B. COMPUTER PROGRAMS

Computer Flow Diagrams

Program Symbols

Computer Programs

B.1 General Accounting Procedure

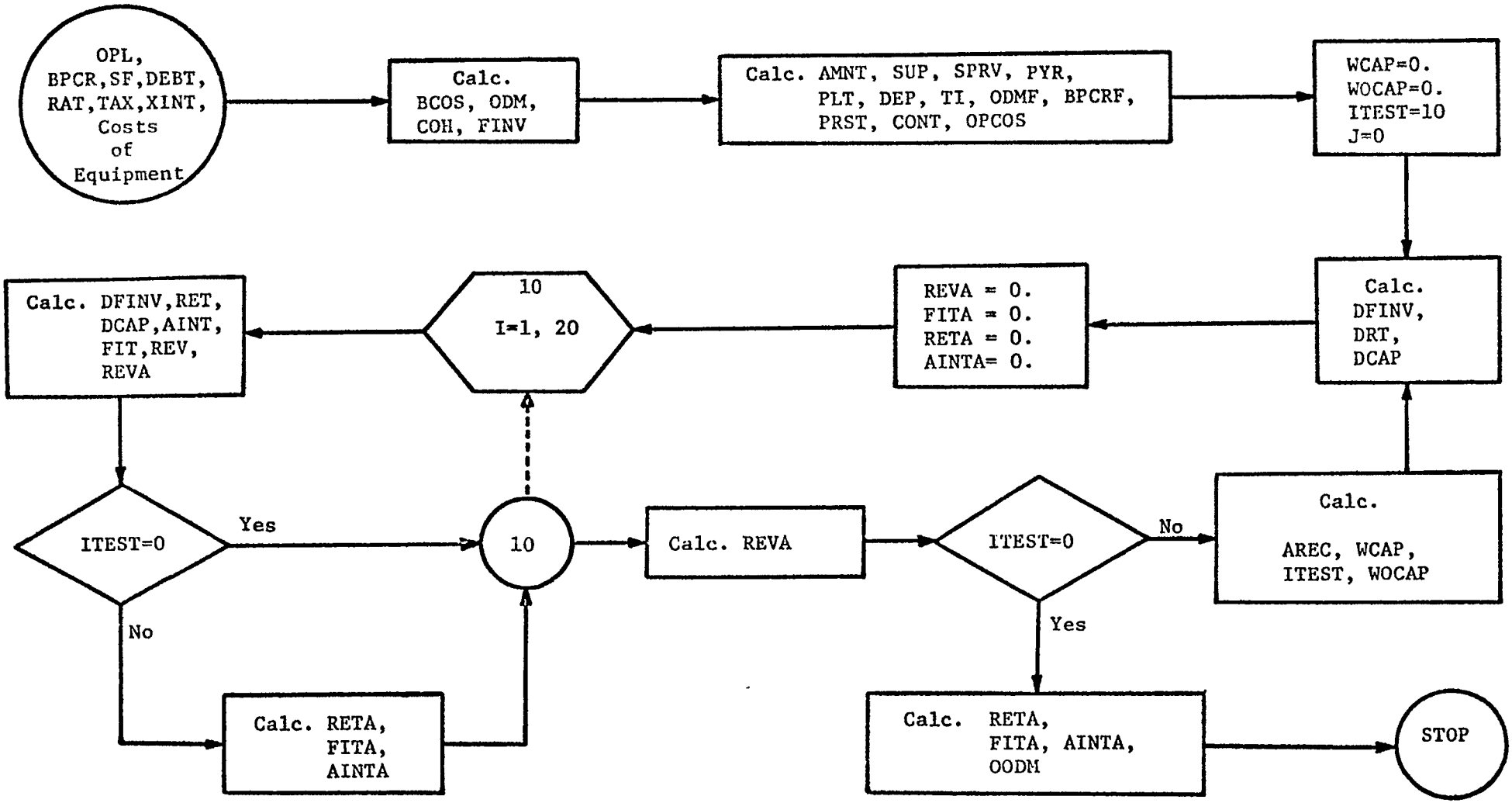
B.2 Gasification

B.3 Shift Conversion

B.4 Gas Purification

B.5 Methanation

B.1 General Accounting Procedure



Computer Flow Diagram for the Calculation of Revenue Requirement

TABLE E.1-1 PROGRAM SYMBOLS AND EXPLANATIONS
FOR O.C.R. GENERAL ACCOUNTING PROCEDURES

Program Symbols	Explanations
BCOS	Bare Costs of the Plant in $1000's
OPL	Operating Labor Cost in $1000's
RAWM	Raw Materials Cost in $1000's
ODM	Other Direct Materials in $1000's
BTU	BTU Produced in Millions of BTU's
SF	Stream Factor, 0.95
DEBT	Fraction of Total Capital Investment Funded by Debt, 0.65
RATE	Rate of Return-On-Rate Base, 0.06, 0.07 etc.
TAX	Nominal Federal Income Tax Rate, 0.50
XINT	Interest Rate on Debt, 0.04, 0.05 etc.
COH	Contractor's Overhead and Profit in $1000's
EINT	Interest During Construction in $1000's
FTNV	Total Fixed Investment in $1000's
AMNT	Maintenance Cost in $1000's
SUP	Supplies in $1000's
SPRV	Supervision in $1000's
PYR	Payroll Overhead in $1000's
PLT	General Plant Overhead in $1000's
DEP	Depreciation in $1000's
TI	Local Taxes and Insurance in $1000's
RAWMF	Cost of Raw Materials Consumed in Process in $1000's

TABLE B.1-1 (Cont.)

Program Symbol	Explanations
ODMF	Cost of Other Direct Material Consumed in Process in $1000's
BPCRF	Revenue from Byproducts Produced in Process in $1000's
PRST	Operating Cost Without Contingencies in $1000's
CONT	Contingencies in $1000's
OPCOS	Operating Cost with Contingenecies and Byproduct Credits in $1000's
WCAP	Working Capital in $1000's
WOCAP	Working Captial in $1000's
VTRY	Materials Inventory Cost in $1000's
ITEST	Computer Test Operator
DFINV	Undepreciated Investment in $1000's
DCAP	Amount of Unretired Debt in $1000's
DRT	Amount of Debt Retired Per Year in $1000's
REVA	20 Year Average Revenue Requirement in $1000's
FITA	20 Year Average Federal Income Tax in $1000's
RETA	20 Year Average Return-on-Rate Base in $1000's
PRGA	20 Year Average Price of Gas, $/MCF or $/MMBTU
AINTA	20 Year Average Interest on Debt in $1000's
RET	Return on Investment in $1000's
AINT	Annual Interest Charge on Debt in $1000's
REV	Annual Revenue Requirement in $1000's
PRG	Annual Price of Gas, $/MCF or $/MMBTU

TABLE B.1-1 (Cont.)

Program Symbols	Explanations
PRINT	Computer Command
I	Year
CONTINUE	Computer Command
ORAWM	Raw Material Inventory in $1000's
OODM	Other Direct Materials Inventory in $1000's
AREC	Accounts Receivable in $1000's
AVG	Average
SHM	0

```
C       AGA ACCOUNTING PROC. GASIFICATION
 15     ACCEPT, BCOS, OPL, RAWM, ODM, SHM, BPCR, BTU, SF
        ACCEPT, DEBT, RATE, TAX, XINT
        COH=BCOS*0.0773
        EINT=XINT*(COH+BCOS)
        FINV=BCOS+COH+EINT
        AMNT=.03*(BCOS-SHM)
        SUP=AMNT*0.15
        SPRV=0.10*OPL
        PYR=(OPL+SPRV)*0.10
        PLT=(OPL+SPRV+AMNT+SUP)*0.5
        DEP=FINV*0.05
        TI=FINV*0.03
        RAWMF=SF*RAWM
        ODMF=SF*ODM
        BPCRF=SF*BPCR
        PRST=RAWMF+ODMF+OPL+AMNT+SUP
        PRST=PRST+SPRV+PYR+PLT+DEP+TI
        CONT=PRST*0.02
        OPCOS=PRST+CONT-BPCRF
        WCAP=0.
        WOCAP=0.
        VTRY=(RAWM+ODM)/12.0
        ITEST=10
        J=0
   12   DFINV=FINV
        DCAP=(FINV+WCAP)*DEBT
        DRT=DCAP*0.05
        DCAP=DCAP+DRT
        REVA=0.
        FITA=0.
        RETA=0.
        PRGA=0.
        AINTA=0.
        DO 10 I= 1,20
    3   DFINV=DFINV-0.05*FINV
        RET=(DFINV+WCAP)*RATE
        DCAP=DCAP-DRT
        AINT=DCAP*XINT
        FIT=(RET-AINT)*TAX/(1.-TAX)-6.50
        REV=RET+FIT+OPCOS
        REVA=REVA+REV
        IF(ITEST)10,11,10
 11     PRG=REV/BTU/SF
        PRINT,I,RET,FIT,REV,PRG,AINT
        RETA=RETA+RET
        FITA=FITA+FIT
        PRGA=PRGA+PRG
        AINTA=AINTA+AINT
   10   CONTINUE
        REVA=REVA/20.
        IF(ITEST)14,13,14
 13     PRINT,
        RETA=RETA/20.
        FITA=FITA/20.
```

```
      PRGA=PRGA/20.
      AINTA=AINTA/20.
      PRINT,J,RETA,FITA,REVA,PRGA,AINTA
      PRINT,
      PRINT,
      ORAWM=RAWM/12.
      PRINT,RAWMF,BCOS,ORAWM
      OODM=ODM/12.
      PRINT,ODMF,COH,OODM
      PRINT,OPL,EINT,AREC
      PRINT, AMNT,FINV,XCAP
      PRINT,SUP
      PRINT,SPRV
      PRINT,PYR
      PRINT,PLT
      PRINT,DEP
      PRINT,TI
      PRINT,CONT
      PRINT,BPCRF
      PRINT,OPCOS
      PRINT,
      PRINT,
      PAUSE,
      GO TO 15
   14 AREC=REVA/(12.*CF)
      XCAP=VTRY+AREC
      ITEST=(XCAP-XOCAP)/10.
      XOCAP=XCAP
      GO TO 12
      END
```

B.2 Gasification

TABLE B.2-1 PROGRAM SYMBOLS AND EXPLANATION FOR GASIFICATION

Program Symbols	Explanations
BTUHA	Heat Manufactured, BTU/100 lb coal
BTUS	Heating Value of Product Gas, BTU/SCF
C	Amount of Reacted Carbon, lb-mole/100 lb coal
CHARI	Enthalphy of Char Entering Reactor, based on 77°F, BTU/100 lb coal
CH4I	Amount of CH_4 Entering Reactor, lb-mole/100 lb coal
CH4X	Amount of CH_4 Leaving Reactor, lb-mole/100 lb coal
COAL	Total Coal Fed into Gasifier, Tons/Day
COI	Amount of CO Entering Reactor, lb-mole/100 lb coal
COX	Amount of CO Leaving Reactor, lb-mole/100 lb coal
CO2I	Amount of CO_2 Entering Reactor, lb-mole/100 lb coal
CO2X	Amount of CO_2 Leaving Reactor, lb-mole/100 lb coal
EK	Water Gas Shift Reaction Equilibrium
EKH2	Apparent Carbon Hydrogen Reaction Equilibrium, atm^{-1}
EKH2O	Apparent Carbon Steam Reaction Equilibrium, atm
G	Heat Required in the Electrothermal Gasifier, BTU/100 lb coal used
HCHARX	Enthalpy of Char Leaving Reactor, based on 77°F, BTU/100 lb coal
HCH4I	Enthalpy of CH_4 Entering Reactor, based on 77°F, BTU/100 lb coal
HCH4X	Enthalpy of CH_4 Leaving Reactor, based on 77°F, BTU/100 lb coal

TABLE B.2-1 (Cont.)

Program Symbols	Explanation
HCOI	Enthalpy of CO Entering Reactor, based on 77°F, BTU/100 lb coal
HCOX	Enthalpy of CO Leaving Reactor, based on 77°F, BTU/100 lb coal
HCO2I	Enthalpy of CO_2 Entering Reactor, based on 77°F. BTU/100 lb coal
HCO2X	Enthalpy of CO_2 Leaving Reactor, based on 77°F. BTU/100 lb coal
HH2I	Enthalpy of H_2 Entering Reactor, based on 77°F, BTU/100 lb coal
HH2OI	Enthalpy of H_2O Entering Reactor, based on 77°F, BTU/100 lb coal
HH2OX	Enthalpy of H_2O Leaving Reactor, based on 77°F, BTU/100 lb coal
HH2X	Enthalpy of H_2 Leaving Reactor, based on 77°F, BTU/100 lb coal
HO2I	Enthalpy of O_2 Entering Reactor, based on 77°F, BTU/100 lb coal
HREAC	Net Heat Generated From The Three Simultaneous Reactions, BTU/100 lb coal
HRH2O	Heat Required Due to Carbon Steam Reaction, BTU/100 lb coal
HRO2	Heat Generated By Carbon Oxygen Reaction, BTU/100 lb coal
H2I	Amount of H_2 Entering Reactor, lb-mole/100 lb coal
H2OA	Amount of Steam Fed, lb-mole/100 lb coal
H2OI	Amount of H_2O Entering Reactor, lb-mole/100 lb coal
H2OX	Amount of H_2O Leaving Reactor, lb-mole/100 lb coal
H2X	Amount of H_2 Leaving Reactor, lb-mole/100 lb coal

TABLE B.2-1 (Cont.)

Program Symbols	Explanations
PROD	Total Amount of Gas Leaving Stage II (Hydrogasifier), lb-mole/100 lb Coal
X	Fraction of Reacted Carbon Which Goes to Carbon Steam Reaction

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                     C
C          DESIGN OF FLUIDIZED BED REACTOR BASED ON                   C
C          BUBBLE ASSEMBLAGE MODEL FOR SIMULTANEOUS                   C
C          REACTIONS.......... CARBON HYDROGEN REACTION               C
C                              ..... CARBON STEAM REACTION            C
C                              ..... WATER GAS SHIFT REACTION         C
C                                                                     C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      COMMON NREAC,JLMF,KAISU,CGAS,FS,GO,RFVER(30),ES2(5,30),HOSEI,PB,
     1XA(5,32),X(30),G(32),DFVE(5,30),W(30),SIGMF(30),RFHOR(30),EK(5),
     2FUGO(5,30)
      DIMENSION DB(15),FM(15),GM(15),HMF(15),HMFTOT(15),HTOT(15),GA(5),
     1EG2(5,30),A(3, 5),SIGMA(5),EG(5),EGM(5),AE(25),AEM(25),GMA(5),
     2TOTEG(5),TOTES(5)
C     INPUT NCOMP,NREAC,A(NR,NC),DT,ALMF,DP,RHOP,CSO,EMF,FS,
C     ALPHA,UMF,UO,UT,TB,PB,DBO,JB
      NCOMP=5
      NREAC=3
      DATA A/2.00,2*-1.,0.,2*1.,0.,-1.,1.,2*0.,-1.,-1.,2*0./
      DATA ALMF,RHOP,CSO,EMF,ALPHA,TB,DBO,JB/
     1 700.,0.256,0.02136,0.6,0.25,927.,3.0,8/
      DP=0.210
      UMF=6.259
      UT=87.2
      UO=15.65
      DT=1352.
      XOUT=0.222
      PB=69.3
      FS=7470.
      EK(2)=40.
      EK(3)=0.6969
 1040 FORMAT(1H0,27HFLUIDIZED BED REACTOR    M=,E12.4,
     18H  DBMAX=,E12.4)
 1050 FORMAT(1H0,2H J,3X,2HDB,6X,1HE,3X,6HHMFTOT,2X,4HHTOT,
     16X,2HBN,10X,2HVB,10X,2HW1,10X,2HW2,10X,2HFM,10X,2HGM)
 1055 FORMAT(1H0,7HDBAVER=,E12.4,5X,3HUB=,E12.4,5X,3HVB=,E12.4,
     15X,3HVC=,E12.4,5X,3HVE=,E12.4)
 1060 FORMAT(I3,F7.1,F7.3,2F7.0,6E12.4)
 1065 FORMAT(1H0,29HHEIGHT OF EACH COMPARTMENT IS, I3,
     123H TIMES BUBBLE DIAMETER.)
 1070 FORMAT(1H0,6HKAISU=,I2,4X,4HLMF=,E12.4)
 1080 FORMAT(I3,F7.4,5F8.4,1X,2E11.4,1X,2E11.4,1X,2E11.4)
 1081 FORMAT(3X,F7.4,5F8.4,1X,2E11.4,1X,2E11.4,1X,2E11.4)
 1090 FORMAT(5H  FS=,E12.4,5H  FB=,E12.4,5H  FE=,E12.4,
     15H  GO=,E12.4,5H  GB=,E12.4,5H  GE=,E12.4)
 1100 FORMAT(13H EQUIL.HIND.=,F6.3)
      DO 20 N=1,NREAC
      SIGMA(N)=0.0
      DO 15 NC=1,NCOMP
      SIGMA(N)=SIGMA(N)+A(N,NC)
   15 CONTINUE
   20 CONTINUE
      KKK=0
   23 CGAS=PB*273./22400./(TB+273.)
      AT=3.14/4.*DT**2
      GO=UO*AT*CGAS
      G(1)=GO
      W(1)=AT*ALMF*(1.-EMF)*CSO
      NDEPXA=NCOMP-NREAC
      KAISU=0
```

```
      WRITE(6,1070) KAISU,ALMF
      CALL CALC1
      KEI=0
      KEII=0
      XAMIN1=1.0
      XAMAX1=0.0
      XAMIN2=1.0
      XAMAX2=0.0
      CHECK2=1.
      DO 65 J=1,JLMF
      II=J*2
      I=II-1
      IIN=II+2
      IN=I+2
   28 DO 40 N=1,NREAC
      EG(N)=G(I)*(XA(N,I)-XA(N,IN))
      IF(JLMF.EQ.1) GO TO 30
      EGM(N)=GM(J)*(XA(N,IIN)-XA(N,IN))
   30 DO 35 NN=1,NREAC
      III=(N-1)*NREAC+NN
      AE(III)=A(N,NN)-SIGMA(N)*XA(NN,IN)
      AEM(III)=AE(III)
   35 CONTINUE
   40 CONTINUE
      IF(G(I).EQ.0.0) GO TO 42
      CALL SIMQ(AE,EG,NREAC,KS)
      IF(JLMF.NE.1) GO TO 42
      DO 41 ND=1,NDEPXA
   41 GA(ND)=G(I)*XA(ND+NREAC,I)
      GO TO 45
   42 CALL SIMQ(AEM,EGM,NREAC,KS)
   45 G(IN)=G(I)
      DO 55 N=1,NREAC
      G(IN)=G(IN)-SIGMA(N)*EG(N)
      IF(G(I).EQ.0.0) GO TO 49
      IF(JLMF-1) 46,46,49
   46 EG2(N,I)=EG(N)
      DO 47 ND=1,NDEPXA
   47 GA(ND)=GA(ND)-A(N,ND+NREAC)*EG(N)
      GO TO 55
   49 EG2(N,I)=EG(N)+EGM(N)
      EG(N)=G(II)*(XA(N,II)-XA(N,IIN))
      DO 50 NN=1,NREAC
      III=(N-1)*NREAC+NN
      AE(III)=A(N,NN)-SIGMA(N)*XA(NN,IIN)
   50 CONTINUE
   55 CONTINUE
      IF(JLMF.NE.1) GO TO 57
      DO 56 ND=1,NDEPXA
   56 XA(ND+NREAC,3)=GA(ND)/G(IN)
      GO TO 63
   57 CALL SIMQ(AE,EG,NREAC,KS)
      G(IIN)=G(II)
      GMJ=GM(J)
      DO 58 ND=1,NDEPXA
      GA(ND)=G(II)*XA(ND+NREAC,II)
      GMA(ND)=0.0
   58 CONTINUE
      DO 60 N=1,NREAC
      G(IIN)=G(IIN)-SIGMA(N)*EG(N)
```

```
      EG2(N,II)=EG(N)-EGM(N)
      GMJ=GMJ-SIGMA(N)*EGM(N)
      DO 59 ND=1,NDEPXA
      GA(ND)=GA(ND)-A(N,ND+NREAC)*EG(N)
      GMA(ND)=GMA(ND)-A(N,ND+NREAC)*EGM(N)
   59 CONTINUE
   60 CONTINUE
      DO 62 ND=1,NDEPXA
      NND=ND+NREAC
      XA(NND,IIN)=GA(ND)/G(IIN)
      GMA(ND)=GMA(ND)+GM(J)*XA(NND,IIN)
      XA(NND,IN)=GMA(ND)/GMJ
   62 CONTINUE
      CHECK2=XA(2,IIN)*XA(3,IIN)-XA(4,IIN)*XA(1,IIN)/EK(3)
      IF(CHECK2.GT.0.0) GO TO 220
      KEII=1
      XAMIN2=XA(3,IIN)
      IF(XAMAX2.GT.XAMIN2) GO TO 210
      XA(3,IIN)=XAMIN2+0.05
      GO TO 28
  210 XA(3,IIN)=(XAMIN2+XAMAX2)/2.
      GO TO 28
  220 IF((KEII.EQ.0).OR.(CHECK2.LT. 0.0001)) GO TO 63
      XAMAX2=XA(3,IIN)
      IF(XAMIN2.LT.XAMAX2) GO TO 230
      XA(3,IIN)=XAMAX2-0.05
      GO TO 28
  230 XA(3,IIN)=(XAMIN2+XAMAX2)/2.
      GO TO 28
   63 XAMIN2=1.0
      XAMAX2=0.0
      CHECK1=XA(2,IN)*XA(3,IN)-XA(4,IN)*XA(1,IN)/EK(3)
      IF(CHECK1.GT.0.0) GO TO 270
      KEI=1
      XAMIN1=XA(3,IN)
      IF(XAMAX1.GT.XAMIN1) GO TO 260
      XA(3,IN)=XAMIN1+0.05
      GO TO 28
  260 XA(3,IN)=(XAMIN1+XAMAX1)/2.
      GO TO 28
  270 IF(KEI.EQ.0) GO TO 64
      IF(CHECK1.GT. 0.0001) GO TO 275
      KEI=1
      GO TO 64
  275 XAMAX1=XA(3,IN)
      IF(XAMIN1.LT.XAMAX1) GO TO 280
      XA(3,IN)=XAMAX1-0.05
      GO TO 28
  280 XA(3,IN)=(XAMIN1+XAMAX1)/2.
      GO TO 28
   64 XAMIN1=1.0
      XAMAX1=0.0
      IF(CHECK2.GT.0.0001) GO TO 65
      KEII=1
   65 CONTINUE
      CALL CALC2
      NEGA=0
      NERROR=0
      DO 66 N=1,3
      TOTEG(N)=(ABS(ES2(N,1))+ABS(EG2(N,1)))
      IF(N.EQ.3) TOTEG(3)=TOTEG(3)*20.
```

```
 66 TOTES(N)=TOTEG(N)
    DO 80 J=1,JLMF
    II=2*J
    I=II-1
    DO 75 N=1,NREAC
    TOTEG(N)=TOTEG(N)+ES2(N,I)
    TOTES(N)=TOTES(N)+ES2(N,I)
    FUGO(N,I)=TOTES(N)
    DEVE(N,I)=TOTEG(N)/TOTES(N)
    IF(DEVE(N,I).GT. 0.02) GO TO 68
    DEVE(N,I)=0.02
    NEGA=1
 68 IF(JLMF.EQ.1) GO TO 73
    TOTEG(N)=TOTEG(N)+EG2(N,II)
    TOTES(N)=TOTES(N)+ES2(N,II)
    FUGO(N,II)=TOTES(N)
    DEVE(N,II)=TOTEG(N)/TOTES(N)
    IF(DEVE(N,II).GT. 0.02) GO TO 69
    DEVE(N,II)=0.02
 69 IF((EG2(N,II)/ES2(N,II)).GT.0.0) GO TO 70
    NEGA=1
 70 ERROR=DEVE(N,II)-1.
    IF((ABS(ERROR).LT. 0.01).AND.(NEGA.EQ.0)) GO TO 75
 72 NERROR=NERROR+1
    GO TO 75
 73 IF(ABS(DEVE(N,1)-1.0).LT. 0.02) GO TO 75
 74 NERROR=NERROR+1
 75 CONTINUE
    IF((KAISU.LT.91).AND.(KAISU.GT.5)) GO TO 80
    WRITE(6,1080) J,X(I),(XA(N,I+2),N=1,5),(EG2(N,I),ES2(N,I),N=1,3)
    IF(JLMF.EQ.1) GO TO 80
    WRITE(6,1081) X(II),(XA(N,II+2),N=1,5),(EG2(N,II),ES2(N,II),
   1N=1,3)
 80 CONTINUE
    IF(JLMF.EQ.1) GO TO 100
    WRITE(6,1100) HUSEI
    IF((NERROR.EQ.0).AND.(NEGA.EQ.0)) GO TO 5000
    IF(KAISU- 95) 25,5000,5000
100 IF((NERROR.EQ.0).AND.(NEGA.EQ.0)) GO TO 140
    IF(KAISU-35) 25,140,140
140 UF=UMF/EMF
    AM=1.4*RHOP*DP*UO/UMF
    DBMAX=(UT/0.71)**2/980.
    WRITE(6,1040) AM,DBMAX
    IF(AM.GE.2.0) GO TO 5555
    IF(DBMAX.GT.DT) DBMAX=DT
    DBAVER=AM*ALMF/2.+DBO
    IF(DBAVER.GT.DBMAX) DBAVER=DBMAX
    UBR=0.711*SQRT(980.*DBAVER)
    UB=UO-UMF+UBR
    AL=ALMF*UB/UBR
    ALMAX=AL*2.-ALMF
    UME=(1.-EMF)*ALMF/AL
    E=1.-UME
    VB=AL-ALMF
    VC=VB*3.*UF/(UBR-UF)
    VE=AL-VB*(1.+ALPHA)-VC
    RL=VB/AL
    UE=UMF-EMF*ALPHA*UB*RL/(1.-RL*(1.+ALPHA))
    G(1)=AT*UE*CGAS
    IF(G(1).GT.0.0) GO TO 152
```

```
      G(1)=0.0
  152 G(2)=GO-G(1)
      WRITE(6,1055) DBAVER,UB,VB,VC,VE
      FB=ALPHA*G(2)/CGAS*(1.-EMF)*CSO-FS*VC/(VB+VC)
      FE=FS+FB
      WRITE(6,1090) FS,FB,FE,GO,G(2),G(1)
  147 WRITE(6,1065) JB
      WRITE(6,1050)
      AH=0.0
      BH=0.0
      BHP=ALMF
      DO 155 J=1,15
      K=JB*(J-1)+JB/2
      DB(J)=2.0*DBO*(2.+AM)**(K-1)/(2.-AM)**K
      IF(DB(J).GT.DBMAX) DB(J)=DBMAX
      UBR=0.711*SQRT(980.*DB(J))
      UB=UO-UMF+UBR
      BH=BH+DP(J)*FLOAT(JB)
      IF(BH.LT.ALMF) GO TO 150
      IF(BH.GT.ALMAX) BH=ALMAX
      E=1.-UMF*(1.-(BH+BHP-2.*ALMF)/4./(AL-ALMF))
      BHP=BH
  150 H=DB(J)*FLOAT(JB)
      IF(BH.EQ.ALMAX) H=BH-HTOT(J-1)
      HMF(J)=(1.-E)/(1.-EMF)*H
      AH=AH+HMF(J)
      HMFTOT(J)=AH
      HTOT(J)=BH
      VB=AT*(H-HMF(J))
      BN=VB/3.14*6./DB(J)**3
      VC=VB*3.*UF/(UBR-UF)
      VE=AT*H-VB*(1.+ALPHA)-VC
      AKS=3.*(1.-EMF)*UMF*UB/EMF/UBR/DB(J)
      FM(J)=VB*AKS*CSO
      AKG=11./DB(J)
      GM(J)=VB*AKG*CGAS
      II=2*J
      SIGMF(II)=FB+FM(J)
      RFVER(II)=FB/SIGMF(II)
      RFHOR(II)=FM(J)/SIGMF(II)
      W(II)=(ALPHA*VB+VC)*(1.-EMF)*CSO
      I=II-1
      SIGMF(I)=SIGMF(II)+FS
      RFVER(I)=FE/SIGMF(I)
      RFHOR(I)=FM(J)/SIGMF(I)
      W(I)=VE*(1.-EMF)*CSO
      IF(W(I).GT.0.) GO TO 154
      W(II)=W(I)+W(II)
      W(I)=W(II)*0.05
  154 WRITE(6,1060) J,DB(J),E,AH,BH,BN,VB,W(I),W(II),FM(J),GM(J)
      IF(BH.EQ.ALMAX) GO TO 170
  155 CONTINUE
      JB=JB+1
      GO TO 147
  170 JLMF=J
      KAISU=49
      GO TO 25
 5000 IF(X(1).LT.XOUT) GO TO 5010
      IF(KKK.EQ.-1) GO TO 5555
      KKK=1
      ALMF=ALMF/1.5
```

```
5010 IF(KKK.EQ.1) GO TO 5555
     KKK=1
     ALMF=ALMF*1.5
     GO TO 23
5555 STOP
     END
```

```
      SUBROUTINE CALC1
C     INPUT XA(NR INDEP COMP,1),ASSUME OR CALCULATE XA(NR,J+2)
      COMMON NREAC,JLMF,KAISU,CGAS,FS,GO,RFVER(30),ES2(5,30),HOSEI,PB,
     1XA(5,32),X(30),G(32),DEVE(5,30),W(30),SIGMF(30),RFHOR(30),EK(5),
     2FUGO(5,30)
      DIMENSION XAM(5)
      IF(KAISU.NE.1) GO TO 510
      XA(1,1)=.1887
      XA(2,1)=.6423
      XA(3,1)=.1494
      XA(4,1)=.0197
      XA(5,1)=0.
      XA(1,3)=.1415
      XA(2,3)=.5609
      XA(3,3)=.0524
      XA(4,3)=.1448
      XA(5,3)=.1003
      X(1)=.222
      XAM(1)=1.0
      XAM(2)=XA(2,1)
      XAM(3)=1.
      JLMF=1
      AMPXE=0.2
      GO TO 550
  510 IF(KAISU.EQ.50) GO TO 530
  512 DO 520 J=1,JLMF
      II=(J+1)*2
      I=II-1
      DO 515 N=1,NREAC
  513 XAI=XA(N,I)/XAM(N)
      XA(N,I)=XAM(N)-XAM(N)*(1.-XAI)**(DEVE(N,I-2)**
     1SIGN(AMPXE*(1.-XAI**3),FUGO(N,I-2)))
      IF(JLMF.EQ.1) GO TO 515
      XAII=XA(N,II)/XAM(N)
      XA(N,II)=XAM(N)-XAM(N)*(1.-XAII)**(DEVE(N,II-2)**
     -1SIGN(AMPXB,FUGO(N,II-2)))
      IF((N.EQ.3).OR.(N.EQ.1)) GO TO 515
      IF(XA(N,I).LT.XA(N,II)) GO TO 515
      XA(N,I)=XA(N,II)
  515 CONTINUE
  520 CONTINUE
      GO TO 550
  530 AMPXB=0.07
      XA(1,2)=XA(1,1)
      XA(2,2)=XA(2,1)
      XA(3,2)=XA(3,1)
      XA(4,2)=XA(4,1)
      XA(5,2)=XA(5,1)
      CH=(1.-X(1))/FLOAT(JLMF)/2.
      X(2)=X(1)
      DO 535 N=1,NREAC
      BH=(XA(N,1)-XA(N,3))/FLOAT(JLMF)
      AH=BH
  535 DO 540 J=1,JLMF
      II=(J+1)*2
      I=II-1
```

```
      XA(N,I)=XA(N,I-2)-AH
      XA(N,II)=XA(N,II-2)-BH
      IF(N.NE.1) GO TO 540
      X(I)=X(I-2)+CH
      X(II)=X(I)
  540 CONTINUE
  533 CONTINUE
  550 RETURN
      END
```

```
      SUBROUTINE CALC2
C     CALCULATE X(I),ES2(N,I)
      COMMON NREAC,JLMF,KAISU,CGAS,FS,GO,RFVER(30),ES2(5,30),HOSEI,PB,
     1XA(5,32),X(30),G(32),DEVE(5,30),W(30),SIGMF(30),RFHOR(30),EK(5),
     2FUGO(5,30)
      DIMENSION Y(30),AA(30),AY( 900)
      IF(KAISU.GE.50) GO TO 620
      IF(KAISU.GT.1) GO TO 610
      ITOT=1
      AKVD1=3.24*CGAS
      AKVD2=0.192*CGAS
      AKVD3=60.*CGAS
  610 EK(1)=0.0161*(1.+5.25*EXP(-3.18*X(1)))
      AH=FS/W(1)/(AKVD1*(XA(1,3)-SQRT(XA(5,3)/PB/EK(1)))
     1+AKVD2*(XA(2,3)-PB*XA(3,3)*XA(1,3)/EK(2)))
      Y(1)=AH/(1.+AH)
      GO TO 660
  620 ITOT=2*JLMF
      ITOT2=ITOT**2
      DO 615 I=1,ITOT2
  615 AY(I)=0.0
      DO 650 J=1,JLMF
      II=2*J
      I=II-1
      IF((W(I)*G(2)).GT.(W(II)*G(1))) GO TO 630
      WTOTAL=W(I)+W(II)
      W(I)=G(1)/GO*WTOTAL
      W(II)=WTOTAL-W(I)
  630 EK(1)=0.0161*(1.+5.25*EXP(-3.18*X(I)))
      AH=SIGMF(I)/W(I)/(AKVD1*(XA(1,I+2)-SQRT(XA(5,I+2)/PB/EK(1)))
     1+AKVD2*(XA(2,I+2)-PB*XA(3,I+2)*XA(1,I+2)/EK(2)))
      AA(I)=AH/(1.+AH)
      L=ITOT*(I-1)+I
      AY(L)=1.0
      LL=L+ITOT
      IF(J.LT.JLMF) GO TO 633
      AY(LL)=-AA(I)*SIGMF(II)/SIGMF(I)
      Y(I)=FS/SIGMF(I)*AA(I)
      GO TO 635
  633 AY(LL)=-AA(I)*RFHOR(I)
      LLL=LL+ITOT
      AY(LLL)=-AA(I)*RFVER(I)
      Y(I)=0.0
  635 EK(1)=0.0161*(1.+5.25*EXP(-3.18*X(II)))
      BH=SIGMF(II)/W(II)/(AKVD1*(XA(1,II+2)-SQRT(XA(5,II+2)/PB/EK(1)))
     1+AKVD2*(XA(2,II+2)-PB*XA(3,II+2)*XA(1,II+2)/EK(2)))
      AA(II)=BH/(1.+BH)
      Y(II)=0.0
      L=ITOT*(II-1)+II
      AY(L)=1.0
      LL=L-ITOT
      IF(J.EQ.1) GO TO 640
      AY(LL)=-AA(II)*RFHOR(II)
      LLL=LL-ITOT
      AY(LLL)=-AA(II)*RFVER(II)
      GO TO 650
  640 AY(LL)=-AA(II)
  650 CONTINUE
      CALL SIMQ(AY,Y,ITOT,KS)
```

