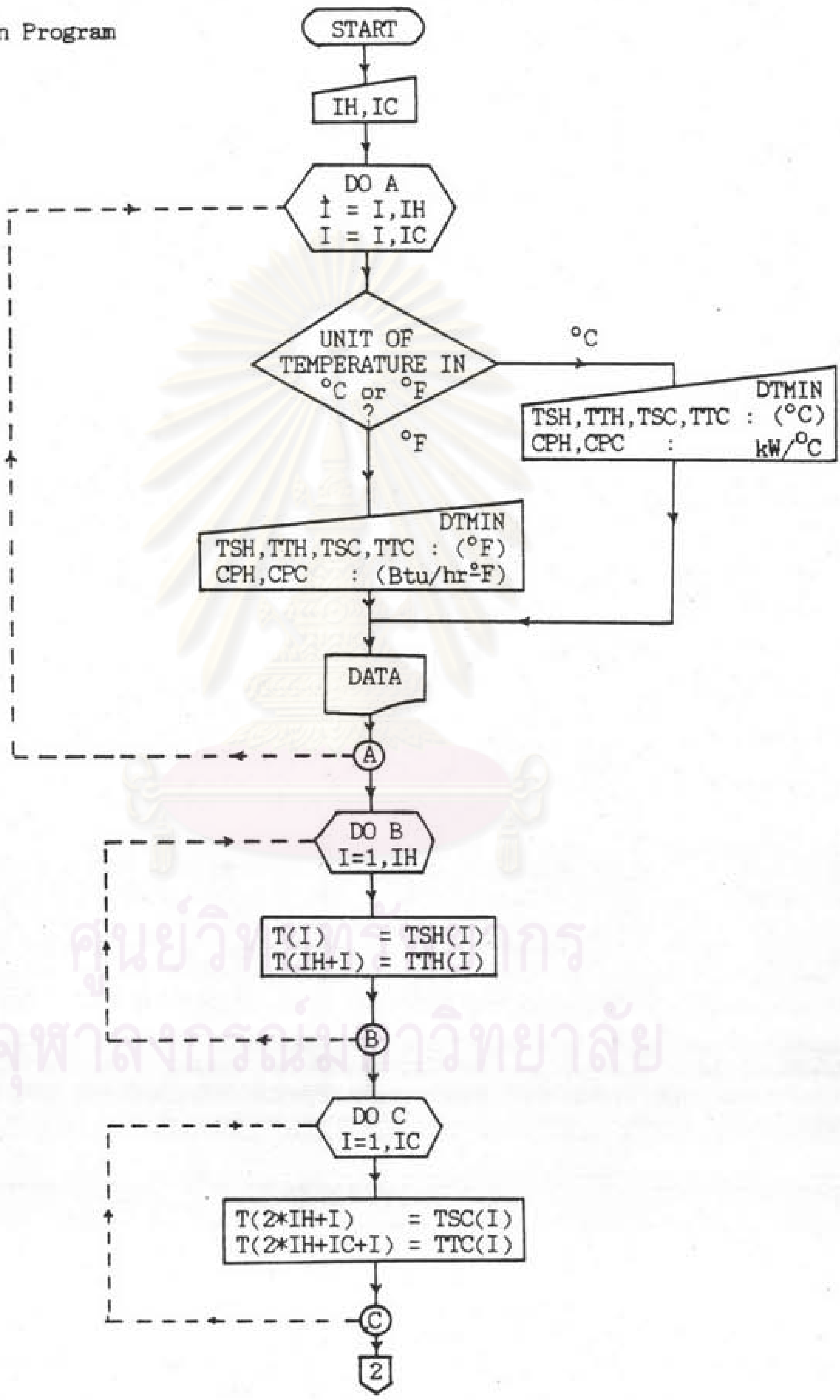
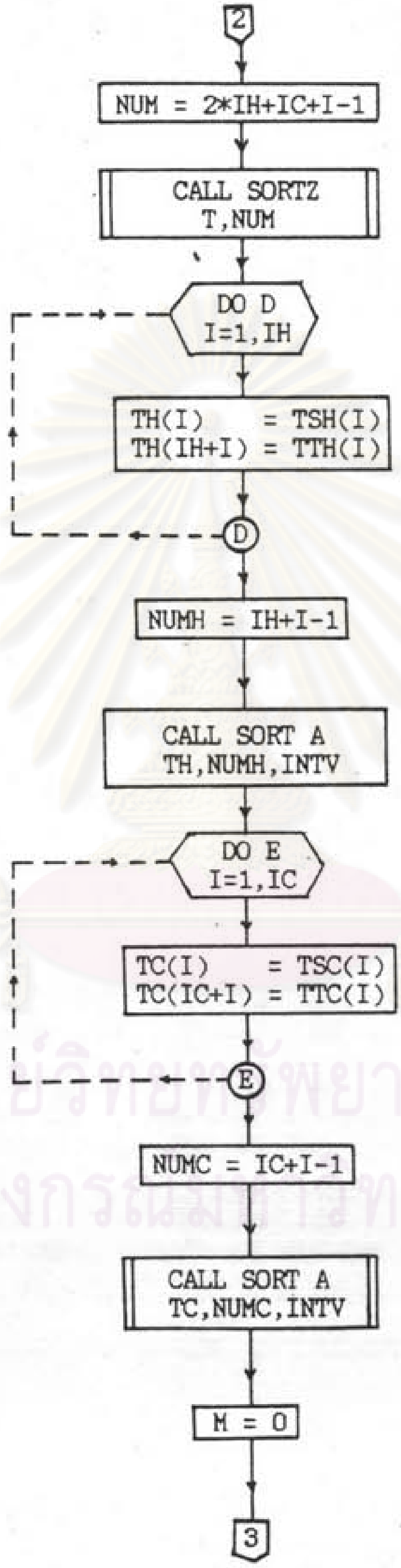
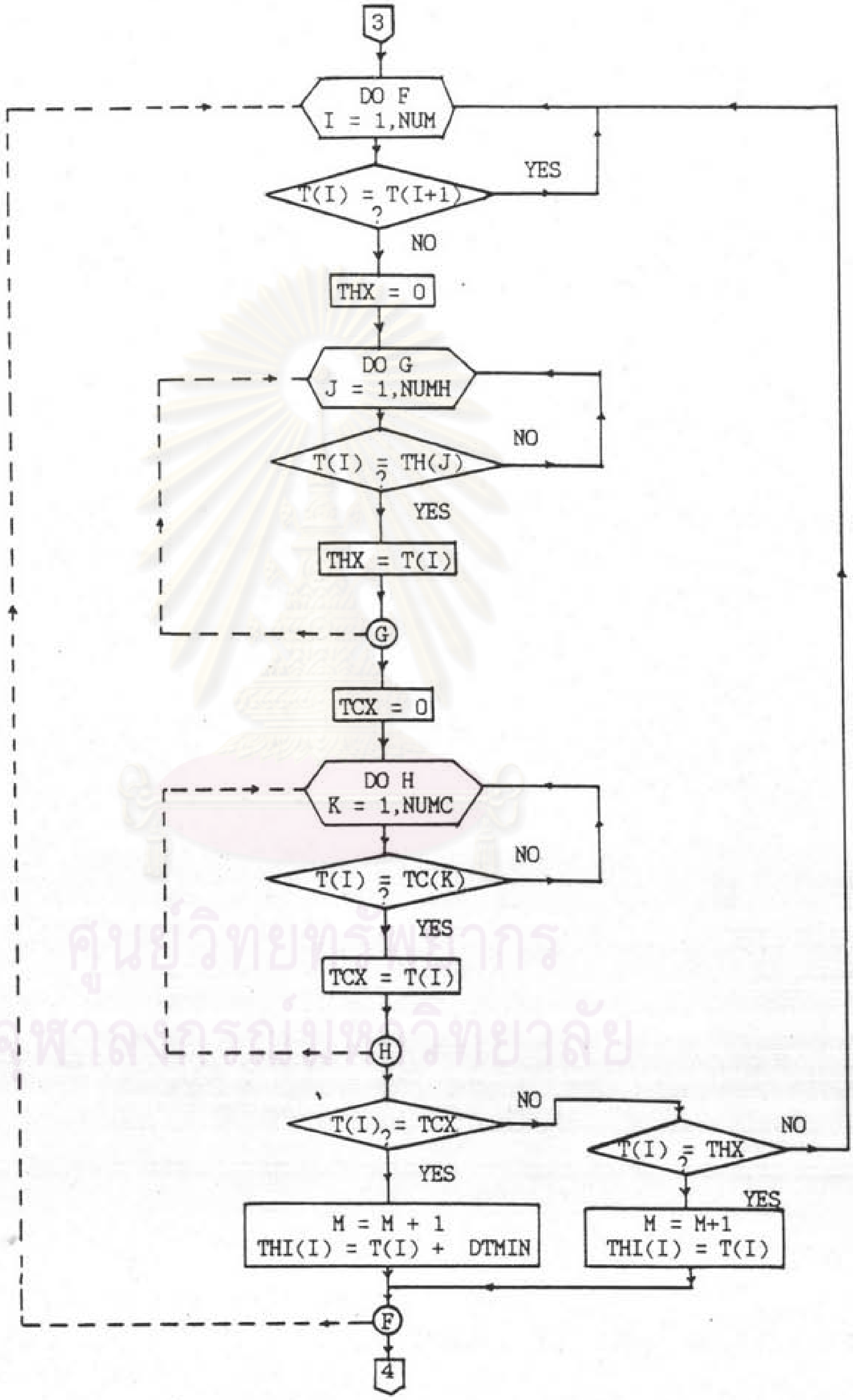
Appendix A