```
  660 DO 670 I=1,ITOT
      X(I)=1.-Y(I)
      EK(1)=0.0161*(1.+5.25*EXP(-3.18*X(I)))
      HE=SQRT(XA(5,I+2)/PB/EK(1))
      HOE=PB*XA(3,I+2)*XA(1,I+2)/EK(2)
      COE=XA(4,I+2)*XA(1,I+2)/XA(2,I+2)/EK(3)
      WY=W(I)*Y(I)
      ES2(1,I)=AKVD1*WY*(XA(1,I+2)-HE)
      ES2(2,I)=AKVD2*WY*(XA(2,I+2)-HOE)
      IF(COE.GT.0.0) GO TO 665
      COE=0.0
  665 ES2(3,I)=AKVD3*WY*(XA(3,I+2)-COE)
  670 CONTINUE
      HOSEI=HE/XA(1,ITOT+2)
  680 RETURN
      END
```

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                     C
C          DESIGN OF FLUIDIZED BED REACTOR BASED ON                   C
C          BUBBLE ASSEMBLAGE MODEL FOR SIMULTANEOUS                   C
C          REACTIONS.......... CARBON OXYGEN REACTION                 C
C                              CARBON STEAM REACTION                  C
C                              WATER GAS SHIFT REACTION               C
C                                                                     C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      COMMON NREAC,JLMF,KAISU,CGAS,FS,GO,RFVER(30),ES2(5,30),HOSEI,PB,
     1XA(5,32),X(30),G(32),DEVE(5,30),W(30),SIGMF(30),RFHOR(30),EK(5),
     2FUGO(5,30)
      DIMENSION DB(15),FM(15),GM(15),HMF(15),HMFTOT(15),HTOT(15),GA(5),
     1EG2(5,30),A(3, 5),SIGMA(5),EG(5),EGM(5),AE(25),AEM(25),GMA(5),
     2TOTEG(5),TOTES(5)
C     INPUT NCOMP,NREAC,A(NR,NC),DT,ALMF,DP,RHOP,CSO,EMF,FS,
C          ALPHA,UMF,UO,UT,TB,PB
      NCOMP=5
      NREAC=3
      DATA A/0.5,3*0.,2*1.,2*-1.,1.,0.,2*-1.,2*0.,-1./
      DATA ALMF,RHOP,CSO,EMF,ALPHA,TB,DBO,JB/
     1 210.,0.256,0.02130,0.6,0.25,1038.,3.0,8/
      DATA DP,UT,UMF,UO,DT/
     1 0.1555,75.3,3.774,9.435,1095./
      EK(2)=128.
      EK(3)=0.510
      PB=69.3
      FS=3957.
      XOUT=0.85
 1040 FORMAT(1H0,27HFLUIDIZED BED REACTOR    M=,E12.4,
     18H  DBMAX=,E12.4)
 1050 FORMAT(1H0,2H J,3X,2HDB,6X,1HE,3X,6HHMFTOT,2X,5HHTOT,
     16X,2HBN,10X,2HV5,10X,2HW1,10X,2HW2,10X,2HFM,10X,2HGM)
 1055 FORMAT(1H0,7HDBAVER=,E12.4,5X,3HUB=,E12.4,5X,3HVB=,E12.4,
     15X,3HVC=,E12.4,5X,3HVE=,E12.4)
 1060 FORMAT(I3,F7.1,F7.3,2F7.0,6E12.4)
 1065 FORMAT(1H0,29HHEIGHT OF EACH COMPARTMENT IS, I3,
     123H TIMES BUBBLE DIAMETER.)
 1070 FORMAT(1H0,6HKAISU=,I2,4X,4HLMF=,E12.4)
 1080 FORMAT(I3,F7.4,5F8.4,1X,2E11.4,1X,2E11.4,1X,2E11.4)
 1081 FORMAT(3X,F7.4,5F8.4,1X,2E11.4,1X,2E11.4,1X,2E11.4)
 1090 FORMAT(5H  FS=,E12.4,5H  FB=,E12.4,5H  FE=,E12.4,
     15H  GO=,E12.4,5H  GB=,E12.4,5H  GE=,E12.4)
      DO 20 N=1,NREAC
      SIGMA(N)=0.0
      DO 15 NC=1,NCOMP
      SIGMA(N)=SIGMA(N)+A(N,NC)
   15 CONTINUE
   20 CONTINUE
      HOSEI=1.0
      KKK=0
   23 CGAS=PB*273./22400./(TB+273.)
      AT=3.14/4.*DT**2
      GO=UO*AT*CGAS
      G(1)=GO
      W(1)=AT*ALMF*(1.-EMF)*CSO
      NDEPXA=NCOMP-NREAC
      KAISU=0
   25 KAISU=KAISU+1
      WRITE(6,1070) KAISU,ALMF
      CALL CALC1
```

```
      DO 65 J=1,JLMF
      II=J*2
      I=II-1
      IIN=II+2
      IN=I+2
   28 DO 40 N=1,NREAC
      EG(N)=G(I)*(XA(N,I)-XA(N,IN))
      IF(JLMF.EQ.1) GO TO 30
      EGM(N)=GM(J)*(XA(N,IIN)-XA(N,IN))
   30 DO 35 NN=1,NREAC
      III=(N-1)*NREAC+NN
      AE(III)=A(N,NN)-SIGMA(N)*XA(NN,IN)
      AEM(III)=AE(III)
   35 CONTINUE
   40 CONTINUE
      IF(G(I).EQ.0.0) GO TO 42
      CALL SIMQ(AE,EG,NREAC,KS)
      IF(JLMF.NE.1) GO TO 42
      DO 41 ND=1,NDEPXA
   41 GA(ND)=G(I)*XA(ND+NREAC,I)
      GO TO 45
   42 CALL SIMQ(AEM,EGM,NREAC,KS)
   45 G(IN)=G(I)
      DO 55 N=1,NREAC
      G(IN)=G(IN)-SIGMA(N)*EG(N)
      IF(G(I).EQ.0.0) GO TO 49
      IF(JLMF-1) 46,46,49
   46 EG2(N,I)=EG(N)
      DO 47 ND=1,NDEPXA
   47 GA(ND)=GA(ND)-A(N,ND+NREAC)*EG(N)
      GO TO 55
   49 EG2(N,I)=EG(N)+EGM(N)
      EG(N)=G(II)*(XA(N,II)-XA(N,IIN))
      DO 50 NN=1,NREAC
      III=(N-1)*NREAC+NN
      AE(III)=A(N,NN)-SIGMA(N)*XA(NN,IIN)
   50 CONTINUE
   55 CONTINUE
      IF(JLMF.NE.1) GO TO 57
      DO 56 ND=1,NDEPXA
   56 XA(ND+NREAC,3)=GA(ND)/G(IN)
      GO TO 65
   57 CALL SIMQ(AE,EG,NREAC,KS)
      G(IIN)=G(II)
      GMJ=GM(J)
      DO 58 ND=1,NDEPXA
      GA(ND)=G(II)*XA(ND+NREAC,II)
      GMA(ND)=0.0
   58 CONTINUE
      DO 60 N=1,NREAC
      G(IIN)=G(IIN)-SIGMA(N)*EG(N)
      EG2(N,II)=EG(N)-EGM(N)
      GMJ=GMJ-SIGMA(N)*EGM(N)
      DO 59 ND=1,NDEPXA
      GA(ND)=GA(ND)-A(N,ND+NREAC)*EG(N)
      GMA(ND)=GMA(ND)-A(N,ND+NREAC)*EGM(N)
   59 CONTINUE
   60 CONTINUE
      DO 62 ND=1,NDEPXA
      NND=ND+NREAC
      XA(NND,IIN)=GA(ND)/G(IIN)
```

```
      GMA(ND)=GMA(ND)+GM(J)*XA(NND,IIN)
      XA(NND,IN)=GMA(ND)/GMJ
   62 CONTINUE
   65 CONTINUE
      CALL CALC2
      NEGA=0
      NERROR=0
      TOTEG(1)=0.0
      TOTES(1)=0.0
      DO 66 N=2,3
      TOTEG(N)=(ABS(ES2(1,1))+ABS(EG2(1,1)))
   66 TOTES(N)=TOTEG(N)
      DO 80 J=1,JLMF
      II=2*J
      I=II-1
      DO 75 N=1,NREAC
      TOTEG(N)=TOTEG(N)+EG2(N,I)
      TOTES(N)=TOTES(N)+ES2(N,I)
      FUGO(N,I)=TOTES(N)
      DEVE(N,I)=TOTEG(N)/TOTES(N)
      IF(DEVE(N,I).GT. 0.02) GO TO 68
      DEVE(N,I)=0.02
      NEGA=1
   68 IF(JLMF.EQ.1) GO TO 73
      TOTEG(N)=TOTEG(N)+EG2(N,II)
      TOTES(N)=TOTES(N)+ES2(N,II)
      FUGO(N,II)=TOTES(N)
      DEVE(N,II)=TOTEG(N)/TOTES(N)
      IF(DEVE(N,II).GT. 0.02) GO TO 69
      DEVE(N,II)=0.02
   69 IF((EG2(N,II)/ES2(N,II)).GT.0.0) GO TO 70
      NEGA=1
   70 ERROR=DEVE(N,II)-1.
      IF((ABS(ERROR).LT. 0.02).AND.(NEGA.EQ.0)) GO TO 75
      IF(N.NE.3) GO TO 72
      IF((ABS(DEVE(3,I)-1.).LT.0.01).AND.(ABS(DEVE(3,II)-1.).LT.0.01))
     1GO TO 75
   72 NERROR=NERROR+1
      GO TO 75
   73 IF(ABS(DEVE(N,1)-1.0).LT. 0.01) GO TO 75
   74 NERROR=NERROR+1
   75 CONTINUE
      IF((KAISU.LT.95).AND.(KAISU.GT.5)) GO TO 80
      WRITE(6,1080) J,X(I),(XA(N,I+2),N=1,5),(EG2(N,I),ES2(N,I),N=1,3)
      IF(JLMF.EQ.1) GO TO 80
      WRITE(6,1081) X(II),(XA(N,II+2),N=1,5),(EG2(N,II),ES2(N,II),
     1N=1,3)
   80 CONTINUE
      IF(JLMF.EQ.1) GO TO 100
      IF((NERROR.EQ.0).AND.(NEGA.EQ.0)) GO TO 5000
      IF(KAISU-100) 25,5000,5000
  100 IF((NERROR.EQ.0).AND.(NEGA.EQ.0)) GO TO 140
      IF(KAISU-45) 25,140,140
  140 UF=UMF/EMF
      AM=1.4*RHOP*DP*UO/UMF
      DBMAX=(UT/0.71)**2/980.
      WRITE(6,1040) AM,DBMAX
      IF(AM.GE.2.0) GO TO 5555
      IF(DBMAX.GT.DT) DBMAX=DT
      DBAVER=AM*ALMF/2.+DBO
      IF(DBAVER.GT.DBMAX) DBAVER=DBMAX
```

```
      UBR=0.711*SQRT(980.*DBAVER)
      UB=UO-UMF+UBR
      AL=ALMF*UB/UBR
      ALMAX=AL*2.-ALMF
      UME=(1.-EMF)*ALMF/AL
      E=1.-UME
      VB=AL-ALMF
      VC=VB*3.*UF/(UBR-UF)
      VE=AL-VB*(1.+ALPHA)-VC
      RL=VB/AL
      UE=UMF-EMF*ALPHA*UB*RL/(1.-RL*(1.+ALPHA))
      G(1)=AT*UE*CGAS
      IF(G(1).GT.0.0) GO TO 152
      G(1)=0.0
  152 G(2)=GO-G(1)
      WRITE(6,1055) DBAVER,UB,VB,VC,VE
      FB=ALPHA*G(2)/CGAS*(1.-EMF)*CSO-FS*VC/(VB+VC)
      FE=FS+FB
      WRITE(6,1090) FS,FB,FE,GO,G(2),G(1)
  147 WRITE(6,1065) JB
      WRITE(6,1050)
      AH=0.0
      BH=0.0
      BHP=ALMF
      DO 155 J=1,15
      K=JB*(J-1)+JB/2
      DB(J)=2.0*DBO*(2.+AM)**(K-1)/(2.-AM)**K
      IF(DB(J).GT.DBMAX) DB(J)=DBMAX
      UBR=0.711*SQRT(980.*DB(J))
      UB=UO-UMF+UBR
      BH=BH+DB(J)*FLOAT(JB)
      IF(BH.LT.ALMF) GO TO 150
      IF(BH.GT.ALMAX) BH=ALMAX
      E=1.-UME*(1.-(BH+BHP-2.*ALMF)/4./(AL-ALMF))
      BHP=BH
  150 H=DB(J)*FLOAT(JB)
      IF(BH.EQ.ALMAX) H=BH-HTOT(J-1)
      HMF(J)=(1.-E)/(1.-EMF)*H
      AH=AH+HMF(J)
      HMFTOT(J)=AH
      HTOT(J)=BH
      VB=AT*(H-HMF(J))
      BN=VB/3.14*6./DB(J)**3
      VC=VB*3.*UF/(UBR-UF)
      VE=AT*H-VB*(1.+ALPHA)-VC
      AKS=3.*(1.-EMF)*UMF*UB/EMF/UBR/DB(J)
      FM(J)=VB*AKS*CSO
      AKG=11./DB(J)
      GM(J)=VB*AKG*CGAS
      II=2*J
      SIGMF(II)=FB+FM(J)
      RFVER(II)=FB/SIGMF(II)
      RFHOR(II)=FM(J)/SIGMF(II)
      W(II)=(ALPHA*VB+VC)*(1.-EMF)*CSO
      I=II-1
      SIGMF(I)=SIGMF(II)+FS
      RFVER(I)=FE/SIGMF(I)
      RFHOR(I)=FM(J)/SIGMF(I)
      W(I)=VE*(1.-EMF)*CSO
      IF(W(I).GT.0.) GO TO 154
      W(II)=W(I)+W(II)
```

```
      W(I)=W(II)*0.05
  154 WRITE(6,1060) J,DB(J),E,AH,BH,BN,VB,W(I),W(II),FM(J),GM(J)
      IF(BH.EQ.ALMAX) GO TO 170
  155 CONTINUE
      JB=JB+1
      GO TO 147
  170 JLMF=J
      KAISU=49
      GO TO 25
 5000 IF(X(1).LT.XOUT) GO TO 5010
      IF(KKK.EQ.-1) GO TO 5555
      KKK=1
      ALMF=ALMF/1.5
      GO TO 23
 5010 IF(KKK.EQ.1) GO TO 5555
      KKK=-1
      ALMF=ALMF*1.5
      GO TO 23
 5555 STOP
      END
```

```
      SUBROUTINE CALC1
C     INPUT XA(NR INDEP COMP,1),ASSUME OR CALCULATE XA(NR,J+2)
      COMMON NREAC,JLMF,KAISU,CGAS,FS,GO,RFVER(30),ES2(5,30),HOSEI,PB,
     1XA(5,32),X(30),G(32),DEVE(5,30),W(30),SIGMF(30),RFHOR(30),EK(5),
     2FUGO(5,30)
      DIMENSION XAM(5)
 1003 FORMAT(3E12.4)
      IF(KAISU.NE.1) GO TO 510
      XA(1,1)=0.1931
      XA(2,1)=0.8069
```

```
      XA(3,1)=0.0
      XA(4,1)=0.0
      XA(5,1)=0.0
      XA(1,3)=0.0001
      XA(2,3)=0.2894
      XA(3,3)=0.2768
      XA(4,3)=0.2955
      YA(5,3)=0.1383
      XAM(1)=XA(1,1)
      XAM(2)=XA(2,1)
      XAM(3)=1.
      JLMF=1
      AMPXE=0.3
      GO TO 550
  510 IF(KAISU.EQ.50) GO TO 530
      IF(KAISU.EQ.65) GO TO 526
  512 DO 520 J=1,JLMF
      II=(J+1)*2
      I=II-1
      DO 515 N=1,NREAC
  513 XAI=XA(N,I)/XAM(N)
      XA(N,I)=XAM(N)-XAM(N)*(1.-XAI)**(DEVE(N,I-2)**
     1SIGN(AMPXE*(1.-XAI**3),FUGO(N,I-2)))
      IF(JLMF.EQ.1) GO TO 515
      XAII=XA(N,II)/XAM(N)
      XA(N,II)=XAM(N)-XAM(N)*(1.-XAII)**(DEVE(N,II-2)**
     1SIGN(AMPXB,FUGO(N,II-2)))
      IF(N.EQ.3) GO TO 515
      IF(XA(N,I).LT.XA(N,II)) GO TO 515
      XA(N,I)=XA(N,II)
  515 CONTINUE
  520 CONTINUE
      GO TO 550
  526 AMPXE=0.2
      AMPXB=0.05
      GO TO 512
  530 AMPXB=0.07
      XA(1,2)=XA(1,1)
      XA(2,2)=XA(2,1)
      XA(3,2)=0.0
      XA(4,2)=0.0
      XA(5,2)=0.0
      DO 533 N=1,NREAC
      AH=(XA(N,1)-XA(N,3)/3.)/FLOAT(JLMF)
      BH=(XA(N,1)-XA(N,3))/FLOAT(JLMF)
      IF(N.NE.3) GO TO 535
      AH=BH
  535 DO 540 J=1,JLMF
      II=(J+1)*2
      I=II-1
      XA(N,I)=XA(N,I-2)-AH
      XA(N,II)=XA(N,II-2)-BH
  540 CONTINUE
  533 CONTINUE
  550 RETURN
      END
```

```
      SUBROUTINE CALC2
C     CALCULATE X(I),ES2(N,I)
      COMMON NREAC,JLMF,KAISU,CGAS,FS,GO,RFVER(30),ES2(5,30),HOSEI,PB,
     1XA(5,32),X(30),G(32),DEVE(5,30),W(30),SIGMF(30),RFHOR(30),EK(5),
     2FUGO(5,30)
      DIMENSION Y(30),AA(30),AY( 900)
      IF(KAISU.GE.50) GO TO 620
      IF(KAISU.GT.1) GO TO 610
      ITOT=1
      AKVD1=1200.0*CGAS
      AKVD2=35.0*CGAS
      AKVD3=180.*CGAS
  610 AH=FS/W(1)/(AKVD1*XA(1,3)+AKVD2*(XA(2,3)-PB*XA(3,3)*XA(4,3)
     1/EK(2)))
      Y(1)=AH/(1.+AH)
      GO TO 660
  620 ITOT=2*JLMF
      ITOT2=ITOT**2
      DO 615 I=1,ITOT2
  615 AY(I)=0.0
      DO 650 J=1,JLMF
      II=2*J
      I=II-1
      IF((W(I)*G(2)).GT.(W(II)*G(1))) GO TO 630
      WTOTAL=W(I)+W(II)
      W(I)=G(1)/GO*WTOTAL
      W(II)=WTOTAL-W(I)
  630 AH=SIGMF(I)/W(I)/(AKVD1*XA(1,I+2)+AKVD2*(XA(2,I+2)-PB*XA(3,I+2)*
     1XA(4,I+2)/EK(2)))
      AA(I)=AH/(1.+AH)
      L=ITOT*(I-1)+I
      AY(L)=1.0
      LL=L+ITOT
      IF(J.LT.JLMF) GO TO 633
      AY(LL)=-AA(I)*SIGMF(II)/SIGMF(I)
      Y(I)=FS/SIGMF(I)*AA(I)
      GO TO 635
  633 AY(LL)=-AA(I)*RFHOR(I)
```

```
      LLL=LL+ITOT
      AY(LLL)=-AA(I)*RFVER(I)
      Y(I)=0.0
  635 BH=SIGMF(II)/W(II)/(AKVD1*XA(1,II+2)+AKVD2*(XA(2,II+2)-PB*
     1XA(3,II+2)*XA(4,II+2)/EK(2)))
      AA(II)=BH/(1.+BH)
      Y(II)=0.0
      L=ITOT*(II-1)+II
      AY(L)=1.0
      LL=L-ITOT
      IF(J.EQ.1) GO TO 640
      AY(LL)=-AA(II)*RFHOR(II)
      LLL=LL-ITOT
      AY(LLL)=-AA(II)*RFVER(II)
      GO TO 650
  640 AY(LL)=-AA(II)
  650 CONTINUE
      CALL SIMQ(AY,Y,ITOT,KS)
  660 DO 670 I=1,ITOT
      X(I)=1.-Y(I)
      WY=W(I)*Y(I)
      ES2(1,I)=AKVD1*WY*XA(1,I+2)
      HOE=PB*XA(3,I+2)*XA(4,I+2)/EK(2)
      ES2(2,I)=AKVD2*WY*(XA(2,I+2)-HOE)
      COE=XA(4,I+2)*XA(5,I+2)/XA(2,I+2)/EK(3)
      IF(COE.GT.0.0) GO TO 665
      COE=0.0
  665 ES2(3,I)=AKVD3*WY*(XA(3,I+2)-COE)
  670 CONTINUE
  680 RETURN
      END
```

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CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                     C
C          DESIGN OF FLUIDIZED BED REACTOR BASED ON                   C
C          BUBBLE ASSEMBLAGE MODEL FOR                                C
C          CARBON HYDROGEN REACTION WITH                              C
C          CO-CURRENT FLOW                                            C
C                                                                     C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      DIMENSION AA(60),RFHOR(60),RFVER(60),W(60),RGACT(60),SIGMF(60),
     1DB(30),FM(30),GM(30),HMF(30),HMFTOT(30),HTOT(30),
     2AY(3600),Y(60),X(60),XA(60),MG(60),MS(60),DEVM(60)
      REAL MG,MS,KV,KVD,MATOT
C     INPUT DATA (DP,RHOP,CSO,TB,PB,UMF,UT,UO,EMF,DBO,
C                 STOIA,STOIB,KV,ALPHA,FS,XAO,XA(J))
      MMM=1
      UMF=12.50
      UO=1.5*UMF
   99 DP=0.1555
      UT=256.
      RHOP=0.256
      CSO=RHOP/12.
      TB=900.
      EKG=0.0192
      PB=69.
      EMF=0.6
      JB=8
      DBO=3.
      KV=5.35
      STOIA=1.4
      STOIB=1.
      ALPHA=0.25
      FS=6260.
      XAO=1.
      KKKK=0
   10 KKK=0
      GO TO 5010
 5000 M=2*JLMF-1
      IF((KKK.GE.0).AND.(X(M).GT.XOUT)) GO TO 5001
      IF((KKK.LE.0).AND.(X(M).LT.XOUT)) GO TO 5002
      GO TO 5555
 5001 KKK=1
      ALMF=ALMF/1.5
      GO TO 40
 5002 KKK=-1
      ALMF=ALMF*1.5
      GO TO 40
C     PERFORMANCE REQUIREMENT (XOUT,XAOUT)
 5010 XOUT=0.34
      XAOUT=0.54
 1004 FORMAT(4E12.4)
 1020 FORMAT(1H1,7H    MA=,E12.4,8H     GO=,E12.4,
     18H     AT=,E12.4,8H     DT=,E12.4)
 1030 FORMAT(1H0,27HCOMPLETE MIXING REACTOR  W=,E12.4,
     18H    LMF=,E12.4)
 1040 FORMAT(1H0,27HFLUIDIZED BED REACTOR    M=,E12.4,
     18H  DBMAX=,E12.4)
 1050 FORMAT(1H0,2H J,3X,2HDB,6X,1HE,3X,6HHMFTOT,2X,4HHTOT,
     16X,2HBN,10X,2HVB,10X,2HW1,10X,2HW2,10X,2HFM,10X,2HGM)
 1055 FORMAT(1H0,7HDBAVER=,E12.4,5X,3HUB=,E12.4,5X,3HVB=,E12.4,
     15X,3HVC=,E12.4,5X,3HVE=,E12.4)
 1060 FORMAT(I3,F7.1,F7.3,2F7.0,6E12.4)
```

```
1065 FORMAT(1H0,29HHEIGHT OF EACH COMPARTMENT IS, I3,
    123H TIMES BUBBLE DIAMETER.)
1070 FORMAT(1H0,6HKAISU=,I2,4X,4HLMF=,E12.4)
1080 FORMAT(4E12.4,4X,4E12.4)
1090 FORMAT(5H  FS=,E12.4,5H  FB=,E12.4,5H  FE=,E12.4,
    15H  GO=,E12.4,5H  GB=,E12.4,5H  GE=,E12.4)
1100 FORMAT(13H EQUIL.MIND.=,F6.3)
     CGAS=PB*273./22400./(T3+273.)
     KVD=KV*CGAS
     STOIR=STOIB/STOIA-1.0
     MATOT=FS*XOUT*STOIA
     GO=MATOT*(1.+STOIR*XAOUT)/(XAO-XAOUT)
     AT=GO/CGAS/UO
     DT=SQRT(4./3.14*AT)
     WRITE(6,1020) MATOT,GO,AT,DT
C    *****
C    PERFORMANCE OF COMPLETE MIXING REACTOR
     A=1./XOUT-1.
     EK=EKG*(1.+5.25*EXP(-3.18*XOUT))
     WTOTAL=FS/A/KVD/(XAOUT-SQRT((1.-XAOUT)/PB/EK))
     ALMF=WTOTAL/CSO/(1.-EMF)/AT
     WRITE(6,1030) WTOTAL,ALMF
C    $$$$$
C    PERFORMANCE OF FLUIDIZED BED REACTOR
     UF=UMF/EMF
     AM=1.4*RHOP*DP*UO/UMF
     DBMAX=(UT/0.71)**2/980.
     WRITE(6,1040) AM,DBMAX
     IF(AM.GE.2.0) GO TO 5555
     IF(DBMAX.GT.DT) DBMAX=DT
  40 DBAVER=AM*ALMF/2.+DBO
     IF(DBAVER.GT.DBMAX) DBAVER=DBMAX
     UBR=0.711*SQRT(980.*DBAVER)
     UB=UO-UMF+UBR
     AL=ALMF*UB/UBR
     ALMAX=AL*2.-ALMF
     UME=(1.-EMF)*ALMF/AL
     E=1.-UME
     VB=AL-ALMF
     VC=VB*3.*UF/(UBR-UF)
     VE=AL-VB*(1.+ALPHA)-VC
     RL=VB/AL
     UE=UMF-EMF*ALPHA*UB*RL/(1.-RL*(1.+ALPHA))
     GE=AT*UE*CGAS
     IF(GE.GT.0.0) GO TO 52
     GE=0.0
  52 GB=GO-GE
     WRITE(6,1055) DBAVER,UB,VB,VC,VE
     FB=ALPHA*GB/CGAS*(1.-EMF)*CSO+FS*VC/(VB+VC)
     FE=FB-FS
     WRITE(6,1090) FS,FB,FE,GO,GB,GE
  47 WRITE(6,1065) JB
     WRITE(6,1050)
     BH=0.0
     BHP=ALMF
     DO 55 J=1,30
     K=JB*(J-1)+JB/2
     DB(J)=2.0*DBO*(2.+AM)**(K-1)/(2.-AM)**K
     IF(DB(J).GT.DBMAX) DB(J)=DBMAX
     UBR=0.711*SQRT(980.*DB(J))
     UB=UO-UMF+UBR
```

```
      BH=BH+DB(J)*FLOAT(JB)
      IF(BH.LT.ALMF) GO TO 50
      IF(BH.GT.ALMAX) BH=ALMAX
      E=1.-UME*(1.-(BH+BHP-2.*ALMF)/4./(AL-ALMF))
      BHP=BH
   50 H=DB(J)*FLOAT(JB)
      IF(BH.EQ.ALMAX) H=BH-HTOT(J-1)
      HMF(J)=(1.-E)/(1.-EMF)*H
      HMFTOT(J)=AH+HMF(J)
      HTOT(J)=BH
      VB=AT*(H-HMF(J))
      BN=VB/3.14*6./DB(J)*M
      VC=VB*3.*UF/(UBR-UF)
      VE=AT*H-VB*(1.+ALPHA)-VC
      AKS=3.*(1.-EMF)*UMF*UB/EMF/UBR/DB(J)
      FM(J)=VB*AKS*CSO
      AKG=11./DB(J)
      GM(J)=VB*AKG*CGAS
      I=2*J
      SIGMF(I)=FB+FM(J)
      RFVER(I)=FB/SIGMF(I)
      RFHOR(I)=FM(J)/SIGMF(I)
      W(I)=(ALPHA*VB+VC)*(1.-EMF)*CSO
      II=I-1
      SIGMF(II)=FE+FM(J)
      RFVER(II)=FE/SIGMF(II)
      RFHOR(II)=FM(J)/SIGMF(II)
      W(II)=VE*(1.-EMF)*CSO
      IF(W(II).GT.0.) GO TO 54
      W(I)=W(I)+W(II)
      W(II)=W(I)*0.1
   54 WRITE(6,1060) J,DB(J),E,AH,BH,BN,VB,W(II),W(I),FM(J),GM(J)
      IF(BH.EQ.ALMAX) GO TO 70
   55 CONTINUE
      JB=JB+1
      GO TO 47
   70 JLMF=J
      ITOT=2*J
      KAISU=0
   60 KAISU=KAISU+1
      IF(KAISU.LT.39) GO TO 61
      WRITE(6,1070) KAISU,ALMF
   61 IF(KAISU.GT.1) GO TO 80
      AH=(XAO-XAOUT)/FLOAT(J)
      CH=(1.-XOUT)/FLOAT(J)/2.
      XA(2)=XAO-AH
      XA(1)=XA(2)
      X(ITOT)=XOUT
      X(ITOT-1)=XOUT
      DO 72 J=2,JLMF
      II=2*J
      IIP=II-2
      XA(II)=XA(IIP)-AH
      I=II-1
      XA(I)=XA(II)
      X(ITOT+2-II)=X(ITOT+2-IIP)-CH
      X(ITOT-I)=X(ITOT+2-II)
   72 CONTINUE
   80 ITOT=2*JLMF
      ITOT2=ITOT**2
      DO 82 I=1,ITOT2
```

```
   82 AY(I)=0.0
      DO 90 J=1,JLMF
      II=2*J
      I=II-1
      IF((W(I)*GB).GT.(W(II)*GE)) GO TO 83
      WTOTAL=W(I)+W(II)
      W(I)=GE/GO*WTOTAL
      W(II)=GB/GO*WTOTAL
C  COCURRENT  *** CHANGE TO FE=FB-FS ***
   83 EK=EKG    *(1.+5.25*EXP(-3.18*X(II)))
      B=SIGMF(II)/W(II)/KVD/(XA(II)-SQRT((1.-XA(II))/PB/EK))
      AA(II)=B/(1.+B)
      L=ITOT*(II-1)+II
      AY(L)=1.
      Y(II)=0.
      LL=L-ITOT
      IF(J.EQ.1) GO TO 87
      AY(LL)=-AA(II)*RFHOR(II)
      LLL=LL-ITOT
      AY(LLL)=-AA(II)*RFVER(II)
      EK=EKG    *(1.+5.25*EXP(-3.18*X(I)))
      A=SIGMF(I)/W(I)/KVD/(XA(I)-SQRT((1.-XA(I))/PB/EK))
      IF(J.EQ.JLMF) A=A*SIGMF(II)/SIGMF(I)
      AA(I)=A/(1.+A)
      L=ITOT*(I-1)+I
      AY(L)=1.
      Y(I)=0.
      LL=L+ITOT
      IF(J.NE.JLMF) GO TO 86
      AY(LL)=-AA(I)
      GO TO 90
   86 AY(LL)=-AA(I)*RFHOR(I)
      LLL=LL+ITOT
      AY(LLL)=-AA(I)*RFVER(I)
      GO TO 90
   87 AY(LL)=-AA(II)
      EK=EKG    *(1.+5.25*EXP(-3.18*X(I)))
      A=SIGMF(II)/W(I)/KVD/(XA(I)-SQRT((1.-XA(I))/PB/EK))
      AA(I)=A/(1.+A)
      AY(1)=1.0
      LL=1+ITOT
      AY(LL)=-AA(I)*RFHOR(II)
      LLL=LL+ITOT
      AY(LLL)=-FE/SIGMF(II)*AA(I)
      Y(1)=FS/SIGMF(II)*AA(I)
   90 CONTINUE
      CALL SIMQ(AY,Y,ITOT,KS)
      DO 100 I=1,ITOT
      RGACT(I)=1./STOIA/(1.+XA(I)*STOIR)
      X(I)=1.-Y(I)
  100 CONTINUE
      IF((KAISU.NE.1).AND.(KAISU.NE.8)) GO TO 140
      IF(KAISU.EQ.8) GO TO 130
      AMPXE=0.3
      AMPXB=0.1
      GO TO 140
  130 AMPXE=0.2
      AMPXB=0.07
  140 TEST=0.0
      NERROR=0
      DO 110 J=1,JLMF
```

```
      II=2*J
      I=II-1
      IIII=I-1
      IIJ=IIII-1
      A=GM(J)*(XA(II)-XA(I)*RGACT(I)/RGACT(II))
      III=II+1
      EK=EKG    *(1.+5.25*EXP(-3.18*X(I)))
      HE=SQRT((1.-XA(I))/PB/EK)
      MS(I)=KVD*W(I)*Y(I)*STOIA*(XA(I)-HE)
      EK=EKG    *(1.+5.25*EXP(-3.18*X(II)))
      HE=SQRT((1.-XA(II))/PB/EK)
      MS(II)=KVD*W(II)*Y(II)*STOIA*(XA(II)-HE)
      IF(J.EQ.1) GO TO 106
      MG(II)=GB*(XA(IIII)*RGACT(IIII)-XA(II)*RGACT(II))-A
      MG(I)=GE*(XA(IIJ)*RGACT(IIJ)-XA(I)*RGACT(I))+A
      GO TO 108
  106 MG(1)=GE*(XA0-XA(1)*RGACT(1))+A
      MG(2)=GB*(XA0-XA(2)*RGACT(2))-A
      TOTMG=0.
      TOTMS=TOTMG
  108 IF(KAISU.LT.39) GO TO 109
      WRITE(6,1080) XA(I),X(I),MG(I),MS(I),XA(II),X(II),MG(II),MS(II)
  109 TOTMG=TOTMG+MG(I)
      TOTMS=TOTMS+MS(I)
      DEVM(I)=TOTMG/TOTMS
      IF(DEVM(I).GT.0.05) GO TO 152
      DEVM(I)=0.05
      TEST=1.0
  152 TOTMG=TOTMG+MG(II)
      TOTMS=TOTMS+MS(II)
      DEVM(II)=TOTMG/TOTMS
      IF(DEVM(II).GT.0.05) GO TO 153
      DEVM(II)=0.05
  153 IF(MG(II).GT.0.0) GO TO 155
      TEST=1.0
  155 ERROR=DEVM(II)-1.
      IF((ABS(ERROR).LT.0.01).AND.(TEST.EQ.0.)) GO TO 156
      NERROR=NERROR+1
      IF(ABS(DEVM(II)-1.).LT.0.01) GO TO 156
      NERROR=NERROR+1
  156 XA(I)=1.-(1.-XA(I))**(DEVM(I)**(AMPXE*(1.-XA(I)**3)))
      XA(II)=1.-(1.-XA(II))**(DEVM(II)**AMPXB)
      IF(XA(I).LE.XA(II)) GO TO 110
      XA(I)=XA(II)
  110 CONTINUE
      HOSEI=HE/XA(ITOT)
      IF(KAISU.LT.39) GO TO 111
      WRITE(6,1100) HOSEI
  111 IF(NERROR.NE.0) GO TO 170
      IF(TEST.EQ.0.0) GO TO 5000
  170 IF(KAISU.LT.40) GO TO 60
      GO TO 5000
 5555 IF(MMM-2) 96,97,98
   96 UO=2.5*UMF
      MMM=MMM+1
      GO TO 99
   97 UO=4.0*UMF
      MMM=MMM+1
      GO TO 99
   98 UO=8.0*UMF
      MMM=MMM+1
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```
      IF(MMM.GE.5) STOP
      GO TO 99
      END
```

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CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                          C
C         DESIGN OF FLUIDIZED BED REACTOR BASED ON         C
C         BUBBLE ASSEMBLAGE MODEL FOR                      C
C          CARBON HYDROGEN REACTION    WITH                  C
C         COUNTER-CURRENT FLOW                             C
C                                                          C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      DIMENSION AA(60),RFHOR(60),RFVER(60),W(60),RGACT(60),SIGMF(60),
     1DB(30),FM(30),GM(30),HMF(30),HMFTOT(30),HTOT(30),
     2AY(3600),Y(60),X(60),XA(60),MG(60),MS(60),DEVM(60)
      REAL MG,MS,KV,KVD,MATOT
C     INPUT DATA (DP,RHOP,CSO,TB,PB,UMF,UT,UO,EMF,DBO,
C                     STOIA,STOIB,KV,ALPHA,FS,XAO,XA(J))
      MMM=1
      UMF=6.123
      UO=1.5*UMF
      DP=0.210
      UT=78.22
      RHOP=0.256
      CSO=RHOP/12.
      TB=816.
      EKG=1000.
      PB=69.3
      EMF=0.6
      JB=8
      DBO=3.
      KV=1.3
      STOIA=2.0
      STOIB=1.
      ALPHA=0.25
      FS=7431.
      XAO=0.8321
      KKKK=0
   10 KKK=0
      GO TO 5010
 5000 M=1
      IF((KKK.GE.0).AND.(X(M).GT.XOUT)) GO TO 5001
      IF((KKK.LE.0).AND.(X(M).LT.XOUT)) GO TO 5002
      GO TO 5555
 5001 KKK=1
      ALMF=ALMF/1.5
      GO TO 40
 5002 KKK=-1
      ALMF=ALMF*1.5
      GO TO 40
C     PERFORMANCE REQUIREMENT (XOUT,XAOUT)
 5010 XOUT=0.35
      XAOUT=0.2796
 1004 FORMAT(4E12.4)
 1020 FORMAT(1H1,7H    MA=,E12.4,8H      GO=,E12.4,
     18H      AT=,E12.4,8H      DT=,E12.4)
 1030 FORMAT(1H0,27HCOMPLETE MIXING REACTOR  W=,E12.4,
     18H    LMF=,E12.4)
 1040 FORMAT(1H0,27HFLUIDIZED BED REACTOR    M=,E12.4,
     18H  DBMAX=,E12.4)
 1050 FORMAT(1H0,2H J,3X,2HDB,6X,1HE,3X,6HHMFTOT,2X,4HHTOT,
     16X,2HBN,10X,2HVB,10X,2HW1,10X,2HW2,10X,2HFM,10X,2HGM)
 1055 FORMAT(1H0,7HDBAVER=,E12.4,5X,3HUB=,E12.4,5X,3HVB=,E12.4,
     15X,3HVC=,E12.4,5X,3HVE=,E12.4)
 1060 FORMAT(I3,F7.1,F7.3,2F7.0,6E12.4)
```

```
 1065 FORMAT(1H0,29HHEIGHT OF EACH COMPARTMENT IS, I3,
     123H TIMES BUBBLE DIAMETER.)
 1070 FORMAT(1H0,6HKAISU=,I2,4X,4HLMF=,E12.4)
 1080 FORMAT(4E12.4,4X,4E12.4)
 1090 FORMAT(5H  FS=,E12.4,5H  FB=,E12.4,5H  FE=,E12.4,
     15H  GO=,E12.4,5H  GB=,E12.4,5H  GE=,E12.4)
 1100 FORMAT(13H EQUIL.HIND.=,F6.3)
      CGAS=PB*273./22400./(TB+273.)
      KVD=KV*CGAS
      STOIR=STOIB/STOIA=1.0
      MATOT=FS*XOUT*STOIA
      GO=MATOT*(1.+STOIR*XAOUT)/(XAO-XAOUT)
      AT=GO/CGAS/UO
      DT=SQRT(4./3.14*AT)
      WRITE(6,1020) MATOT,GO,AT,DT
C     *****
C     PERFORMANCE OF COMPLETE MIXING REACTOR
      A=1./XOUT-1.
      EK=EKG*(1.+5.25*EXP(-3.18*YOUT))
      WTOTAL=FS/A/KVD/(XAOUT-SQRT((1.-XAOUT)/PB/EK))
      ALMF=WTOTAL/CSO/(1.-EMF)/AT
      WRITE(6,1030) WTOTAL,ALMF
C     $$$$$
C     PERFORMANCE OF FLUIDIZED BED REACTOR
      UF=UMF/EMF
      AM=1.4*RHOP*DP*UO/UMF
      DBMAX=(UT/0.71)**2/980.
      WRITE(6,1040) AM,DBMAX
      IF(AM.GE.2.0) GO TO 5555
      IF(DBMAX.GT.DT) DBMAX=DT
   40 DBAVER=AM*ALMF/2.+DBO
      IF(DBAVER.GT.DBMAX) DBAVER=DBMAX
      UBR=0.711*SQRT(980.*DBAVER)
      UB=UO-UMF+UBR
      AL=ALMF*UB/UBR
      ALMAX=AL*2.-ALMF
      UME=(1.-EMF)*ALMF/AL
      E=1.-UME
      VB=AL-ALMF
      VC=VB*3.*UF/(UBR-UF)
      VE=AL-VB*(1.+ALPHA)-VC
      RL=VB/AL
      UE=UMF-EMF*ALPHA*UB*RL/(1.-RL*(1.+ALPHA))
      GE=AT*UF*CGAS
      IF(GE.GT.0.0) GO TO 52
      GE=0.0
   52 GB=GO-GE
      WRITE(6,1055) DBAVER,UB,VB,VC,VE
      FB=ALPHA*GB/CGAS*(1.-EMF)*CSO-FS*VC/(VB+VC)
      FE=FS+FB
      WRITE(6,1090) FS,FB,FE,GO,GB,GE
   47 WRITE(6,1065) JB
      WRITE(6,1050)
      BH=0.0
      BHP=ALMF
      DO 55 J=1,30
      K=JB*(J-1)+JB/2
      DB(J)=2.0*DBO*(2.+AM)**(K-1)/(2.-AM)**K
      IF(DB(J).GT.DBMAX) DB(J)=DBMAX
      UBR=0.711*SQRT(980.*DB(J))
      UB=UO-UMF+UBR
```

```
      BH=BH+DB(J)*FLOAT(JB)
      IF(BH.LT.ALMF) GO TO 50
      IF(BH.GT.ALMAX) BH=ALMAX
      E=1.-UME*(1.-(BH+BHP-2.*ALMF)/4./(AL-ALMF))
      BHP=BH
   50 H=DB(J)*FLOAT(JB)
      IF(BH.EQ.ALMAX) H=BH-HTOT(J-1)
      HMF(J)=(1.-E)/(1.-EMF)*H
      HMFTOT(J)=AH+HMF(J)
      HTOT(J)=BH
      VB=AT*(H-HMF(J))
      BN=VB/3.14*6./DB(J)*M
      VC=VB*3.*UF/(UBR-UF)
      VE=AT*H-VB*(1.+ALPHA)-VC
      AKS=3.*(1.-EMF)*UMF*UB/EMF/UBR/DB(J)
      FM(J)=VB*AKS*CSO
      AKG=11./DB(J)
      GM(J)=VB*AKG*CGAS
      I=2*J
      SIGMF(I)=FB+FM(J)
      RFVER(I)=FB/SIGMF(I)
      RFHOR(I)=FM(J)/SIGMF(I)
      W(I)=(ALPHA*VB+VC)*(1.-EMF)*CSO
      II=I-1
      SIGMF(II)=FE+FM(J)
      RFVER(II)=FE/SIGMF(II)
      RFHOR(II)=FM(J)/SIGMF(II)
      W(II)=VE*(1.-EMF)*CSO
      IF(W(II).GT.0.) GO TO 54
      W(I)=W(I)+W(II)
      W(II)=W(I)*0.1
   54 WRITE(6,1060) J,DB(J),E,AH,BH,BN,VB,W(II),W(I),FM(J),GM(J)
      IF(BH.EQ.ALMAX) GO TO 70
   55 CONTINUE
      JB=JB+1
      GO TO 47
   70 JLMF=J
      ITOT=2*J
      KAISU=0
   60 KAISU=KAISU+1
      IF(KAISU.LT.39) GO TO 61
      WRITE(6,1070) KAISU,ALMF
   61 IF(KAISU.GT.1) GO TO 80
      AH=(XA0-XAOUT)/FLOAT(J)
      CH=(1.-XOUT)/FLOAT(J)/2.
      XA(2)=XA0-AH
      XA(1)=XA(2)
      X(ITOT)=XOUT
      X(ITOT-1)=XOUT
      DO 72 J=2,JLMF
      II=2*J
      IIP=II-2
      XA(II)=XA(IIP)-AH
      I=II-1
      XA(I)=XA(II)
      X(ITOT+2-II)=X(ITOT+2-IIP)+CH
      X(ITOT-I)=X(ITOT+2-II)
   72 CONTINUE
   80 ITOT=2*JLMF
      ITOT2=ITOT**2
      DO 82 I=1,ITOT2
```

```
   82 AY(I)=0.0
      DO 90 J=1,JLMF
      II=2*J
      I=II-1
      IF((W(I)*GB).GT.(W(II)*GE)) GO TO 83
      WTOTAL=W(I)+W(II)
      W(I)=GE/GO*WTOTAL
      W(II)=GB/GO*WTOTAL
C  COUNTER CURRENT  *** CHANGE TO FE=FB+FS ***
   83 A=SIGMF(I)/W(I)/KVD/XA(I)
      AA(I)=A/(1.+A)
      L=ITOT*(I-1)+I
      AY(L)=1.0
      LL=L+ITOT
      IF(J.LT.JLMF) GO TO 85
      AY(LL)=-AA(I)*SIGMF(II)/SIGMF(I)
      Y(I)=FS/SIGMF(I)*AA(I)
      GO TO 86
   85 AY(LL)=-AA(I)*RFHOR(I)
      LLL=LL+ITOT
      AY(LLL)=-AA(I)*RFVER(I)
      Y(I)=0.0
   86 B=SIGMF(II)/W(II)/KVD/XA(II)
      AA(II)=B/(1.+B)
      L=ITOT*(II-1)+II
      AY(L)=1.0
      Y(II)=0.0
      LL=L-ITOT
      IF(J.EQ.1) GO TO 87
      AY(LL)=-AA(II)*RFHOR(II)
      LLL=LL-ITOT
      AY(LLL)=-AA(II)*RFVER(II)
      GO TO 90
   87 AY(LL)=-AA(II)
   90 CONTINUE
      CALL SIMQ(AY,Y,ITOT,KS)
      DO 100 I=1,ITOT
      RGACT(I)=1./STOIA/(1.+XA(I)*STOIR)
      X(I)=1.-Y(I)
  100 CONTINUE
      IF((KAISU.NE.1).AND.(KAISU.NE.8)) GO TO 140
      IF(KAISU.EQ.8) GO TO 130
      AMPXE=0.3
      AMPXB=0.1
      GO TO 140
  130 AMPXE=0.2
      AMPXB=0.07
  140 TEST=0.0
      NERROR=0
      DO 110 J=1,JLMF
      II=2*J
      I=II-1
      IIII=I-1
      IIJ=IIII-1
      A=GM(J)*(XA(II)-XA(I)*RGACT(I)/RGACT(II))
      III=II+1
      EK=EKG    *(1.+5.25*EXP(-3.18*X(I)))
      HE=SQRT((1.-XA(I))/PB/EK)
      MS(I)=KVD*W(I)*Y(I)*STOIA*(XA(I)-HE)
      EK=EKG    *(1.+5.25*EXP(-3.18*X(II)))
      HE=SQRT((1.-XA(II))/PB/EK)
```

```
      MS(II)=KVD*W(II)*Y(II)*STOIA*(XA(II)-HE)
      IF(J.EQ.1) GO TO 106
      MG(II)=GB*(XA(IIII)*RGACT(IIII)-XA(II)*RGACT(II))-A
      MG(I)=GE*(XA(IIJ)*RGACT(IIJ)-XA(I)*RGACT(I))+A
      GO TO 108
  106 MG(1)=GE*(XAO-XA(I)*RGACT(1))+A
      MG(2)=GB*(XAO-XA(2)*RGACT(2))-A
      TOTMG=0.
      TOTMS=TOTMG
  108 IF(KAISU.LT.39) GO TO 109
      WRITE(6,1080) XA(I),X(I),MG(I),MS(I),XA(II),X(II),MG(II),MS(II)
  109 TOTMG=TOTMG+MG(I)
      TOTMS=TOTMS+MS(I)
      DEVM(I)=TOTMG/TOTMS
      IF(DEVM(I).GT.0.05) GO TO 152
      DEVM(I)=0.05
      TEST=1.0
  152 TOTMG=TOTMG+MG(II)
      TOTMS=TOTMS+MS(II)
      DEVM(II)=TOTMG/TOTMS
      IF(DEVM(II).GT.0.05) GO TO 153
      DEVM(II)=0.05
  153 IF(MG(II).GT.0.0) GO TO 155
      TEST=1.0
  155 ERROR=DEVM(II)-1.
      IF((ABS(ERROR).LT.0.01).AND.(TEST.EQ.0.)) GO TO 156
      NERROR=NERROR+1
      IF(ABS(DEVM(II)-1.).LT.0.01) GO TO 156
      NERROR=NERROR+1
  156 XA(I)=1.-(1.-XA(I))**(DEVM(I)**(AMPXE*(1.-XA(I)**3)))
      XA(II)=1.-(1.-XA(II))**(DEVM(II)**AMPXB)
      IF(XA(I).LE.XA(II)) GO TO 110
      XA(I)=XA(II)
  110 CONTINUE
      HOSEI=HE/XA(ITOT)
      IF(KAISU.LT.39) GO TO 111
      WRITE(6,1100) HOSEI
  111 IF(NERROR.NE.0) GO TO 170
      IF(TEST.EQ.0.0) GO TO 5000
  170 IF(KAISU.LT.40) GO TO 60
      GO TO 5000
 5555 STOP
      END
```

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                             C
C          ALTERNATIVE I --------   2700. F                   C
C                                                             C
C          INTEGRATED SYSTEM                                  C
C                                                             C
C          ALL CALCULATIONS BASED ON 100 IB COAL              C
C                FED INTO GASIFIER                            C
C                                                             C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      VH2O=9.00
   99 IF(VH2O.LE.1.00) VH2O=VH2O+1.00-0.200
      VH2O=VH2O-1.00
      WRITE(6,702)
  702 FORMAT(1H1////)
      D=4.959
      C=D
      COC=0.5
      N=0
      H2=0.
      H2O=0.
      H2OA=VH2O
      H2OB=H2OA
C         ASSUME X, FRACTION OF CARBON WHICH GOES TO C+H2O REACTION
      X=0.60
   10 HRO2=C*(1.-X)*169700.
      HRH2O=-C*X*56484.
C         INLET STEAM, IB MOLES
C         GAS COMPOSITION AFTER C+O2 AND C+H2O REACTIONS, IB MOLES
      COX=C*X
      H2OX=H2OA+H2O-C*X
      H2X=C*X+H2
      CO2X=C*(1.-X)
      CH4X=0.
C         OXYGEN REQUIRED, IN MOLES
      O2A=C*(1.-X)
C         GAS COMPOSITION AFTER WATER GAS SHIFT REACTION, IB MOLES
      EK=0.250
      A=(H2X+CO2X+EK*(H2OX+COX))/(1.-EK)
      B=(H2X*CO2X-EK*COX*H2OX)/(1.-EK)
      Y=(-A+SQRT(A*A-4.*B))/2.
      CO2X=CO2X+Y
      COX=COX-Y
      H2OX=H2OX-Y
      H2X=H2X+Y
C         VOLATILE MATTER ADDED AND SHIFT TO EQUILIBRIUM
      COX=COX+0.427
      H2X=H2X+0.4125-0.125
      H2OX=H2OX+0.017
      CH4X=CH4X+0.545
```

```
      EK=0.250
      A=(H2X+CO2X+EK*(H2OX+COX))/(1.-EK)
      B=(H2X*CO2X-EK*COX*H2OX)/(1.-EK)
      Y=(-A+SQRT(A*A-4.*B))/2.
      CO2X=CO2X+Y
      COX=COX-Y
      H2OX=H2OX-Y
      H2X=H2X+Y
C         INLET HEAT CARRIED BY INLET GASES, COAL AND HEAT REACTION
      HH2OI=H2OA*20304.
      HO2I=O2A*1561.3
      CHARI=0.325*100.*(300.-77.)
      HREAC=HFO2+HFH2O+Y*176904.
      HCOAL=12341.*100.
      HI=HH2OI+HO2I+CHARI+HREAC+HCOAL
C         OUTLET HEAT CARRIED BY OUTLET GASES AND CHAR
      HCO2X=CO2X*3289.5
      HCOX=COX*2069.0
      HH2OX=H2OX*4261.5
      HH2X=H2X*1905.2
      HCH4X=CH4X*44515.4
      HGASX=HCO2X+HCOX+HH2OX+HH2X+HCH4X
      HCAR=(O-C)*12.*169700.
      HTGAS=38300.*CH4X+123000.*(H2X+COX)
      WCHARX=12.0+(O-C)*12.
      HCHARX=WCHARX*.22*(2700.-77.)
      HOUT=HGASX+HCHARX+HTGAS+HCAR
      H=(HOUT-HI)/HI
      IF(ABS(H).LT.0.005) GO TO 40
      IF(H) 30,20,20
   20 X=X/1.05
      GO TO 10
   30 X=X*1.10
      GO TO 10
C         H2S,0.125 AND N2, 0.05 IB MOLES ARE ADDED
   40 TOTAL=H2X+H2OX+COX+CO2X+CH4X+0.175
C         CHECK CARBON STEAM REACTION EQULIBRIUM
      HK=COX*H2X*69.3/H2OX/TOTAL
      PRINT,' GASIFICATION'
      WRITE(6,1) H2OA,O2A,X,Y
      WRITE(6,1) CO2X,COX,H2OX,H2X,CH4X
    1 FORMAT(5X,6E13.5)
      WRITE(6,2) HH2OI,HO2I, CHARI,HREAC,HI
      WRITE(6,2) HGASX,HCHARX,HOUT
    2 FORMAT(5X,6E13.5)
      WRITE(6,1) HK
      IF(HK.GT.2300.) STOP
C     SHIFT CONVERSION
      H2W=H2X
      CO2W=CO2X
```

```
      COW=COX
      H2OW=H2OX
      CH4W=CH4X
  800 TOT=H2W+COW+CO2W+CH4W+0.175
      N=N+1
      WRITE(6,1) COC
      CO2=COW/TOT
      CH4Z=CH4W/TOT
      H2Z=H2W/TOT
      SHG=1.2/1.35*(3.*CO2+CH4Z+H2Z)
      STEAM=SHG*TOT-H2OW
      IF(STEAM.LT.0.) STEAM=0.
      H2OX=STEAM+H2OW
      Y=COC*COW
      CO2X=CO2W+Y
      COX=COW-Y
      H2X=H2W+Y
      H2OX=H2OW-Y
      CH4X=CH4W
      PRINT,' SHIFT CONVERSION'
      WRITE(6,1) CO2X,COX,H2OX,H2X,STEAM
C     PURIFICATION
      H2OX=(CO2X+CH4X+H2X)*0.9487/(1000.-0.9487)
      CO2X=CO2X+0.018
      PRINT,' PURIFICATION'
      WRITE(6,1) CO2X,COX,H2OX,H2X
      TOTAL=CO2X+COX+H2X+H2OX+CH4X+0.05
      CO2Z=CO2X/TOTAL
      COZ=COX/TOTAL
      H2Z=H2X/TOTAL
      H2OZ=H2OX/TOTAL
      CH4Z=CH4X/TOTAL
      WRITE(6,1) CO2Z,COZ,H2Z,H2OZ,CH4Z
      CH4X=CH4X+COX*0.9833
      H2X=H2X-3.*0.9833*COX
      COX=0.0167*COX
      PRINT,' METHANATION'
      WRITE(6,1) CO2X,COX,H2X,H2OX,CH4X
      PROD=CH4X+COX+CO2X+H2X+H2OX+0.050
      BTUS=(CH4X*382930.+H2X*123100.+COX*122400.)/PROD/385.2
      BTUHA=BTUS*PROD*385.2
      WH2O=STEAM+H2OB
      BTUHA=PROD*385.2*BTUS
      COAL=250.*10**9/BTUHA*100./2000.
      CCOAL=COAL*2000.*(D-C)/100.
      CC=CCOAL*159700./13063./2000.
      WRITE(6,600) BTUS,BTUHA,COAL,CCOAL,CC
  600 FORMAT(5X,5E13.6)
      WH2OA=WH2O+20.*COAL/(13063.*0.75)*18.*1188.3/2000.
      WH2OC=H2OB/WH2O*WH2OA
```

```
      CFO=COAL*20.*.02A*32./2000.*.443*1000./2.93/1.3063/.35/2000.
      TOTAL=    +WH2OA  +COAL*1.356-CC+CFO
      TOTAL=TOTAL*(1.-0.122)
      WRITE(6,700) WH2OC
      WRITE(6,700)     WH2OA,CFO,TOTAL
  700 FORMAT(5X,3E13.5,4X,E12.5)
      IF((BTUS.GT.900.).AND.(BTUS.LT.920.)) GO TO 99
      IF(N.GE.10)  GO TO 99
   50 IF(BTUS-910.)7,6,6
    7 COC=COC/1.015
      GO TO 800
    6 COC=COC*1.025
      GO TO 800
      END
$ENTRY
$IBSYS
```

```
C                                                                       C
C          ALTERNATIVE II,     INTEGRATED SYSTEM                        C
C                                                                       C
C           2700. F  ------------   1700. F                             C
C                                                                       C
0001            IMPLICIT REAL *8 (A-H,O-$)
0002            DATA NCYL,NNA,IFLAG,SFS/9000,2,1,1.D-9/
0003            DIMENSION V(9),P(9)     ,FV(9),FVH(9)
0004            DIMENSION SFX(7),XH(7),XL(7),PARA(7),CONS(6),XS(7)
0005            COMMON HH2,HH2O,HAIR,HCH4,HCO2,HCO,HO2,HN2
0006            COMMON F0,F2,F3,F4,F5,F6,F7,F8,F9,F10
0007          697 FORMAT(3X,'I=',I3,5X,'V(1)=',F14.7,5X,'V(3)=',F14.7,5X,2F14.7)
0008          603 FORMAT(1H1//,3X,' CARBON CONVERSION = ',F10.2)
0009          604 FORMAT(   3X,'HEAT REMOVED =',F10.2,5X,'A2=',F5.2,5X,
                 1'H.G. TEMP=',F7.2,5X,'INLET TEMP=',F7.2)
0010          601 FORMAT(/4X,' CO2 =',F7.3,'  CO =',F7.3,'  CH4 =',F7.3,'  H2O ='
                 1F7.3,'  H2 =',F7.3/4X,'   STEAM  REQUIRED =',F8.3/
                 24X,' C-H2O EQUV. EQUI. =',F10.2,'WATER-GAS EQU =',F10.3,
                 3'   C-H2 EQUILIBRIUM =',F10.3)
0011          500 FORMAT(6F10.4)
0012              READ(5,500) CP1,CP2,CP3,CP4,CP5,T
0013              READ(5,500)BCP1,BCP2,BCP3,BCP4,BCP5,T3
0014              WH2O=1.00
0015           39 WH2O=WH2O+0.2
0016              IF(WH2O.GE.3.0) STOP
0017              CCON=0.25
0018           36 CCON=CCON+0.05
0019              IF(CCON.GE.0.75)  GO TO 39
0020              CLC=0.7028
0021              CLH=0.0507
0022              CLO=0.0595
0023              CALO=13063.
0024              CLW=0.0129
0025              ASH=0.1205
0026              CPCL=0.325
0027              EKCHM=0.043735
0028              BE=0.881
0029              CALO=13063.
0030              HXE=0.9
0031           37 FORMAT(2F10.2)
0032              WRITE(6,603)CCON
                C       GASIFER
0033              CON=1.
0034              C=CLC*100.*(1.-CCON)
0035              PP=69.3
0036              W=0.
```

```
0037                O=0.
0038                H=0.
0039                HLIN=0.0
0040                S=0.
0041                CN=0.
0042                QCOAL=C/12.*169700.
0043                TF=2700.
0044                EK=0.179
0045                TC=1700.
0046                Y=2.303*(7.2-12096./(TF+460.))
0047                FK=DEXP(Y)
0048                HPS=21452.3
0049                T=(TF-32.)/1.8+273.
0050                CALL ENTHA(T)
0051                HES=HH2O
0052                HE=(1.-CON)*C/12.*.23*(TF-77.)
0053                HP=0.3*(TC-77.)*100.
0054                A=(1.-HLIN)*QCOAL-(1.-CON)*C*169700./12.
0055                Q=A+HP+HPS-HE
0056                QCO=121000.+HCO
0057                QW=123000.+HH2
0058                D=QCO-QW+HES-HCO2
0059                A=2.*QW-2.*HES+HO2
0060                CONE=CON*C/12.
0061                B=QW*(H/2.+S/32.+2.*CONE)+HES*(WH2O-2.*CONE)+HCO2*CONE-Q
0062                A=A/D
0063                B=B/D
0064                E=A*(A+2.)*(1.-EK)
0065                U=CONE+B
0066                Q=B+2.*CONE-WH2O
0067                R=B+H/2.+S/32.+2.*CONE
0068                F=R*A+U*(2.+A)-EK*B*(2.+A)-EK*Q*A
0069                G=R*U-EK*B*Q
0070                F=F/E
0071                G=G/E
0072                G=F*F-4.*G
0073                G=DSQRT(G)
0074                WO2=(F-G)/2.
0075                WFA=WO2-O/32.
0076                VCO=A*WO2-B
0077                VCO2=U-A*WO2
0078                VH2O=(2.+A)*WO2-Q
0079                VH2=R-(2.+A)*WO2
0080                X=CONE+H/2.+W/18.+WH2O+CN/28.
0081                XCO=VCO
0082                XCO2=VCO2
0083                XH2=VH2
0084                XN2=0.
```

```
0085                XH2O=VH2O
0086                WRITE(6,700)
0087            700 FORMAT(/,15X,'GASIFICATION')
0088                EKCS=PP*XCO*XH2/((XCO2+XCO+XH2O+XH2+XN2)*XH2O)
0089                EKS=XCO2*XH2/(XCO*XH2O)
0090                WRITE(6,30)WH2O,WO2,XCO2,XCO,XH2O,XH2,EKS,EKCS
0091             30 FORMAT(/' STEAM USED =',F5.2,'    OXYGEN REQUIRED =',F5.2/
                   14X,'CO2=',F6.2,4X,'CO=',F6.2,4X,'H2O=',F6.2,4X,'H2=',F6.2,
                   2'WATER-GAS EQUI. CONS.=',F6.3,4X,'C-H2O EQUI. CONS.=',F9.3)
0092                IF(XCO.LT.0.) GO TO 36
0093                IF(VCO2.LT.0.) GO TO 36
0094                IF(VH2O.LT.0.) GO TO 36
0095                IF(VH2.LT.0.) GO TO 36
                C       SHIFT CONVERTER
0096                VCO=XCO
0097                VCO2=XCO2
0098                VH2=XH2
0099                VH2O=XH2O
0100                TF=770.
0101                T=(TF-32.)/1.8+273.
0102                FB=VH2/VCO
0103                FA=FB
0104                F=0.
0105                TF=880.
0106                WRITE(6,822) TF,FA
0107            822 FORMAT(3X,'TF=',F10.2,5X,'FA=',F10.2)
0108                Z=8240./(TF+460.)-4.33
0109                EK=DEXP(Z)
0110                VC=(FA*VCO-VH2)/(1.+FA)
0111                F=(FA*(VCO+VC)/EK-VH2O+VC)/X
0112                VCO=VCO-VC
0113                VH2=VH2+VC
0114                VCO2=VCO2+VC
0115                IF(F-0.) 103,103,102
0116            103 F=0.
0117            102 FX=F*X
0118                WWH2O=FX
0119                VH2O=VH2O+FX-VC
0120                WRITE(6,701)
0121            701 FORMAT(/,15X,'1ST SHIFT CONVERSION')
0122                WRITE(6,40) FB,FA,F,FX,VC,VCO2,VCO,VH2O,VH2,X
0123             40 FORMAT(4X,'ORIG. RATIO=',F5.2,6X,'REQUIRED RATIO=',F5.2,F10.2,
                   14X,'STEAM REQUIRED=',F6.3,4X,'AMOUNT SHIFTED =',F6.3/
                   24X,'CO2 =',F6.3,4X,'CO =',F6.3,4X,'H2O =',F6.3,4X,'H2=',F6.3,
                   3'TOTAL MOLES =',F10.3)
                C       HYDROGASIFIER
0124                T3=2700.
0125                EKWGS=0.6969
```

```
0126                P(1)=VCO2
0127                P(2)=VCO
0128                P(3)=0.
0129                P(4)=VH2O
0130                P(5)=VH2
0131                WRITE(6,641)  (P(I),I=1,5)
0132             31 CLC=CLC/12.
0133                CLH=CLH/2.
0134                EP=0.001
0135                CLO=CLO/32.
0136                CLW=CLW/18.
0137                AA2=2.
0138                PRE=1176.
0139                EKCHM=EKCHM*AA2*PRE/14.7
0140                COAL=100.
0141                CP4S=8.21
0142                TS=545.
0143                TCL=400.
0144                TTC=P(1)+P(2)+P(3)+COAL*CLC*CCON
0145                T=1700.
0146                WRITE(6,702)
0147            702 FORMAT(/,15X,'HYDROGASIFICATION')
0148                PHL=0.
0149                WRITE(6,604) PHL, AA2,T,T3
0150                Z1=CCON*COAL *CLC+P(1)+P(2)+P(3)
0151                Z2=COAL *CLO+0.5*(COAL *CLW+P(2)+P(4))+P(1)
0152                Z3=COAL *(CLH+CLW)+2.*P(3)+P(4)+P(5)
0153                A1=CP1*(T-77.)-169700.
0154                A2=CP2*(T-77.)-47800.
0155                A3=CP3*(T-77.)-32200.
0156                A4=CP4*(T-77.)-104150.
0157                A5=CP5*(T-77.)
0158                A6=CP4S*(TS-77.)-104150.
0159                Z4=P(1)*(BCP1*(T3-77.)-169700.)+P(2)*(BCP2*(T3-77.)-47800.)
                   1+P(3)*(BCP3*(T3-77.)-32200.)+P(4)*(BCP4*(T3-77.)-104150.)
                   2+P(5)* BCP5*(T3-77.)-COAL *(CALO*PHL+CPCL*((1.-CCON)*CLC*12.
                   3+ASH)*(T  -77.)+(2.*CLO+CLW)*123000.-CPCL*(TCL-77.)
                   4+(CLC*169700.+(CLH-2.*CLO)*123000.-CALO))
0160                B1=A1/A6
0161                B2=A2/A6
0162                B3=A3/A6
0163                B4=A4/A6
0164                B5=A5/A6
0165                B6=Z4/A6
0166                B7=2.*Z2-Z3
0167                B8=B3-2.
0168                B9=B4-1.
0169                B10=B5-1.
```

```
0170              B11=B6-Z3
0171              C1=B1/B10
0172              C2=B2/B10
0173              C3=B8/B10
0174              C4=B9/B10
0175              C5=B11/B10
0176              D1=2.+C1
0177              D2=1.+C2
0178              D3=-2.+C3
0179              D4=B7+C5
0180              D5=D1/C4
0181              D6=D2/C4
0182              D7=D3/C4
0183              D8=D4/C4
0184              E1=2.-D5
0185              E2=1.-D6
0186              E3=-(2.+D7)
0187              E4=Z1+D8-B7
0188              E5=Z1-B7
0189              F0=-(3.+EKWGS*(D7-D6)+EKWGS*(D5-D6))/(1.-EKWGS*(D5-D6))
0190              F2=-EKWGS*(D7-D6)/(1.-EKWGS*(D5-D6))
0191              F3=(E5+EKWGS*Z1*(D5-D6)-EKWGS*(D6*Z1-D3))/(1.-EKWGS*(D5-D6))
0192              F4=(EKWGS*Z1*(D7-D6)-EKWGS*(D6*Z1-D8))/(1.-EKWGS*(D5-D6))
0193              F5=EKWGS*Z1*(D6*Z1-D8)/(1.-EKWGS*(D5-D6))
0194              E6=Z1-B7
0195              E7=(E1-E2)/EKCHM
0196              E8=(E3-E2)/EKCHM
0197              E9=(E2*Z1+E4)/EKCHM
0198              F6=-(6.+E7)
0199              F7=9.-E8
0200              F8=2.*E6
0201              F9=-(6.*E6+E9)
0202              F10=E6*E6
0203              WRITE (6,641) F0,   F2,F3,F4,F5,F6,F7,F8,F9,F10
0204          641 FORMAT(10F10.3)
0205              XL(1)=2.0
0206              XH(1)=3.0
0207              XL(2)=1.4
0208              XH(2)=1.80
0209              NR=2
0210              CONS(1)=1.
0211              CALL SIMPLX(NNA,XH,XL,NCYL,IFLAG,SFS,SFX,CONS,PARA,IER,NR)
0212              WRITE(6,697) IER,PARA(1),PARA(2),SFX(1),SFX(2)
0213              V(1)=PARA(1)
0214              V(3)=PARA(2)
0215              V(2)=Z1-V(1)-V(3)
0216              V(4)=D8-D5*V(1)-D6*V(2)-D7*V(3)
0217              V(5)=2.*V(1)+V(2)-2.*V(3)-B7
```

```
0218              V(6)=2.*V(1)+V(2)+V(4)-2.*Z2
0219              TMOLE=V(1)+V(2)+V(3)+V(4)+V(5)
0220              CEKCST=PRE*V(2)*V(5)/(14.7*TMOLE*V(4))
0221              EKS=V(1)*V(5)/(V(2)*V(4))
0222              EKM=TMOLE*V(3)*14.7/(PRE*V(5)*V(5))
0223              THAMG=121900.*V(2)+123000.*V(5)+383000.*V(3)
0224              WRITE(6,601) (V(I),I=1,6), CEKCST ,EKS,EKM
0225              DO 21 I=1,5
0226           21 FV(I)=V(I)/TMOLE
0227              WRITE(6,601) (FV(I),I=1,5)
0228              TMOLEW=TMOLE-V(4)
0229              AAA=V(4)
0230              V(4)=0.
0231              DO 22 I=1,5
0232           22 FVH(I)=V(I)/TMOLEW
0233              WRITE(6,631)(FVH(I),I=1,5)
0234          631 FORMAT(/4X,' CO2 =',F7.3,'  CO =',F7.3,'  CH4 =',F7.3,'  H2O =
                 1F7.3,'  H2 =',F7.3)
0235              AV5=V(5)/3.
0236              IF(V(2).GE.AV5) GO TO 100
0237              AMETH=V(2)+V(3)
0238              PMETH=AMETH/(V(3)+V(5)-V(2)+V(1)*0.018)
0239              V(1)=V(1)*0.018
0240              V(3)=AMETH
0241              V(5)=V(5)-3.*V(2)
0242              V(2)=0.
0243              V(4)=(V(1)+V(3)+V(5)) *0.9487/(1000.-0.9487)
0244              PROD=V(1)+V(2)+V(3)+V(4)+V(5)
0245              WRITE(6,705)
0246           705 FORMAT(/,15X,'DIRECT METHANATION')
0247              WRITE(6,610) (V(I),I=1,5)   ,PROD
0248           610 FORMAT(/4X,' CO2 =',F7.3,'  CI =',F7.3,'  CH4 =',F7.3,'  H2O =
                 1F7.3,'  H2 =',F7.3,4X,'   TOTAL MOLES =',F10.3)
0249              DO 200 I=1,5
0250           200 FV(I)=V(I)/PROD
0251              WRITE(6,631) (FV(I),I=1,5)
0252              PVCO2=V(1)
0253              PVCO=V(2)
0254              PVCH4=V(3)
0255              PVH2O=V(4)
0256              PVH2=V(5)
0257              WVH2O=0.
0258              GO TO 101
0259           100 VCO2=V(1)
0260              VCO=V(2)
0261              VCH4=V(3)
0262              VH2O=AAA
0263              VH2=V(5)
```

```
0264              FB=VH2/VCO
0265              X=VCO+VCO2+VH2+VH2O+VCH4
0266              TF=770.
0267              T=(TF-32.)/1.8+273.
0268              FAA=(VCH4+VCO*0.999-6.2*(0.01*VCO2-2.996*VCO+VH2))/25.8362
0269              FA=(VH2+FAA)/(VCO-FAA)
0270              TF=880.
0271              Z=8240./(TF+460.)-4.33
0272              EK=DEXP(Z)
0273              VC=(FA*VCO-VH2)/(1.+FA)
0274              F=(FA*(VCO+VC)/EK-VH2O+VC)/X
0275              IF(F.LT.0.) GO TO 33
0276              VCO=VCO-VC
0277              VH2=VH2+VC
0278              VCO2=VCO2+VC
0279              FX=F*X
0280              WVH2O=FX
0281              VH2O=VH2O+FX-VC
0282              WRITE(6,703)
0283          703 FORMAT(/,15X,' 2ND SHIFT CONVERSION')
0284              WRITE(6,40) FB,FA,F,FX,VC,VCO2,VCO,VH2O,VH2,X
0285              GO TO 34
0286           33 A=(VH2+VC)*(VCO2+VC)/((VCO-VC)*(VH2O-VC))
0287              TF=8240./(DLOG(A)+4.33)-460.
0288              VH2O=VH2O-VC
0289              VCO=VCO-VC
0290              VH2=VH2+VC
0291              VCO2=VCO2+VC
0292              WVH2O=0.
0293              FX=0.
0294              WRITE (6,711)
0295          711 FORMAT(/,15X,'SHIFT WITHOUT ADDING STEAM')
0296              WRITE(6,40) FB,FA,F,FX,VC,VCO2,VCO,VH2O,VH2,X
0297           34 PVCO2=VCO2*0.018
0298              PVCO=0.
0299              PVCH4=VCH4+VCO
0300              PVH2=VH2-3.*VCO
0301              PVH2O=(PVCO2+PVCH4+PVH2)*0.9487/(1000.-0.9487)
0302              THAMT=383000.*PVCH4+121900.*PVCO+123000.*PVH2
0303              PROD=PVCO2+PVCO+PVCH4+PVH2O+PVH2
0304              WRITE(6,704)
0305          704 FORMAT(/,15X,'METHANATION')
0306              WRITE(6,610) PVCO2,PVCO,PVCH4,PVH2O,PVH2,PROD
0307              FVH(1)=PVCO2/PROD
0308              FVH(2)=PVCO/PROD
0309              FVH(3)=PVCH4/PROD
0310              FVH(4)=PVH2O/PROD
0311              FVH(5)=PVH2/PROD
```

```
0312              WRITE(6,601) (FVH(I),I=1,5)
0313          101 TSTM=WH2O+WWH2O+WVH2O+V(6)
0314              WRITE(6,622) WH2O,WWH2O,WVH2O,V(6),TSTM
0315          622 FORMAT(4X,'   STEAM FOR GASIFIER =',F6.2,'          FOR 1ST SHI
                 1CONVERSION =',F6.3,'          FOR 2ND SHIFT CONVERSION =',F6.3,
                 2 '  FOR HYDROGASIFICATION =',F6.3/4X, '  TOTAL STEAM =',F8.3)
0316              CFSTM=TSTM*0.13484/(BE*PVCH4)
0317              CFGAS=100.*CLC/PVCH4
0318              CRHX=100.*CALO*PHL*HXE/(16923.24*PVCH4)/10.
0319              THAMC=(CFSTM+CFGAS+CRHX)*PVCH4*CALO
0320              THAMG=THAMG/THAMC
0321              THAMT=THAMT/THAMC
0322              HGSTMP=100.*CALO*PHL/(22827.06*PVCH4)  *HXE
0323              CU=CFSTM+CFGAS+CRHX
0324              CUT=CU+650.61*WO2*PROD/(CALO*PVCH4*PVCH4)
0325              SG=770.4*CLC*PROD/(CUT*PVCH4)
0326              DCOAL=277777./SG
0327              WRITE(6,621)CFSTM,CFGAS,CRHX,HGSTMP,CU,CUT,SG,DCOAL,THAMG,THAMT
0328          621 FORMAT(10F10.3)
0329           38 GO TO 36
0330              END
```

```
0001                SUBROUTINE ENTHA(T)
0002                IMPLICIT REAL *8 (A-H,O-$)
0003                DIMENSION V(9),P(9)    ,FV(9),FVH(9)
0004                DIMENSION SFX(2),XH(2),XL(2),PARA(2),CONS(1),XS(2)
0005                COMMON HH2,HH2O,HAIR,HCH4,HCO2,HCO,HO2,HN2
0006                COMMON F0,F2,F3,F4,F5,F6,F7,F8,F9,F10
0007                HH2=(6.946*T-0.196*T*T/2000.+.4757*(T/100.)**3/3.-2065.4)*1.8
0008                HH2O=(7.136*T+2.64*T*T/2000.+.0459*(T/100.)**3/3.-2244.2)*1.8
0009                HH2O=HH2O+18948.
0010                HAIR=(6.386*T+1.762*T*T/2000.-.2656*(T/100.)**3/3.-1978.9)*1.
0011                HCH4=(3.204*T+18.41*T*T/2000.-4.48*(T/100.)**3/3.-1732.7)*1.8
0012                HCO2=(6.339*T+10.14*T*T/2000.-3.415*(T/100.)**3/3.-2309.1)*1.
0013                HCO=(6.35*T+1.811*T*T/2000.-.2675*(T/100.)**3/3.-1970.4)*1.8
0014                HO2=(6.117*T+3.167*T*T/2000.-1.005*(T/100.)**3/3.-1954.6)*1.8
0015                HN2=(6.457*T+1.389*T*T/2000.-.069*(T/100.)**3/3.-1985.3)*1.8
0016                RETURN
0017                END
```