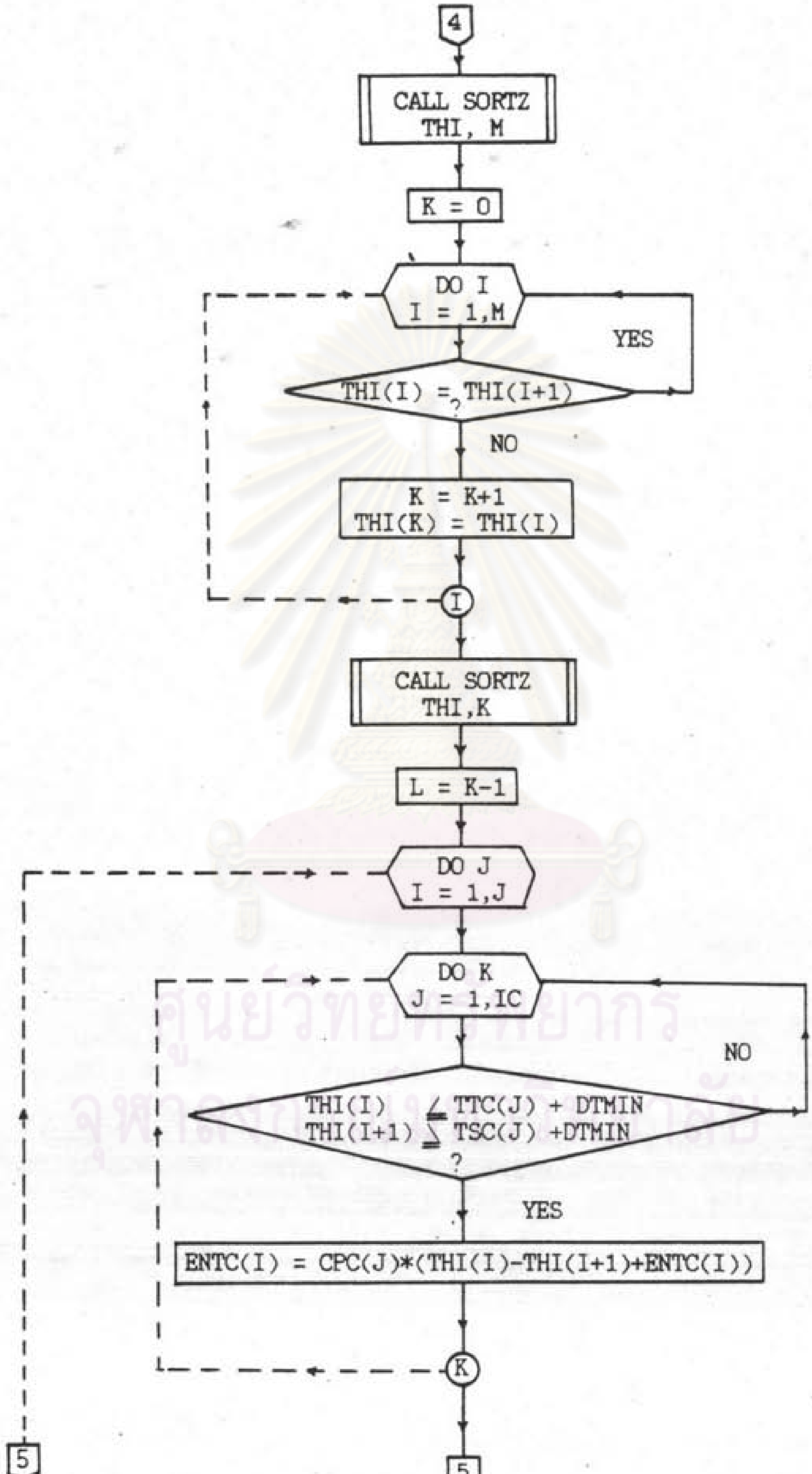
Computer Program Flow Chart

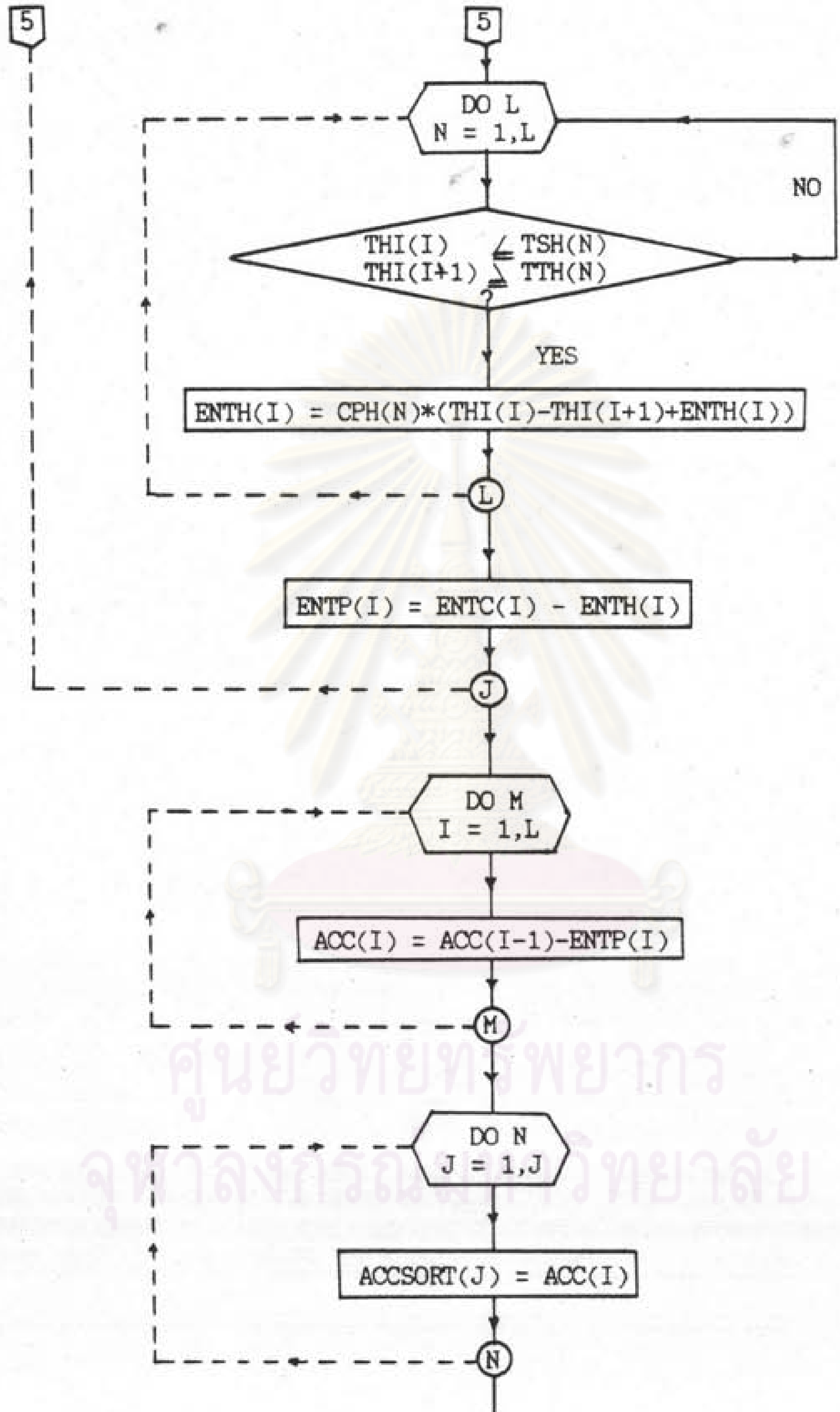
A) Main Program

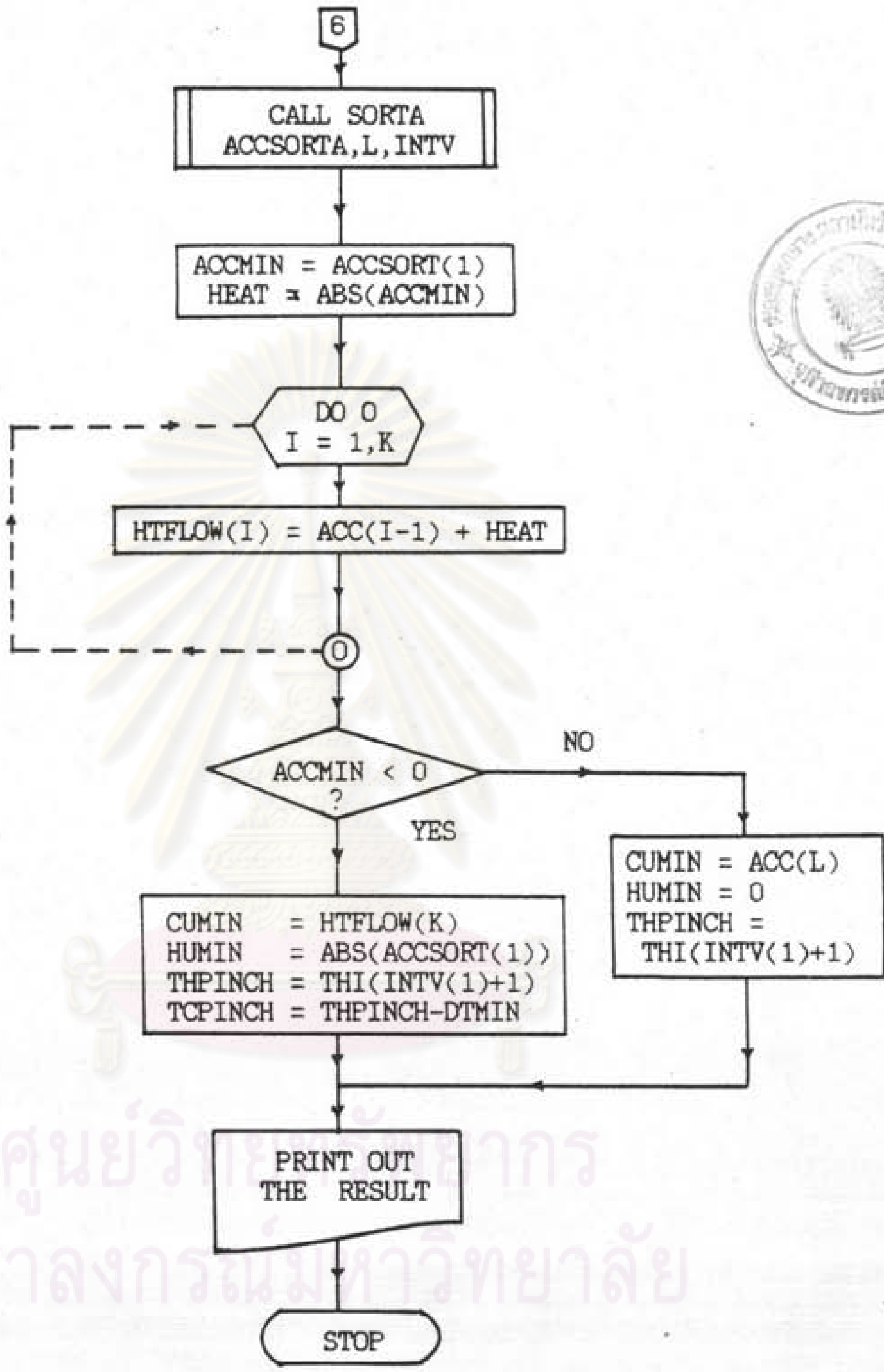



2
NUM = 2*IH+IC+I-1
CALL SORTZ
T,NUM
DO D
I=1,IH
TH(I) = TSH(I)
TH(IH+I) = TTH(I)
D
NUMH = IH+I-1
CALL SORT A
TH,NUMH,INTV
DO E
I=1,IC
TC(I) = TSC(I)
TC(IC+I) = TTC(I)
E
NUMC = IC+I-1
CALL SORT A
TC,NUMC,INTV
M = 0
3

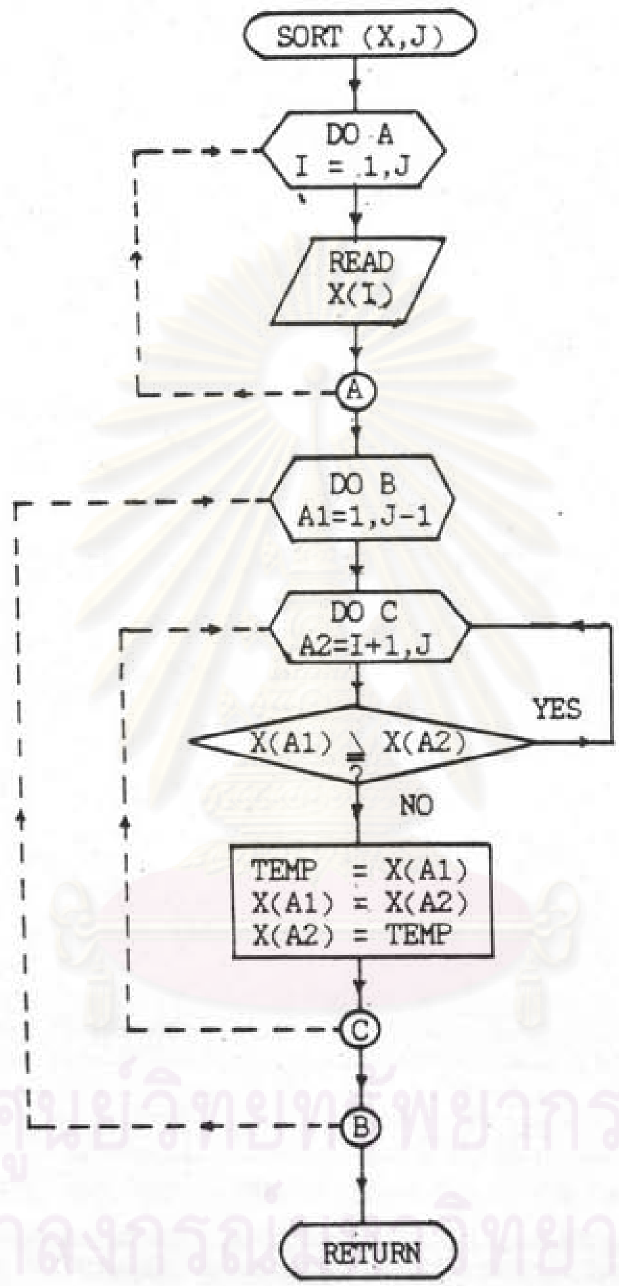

3
DO F
I = 1,NUM
T(I) = T(I+1)
?
YES
NO
THX = 0
DO G
J = 1,NUMH
T(I) = TH(J)
?
NO
YES
THX = T(I)
G
TCX = 0
DO H
K = 1,NUMC
T(I) = TC(K)
?
NO
YES
TCX = T(I)
H
T(I) = TCX
?
NO
YES
T(I) = THX
?
NO
YES
M = M + 1
THI(I) = T(I) + DTMIN
M = M+1
THI(I) = T(I)
F
4


4
CALL SORTZ
THI, M
K = 0
DO I
I = 1,M
YES
THI(I) = THI(I+1)
?
NO
K = K+1
THI(K) = THI(I)
I
CALL SORTZ
THI,K
L = K-1
DO J
I = 1,J
DO K
J = 1,IC
NO
THI(I) ≤ TTC(J) + DTMIN
THI(I+1) ≤ TSC(J) +DTMIN
?
YES
ENTC(I) = CPC(J)*(THI(I)-THI(I+1)+ENTC(I))
K
5
5