```
0001                SUBROUTINE FUN(SFX,CONS,XS)
0002                IMPLICIT REAL *8 (A-H,O-S)
0003                DIMENSION V(9),P(9)     ,FV(9),FVH(9)
0004                DIMENSION SFX(7),XH(7),XL(7),PARA(7),CONS(6),XS(7)
0005                COMMON HH2,HH2O,HAIR,HCH4,HCO2,HCO,HO2,HN2
0006                COMMON F0,F2,F3,F4,F5,F6,F7,F8,F9,F10
0007                SFX(1)=      F0*XS(1)*XS(2)+F2*XS(2)*XS(2)+F3*XS(1)+XS(1)*XS(1:
                   1F4*XS(2)+F5
0008                SFX(2)=XS(1)*XS(1)+F6*XS(1)*XS(2)+F7*XS(2)*XS(2)+F8*XS(1)+
                   1F9*XS(2)+F10
0009                RETURN
0010                END
```

B.3 Shift Conversion

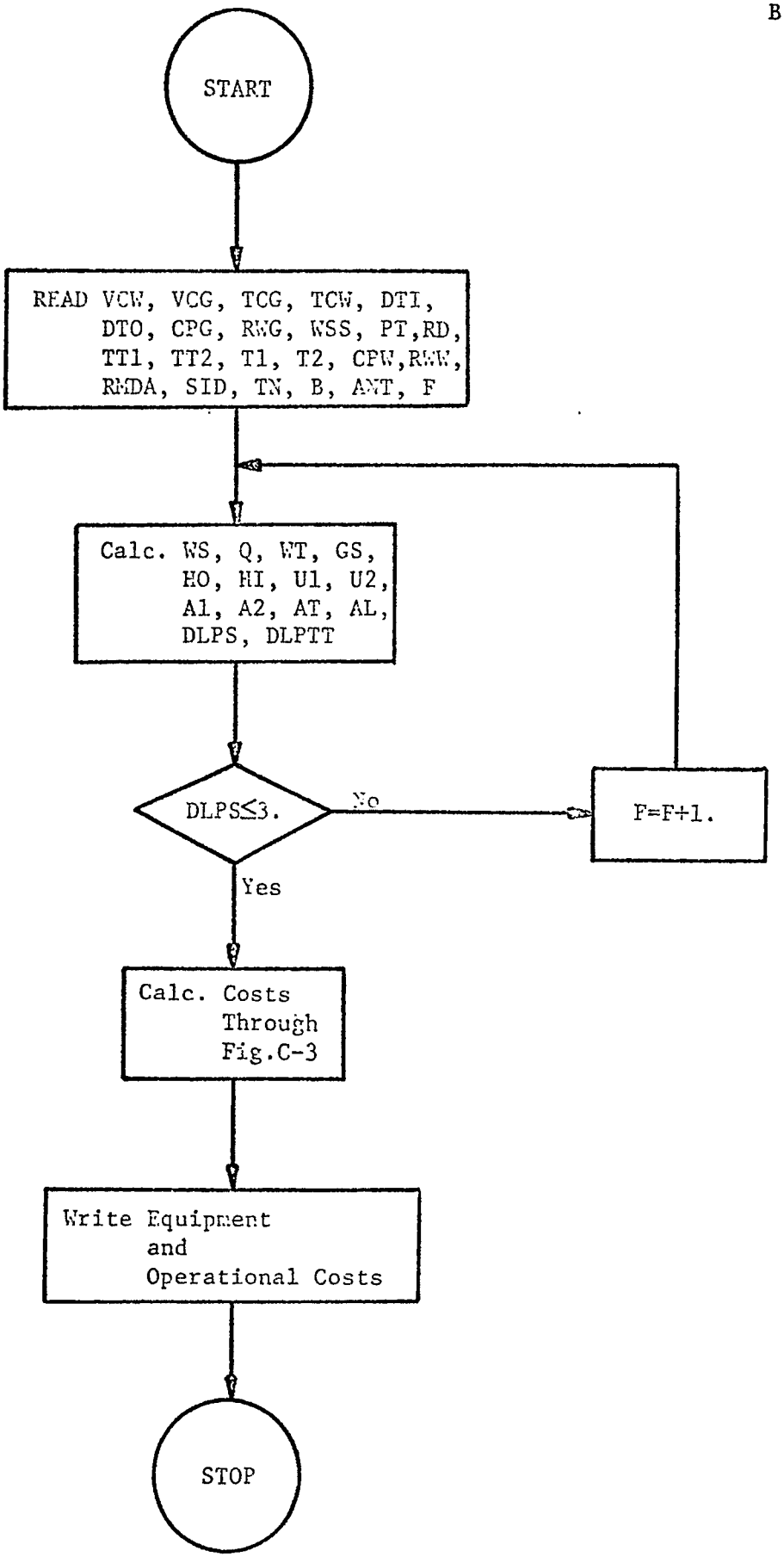

FIGURE B.3-1 COMPUTER FLOW DIAGRAM FOR HEAT EXCHANGERS

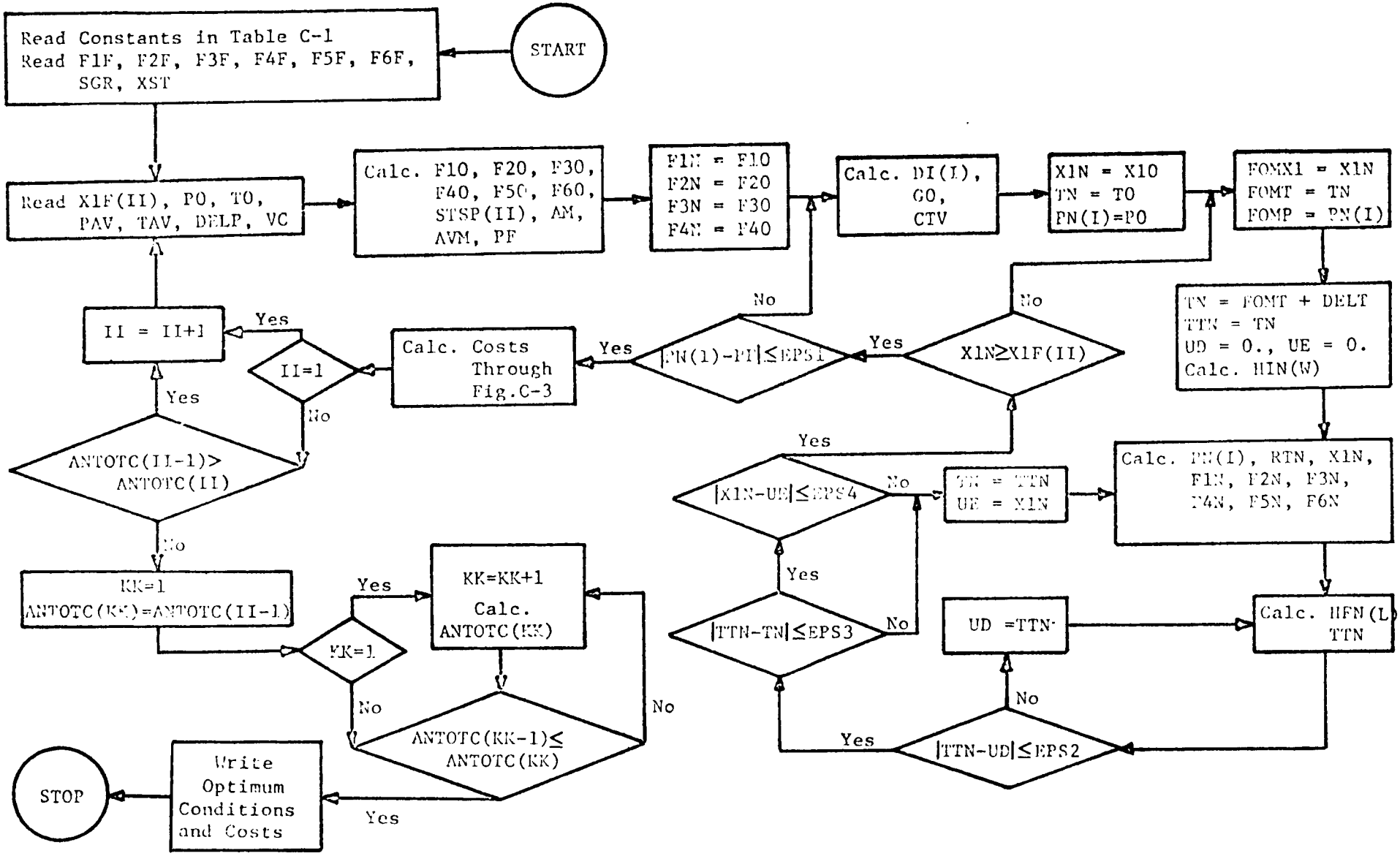

FIGURE B.3-2 COMPUTER FLOW DIAGRAM FOR THE OPTIMIZATION OF ADIABATIC WATER-GAS SHIFT CONVERSION PROCESS

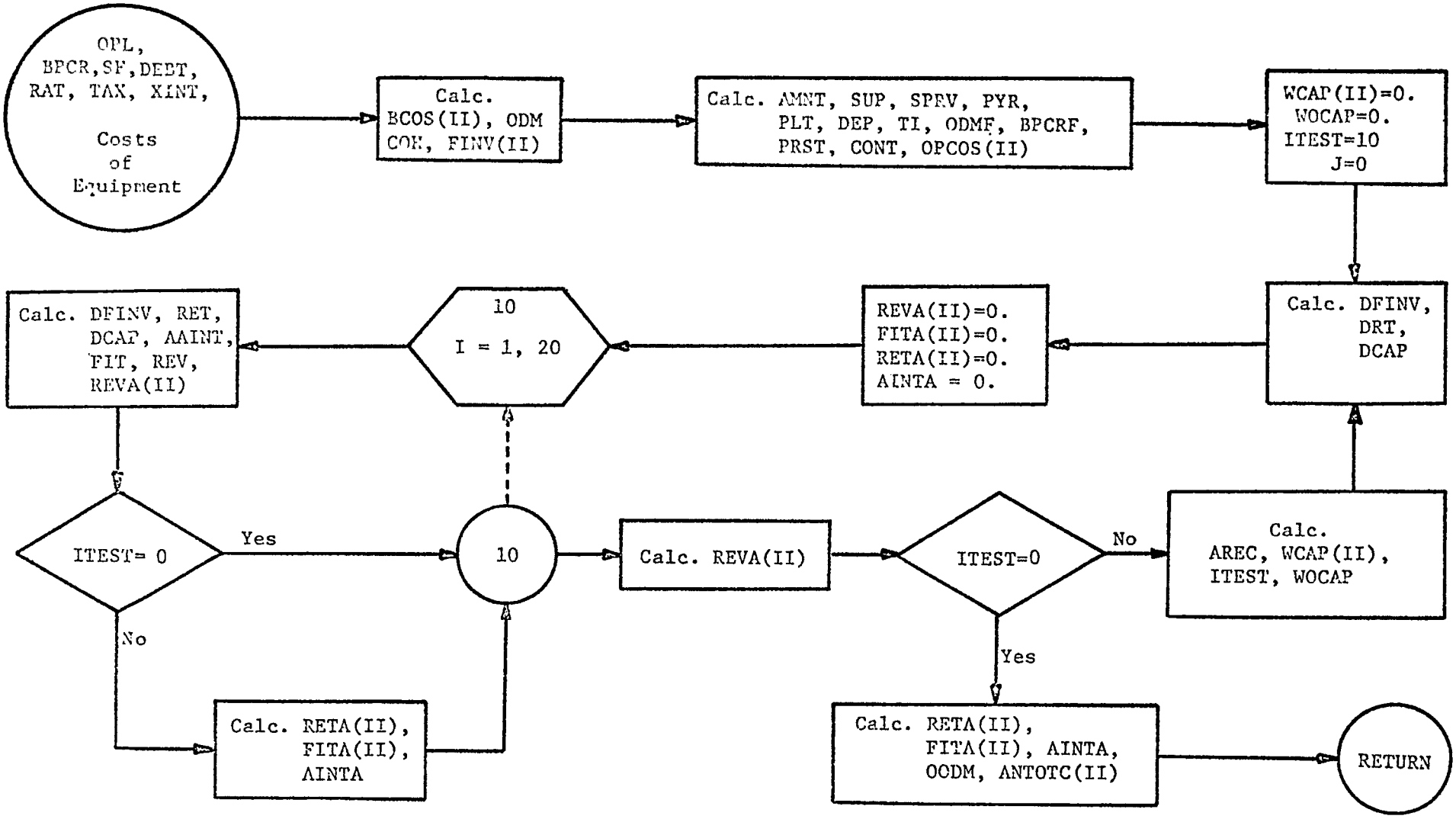

FIGURE B.3-3 COMPUTER FLOW DIAGRAM FOR COST ESTIMATION

TABLE B.3-1 PROGRAM SYMBOLS AND EXPLANATIONS FOR ADIABATIC WATER-GAS SHIFT REACTION

Program Symbols	Explanations	Mathematical Symbols
A, A1	Dummy variables	
A(V)	Temperature coefficient in heat capacity of gas	
AAINT	Annual interest charge on debt	
AINTA	20-year average interest on debt	
AL	Unit cell length	C_L
AM	Mass flow rate of gases	
AMNT	Maintenance cost	
AN (JJ)	Number of parallel reactors	
ANTOTC(II)	Annual total cost	
AREC	Accounts receivable	
AVM	Average molecular weight of gas phase	
B,B1,B2	Dummy variables	
B(V)	Temperature coefficient in heat capacity of gas	
BCOS(II)	Bare cost of the plant	
BM1,BM2, BM3,BM4, BM4,BM6	Molecular weight of CO, H_2O, H_2, CO_2, CH_4, and N_2 respectively	
BPCRF	Revenue from byproducts produced in process	
C, C1, C2	Dummy variables	
C(V)	Temperature coefficient in heat capacity of gas	
COH	Contractor's overhead and profit	
CONT	Contingencies	
CPMF(M)	Mean heat capacity of gases	C_{pm}

TABLE B.3-1 (Cont.)

Program Symbols	Explanations	Mathematical Symbols
CTC (II)	Catalyst cost	E_c
CTV	Catalyst volume of unit cell	
CVLC (II)	Control valve cost	
D	Dummy variable	
D(V)	Temperature coefficient in heat capacity of gas	
DCAP	Amount of unretired debt	
DE1	Effective diffusivity of CO in catalyst pores at 1 atm.	D_{e_1}
BEBT	Fraction of total capital investment funded by debt	
DELP	Pressure drop in reactor	Δ_p
DELT	Assumed temperature increase in cell	Δ_T
DEP	Depreciation	
DFINV	Undepreciated investment	
DI(I)	Diameter of reactor in trial calculation	D
DIAM	First approximated diameter of reactor	D
DII(II)	Correct diameter of reactor	D
DP	Diameter of catalyst particle	d_p
DRT	Amount of debt retired per year	
E	Void fraction of catalyst bed	E
EF	Efficiency of longitudinal joints in cylindrical shells	E'
EFF	Effectiveness factor at 1 atm	η_1
EINT	Interest during construction	

TABLE B.3-1 (Cont.)

Program Symbols	Explanations	Mathematical Symbols
EK	Equilibrium constant	K
EPS1,EPS2, EPS3,EPS4	Allowable errors	ϵ_1 , ϵ_2 ϵ_3 , ϵ_4
F	Dummy variable	
F1O, F2O, F3O, F4O, F5O, F6O	Molar flow rates of CO, H_2O, H_2, CO_2, CH_4, H_2 at the reactor inlet	
F1F, F2F F3F, F4F F5F, F6F	Molar flow rates of CO, H_2O, H_2, CO_2, CH_4, N_2, at the exit of waste heat boiler	
F1N, F2N F3N, F4N F5N, F6N	Molar flow rates of CO, H_2O, H_2, CO_2, CH_4, N_2, at the cells of reactor	
FBD	Flat blank diameter of top and bottom domes of reactor	Fd
FC	Cummulative number of moles of CO converted from the inlet to any position in reactor	
FD	Number of moles of CO converted at each cell	
FDT	Molar flow rate of dry gas at the inlet of reactor	
FINV (II)	Total fixed investment	
FITA(II)	20-year average federal income tax	
FN	Number of reactors	
FOMP	Exit pressure of previous cell	
FOMT	Exit temperature of previous cell	
FOMX1	Cummulative conversion of CO at the exit of previous cell	
FR	Fraction of gases entering reactor	
FTO	Total flow rate of wet gases in the reactor	
G	Dummy variable	

TABLE B.3-1 (Cont.)

Program Symbols	Explanations	Mathematical Symbols
GC	Gravitational acceleration	g
GO	Mass velocity of total wet gases at reactor inlet	
HFN(L)	Gas enthalpies per unit mole at the exit of cell	
HIN(W)	Gas enthalpies per unit mole at the inlet of cell	
ITEST	Computer test operator	
ODI	Outside diameter of reactor	
ODM	Other direct materials	
ODMF	Cost of other direct materials consumed in process	
OODM	Other direct materials inventory	
ORAWM	Raw material inventory	
OPCOS(II)	Operating cost with contingencies and by-product credits	
OPL	Operating labor cost	
PAV	Approximated average pressure in reactor	
PF	Exit pressure of reactor	
PLT	General plant overhead	
PN(I)	Pressure at the each cell of reactor	
PO	Inlet pressure of reactor	
PRST	Operating cost without contingencies	
PYR	Payroll overhead	
QDF	Enthalpy increased at each cell	
QFO	Heat of reaction at standard temperature	ΔH_{T_o}
RAT	Rate of return-on-rate base	
RAWM	Raw materials cost	
RCTC(II)	Reactor cost	
RCMV	Volume of reactor shell	
RCMW	Weight of reactor shell	

TABLE B.3-1 (Cont.)

Program Symbols	Explanations	Mathematical Symbols
RET	Return on investment	
RETA(II)	20-year average return-on-rate base	
REV	Annual revenue requirement	
REVA(II)	20-year average revenue requirement	
RKA1	Apparent catalyst activity at 1 atm	k_{a1}
RKAP	Apparent catalyst activity at pressure P	k_{ap}
RKO	Apparent catalyst activity of pressure p	k_{ap}
RKS	Intrinsic catalyst activity	k_s
RKV1	Intrinsic rate constant at 1 atm	k_{v1}
RTN	Reaction rate at each cell	
RWM	Density of reactor shell material	ρ_m
RWp	Density of catalyst pellet	ρ_p
S	Maximum allowable stress value	S
SF	Stream factor	
SGR	Steam to gas ratio	
SP	Specific surface area of catalyst pellet	S_p
SPRV	Supervision	
STC(II)	Steam cost	
STSP(II)	Amount of steam supplied in the reactor	
SUP	Supplies	
SV	Space velocity at standard condition	S_v
TAV	Approximated average temperature in reactor	

TABLE B.3-1 (Cont.)

Program Symbols	Explanations	Mathematical Symbols
TAX	Nominal federal income tax rate	
TF	Exit temperature of reactor	
TH(II)	Thickness of reactor wall	T_h
TI	Local taxes and insurance	
TK	Temperature in Kelvin	
TLM	Thiele modulus at 1 atm	ϕ_1
TN	True exit temperature of a cell	
TOL	Reactor length	L
TO	Reactor inlet temperature	
TRC(II)	Cost of catalyst supporting tray	E_S
TRN	Number of trays in reactor	N
TST	Standard temperature taken as 537°R	To
TTN	Calculated exit temperature of a cell by iteration	
UD,UE	Dummy variables	
VC	Viscosity of gases	
VTRY	Materials inventory cost	
WCAP	Working capital	
WOCAP	Working capital	
X1	Conversion of CO	X_{co}
X1O	Conversion of CO at reactor inlet	
X1F(II)	Final conversion of CO to be achieved in reactor	
X1N	Cummulative conversion of CO at any cell in reactor	
XE	Equilibrium conversion of CO	X_{co_e}
XINT	Interest rate on debt	

TABLE B.3-1 (Cont.)

Program Symbols	Explanations	Mathematical Symbols
Y1N, Y2N, Y3N, Y4N, Y5N, Y6N	Mole fractions of CO, H_2O, H_2 CO_2, CH_4, N_2 in reactor	

TABLE C-3 COMPUTER PROGRAM FOR
ADIABATIC WATER-GAS SHIFT CONVERSION PROCESS

```
      INTEGER U,V,W,Z
      DIMENSION A(6),AN(50),B(6),C(6),CPMF(6),D(6),DI(6),HIN(6),
     1HFN(6),X1F(5),TH(30)
      COMMON CTV
      COMMON /S1/ TN,PN(20),F1N,F2N,F3N,F4N,F10,FTO,FOMX1, DP,RWP,SP,
     1E,RTN,X1N,FC,I
      COMMON /S2/ DII(30),RCMW,TOL(30),AL,FN,STSP(30),STC(30),CTC(30),
     1ANTOTC(30),RCTC(30),TRC(30),CVLC(30),BCOS(30),II,OPCOS(30),
     2FINV(30),WCAP(30),RETA(30),FITA(30),REVA(30),OPL,BPCR,SF,DEBT,
     3RAT,TAX,XINT
 1050 FORMAT(7F10.4)
 1100 FORMAT(4F10.2,3E12.3)
 1200 FORMAT(6F10.2,E12.4)
 1300 FORMAT(6F10.1,2F7.3)
 1400 FORMAT(5F10.1,F10.4)
 1500 FORMAT(5F10.3)
 1550 FORMAT(6F10.3)
 1600 FORMAT(4E14.4/(4E14.4))
 1750 FORMAT(10X,7F12.1,F10.3)
 1800 FORMAT(/10X,6F12.1,F10.3)
 1867 FORMAT(22X,32HFINAL CONDITIONS AND COMPOSITION/1X,4F8.2,1X,6F10.6)
 1880 FORMAT(/22X,41HREACTOR SIZE AND COST FOR EACH CONVERSION)
 1900 FORMAT(1X,2F7.1,2F7.3,7E14.6/29X,6E14.6)
 1980 FORMAT(//22X,39HOPTIMUM NUMBER OF REACTORS AND DIAMETER)
 2000 FORMAT(3X,2F8.1,F10.3,7E14.6/29X,6E14.6)
      GC=0.416975E 09
      RWM=7.7*62.43
      READ(5,1050) OPL,BPCR,SF,DEBT,RAT,TAX,XINT
      READ(5,1100) DELT,RWP,E,TST,SP,S,AL
      READ(5,1200) EPS1,EPS2,EPS3,EPS4,X10,EF,DP
      READ(5,1600) (A(V),B(V),C(V),D(V),V=1,6)
      READ(5,1550) BM1,BM2,BM3,BM4,BM5,BM6
      DO 1 U=1,6
      B(U)=B(U)/1.8
      C(U)=C(U)/1.8**2
    1 D(U)=D(U)/1.8**3
      READ(5,1300) F1F,F2F,F3F,F4F,F5F,F6F,SGR,XST
      WRITE(6,1750) F1F,F2F,F3F,F4F,F5F,F6F,SGR,XST
    2 READ(5,1500) (X1F(II),II=1,5)
      READ(5,1400) P0,T0,PAV,TAV,DELP,VC
      II=1
    3 FR=XST/X1F(II)
      F10=F1F*FR
      F30=F3F*FR
      F40=F4F*FR
      F50=F5F*FR
      F60=F6F*FR
      FDT=F10+F30+F40+F50+F60
      F20=FDT*SGR
      STSP(II)=F20-F2F*FR
      WRITE(6,1800) F10,F20,F30,F40,F50,F60,X1F(II)
      FTO=FDT+F20
      AM=F10*BM1+F20*BM2+F30*BM3+F40*BM4+F50*BM5+F60*BM6
      AVM=AM/FTO
      PF=P0-DELP
      F1N=F10
      F2N=F20
      F3N=F30
      F4N=F40
      I=1
      IF(II-2) 5,6,6
    5 DI(I)=DIAM(TAV,F10,F20,F30,F40,RWP,SP, DP,E,PAV,X1F(II),FTO,AM,
```

```
     1DELP)
      GO TO 7
6     Z=II-1
      DI(I)=DII(Z)
7     GO=4.*AM/(3.1416*DI(I)**2)
      CTV=3.1416*DI(I)**2/4.*AL*(1.-E)
      X1N=X10
      N=1
      TN=T0+460.
      PN(I)=P0
10    FOMP=PN(I)
      FOMT=TN
      FOMX1=X1N
      TN=FOMT+DELT
      TTN=TN
      UD=0.
      DO 22 W=1,6
22    HIN(W)=A(W)*(FOMT-TST)+B(W)/2.*(FOMT**2-TST**2)+C(W)/3.*
     1(FOMT**3-TST**3)+D(W)/4.*(FOMT**4-TST**4)
      QF0=-17697.5
      UE=0.
25    A1=(150.*(1.-E)*VC/(DP*G0)+1.75)*(G0**2*AL*(1.-E)*1544.*TN)/(GC*
     1DP*E**3*144.*144.*AVM)
      PN(I)=SQRT(FOMP**2-2.*A1)
      CALL RATE
      F1N=F10-FC
      F2N=F20-FC
      F3N=F30+FC
      F4N=F40+FC
      F5N=F50
      F6N=F60
43    DO 45 L=1,6
45    HFN(L)=A(L)*(TTN-FOMT)+B(L)/2.*(TTN**2-FOMT**2)+C(L)/3.*
     1(TTN**3-FOMT**3)+D(L)/4.*(TTN**4-FOMT**4)
      DO 50 M=1,6
50    CPMF(M)=HFN(M)/(TTN-FOMT)
      FD=F10*(X1N-FOMX1)
      QDF=FD*(-HIN(1)-HIN(2)+HIN(3)+HIN(4)+QF0)
      QIC=F1N*CPMF(1)+F2N*CPMF(2)+F3N*CPMF(3)+F4N*CPMF(4)+F5N*CPMF(5)+
     1F6N*CPMF(6)
      TTN=FOMT-QDF/QIC
      IF(ABS(TTN-UD) .LE. EPS2) GO TO 60
      UD=TTN
      GO TO 43
60    IF(ABS(TN-TTN) .LE. EPS3) GO TO 65
      TN=TTN
      UE=X1N
      GO TO 25
65    IF(ABS(X1N-UE) .LE. EPS4) GO TO 70
      UE=X1N
      TN=TTN
      GO TO 25
70    IF(X1N .GT. X1F(II)) GO TO 80
      N=N+1
      GO TO 10
80    IF(ABS(PN(I)-PF)-EPS1) 180,180,110
110   IF(PN(I)-PF) 120,180,130
120   IF(I .GT. 1) GO TO 150
      I=2
      DI(I)=DI(1)+0.5
      GO TO 7
130   IF(I .GT. 1) GO TO 150
      I=2
      DI(I)=DI(1)-0.5
```

```
      GO TO 7
  150 I=I+1
      J=I-1
      K=J-1
      DI(I)=DI(J)+(PF-PN(J))/(PN(J)-PN(K))*(DI(J)-DI(K))
      GO TO 7
  180 TF=TN-460.
      Y1N=F1N/FTO
      Y2N=F2N/FTO
      Y3N=F3N/FTO
      Y4N=F4N/FTO
      Y5N=F5N/FTO
      Y6N=F6N/FTO
      WRITE(6,1867) TO,PO,TF,PN(I),Y1N,Y2N,Y3N,Y4N,Y5N,Y6N
      DII(II)=DI(I)
      TOL(II)=AL*FLOAT(N)
      TH(II)=PO*12.*DII(II)/(2.*(S*EF-0.6*PO))+0.25
      ODI=DII(II)+TH(II)/6.
      FBD=16.15*DII(II)/12.
      RCMV=3.1416/4.*(TOL(II)*(ODI**2-DII(II)**2)+FBD**2*TH(II)/6.)
      RCMW=RWM*RCMV
      FN=1.
      CALL COST
      IF(II .GT. 1) GO TO 210
  205 II=II+1
      IF(II .GT. 5) GO TO 360
      GO TO 3
  210 JJ=II-1
      IF(ANTOTC(JJ)-ANTOTC(II)) 240,240,205
  240 WRITE(6,1880)
      DO 245 MM=1,II
  245 WRITE(6,1900) DII(MM),TOL(MM),TH(MM),X1F(MM),RCTC(MM),CTC(MM),
     1TRC(MM),CVLC(MM),STC(MM),BCOS(MM),OPCOS(MM),FINV(MM),WCAP(MM),
     2RETA(MM),FITA(MM),REVA(MM),ANTOTC(MM)
      KK=JJ+1
      AN(JJ)=1.
  315 AN(KK)=1.+FLOAT(KK-JJ)
      FN=AN(KK)
      DII(KK)=DII(JJ)/SQRT(AN(KK))
      CTV=3.1416*DII(KK)**2/4.*AL*(1.-E)
      TOL(KK)=TOL(JJ)
      STSP(KK)=STSP(JJ)
      TH(KK)=PO*12.*DII(KK)/(2.*(S*EF-0.6*PO))+0.25
      ODI=DII(KK)+TH(KK)/6.
      FBD=16.15*DII(KK)/12.
      RCMV=3.1416/4.*(TOL(KK)*(ODI**2-DII(KK)**2)+FBD**2*TH(KK)/6.)
      RCMW=RWM*RCMV
      II=KK
      CALL COST
      LL=KK-1
      IF(ANTOTC(LL)-ANTOTC(KK)) 340,340,320
  320 KK=KK+1
      GO TO 315
  340 WRITE(6,1980)
      DO 350 NN=JJ,KK
  350 WRITE(6,2000) AN(NN),DII(NN),TH(NN),RCTC(NN),CTC(NN),TRC(NN),
     1CVLC(NN),STC(NN),BCOS(NN),OPCOS(NN),FINV(NN),WCAP(NN),RETA(NN),
     2FITA(NN),REVA(NN),ANTOTC(NN)
  360 GO TO 2
      END
$IBFTC F1
      FUNCTION DIAM(T,F1,F2,F3,F4,RW,S,DP,E,P,X,FT,AM,DEP)
      TK=(T+460.)/1.8
      EK=EXP(8240./(T+460.)-4.33)
```

```
      A=F1**2*(EK-1.)
      B=F1*(EK*(F1+F2)+F3+F4)
      C=EK*F1*F2-F3*F4
      XE=(B-SQRT(B**2-4.*A*C))/(2.*A)
      RKS=0.398*EXP(-27300./(1.987*TK))
      RKV1=RW*S*82.06*TK*RKS
      DE1=0.043*(TK/673.)**1.5
      TLM=30.48*DP/2.*SQRT(RKV1/DE1)
      C1=EXP(TLM)+EXP(-TLM)
      C2=EXP(TLM)-EXP(-TLM)
      RKA1=273./TK*3600.*RKV1*3./TLM*(C1/C2-1./TLM)*(1.-E)
      RK0=RKA1*((P/14.7)**0.35-1./TLM)/(1.-1./TLM)
      SV=-RK0/ALOG(1.-X/XE)
      CC=0.174E-03
      D=FT**2/SV
      F=AM/DEP
      G=CC*D*F*(T+460.)/P
      DIAM=G**(1./6.)
      RETURN
      END
$IBFTC P1
      SUBROUTINE RATE
      COMMON CTV
      COMMON /S1/ TN,PN(20),F1N,F2N,F3N,F4N,F10,FTO,FOMX1, DP,RWP,SP,
     1E,RTN,X1N,FC,I
      TK=TN/1.8
      RKS=0.398*EXP(-27300./(1.987*TK))
      RKV1=RWP*SP*82.06*TK*RKS
      DE1=0.043*(TK/673.)**1.5
      TLM=30.48*DP/2.*SQRT(RKV1/DE1)
      B1=EXP(TLM)+EXP(-TLM)
      B2=EXP(TLM)-EXP(-TLM)
      EFF=3./TLM*(B1/B2-1./TLM)
      RKA1=273./TK*3600.*RKV1*EFF*(1.-E)
      RKAP=RKA1*((PN(I)/14.7)**0.35-1./TLM)/(1.-1./TLM)
      SV=359.*FTO/CTV
      RKOT=RKAP/SV
      EK=EXP(8240./TN-4.33)
      A=F1N**2*(EK-1.)
      B=F1N*(EK*(F1N+F2N)+F3N+F4N)
      C=EK*F1N*F2N-F3N*F4N
      XE=(B-SQRT(B**2-4.*A*C))/(2.*A)
      X1=XE*(1.-EXP(-RKOT))
      RTN=F1N*X1/CTV
      X1N=FOMX1+F1N*X1/F10
      FC=F10*X1N
      RETURN
      END
$IBFTC P2
      SUBROUTINE COST
      COMMON CTV
      COMMON /S2/ DII(30),RCMW,TOL(30),AL,FN,STSP(30),STC(30),CTC(30),
     1ANTOTC(30),RCTC(30),TRC(30),CVLC(30),BCOS(30),II,OPCOS(30),
     2FINV(30),WCAP(30),RETA(30),FITA(30),REVA(30),OPL,BPCR,SF,DEBT,
     3RAT,TAX,XINT
      RAWM=0.
      RCTC(II)=RCMW*0.5*FN*3.
      CTC(II)=CTV*TOL(II)/AL*20.*FN
      TRN=AINT(TOL(II)/3.3)
      TRC(II)=TRN*0.216*(DII(II)+5.)**3.13*FN*3.
      CVLC(II)=8000.*(FN+1.)
      BCOS(II)=RCTC(II)+TRC(II)+CVLC(II)
```

```
      COH=BCOS(II)*.0773
      EINT=XINT*(COH+BCOS(II))
      FINV(II)=BCOS(II)+COH+EINT
      AMNT=.03*BCOS(II)
      SUP=AMNT*0.15
      SPRV=0.1*OPL
      PYR=(OPL+SPRV)*0.1
      PLT=(OPL+SPRV+AMNT+SUP)*0.5
      DEP=FINV(II)*0.05
      TI=FINV(II)*0.03
      ODMF=SF*ODM
      BPCRF=SF*BPCR
      PRST=ODMF+OPL+AMNT+SUP+SPRV+PYR+PLT+DEP+TI
      CONT=PRST*0.02
      OPCOS(II)=PRST+CONT-BPCRF
      WCAP(II)=0.
      WOCAP=0.
      VTRY=ODM/12.
      ITEST=10
      J=0
12    DFINV=FINV(II)
      DCAP=(FINV(II)+WCAP(II))*DEBT
      DRT=DCAP*0.05
      DCAP=DCAP+DRT
      REVA(II)=0.
      FITA(II)=0.
      RETA(II)=0.
      AINTA=0.
      DO 10 I=1,20
3     DFINV=DFINV-0.05*FINV(II)
      RET=(DFINV+WCAP(II))*RAT
      DCAP=DCAP-DRT
      AAINT=DCAP*XINT
      FIT=(RET-AAINT)*TAX/(1.-TAX)-6.50
      REV=RET+FIT+OPCOS(II)
      REVA(II)=REVA(II)+REV
      IF(ITEST) 10,11,10
11    RETA(II)=RETA(II)+RET
      FITA(II)=FITA(II)+FIT
      AINTA=AINTA+AAINT
10    CONTINUE
      REVA(II)=REVA(II)/20.
      IF(ITEST) 14,13,14
13    RETA(II)=RETA(II)/20.
      FITA(II)=FITA(II)/20.
      AINTA=AINTA/20.
      ORAWM=RAWM/12.
      OODM=ODM/12.
      ANTOTC(II)=REVA(II)+STC(II)
      RETURN
14    AREC=REVA(II)/(12.*SF)
      WCAP(II)=VTRY+AREC
      ITEST=(WCAP(II)-WOCAP)/10.
      WOCAP=WCAP(II)
      GO TO 12
      END
$ENTRY
    28500.          0.        0.95        0.65        0.07        0.50        0.05
      0.2         2.2          0.4       537.0   0.240E 06   0.175E 05   0.833E-0
      0.3         0.1          0.1        0.01          0.         0.8  0.2657E-01
   0.6726E 01    0.4001E-03    0.1283E-05   -0.5307E-09
   0.7700E 01    0.4594E-03    0.2521E-05   -0.8587E-09
   0.6952E 01   -0.4576E-03    0.9563E-06   -0.2079E-09
   0.5316E 01    0.1429E-01   -0.8362E-05    0.1784E-08
```

```
     0.4750E 01     0.1200E-01     0.3030E-05    -0.2630E-08
     0.6903E 01    -0.3753E-03     0.1930E-05    -0.6861E-09                    B.3-16
     28.010    18.016     2.016     44.010     16.040     28.020
C      INPUT DATA FOR CASE 1
      9209.   19155.8   17817.4   11567.3   19721.    716.3     1.0     0.3
      0.892     0.887     0.882     0.877     0.872
     1100.      600.     1095.      690.      10.     0.0565
      0.878     0.873     0.868     0.863     0.858
     1100.      650.     1095.      740.      10.     0.0589
      0.865     0.860     0.855     0.850     0.845
     1100.      700.     1095.      790.      10.     0.0609
      0.837     0.832     0.827     0.822     0.817
     1100.      750.     1095.      830.      10.     0.0630
C      INPUT DATA FOR CASE 2
   20932.3   30692.5   54585.1    8447.3    8831.2    371.6     1.2   0.116
      0.890     0.885     0.88      0.875     0.870
      380.      600.      375.      730.      10.     0.0594
      0.848     0.843     0.838     0.833     0.828
      0.873     0.868     0.863     0.858     0.853
      380.      650.      375.      780.      10.     0.0614
      380.      700.      375.      820.      10.     0.0630
      0.828     0.823     0.818     0.813     0.808
      380.      740.      375.      850.      10.     0.0642
C      INPUT DATA FOR CASE 3
  31850.6   11767.5   19220.3   12002.9   14591.7    784.5     1.6    0.61
      0.911     0.906     0.901     0.896     0.891
     1050.      550.     1045.      750.      10.     0.0611
      0.896     0.891     0.886     0.881     0.876
     1050.      600.     1045.      800.      10.     0.0636
      0.883     0.878     0.873     0.868     0.863
     1050.      650.     1045.      850.      10.     0.0658
$IBSYS
```

TABLE B.3-2 PROGRAM SYMBOLS AND EXPLANATIONS FOR HEAT EXCHANGERS*

Program Symbols	Explanations	Mathematical Symbols
A1, A2	Heat transfer area for heating zone and vaporization zone, respectively	A_1, A_2
AL	Length of heat exchanger	L_H
ANT	Number of tubes in heat exchanger	
ASS	Flow area in shell side	
ATS	Flow area per tube	
ATTS	Total flow area per pass in tube side	
B	Baffle spacing	B'
BH	Brake horse power	B_p
C	Clearance between tubes	C'
COOL	Cooling water cost	
CPG	Heat capacity of gases	C_{pG}
CPW	Heat capacity of water	C_{pw}
DE	Equivalent diameter for heat transfer	D_e
PLPR	Return pressure drop	Δp_r
PLPS	Shell-side pressure drop	Δp_s
PLPT	Tube pressure drop	Δp_t
PLPTT	Total tube-side pressure drop	Δp_T
DTI	Inside diameter of tube	
DTMN1	Log-mean temperature difference in heating zone	
DTMN2	Log-mean temperature difference in vaporization zone	
DTO	Outside diameter of tube	

* Refer to Table B.3-1 for symbols related to costs.

TABLE B.3-2 (Cont.)

Program Symbols	Explanations	Mathematical Symbols
ELEC	Electricity cost	
F	Number of heat exchangers	
FS	Friction factor for shell side	
FTT	Friction factor for tube side	
GS	Shell side mass velocity	G_s
GT	Tube side mass velocity	G_i
HCOST	Heat exchanger cost	E_H
HI	Inside film heat transfer coefficient	h_i
HO	Outside film heat transfer coefficient	h_o
PCOST	Pump cost	
PRS	Prandtl number for shell side	
PRT	Prandtl number for tube side	
PT	Tube pitch	P_T
Q	Heat duty of heat exchanger	Q
RATE	Rate of return - on - rate base	
RD	Combined dirt factor	Rd
RES	Reynolds number for shell side	
RET	Reynolds number for tube side	
RMDA	Latent heat of water	λ
RWG	Density of gas	ρ_G
RWW	Density of water	ρ_W
S	Specific gravity	s
SHM	Shale mining cost	
SID	Inside diameter of shell	

TABLE B .3-2 (Cont.)

Program Symbols	Explanations	Mathematical Symbols
T1, T2	Temperature of tube side at inlet and outlet, respectively	t_1 , t_2
TT1, TT2	Temperature of shell side at outlet and inlet, respectively	T_1 , T_2
TCG	Thermal conductivity of gases	
TCW	Thermal conductivity of water	
TN	Number of passes	
TTM	Shell side gas temperature at which vaporization of water starts to take place	Tm
U1, U2	Overall heat transfer coefficients in heating zone, and vaporization zone, respectively	U_1, U_2
VCG	Viscosity of gases	μ_G
VCW	Viscosity of water	μ_W
VT	Linear velocity of fluid in tube side	
WS	Mass flow rate of gases per heat exchanger	
WSS	Total mass flow rate of gases	
WT	Flow rate of cooling water	

TABLE C-4 COMPUTER PROGRAM
FOR HEAT EXCHANGERS

```
100   FORMAT(11F7.3)
150   FORMAT(7F11.7)
200   FORMAT(6F10.4,E12.5)
250   FORMAT(3X,F10.1,4F10.3,3E15.7)
300   FORMAT(5X,9E13.6)
350   FORMAT(5X,4E14.6)
400   FORMAT(9F8.4)
500   FORMAT(1X,9E13.6/)
      SID=39./12.
      B=26./12.
      READ(5,400) OPL,RAWM,ODM,SHM,SF,DEBT,RATE,TAX,XINT
      READ(5,100) VCW,TCW,DTI,DTO,PT,T1,T2,CPW,RMDA,RWW,RD
      READ(5,150) F,TN,ANT,X1,Y1,X2,Y2
2     READ(5,200) VCG,TCG,CPG,RWG,TT1,TT2,WSS
      ATS=3.1416/4.*DTI**2/144.
      C=(PT-DTO)/12.
      DE=4.*(0.86*PT**2-3.1416*DTO**2/4.)/(3.1416*DTO*12.)
6     WS=WSS/F
      Q=WS*CPG*(TT2-TT1)
      WT=Q/(CPW*(T2-T1)+0.5*RMDA)
20    ASS=12.*SID*C*B/PT
      GS=WS/ASS
50    ATTS=ANT*ATS/TN
      GT=WT/ATTS
      VT=GT/(3600.*RWW)
      RET=(DTI/12.)*GT/VCW
      RES=DE*GS/VCG
      PRT=CPW*VCW/TCW
      PRS=CPG*VCG/TCG
      HO=0.36*(TCG/DE)*PRS**0.333*RES**0.55
      HI=0.027*(12.*TCW/DTI)*PRT**0.333*RET**0.8
      HI=HI*DTI/DTO
      U1=HO*HI/(HO+HI)
      U2=HO*1500./(1500.+HO)
      U1=U1/(1.+RD*U1)
      U2=U2/(1.+RD*U2)
      TTM=TT1+WT*CPW*(T2-T1)/(WS*CPG)
      DTMN1=((TTM-T2)-(TT1-T1))/(ALOG((TTM-T2)/(TT1-T1)))
      DTMN2=((TT2-T2)-(TTM-T2))/(ALOG((TT2-T2)/(TTM-T2)))
      A1=WT*CPW*(T2-T1)/(U1*DTMN1)
      A2=0.5*RMDA*WT/(U2*DTMN2)
      AT=A1+A2
      AL=12.*AT/(3.1416*DTO*ANT)
      FS=X1*RES**Y1
      S=RWG/62.43
      DLPS=FS*GS**2*SID*AL/(0.522E 11 *DE*S*B)
      FTT=X2*RET**Y2
      DLPT=FTT*GT**2*AL*TN/(0.522E 11 *DTI/12.)
      DLPR=4.*TN*VT**2*62.5/(2.*32.17*144.)
      DLPTT=DLPT+DLPR
      IF(DLPS .LE. 3.) GO TO 60
      F=F+1.
      GO TO 6
60    WRITE(6,250) F,SID,B,VT,AL,GS,ANT,RES
      WRITE(6,300) HI,HO,U1,U2,DLPS,DLPT,DLPR,DLPTT,AT
      HCOST=1.20*3.0*(850.*(AT*F/50.)**0.562)
      BH=WT/60.*7.481/62.43*3.*144./(246800.*0.8)
      PCOST=684.*BH**0.467*F
      BCOS=HCOST+PCOST
      ELEC=BH*0.7457*0.011*F*8200.
      BPCR=0.3*WT/1000.*0.5*F*8200.
      COOL=0.5*WT*F/62.43*7.481/1000.*0.12*8200.
```

```
      COH=BCOS*0.0773
      EINT=XINT*(COH+BCOS)
      FINV=BCOS+COH+EINT
      AMNT=.03*(BCOS-SHM)
      SUP=AMNT*0.15
      SPRV=0.10*OPL
      PYR=(OPL+SPRV)*0.10
      PLT=(OPL+SPRV+AMNT+SUP)*0.5
      DEP=FINV*0.05
      TI=FINV*0.03
      RAWMF=SF*RAWM
      ODMF=SF*ODM
      BPCRF=SF*BPCR
      PRST=RAWMF+ODMF+OPL+AMNT+SUP+SPRV+PYR+PLT+DEP+TI
      CONT=PRST*0.02
      OPCOS=PRST+CONT+ELEC+COOL
      WCAP=0.
      WOCAP=0.
      VTRY=(RAWM+ODM)/12.0
      ITEST=10
      J=0
   12 DFINV=FINV
      DCAP=(FINV+WCAP)*DEBT
      DRT=DCAP*0.05
      DCAP=DCAP+DRT
      REVA=0.
      FITA=0.
      RETA=0.
      AINTA=0.
      DO 10 I= 1,20
    3 DFINV=DFINV-0.05*FINV
      RET=(DFINV+WCAP)*RATE
      DCAP=DCAP-DRT
      AINT=DCAP*XINT
      FIT=(RET-AINT)*TAX/(1.-TAX)-6.50
      REV=RET+FIT+OPCOS
      REVA=REVA+REV
      IF(ITEST)10,11,10
   11 RETA=RETA+RET
      FITA=FITA+FIT
      AINTA=AINTA+AINT
   10 CONTINUE
      REVA=REVA/20.
      IF(ITEST)14,13,14
   13 RETA=RETA/20.
      FITA=FITA/20.
      AINTA=AINTA/20.
      ORAWM=RAWM/12.
      OODM=ODM/12.
      WRITE(6,500) HCOST,PCOST,ELEC,COOL,BPCRF,OPCOS,RETA,FITA,REVA
      GO TO 2
   14 AREC=REVA/(12.*SF)
      WCAP=VTRY+AREC
      ITEST=(WCAP-WOCAP)/10.
      WOCAP=WCAP
      GO TO 12
      END
$ENTRY
      0.       0.       0.       0.     0.95     0.65     0.07     0.50     0.05
   0.37  0.379    0.62    0.75       1.    285.    456.    1.07   767.4   55.05  0.0
         1.           4.       1128.     0.01185     -0.1876  0.0031164    -0.264
C      INPUT DATA FOR CASE1
```

```
0.0661      0.060      0.556      1.487      765.3      1000.  0.14844E 07
0.0669      0.0608     0.558       1.41      837.0      1000.  0.14844E 07
  FOR PRODUCT GAS COOLER
0.0529      0.0447     0.599       1.84       460.      726.8  0.17299E 07
0.0540      0.0472     0.578      1.741       460.      787.7  0.17368E 07
 .0554      0.0470     0.600       1.74       460.      847.7  0.17437E 07
  INPUT DATA FOR CASE 2
  FOR WASTE HEAT BOILER
0.0757      0.0891     0.625      0.315      709.9      1600.  0.17731E 07
0.0776       0.091     0.627      0.310       793.      1600.  0.17731E 07
0.0789      0.0929     0.630      0.299      875.8      1600.  0.17731E 07
0.0810      0.0939     0.635      0.296      941.8      1600.  0.17731E 07
  FOR PRODUCT GAS COOLER
0.0531      0.0607     0.591      0.493       460.      723.7  0.19647E 07
0.0550      0.0620     0.593      0.475       460.      798.9  0.19694E 07
0.0560      0.0638     0.595      0.459       460.      873.3  0.19742E 07
0.0574      0.0653     0.588      0.446       460.      932.5  0.19792E 07
  INPUT DATA FOR CASE 3
  FOR WASTE HEAT BOILER
0.0810      0.0640     0.473       1.32      549.3      1700.  0.19272E 07
0.0831       0.066     0.471       1.26      661.1      1700.  0.19272E 07
0.0857      0.0680     0.470       1.26      771.1      1700.  0.19272E 07
  FOR PRODUCT GAS COOLER
0.0547      0.0438     0.571       1.80       460.      769.1  0.32993E 07
0.0580      0.0460     0.571       1.77       460.      823.7  .33228E 07
0.0572      0.0455     0.572      1.565       460.      878.1  0.33345E 07
:BSYS
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B.4 Gas Purification

TABLE B.4-1 PROGRAM SYMBOLS AND EXPLANATIONS FOR OPTIMIZATION OF ABSORBERS AND REGENERATORS

Program Symbols	Explanations
A	Contact Area Per Unit Volume
AG	Substituted Quantity Used in Calculation of T_G
AH	Heat Transfer Area
AH4	Heat Transfer Area for Solution Heat Exchanger
AH5	Heat Transfer Area for Heat Exchanger No. 5
AMW	Average Molecular Weight of Liquid
ANO	Number of Absorbers
B	Brake Horsepower of Water Pump for Solution Cooler
BPH	Brake Horsepower of Pump for Feed Gas Cooler
CA	Cost of Absorber
CMEA	Monoethanol-Amine Cost
CPB	Substitute Quantity
CPCA	Heat Capacity of CO_2 in Absorber
CPCR	Heat Capacity of CO_2 in Regenerator
CPK	Packing Cost
CPN	Heat Capacity of Inert Gas in Absorber
CP1	Heat Capacity of Feed Gas in Reboiler
CP2	Heat Capacity of Feed Gas Cooler
CR	Cost of Regenerator
CS	Cost of Steam

TABLE B.4-1 (Cont.)