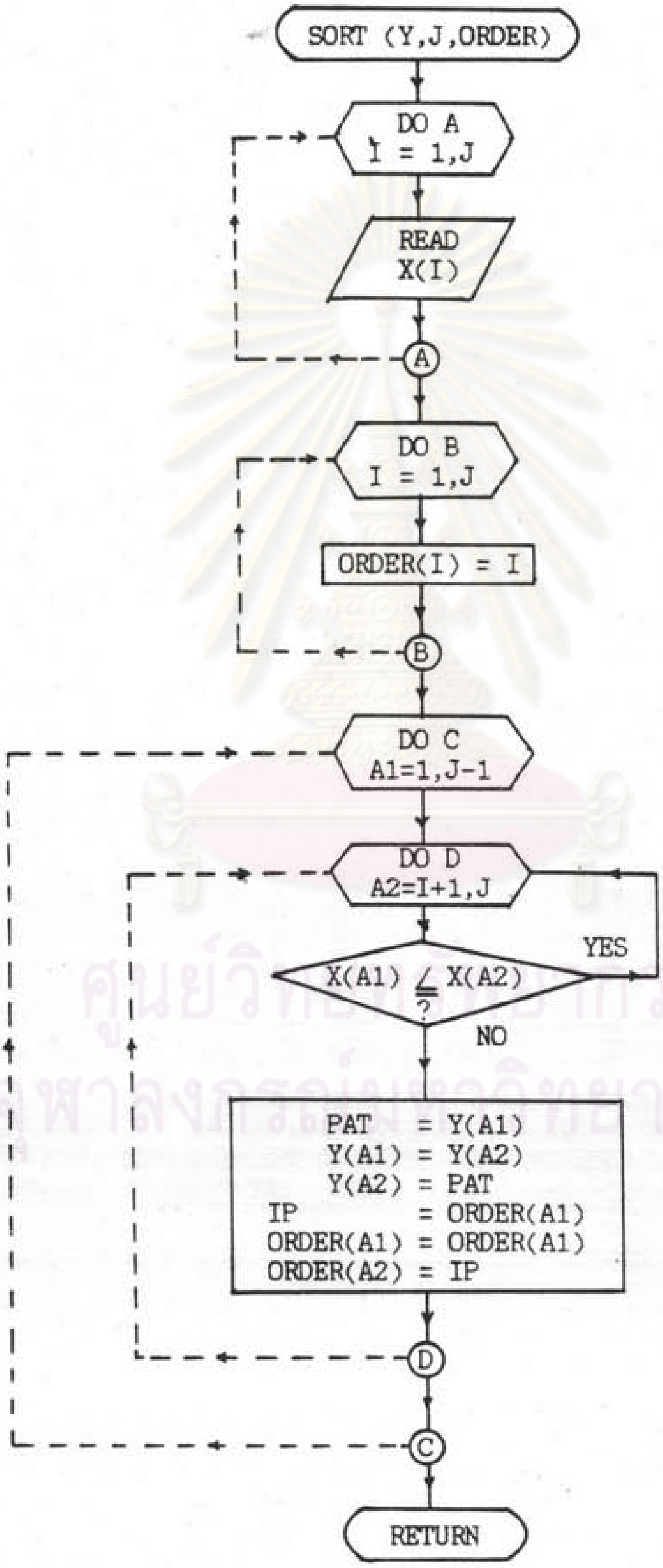

5
5
DO L
N = 1,L
NO
THI(I) ≤ TSH(N)
THI(I+1) ≥ TTH(N)
?
YES
ENTH(I) = CPH(N)*(THI(I)-THI(I+1)+ENTH(I))
L
ENTP(I) = ENTC(I) - ENTH(I)
J
DO M
I = 1,L
ACC(I) = ACC(I-1)-ENTP(I)
M
DO N
J = 1,J
ACCSORT(J) = ACC(I)
N
6


6
CALL SORTA
ACCSORTA,L,INTV
ACCMIN = ACCSORT(1)
HEAT = ABS(ACCMIN)
DO 0
I = 1,K
HTFLOW(I) = ACC(I-1) + HEAT
0
ACCMIN < 0
?
NO
YES
CUMIN = HTFLOW(K)
HUMIN = ABS(ACCSORT(1))
THPINCH = THI(INTV(1)+1)
TCPINCH = THPINCH-DTMIN
CUMIN = ACC(L)
HUMIN = 0
THPINCH =
THI(INTV(1)+1)
PRINT OUT
THE RESULT
STOP

B) Subprogram SORTZ(X,J)



C) Subprogram SORTA(Y,J,ORDER)



Appendix B

List of Energy Targeting Program

```
C===============================================================
C
C                            THESIS PROGRAM
C
C===============================================================
C
C             THE PROGRAM WAS DEVELOPED TO EVALUATE MINIMUM
C      UTILITY REQUIREMENTS AND PINCH POINT TEMPERATURE FOR
C      THE MINIMUM ENERGY RECOVERY (MER) DESIGN.
C
C********** DEFINE VARIABLES AND ASSIGN DIMENSIONS **********
C234567890
      REAL TSH(10),TTH(10)
      REAL TSC(10),TTC(10)
      REAL TH(20),TC(20),T(30),THI(30)
      REAL CPH(10),ENTH(30)
      REAL CPC(10),ENTC(30)
      REAL ENTP(30),ACC(30)
      REAL ACCSORTA(30),HTFLOW(30)
      INTEGER IH,IC,NUM,NUMH,NUMC,M,L,K
      INTEGER INTV(30),ITEMP
C
C***************** START TO RUN THE PROGRAM *****************
      WRITE(*,101)
  101 FORMAT(/1X,'INPUT THE FOLLOWING DATA')
      WRITE(*,102)
  102 FORMAT(/1X,'NO. OF HOT STREAMS = ')
      READ(*,001)IH
  001 FORMAT(I4)
      WRITE(*,103)
  103 FORMAT(/1X,'NO. OF COLD STREAMS = ')
      READ(*,001)IC
      WRITE(*,104)
  104 FORMAT(//1X,'INPUT TEMPERATURES IN UNIT OF (oF) or (oC) ',
     *//3X,'IF TEMPERATURE UNIT IS oF : KEY 1',
     *//3X,'IF TEMPERATURE UNIT IS oC : KEY 2')
      READ(*,001)ITEMP
C
C***** TEMPERATURE UNIT IN oF ********************************
      IF(ITEMP.EQ.1) THEN
C
C****************** INPUT HOT STREAM DATA ******************
      WRITE(*,105)
  105 FORMAT(/6X,'HOT-STREAM DATA : ',/)
      DO 110 I=1,IH
      WRITE(*,106)I
  106 FORMAT(2X,'HOT STREAM No.',I2)
      WRITE(*,107)
  107 FORMAT(2X,'SUPPLY TEMPERATURE (oF) = ')
      READ(*,002)TSH(I)
```

```
  002 FORMAT(F8.2)
      WRITE(*,108)
  108 FORMAT(2X,'TARGET TEMPERATURE (oF) = ')
      READ(*,002)TTH(I)
      WRITE(*,109)
  109 FORMAT(2X,'HEAT CAPACITY FLOWRATE (BTU/hr-F)')
      READ(*,002)CPH(I)
      WRITE(*,003)
  003 FORMAT(' ')
  110 CONTINUE
C
C******************** INPUT COLD STREAM DATA *****************
      WRITE(*,111)
  111 FORMAT(/6X,'COLD-STREAM DATA : ',/)
      DO 116 I=1,IC
      WRITE(*,112)I
  112 FORMAT(2X,'COLD STREAM No.',I2)
      WRITE(*,113)
  113 FORMAT(2X,'SUPPLY TEMPERATURE (oF) = ')
      READ(*,002)TSC(I)
      WRITE(*,114)
  114 FORMAT(2X,'TARGET TEMPERATURE (oF) = ')
      READ(*,002)TTC(I)
      WRITE(*,115)
  115 FORMAT(2X,'HEAT CAPACITY FLOWRATE (BTU/hr-F) = ')
      READ(*,002)CPC(I)
      WRITE(*,003)
  116 CONTINUE
C
C*********** SPECIFY MINIMUM TEMPERATURE DIFFERENCE **********
      WRITE(*,117)
  117 FORMAT(2X,'MINIMUM TEMPERATURE DIFFERENCE (oF) = ')
      READ(*,002)DTMIN
C
C***** TEMPERATURE UNIT IN oC *******************************
      ELSE
C
C******************* INPUT HOT STREAM DATA *******************
      WRITE(*,118)
  118 FORMAT(/6X,'HOT-STREAM DATA : ',/)
      DO 123 I=1,IH
      WRITE(*,119)I
  119 FORMAT(2X,'HOT STREAM No.',I2)
      WRITE(*,120)
  120 FORMAT(2X,'SUPPLY TEMPERATURE (oC) = ')
      READ(*,002)TSH(I)
      WRITE(*,121)
  121 FORMAT(2X,'TARGET TEMPERATURE (oC) = ')
      READ(*,002)TTH(I)
      WRITE(*,122)
  122 FORMAT(2X,'HEAT CAPACITY FLOWRATE (kW/oC) = ')
      READ(*,002)CPH(I)
      WRITE(*,003)
  123 CONTINUE
C
```

```
C******************** INPUT COLD STREAM DATA *****************
      WRITE(*,124)
  124 FORMAT(/6X,'COLD-STREAM DATA : ',/)
      DO 129 I=1,IC
      WRITE(*,125)I
  125 FORMAT(2X,'COLD STREAM No.',I2)
      WRITE(*,126)
  126 FORMAT(2X,'SUPPLY TEMPERATURE (oC) = ')
      READ(*,002)TSC(I)
      WRITE(*,127)
  127 FORMAT(2X,'TARGET TEMPERATURE (oC) = ')
      READ(*,002)TTC(I)
      WRITE(*,128)
  128 FORMAT(2X,'HEAT CAPACITY FLOWRATE (kW/oC) = ')
      READ(*,002)CPC(I)
      WRITE(*,003)
  129 CONTINUE
C
C******** SPECIFY MINIMUM TEMPERATURE DIFFERENCE ************
      WRITE(*,130)
  130 FORMAT(2X,'MINIMUM TEMPERATURE DIFFERENCE (oC) = ')
      READ(*,002)DTMIN
      END IF
C
C**************** PRINT OUT HOT-STREAM DATA *****************
      WRITE(*,131)
  131 FORMAT('0',//T34,'HOT-STREAM DATA',/)
      WRITE(*,132)
  132 FORMAT(T8,'-------------------------------------',0X,
     *'----------------------')
      WRITE(*,133)
  133 FORMAT(T8,'HOT STREAM',T23,'SUPPLY TEMP.',T39,
     *'TARGET TEMP.',T54,'HEAT CAPACITY')
      WRITE(*,134)
  134 FORMAT(T12,'No.',T56,'FLOWRATE')
      WRITE(*,132)
      DO 136 I=1,IH
      WRITE(*,135)I,TSH(I),TTH(I),CPH(I)
  135 FORMAT(T11,I3,T23,F8.2,T40,F8.2,T55,F8.2)
  136 CONTINUE
      WRITE(*,003)
      WRITE(*,132)
C
C**************** PRINT OUT COLD-STREAM DATA ****************
      WRITE(*,137)
  137 FORMAT('0',//T33,'COLD-STREAM DATA',/)
      WRITE(*,132)
      WRITE(*,138)
  138 FORMAT(T8,'COLD STREAM',T23,'SUPPLY TEMP.',T39,
     *'TARGET TEMP.',T54,'HEAT CAPACITY')
      WRITE(*,134)
      WRITE(*,132)
      DO 140 I=1,IC
      WRITE(*,139)I,TSC(I),TTC(I),CPC(I)
  139 FORMAT(T11,I3,T23,F8.2,T40,F8.2,T55,F8.2)
  140 CONTINUE
```

```
      WRITE(*,003)
      WRITE(*,132)
      WRITE(*,141)DTMIN
  141 FORMAT('0',/20X,'MINIMUM TEMPERATURE DIFFERENCE =',F8.2)
C
C********** RESET TEMPERATURES TO THE SAME VARIABLE **********
      DO 142 I = 1,IH
      T(I)    = TSH(I)
      T(IH+I) = TTH(I)
  142 CONTINUE
      DO 143 I = 1,IC
      T(2*IH+I)    = TSC(I)
      T(2*IH+IC+I) = TTC(I)
  143 CONTINUE
      NUM = 2*IH+IC+I-1
C
C****************** SORT ALL TEMPERATURES ******************
      CALL SORTZ(T,NUM)
C
C****************** SORT HOT TEMPERATURES ******************
      DO 144 I = 1,IH
      TH(I)    = TSH(I)
      TH(IH+I) = TTH(I)
  144 CONTINUE
      NUMH = IH+I-1
      CALL SORTA (TH,NUMH,INTV)
C
C****************** SORT COLD TEMPERATURES *****************
      DO 145 I = 1,IC
      TC(I)    = TSC(I)
      TC(IC+I) = TTC(I)
  145 CONTINUE
      NUMC = IC+I-1
      CALL SORTA (TC,NUMC,INTV)
C
C****************** SORT TEMPERATURE INTERVALS *************
      M    = 0
      DO 148 I = 1,NUM
      IF (T(I).EQ.T(I+1))GO TO 148
C
C****** CHECK IF ANY T(I) EQUAL TO ANY STARTING OR TARGET ****
C                    TEMPERATURE OF HOT STREAM
      THX = 0
      DO 146 J = 1;NUMH
      IF (T(I)-TH(J).EQ.0) THX = T(I)
  146 CONTINUE
C
C******* CHECK IF ANY T(I) EQUAL TO ANY STARTING OR TARGET ****
C                     TEMPERATURE OF COLD STREAM
      TCX = 0
      DO 147 K = 1,NUMC
      IF (T(I)-TC(K).EQ.0) TCX = T(I)
  147 CONTINUE
C
C******* FIND TEMPERATURE INTERVAL FOR EACH SUB NETWORK ******
      IF (T(I).EQ. TCX) THEN
```

```
          M = M+1
          THI(M) = T(I)+DTMIN
        END IF
        IF (T(I).EQ. THX) THEN
          M = M+1
          THI(M) = T(I)
        END IF
  148 CONTINUE
        CALL SORTZ (THI,M)
C
C************** DELETE THE ITERATED TEMPERATURES ************
        THI(M+1) = 10000
        K=0
        DO 149 I=1,M
        IF (THI(I) .EQ. THI(I+1)) GOTO 149
        K = K+1
        THI(K) = THI(I)
  149 CONTINUE
        CALL SORTZ(THI,K)
C
C********* CALCULATE DEFICIENT HEAT IN EACH SUBNETWORK *******
        L = K-1
        DO 152 I=1,L
C
C********* CALCULATE HEAT REQUIREMENT FOR COLD STREAM ********
        DO 150 J=1,IC
        IF ((TTC(J)+DTMIN.GE.THI(I)).AND.(TSC(J)+DTMIN.LE.THI(I+1)))
       *ENTC(I) = CPC(J)*(THI(I)-THI(I+1))+ENTC(I)
  150 CONTINUE
C
C************ CALCULATE EXCESS HEAT FROM HOT STREAM **********
        DO 151 N=1,IH
        IF ((TSH(N).GE.THI(I)).AND.(TTH(N).LE.THI(I+1)))
       *ENTH(I) = CPH(N)*(THI(I)-THI(I+1))+ENTH(I)
  151 CONTINUE
        ENTP(I) = ENTC(I)-ENTH(I)
  152 CONTINUE
C
C*************** CALCULATE TOTAL ENTHALPY OUTPUT *************
        DO 153 I=1,L
        ACC(I) = ACC(I-1)-ENTP(I)
  153 CONTINUE
C
C** CALCULATE MINIMUM VALUE OF ACC(I) AND PINCH TEMPERATURE **
        DO 154 I=1,L
        ACCSORTA(I) = ACC(I)
  154 CONTINUE
        CALL SORTA(ACCSORTA,L,INTV)
        ACCMIN = ACCSORTA(1)
        HEAT  = ABS(ACCMIN)
        DO 155 I=1,K
        HTFLOW(I) = ACC(I-1) + HEAT
  155 CONTINUE
        IF(ACCMIN.LT.0) THEN
        CUMIN = HTFLOW(K)
        HUMIN = HEAT
```

```
      ELSE
      CUMIN = ACC(L)
      HUMIN = 0
      END IF
      IF((CUMIN.EQ.0).OR.(HUMIN.EQ.0))THEN
      WRITE(*,156)
  156 FORMAT('0',//T37,'CAUTION !')
      WRITE(*,157)
  157 FORMAT(3X,/T14,'THIS PROGRAM IS THE THRESHOLD CASE.',2X,
     *'THE PROGRAM IS NOT',/T6,'DESIGNED FOR SOLVING IT.',2X,
     *'THE RESULT BELOW MIGHT BE INCORRECTED.',
     */T6,'PLEASE CHECK IT BY DRAWING COMPOSITE CURVE.')
      END IF
      THPINCH = THI(INTV(1)+1)
      TCPINCH = THPINCH-DTMIN
C
C**************** PRINT OUT THE RESULT *********************
      WRITE(*,158)
  158 FORMAT('0',///T35,'RESULT',/)
      WRITE(*,159)
  159 FORMAT(T7,'-------------------------------------------',0X,
     *'-------------------')
      WRITE(*,160)
  160 FORMAT(T8,'INTERVAL',T19,'HOT - STREAM',T33,'DEFICIT',
     *T44,'CUMULATIVE',T58,'HEAT FLOW')
      WRITE(*,161)
  161 FORMAT(T11,'No.',T19,'TEMPERATURE',T46,'OUTPUT')
      WRITE(*,159)
      DO 167 I=1,K
      IF (I.LE.K-1)THEN
      WRITE(*,163)THI(I),HTFLOW(I)
  163 FORMAT(T20,F8.2,T58,F8.2)
      WRITE(*,164)I,ENTP(I),ACC(I)
  164 FORMAT(T10,I3,T32,F8.2,T44,F8.2)
      ELSE
      WRITE(*,165)THI(K),HTFLOW(K)
  165 FORMAT(T20,F8.2,T58,F8.2)
      WRITE(*,003)
      WRITE(*,159)
      END IF
  167 CONTINUE
C
C***************** CHECK UNIT OF THE RESULT ****************
C
C***** TEMPERATURE UNIT IN oF ******************************
      IF(ITEMP.EQ.1) THEN
      WRITE(*,168)DTMIN
  168 FORMAT(/10X,'MINIMUM TEMPERATURE DIFFERENCE          =',F8.2,
     *4X,'oF')
      WRITE(*,169)TCPINCH
  169 FORMAT(10X,'PINCH IS LOCATED AT COLD TEMPERATURE    =',F8.2,
     *4X,'oF')
      WRITE(*,170)THPINCH
  170 FORMAT(10X,'PINCH IS LOCATED AT HOT TEMPERATURE     =',F8.2,
     *4X,'oF',/)
      WRITE(*,171)
```

```
  171 FORMAT('0',T8,'************************* ENERGY TARGET ',0X,
     *'*************************')
      WRITE(*,172)HUMIN
  172 FORMAT(/10X,'MINIMUM HOT UTILITY REQUIREMENT          =',F8.2,
     *4X,'BTU/hr')
      WRITE(*,173)CUMIN
  173 FORMAT(10X,'MINIMUM COLD UTILITY REQUIREMENET         =',F8.2,
     *4X,'BTU/hr',/)
C
C***** TEMPERATURE UNIT IN oC *********************************
      ELSE
      WRITE(*,174)DTMIN
  174 FORMAT(/10X,'MINIMUM TEMPERATURE DIFFERENCE           =',F8.2,
     *4X,'oC')
      WRITE(*,175)TCPINCH
  175 FORMAT(10X,'PINCH IS LOCATED AT COLD TEMPERATURE      =',F8.2,
     *4X,'oC')
      WRITE(*,176)THPINCH
  176 FORMAT(10X,'PINCH IS LOCATED AT HOT TEMPERATURE       =',F8.2,
     *4X,'oC',/)
      WRITE(*,171)
      WRITE(*,178)HUMIN
  178 FORMAT(/10X,'MINIMUM HOT UTILITY REQUIREMENT          =',F8.2,
     *4X,'kW')
      WRITE(*,179)CUMIN
  179 FORMAT(10X,'MINIMUM COLD UTILITY REQUIREMENET         =',F8.2,
     *4X,'kW',/)
      END IF
  180 STOP
      END
```

```
C
C
C************ SUBPROGRRAM  #1 : SORTING MAX TO MIN ***********
C
      SUBROUTINE SORTZ(X,J)
      INTEGER J,A1,A2
      REAL X(J),TEMP
  100 IF (J .LE. 1) GOTO 101
  200 DO 201 A1 = 1,J-1
  300 DO 301 A2 = A1 + 1,J
  400 IF (X(A1) .GE. X(A2)) GOTO 401
      TEMP  = X(A1)
      X(A1) = X(A2)
      X(A2) = TEMP
  401 CONTINUE
  301 CONTINUE
  201 CONTINUE
  101 CONTINUE
      RETURN
      END
C
C*********** SUBPROGRRAM  #2 : SORTINNG MIN TO MAX ***********
C
      SUBROUTINE SORTA(Y,J,ORDER)
      INTEGER J,A1,A2,ORDER(J),IP
      REAL Y(J),PAT
  100 IF (J .LE. 1) GOTO 101
      DO 200 I=1,J
      ORDER(I)=I
  200 CONTINUE
  300 DO 301 A1 = 1,J-1
  400 DO 401 A2 = A1 + 1,J
  500 IF (Y(A1) .LE. Y(A2)) GOTO 501
      PAT   = Y(A1)
      Y(A1) = Y(A2)
      Y(A2) = PAT
      IP          = ORDER(A1)
      ORDER(A1)  = ORDER(A2)
      ORDER(A2)  = IP
  501 CONTINUE
  401 CONTINUE
  301 CONTINUE
  101 CONTINUE
      RETURN
      END
```