Program Symbol	Explanations
CTMP	Total Cost of Work Exchanger
CV	Valve Cost
DL	Diffusivity of CO_2 in Solution
DTA	Absorber Diameter
DTC	Temperature Difference of Coolants in Heat Exchanger
DTH	Temperature Difference for Feed Gas Cooler
DWC	Water Condensed from Gas in Feed Gas Cooler
DWT	Water Removed (water in feed gas; water in gas entering absorber)
EH	Cost of Feed Gas Cooler
EHR	Cost of Reboiler
EH4	Cost of Solution Heat Exchanger
EH5	Cost of Solution Cooler
ELCH	Cost of Electricity for Pump
ELCT	Cost of Electricity for Work Exchanger
ELC5	Cost of Electricity for Pump
EPH	Cost of Pump
EP5	Cost of Water Pump
G	Gas Flow Rate at Bottom of Absorber
G1	Feed Gas Flow Rate
GC	Molar Flow Rate of CO_2 in Regenerator

TABLE B.4-1 (Cont.)

Program Symbols	Explanations
GCO_2	Molar Flow Rate of CO_2 in Feed Gas
GH	Molar Flow Rate of H_2S in Regenerator
GH_2S	Molar Flow Rate of H_2S in Feed Gas
GKA	Gas-Side Mass Transfer Coefficient
GKAC	Over-All Mass Transfer Coefficient for CO_2
GKAH	Over-All Mass Transfer Coefficient for H_2S
GN	Inert Gas Flow Rate
GNO	Inert Gas Flow Rate Per Cross-Sectional Area
GRAIN	Grain
GW	Molar Flow Rate of H_2O in Feed Gas
H	Solubility of CO_2 in Water
HHA	Heat Transfer Coefficient in Absorber
HRC	Heat of Reaction
HSG	H_2S in Gas
HSL	H_2S in Liquid in Absorber
HTA	Total Height of Absorber
HTR	Total Height of Regenerator
I	Number of Assigned Values for Variable
IC	Case Number, 1,2,3
KAM	Reaction Rate Constant
KL	Liquid-Side Mass Transfer Coefficient
L	Liquid Flow Rate

TABLE B.4-1 (Cont.)

Program Symbols	Explanations
LC	Amount of Water Condesned in Regenerator
LO	Liquid Flow Rate Per Cross Sectional Area
LR	Reflux Rate
MORTOR	Motor Cost
N	Cell Number
NP	Number of Pumps in Calculating Cost of Work Exchanger
PA	Absorber Pressure (atm) or Regenerator Pressure (atm)
PCE	Equilibrium Pressure of CO_2
PCW	Total Pressure of H_2O, CO_2, and H_2S
PH	Equilibrium Pressure of H_2S for $x < 0.15$
PHA	Partial Pressure of H_2S in Absorber
PHE	Equilibrium Pressure of H_2S in Absorber
PR	Regenerator Pressure (atm)
PW	Equilibrium Pressure of H_2O
P2	Outlet Pressure of Work Exchanger (PSI)
QA	Heat Generated in Absorber by Absorption
QH	Heat Duty of Feed Gas Cooler
QR	Heat Duty of Reboiler
QS	Heat Supply from Steam
Q4	Solution Heat Exchanger Heat Duty
Q5	Heat Duty of Heat Exchanger No. 5
R	Rate of Absorption of CO_2

TABLE B.4-1 (Cont.)

Program Symbols	Explanations
RH	Rate of Absorption of H_2S
ROGA	Density of Gas in Absorber
ROL	Density of Liquid
SA	Total Cross-Sectional Area of Absorber
ST	Steam Rate at Bottom of Regenerator
T	Inlet Gas Temperature in Condenser
TAB	Temperature of Liquid at Bottom of Absorber
TAT	Temperature of Liquid at Top of Absorber
TB	Temperature of Liquid in Reboiler
TBN	Turbine Cost
TG	Temperature of Gas
TG1	Temperature of Gas at Bottom of Absorber
THA	Thickness of Absorber
THR	Thickness of Regenerator
TL	Temperature of Liquid
TR	Absolute Temperature in Rankin
TRB	Temperature of Liquid at Bottom of Regenerator
TRT	Temperature of Liquid at Top of Regenerator
T1	Feed Gas Temperature
T4	Temperature of Liquid Entering Flash Drum
T5	Temperature of Liquid Entering Solution Cooler
UWC	Untreated Water Cost

TABLE B.4-1 (Cont.)

Program Symbols	Explanations
UW5	Water Cost
UW5	Water Required for Solution Cooler
VIS	Viscosity of Liquid
WE	Additional Horsepower Needed for Work Exchanger
X	Mole Ratio of CO_2 to MEA in Liquid
XF	Mole Ratio of CO_2 to MEA in Liquid in Flash Drum
XH	Mole Ratio of H_2S to MEA in Liquid
XH1	Mole Ratio of H_2S to MEA in Liquid at Top of Absorber
XH2	Mole Ratio of H_2S to MEA in Liquid at Bottom of Absorber
XRB	Mole Ratio of CO_2 to MEA in Liquid at Bottom of Regenerator
XRT	Mole Ratio of CO_2 to MEA in Liquid at Top of Regenerator
X1	Mole Ratio of CO_2 to MEA in Liquid at Top of Absorber
X2	Mole Ratio of CO_2 to MEA in Liquid at Bottom of Absorber
Y	Mole Fraction of CO_2
YC	Number of Moles of CO_2 per Mole of Inert Gas
YC1	Mole Fraction of CO_2 at Top of Absorber
YH	Mole Fraction of H_2S
YW	Mole Fraction of Water in Feed Gas
YWA	Mole Fraction of Water at Bottom of Absorber
Z	Mole Fraction of Amine in Original Solution

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C     REDUCE CO2 TO OPTIMUM CONCENTRATION BY HOT POTASH PROCESS
      REAL KGA,KL,K2,L,LO,MWL,MWT,M,MG,MF,ML,MUL,MUW,NR,MOTOR,LF,LC,LR
      COMMON DT,GS,GO,GR,A,KGA,L,LO,MF,NO,XRT,TL,XT,XB,Y1,YS,Z,G,X,AKG,
     1ASA,LC,LF,LR,PR
C     OPTIMIZATION OF AN ADIABATIC GAS PURIFIER SYSTEM
      YS=0.4
      Z=0.079872
      Y2=0.03/(1.-0.03)
      DATA YL,HR,HS,CPL,CPG,CPS,CPC,H,HHA,HHR/0.08,11490.,5375.,25.042,
     18.09,8.1,9.3,0.25,72.3,346./
      DO 91 KC=1,3
      READ (5,2001) G1,YW,T1,P,GCO2,GH2S,CP,TC,X1,X2,STM,TGB,AKG,PD,IC
 2001 FORMAT(7F10.2/7F10.4,I1)
      IF(IC.EQ.1) Y2=0.0036/(1.-0.0036)
      IF(IC.EQ.2) Y2=0.008/(1.-0.008)
      IF(IC.EQ.3) Y2=0.011/(1.-0.010)
      PRINT 2002, IC
 2002 FORMAT(1H1,5X,5HCASE ,I1)
      PRINT 2003, G1,YW,T1,P,GCO2,GH2S,CP,TC,Y2,X1,X2,STM,TGB,AKG,IC
 2003 FORMAT(1H0,5X,3HG1=F10.1,3X,3HYW=F6.4,3X,3HT1=F6.2,3X,2HP=F7.1,
     23X,5HGCO2=F10.2/4X,5HGH2S=F9.2,3X,3HCP=F7.4,3X,3HTC=F7.2,3X,3HY2=F
     27.4,3X,3HX1=F6.4/4X,3HX2=F6.4,3X,4HSTM=F10.1,3X,4HTGB=F6.2,3X,
     34HAKG=F7.4,3X,3HIC=I1)
      DO 11 I=1,1
      XT=X1
      XB=X2
      GS=STM
      TG=TGB
      TG1=TG
      PR=PD
C     FRONT HEAT EXCHANGER
      X=XT
      TL=270.
   31 PW=EXP(-8932.32/(460.+TL)+12.9686+0.5174*(XT-1./3.))
      E15=EXP(7.1E-3*(TL-32.))
      S=1000.*(1.+YS)/(18.+(120.+44.*X)*YL)/(2380.*E15-1600.)
      E16=EXP(6.9*YL-TL/150.)
      PCE=X**2/(1.-X)/S*YS/(1.-YS)*0.0454/E16*0.06805
      PCW=PCE+PW
      IF(ABS(PR-PCW).LE.0.01) GO TO 32
      IF(PR.GT.PCW) TL=TL+0.3
      IF(PR.LT.PCW) TL=TL-0.3
      GO TO 31
   32 TRB=TL
      PRINT 6001, PR,PW,PCE,TL,PCW
 6001 FORMAT(    5X,3HPR=F8.3,3X,3HPW=F8.3,3X,4HPCE=F8.3,3X,3HTL=F8.3,
     15X,4HPCW=F10.4)
      TS=TRB
      TG=TRB+15.
      DW=G1*(YW-PV(TG)/P)/(1.-PV(TG)/P)
      Q=(T1-TG)*G1*CP+18.*DW*HV(TG)
      TE=(TS+TC)/2.
      W=Q/(TS-TE+0.5*HV(TS))
      STEAM=W/2./18.
      TMR=TS+30.
    1 TMI=T1-(0.5*HV(TS)*W-18.*(YW*P-PV(TMR))*HV(TMR)*G1/P)/(G1*CP)
      IF(ABS(TMI-TMR).LE.1.0) GO TO 2
      IF(TMI.GT.TMR) TMR=TMR+0.25
      IF(TMI.LT.TMR) TMR=TMR-0.25
      GO TO 1
    2 DTM1=((TMI-TS)-(TG-TE))/ALOG((TMI-TS)/(TG-TE))
```

```
      DTM2=((T1-TS)-(TMI-TS))/ALOG((T1-TS)/(TMI-TS))
      AH=W*((TS-TE)/DTM1+0.5*HV(TS)/DTM2)/100.
      EH=1.2*3.*850.*(AH/50.)**0.562
      BP=0.5*W*7.481*(PV(TS)-14.7+3.)*144./(62.4*60.*0.8*246800.)
      EP=684.*BP**0.467
      EPH=EP
      ELCH=8500.*BP*0.7457*0.011/0.8
      G=G1-DW
      GINT=G-GCO2-GH2S
      Y1=GCO2/GINT
      YH1=GH2S/GINT
      YCO2=GCO2/G
      PA=P/14.7
C       SIMULATION FOR THE ABSORBER
      L=(Y1-Y2)*GINT/(Z*(XB-XT))
C       ESTIMATE TAB
      F=L*Z
      FX=F*(XB-XT)
      TAT=TRB
      QA=FX*HR-GH2S*HS*0.8
      TAB=TAT+ GINT*(CPG+Y1*CPC)*(TG-TAT)+QA)/(L*(CPL+Z*XB*CPC))
      PRINT 100, Q,STEAM,EH,EP,ELCH,G,GINT,Y1,YCO2,YH1,PR,TRB,L,TAT,QA,
     1TAB
  100 FORMAT(1H0,15X,'HEAT EXCHANGER'/10X,2HQ=E13.7,4X,6HSTEAM=E13.7,4X,
     13HEH=E13.7/10X,3HEP=E13.7,4X,5HELCH=E13.7//15X,'GAS ENTERING ABSOR
     2BER'/10X,2HG=E13.7,4X,5HGINT=E13.7,4X,3HY1=F9.5,4X,5HYCO2=F9.5,4X,
     34HYH1=F9.5/10X,3HPR=F8.3,3X,4HTRB=F8.3,3X,2HL=E13.6,3X,4HTAT=F8.3,
     33X,3HQA=E13.6,3X,4HTAB=F8.3)
      PRINT 102
  102 FORMAT(1H0,15X,'ABSORBER')
      TL=TAB
      CALL DIA(1)
      DTA=DT
      ANO=FLOAT(NO)
      AS=ASA
      PRINT 103
  103 FORMAT(1H0,2X,1HX,12X,1HY,12X,2HTL,11X,2HTG,11X,2HYH,11X,3HHSL,10X
     1,2HYC,11X,3HYHS,10X,3HHTA)
      N=1
      AKL=0.2968*(LO*30./3350.)**0.75*28./115.
      AKHS=1./(1./AKG+1./AKL)
      X=XB
      Y=Y1
      YC=Y1/(1.+Y1+YH1)
      YH=YH1
      YHS=YH1/(1.+YH1+Y1)
      HSL=0.
      XHS=0.001+GH2S/(L*Z)
      TL=TAB
      HTA=0.
      PRINT 104, X,Y,TL,TG,YH,HSL,YC ,YHS ,HTA
      H=0.5
      HAH=H*A*HHA
    5 N=N+1
      AN1=GO*CPG+GO*Y*CPC
      ALN1=LO*(CPL+Z*X*CPC)
      CALL FNCTNS(1)
      E15=EXP(7.1E-3*(TL-32.))
      S=1000.*(1.+YS)/(18.+(120.+44.*X)*YL)/(2380.*E15-1600.)
      E16=EXP(6.9*YL-TL/150.)
      PCE=X**2/(1.-X)/S*YS/(1.-YS)*0.0454/E16*0.06805
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      BB=0.5*(Y+KGA*H/GO*(PCE-PA)-1.-YH)
      CC=(Y+KGA*H*PCE/GO)*(1.+YH)
      Y=BB+SQRT(BB**2+CC)
      PC=Y/(1.+Y+YH)*PA
      PHE=(0.14+0.0015*TL)*XHS/0.0788/14.7
      B1=1.+Y
      B2=(AKHS*H*PHE)/GO
      B3=AKHS*H*PA/GO
      C1=(YH-B1-B3+B2)/2.
      C2=B1*YH+B1*B2
      YH=C1+SQRT(C1**2+C2)
      DNH=AKHS*H*(PA*YH/(1.+Y+YH)-PHE)
      XHS=XSH-DNH/(Z*LO)
      YHS=YH/(1.+Y+YH)
      HSL=HSL+DNH*AS
      NR=KGA*H*(PC-PCE)
      X=X-NR/(Z*LO)
      YC=Y/(1.+Y+YH)
      AN=GO*(CPG+Y*CPC)
      ALN=LO*(CPL+Z*X*CPC)
      TG=(AN1*TG*(ALN-HAH)+HAH*(ALN1*TL-NR*HR))/(AN*ALN-AN*HAH+ALN*HAH+
     1ALN*NR*CPC)
      TL=(ALN1*TL-NR*HR-(HAH+NR*CPC)*TG)/(ALN-HAH)
      HTA=H*FLOAT(N-1)
  104 FORMAT(1X,9E13.5)
  119 IF((PC-PCE).LE.0.00005) GO TO 11
      PRINT 104,X,Y,TL,TG,YH,HSL,YC,YHS,HTA
      IF(Y.LE.Y2) GO TO 6
      GO TO 5
    6 CONTINUE
      PRINT 103
      GCA=Y2*GINT
      GHA=GINT*YH
      GWA=(GINT+GHA+GCA)*PV(TAT)/(P-PV(TAT))
      GT=GCA+GHA+GINT-(G1*YW-DW)+GWA
      GRAIN=YHS/0.0000163
      DHS=GH2S-GHA
      PRINT 1009, GT,GCA,GHA,GWA,DHS,GRAIN
 1009 FORMAT(1H0,5X,3HGT=F10.2,5X,4HGCA=F7.2,5X,4HGHA=F6.2,5X,4HGWA=F7.2
     1,5X,4HDHS=F7.2,5X,6HGRAIN=F8.5)
C     SIMULATION FOR THE REGENERATOR
C     CALCULATE TRT AND XRT
      TL=258.
      X=0.51
   42 PW=EXP(-8932.32/(460.+TL)+12.9686+0.5174*(X -1./3.))
      E15=EXP(7.1E-3*(TL-32.))
      S=1000.*(1.+YS)/(18.+(120.+44.*X)*YL)/(2380.*E15-1600.)
      E16=EXP(6.9*YL-TL/150.)
      PCE=X**2/(1.-X)/S*YS/(1.-YS)*0.0454/E16*0.06805
      PCW=PCE+PW
      IF(ABS(PR-PCW).LE.0.01) GO TO 43
      IF(PR.GT.PCW) TL=TL+0.3
      IF(PR.LT.PCW) TL=TL-0.3
      GO TO 42
   43 CONTINUE
      GCF=L*Z*(XB-X)
      LF=PW/PCE*GCF
      TF =TAB-(GCF*HR+LF*14950.)/(L*(CPL+Z*XB*CPC))
      IF(ABS(TL-TF ).LE.1.) GO TO 45
      IF(TF .GT.TL) X=X-0.005
      IF(TF .LT.TL) X=X+0.005
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      GO TO 42
   45 CONTINUE
      XRT=X
      LC=(L*(CPL+Z*XT*CPC)*(TRB-TF )+L*Z*(XRT-XT)*HR+0.8*GH2S*HS-GS*CPS*
     1(TRB-TF ))/14950.
      PRINT 6002,TL,XRT,LF,LC,GS,TF
 6002 FORMAT(1H0,9X,3HTL=F8.4,5X,4HXRT=F8.4 ,5X,3HLF=F10.2,5X,3HLC=F10.3
     1,5X,3HGS=F10.3,5X,4HTF =F8.3)
      TRT=(TF*L*(CPL+Z*XRT*CPC+Z*XHRT*CPH)-1800.*(LF-LC))/(L*(CPL+Z*XRT
     1*CPC+Z*XHRT*CPH)+(LF-LC)*18.)
      PRINT 7001, GCF,LF,TRT,X
 7001 FORMAT(5X,4HGCF=F11.2,5X,3HLF=F13.2,5X,4HTRT=F8.2,5X,2HX=F8.3)
      PRINT 106
  106 FORMAT(1H0,15X,'REGENERATOR')
      TL=TRT
      CALL DIA(2)
      DTR=DT
      RNO=FLOAT(NO)
      RS=ASA
      H=1.
      PRINT 303
  303 FORMAT(1H0,2X,1HX,12X,2HYC,11X,2HTL,11X,2HGC,11X,2HDW,11X,2HGH,11X
     1,2HGT,11X,3HHTR)
      GT=GS
      YC=0.
      TL=TRB
      X=XT
      FO=F/RS
      DW=0.
      GC=0.
      GH=0.
      B8=LC/(XRT-XT)
      B9=(GH2S-GHA)/(XRT-XT)
      B10=(TRB-TRT)/(XRT-XT)
      N=1
      HTR=0.
      PRINT 204, X,YC,TL,GC,DW,GH,GT,HTR
    7 CALL FNCTNS(2)
  204 FORMAT(1X,8E13.5)
  219 E15=EXP(7.1E-3*(TL-32.))
      S=1000.*(1.+YS)/(18.+(120.+44.*X)*YL)/(2380.*E15-1600.)
      E16=EXP(6.9*YL-TL/150.)
      PCE=X**2/(1.-X)/S*YS/(1.-YS)*0.0454/E16*0.06805
      PC=YC*PR
      NR=KGA*H*(PCE-PC)
      X=X+NR/(Z*LO)
      TL=TRB-B10*(X-XT)
      DW=B8*(X-XT)
      GC=F*(X-XT)
      GH=B9*(X-XT)
      YC=GC/(GS-DW+GC+GH)
      HTR=H*FLOAT(N)
      IF((PCE-PC).LE.0.00005) GO TO 11
      PRINT 204, X, YC,TL,GC,DW,GH,GT,HTR
      IF(X.GE.XRT) GO TO 8
      N=N+1
      GO TO 7
    8 CONTINUE
      PRINT 303
C     COST TURBINE-MOTOR-PUMP
      X=XB
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```
      TL=TAB
      PW=EXP(-8932.32/(460.+TL)+12.9686+0.5174*(XB-1./3.))
      E15=EXP(7.1E-3*(TL-32.))
      S=1000.*(1.+YS)/(18.+(120.+44.*X)*YL)/(2380.*E15-1600.)
      E16=EXP(6.9*YL-TL/150.)
      PCE=X**2/(1.-X)/S*YS/(1.-YS)*0.0454/E16*0.06805
      P2=(PW+PCE)*14.7
      P3=PR*14.7
      DP=P-P3
      NP=1+IFIX(0.04043*L/2000.)
      CF=0.04043*L/FLOAT(NP)
      ROL=1.4 *62.428
      BP=CF*(DP*144.+ROL*HTA)/(0.8*246800.)
      PUMP=FLOAT(NP)*1.8*684.*(BP)**0.467
      TBN=PUMP
      WE=0.04043*L*(144.*(0.1*(P-P2)+P2-P3)+ROL*HTA)/(0.8*246800.)
      MOTOR=FLOAT(NP)*46.*(WE/FLOAT(NP))**0.955
      CTMP=TBN+MOTOR+PUMP
      ELCT=WE*0.7457*8760.*0.011
      PRINT 203, CTMP,ELCT,NP,PUMP,MOTOR,TBN,BP
  203 FORMAT(1H0,10X,18HTURBINE-MOTOR-PUMP/10X,5HCTMP=E11.5,5X,5HELCT=E1
     11.5,5X,3HNP=I3,5X,5HPUMP=E11.5/10X,6HMOTOR=E11.5,5X,4HTBN=E11.5,
     25X,3HBP=E11.5)
C     COST OF ABSORBER AND REGENERATOR
      THA=0.03639*DTA+1./48.
      HTA=HTA+5.
      CA=566.325*ANO*(((DTA+2.*THA)**2-DTA**2)*HTA+2.*THA*(1.346*DTA)**2
     1)
      THR=(5.06763/10.**4)*DTR+1./48.
      HTR=HTR+5.
      CR=566.325*RNO*(((DTR+2.*THR)**2-DTR**2)*HTR+2.*(1.346*DTR)**2*THR
     1)*(1.+(XB-XRT)/(XRT-XT))
C     VALVE COST
      CV=16000*(ANO+RNO)
      PRINT 244, THA,CA,THR,CR,CPK,CK2CO3,CV
  244 FORMAT(1H0,10X,20HABSORBER-REGENERATOR/10X,4HTHA=E10.5,5X,3HCA=E10
     1.5,5X,4HTHR=E10.5,5X,3HCR=E10.5/10X,4HCPK=E10.5,5X,7HCK2CO3=E10.5,
     25X,3HCV=E10.5)
C     K2CO3 COST
      CK2CO3=0.035*0.2*3.1416/4.*(DTA**2*HTA*ANO+DTR**2*HTR*RNO)*1.48*
     162.4*0.4+G/27855.*21700.
C     PACKING COST
      CPK=5.*3.142/4.*(DTA**2*HTA*ANO+DTR**2*HTR*RNO)*2.
C     STEAM COST
      IF(STEAM.GE.GS) CS=0.
      IF(STEAM.LT.GS) CS=(GS-STEAM)*.15*18./1000.*8760.
C     CONDENSER
      GSC=GS+LF-LC
      Q=GSC*14950.+(GSC*CPS+FX*CPC+(GH2S-GHA)*8.52)*(TRT-100.)
      DTC=((TRT-150.)-(100.-85.))/ALOG((TRT-150.)/(100.-85.))
      AC=Q/(200.*DTC)
      CW=Q/(150.-85.)
      TW=W/2.
      UW=CW-TW
      PRINT 310, Q,TW,UW,CK2CO3,CPK,CS
  310 FORMAT(1H0, 1X,2HQ=E10.5,5X,3HTW=E10.5,5X,3HUW=E10.5,5X,7HCK2CO3=
     1E13.6,5X,4HCPK=E13.6,5X,3HCS=E13.6)
      UWC =8760.*UW*(7.481/62.4)*0.05/1000.
      TWC =8760.*TW*(7.481/62.4)*0.12/1000.
      A1=TW*AC/CW
      A2=UW*AC/CW
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      EC1=1.2*3.*850.*(A1/50.)**0.562
      EC2=1.2*3.*850.*(A2/50.)**0.562
      BPC=CW*7.481*2.*144./(62.4*60.*0.8*246800.)
      BPC1=TW/CW*BPC
      BPC2=UW/CW*BPC
      EPC1=684.*(BPC1)**0.467
      EPC2=684.*(BPC2)**0.467
      ELCC=8760.*BPC*0.7457*0.011/0.8
      PRINT 300, EC1,EC2,EPC1,EPC2,ELCC,TWC,UWC
  300 FORMAT (1H0,9X,4HEC1=E10.5,5X,4HEC2=E10.5,5X,5HEPC1=E10.5,5X,5HEPC
     12=E10.5/9X,5HELCC=E10.5,5X,4HTWC=E10.5,6X,4HUWC=E10.5)
      BCOS=(EH+EPH+CTMP+CA+CR+CPK+CV+EC1+EC2+EPC1+EPC2)/1000.
      OPL=60.
      RAWM=0.
      ODM=(CK2CO3)/1000.
      UTC=(ELCT+ELCH+TWC+UWC+ELCC+CS)/1000.
      CALL COST(REVA,BCOS,ODM,OPL,UTC)
      PRINT 511
  511 FORMAT(1H0,5X,'$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$')
      PRINT 402,REVA,BCOS,OPL,ODM,UTC
  402 FORMAT(1H0,10X,10X,10HCOST IN $M/9X,4HREVA,10X,4HBCOS,10X,3HOPL,11
     1X,3HODM,11X,3HUTC/6X,5E14.5)
      PRINT 510,XT,XB,GS,TG1,TAB,TAT,TF,PR
  510 FORMAT(1H0, 1X,3HXT=F8.4,1X,3HXB=F8.4,1X,3HGS=F13.5,1X,4HTG1=F8.4,
     11X,4HTAB=F8.4,1X,4HTAT=F8.3,1X,3HTF=F8.3,1X,3HPR=F6.3)
      PRINT 511
   11 CONTINUE
   91 CONTINUE
      END
      SUBROUTINE FNCTNS(KK)
      REAL KGA,KL,K2,L,LO,MWL,MWT,M,MG,MF,ML,MUL,MUW,NR,MOTOR,LF,LC,LR
      COMMON DT,GS,GO,GR,A,KGA,L,LO,MF,NO,XRT,TL,XT,XB,Y1,YS,Z,G,X,AKG,
     1ASA,LC,LF,LR
      DATA E,MF,R/15258.,7.2E-4,1.98/
      TLC=(TL-32.)/1.8
      TLA=TLC+273.2
      K2=1700.*EXP(27.52-E/(R*TLA))*57666.6
      D= 5.148*10.**(-9)*EXP(0.03255*TLA)
      M=1000./(138.2/YS-138.2)
      ROL=(-3.25*10.**(-4)*TLA+1.09589*YS    +1.095)*62.428
      MWL=30.
      AW=A*(1.-EXP(-0.4233*MWL*LO/ROL))
      MUL=(MF/(2.1482*((TLC-8.435)+SQRT(8078.4+(TLC-8.435)**2.))-120.))
     1*241.8
      PH=1.255*(8.20-1.75*X)*M**(-0.015)
      CR= 10.**(-14)*(10.**PH)*0.06243
      SC=MUL/(ROL*D)
      RE=LO/(AW*MUL)*MWL
      P=(MUL**2/(GR*ROL**2))**(1./3.)
      Q=P*(K2*CR/D)**(1./2.)
      HA=Q/TANH(Q)
      KL=0.0165*D/P*RE**(2./3.)*SC**(1./3.)*HA
      IF(KK.EQ.1) KGA=1./(1./AKG+1./(MF*KL*AW))
      IF(KK.EQ.2) KGA=MF*KL*AW
      RETURN
      END
      SUBROUTINE DIA(II)
      REAL KGA,KL,K2,L,LO,MWL,MWT,M,MG,MF,ML,MUL,MUW,NR,MOTOR,LF,LC,LR
      COMMON DT,GS,GO,GR,A,KGA,L,LO,MF,NO,XRT,TL,XT,XB,Y1,YS,Z,G,X,AKG,
     1ASA,LC,LF,LR,PR
      MF=4.1154
```

```
      GR=4.17E8
      DATA DIAP,MWT,MUW,EP/0.1667,19.1,2.419,0.74/
      IF(II.EQ.2) GO TO 12
      ROG =2.53
      MG=G*MWT
      ADT=10.
      A=4.7/DIAP
      YY=Y1
      GG=G
      GO TO 10
   12 AWGR=(18.*(GS-LC+LF)+L*Z*(XB-XT)*44.)/(GS-LC+LF+L*Z*(XB-XT))
      ROG=PR/(0.0805*((TL-32.)/1.8+273.))*0.06243*AWGR
      MG=L*Z*(XRT-XT)*44.+(GS-LC+LF)*18.
      ADT=15.
      YY=L*Z*(XRT-XT)/(GS-LC)
      GG=GS-LC+L*Z*(XRT-XT)
   10 ML=L*100.*(1.+XB    *YS)/(5.5555-4.832*YS+1.2741*XB    *YS)
      TLC=(TL-32.)/1.8
      MUL=(MF/(2.1482*((TLC-8.435)+SQRT(8078.4+(TLC-8.435)**2.))-120.))
     1*241.8
      TLA=273.2+TLC
      ROL=(-3.25E-4*TLA+1.09589*YS+1.095)*62.428
      E50=A*(MUL/MUW )**0.2/(GR*EP**3*ROL)
      E51=4.*(ML/MG )**0.25*(POG /ROL)**0.125
      GF=(ROG /E50*EXP(-E51))**0.5
      GACT=0.9*GF
      ASA=MG /GACT
      ANO=ASA/(3.1416*(ADT/2.)**2)
      NO=ANO+1.
      SA=ASA/FLOAT(NO)
      DT=2.*(SA/3.1416)**0.5
      GO=GG/(YY+1.)/ASA
      LO=L/ASA
      PRINT 300, ROG,ROL,MUW,MUL,     GF,GACT,NO,SA,DT,GO,LO
  300 FORMAT(1H0,5X,4HROG=F8.4,5X,4HROL=F8.4,5X,4HMUW=F8.4,5X,4HMUL=F8.4
     1/5X,          3HGF=E13.5,5X,5HGACT=E13.5,5X,3HNO=I4,5X,3HSA=E13.5
     2/5X,3HDT=F9.5,5X,3HGO=E13.5,5X,3HLO=E13.5)
      RETURN
      END
      FUNCTION HV(T)
      HV=.10913906E4-.5124117*T-.32424927E-3*T**2+.66310167E-6*T**3
     1-.19645086E-8*T**4
      RETURN
      END
      FUNCTION PV(T)
      PV=2.96875-.0957031*T+.12207031E-2*T**2-.6604939E-5*T**3+.1995295E
     1-7*T**4
      RETURN
      END
      SUBROUTINE COST(REVA,BCOS,ODM,OPL,UTC)
C     AGA ACCOUNTING PROCEDURE WVU
      DATA RAWM,SHM,BPCR,BTU,SF,DEBT,RATE,TAX,XINT/4*0.,0.95,0.65,0.07,
     10.5,0.05/
      COH=BCOS*0.0773
      EINT=XINT*(COH+BCOS)
      FINV=BCOS+COH+EINT
      AMNT=.03*(BCOS-SHM)
      SUP=AMNT*0.15
      SPRV=0.10*OPL
      PYR=(OPL+SPRV)*0.1
```

```
      DEP=FINV*0.05
      TI=FINV*0.03
      RAWMF=SF*RAWM
      ODMF=SF*ODM
      BPCRF=SF*BPCR
      PRST=RAWMF+ODMF+OPL+AMNT+SUP+SPRV+PYR+PLT+DEP+TI
      CONT=PRST*0.02
      OPCOS=PRST+CONT-BPCRF+UTC
  201 FORMAT(1H0,20X,6HOPCOS=E10.5)
      WCAP=0.
      WOCAP=0.
      VTRY=(RAWM+ODM)/12.0
      ITEST=10
      J=0
   12 DFINV=FINV
      DCAP=(FINV+WCAP)*DEBT
      DRT=DCAP*0.05
      DCAP=DCAP+DRT
      REVA=0.
      FITA=0.
      RETA=0.
      PRGA=0.
      AINTA=0.
      DO 10 I=1,20
    3 DFINV=DFINV-0.05*FINV
      RET=(DFINV+WCAP)*RATE
      DCAP=DCAP-DRT
      AINT=DCAP*XINT
      FIT=(RET-AINT)*TAX/(1.-TAX)-0.65
      REV=RET+FIT+OPCOS
      REVA=REVA+REV
      IF(ITEST)10,11,10
  101 FORMAT(1H0,10X,I5,5E10.4)
   11 RETA=RETA+RET
      FITA=FITA+FIT
      PRGA=0.
      AINTA=AINTA+AINT
   10 CONTINUE
      REVA=REVA/20.
      IF(ITEST)14,13,14
   13 RETA=RETA/20.
      FITA=FITA/20.
      PRGA=PRGA/20.
      AINTA=AINTA/20.
      ORAWM=RAWM/12.
      RETURN
   14 AREC=REVA/(12.+SF)
      WCAP=VTRY+AREC
      ITEST=(WCAP-WOCAP)/10.
      WOCAP=WCAP
      GO TO 12
      END
```

```
      C MONOETHANOL-AMINE PROCESS
        REAL L,LO,KL,KAM,MOTOR,LC,LF,LR
        COMMON AG(100),AL(100),GKAC(100),GKAH(100),R(100),RH(100),TL(100),
       1X(100),XH(100),Y(100),YC(100),YH(100),A,AC,AMW,CPCA,CPN,DL,DNC,DR,
       2GKA,GNO,H,HRC,KAM,KL,LO,N,PA,PCE,PHE,QN,ROL,VIS,YI,YHI,CAM(100),Z
        DIMENSION DW(100),GH(100),GC(100),TG(100),HT(100),YHS(100)
        READ(5,2004) Z,A,HRC,CPCA,CPCR,CPS,HHA,CPN,CP1,CP2,HW,DR
 2004 FORMAT(7F10.4/5F10.4)
        PRINT 5000,  Z,A,HRC,CPCA,CPCR,CPS,HHA,CPN,CP1,CP2,HW,DR
 5000 FORMAT(3X,2HZ=F8.4,2X,1X,2HA=F5.2,3X,4HHRC=F10.4,  3X,5HCPCA=F8.4,
      13X,5HCPCR=F8.4,3X,4HCPS=F8.4/4X,4HHHA=F10.4,3X,4HCPN=F8.4,3X,4HCP1
      2=F8.4,3X,4HCP2=F8.4,3X,3HHW=F10.4,3X,3HDR=F10.4)
        DO 20 II=1,3
        READ(5,2001) G1,GW,T1,P,GCO2,GH2S,ROGA,AWGA,GKA,ST,X1,X2,TAT,IC
 2001 FORMAT(F10.2,6F10.4/2F10.5,F10.1,3F10.4,I1)
        IF(IC.EQ.1) PRINT 3002,IC
        IF(IC.NE.1) PRINT 2002,IC
 2002 FORMAT(1H1,5X,5HCASE ,I1)
 3002 FORMAT(1H0,5X,5HCASE ,I1)
        PRINT 2003,  G1,GW,T1,P,GCO2,GH2S,ROGA,AWGA,GKA,ST,X1,X2,IC,TAT
 2003 FORMAT(1H0,5X,3HG1=F10.2,3X,3HGW=F10.2,3X,3HT1=F8.2,3X,2HP=F8.2/6X
     1,5HGCO2=F10.3,3X,5HGH2S=F9.3,3X,5HROGA=F10.3,3X,5HAWGA=F8.3/6X,4HG
      2KA=F6.4,3X,3HST=F10.2,3X,3HX1=F8.4,3X,3HX2=F8.4,3X,3HIC=I1/6X,4HTA
      3T=F8.2)
        DO 143 I=1,5
        XT=X1
        XB=X2
        GS=ST
        TG1=146.
        IF(XB.GT.0.5) GO TO 143
        PR=1.+10./14.7
        YW=GW/G1
        YC2=0.00001
        DWT=(P*YW-PV(TG1))/P*G1/(1.-PV(TG1)/P)
        GN=G1-DWT-GH2S-GCO2
        YC1=GCO2/GN
        L=(YC1-YC2)*GN/(Z*(XB-XT))
C       CALCULATE TRT,TB
        XH1=GH2S/(Z*L)+0.0001
        XH2=0.0001
        T=240.9
      1 PW=(1.-Z)*PV(T)/14.7
        PCE=1.316E-3*EXP(0.5154+12.574*XT-18240.*(1./(460.+T)-1.488E-3))
        PHE=XH2*XT**(9.4763+5.0978*ALOG(XT)+0.9766*(ALOG(XT))**2)*EXP(
       1-7079.32/(T+460.)+16.2718)
        PCW=PCE+PW+PHE
        PRINT 1001,PR,PW,PCE,T,PCW,PHE
 1001 FORMAT(5X,3HPR=F8.3,3X,3HPW=F8.3,3X,4HPCE=F8.3,3X,2HT=F8.3,3X,4HPC
      1W=F10.3,3X,4HPHE=E13.6)
        IF(ABS(PR-PCW).LE.0.01) GO TO 2
        IF(PR.GT.PCW) T=T+0.3
        IF(PR.LT.PCW) T=T-0.3
        GO TO 1
      2 TB=T
        GCB=GS/PW*PCE
        GHB=GS/PW*PHE
        T4=TB-15.
        IF(XB.LE.0.375) GO TO 903
        T=225.3
        XF=0.435
```

```
      PHE=XH1*XF**(9.4763+5.0978*ALOG(XF)+0.9766*(ALOG(XF))**2)*EXP(
     1-7079.32/(T+460.)+16.2718)
      PCW=PCE+PW
      IF(ABS(PR-PCW).LE.0.01) GO TO 43
      IF(PR.GT.PCW) T=T+0.3
      IF(PR.LT.PCW) T=T-0.3
      GO TO 42
   43 CONTINUE
      GCF=L*Z*(XB-XF)
      LF=PW/PCE*GCF
      CPB=(0.9028+3.875E-4*(T4-10.))*(Z*61.1+(1.-Z)*18.)+Z*XB*CPCR
      TRT=T4-(GCF*HRC+LF*HW)/(L*CPB)
      IF(ABS(T-TRT).LE.1.) GO TO 45
      IF(TRT.GT.T) XF=XF-0.004
      IF(TRT.LT.T) XF=XF+0.004
      GO TO 42
   45 CONTINUE
      GO TO 904
  903 GCF=0.
      LF=0.
      TRT=T4
      XF=XB
  904 PRINT 7001,GCF, LF,TRT,XF
 7001 FORMAT(5X,4HGCF=E13.6,3X,3HLF=E13.6,3X,4HTRT=F8.3,3X,3HXF=F8.3)
      XRT=XF
      F=L*Z
      PRINT 555, L,F
  555 FORMAT(1H0,10X,2HL=E13.6,5X,2HF=E13.6)
      XRB=XT+GCB/F
      FX=F*(XB-XT)
C     HEAT BALANCE AROUND REGENERATOR AND REBOILER
      TRB=TB-(TB-TRT)/(XRT-XT)*(XPB-XT)
      CPRB=20.172*(0.9028+3.875E-4*(TRT+TRB)/2.)+Z*XRB*CPCR
      LC=(L*CPRB*(TRB-TRT)+(  -LF)*18.*(TRB-TRT)+F*(XRT-XRB)*HRC-(GS*CPS
     1+GCB*CPCR)*(TB-TRT))/(HW-18.*(TRB-TRT))
      CPB=20.172*(0.9028+3.875E-4*(TB+TRT)/2.)+Z*XT*CPCR
      QR=L*CPB*(TB-TRT)+F*(XRT-XT)*HRC+(GS-LC)*HW+(LF+GS-LC)*18.*(TRT-
     1100.)
      PRINT 5123, LC,TB ,LF,QR,TRB
 5123 FORMAT(1H0,5X,3HLC=E13.6,3X,4HTB =F8.3,3X,3HLF=E13.6,3X,3HQR=E13.6
     1,3X,4HTRB=F8.3)
C     REBOILER
      QS=QR
      ASTM=QS/(HV(265.))
      DTS=265.-TB
      ARS=QS/(DTS*300.)
      EHR=3.6*850.*((    ARS)/50.)**0.562
      CS=8700*ASTM*.15/1000.
      PRINT 1005,QR,    QS,EHR,ASTM,CS,   LC,TRB,XRB
 1005 FORMAT(1H0,3X,3HQR=E13.6,3X,                3HQS=E13.6,3X,4HEHR=E13
     1.6/4X,5HASTM=E13.6,2HLB,3X,3HCS=E13.6,3X,              3HLC=E13.6,
     23X,4HTRB=F8.3,3X,4HXRB=F8.4)
C     FEED GAS COOLER
    6 DWC=(P*YW -PV(TG1))/P*G1/(1.-PV(TG1)/P)
      YWA=(YW *G1-DWC)/(G1-DWC)
      G=G1-DWC
      QH=G1*CP2*(T1-TG1)+18.*HV(TG1)*DWC
      WH=QH/(150.-85.)
      DTH=((T1-150.)-(TG1-85.))/ALOG((T1-150.)/(TG1-85.))
      AH=QH/(85.*DTH)
      EH=3.6*850.*(AH/50.)**0.562
```

```
      BPH=WH*7.481*5.*144./(62.4*60.*0.8*24800)
      EPH=684.*BPH**0.467
      ELCH=8760.*BPH*0.7457*0.011/0.8
      UWC=8700.*WH*(7.481/62.4)*0.05/1000.
      PRINT 1007,G,YWA,QH,WH,EH,EPH,ELCH,UWC
 1007 FORMAT(1H0,5X,2HG=E13.6,3X,4HYWA=F8.4,3X,3HQH=E13.6,3X,3HWH=E13.6/
     16X,3HEH=E13.6,3X,4HEPH=E13.6,3X,5HELCH=E13.6,3X,4HUWC=E13.6)
      GN=G-GCO2-GH2S
      YC1=GCO2/GN
      YHS1=GH2S/GN
      L=(YC1-YC2)*GN/(Z*(XB-XT))
      XH1=GH2S/(Z*L)+0.0001
C     CALCULATE TAB
      CPLA=(0.9028+3.875E-4*(TAT+10.))*(Z*61.1+(1.-Z)*18.)
      QA=(YC1-YC2)*GN*HRC
      ALT=(0.9028+3.875E-4*TAT)*(Z*(44.*XT+61.1)+(1.-Z)*18.)*L
      AGT=GN*(CPN+YC2*CPCA)
      AGB=GN*(CPN+YC1*CPCA)
      ALB=L*(0.9028+3.875E-4*(TAT+30.))*(Z*(44.*XB+61.1)+(1.-Z)*18.)
      TAB=(QA+AGB*TG1+ALT*TAT-AGT*TAT)/ALB
      IF(IC.EQ.1) TAB=TAT+QA/(ALT+ALB)*2.
      PRINT 901, TAT,L,GN,CPLA,QA,TAB,ALT,AGT,AGB,ALB
  901 FORMAT(1H0,5X,4HTAT=F8.3,3X,2HL=E13.6,3X,3HGN=E13.6,3X,5HCPLA=F8.5
     1,3X,3HQA=E13.6/4X,4HTAB=F8.3,3X,4HALT=E13.6,3X,4HAGT=E13.6,3X,
     24HAGB=E13.6,3X,4HALB=E13.6)
      PRINT 1008, TAB,L,CPLA,G,GN
 1008 FORMAT(1H0,5X,4HTAB=F8.3,3X,2HL=E13.6,3X,5HCPLA=F8.3,3X,2HG=E13.6,
     13X,3HGN=E13.6)
C     CALCULATE TOTAL CROSS SECTIONAL AREA OF OF THE ABSORBER
      AMW=(1.-Z)*18.+Z*(XB*44.+61.1)
      ROL=(1.0177-2.15E-4*TAB-8.33E-8*TAB**2)*62.4*AMW/(AMW-Z*XB*44.)
      AA=A/(4.17E8*(0.74)**3*ROL)*(2.589/2.419)**0.2
      BB=4.*(L*AMW/G/AWGA)**0.25*(ROGA/ROL)**0.125
      GFT=SQRT(ROGA/AA*EXP(-BB))*0.90
      SA=G*AWGA/GFT
      NO=IFIX(SA/(3.1416*25.))
      ANO=1.+FLOAT(NO)
      DTA=((SA/ANO)/3.1416)**0.5*2.
      LO=L/SA
      GNO=GN/SA
      PRINT 299, L,G,AMW,TAB,Z,XT,XB,ROL,AA,BB,AWGA,ROGA,GFT
  299 FORMAT(1H0,5X,6(E13.6,4X)/5X,7(E13.6,3X))
      PRINT 300, SA,ANO,DTA,LO,GNO
  300 FORMAT(1H0,5X,'ABSORBER   '/5X,3HSA=F9.4 ,5X,4HANO=F8.4,5X,4HDTA=F
     18.4,5X,3HLO=E13.6,5X,4HGNO=E13.6)
C     SIMULATION FOR THE ABSORBER
      GKA=0.682*(G/SA/145.5)**0.75
      PRINT 906, GKA
  906 FORMAT(1H0,10X,4HGKA=F10.4)
      N=1
      TL(N)=TAB
      Y(1)=YC1/(1.+YC1+YHS1)
      X(N)=XB
      DNC=0.
      XH(N)=XH1
      YH(1)=YHS1/(1.+YC1+YHS1)
      TG(1)=TG1
      PA=P/14.7
      YC(1)=YC1
      YHS(1)=YHS1
      WG1=0
```

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      HT(1)=0.
      CALL NAME(1)
      PRINT 110, N,Y(N),X(N),YH(N),XH(N),HSL,CAM(N),R(N),TL(N),TG(N),
     1GKAC(N),GKAH(N),HT(N),RH(N)
  110 FORMAT(3X,2HN=I3,3X,   2HY=E13.6,3X,2HX=F8.6,3X,3HYH=E13.6,3X,
     13HXH=F8.6,3X,4HHSL=F9.4,3X,4HCAM=F9.4/2X,2HR=E13.6,3X,3HTL=F8.4,3X
     2,3HTG=F8.4,3X,5HGKAC=F8.4,3X,5HGKAH=F8.4,3X,3HHT=F8.4,3X,3HRH=E13.
     36)
      KN=31
      DO 10 N=2,KN
      YHS(N)=YHS(N-1)
      YC(N)=YC1-FLOAT(N-1)*(YC1-YC2)/FLOAT(KN-1)
      YH(N)=YH(N-1)
      Y(N)=YC(N) /(1.+YC(N)+YHS(N))
      DNC=(YC(N-1)-YC(N))*GNO
      X(N)=X(N-1)-DNC/(Z*LO)
      XH(N)=XH(N-1)
      TL(N)=TAB+(TAT-TAB)/(XT-XB)*(X(N)-XB)
      CALL NAME(1)
      IF(PCE.GE.PA*Y(N)) Y(N)=Y(N-1)
      HT(N)=DNC/(A*(R(N)+R(N-1))*0.5)
      HAH=A*HT(N)*HHA
      TG(N)=(AG(N-1)*TG(N-1)*(AL(N)-HAH)+HAH*(AL(N-1)*TL(N-1)-GN))/
     1(AG(N)*AL(N)+HAH*(AL(N)-AG(N))+AC*AL(N))
      YHS(N)=(YHS(N-1)+0.5*(GKAH(N)+GKAH(N-1))*HT(N)*PHE/GNO)/(1.+0.5*
     1(GKAH(N)+GKAH(N-1))*HT(N)*PA/(GNO*(1.+YC(N))))
      DNH=(YHS(N-1)-YHS(N))*GNO
   18 YH(N)=YHS(N)/(1.+YHS(N)+YC(N))
      PHA=PA*YH(N)
      IF(PHE.GE.PHA) GO TO 143
      XH(N)=XH(N-1)-DNH/(Z*LO)
      HSL=HSL+DNH*SA
      GRAIN=YH(N)/0.0000163
      PRINT 110, N,Y(N),X(N),YH(N),XH(N),HSL,CAM(N),R(N),TL(N),TG(N),
     1GKAC(N),GKAH(N),HT(N),RH(N)
      PRINT 6005, PHA,PHE,GRAIN
 6005 FORMAT(10X,4HPHA=E13.6,10X,4HPHE=E13.6,10X,6HGRAIN=F10.7)
   10 CONTINUE
      HTA=5.
      DO 8 J=1,KN
      HTA=HTA+HT(J)
    8 CONTINUE
  530 N=N+1
      PRINT 86, HTA
      PRINT 6005, PHA,PHE,GRAIN
      AI=2.**I
      IF(GRAIN.LE.0.4/AI) GO TO 519
      XH(N)=XH2
      X(N)=XT
      YC(N)=YC2
      Y(N)=Y(N-1)
      HT(N)=5.
      HTA=HTA+HT(N)
      GKAH(N)=GKAH(N-1)
      TL(N)=TL(N-1)
      TR=TL(N)+460.
      PHE=XH(N)*X(N)**(9.4763+5.0978*ALOG(X(N))+0.9766*(ALOG(X(N)))**2)*
     1EXP(-7079.32/TR+16.2718)
      PH =XH(N)*0.15**(9.4763+5.0978*ALOG(0.15)+0.9766*(ALOG(0.15))**2)*
     1EXP(-7079.32/TR+16.2718)*(7./17.+10./17.*X(N)/0.15)
      IF(X(N).LT.0.15) PHE=PH
```

```
      YHS(N)=(YHS(N-1)+0.5*(GKAH(N)+GKAH(N-1))*HT(N)*PHE/GNO)/(1.+0.5*
     1(GKAH(N)+GKAH(N-1))*HT(N)*PA/(GNO*(1.+YC(N))))
      DNH=(YHS(N-1)-YHS(N))*GNO
      YH(N)=YHS(N)/(1.+YHS(N)+YC(N))
      PHA=PA*YH(N)
      IF((PHA-PHE).LE.0.000000001) GO TO 143
      IF(N.GE.100) GO TO 143
      GRAIN=YH(N)/0.0000163
      GO TO 530
  519 CONTINUE
   86 FORMAT(1H0,5X,'HEIGHT OF ABSORBER HTA=',F10.5)
C     CALCULATE CROSS-SECTIONAL AREA OF THE REGENERATOR
      AMW=(1.-Z)*18.+Z*(XB*44.+61.1)
      ROL=(1.0177-2.15E-4*TRT-8.33E-8*TRT**2)*62.4*AMW/(AMW-Z*XB*44.)
      GRT=GS-LC+LF+L*Z*(XB-XT)
      AWGR=(18.*(GS-LC+LF)+L*Z*(XB-XT)*44.)/GRT
      ROGR=PR/(0.0805*((TRT-32.)/1.8+273.))*0.06243*AWGR
      AA=A/(4.17E8*(0.74)**3*ROL)*(2.589/2.419)**0.2
      BB=4.*(L*AMW/GRT/AWGR)**0.25*(ROGR/ROL)**0.125
      GFT=SQRT(ROGR/AA*EXP(-BB))*0.90
      SR=GRT*AWGR/GFT
      NO=IFIX(SR/(3.1416*7.5*7.5))
      RNO=1.+FLOAT(NO)
      DTR=((SR/RNO)/3.1416)**0.5*2.
      LO=L/SR
      GSO=GS/SR
      PRINT 200,SR,RNO,DTR,LO,GSO
  200 FORMAT(1H0,5X,'REGENERATOR'/5X,3HSR=F9.4 ,5X,4HRNO=F8.4,5X,4HDTR=F
     18.4,5X,3HLO=E13.6,5X,4HGSO=E13.6)
C     SIMULATION FOR THE REGENERATOR
      N=1
      X(N)=XRB
      Y(1)=GCB/(GS+GCB+GHB)
      XH(N)=XH(KN)+GHB/F
      TL(N)=TRB
      PA=PR
      HSG=GHB
      DNC=0.
      GC(1)=GCB
      DW(1)=0.
      GH(1)=GHB
      YH(1)=GH(1)/(GS-DW(1)+GC(1)+GH(1))
      C4=LC/(XRB-XRT)
      C5=(TRB-TRT)/(XRB-XRT)
      HT(1)=0.
      CALL NAME(2)
      PRINT 310,N,Y(N),X(N),YH(N),XH(N),GH(N),CAM(N),R(N),TL(N),DW(N),
     1GKAC(N),GKAH(N),HT(N),RH(N),GC(N)
  310 FORMAT(2X,2HN=I3,1X,2HY=F8.6,1X,2HX=F8.6,1X,3HYH=E12.6,1X,3HXH=
     1F8.6,1X,3HGH=F8.4,1X,4HCAM=F9.5,1X,2HR=E12.6,/1X,3HTL=F8.4,1X,3HDW
     2=F9.2,1X,5HGKAC=F8.4,1X,5HGKAH=F8.4,1X,3HHT=F8.4,1X,3HRH=E12.6,1X,
     23HGC=F10.2)
      YRT=F*(XRT-XT)/(GS-LC+F*(XRT-XT)+GH2S)
      KR=31
      DO 49 N=2,KR
      GH(N)=GH(N-1)
      XH(N)=XH(N-1)
      Y(N)=Y(1)+FLOAT(N-1)*(YRT-Y(1))/FLOAT(KR-1)
      C6=Y(N)/(1.-Y(N))
      X(N)=(GC(N-1)-F*X(N-1)-C6*(GS+GH(N)-C4*XRB))/(C6*C4-F)
      DW(N)=C4*(XRB-X(N))
```

```
      GC(N)=L*Z*(X(N)-X(N-1))+GC(N-1)
      TL(N)=TRB-C5*(XRB-X(N))
      YH(N)=GH(N)/(GS-DW(N)+GC(N)+GH(N))
      DNC=(GC(N)-GC(N-1))/SR
      CALL NAME(2)
      HT(N)=DNC/(A*(R(N)+R(N-1))*0.5)
      DNH=HT(N)*0.5*(GKAH(N)+GKAH(N-1))*(PHE-PA*YH(N))
      GH(N)=GH(N-1)+DNH*SR
      IF(GH(N).GE.HSL) GH(N)=GH(N-1)
      XH(N)=XH(N-1)+(GH(N)-GH(N-1))/F
      YH(N)=GH(N)/(GS-DW(N)+GC(N)+GH(N))
      IF(ABS(PCE-Y(N)*PA).LE.0.000001) GO TO 143
      IF((PCE-PA*Y(N)).LE.0.00001) GO TO 143
      IF((PHE-PA*YH(N)).LE.0.00001) GO TO 143
   49 CONTINUE
      PRINT 310,N,Y(N),X(N),YH(N),XH(N),GH(N),CAM(N),R(N),TL(N),DW(N),
     1GKAC(N),GKAH(N),HT(N),RH(N),GC(N)
      HTR=5.
      DO 28 J=1,KR
      HTR=HTR+HT(J)
   28 CONTINUE
      PRINT 87, HTR
   87 FORMAT(1H0,5X,'HEIGHT OF REGENERATOR HTR=',F10.5)
C     NO. 4 HEAT EXCHANGER
      Q4=L*(T4-TAB)*(0.9028+3.875E-4*0.5*(T4+TAB))*(Z*(44.*XB+61.1)+(1.-
     1Z)*18.)
      DT4=15.
      T5=TAB+15.
      AH4=Q4/(200.*DT4)
      EH4=3.6*850.*(AH4/50.)**0.562
      PRINT 124, T4,T5,Q4,EH4
  124 FORMAT(1H0,5X,3HT4=F8.4,3X,3HT5=F8.4,3X,3HQ4=E13.6,3X,4HEH4=E13.6)
C     NO. 5 HEAT EXCHANGER
      Q5=L*(T5 -TAT)*(0.9028+3.875E-4*(T5 +TAT)/2.)*(Z*(44.*XT+61.1)+(1.
     1-Z)*18.)
      DT5=((T5 -120.)-(TAT-85.))/ALOG((T5 -120.)/(TAT-85.))
      AH5=Q5/(DT5*200.)
      EH5=3.6*850.*(AH5/50.)**0.562
      UW5=Q5/(120.-85.)
      BP=UW5*7.481*2.*144./(62.4*60.*0.8*246800.)
      EP5 =684.*(BP)**0.467
      ELC5=8760.*BP*0.7457*0.01/0.8
      UWC5=Q5/(150.-85.)*8760.*(7.481/62.4)*0.05/1000.
      PRINT 102, T5,Q5,EH5,UWC5,EP5,ELC5
  102 FORMAT(1H0,5X,4HT5 =F8.3,5X,3HQ5=E13.6,5X,4HEH5=E13.6,5X,5HUWC5=E1
     13.6/5X,5HEP5 =E13.6,5X,5HELC5=E13.6)
C     COST OF TURBINE-MOTOR-PUMP
      T=T4
      PCE=1.316E-3*EXP(0.5154+12.574*XB-18240.*(1./(460.+T)-1.488E-3))
      PW=(1.-Z)*PV(T)
      P2=(PW+PCE)*14.7
      P3=PR*14.7
      DP=P-P3
      NP=1+IFIX(0.04043*L/2000.)
      CF=0.04043*L/FLOAT(NP)
      BP=CF*(DP*144.+ROL*HTA)/(0.8*246800.)
      PUMP=FLOAT(NP)*1.8*684.*(BP)**0.467
      TBN=PUMP
      WE=.04043*L*(144.*(0.1*(P-P2)+P2-P3)+ROL*HTA)/(0.8*246800.)
      MOTOR=FLOAT(NP)*46.*(WE/FLOAT(NP))**0.955
      CTMP=TBN+MOTOR+PUMP
```

```
      ELCT=WE*0.7457*8760.*0.011
      PRINT 203, CTMP,ELCT,NP,PUMP,MOTOR,TBN,BP
  203 FORMAT(1H0,10X,18HTURBINE-MOTOR-PUMP/10X,5HCTMP=E11.5,5X,5HELCT=E1
     11.5,5X,3HNP=I3,5X,5HPUMP=E11.5/10X,6HMOTOR=E11.5,5X,4HTBN=E11.5,
     25X,3HBP=E11.5)
C     COST OF ABSORBER AND REGENERATOR
      THA=0.03639*DTA+1./48.
      HTA=HTA+5.
      CA=566.325*ANO*(((DTA+2.*THA)**2-DTA**2)*HTA+2.*THA*(1.346*DTA)**2
     1)
      THR=(5.06763/10.**4)*DTR+1./48.
      HTR=HTR+5.
      CR=566.325*RNO*(((DTR+2.*THR)**2-DTR**2)*HTR+2.*(1.346*DTR)**2*THR
     1)*(1.+(XB-XRT)/(XRT-XRB))
C     VALVE COST
      CV=16000*(ANO+RNO)
C     MEA COST
      CMEA  =0.35 *0.2*3.1416/4.*(DTA**2*HTA*ANO+DTR**2*HTR*RNO)*7.481
C     PACKING COST
      CPK=5.*3.142/4.*(DTA**2*HTA*ANO+DTR**2*HTR*RNO)
      PRINT 204, THA,CA,THR,CR,CPK,CMEA  ,CV
  204 FORMAT(1H0,10X,20HABSORBER-REGENERATOR/10X,4HTHA=E10.5,5X,3HCA=E10
     1.5,5X,4HTHR=E10.5,5X,3HCR=E10.5/10X,4HCPK=E10.5,5X,5HCMEA=E10.5,
     25X,3HCV=E10.5)
C     CONDENSER
      DTC=((TRT-150.)-(100.-85.))/ALOG((TRT-150.)/(100.-85.))
      T=(0.5*(TRT+100.)-32.)/1.8+273.
      G8=GS-LC+LF
      Q=G8*(7.256+2.298E-3*T+2.83E-7*T**2)*(TRT-100.)+L*Z*(XB-XT)*(6.214
     1+10.396E-3*T-35.45E-7*T**2)*(TRT-100.)+G8*18.*1036.4
      AC=Q/(200.*DTC)
      CW=Q/(150.-85.)
      UWCC=8760.*CW*(7.481/62.4)*0.05/1000.
      EC=3.6*850.*(AC/50.)**0.562
      BPC=CW*7.481*2.*144./(62.4*60.*0.8*246800.)
      EPC=684.*(BPC)**0.467
      ELCC=8760.*BPC*0.7457*0.011/0.8
      PRINT 600, Q,EC,EPC,ELCC,UWCC
  600 FORMAT(1H0,5X,2HQ=E13.6,3X,3HEC=E13.6,3X,4HEPC=E13.6,3X,5HELCC=E13
     1.6,3X,5HUWCC=E13.6)
      BCOS=(CTMP+CA+CR+CPK+CV+EHR+EH +EH4+EH5+EPH+EC+EP5+EPC)/1000.
      OPL=60.
      RAWM=0.
      ODM=CMEA/1000.
      UTC=(UWC+ELCH+CS+UWC5+ELC5+UWCC+ELCC+ELCT)/1000.
      CALL COST(REVA,BCOS,ODM,OPL,UTC)
      PRINT 511
  511 FORMAT(1H0,5X,'$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$')
      PRINT 402,REVA,BCOS,OPL,ODM,UTC
  402 FORMAT(1H0,10X,10X,10HCOST IN $M/9X,4HREVA,10X,4HBCOS,10X,3HOPL,11
     1X,3HODM,11X,3HUTC/6X,5E14.5)
      PRINT 510, XT,XB,GS,TRT,   L,HTA,DTA,ANO,HTR,DTR,RNO
  510 FORMAT(1H0,10X,3HXT=F8.5,3X,3HXB=F8.5,3X,3HGS=F10.2,3X,4HTRT=F8.2,
     13X,          2HL=F10.2/11X,4HHTA=F6.2,3X,4HDTA=F8.5,3X,4HANO=
     2F5.1,3X,4HHTR=F6.2,3X,4HDTR=F8.5,3X,4HANO=F5.1)
      PRINT 511
   90 CONTINUE
  143 CONTINUE
   20 CONTINUE
      END
      SUBROUTINE NAME(IR)
```

```
      REAL L,LO,KL,KAM,MOTOR,LC,LF,LR
      COMMON AG(100),AL(100),GKAC(100),GKAH(100),R(100),RH(100),TL(100),
     1X(100),XH(100),Y(100),YC(100),YH(100),A,AC,AMW,CPCA,CPN,DL,DNC,DR,
     2GKA,GNO,H,HRC,KAM,KL,LO,N,PA,PCE,PHE,QN,ROL,VIS,YI,YHI,CAM(100),Z
      T=TL(N)
      TR=T+460.
      TC=(T-32.)/1.8
      TK=TC+273.
      H=0.062430*10.**(1140./TK-5.3)
      AMW=18.*(1.-Z)+Z*(X(N)*44.+61.1)
      ROL=(1.0177-2.15E-4*T-8.33E-8*T**2)*62.4*AMW/(AMW-Z*X(N)*44.)
      DL=2.325E-5*(1.11+0.01675*TC+0.000575*TC**2)
      VIS=0.03875*ROL*3.994*EXP(-0.01275*T)
      KL=0.0165*DL*(VIS**2/(4.17E8*ROL**2))**(-1./3.)*(LO*AMW/(A*VIS))**
     1(2./3.)*(VIS/(ROL*DL))**(1./3.)
      KAM=57661.*EXP(25.432-4915.33/TK)
      CAM(N)=(1.-2.*X(N))*Z*ROL/AMW
      PCE=1./760.*EXP(0.5154+12.574*X(N)  -18240.*(1./TR-1./672.))
      PHE=XH(N)*X(N)**(9.4763+5.0978*ALOG(X(N))+0.9766*(ALOG(X(N)))**2)*
     1EXP(-7079.32/TR+16.2718)
      PH =XH(N)*0.15**(9.4763+5.0978*ALOG(0.15)+0.9766*(ALOG(0.15))**2)*
     1EXP(-7079.32/TR+16.2718)*(7./17.+10./17.*X(N)/0.15)
      IF(X(N).LT.0.15) PHE=PH
      IF(IR.EQ.2) GO TO 2
      YI2=(GKA*PA* Y(N)-A*KL*CAM(N)*SQRT(DR)/2.)/(PA*(A*KL*H   /SQRT(DR)
     1+GKA))
      YJ=(A*H*PCE*SQRT(KL**2+DL*KAM*CAM(N))+GKA*PA*Y(N))/(A*H*PA*
     1SQRT(KL**2+DL*CAM(N)*KAM)+GKA*PA)
      IF(YI2.GE.YJ) YI=YI2
      IF(YI2.LT.YJ) YI=YJ
      IF(N.GE.16) YI=YJ
      R(N)=GKA*PA*(Y(N)-YI)/A
      GKAC(N)=R(N)*A/(Y(N)*PA-PCE)
      GKL=1./(1./GKAC(N)-1./GKA)
      AG(N)=GNO*(CPN+YC(N)*CPCA)
      AL(N)=LO*(0.9028+3.875E-4*T)*(Z*(44.*X(N)+61.1)+(1.-Z)*18.)
      AC=DNC*CPCA
      GN=DNC*HRC
      YHI=(A*3.*H*PHE*SQRT(KL**2+DL*KAM*CAM(N))+GKA*PA*YH(N))/(A*3.*H*
     1PA*SQRT(KL**2+DL*KAM*CAM(N))+GKA*PA)
      RH(N)=GKA*PA*(YH(N)-YHI)/A
      GKAH(N)=RH(N)*A/(YH(N)*PA-PHE)
      GKAH(N)=1./(1./GKA+1./6./GKL)
      GO TO 3
    2 CONTINUE
      YI=(A*H*PCE*SQRT(KL**2+DL*KAM*CAM(N))+12.*PA*Y(N)) /(12.*PA+A*H*
     1PA*SQRT(KL**2+DL*KAM*CAM(N)))
      R(N)=H*(PCE-PA*YI)*SQRT(KL**2+DL*KAM*CAM(N))
      GKAC(N)=R(N)*A/(PCE-PA*Y(N))
      YHI=(A*3.*H*PHE+SQRT(KL**2+DL*KAM*CAM(N))+12.*PA*YH(N))/(12.*PA+
     1H*3.*PA*SQRT(KL**2+DL*KAM*CAM(N)))
      RH(N)=3.*H*(PHE-PA*YHI)*SQRT(KL**2+DL*KAM*CAM(N))
      GKAH(N)=RH(N)*A/(PHE-PA*YH(N))
      GKAH(N)=12.
    3 CONTINUE
      RETURN
      END
      FUNCTION HV(T)
      HV=.10913906E4-.5124117*T-.32424927E-3*T**2+.66310167E-6*T**3
     1-.19645086E-8*T**4
      RETURN
```

```
      END
      FUNCTION PV(T)
      PV=2.96875-.0957031*T+.12207031E-2*T**2-.6604939E-5*T**3+.1995295E
     1-7*T**4
      RETURN
      END
      SUBROUTINE COST(REVA,BCOS,ODM,OPL,UTC)
C     AGA ACCOUNTING PROCEDURE WVU
      DATA RAWM,SHM,BPCR,BTU,SF,DEBT,RATE,TAX,XINT/4*0.,0.95,0.65,0.07,
     10.5,0.05/
      COH=BCOS*0.0773
      EINT=XINT*(COH+BCOS)
      FINV=BCOS+COH+EINT
      AMNT=.03*(BCOS-SHM)
      SUP=AMNT*0.15
      SPRV=0.10*OPL
      PYR=(OPL+SPRV)*0.10
      PLT=(OPL+SPRV+AMNT+SUP)*0.5
      DEP=FINV*0.05
      TI=FINV*0.03
      RAWMF=SF*RAWM
      ODMF=SF*ODM
      BPCRF=SF*BPCR
      PRST=RAWMF+ODMF+OPL+AMNT+SUP+SPRV+PYR+PLT+DEP+TI
      CONT=PRST*0.02
      OPCOS=PRST+CONT-BPCRF+UTC
  201 FORMAT(1H0,20X,6HOPCOS=E10.5)
      WCAP=0.
      WOCAP=0.
      VTRY=(RAWM+ODM)/12.0
      ITEST=10
      J=0
   12 DFINV=FINV
      DCAP=(FINV+WCAP)*DEBT
      DRT=DCAP*0.05
      DCAP=DCAP+DRT
      REVA=0.
      FITA=0.
      RETA=0.
      PRGA=0.
      AINTA=0.
      DO 10 I=1,20
    3 DFINV=DFINV-0.05*FINV
      RET=(DFINV+WCAP)*RATE
      DCAP=DCAP-DRT
      AINT=DCAP*XINT
      FIT=(RET-AINT)*TAX/(1.-TAX)-0.65
      REV=RET+FIT+OPCOS
      REVA=REVA+REV
      IF(ITEST)10,11,10
  101 FORMAT(1H0,10X,I5,5E10.4)
   11 RETA=RETA+RET
      FITA=FITA+FIT
      PRGA=0.
      AINTA=AINTA+AINT
   10 CONTINUE
      REVA=REVA/20.
      IF(ITEST)14,13,14
   13 RETA=RETA/20.
      FITA=FITA/20.
      PRGA=PRGA/20.
```

```
      AINTA=AINTA/20.
      ORAWM=RAWM/12.
      RETURN
   14 AREC=REVA/(12.*SF)
      WCAP=VTRY+AREC
      ITEST=(WCAP-WOCAP)/10.
      WOCAP=WCAP
      GO TO 12
      END
```

TABLE B.4-2 PROGRAM SYMBOLS AND EXPLANATIONS FOR OPTIMIZATION OF IRON OXIDE BED

Program Symbols	Explanations
AMAT	Amount of H_2S at Bottom in the Gas (lb-moles/sec)
AMAT	Amount of H_2S at Bottom in a Particle (g-moles/sec)
AMU	Viscosity of the Gas (Poise)
AMW	Molecular Weight of the Gas
AN	Number of Beds in Operation
ANOP	Number of the Beds
B	Stoichiometric Factor in the Reaction
BCOS	Bare Equipment Cost (Dollars)
CAOB CAOT CAOM	Concentration of H_2S at Bottom, Top and Log-Mean
DAY	Changeout Day in Practical Case (Day)
DAYCAL	Changeout Day Calculated (Day)
DP	Particle Diameter (cm)
DT	Diameter of the Bed (cm)
DTA	Diameter of Bed (ft)
EP	Void Fraction (-)
F	Friction Factor (-)
G	Molar Rate of the Gas (lb-moles/sec-bed)
GC	Conversion Factor of Gravitational Force (980 kg-cm/kg -- sq.sec)
GO	Molar rate of the Gas (lb-moles/sec)
GRAIN	Concentration Unit for H_2S in the Gas

TABLE B .4-2 (Cont.)

Program Symbols	Explanations
GTOTAL	Total Gas Rate Treated (lb-moles/hr)
HTA	Height of Bed (ft)
HT	Height of the Bed (ft)
NO	Total Number of Beds
OPL	Operational Cost (Dollars)
PDP	Pressure Drop (PSI)
PT	Total Pressure
R	Radius of a Particle (cm)
RC	Reaction Radius in a Particle at Outlet (cm)
RE	Reynolds Number of the Gas
RRK	Reaction Rate Constant (cm/sec)
ROG	Density of the Gas (g/cu.cm)
S	Cross Sectional Area of the Bed (sq.cm)
SUMMAT	Amount of H_2S at Bottom in the Gas (g-moles/sec)
TF	Temperature of the Gas (Degree F)
THA	Thickness of the Wall of Bed (ft)
U	Gas Velocity (cm/sec)
UTC	Utility Cost (Dollars)
VBED	Volume of the Bed (cu.cm)
XCAOB XCAOT	Mole Fraction of H_2S at Bottom and Top
Z	Height of the Bed (cm)

```
C       OPTIMIZATION OF IRON OXIDE BED
C       EFFECT ON REVENUE COST WITH CHANGE IN NUMBER OF BEDS
        DT=30.48*5.
        AMU=0.000177
        DP=0.3
        TF=100.
        PDP=1.
        GC=980.
        EP=0.4
        GRAIN=10.
        AN=1.
        M=1
   15   I=1
   34   IF(I-2)3,4,5
    3   PRINT 6
    6   FORMAT(1HC/10X,6HCASE 1//)
        GO=4003C./3600.
        PT=1047./14.7
        ROG=0.0406
        AMW=13.82
        GO TO 9
    4   PRINT 7
    7   FORMAT(1HC/10X,6HCASE 2//)
        GO=48000./3600.
        PT=1067./14.7
        ROG=0.0362
        AMW=12.30
        GO TO 9
    5   PRINT 8
    8   FORMAT(1HC/10X,6HCASE 3//)
        GO=67180./3600.
        PT=1047./14.7
        ROG=0.0318
        AMW=10.81
        GO TO 9
    9   G=GO/AN
        XCAOB=0.0000163*GRAIN
        XCAOT=0.000000163
        CAOB=XCAOB/(22400./PT*(TF/1.8-32.+273.)/273.)
        CAOT=0.000000163/(22400./PT*(TF/1.8-32.+273.)/273.)
        CAOM=(CAOB-CAOT)/ALOG(CAOB/CAOT)
        R=0.3
        RC=0.5*R
        RK=0.0105
        AMAT=XCAOB*G
        AMA=4.*3.14*RC**2*RK*CAOM
        SUMMAT=454.*AMAT
        ANOP=SUMMAT/AMA
        ROB=30.*0.01602/100.
        B=1./3.
        DAYCAL=ROB*(R-RC)/(B*RK*CAOM*3600.*24.)
        GTOTAL=GO*3600.
        PRINT 350,GRAIN,GTOTAL
  350   FORMAT(2X,6HGRAIN=E11.5,1X,7HGTOTAL=E11.5)
   10   S=0.785*DT**2
        U=G*454.*AMW/(S*ROG)
        RE=DP*G*454.*AMW/(S*AMU)
```

```
      F=150.*(1.-EP)/RE+1.75
      Z=4.*4.*DP**3*ANCP/(3.*DT**2*AN*0.6)
      PDP=F*G*454.*AMW/S*L/GC/DP*(1.-EP)/EP**3*Z*0.01422
      IF(PDP-1.)98,98,97
   97 DT=DT+0.10*30.48
      GO TO 10
   98 PRINT  100,R,RK,TF,XCAOB,PT,AMAT,CAOB,CAOT,CACM,AMA,
     1SUMMAT,ANCP,L,RCG,AMU,RE,F,DP,PDP
  100 FORMAT(1HC,5X,2HR=E11.5,4X,3HRK=E11.5,4X,
     13HTF=F11.5,1X,6HXCAOB=E11.5,
     2/5X,3HPT=E11.5,2X,5HAMAT=E11.5,2X,5HCAOB=E11.5,
     32X,5HCAOT=E11.5/3X,5HCAOM=E11.5,3X,
     44HAMA=E11.5,7HSUMMAT=E11.5,2X,5HANCP=E11.5/
     58X,11X,5X,2HL=E11.5,
     63X,4HRCG=E11.5/4X,4HAMU=E11.5,4X,3HRE=E11.5,
     7 5X,2HF=E11.5,4X,3HDP=E11.5 ,3X,4HPDP=E11.5)
  400 NC=INT(AN*2.0)
      DT=(S/(0.785*AN))**0.5
      HT=Z/30.48
      DIABEC=DT/30.48
      PRINT 300,DIABEC,HT,NC,DAYCAL
  300 FORMAT(1HC,7HDIABEC=E11.5,5X,2HZ=E11.5,4X,3HNC=I3,
     18X,3X,4HDAY=E11.5)
C     COST OF H2S REMOVERS
      HTA=HT+2.
      DTA=DT/30.48
      THA=0.0369*DTA+1./48.
      CA=566.325*FLOAT(NC)*(((DTA+2.*THA)**2-DTA**2)*HTA+
     12.*THA*(1.346*DTA)**2)
      CV=4000.*FLOAT(NC)
      CP=FLOAT(NC)*3.14*5.**2*10.*0.05*30.
      TOTAL=CA+CV+CP
      PRINT 200,CA,CV,CP,TOTAL
  200 FORMAT(8X,3HCA=E11.5,4X,3HCV=E11.5,4X,3HCP=E11.5,
     11X,6HTOTAL=E11.5)
      RAWM=0.
      CPL=60.*FLOAT(NC)
      ODM=CP/1000.*330./DAYCAL
      UTC=0.
      BCCS=(CA+CV)/1000.
      CALL COST(REVA,BCCS,ODM,CPL,UTC)
      PRINT 502,REVA,BCCS,OPL,ODM,UTC
  502 FORMAT(10X,10HCOST IN $M/3X,5HREVA=E11.5,2X,5HBCCS=E11.5,
     13X,4HCPL=E11.5,3X,4HODM=E11.5/4X,4HUTC=E11.5///)
      IF(AN-11.)13,32,32
   13 AN=AN+1.
      GO TO 400
   32 IF(I-2)33,33,14
   33 I=I+1
      AN=1.
      DT=30.48*5.
      GO TO 34
   14 STOP
      END
```

```
      SUBROUTINE COST(REVA,BCOS,CCM,OPL,UTC)
C     AGA ACCOUNTING PROCEDURE WVU
      DATA RAWM,SHM,BPCR,BTU,SF,DEBT,RATE,TAX,XINT/4*0.,0.95,
     10.65,0.07,0.5,0.05/
      COH=BCOS*0.0773
      EINT=XINT*(COH+BCOS)
      FINV=BCOS+COH+EINT
      AMNT=.03*(BCOS-SHM)
      SUP=AMNT*0.15
      SPRV=0.10*OPL
      PYR=(OPL+SPRV)*0.10
      PLT=(OPL+SPRV+AMNT+SUP)*0.5
      DEP=FINV*0.05
      TI=FINV*0.03
      RAWMF=SF*RAWM
      CCMF=SF*CCM
      BPCRF=SF*BPCR
      PRST=RAWMF+CCMF+OPL+AMNT+SUP+SPRV+PYR+PLT+DEP+TI
      CONT=PRST*0.02
      OPCOS=PRST+CONT-BPCRF+UTC
      WCAP=0.
      WCCAP=0.
      VTRY=(RAWM+CCM)/12.0
      ITEST=10
      J=0
   12 DFINV=FINV
      DCAP=(FINV+WCAP)*DEBT
      DRT=DCAP*0.05
      DCAP=DCAP+DRT
      REVA=0.
      FITA=0.
      RETA=0.
      PRGA=0.
      AINTA=0.
      DO 10 I=1,20
    3 DFINV=DFINV-0.05*FINV
      RET=(DFINV+WCAP)*RATE
      DCAP=DCAP-DRT
      AINT=DCAP*XINT
      FIT=(RET-AINT)*TAX/(1.-TAX)-0.65
      REV=RET+FIT+OPCOS
      REVA=REVA+REV
      IF(ITEST)10,11,10
   11 RETA=RETA+RET
      FITA=FITA+FIT
      PRGA=0.
      AINTA=AINTA+AINT
   10 CONTINUE
      REVA=REVA/20.
      IF(ITEST)14,13,14
   13 RETA=RETA/20.
      FITA=FITA/20.
      PRGA=PRGA/20.
      AINTA=AINTA/20.
      CRAWM=RAWM/12.
      RETURN
   14 AREC=REVA/(12.*SF)
      WCAP=VTRY+AREC
      ITEST=(WCAP-WCCAP)/10.
```

```
154           hOCAP=WCAP
155           GO TO 12
156           END
```

```
      $ENTRY
```

TABLE B.4-3 PROGRAM SYMBOLS AND EXPLANATIONS FOR OPTIMIZATION OF ACTIVATED CARBON BED

Program Symbols	Explanations
AN	Number of Beds in Operation
AKFAV	Overall Mass Transfer Coefficient, C_6H_6 0.2%
AMU	Viscosity of the Gas (Poise)
AMW	Molecular Weight of the Inlet Gas
AN	Number of Beds
ANM	Number of Transfer Unit
BCOS	Bare Equipment Cost (Dollars)
BS	Brake Horse Power (HP)
BZN	Amount of Benzene Removed (kg/year)
CA	Cost of the Packed Bed (Dollars)
CAVP	Cost of Beds, Valves, and Packings (Dollars)
CB	Concentration of Benzene in Outlet Gas (g/cu.cm)
CCOMP	Cost of a Compressor (Dollars)
CF	Concentration of Benzene in Feed Gas (g/cu.cm)
CP	Packing Cost (Dollars)
CSD	Cost of the Drum (Dollars)
CSTM	Cost of Steam (Dollars)
CV	Valve Cost (Dollars)
D	Diffusivity of the Gas (sq.cm/hr)
DIABED	Diameter of the Bed

TABLE B .4-3 (Cont.)