Apppendix C

Calculation Data

Table C.1 Direct fired heater data sheet
(F-1Q1 : Crude Heater)

UNIT PERFORMANCE			
1. FLUID CHARGE		CRUDE	STEAM
TOTAL FLUID	lb/hr	619,150	33,780
2. INLET FLOW			
VAPOR	lb/hr	0	33,780
LIQUID	lb/hr	619,150	0
MOL. WT. OF VAPOR			18
TEMPERATURE	°F	444	289
PRESSURE	PSIG	170	50
3. OUTLET FLOW			
VAPOR	lb/hr	391,300	33,780
LIQUID	lb/hr	227,850	0
MOL. WT. OF VAPOR		159.7	18
TEMPERATURE	°F	723	600
PRESSURE	PSIG	20	45
4. HEAT ABSORBED	MMBtu/hr	149.4	5.1
5. HEAT LIBERATED	MMBtu/hr	187.273	(OIL FIRED)
6. THERMAL EFFICIENCY (LHV)	%	82.5	(CALCULATED)
7. HEAT LOSS	%	1.5	(RADIANT&CONV.)
	%	16.0	(STACK)
8. FLUE GAS TEMPERATURE	°F	656	(LEAVING)
9. AIR TEMPERATURE	°F	77.0	
10. FUEL CHARACTERISTICS			
FLUE		15 oAPI OIL	
HEATING VALUE (LHV)	Btu/hr	17,500	
FLUE CONSUMPTION		10,623.6	(CALCULATED)

Table C.2 : Heat exchanger specification sheet

NO.	EQUIPMENT	FLUID CIRCULATING	FLOW RATE IN-OUT (lb/hr)	TEMP.(°F)		°API	HEAT EXCHANGE (MBtu/hr)
				IN	OUT		
1	E-101	S.S. : CRUDE T.S. : LIGHT DISTILLATE `	619,150 350,000	80 346	199 176	35.0 50.9	35.0
2	E-102	S.S. : CRUDE T.S. : KEROSENE	619,150 94,092	119 229	383 229	35.0 43.9	8.8
3	E-103	S.S. : CRUDE T.S. : DIESEL	619,150 98,029	229 272	510 272	35.0 34.3	14.4
4	E-104	S.S. : CRUDE T.S. : DIESEL CIR. REFLUX	619,150 134,000	272 540	310 390	35.0 35.3	59.5
5	E-105	S.S. : REDUCED CRUDE T.S. : CRUDE	241,040 :619,150	697 345	310 452	15.3 35.0	56.4
6	E-403	S.S. : LIGHT NAPHTHA T.S. : DIESEL OIL	* 311,600 116,000	303 540	314 390	76.6 35.3	11.6
7	E-106	S.S. : FRACTIONATOR OVHD T.S. : WATER	* 476,540 5,605,000	252 115	187 60		89.2
8	E-107	S.S. : FRAC. OVHD PRODUCT T.S. : WATER	* 84,469 4,580,000	187 95	100 100		22.9
9	E-108	S.S. : HEAVY NAPHTHA T.S. : WATER	59,565 250,000	270 95	120 115	53.6	5.0
10	E-109	S.S. : KEROSENE T.S. : WATER	94,029 257,500	229 95	120 115	43.9	5.15
11	E-110	S.S. : DIESEL T.S. : WATER	98,029 393,000	272 95	120 115	34.3	7.86
12	E-111	S.S. : GAS OIL T.S. : WATER	50,245 730,000	611 95	120 115	27.3	14.6
13	E-112	S.S. : REDUCED CRUDE T.S. : WATER	241,040 1,130,000	364 95	180 115	15.3	22.6

Remark : * Light naphtha, fractionator overhead, and fractionator overhead product ,respectively, circulated in shell side of exchanger No. E-403, E-106, and E-107 are two phase components. Their compositions are detailed in Table C.4.

- S.S. means shell side, and T.S. means tube side.

Table C.3 Phase compositions of E-403, E-106, E-107

NO.	EQUIPMENT	PHASE COMPOSITION	ENTERING			LEAVING		
			(lb/hr)		BUBLE OR DEW Pt.(°F)	(lb/hr)		BUBLE OR DEW Pt.(°F)
			VAPOR	LIQUID		VAPOR	LIQUID	
1	E-403	S.S. : LIGHT NAPHTHA	-	311,600	303	93,470	218,130	314.0
2	E-106	S.S. : H.C.	442,760	-	249	76,179	366,581	187.0
		: STEAM	33,780	-	205	8,290	25,490	187.0
3	E-107	S.S. : H.C.	76,179	-	186	-	76,179	108.0
		: STEAM	8,290	-	186	-	8,290	108.0

Remark : - S.S. means shell side.

MB100-1

TABLE C.4 : MATERIAL BALANCE DATA

TOPPING UNIT : 100

DESIGN BASIS : 50,000 B/D

STREAM No.	1	2	3	4	5	6	7	8
COMPONENT	CRUDE CHARGE (LBS/HR)	STEAM TO TRANSFER LINE (LBS/HR)	STEAM TO RESIDUE STRIPPER (LBS/HR)	FRAC'TION REDUCED CRUDE (LBS/HR)	GAS OIL STRIPPER FEED (LBS/HR)	GAS OIL TO PLATED No. #3 (LBS/HR)	GAS OIL TO STORAGE (LBS/HR)	GAS OIL STRIPPER OVERHEAD (LBS/HR)
TOTAL H.C.	619150	-	-	241040	60257		50245	10012
STREAM	-	16000	8953	-	-		1333	
WATER	-	-	-	-	-		-	
TOTAL	619150	16000	8953	241040	60257		50245	11345
MOLES/HR	2926	889	497	470	200		159	115
AVERAGE MW	211.6	18	18	512.9	301.3		316.0	98.7
API DEGREE	35.0	-	-	15.3	28.0		27.3	-
GMP @ TEMP	1475	-	-	518	180		132	-
BPSD	50,000	-	-	17156	4661		3863	-
SCFM	-	546	3140	-	-		-	726
MMSCFD	-	8.09	4.52	-	-		-	1.05

MB100-2

TABLE C.4 (CONTINUED)

TOPPING UNIT : 100

STREAM No.	9	10	11	12	13	14	15	16
COMPONENT	STEAM TO GAS OIL STRIPPER (LBS/HR)	FRAC'TION DIESEL DRAW (LBS/HR)	DIESEL CIRCULATED REFLUX (LBS/HR)	DIESEL CIRCULATED VS. CRUDE (LBS/HR)	DIESEL TO E-403 (LBS/HR)	DIESEL STRIPPER FEED (LBS/HR)	STEAM TO DIESEL STRIPPER (LBS/HR)	DIESEL STRIPPER OVERHEAD (LBS/HR)
TOTAL H.C.	-	372810	250000	134000	116000	122810	-	24781
STREAM	1333	-	-	-	-	-	2792	2792
WATER	-	-	-	-	-	-	-	-
TOTAL	1333	372810	250000	134000	116000	122810	2792	27573
MOLES/HR	74	1609	1079	578	501	530	155	279
AVERAGE MW	18	231.7	231.7	231.7	231.7	231.7	18	98.8
API DEGREE	-	35.3	35.3	35.3	35.3	35.3	-	-
GMP @ TEMP	-	1148	770	413	357	378	979	1762
BPSD	-	30612	20226	10841	9385	9936	1.41	2.54
SCFM	467	-	-	-	-	-	-	-
MMSCFD	0.67	-	-	-	-	-	-	-

MB100-3

TABLE C.4 (CONTINUED)

TOPPING UNIT : 100

STREAM No.	17	18	19	20	21	22	23	24
COMPONENT	DIESEL FRAC'TION COALESCER (LBS/HR)	DIESEL FOR MIDDLE DISTILATE (LBS/HR)	DIESEL TO BATTERY LIMIT (LBS/HR)	KEROSENE STRIPPER FEED (LBS/HR)	STEAM TO KEROSENE STRIPPER (LBS/HR)	KEROSENE STRIPPER OVERHEAD (LBS/HR)	KEROSENE TO COALESCER (LBS/HR)	KEROSENE TO MIDDLE DISTILATE (LBS/HR)
TOTAL H.C.	98029	16172	81857	117428	-	23336	94092	15277
STREAM	-	-	-	-	2792	2792	-	-
WATER	-	-	-	-	-	-	-	-
TOTAL	98029	16172	81857	117428	2792	26128	94092	15277
MOLES/HR	406	67	339	694	155	309	540	88
AVERAGE MW	241.5	241.5	241.5	169.2	18	84.6	174.4	174.4
API DEGREE	34.3	34.3	34.3	44.8	-	-	43.9	43.9
GMP @ TEMP	236	39	197	368	-	-	241	39
BPSD	7880	1300	6580	10042	-	-	8007	1300
SCFM	-	-	-	-	979	1952	-	-
MMSCFD	-	-	-	-	1.41	2.81	-	-

MB100-4

TABLE C.4 (CONTINUED)

TOPPING UNIT : 100

STREAM No.	25	26	27	28	29	30	31	32
COMPONENT	KEROSENE TO BATTERY LIMIT (LBS/HR)	MIDDLE DISTILATE TO BATTERY LIMIT (LBS/HR)	HEAVY NAPHTHA STRIPPER FEED (LBS/HR)	STEAM TO HEAVY NAPHTHA STRIPPER (LBS/HR)	HEAVY NAPHTHA STRIPPER OVERHEAD (LBS/HR)	HEAVY NAPHTHA TO PRETREATER (LBS/HR)	HEAVY NAPHTHA TO STORAGE (LBS/HR)	KEROSENE CIRCULATED REFLUX (LBS/HR)
TOTAL H.C.	78815	31449	72407	-	12842	59565	NORMALLY	350000
STREAM	-	-	-	1910	1910	-	NO FLOW	-
WATER	-	-	-	-	-	-		-
TOTAL	78815	31449	72407	1910	14752	59565		350000
MOLES/HR	452	155	572	106	216	462	DESIGN FOR	2518
AVERAGE MW	174.4	202.9	126.6	18	68.3	128.9	(30)	139.0
API DEGREE	43.9	39	54.4	-	-	53.6	AT 120 oF	50.9
GMP @ TEMP	202	78	223	-	-	178		1085
BPSD	6707	2600	6529	-	-	5348		30946
SCFM	-	-	-	670	1364	-		-
MMSCFD	-	-	-	0.96	1.96	-		-

MB100-5

TABLE C.4 (CONTINUED)

TOPPING UNIT : 100

STREAM No.	33	34	35	36	37	38	39	40	41
COMPONENT	FRICTION OR OVERHEAD (LBS/HR)	REFLUX CONDENSER OUTLET (LBS/HR)	REFLUX CONDENSE BYPASS (LBS/HR)	VAPOR FROM REFLUX DRUM (LBS/HR)	FRACTATOR REFLUX (LBS/HR)	REFLUX DRUM FOR WATER (LBS/HR)	OVERHEAD RECYCLE WATER (LBS/HR)	WILD LIGHT NAPHTHA (LBS/HR)	STEAM TO SUPER HEATED (LBS/HR)
METHANE								2	
ETHANE								25	
PROPANE								964	
ISOBUTANE								867	
N-BUTANE								5787	
LIGHT NAPHTHA								68534	
TOTAL H.C.	442760	442760	NORMALLY	76179	366581	-	-	76179	-
STEAM	33780	8290	NO	8290	-	-	-	-	33780
WATER	-	25490	FLOW	-	-	25490	8290	-	-
TOTAL	476540	476540		84469	366581	25490	8290	76179	33780
MOLES/HR	6266	6260	DESIGN	1349	3501	1416	460	889	1876
AVERAGE MW	76.1	MULTIPHASE	FOR	62.9	104.7	18	18	85.7	18
API DEGREE	-	SEE (36)	25 %	-	64.6	-	-	78.0	-
GMP @ TEMP	-	FOR VAPOR	STREAM	-	1118	53	17	231	-
BPSD	-	AND	(33)	-	34872	-	-	7746	-
SCFM	39582	(37)+(38)		8522	-	-	-	-	11851
MMSCFD	57.0	FOR LIQ		12.27	-	-	-	-	1706

Appendix D

Material and Energy Balance

D.1 Material and Energy Balance Around F-101

Data

1. Crude charge :

   Input : liquid phase = 619,150 lb/hr, T = 444 ^{o}F, ^{o}API = 35

   Output : liquid phase = 391,300 lb/hr, gas phase = 227,850 lb/hr

   T = 723 ^{o}F, latent heat (at T = 520 ^{o}F) is 105.8 Btu/lb

2. Steam :

   Input : Saturated steam T = 298 ^{o}F, P = 64.7 psia,

   Enthalpy = 1179.1 Btu/lb-F

   Output : Superheated steam T = 600 ^{o}F, P = 59.7 psia,

   Enthalpy = 1330.4 Btu/lb-F

3. Fuel oil :

   Feed 10,623.6 lb/hr, T = 200 ^{o}F,

   heating value (LHV) = 17,500 Btu/lb = 9697,7 kcal/kg fuel

4. Air :

   T = 80 ^{o}F, 25 % excess, density (at 0 ^{o}C) = 1.2928 kg/cu.m.

5. Flue gas :

   T = 656 ^{o}F, Cpm hot air (T = 656 to 80 ^{o}F) = 0.267 Btu/lb-F

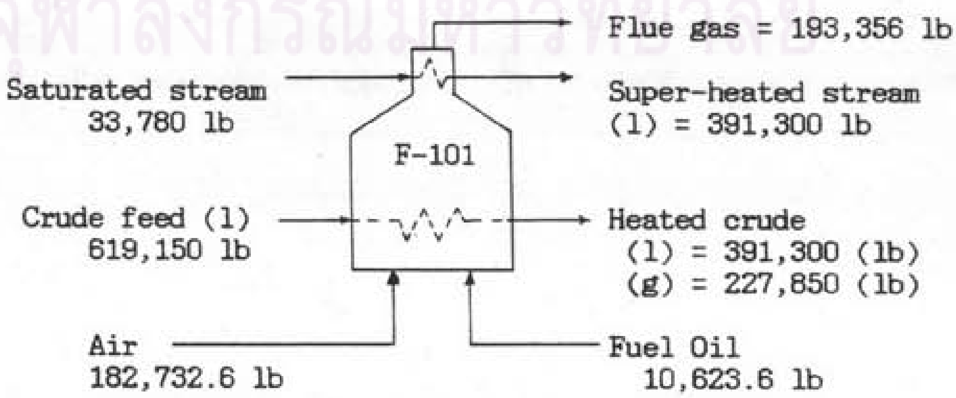


Figure D.1 Material balance of crude heater

D1.1 Material Balance Around F-101

To determine the amount of air for combustion, we use Boie's Equation [31]

$$Ao = \frac{(12.38)(H1-1100)}{10000} \quad m^3/kg\ fuel$$

$$A = mAo \quad m^3/kg\ fuel$$

$$Go = \frac{(15.75)(H1-1100)}{10000} - 2.18 \quad m^3/kg\ fuel$$

$$G = Go + (m-1)Ao \quad m^3/kg\ fuel$$

where
- Ao = quantity of air theoretically required for complete combustion
- A = quantity of air actually used for combustion
- Go = quantity of stack gas theoretically occured
- G = quantity of stack gas actually occured
- H1 = low heating value of fuel (kcal/kg fuel)
- m = air ratio (-)

Therefore,

$$Ao = \frac{(12.38)(9697.7-1100)}{10000} = 10.64 \quad m^3/kg\ fuel$$

$$A = 1.25(10.64) = 13.3 \quad m^3/kg\ fuel$$

Since, density of air (ρ) = 1.2928 kg/m^3, therefore

$$A = \frac{13.3\ m^3}{kg\ fuel} \left| \frac{1.2928\ kg\ air}{m^3} \right.$$

$$= 17.20 \quad kg/kg\ fuel\ (or\ lb/lb\ fuel)$$

$$\text{Total air feed} = 17.20\ \frac{lb}{lb\ fuel} * 10623.6\ lb\ fuel$$

$$= 182,732.58\ lb\ air$$

$$Go = \frac{(15.75)(9697.7-1100)}{10000} - 2.18$$

$$= 11.3614 \quad m^3/kg\ fuel$$

$$G = 11.3614 + (1.25-1)(10.64)$$

$$= 14.02 \quad m^3/kg\ fuel$$

$$= \frac{14.02\ m^3}{kg\ fuel} \Big| \frac{1.2928\ kg\ air}{m^3}$$

$$= 18.127 \quad kg/kg\ fuel\ \ (or\ lb/lb\ fuel)$$

$$\text{Total stack gas} = 18.127 \frac{lb}{lb\ fuel} * 10623.6\ lb\ fuel$$

$$= 192,572.26 \quad lb\ air$$

Note that in the subsequent calculation, we will use the summation between weight of fuel oil feed and air feed ,i.e., 193,356.18 lb (182,732.58 + 10,623.6) as the weight of flue gas.

Overall Material Balance Around F-101

Input	lb
1. crude feed (liquid)	619,150.0
2. saturated steam feed	33,780.0
3. fuel oil feed	10,623.6
4. air feed	182,732.6
Total	846,286.2

Output	lb
1. heated crude (liquid)	391,300.0
(vapor)	227,850.0
2. superheated steam	33,780.0
4. dry flue gas	193,356.2
Total	846,286.2

Remark : Amount of water vapor entering as air humidity is substracted from the amount of water vapor in the flue gas.