Program Symbols	Explanations
DP	Diameter of a Particle (cm)
DT	Diameter of the Bed (cm)
DTA	Diameter of the Bed (cm)
EP	Void Fraction in Packed Bed (-)
F	Correlated Friction Factor (-)
G	Molar Gas Flow Rate (lb-moles/hr-bed)
GAMMA	Packing Density of Activated Carbon in Packed Bed (g/cu.cm)
GC	Conversion Factor of Gravitational Force (980X3600X3600)
GTOTAL	Total Gas Rate Treated (lb-moles/hr) (kg-cm/sq.hr)
GTOTAL	Total Gas Rate (lb-moles/hr)
HTA	Height of the Bed (ft)
NO	Total Number of the Bed
OPL	Operational Cost (Dollars)
PDP	Pressure Drop in Packed Bed (PSI)
RE	Reynolds Number of the Gas (-)
REVA	Revenue Requirement (Dollars)
RDG	Density of the Inlet Gas (g/cu.cm)
S	Cross-Sectional Area of the Bed (sq.cm)
RS	Radius of a Surge Drum (ft)
STM	Amount of Steam Required (lb/hr)
TB	Break Through Time (hr)
THA	Thickness of the Wall of the Bed (ft)

TABLE B.4-3 (Cont.)

Program Symbols	Explanations
THS	Thickness of a Surge Drum (ft)
U	Superficial Velocity of the Gas (cm/hr)
UTC	Utility Cost (Dollars)
VA	Volume of a Bed (cu.ft)
VF	Volume Rate of Feed Gas (cu.cm/hr)
VS	Volume of a Surge Drum (ft)
VSOUT	Volume of Outside of a Surge Drum (cu.ft)
WS	Weight of a Surge Drum (cu.ft)
Z	Height of the Bed (ft)
ZA	Height of Mass Transfer Zone (ft)

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```
C      OPTIMIZATION OF ACTIVATED CARBON BED
C      EFFECT ON REVENUE COST WITH CHANGE IN NUMBER OF BEDS
0001          CE=0.0000226
0002          ANU=0.000177*3600.
0003          EP=0.32
0004          E=0.001052*3600.
0005          CF=0.0006775
0006          ANN=3.177C
0007          EP=0.4
0008          CC=580.*3600.**2
0009          GAMMA=0.41
0010          N=1
0011          AN=1.
0012          TE=AN
0013          DT=30.48*3.
0014          I=1
0015       96 IF(1-2)93,94,95
0016       93 PRINT 85
0017       85 FORMAT(1HC,/// 1CX,6HCASE 1 )
0018          QC=4015C.
0019          VF=6204.7*100.**3
0020          RCG=0.0406
0021          ANW=13.82
0022          P=1048.
0023          GO TO 92
0024       94 PRINT 90
0025       90 FORMAT(1HC,/// 1CX,6HCASE 2 )
0026          QC=4814C.
0027          VF=7426.0*100.**3
0028          RCG=0.0362
0029          ANW=12.30
0030          P=1088.
0031          GO TO 92
0032       95 PRINT 91
0033       91 FORMAT(1HC,/// 1CX,6HCASE 3 )
0034          QC=6738C.
0035          VF=10398.9*100.**3
0036          RCG=0.0318
0037          ANW=10.81
0038          P=1048.
```

```
CC39              GO TO 92
CC40           92 PRINT 100,  RCG,AMW,TB,CF,CB,AML,DP,D,ANM,EP,GC,GAMMA
CC41          100 FORMAT(1HC,3X,4HRCG=E11.5,3X,4HAML=E11.5,
                 14X,3HTB=E11.5,4X,3HCF=E11.5/5X,3HCB=E11.5,
                 23X,4HAML=E11.5,4X,3HDP=E11.5,5X,2HD=E11.5/4X,4HANM=E11.5,
                 34X,3HEP=E11.5,4X,3HGC=E11.5,1X,6HGAMMA=E11.5)
CC42          102 C=GG/AN
CC43           10 S=0.785*DT**2
CC44              L=C*454.*AMW/(S*RCG)
CC45              RE=DP*C*454.*AMW/(S*AML)
CC46              AKFAV=3.11027*RE**0.4774*D/DP**2/2.
CC47              ZA=L*ANM/AKFAV*0.02281
CC48              Z=(L*TB/1075./GAMMA)*0.02281+ZA/2.
CC49              F=150.*(1.-EP)/RE+1.75
CC50              FDP=F*C*454.*AMW/S*L/GC/DP*(1.-EP)/EP**3*Z*0.01422/0.032 1
CC51              IF(FDP-0.5)98,98,97
CC52           97 DT=DT+30.48*0.1
CC53              GO TO 10
CC54           98 NC=INT(2.*AN)
CC55              EZN=(CF-CB)*VF*8200./1000.
CC56              STM=EZN*3.62*2.2046/8200.
CC57              CSTM=STM*0.15/1000.*8200.
CC58              DIAREC=DT/30.48
CC59              PRINT 101,S,L,RE,AKFAV,F,FDP,ZA,Z,EZN,STM,GC
CC60          101 FORMAT(1HC,5X,2HS=E11.5,
                 45X,2HL=E11.5,4X,3HRE=E11.5,1X,6HAKFAV=E11.5/6X,2HF=E11.5
                 53X,4HFDP=E11.5,4X,3HZA=E11.5,5X,2HZ=E11.5/4X,
                 64HEZN=E11.5,3X,4HSTM=E11.5,4X,3HGC=E11.5)
                C     COST OF ACTIVATED CARBON BED
CC61              DT=(S/(0.785    ))**0.5
CC62              HTA=Z+4.
CC63              DTA=DT*0.02281
CC64              THA=0.03639*DTA+1./48.
CC65              CA=566.325*FLOAT(NC)*(((DTA+2.*THA)**2-DTA**2)*HTA+
                 12.*THA*(1.346*DTA)**2)
CC66              CV=4000.*FLOAT(NC)+4000.*FLOAT(NC)
CC67              CP=0.785*DTA**2*Z*0.5*12.3*FLOAT(NC)
CC68              CAVP=CA+CV+CP
CC69              DIAREC=DT/30.48
                C     COST OF A SURGE DRUM AND A COMPRESSOR
CC70              VA=0.785*DT**2*Z*EP/30.48**2
CC71              VS=(1061.*VA-14.7*VA)/14.7
CC72              RS=(3.*VS/4./3.14)**(1./3.)
CC73              THS=(12.*1061.*RS/(2.*15105.-0.2*P)+0.25)/12.
CC74              VSCLT=4.*3.14*(RS+THS)**3/3.
CC75              HS=450.*(VSCLT-VS)
CC76              CSD=0.5*3.*HS
CC77              BS=560.*0.0643*VS    /(60.*4.)/(0.8*0.240)/
```

```
                1520.*((1C61./14.7)**C.24C-1.)
CC78              CCCMP=656.*BS**C.61
CC79          6CC FRINT 3CC,DIABEC,C,NC,TP,VA,VS,RS,THS,VSCLT,WS,BS
CC8C          3CC FORMAT(    1X,7HDIABEC=E11.5,5X,2HC=E11.5,4X,3HNC=I3,
               11CX,3HTE=E11.5/5X,3HVA=E11.5,4X,3HVS=E11.5,4X,3HRS=E11.5,
               23X,4HTHS=E11.5/2X,6HVSCLT=E11.5,4),3HWS=E11.5,4X,3HBS=E1 .
CC81              FRINT 2CC,CA,CV,CP,CAVP ,CSC,CCCMP,CSTM
CC82          2CC FORMAT(5X,3HCA=E11.5,4X,3HCV=E11.5,4X,3HCP=E11.5,
               12X, 5HCAVP=E11.5/4X,4HCSC=E11.5,1X,6HCCCMP=E11.5,2X,
               25HCSTM=E11.5)
CC83              RAWM=C.
CC84              CPL=6C.
CC85              CLM=C.
CC86              LTC=CSTM/1CCC.+C.C1*C.75*BS*62CC./1CCC.
CC87              BCCS=(CA+CV+CP)/1CCC.+(CSC+CCCMP)/1CCC.
CC88              CALL CCST(REVA,BCCS,CCM,CPL,LTC)
CC89              FRINT 5C2,REVA,BCCS,CPL,CCM,LTC
CC9C          5C2 FORMAT(3X,1CHCCST IN $M/4X,4HREVA,1CX,4HBCCS,1CX,
               13HCPL,11X,3HCCM,11X,3HLTC/3X,5E14.5)
CC91              IF(AN-11.)16,15,15
CC92           16 AN=AN+1.
CC93              1B=AN
CC94              DT=3C.48*3.
CC95              GC TC 1C2
CC96           15 IF(I-2)11,11,14
CC97           11 I=I+1
CC98              AN=1.
CC99              TE=AN
C1CC              DT=3C.48*3.
C1C1              GC TC 56
C1C2           14 STCP
C1C3              END
```

```
CCC1            SUBROUTINE COST(REVA,ECCS,CDM,CPL,LTC)
                C     AGA ACCOUNTING PROCEDURE HVL
CCC2            DATA RAWM,SFM,EPCR,BTL,SF,DEBT,RATE,TAX,XINT/4*0.,0.55,
               1C.65,0.07,0.5,0.05/
CCC3            CCH=ECCS*0.0773
CCC4            EINT=XINT*(CCH+ECCS)
CCC5            FINV=ECCS+CCH+EINT
CCC6            AMNT=.03*(ECCS-SFM)
CCC7            SLP=AMNT*0.15
CCC8            SPRV=0.10*CPL
CCC9            PYR=(CPL+SPRV)*0.10
CC10            PLT=(CPL+SPRV+AMNT+SLP)*0.5
CC11            DEP=FINV*0.05
CC12            TI=FINV*0.03
CC13            RAWMF=SF*RAWM
CC14            CDMF=SF*CDM
CC15            EPCRF=SF*EPCR
CC16            PRST=RAWMF+CDMF+CPL+AMNT+SLP+SPRV+PYR+PLT+DEP+TI
CC17            CONT=PRST*0.02
CC18            CPCCS=PRST+CONT-EPCRF+LTC
CC19            WCAP=0.
CC20            WCCAP=0.
CC21            VTRY=(RAWM+CDM)/12.0
CC22            ITEST=10
CC23            J=0
CC24         12 DFINV=FINV
CC25            DCAP=(FINV+WCAP)*DEBT
CC26            DRT=DCAP*0.05
CC27            DCAP=DCAP+DRT
CC28            REVA=0.
CC29            FITA=0.
CC30            RETA=0.
CC31            PROA=0.
CC32            AINTA=0.
CC33            DO 10 I=1,20
CC34          3 DFINV=DFINV-0.05*FINV
CC35            RET=(DFINV+WCAP)*RATE
CC36            DCAP=DCAP-DRT
CC37            AINT=DCAP*XINT
CC38            FIT=(RET-AINT)*TAX/(1.-TAX)-0.65
CC39            REV=RET+FIT+CPCCS
CC40            REVA=REVA+REV
CC41            IF(ITEST)10,11,10
CC42         11 RETA=RETA+RET
CC43            FITA=FITA+FIT
CC44            PROA=0.
CC45            AINTA=AINTA+AINT
CC46         10 CONTINUE
```

```
CC47                REVA=REVA/2C.
CC48                IF(ITEST)14,13,14
CC49             13 RETA=RETA/2C.
CC5C                FITA=FITA/2C.
CC51                FRCA=FRCA/2C.
CC52                AINTA=AINTA/2C.
CC53                CRAWM=RAWM/12.
CC54                RETURN
CC55             14 AREC=REVA/(12.*SF)
CC56                WCAP=VTRY+AREC
CC57                ITEST=(WCAP-WCCAP)/1C.
CC58                WCCAP=WCAP
CC59                GC TC 12
CC6C                END
```

B.5 Methanation

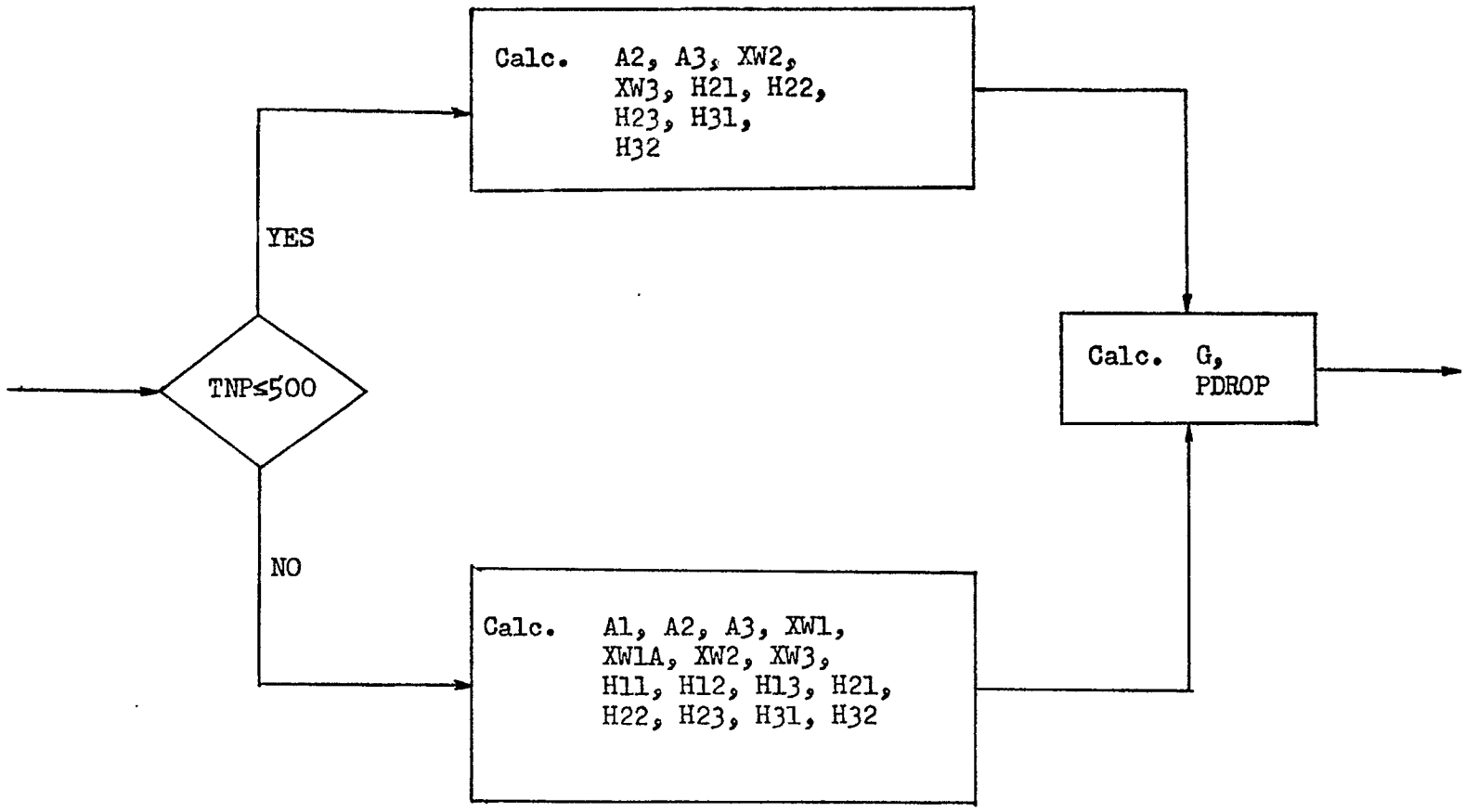

FIGURE B.5-1 COMPUTER FLOW DIAGRAM FOR HEAT EXCHANGERS

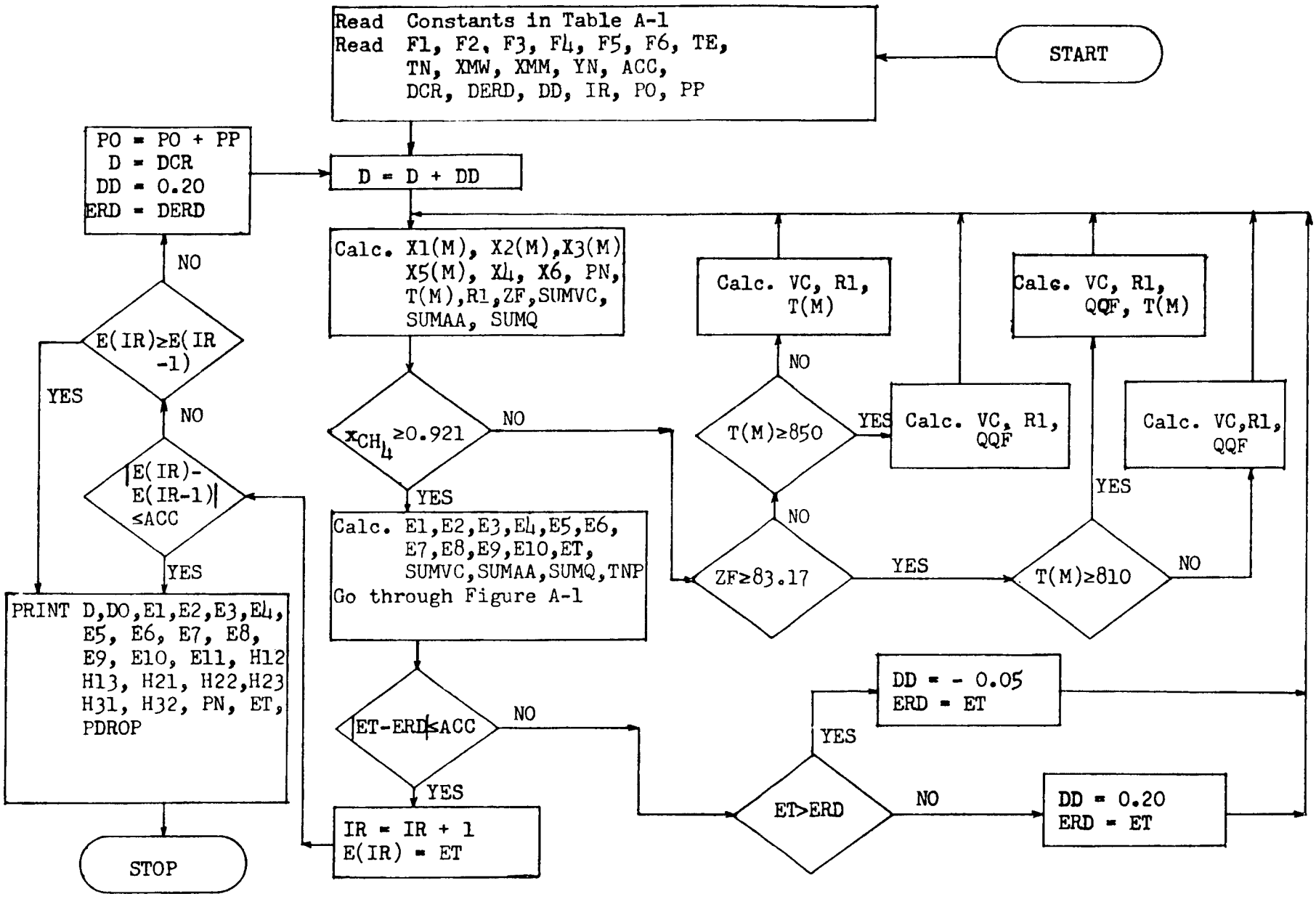

FIGURE B.5-2 COMPUTER FLOW DIAGRAM IN HIGH CO CASE FOR HEAT EXTRACTION SYSTEM

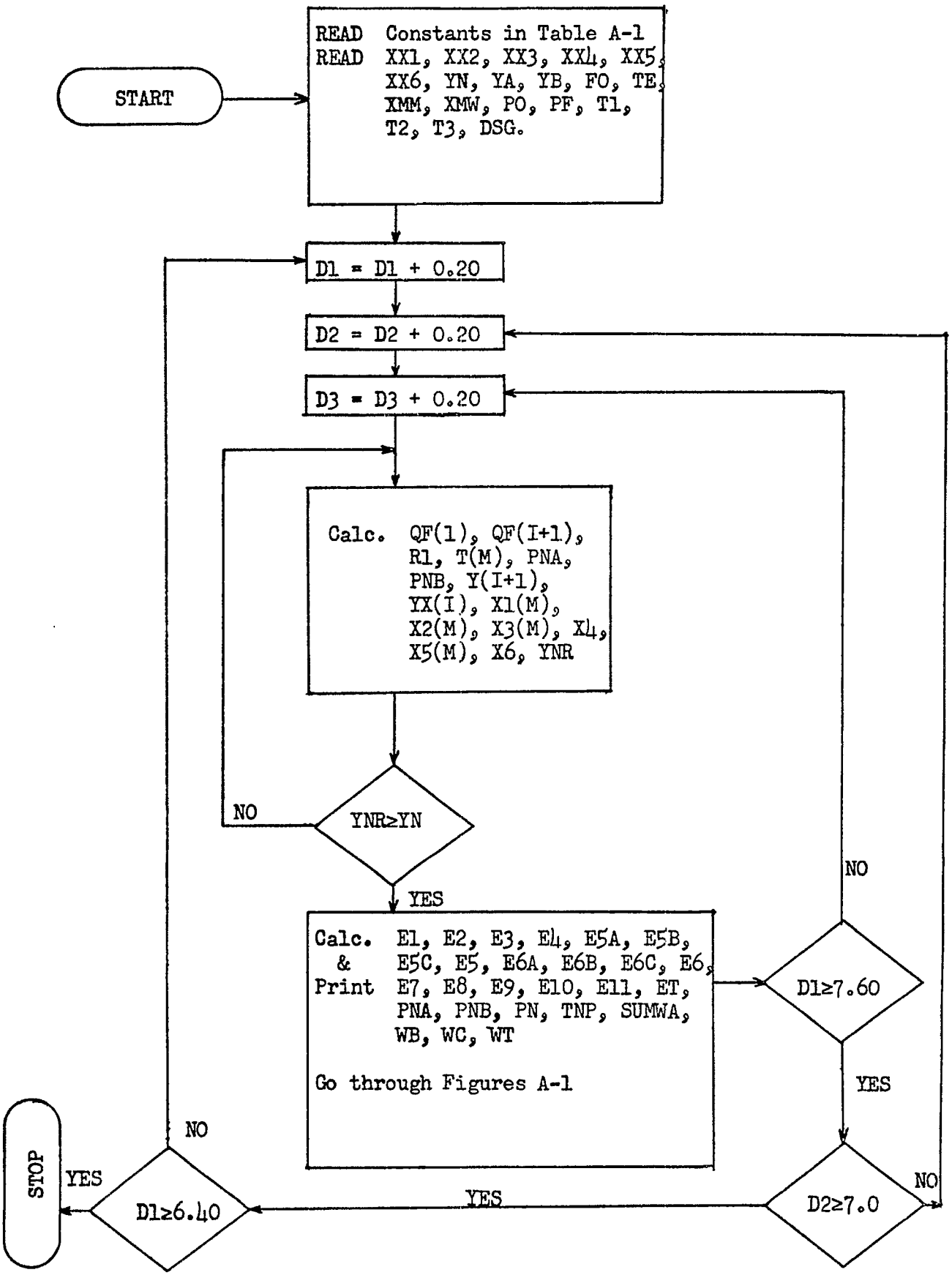

FIGURE B.5-3 COMPUTER FLOW DIAGRAM IN HIGH CO CASE FOR COLD QUENCH SYSTEM

TABLE B.5-1 PROGRAM SYMBOLS AND NUMERICAL CONSTANTS

Program Symbols	Explanations	Mathematical Symbols
CL	Unit cell length, 1 inch	C_L'
CNT	Number of cells per tray, 40	
COCW	Cost of spent water, \$0.05/1000 gallons	C_2
COHS	Cost of 400 psia steam, \$0.30/1000 lbs.	C_3
COLS	Cost of 35 psia steam, \$0.15/1000 lbs.	C_4
COPW	Cost of treated water, \$0.12/1000 gallons	C_1
DI	Outside diameter of fin tubes, 1 inch	
DP	Particle diameter of catalyst, 1/4 inches	d_p
DSC	Catalyst density, 71 lb./ft.^{3}	ρ_c
EV	Packed voidage of sphere, 0.38	ϵ
GCH	Gravitational constant, 4.17 x 10^8 ft./hr.^{2}	
HCA	Distance between tubes, 0.0208 ft.	
HDB	Distance between baffles in heat exchangers, 4 ft.	B'
HDI	Inside tube diameter in heat exchangers, 0.0516 ft.	D_i
HDO	Outside tube diameter in heat exchangers, 0.0625 ft.	
HHR	Hydraulic radius of tube banks in heat exchangers, 0.0792 ft.	D_e
HPL	Pitch length in heat exchangers, 0.0834 ft.	
HZ	Vaporization heat of saturated water at 445°F, 780.4 B.t.u./lb.	λ_c
T1	Temperature entering the top of the reactor, 550°F	$T^{(1)}$

TABLE B.5-1(CONT.)

Program Symbols	Explanations	Mathematical Symbols
TCC	Inlet temperature of spent water, 85°F	t_c
TC1	Outlet temperature of the product gas cooler I, 445°F	t_{c1}
TC2	Outlet temperature of the product gas cooler II, 260°F	t_{c2}
TC3	Outlet temperature of the product gas cooler III, 150°F	t_{c3}
TF	Feed temperature, 100°F	T^F
TN	Outlet reactor temperature, 850°F	T^N
TNP2	Product gas temperature after product gas cooler I, 460°F	T^I
TNP3	Product gas temperature after product gas cooler II, 270°F	T^{II}
UC1	Overall heat transfer coefficient of product gas cooler I, 85 B.t.u./hr.ft.^{2}°F	U^I
UC2	Overall heat transfer coefficient of product gas cooler II, 90 B.t.u./hr.ft.^{2}°F	U^{II}
UC3	Overall heat transfer coefficient of product gas cooler III, 80 B.t.u./hr.ft.^{2}°F	U^{III}
UIC	Overall heat transfer coefficient of intermediate cooler, 85 B.t.u./hr.ft.^{2}°F	
UO	Overall heat transfer coefficient of fin tubes 11.0 B.t.u./hr.ft.^{2}°F	U_o
UP	Overall heat transfer coefficient of preheater, 70 B.t.u./hr.ft.^{2}°F	U_p
VI	Gas viscosity, 0.0484 lb./ft.hr	μ
Z	Unit fin tube length, 25 ft.	

TABLE B.5-2 PROGRAM SYMBOLS AND EXPLANATIONS IN THE HEAT EXCHANGER PROGRAM

Program Symbols	Explanations	Mathematical Symbols
A1	Total heat transfer surface area of the product gas cooler I, $ft.^2$	A^I
A2	Total heat transfer surface area of the product gas cooler II, $ft.^2$	A^{II}
A3	Total heat transfer surface area of the product gas cooler III, $ft.^2$	A^{III}
G	Assumed maximum mass flow rate of gas, $lbs./ft.^2hr.$	G_S
H11	Cost of the product gas cooler I, $	
H12	Cost of treated water in the product gas cooler I, $/hr.	
H13	Cost of steam generated in the product gas cooler I, $/hr.	
H21	Cost of the product gas cooler II, $	
H22	Cost of treated water in the product gas cooler II, $/hr.	
H23	Cost of steam generated in the product gas cooler II, $/hr.	
H31	Cost of the product gas cooler III,$	
H32	Cost of spent water in the product gas cooler III,$/hr.	
PDROP	Maximum pressure drop through three product gas coolers, psi	ΔP_s
XW1	Rate of 400 psia steam in the product gas cooler I, lbs./hr.	
XW1A	Flow rate of treated water in the product gas cooler I, lbs./hr.	
XW2	Flow rate of treated water in the product gas cooler II, lbs./hr.	
XW3	Flow rate of spent water in the product gas cooler III, lbs./hr.	W_2

TABLE B.5-3 PROGRAM SYMBOLS AND EXPLANATIONS IN HIGH CO CASE FOR HEAT EXTRACTION SYSTEM

Program Symbols	Explanations	Mathematical Symbols
ACC	Required accuracy for searching the optimum equipment cost, $	
D	Reactor diameter, ft.	D
DCR	Initially assumed reactor diameter, ft.	
DD	Increment of reactor diameter, ft.	
DERD	Initially assumed total equipment cost, $	
DSG	Gas density varied with operating pressure, lb./ft.^{3}	ρ
E1	Fin tube cost, $	E_F
E2	Catalyst cost, $	E_C
E3	Reactor cost, $	E_R
E4	Tray cost, $	E_{ST}
E5	Control valve cost, $	
E6	Treated water cost, $/hr.	
E7	Steam cost, $/hr.	
E8	Feed compressor cost, $	E_{cp}
E9	Product gas compressor cost, $	E_{cp}
E10	Preheater cost, $	
ET	Total equipment cost, $	E_T
F1	Molar flow rate of CH_4 in feed, lb.moles/hr.	F_1^0
F2	Molar flow rate of CO in feed, lb.moles/hr.	F_2^0
F3	Molar flow rate of H_2 in feed, lb.moles/hr.	F_3^0

TABLE B.5-3 (CONT.)

Program Symbols	Explanations	Mathematical Symbols
F4	Molar flow rate of CO_2 in feed, lb.moles/hr.	F_4^0
F5	Molar flow rate of H_2O in feed, lb.moles/hr.	F_5^0
F6	Molar flow rate of N_2 in feed, lb.moles/hr.	F_6^0
P1	Molar flow rate of CH_4 in product, lb.moles/hr.	
P2	Molar flow rate of CO in product, lb.moles/hr.	
P3	Molar flow rate of H_2 in product, lb.moles/hr.	
P4	Molar flow rate of CO_2 in product, lb.moles/hr.	
P5	Molar flow rate of H_2O in product, lb.moles/hr.	
P6	Molar flow rate of N_2 in product, lb.moles/hr.	
PD	Increment of pressure, psi	
PF	Feed gas pressure, pisa	
PN	Product gas pressure, psia	P^N
PO	Operating pressure, psia	P^0
R1	Reaction rate, lb.moles of CH_4 formed/lb.cata.,hr.	r_{CH_4}
SUMVC	Total catalyst weight, lbs.	
SUMAA	Total heat transfer surface area of fin tubes based on bare tube, $ft.^2$	
SUMQ	Total amount of heat removed by fin tubes, B.t.u./hr.	
T(M)	Gas temperature at (n-1) th cell, °F	T^{n-1}
TE	Exit reactor temperature, °F	T^E
TNP	Product gas temperature after preheater, °F	T^P

TABLE B.5-3 (CONT.)

Program Symbols	Explanations	Mathematical Symbols
x_{CH_4}	Composition of CH_4, mole %	
X1(M)	Molar flow rate of CH_4 in (n-1) th cell, lb.moles/hr.	F_1^{n-1}
X2(M)	Molar flow rate of CO in (n-1) th cell, lb.moles/hr.	F_2^{n-1}
X3(M)	Molar flow rate of H_2 in (n-1)th cell, lb.moles/hr.	F_3^{n-1}
X4	Molar flow rate of CO_2 in (n-1)th cell, lb.moles/hr.	F_4^{n-1}
X5(M)	Molar flow rate of H_2O in (n-1)th cell, lb.moles/hr.	F_5^{n-1}
X6	Molar flow rate of N_2 in (n-1)th cell, lb.moles/hr.	F_6^{n-1}
XMW	Average molecular weight of gas	$\bar{M}$
XMM	Feed gas molecular weight	
YN	Conversion of CO to CH_4	Y^N
ZF	Mass action law ratio of product gas in methanation reaction	K_{x1}

TABLE B.5-4 PROGRAM SYMBOLS AND EXPLANATIONS IN HIGH CO CASE FOR COLD QUENCH SYSTEM

Program Symbols	Explanations	Mathematical Symbols
D1	First reactor diameter, ft.	
D2	Second reactor diameter, ft.	
D3	Third reactor diameter, ft.	
DSG	Gas density varied with operating pressure, lb./ft.^{3}	ρ
E1	Preheater cost, $	
E2	Intermediate cooler I cost, $	
E3	Intermediate cooler II cost, $	
E4	Catalyst cost, $	E_C
E5	Total reactor cost, $	E_R
E5A	First reactor cost, $	
E5B	Second reactor cost, $	
E5C	Third reactor cost, $	
E6	Total tray cost, $	E_{ST}
E6A	Tray cost in first reactor, $	
E6B	Tray cost in second reactor, $	
E6C	Tray cost in third reactor, $	
E7	Control valve cost, $	
E8	Feed compressor cost, $	E_{CP}
E9	Product gas compressor cost, $	E_{CP}
E10	Treated water cost in intermediate coolers, $/hr.	

TABLE B.5-4 (Cont.)

Program Symbols	Explanations	Mathematical Symbols
E11	Steam cost in intermediate coolers, $/hr.	
ET	Total equipment cost, $	E_T
PF	Feed gas pressure, psia	
PN	Product gas pressure, psia	P^N
PNA	Exit gas pressure of first reactor, psia	
PNB	Exit gas pressure of second reactor, psia	
PO	Operating pressure, psia	P^O
QF(1)	Fraction of feed gas entering the top of the first reactor	λ_1'
QF(I+1)	Fraction of feed gas entering the first reactor at I-th quench	
R1	Reaction rate, lb.moles of CH_4 formed/lb.cata.,hr.	r_{CH_4}
SUMWA	Catalyst weight in the first reactor, lbs.	
T1	Gas temperature entering the top of the first reactor, °F	$T^{(1)}$
T2	Gas temperature entering the top of the second reactor, °F	$T^{(2)}$
T3	Gas temperature entering the top of the third reactor, °F	$T^{(3)}$
T(M)	Gas temperature at (n-1)th cell, °F	T^{n-1}
TE	Gas temperature after the third reactor,°F	T^E
TNP	Product gas temperature after preheater,°F	T^P
WB	Catalyst weight in the second reactor, lbs.	
WC	Catalyst weight in the third reactor, lbs.	

TABLE B.5-4 (Cont.)

Program Symbols	Explanations	Mathematical Symbols
WT	Total catalyst weight, lbs.	
X1(M)	Molar flow rate of CH_4 at (n-1)th cell, lb.moles/hr.	F_1^{n-1}
X2(M)	Molar flow rate of CO at (n-1)th cell, lb.moles/hr.	F_2^{n-1}
X3(M)	Molar flow rate of H_2 at (n-1)th cell, lb.moles/hr.	F_3^{n-1}
X4	Molar flow rate of CO_2 at (n-1)th cell, lb.moles/hr.	F_4^{n-1}
X5(M)	Molar flow rate of H_2O at (n-1)th cell, lb.moles/hr.	F_5^{n-1}
X6	Molar flow rate of N_2 at (n-1)th cell, lb.moles/hr.	F_6^{n-1}
XMM	Feed gas molecular weight	
XMW	Average gas molecular weight	$\bar{M}$
Y(I+1)	Conversion of CO to CH_4 after (I+1)th quench	
YA	Conversion of CO to CH_4 after the first reactor	$Y^{(2)}$
YB	Conversion of CO to CH_4 after the second reactor	$Y^{(3)}$
YN	Total conversion of CO to CH_4	Y^N
YNR	Conversion of CO to CH_4	
YX(I)	Conversion of CO to CH_4 before (I+1)th quench	

TABLE B.5-5 COMPUTER PROGRAM IN HIGH CO CASE FOR HEAT EXTRACTION SYSTEM

```
      DIMENSION X1(721),X2(721),X3(721),X5(721),X7(721),T(721)
      DIMENSION S(721),TNF(80),E(100)
 5002 FORMAT(4F7.2/4E10.3)
 5003 FORMAT(6F10.3/6F10.3)
 5004 FORMAT(//10X,6F10.3/10X,6F10.3)
 5005 FORMAT(//14X,8E14.7/14X,8E14.7/14X,7E14.7)
 5006 FORMAT(6F10.6)
 5007 FORMAT(9F8.4/F8.4,3E10.5)
 5008 FORMAT(6F10.6)
 5009 FORMAT(E10.5,2F10.2)
      READ(5,5007)DSC,EV,HV,HZ,VI,Z,CNT,UO,TI,TF,GCH,DP,DI
      READ(5,5003)P1,P2,P3,P4,P5,P6,F1,F2,F3,F4,F5,F6
      WRITE(6,5004)P1,P2,P3,P4,P5,P6,F1,F2,F3,F4,F5,F6
      READ(5,5006) HDI,HDC,HPL,HCA,HHR,HDS
      READ(5,5002)TCC,TC1,TC2,TC3,COP%,COC%,COLS,COHS
      READ(5,5008) TE,TN,XM%,YN,XMM
      FTND=0.20
      READ(5,5009) DERD,DCR,ACC
      PO=600.
      PD=100.
      DD=0.20
      ERD=DERD
      D=DCR
    5 D=D+DD
      DSG=0.016875*PO/14.70
      PF=PO
      CL=1./12.
      V=3.14*D**2*CL/4.0
      SUMVC=0.0
      SUMAA=0.0
      SUMG=0.0
      PRES=0.0
      II=0
      I=0
      J=0
      IR=1
      E(1)=DERD
      XF=F1+F2+F3+F4+F5+F6
      XFM%=XF*XMM
      G=4.0*XMM*XF/(3.1415*D**2)
      GU=150.*(1.-EV)*VI/(DP**3)+1.75
      GD=(EV**3/(1.-EV))*(DP/CL)*(GCH*DSG/G**2)
      GT=GU/(GD*144.0)
      X7(1)=PO
      X1(1)=F1
      X2(1)=F2
      X3(1)=F3
      X4=F4
      X5(1)=F5
      X6=F6
      T(1)=T1
      M=1
   35 M=M+1
      IF(II-0) 43,36,43
```

```
 36 IF(T(M-1)-850.) 40,42,42
 40 VC=V*(1.-EV)
    GO TO 50
 42 VFF=0.6*V
    FTN=2.4*V/(3.1416*(D1+0.50/12.)**2*Z)
    VC=0.248*V
    VF=0.1353542*FTN
    CSA=3.1416*D**2*((V-VF)/V)/4.0
    XX=X1(M-1)+X2(M-1)+X3(M-1)+X4      +X5(M-1)+X6
    G=XMW*XX/CSA
    CL=0.4*V/CSA
    GU=150.*(1.-EV)*V1/(DP*G)+1.75
    GD=(EV**3/(1.-EV))*(DP/CL)*(GCH*DSG/G**2)
    GT=GU/(GD*144.0)
    AA=35.3744*D1*Z*FTN
    QQF=U0*AA*405.
    RR1=0.0
    RC2=X2(M-1)
    RC3=X3(M-1)
    CALL RATE(R1    ,X2(M-1),X3(M-1),X7(M-1),XX,T(M-1))
    GO TO 760
755 CALL RATE(R1,X2(M),X3(M),X7(M),XX,T(M-1))
760 X1(M)=X1(M-1)+DSC*VC*R1
    X2(M)=X2(M-1)-DSC*VC*R1
    X3(M)=X3(M-1)-3.0*DSC*VC*R1
    X5(M)=X5(M-1)+DSC*VC*R1
    X7(M)=X7(M-1)-GT
    IF(ABS(X2(M)-RC2)-0.001    ) 765,765,770
765 IF(ABS(X3(M)-RC3)-0.001    ) 775,775,770
770 XX=X1(M)+X2(M)+X3(M)+X4    +X5(M)+X6
    RC2=X2(M)
    RC3=X3(M)
    GO TO 755
775 H1=93845.75
    QQ=DSC*VC*H1*R1
    IF(QQF-QQ)  780,43,43
780 VC=QQF/(DSC*H1*R1)
    CL=(VC/0.627)/CSA
    GU=150.*(1.-EV)*V1/(DP*G)+1.75
    GD=(EV**3/(1.-EV))*(DP/CL)*(GCH*DSG/G**2)
    GT=GU/(GD*144.0)
    GO TO 790
785 CALL RATE(R1,X2(M),X3(M),X7(M),XX,T(M-1))
790 X1(M)=X1(M-1)-DSC*VC*R1
    X2(M)=X2(M-1)-DSC*VC*R1
    X3(M)=X3(M-1)-3.0*DSC*VC*R1
    X5(M)=X5(M-1)+DSC*VC*R1
    X7(M)=X7(M-1)-GT
    IF(ABS(RR1-R1)-0.001  ) 800,800,795
795 VC=QQF/(DSC*H1*R1)
    RR1=R1
    XX=X1(M)+X2(M)+X3(M)+X4    +X5(M)+X6
    G=XMW*XX/CSA
    CL=(VC/0.62)/CSA
    GU=150.*(1.-EV)*V1/(DP*G)+1.75
    GD=(EV**3/(1.-EV))*(DP/CL)*(GCH*DSG/G**2)
```