D1.2 Energy Balance Around F-101

1. Calculate Useful Heat to Hydrocarbon (H.C.) Crude

Temperature refence = 444 ^{o}F

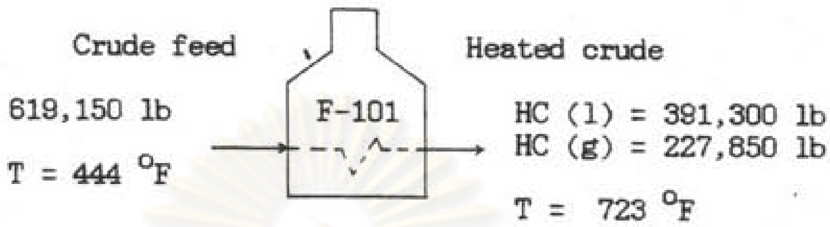


Figure D.2 H.C. balance around F-101

1. Enthalpy of H.C. (liquid phase) : at T = 444 to 520 ^{o}F

   (^{o}API = 35 -- Cpm = 0.71 Btu/lb-^{o}F)

   H = 619,150(0.71)(520-444) = 33.41 MBtu/hr

2. Enthalpy of H.C. (liquid phase) : at T = 520 to 723 ^{o}F

   (^{o}API = 42.5 -- Cpm = 0.74 Btu/lb-^{o}F)

   H = 391,300(0.74)(723-520) = 59.04 MBtu/hr

3. Enthalpy of H.C. (gas phase) : at T = 520 to 723 ^{o}F

   (Cpm = 0.67)

   H = 227,850(0.67)(723-520) = 30.99 MBtu/hr

4. Latent heat of H.C. (gas phase) : at T = 520 ^{o}F

   H = 227,850(105.8) = 24.12 MBtu/hr

The net heat absorbed by H.C. is 148.71 MBtu. Note that the calculated result above is extremely closed to the designed data (149.4 MBtu/hr) given in Table C.1, Appendix C.

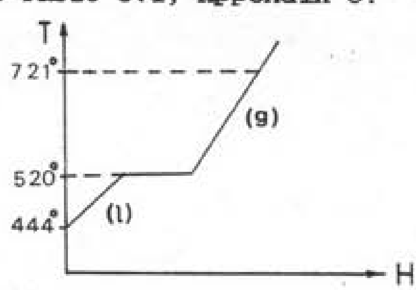


Figure D.3 Enthalpy calculation diagram for H.C. balance

2. <u>Calculate Useful Heat to Steam</u>

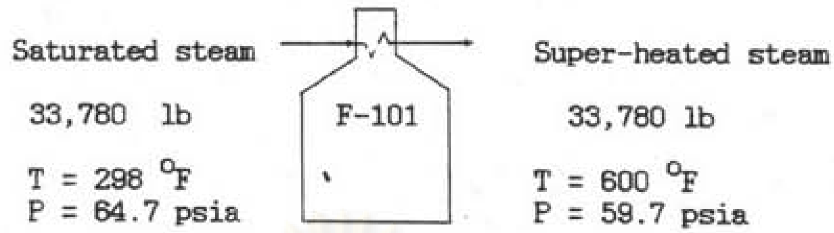


Figure D.4 Steam balance around F-101

1. Enthalpy of saturated steam : at T = 298 °F, P = 64.7 psia

$$H = 1179.1(33780) = 39.83 \quad \text{MBtu/hr}$$

2. Enthalpy of superheated steam : at T = 600 °F, P = 59.7 psia

$$H = 1330.4(33780) = 44.94 \quad \text{MBtu/hr}$$

The net heat absorbed by steam is ,therefore,

$$Q = 44.94 - 39.83 = 5.11 \quad \text{MBtu/hr}$$

The calculated heat absorbed by steam above is equal to the design data (5.1 MBtu) given in Table C.1, Appendix C.

Overall Energy Balance Around F-101

Reference temperature is 80 ^{o}F

Input		MBtu/hr	%
1. Enthalpy of fuel oil			
a. sensible heat = 10623.6(0.43)(200-80)	=	0.54	0.28
b. heating value = 10623.6(17500)	=	185.91	99.71
2. Enthalpy of air (T = 80 ^{o}F)	=	0.00	0.00
Total	=	186.45	100.00

Output		MBtu/hr	%
1. Useful heat to H.C.	=	148.71	79.76
2. Useful heat to steam	=	5.11	2.74
3. Heat to dry flue gas			
= 193356.18(0.267)(656-80)	=	29.74	16.0
4. Loss and radiation (by difference)	=	2.89	1.55
Total	=	186.45	100.00

$$\text{Thermal efficiency} = \frac{(148.71 + 5.11) * 100}{186.45}$$

$$= 82.5 \%$$

<u>Remark</u> : Compared below are the results of the above calculation versus the design data taken from the direct fired heater data sheet, Table C.1, Appendix C. Little difference on each pair of comparison has been obtained. This means that the data received from the plant is quite accurate and reliable.

		Calculated	Design data	% Difference
1. heat liberated (oil fired)	MBtu	186.45	187.273	0.41
2. heat absorbed	MBtu			
by crude		148.71	149.4	0.46
by steam		5.11	5.1	0.19
3. thermal efficiency	%	82.5	82.5	0.0
4. heat to stack gas	%	16.0	16.0	0.0
5. heat loss	%	1.55	1.6	3.1

D.2 Material and Energy Balance Around Exchangers

Table D.1 summarizes heat exchange between each pair of streams. The design data are also illustrated for comparison.

Table D.1 Calculated heat load vs design data for heat exchangers

NO.	EQUIPMENT	FLUID CIRCULATING	FLOW RATE IN-OUT (lb/hr)	TEMP.(°F)		°API	HEAT EXCHANGE (MBtu/hr)	
				IN	OUT		CALCULATED	DESIGNED
1	E-101	S.S. : CRUDE T.S. : LIGHT DISTILLATE	619,150 350,000	80 346	199 176	35.0 50.9	34.98 34.09	35.0
2	E-102	S.S. : CRUDE T.S. : KEROSENE	619,150 94,092	199 383	229 229	35.0 43.9	9.52 8.41	8.8
3	E-103	S.S. : CRUDE T.S. : DIESEL	619,150 98,029	229 510	272 272	35.0 34.3	14.14 14.01	14.4
4	E-104	S.S. : CRUDE T.S. : DIESEL CIR. REFLUX	619,150 134,000	272 540	310 390	35.0 35.3	12.98 12.87	13.4
5	E-105	S.S. : REDUCED CRUDE T.S. : CRUDE	241,040 :619,150	697 310	345 452	15.3 35.0	52.18 52.51	56.4
6	E-403	S.S. : LIGHT NAPHTHA T.S. : DIESEL OIL	311,600 116,000	303 540	314 390	76.6 35.3	11.29 11.59	11.6
7	E-106	S.S. : FRACTIONATOR OVHD T.S. : WATER	476,540 5,605,000	252 115	187 99.1		89.10 89.12	89.2
8	E-107	S.S. : FRAC. OVHD PRODUCT T.S. : WATER	84,469 4,580,000	187 95	100 100		22.88 22.90	22.9
9	E-108	S.S. : HEAVY NAPHTHA T.S. : WATER	59,565 250,000	270 95	120 115	53.6	4.87 5.00	5.0
10	E-109	S.S. : KEROSENE T.S. : WATER	94,092 257,500	229 95	120 115	43.9	5.27 5.15	5.15
11	E-110	S.S. : DIESEL T.S. : WATER	98,029 393,000	272 95	120 115	34.3	7.47 7.86	7.86
12	E-111	S.S. : GAS OIL T.S. : WATER	50,245 730,000	611 95	120 115	27.3	14.05 14.60	14.6
13	E-112	S.S. : REDUCED CRUDE T.S. : WATER	241,040 1,130,000	364 95	180 115	15.3	21.55 22.60	22.6

Remark : - S.S. means shell side, and T.S. means tube side.

Appendix E

Physical Properties and Coefficients

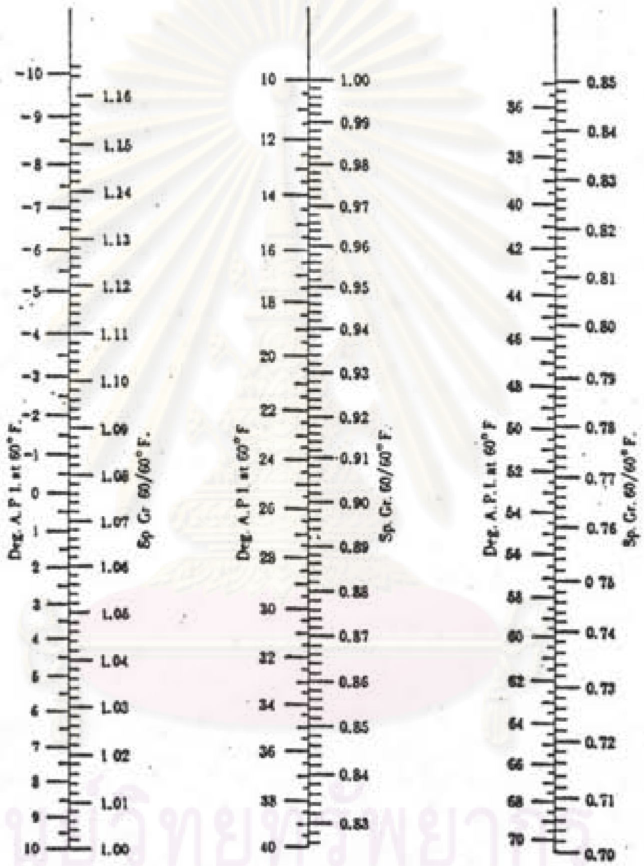


Figure E.1 Gravity conversions

Table E.1 Conversion table

Unacceptable unit	Acceptable SI unit with unit conversion factor
ångström	0.1 nm*
atmosphere (standard)	101.325 kPa
Btu†	1.055 056 kJ
Btu/(lb$_m$·°F) (heat capacity)	4.186 8 kJ/(kg·K)*
Btu/h	0.293 971 1 W
Btu/ft^3	11.356 53 kJ/m^3
Btu/(ft^2·h·°F) (heat transfer coefficient)	5.678 263 J/(m^2·s·K)
Btu/(ft^2·h) (heat flux)	3.154 591 J/(m^2·s)
Btu/(ft·h·°F) (thermal conductivity)	1.730 735 J/(m·s·K)
calorie†	4.186 8 J*
cal/(g·°C) (heat capacity)	4.186 8 kJ/(kg·K)*
centipoise (absolute viscosity)	1.0 mPa·s*
centistoke (kinematic viscosity)	1.0 × 10^{-6} m^2/s*
t (°F)	(t + 459.67)/(1.8) K
t (°R)	t/(1.8) K*
dyne	10.0 μN*
erg	100 pJ*
foot‡	0.3048 m*
ft^2	9.290 304 × 10^{-2} m^2*
ft^3	2.831 685 × 10^{-2} m^3
gallon (U.S. liquid)	3.785 412 × 10^{-3} m^3
horsepower (550 ft·lb$_f$/s)	745.699 9 W
inch	2.54 × 10^{-2} m*
in. Hg (60°F) (inches mercury pressure)	3.376 85 kPa
in. H_2O (60°F) (inches water pressure)	0.248 84 kPa
kg$_f$ (kilogram force)	9.806 65 N*
mile	1 609.344 m*
mm Hg (0°C) (millimeters mercury pressure)	0.133 322 kPa
poise (absolute viscosity)	0.1 Pa·s*
lb$_f$ (pounds force)	4.448 222 N
lb$_m$ (pounds mass–avoirdupois)	0.453 592 4 kg
psi (pounds per square inch pressure)	6.894 757 kPa
stoke (kinematic viscosity)	1.0 × 10^{-4} m^2/s*
yard	0.9144 m*

* Exact equivalence.

† British thermal unit and calorie are reported as the International Table values as adopted in 1956 for all cases in this table. The exact conversion factor for Btu (International Table) to kJ is 1.055 055 852 62. The Btu (thermochemical) is 1.054 350 kJ and the calorie (thermochemical) is exactly 4.184 J. (See footnote § for Table 6).

‡ The foot is reported as the International Table value and holds for all cases of length in this table.

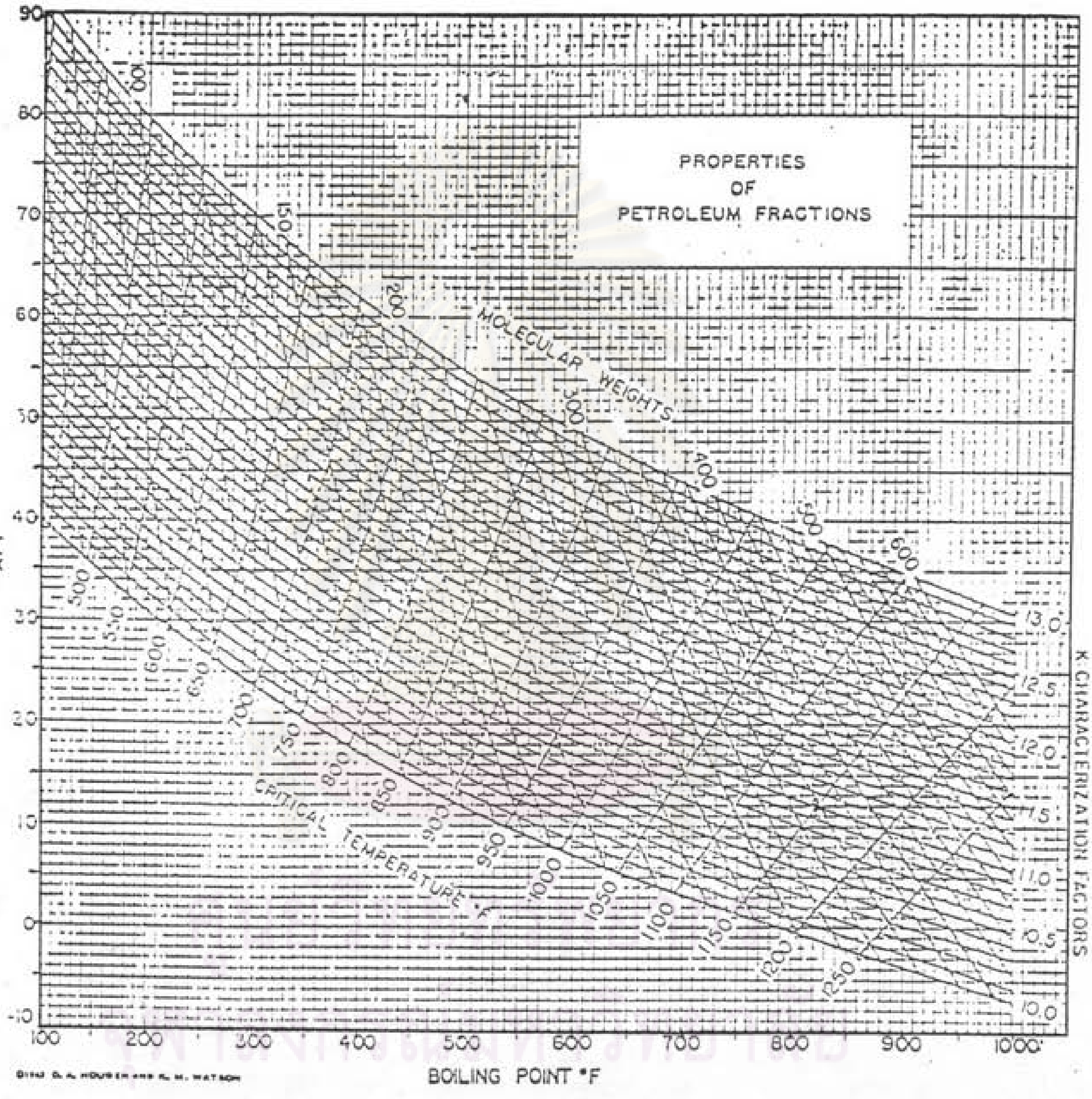


Figure E.2 Properties of petroleum fractions

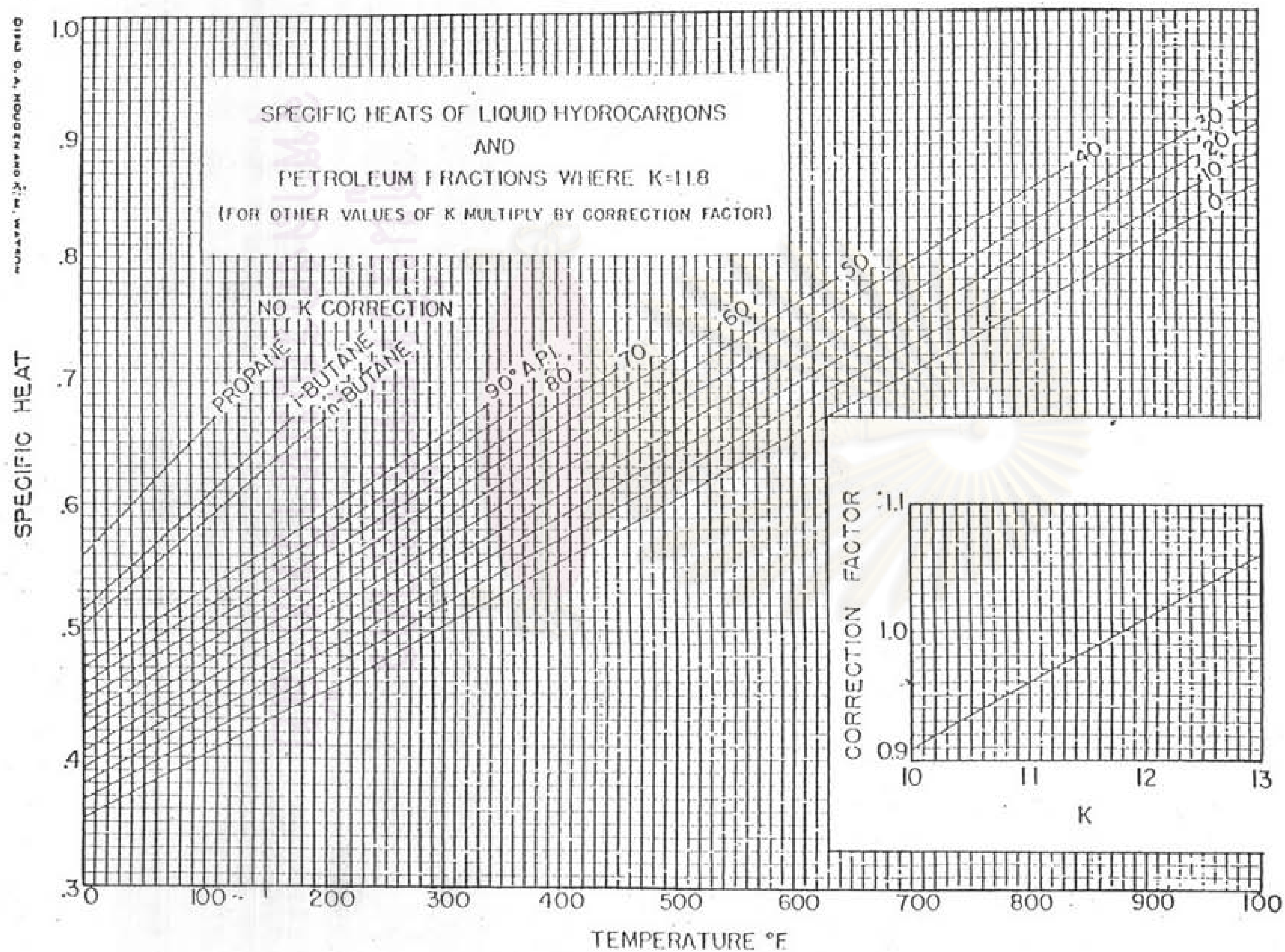


Figure E.3 Specific heat of liquid hydrocarbon

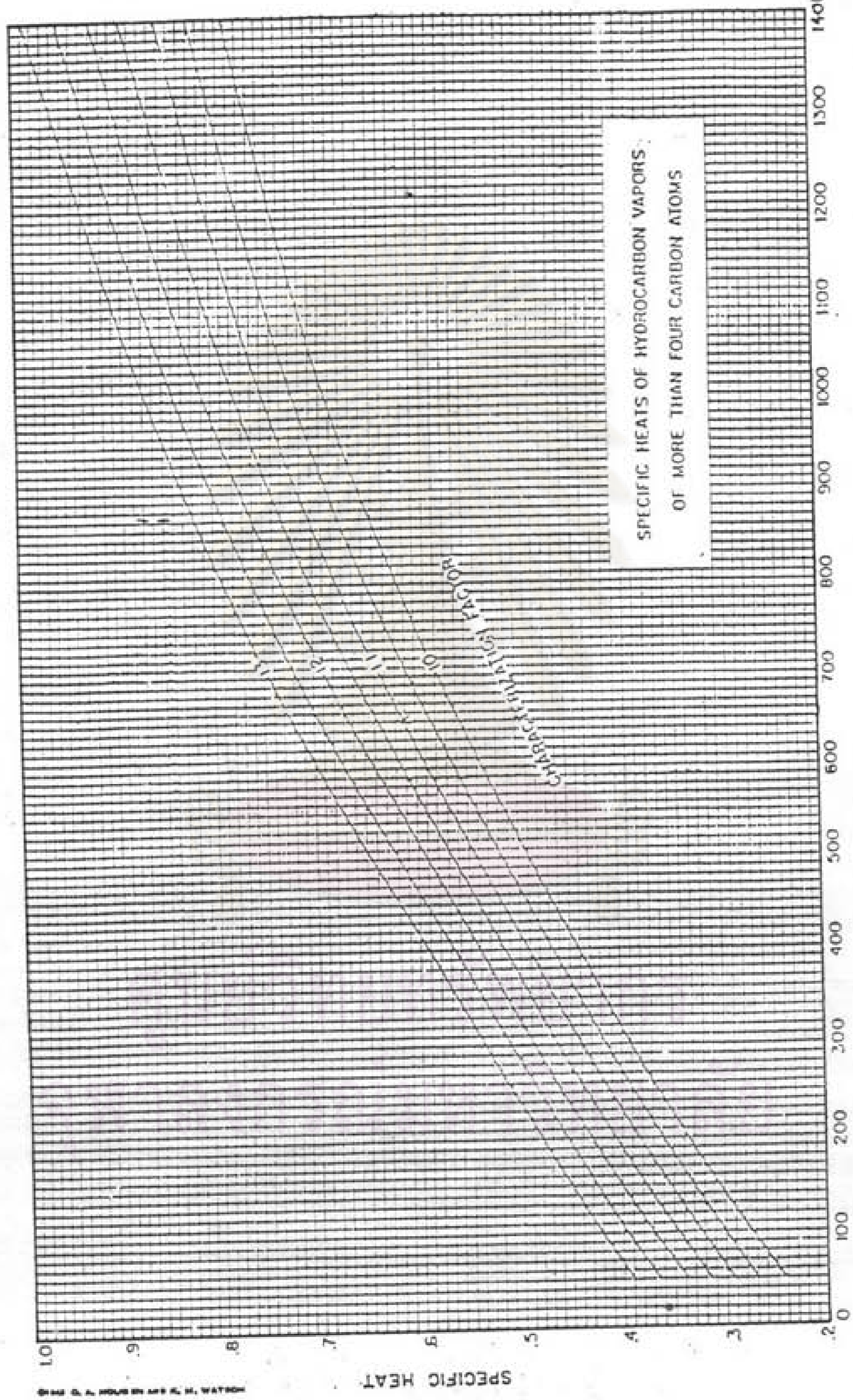


Figure E.4 Specific heat of hydrocarbon vapor

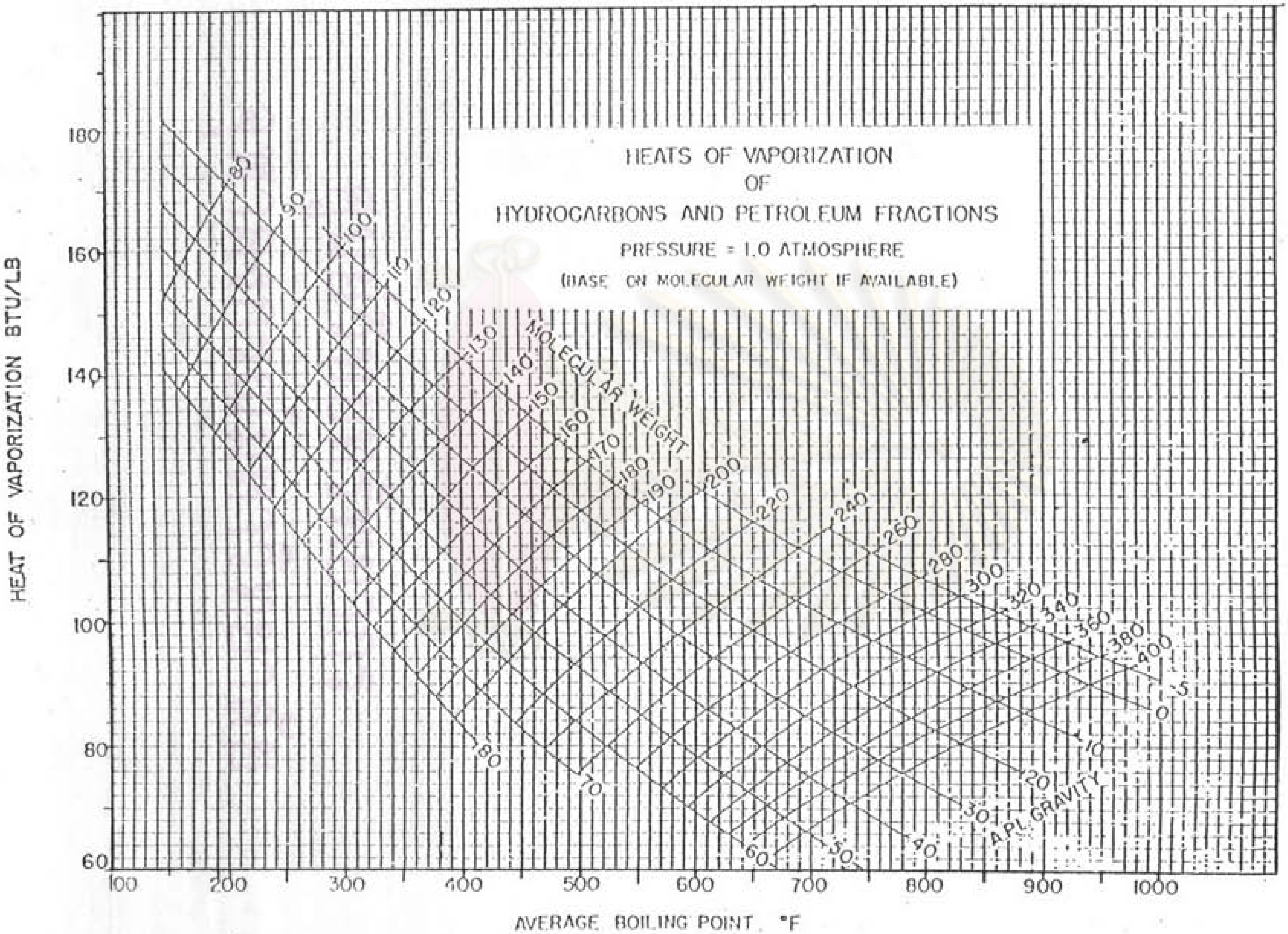


Figure E.5 Heat of vaporization of hydrocarbon and petroleum fractions

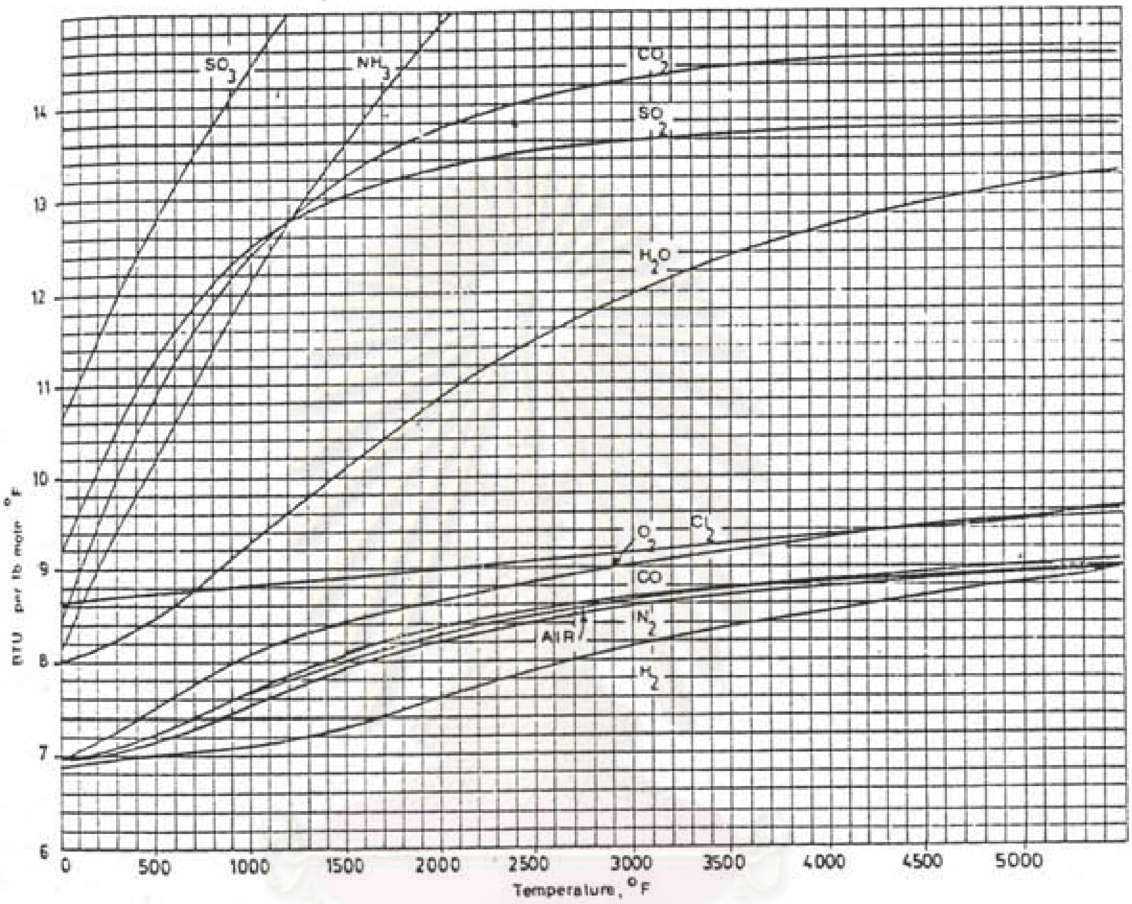


Figure E.6 Heat capacity per mole of gas at constant pressure

Appendix F

Cost Estimation Data

F.1 Heat Transfer Area

The required transfer area, A, for a heat exchanger is determined from the expression

$$A = \frac{Q}{U * DTLM}$$

where Q = net amount of heat transfer

U = overall heat transfer coefficient

DTLM = log mean temperature difference

$$= \frac{(\triangle T2 - \triangle T1)}{\ln(\triangle T2 / \triangle T1)}$$

Note that, $\triangle$ T1 and $\triangle$ T2 are defined as shown in Figure F.1

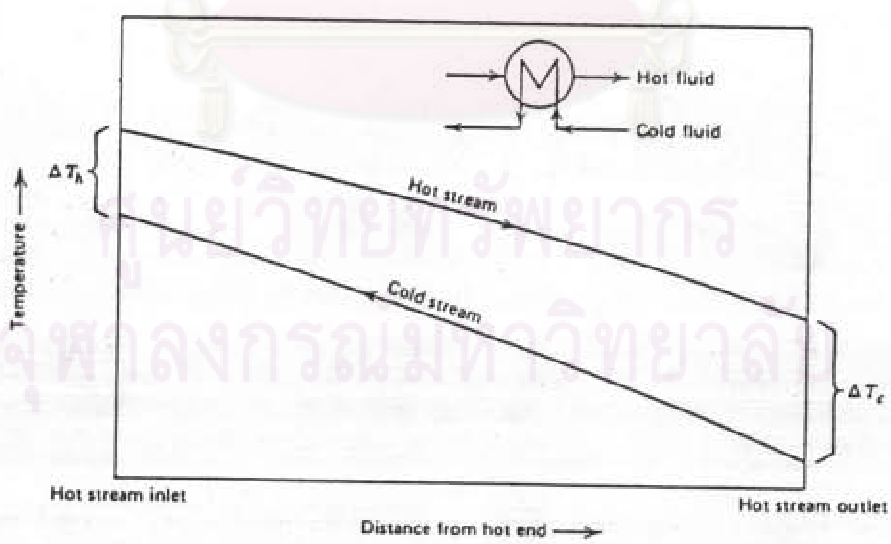


Figure F.1 Temperature profiles for a countercurrent heat exchanger

F.2 Overall Heat Transfer Coefficients

The estimates of the overall heat transfer coefficients, U, (including fouling and wall resistances) used in the present study are listed below

Table F.1 Overall heat transfer coefficient

System	U, Btu/(hr*ft^2*^{o}F)
Condensing vapor to boiling liquid	250
Condensing vapor to flowing liquid	150
Condensing vapor to gas	20
Liquid to liquid	50
Liquid to gas	20
Gas to gas	10
Partial condenser	30

F.3 Cost Data

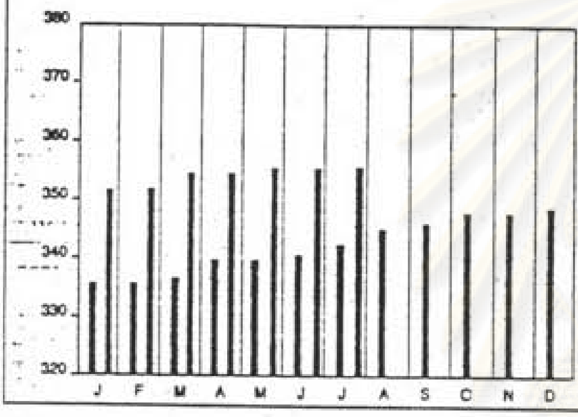
a) Cost Index

Source : Chemical Engineering Journal, McGraw-Hill, September, 1989.

ECONOMIC INDICATORS

1988 1989

CHEMICAL ENGINEERING PLANT COST INDEX

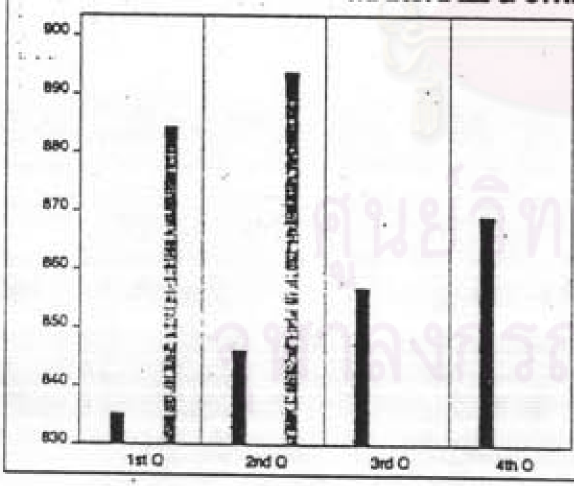


(1957-59 = 100)	July'89 Prelim.	June'89 Final	July'88 Final
CE INDEX	355.9	355.6	343.0
Equipment	392.8	392.4	374.2
Heat exchangers & tanks	375.4	375.4	360.5
Process machinery	363.3	363.0	347.6
Pipe, valves & fittings	463.6	463.7	432.7
Process instruments	351.1	351.4	339.7
Pumps & compressors	484.8	481.5	450.7
Electrical equipment	287.0	285.8	269.6
Structural supports & misc.	374.6	373.2	368.1
Construction labor	268.5	268.8	265.0
Buildings	327.2	327.1	315.6
Engineering & supervision	343.7	342.1	343.2

Annual Index

1983 = 316.9
1984 = 322.7
1985 = 325.3
1986 = 318.4
1987 = 323.8
1988 = 342.5

MARSHALL & SWIFT EQUIPMENT COST INDEX



(1926 = 100)	2nd Q 1989	1st Q 1989	2nd Q 1988
M & S Index	894.7	884.7	846.7
Process industries, average	913.8	902.7	864.8
Cement	908.5	898.9	862.4
Chemical	904.2	892.9	854.2
Clay products	896.0	884.6	848.3
Glass	849.3	839.1	801.5
Paint	913.8	902.5	863.0
Paper	860.7	850.5	814.0
Petroleum products	950.1	938.7	902.3
Rubber	968.3	956.8	917.9
Related industries,			
Electrical power	875.0	869.6	820.4
Mining, milling	914.1	905.5	864.8
Refrigerating	1059.1	1046.2	1000.6
Steam power	900.5	888.7	846.2

Annual index

1983 = 760.8
1984 = 780.4
1985 = 789.6
1986 = 797.6
1987 = 813.6
1988 = 852.0

b) Cost of Utilities

- fuel (unit cost as fuel) = 4.30 US$/MBtu
- cooling water = 0.021 US$/$m^3$

F.4 Cold Utility Calculation

a) MER design

Given : 1. cold utility saved by MER design = 36.32 MBtu/hr

2. Temperature condition of cold stream (cooling water)

$$T_{in} = 95\ ^{o}F\ ,\quad T_{out} = 115\ ^{o}F$$

3. Heat capacity (Cp) of cooling water is 1 Btu/lb ^{o}F

4. Density (ρ) of cooling water is 1 gm/cm^3

The amount of heat absorbed by the cooling water is determined by

$$Q = m\,Cp\,\triangle T$$

Thus, the required mass flowrate of cooling water is

$$m = Q / Cp * \triangle T$$

$$\therefore \text{mass flowrate} = \frac{36.32 \times 10^{6}}{1 \times (115-95)}$$

$$= 1.816 \times 10^{6} \quad \text{lb/hr}$$

$$\text{or} \quad = 823.74 \times 10^{6} \quad \text{gm/hr}$$

According to the correlation of Density = mass/volume , and the density water is 1 gm/cm^3

then, $\text{volume flowrate} = 823.74 \times 10^{6} \quad \text{cm\^{}3/hr}$

$$\text{or} \quad = 823.74 \quad \text{m\^{}3/hr}$$

b) Relaxed Design

cold utility saved by relaxed design = 23.31 MBtu/hr

$$\therefore \text{mass flowrate} = \frac{23.31 \times 10^{6}}{1 \times (115-95)}$$

$$= 1.16 \times 10^{6} \quad \text{lb/hr}$$

$$\text{or} \quad = 528.67 \times 10^{6} \quad \text{gm/hr}$$

then, $\text{volume flowrate} = 528.67 \times 10^{6} \quad \text{cm\^{}3/hr}$

$$\text{or} \quad = 528.67 \quad \text{m\^{}3/hr}$$

VITA

Mr. Chaiyot Worravitudomsuk graduated high school from Triam Udom Suksa school in 1982 and received a BS degree in Chemical Engineering from the Department of Chemical Technology, Faculty of Science, Chulalongkorn University in 1986. After then he subsequently studied for a requirement of the Master's Degree in Chemical Engineering at the Department of Chemical Engineering, Faculty of Engineering, Chulalongkorn University from 1986 till 1989.

He also has an experience in working as process engineer at Seagate Technology Co., Ltd. from the early of 1988 till 1989.