```
      GO TO 785
  800 T(M)=850.
      AFIN=3.1416*DI*Z*FTN
      SUMVC=SUMVC+VC
      SUMAA=SUMAA+AFIN
      SUMQ=SUMQ+QQF
      GO TO 35
   43 FTN=2.80
      II=II+1
   45 VFF=3.1416*(DI+0.80/12.)**2*Z*FTN/4.0
      VC=(V-VFF)*(1.0-EV)
      VF=3.1416*DI**2*Z*FTN/4.0
      CSA=3.1416*D**2*((V-VF)/V)/4.0
      XX=X1(M-1)+X2(M-1)+X3(M-1)+X4       +X5(M-1)+X6
      G=XMW*XX/CSA
      CL=(VC/(1.-EV))/CSA
      GU=150.*(1.-EV)*VI/(DP*G)+1.75
      GD=(EV**3/(1.-EV))*(DP/CL)*(GCH*DSG/G**2)
      GT=GU/(GD*144.0)
   50 XX=X1(M-1)+X2(M-1)+X3(M-1)+X4       +X5(M-1)+X6
      RC2=X2(M-1)
      RC3=X3(M-1)
      CALL RATE(R1    ,X2(M-1),X3(M-1),X7(M-1),XX,T(M-1))
      GO TO 60
   55 CALL RATE(R1,X2(M),X3(M),X7(M),XX,T(M-1))
   60 X1(M)=X1(M-1)+DSC*VC*R1
      X2(M)=X2(M-1)-DSC*VC*R1
      X3(M)=X3(M-1)-3.0*DSC*VC*R1
      X5(M)=X5(M-1)+DSC*VC*R1
      X7(M)=X7(M-1)-GT
      IF(ABS(X2(M)-RC2)-0.001    ) 65,65,70
   65 IF(ABS(X3(M)-RC3)-0.001    )75,75,70
   70 XX=X1(M)+X2(M)+X3(M)+X4    +X5(M)+X6
      RC2=X2(M)
      RC3=X3(M)
      GO TO 55
   75 IF(T(M-1)-850.) 80,85,85
   80 YM1=(X1(M-1)-X1(1))/XF
      CPP=0.493+0.00044*T(M-1)
      CPR=0.625+0.00038*T(M-1)
      CPN1=(1.-YM1/YN)*CPR+YM1*CPP/YN
      XXN1=XFMW*CPN1
      RTEMP=T(M-1)
      YM2=(X1(M)-X1(1))/XF
      H1=87787.8+11.57*T(M-1)-0.00858*T(M-1)**2
      GO TO 82
   81 CPP=0.493+0.00044*T(M)
      CPR=0.625+0.00038*T(M)
      H1=87787.8+11.57*T(M)-0.00858*T(M)**2
   82 CPN2=(1.-YM2/YN)*CPR+YM2*CPP/YN
      XXN2=XFMW*CPN2
      HH=DSC*VC*H1*R1
      T(M)=(XXN1*T(M-1)+HH)/XXN2
      IF(ABS(T(M)-RTEMP)-0.1)   84,84,83
   83 RTEMP=T(M)
      GO TO 81
```

```
      DXMM=X1(M)+X2(M)+X3(M)+X4+X6
      COM=X1(M)/DXMM
      IF(COM-0.921)   85,146,146
   85 T(M)=950.
      H1=92845.75
      QQ=DSC*VC*H1*R1
      AA=35.3744*DI*Z*FTN
      QQF=UO*AA*(T(M)-445.)
      IF(QQF-QQ)   89,90,90
   89 FTN=FTN+FIND
      GO TO 45
   90 I=I+1
      TNF(I)=FTN
      N=I
      ZY=XX**2*X1(M)*X5(M)/(X2(M)*X3(M)**3)
      ZAHA=0.90-0.000185*X7(M)
      ZF=ZY*ZAHA*(14.7/X7(M))**2
      DXMM=X1(M)+X2(M)+X3(M)+X4+X6
      COM    =X1(M)/DXMM
      IF(COM    -0.921) 95,100,100
   95 IF(ZF-83.17)   95,97,97
   96 IF(I-40)  35,100,100
   97 PRES=7.0
  100 STNF=0.0
      DO 105 I=1,N
  105 STNF=STNF+TNF(I)
      TNN=N
      FTN=STNF/TNN
      K=M
      M=M-N
      VF=3.1416*DI**2*Z*FTN/4.0
      VFF=3.1416*(DI-0.80/12.)**2*Z*FTN/4.0
      VC=(V-VFF)*(1.0-EV)
      CSA=3.1416*D**2*((V-VF)/V)/4.0
      XX=X1(M-1)+X2(M-1)+X3(M-1)+X4       -X5(M-1)+X6
      G=XMW*XX/CSA
      CL=(VC/(1.-EV))/CSA
      GU=150.*(1.-EV)*VI/(DP*G)+1.75
      GD=(EV**3/(1.-EV))*(DP/CL)*(SCH*DSO/G**2)
      GT=GU/(GD*144.0)
      AFIN=3.1415*DI*Z*FTN
  110 M=M+1
      XX=X1(M-1)+X2(M-1)+X3(M-1)+X4       +X5(M-1)+X6
      RC2=X2(M-1)
      RC3=X3(M-1)
      CALL RATE(R1    ,X2(M-1),X3(M-1),X7(M-1),XX,T(M-1))
      GO TO 120
  115 CALL RATE(R1,X2(M),X3(M),X7(M),XX,T(M-1))
  120 X1(M)=X1(M-1)+.05C*VC*R1
      X2(M)=X2(M-1)-DSC*VC*R1
      X3(M)=X3(M-1)-3.0*DSC*VC*R1
      X5(M)=X5(M-1)+DSC*VC*R1
      X7(M)=X7(M-1)-GT
      IF(ABS(X2(M)-RC2)-0.001    )125,125,130
  125 IF(ABS(X3(M)-RC3)-0.001    )135,135,130
  130 AX=X1(M)-X2(M)+X3(M)+X4    -X5(M)-X6
```

```
      RC3=X3(M)
      GO TC 115
  135 T(M)=850.
      H1=93845.75
      J=J+1
      NN=J
      G(J)=DSC*VC*H1*R1
      SUMVC=SUMVC+VC
      SUMAA=SUMAA+AFIN
      IF(M-K) 110,137,137
  137 IF(PRES-0.0) 901,138,901
  138 I=0
      GO TO 35
  901 M=M+1
      VFF=0.6*V
      FTN=2.4*V/(3.1416*(DI+0.80/12.)**2*Z)
      VC=0.248*V
      VF=0.1360542*FTN
      CSA=3.1416*D**2*((V-VF)/V)/4.0
      XX=X1(M-1)+X2(M-1)+X3(M-1)+X4      +X5(M-1)+X6
      G=XMW*XX/CSA
      CL=0.4*V/CSA
      GU=150.*(1.-EV)*VI/(DP*G)+1.75
      GD=(EV**3/(1.-EV))*(DP/CL)*(GCH*DSG/G**2)
      GT=GU/(GD*144.0)
      AA=38.3744*DI*Z*FTN
      GQF=UC*AA*(T(M-1)-445.)
      RC2=X2(M-1)
      RC3=X3(M-1)
      CALL RATE(R1    ,X2(M-1),X3(M-1),X7(M-1),XX,T(M-1))
      GO TO 960
  955 CALL RATE(R1,X2(M),X3(M),X7(M),XX,T(M-1))
  960 X1(M)=X1(M-1)+DSC*VC*R1
      X2(M)=X2(M-1)-DSC*VC*R1
      X3(M)=X3(M-1)-3.0*DSC*VC*R1
      X5(M)=X5(M-1)+DSC*VC*R1
      X7(M)=X7(M-1)-GT
      IF(ABS(X2(M)-RC2)-0.001    ) 965,965,970
  965 IF(ABS(X3(M)-RC3)-0.001    ) 975,975,970
  970 XX=X1(M)+X2(M)+X3(M)+X4    +X5(M)+X6
      RC2=X2(M)
      RC3=X3(M)
      GO TO 955
  975 H1=87737.5+11.87*T(M-1)-0.00558*T(M-1)**2
      YM1=(X1(M-1)-X1(1))/XF
      CPP=0.493+0.000444*T(M-1)
      CPR=0.625+0.000386*T(M-1)
      CPN1=(1.-YM1/YN)*CPR+YM1*CPP/YN
      XXN1=XFW*CPN1
      RTEMP=T(M-1)
      YM2=(X1(M)-X1(1))/XF
      GO TO 982
  981 CPP=0.493+0.000444*T(M)
      CPR=0.625+0.000386*T(M)
      H1=87787.5+11.87*T(M)-0.00558*T(M)**2
  982 CPN2=(1.-YM2/YN)*CPR+YM2*CPP/YN
      XXN2=XFW*CPN2
```

```
      HH=DSC*VC*H1*R1
      QH=QQF-HH
      T(M)=(XXN1*T(M-1)-QH)/XXN2
      IF(ABS(T(M)-RTEMP)-0.1)   984,984,983
  983 RTEMP=T(M)
      GO TO 981
  984 J=J+1
      NN=J
      Q(J)=QQF
      SUMVC=SUMVC+VC
      AFIN=3.1416*DI*Z*FTN
      SUMAA=SUMAA+AFIN
      IF(T(M)-810.)  901,602,602
  602 FTN=1.80
      M=M+1
  645 VFF=3.1416*(DI+0.20/12.)**2*Z*FTN/4.0
      VC=(V-VFF)*(1.0-EV)
      VF=3.1416*DI**2*Z*FTN/4.0
      CSA=3.1416*D**2*((V-VF)/V)/4.0
      XX=X1(M-1)+X2(M-1)+X3(M-1)+X4       +X5(M-1)+X6
      G=XW*XX/CSA
      CL=(VC/(1.-EV))/CSA
      GU=150.*(1.-EV)*VI/(DP*G)-1.75
      GD=(EV**3/(1.-EV))*(DP/CL)*(GC*DS3/G**2)
      GT=GU/(GD*144.0)
      RC2=X2(M-1)
      RC3=X3(M-1)
      CALL RATE(R1    ,X2(M-1),X2(M-1),X7(M-1),XX,T(M-1))
      GO TO 660
  655 CALL RATE(R1,X3(M),X3(M),X7(M),XX,T(M-1))
  660 X1(M)=X1(M-1)+DSC*VC*R1
      X2(M)=X2(M-1)-DSC*VC*R1
      X3(M)=X3(M-1)-3.0*DSC*VC*R1
      X5(M)=X5(M-1)+DSC*VC*R1
      X7(M)=X7(M-1)-GT
      IF(ABS(X2(M)-RC2)-0.001    ) 665,665,670
  665 IF(ABS(X3(M)-RC3)-0.001    )675,675,670
  670 XX=X1(M)+X2(M)+X3(M)+X4    +X5(M)+X6
      RC2=X2(M)
      RC3=X3(M)
      GO TO 655
  675 T(M)=810.
      H1=93741.5
      QC=DSC*VC*H1*R1
      AA=3.1416*DI*Z*FTN
      QQF=QQ+AA*Dxx.
      IF(QQF-QQ)  689,690,690
  689 FTN=FTN-FTN2
      GO TO 645
  690 J=J+1
      NN=J
      Q(J)=QQF
      SUMVC=SUMVC+VC
      AFIN=3.1416*DI*Z*FTN
      SUMAA=SUMAA+AFIN
      DXX=X1(M)+X2(M)+X3(M)+X4+X5
      CQQ=X1(M)/DXX
```

```
      IF(COM-0.921) 602,140,140
  140 DO 145 J=1,NN
  145 SUMQ=SUMQ+Q(J)
  146 PN=X7(M)
      TNN=M-1
      TNM=NN
      TMM=TNN-TNM
      E1=350.*(SUMAA/60.)**0.862*1.40*4.0
      E2=2.50*DSC*SUMVC
      PS=(PO+PN)/2.
      TH1=(PS-14.7)*D*6.0/(15105.-0.6*(PS-14.7))
      TH=TH1+0.25
      IF(PO-600.0) 155,150,150
  150 FD=16.15*D/12.
      GO TO 160
  155 FD=15.5*D/12.
  160 CL=1./12.
      E3C=CL*TNN*((D+TH/12.)**2-D**2)
      E3 =    754.37*(E3C+FD**2*TH/6.)
      E4 =    (TNN/CNT)*0.206*(D+5.0)**3.13*4.0
      E5=    4000.*TNN/CNT
      XF=F1+F2+F3+F4+F5+F6
      XP=X1(M)+X2(M)+X3(M)+X4+X5(M)+X6
      IF(PF-X7(1)) 165,180,180
  165 BF=0.004065*(TF+460.)*/F**((X7(1)/PF)**0.240-1.0)
      E8=698.*BF**0.81
      GO TO 185
  180 BF=0.0
      E8=0.0
  185 IF(PN-1014.)  190,194,194
  190 BP=0.004065*(100.+460.)*XP*((1014./PN)**0.240-1.)
      E9=698.*BP**0.81
      GO TO 195
  194 E9=0.0
  195 UP=70.*(PO/1064.7)**0.3
      UC1=65.*(PO/1064.7)**0.3
      UC2=UC1
      UC3=80.*(PO/1064.7)**0.3
      CPOP=1.+1.9371*(PO/1064.7-1.)
      CPFPF=0.625+0.000386*TF
      CPFP1=0.625+0.000386*T1
      CPPP=0.493+0.0.0444*87E.
      QP=XF*11.87*(CPFP1*T1-CPFPF*TF)
      TNP=TE-(QP/(XF*11.87*CPPP))
      TAVP=((TE-T1)-(TNP-TF))/ALOG((TE-T1)/(TNP-TF))
      AP=QP/(UP*TAVP)
      E10=880.*(AP/80.)**0.562*1.40*4.0
      E6=SUMQ*0.12/(HV*6030.)
      E7=0.30*SUMQ/(HV*1000.)
      CP=1.0
      PI=PN-1.0
      PW=PI*(X5(M)/XP)
      IF(TNP-500.) 801,802,802
  801 TNP2=TNP
      GO TO 803
  802 TNP2=450.
  803 TNP3=270.
```

```
      PV=1.176*(TNP3-250.)+35.429
      CPPF=0.493+0.000444*TF
      CPNP1=0.493+0.000444*TNP
      CPNP2=0.493+0.000444*TNP2
      CPNP3=0.493+0.000444*TNP3
      IF(PV-PW) 806,805,805
  805 QC2=XFMW*(CPNP2*TNP2-CPNP3*TNP3)
      XW2=QC2/(CPW*(TC2-TCC)+     HV)
      TM2=TNP3+(XW2*CPW/(XFMW*CPNP3))*(TC2-TCC)
      GO TO 807
  806 QC2=XFMW*(CPNP2*TNP2-CPNP3*TNP3)+HZ*((PW-PV)/PI)*18.*XP
      XW2=QC2/(CPW*(TC2-TCC)+     HV)
      RTM2=TNP3+2.
  816 RTM2=RTM2+3.0
      PVM=1.176*(RTM2-250.)+35.429
      IF(PVM-PW) 818,818,817
  817 PVM=PW
  818 TM2=TNP3+ (XW2*CPW*(TC2-TCC)-HZ*((PV-PV)/PI)*19.*XP)/(XFMW*CPNP3)
      IF(ABS(TM2-RTM2)-5.)  807,807,816
  807 IF(TNP-300.) 804,810,810
  804 A1=0.0
      H11=0.0
      H12=0.0
      H13=0.0
      GO TO 821
  810 QC1=XFMW*(CPNP1*TNP-CPNP2*TNP2)
      TCC1=(0.5*XW2*(CPW*TC1+     HV)*(TC2-TCC)+0.5*QC1*(TC1-TCC))/(QC1+0
     1.5*XW2*(TC2-TCC))
      TRC1=(TC1+TC2)/2.0
      IF(TCC1-TRC1) 823,822,822
  822 XW1A=0.0
      TCC1=TRC1
      XW1=QC1/(CPW*(TC1-TCC1)+      HV)
      GO TO 824
  823 XW1=QC1/(CPW*(TC1-TCC1)+      HV)
      XW1A=0.5*(XW1-XW2)
  824 TM1=TNP2+(XW1*CPW*(TC1-TCC1))/(XFMW*CPNP2)
      IF(TM1-TC1)  235,235,814
  814 TAV1A=((TM1-TC1)-(TNP2-TCC1))/ALOG((TM1-TC1)/(TNP2-TCC1))
      TAV1B=((TNP-TC1)-(TM1-TC1))/ALOG((TNP-TC1)/(TM1-TC1))
      A1A=(XW1*CPW*(TC1-TCC1))/(QC1*TAV1A)
      A1B=(      HV*XW1)/(QC1*TAV1B)
      A1=A1A+A1B
      H11=850.*(A1/50.)**0.62*1.40*4.0*CFOP
      H12=CCPW*XW1A
      H13=CCHE*1.50*XW1
  821 IF(TM2-TC2)  235,235,815
  815 TAV2A=((TM2-TC2)-(TNP3-TCC))/ALOG((TM2-TC2)/(TNP3-TCC))
      TAV2B=((TNP3-TC2)-(TM2-TC2))/ALOG((TNP3-TC2)/(TM2-TC2))
      A2A=XW2*CPW*(TC2-TCC)/(QC2*TAV2A)
      A2B=     HV*XW2/(QC2*TAV2B)
      A2=A2A+A2B
      H21=850.*(A2/50.)**0.62*1.40*4.0*CFOP
      H22=CCPW*XW2
      H23=0.50*CCLE*XW2
      IF(PV-PW)  808,809,809
  808 PV=PW
```

```
  809 GC3=XFM**(CPNP3*TNP3-CPPF*TF)+(PV/PI)*HZ*16.*XP
      TAV3=((TNP3-TC3)-(TF-TCC))/ALOG((TNP3-TC3)/(TF-TCC))
      A3=QC3/(UC3*TAV3)
      XW3=QC3/(CPW*(TC3-TCC))
      H31=850.*(A3/50.)**0.562*1.40*4.0*CFOP
      H32=COCW*XW3
      G=100000.*(PO/1064.7)**0.5
      HDI=(HPL*XW**XP)/(G*HCA*HDB)
      HNT=130.894*HDI**2
      HL=(A1+A2+A3)/(3.1416*HDO*HNT)
      HN1=HL/HDB
      HS=0.197E-05*XW**PI
      HFF=0.012/(HHR*G/VI)**0.189
      PDROP=(HFF*G**2/0.522E+11)*(HDI*HN1/(HHR*HS))
      ET=E1+E2+E3+E4+E5+E8+E9+E10+H11+H21+H31
      IF(ABS(ET-ERD)-ACC)  270,270,240
  240 IF(ET-ERD) 242,270,244
  242 DD=-0.05
      GO TO 245
  244 DD=0.20
  245 ERD=ET
      GO TO 5
  270 IR=IR+1
      E(IR)=ET
      IF(ABS(E(IR)-E(IR-1))-ACC) 290,290,272
  272 IF(E(IR)-E(IR-1))  275,290,290
  275 PO=PO+PD
      D=DCR
      DD=0.20
      ERD=DERD
      GO TO 5
  290 WRITE(6,500F) D,E1,E2,E3,E4,E5,E6,E7,E8,E9,E10,H11,H12,H13,H21,H22
     1,H23,H31,H32,PN,PDROP,ET,PO
  235 STOP
      END
$IBFTC RATE
      SUBROUTINE RATE (S1,S2,S3,S4,S5,S6)
      R=1.987
      EA=8700.
      C1=120.
      IF(S6-600.) 300,305,305
  300 A=C1*EXP(-EA/(R*(S6+460.)/1.8))
      GO TO 310
  305 A=C1*EXP(-EA/(R*1060./1.8))
  310 S1=A*(S4/(14.7*S5))*(S3)**0.3*(S2)**0.7
      RETURN
      END
```

```
C      INPUT DATA
 71.          .38  390.2   780.4        .0484 25.      40.      11.123 550.
100.     .41700E+09.02080E+00.08333E+00
 26386.650     28.650  1375.200     85.95      57.30     716.25
 19721.      6446.25  20580.25     143.25      47.75     716.25
   .0516      .0625      .0834      .0208      .0792     4.0
  85.   445.    260.    150.
 0.144E-04 0.600E-05 0.150E-03 0.300E-03
810.       850.         13.80        .134533 11.87
.10000E+10       7.0     1000.
```

TABLE B.5-6 COMPUTER PROGRAM IN HIGH CO CASE FOR COLD QUENCH SYSTEM

```
      DIMENSION X1(500),X2(500),X3(500),X5(500),X7(500),T(500)
      DIMENSION YX(500),QF(500),Y(500)
 5002 FORMAT(4E10.3)
 5003 FORMAT(//14X,8E14.7/14X,8E14.7/14X,8E14.7/14X,8E14.7/14X, 2E14.7)
 5004 FORMAT(10F7.3/5F7.3,4F9.6)
 5005 FORMAT(7E10.5/6E10.5)
 5006 FORMAT(6F10.6)
      READ(5,5006) HDI,HDO,HPL,HCA,HHR,HDB
      READ(5,5002) COPW,COCW,COLS,COHS
      DSC=71.
      GCH=+4.175+08
      READ(5,5005) XX1,XX2,XX3,XX4,XX5,XX6,YN,FO,YA,YB,TE,TF,XMM
      PF=1064.7
      PO=1064.7
    5 READ(5,5004) TCC,TC1,TC2,TC3,UC1,UC2,UC3,UIC,UP,HV,HZ,XMW,TN,EV,TO
     1,DP,VI,CL,DSG
      T1=550.
      T2=550.
      T3=550.
      XFMW=FO*XMM
      D1=5.60
    6 D1=D1+0.20
      D2=6.00
    7 D2=D2+0.20
      D3=6.60
    8 D3=D3+0.20
      CL=1./12.
      CPRE=0.625+0.000386*TE
      CPPE=0.493+0.000444*TE
      CPRN=0.625+0.000386*TN
      CPPN=0.493+0.000444*TN
      CPP3=0.493+0.000444*T3
      CPR3=0.625+0.000386*T3
      HA=7851.34
      CPP2=0.493+0.000444*T2
      CPR2=0.625+0.000386*T2
      CPET=(1.-YA/YN)*CPRN+YA*CPPN/YN
   15 CPRF=0.625+0.000386*TF
      CPR1=0.625+0.000386*T1
      QF(1)=(CPET*TN-CPPF*TF-HA*YA)/(CPR1*T1-CPRF*TF)
      X1(1)=FO*XX1*QF(1)
      X2(1)=FO*XX2*QF(1)
      X3(1)=FO*XX3*QF(1)
      X4=FO*XX4*QF(1)
      X5(1)=FO*XX5*QF(1)
      X6=FO*XX6*QF(1)
      X7(1)=PO
      XP=X1(1)+X2(1)+X3(1)+X4+X5(1)+X6
      G=4.0*XMW *XP/(3.14*D1**2)
      GU=150.*(1.-EV)*VI/(DP*G)+1.75
      GL=(EV**3/(1.-EV))*(DP/CL)*(GCH*DSG/G**2)
      GT=GU/(GD*144.0)
      T(1)=T1
      VC=(1.-EV)*(3.1416*D1**2/4E.)
```

```
      M=1
   50 M=M+1
      XX=X1(M-1)+X2(M-1)+X3(M-1)+X4       +X5(M-1)+X6
      RC2=X2(M-1)
      RC3=X3(M-1)
      CALL RATE(R1    ,X2(M-1),X3(M-1),X7(M-1),XX,T(M-1))
      GO TO 60
   55 CALL RATE(R1,X2(M),X3(M),X7(M),XX,T(M-1))
   60 X1(M)=X1(M-1)+DSC*VC*R1
      X2(M)=X2(M-1)-DSC*VC*R1
      X3(M)=X3(M-1)-3.0*DSC*VC*R1
      X5(M)=X5(M-1)+DSC*VC*R1
      X7(M)=X7(M-1)-GT
      IF(ABS(X2(M)-RC2)-0.001    ) 65,65,70
   65 IF(ABS(X3(M)-RC3)-0.001    ) 75,75,70
   70 XX=X1(M)+X2(M)+X3(M)+X4    +X5(M)+X6
      RC2=X2(M)
      RC3=X3(M)
      GO TO 55
   75 YM1=(X1(M-1)-X1(1))/(FO*QF(1))
      CPP=0.493+0.000444*T(M-1)
      CPR=0.625+0.000386*T(M-1)
      CPN1=(1.-YM1/YN)*CPR+YM1*CPP/YN
      XXN1=XF**CPN1*QF(1)
      RTEMP=T(M-1)
      YM2=(X1(M)-X1(1))/(FO*QF(1))
      H1=87787.8+11.87*T(M-1)-0.00888*T(M-1)**2
      GO TO 77
   76 CPP=0.493+0.000444*T(M)
      CPR=0.625+0.000386*T(M)
      H1=87787.8+11.87*T(M)-0.00888*T(M)**2
   77 CPN2=(1.-YM2/YN)*CPR+YM2*CPP/YN
      XXN2=XF**CPN2*QF(1)
      HH=DSC*VC*H1*R1
      T(M)=(XXN1*T(M-1)+HH)/XXN2
      IF(ABS(T(M)-RTEMP)-0.1) 79,79,78
   78 RTEMP=T(M)
      GO TO 76
   79 IF(T(M)-850.) 80,80,80
   80 TAM=M
      WA=DSC*VC*TAM
      Y(1)=0.0
      I=0
      SUMWA=WA
   85 I=I+1
      YX(I)=(X1(M)-FO*XXN1*QF(I))/(FO*QF(I))
      CPPO=0.493+0.000444*TO
      CPRO=0.625+0.000386*TO
      CPN=(1.-YX(I)/YN)*CPRN+YX(I)*CPPN/YN
      RQF=2.0
      CPO=(1.-YX(I)/YN)*CPRO+YX(I)*CPPO/YN
      GO TO 87
   86 CPO=(1.-Y(I+1)/YN)*CPRO+Y(I+1)*CPPO/YN
   87 QF(I+1)=QF(I)*(CPN*TN-CPO*TF)/(CPO*TO-CPO*TF)
      Y(I+1)=QF(I)*YX(I)/QF(I+1)
      IF(ABS(QF(I+1)-RQF)-0.01)  88,85,85
   88 RQF=QF(I+1)
```

```
      GO TO 86
   59 IF(QF(I+1)-1.) 90,135,135
   90 T(1)=TO
      X1(1)=FO*QF(I+1)*(XX1+Y(I+1))
      X2(1)=FO*QF(I+1)*(XX2-Y(I+1))
      X3(1)=FO*QF(I+1)*(XX3-3.*Y(I+1))
      X4=FO*QF(I+1)*XX4
      X5(1)=FO*QF(I+1)*(XX5+Y(I+1))
      X6=FO*QF(I+1)*XX6
      XP=X1(1)+X2(1)+X3(1)+X4+X5(1)+X6
      G=4.0*XMW *XP/(3.14*D1**2)
      GU=150.*(1.-EV)*VI/(DP*G)+1.75
      GD=(EV**3/(1.-EV))*(DP/CL)*(GCH*DSG/G**2)
      GT=GU/(GD*144.0)
      X7(1)=X7(M)
      M=1
   95 M=M+1
      XX=X1(M-1)+X2(M-1)+X3(M-1)+X4      -X5(M-1)+X6
      RC2=X2(M-1)
      RC3=X3(M-1)
      CALL RATE(R1    ,X2(M-1),X3(M-1),X7(M-1),XX,T(M-1))
      GO TO 105
  100 CALL RATE(R1,X2(M),X3(M),X7(M),XX,T(M-1))
  105 X1(M)=X1(M-1)-DSG*VC*R1
      X2(M)=X2(M-1)-DSG*VC*R1
      X3(M)=X3(M-1)-3.0*DSG*VC*R1
      X5(M)=X5(M-1)+DSG*VC*R1
      X7(M)=X7(M-1)-GT
      IF(ABS(X2(M)-RC2)-0.001    ) 110,110,115
  110 IF(ABS(X3(M)-RC3)-0.001    ) 120,120,115
  115 XX=X1(M)+X2(M)+X3(M)+X4    +X3(M)+X6
      RC2=X2(M)
      RC3=X3(M)
      GO TO 100
  120 YM1=(X1(M-1)-XX*FO*QF(I+1))/(FO*QF(I+1))
      CPP=0.493+0.00044*T(M-1)
      CPR=0.52E+0.000386*T(M-1)
      CPN1=(1.-YM1/Y.)*CPP+YM1*CPR/YM
      XXN1=XFN*CPN1*QF(I+1)
      RTEMP=T(M-1)
      YM2=(X1(M)-XX1*FO*QF(I+1))/(FO*QF(I+1))
      H1=27737.8+11.37*(M-1)-0.00866*T(M-1)**2
      GO TO 122
  121 CPP=0.493+0.00044*T(M)
      CPR=0.525+0.000386*T(M)
      H1=27737.8+11.37*T(M)-0.00866*T(M)**2
  122 CPN2=(1.-YM2/Y.)*CPP+YM2*CPR/YM
      XXN2=XFN*CPN2*QF(I+1)
      HH=DSG*VC*H1*R1
      T(M)=(XXN1*T(M-1)+HH)/XXN2
      IF(ABS(T(M)-RTEMP)-0.1) 124,124,123
  123 RTEMP=T(M)
      GO TO 121
  124 IF(T(M)-555.) 95,130,130
  130 TAN=M
      XAZ=DFO*DG*TAN
```

```
      GO TO 85
  135 Y(I+1)=OF(I)*YX(I)
      CPN=(1.-YX(I)/YN)*CPRN+YX(I)*CPPN/YN
      RTA=TO
      CPRA=CPRO
      CPPA=CPPO
      GO TO 137
  136 CPRA=0.625+0.000386*TA
      CPPA=0.493+0.000444*TA
  137 CPA=(1.-Y(I+1)/YN)*CPRA+Y(I+1)*CPPA/YN
      TA=(OF(I)*CPN*TN+(1.-OF(I))*CPRF*TF)/CPA
      IF(ABS(TA-RTA)-0.50) 139,139,138
  138 RTA=TA
      GO TO 136
  139 T(I)=TA
      X1(I)=FO*(XX1+Y(I+1))
      X2(I)=FO*(XX2-Y(I+1))
      X3(I)=FO*(XX3-3.*Y(I+1))
      X4=FO*XX4
      X5(I)=FO*(XX5+Y(I+1))
      X6=FO*XX6
      X7(I)=X7(M)
      XP=X1(I)+X2(I)+X3(I)+X4+X5(I)+X6
      G=4.0*XM* *XP/(3.14*D1**2)
      GU=150.*(1.-EV)*VI/(DP*G)+1.75
      GD=(EV**3/(1.-EV))*(DP/DL)*(GO*DSO/G**2)
      GT=GU/(GO*144.0)
      M=1
  140 M=M+1
      XX=X1(M-1)+X2(M-1)+X3(M-1)+X4      +X5(M-1)+X6
      RO2=X2(M-1)
      RO3=X3(M-1)
      CALL RATE(R1    ,X2(M-1),X3(M-1),X7(M-1),XX,T(M-1))
      GO TO 150
  145 CALL RATE(R1,X2(M),X3(M),X7(M),XX,T(M-1))
  150 X1(M)=X1(M-1)+DSO*VO*R1
      X2(M)=X2(M-1)-DSO*VO*R1
      X3(M)=X3(M-1)-3.0*DSO*VO*R1
      X5(M)=X5(M-1)+DSO*VO*R1
      X7(M)=X7(M-1)-GT
      IF(ABS(X2(M)-RO2)-0.001    ) 155,155,160
  155 IF(ABS(X3(M)-RO3)-0.001    ) 165,165,160
  160 XX=X1(M)+X2(M)+X3(M)+X4    +X5(M)+X6
      RO2=X2(M)
      RO3=X3(M)
      GO TO 145
  165 YM1=(X1(M-1)-XX1*FO)/FO
      CPP=0.493+0.000444*T(M-1)
      CPR=0.625+0.000386*T(M-1)
      CPN1=(1.-YM1/YN)*CPR+YM1*CPP/YN
      XXN1=XFN**CPN1
      RTEMP=T(M-1)
      YM2=(X1(M)-XX1*FO)/FO
      R1=67787.9+11.87*T(M-1)-0.01505*T(M-1)**2
      GO TO 167
  166 CPP=0.493+0.000444*T(M)
      CPR=0.625+0.000386*T(M)
```

```
      H1=67787.8+11.E7*T(M)-0.0035*T(M)**2
  167 CPN2=(1.-YY2/YN)*CPR+YY2*CPP/YN
      XXN2=XF**CPN2
      HH=DSC*VC*R1*R1
      T(M)=(XXN1*T(M-1)+HH)/XXN2
      IF(ABS(T(M)-RTEMP)-0.1) 169,169,168
  168 RTEMP=T(M)
      GO TO 166
  169 YAR=(X1(M)-FO*XX1)/FO
      IF(YAR-YA) 140,170,170
  170 TAA=M
      WAM=DSC*VC*TAA
      SUMWA=SUMWA+WAM
      PNA=X7(M)
      X1(1)=FO*(XX1+YA)
      X2(1)=FO*(XX2-YA)
      X3(1)=FO*(XX3-3.0*YA)
      X4=FO*XX4
      X5(1)=FO*(XX5+YA)
      X6=FO*XX6
      X7(1)=X7(M)
      VC=(1.-EV)*(3.1416*D2**2/48.)
      XP=X1(1)+X2(1)+X3(1)+X4+X5(1)+X6
      G=4.0*XM  *XP/(2.14*D2**2)
      GJ=180.*(1.-EV)*VI/(DP*G)+1.75
      GD=(EV**3/(1.-EV))*(DP/CL)*(GCM*DSG/G**2)
      GT=GJ/(GD*144.0)
      T(1)=T2
      M=1
  180 M=M-1
      XX=X1(M-1)+X2(M-1)+X3(M-1)+X4      +X5(M-1)+X6
      RC2=X2(M-1)
      RC3=X3(M-1)
      CALL RATE(R1    ,X2(M-1),X3(M-1),X7(M-1),XX,T(M-1))
      GO TO 190
  185 CALL RATE(R1,X2(M),X3(M),X7(M),XX,T(M-1))
  190 X1(M)=X1(M-1)+DSC*VC*R1
      X2(M)=X2(M-1)-DSC*VC*R1
      X3(M)=X3(M-1)-3.0*DSC*VC*R1
      X5(M)=X5(M-1)+DSC*VC*R1
      X7(M)=X7(M-1)-GT
      IF(ABS(X2(M)-RC2)-0.001    ) 195,195,200
  195 IF(ABS(X3(M)-RC3)-0.001    ) 205,205,200
  200 XX=X1(M)+X2(M)+X3(M)+X4    +X5(M)+X6
      RC2=X2(M)
      RC3=X3(M)
      GO TO 185
  205 YY1=(X1(M-1)-XX1*FO)/FO
      CPP=0.493+0.000444*T(M-1)
      CPR=0.623+0.000366*T(M-1)
      CPN1=(1.-YY1/YN)*CPR+YY1*CPP/YN
      XXN1=XF**CPN1
      RTEMP=T(M-1)
      YY2=(X1(M)-XX1*FO)/FO
      H1=67787.8+11.E7*T(M-1)-0.0035*T(M-1)**2
      GO TO 215
  210 CPP=0.493+0.000444*T(M)
```

```
      CPR=0.625+0.000086*T(M)
      H1=57787.5+11.37*T(M)-0.0055B*T(M)**2
  215 CPN2=(1.-YM2/YN)*CPR+YM2*CPP/YN
      XXN2=XFM*CPN2
      HH=DSC*VC*H1*R1
      T(M)=(XXN1*T(M-1)+HH)/XXN2
      IF(ABS(T(M)-RTEMP)-0.1) 225,225,220
  220 RTEMP=T(M)
      GO TO 210
  225 YSR=(X1(M)-XX1*FO)/FO
      IF(YSR-YB) 180,230,230
  230 TBM=M
      WB=DSC*VC*TBM
      PNB=X7(M)
      X1(1)=FO*(XX1+YB)
      X2(1)=FO*(XX2-YB)
      X3(1)=FO*(XX3-3.0*YB)
      X4=FO*XX4
      X5(1)=FO*(XX5+YB)
      X6=FO*XX6
      X7(1)=PNB
      VC=(1.-EV)*(3.1416*D3**2/48.)
      XP=X1(1)+X2(1)+X3(1)+X4+X5(1)+X6
      G=4.0*XMW*XP/(3.14*D3**2)
      GU=180.*(1.-EV)*VI/(DP*G)+1.75
      GD=(EV**3/(1.-EV))*(DP/CL)*(GCH*DSG/G**2)
      GT=GU/(GD*144.0)
      T(1)=T3
      M=1
  235 M=M+1
      XX=X1(M-1)+X2(M-1)+X3(M-1)+X4      +X5(M-1)+X6
      RC2=X2(M-1)
      RC3=X3(M-1)
      CALL RATE(R1    ,X2(M-1),X3(M-1),X7(M-1),XX,T(M-1))
      GO TO 245
  240 CALL RATE(R1,X2(M),X3(M),X7(M),XX,T(M-1))
  245 X1(M)=X1(M-1)+DSC*VC*R1
      X2(M)=X2(M-1)-DSC*VC*R1
      X3(M)=X3(M-1)-3.0*DSC*VC*R1
      X5(M)=X5(M-1)+DSC*VC*R1
      X7(M)=X7(M-1)-GT
      IF(ABS(X2(M)-RC2)-0.001    ) 250,250,255
  250 IF(ABS(X3(M)-RC3)-0.001    ) 260,260,255
  255 XX=X1(M)+X2(M)+X3(M)+X4    +X5(M)+X6
      RC2=X2(M)
      RC3=X3(M)
      GO TO 240
  260 YM1=(X1(M-1)-XX1*FO)/FO
      CPP=0.493+0.000444*T(M-1)
      CPR=0.625+0.000086*T(M-1)
      CPN1=(1.-YM1/YN)*CPR+YM1*CPP/YN
      XXN1=XFM*CPN1
      RTEMP=T(M-1)
      YM2=(X1(M)-XX1*FO)/FO
      H1=57787.8+11.37*T(M-1)-0.0055B*T(M-1)**2
      GO TO 270
```

```
      CPR=0.625+0.000386*T(M)
      H1=87787.2+11.87*T(M)-0.00555*T(M)**2
  270 CPN2=(1.-Y**2/YN)*CPR+Y**2*CPP/YN
      XXN2=XFM*CPN2
      HH=DSC*VC*H1*R1
      T(M)=(XXN1*T(M-1)+HH)/XXN2
      IF(ABS(T(M)-RTEMP)-0.1) 280,280,275
  275 RTEMP=T(M)
      GO TO 265
  280 YNR=(X1(M)-F0*XX1)/F0
      IF(YNR-YN)  285,285,285
  285 TCM=M
      WC=DSC*VC*TCM
      PN=X7(M)
      UP=70.*(P0/1064.7)**0.3
      UC1=85.*(P0/1064.7)**0.3
      UC2=UC1
      UC3=80.*(P0/1064.7)**0.3
      CFOP=1.+1.8371*(P0/1064.7-1.)
      CPFPF=0.625+0.000386*TF
      CPFP1=0.625+0.000386*T1
      CPPP=0.493+0.000444*575.
      QP=QF(1)*F0*11.87*(CPFP1*T1-CPFPF*TF)
      TNP=TE-(QP/(F0*11.87*CPPP))
      TAVP=((TE-T1)-(TNP-TF))/ALOG((TE-T1)/(TNP-TF))
      AP=QP/(UP*TAVP)
      E1=550.*(AP/50.)**0.562*1.40*4.0*CFOP
      XF=F0
      CPPT3=0.493+0.000444*T3
      CPPT2=0.493+0.000444*T2
      CPPT2=0.625+0.000386*T2
      CPIC2=(1.-YA/YN)*CPRT2+YA*CPPT2/YN
      CPICA=(1.-YA/YN)*CPRN-YA*CPPN/YN
      TCA1=0.5*(TC1-TCC)
      XWICA=XF*11.87*(CPICA*TN-CPIC2*T2)/(CPW*(TC1-TCA1)+HV)
      TICAM=T2+(XWICA*CPW*(TC1-TCA1)/(XF*11.87*CPIC2))
      TAVA1=((TICAM-TC1)-(T2-TCA1))/ALOG((TICAM-TC1)/(T2-TCA1))
      TAVA2=((TN-TC1)-(TICAM-TC1))/ALOG((TN-TC1)/(TICAM-TC1))
      AIC1=XWICA*CPW*(TC1-TCA1)/(UIC*TAVA1)
      AIC2=XWICA*HV/(UIC*TAVA2)
      AI=AIC1+AIC2
      E2=550.*(AI/50.)**0.562*1.40*4.0*CFOP
      CPICB=(1.-YB/YN)*CPRN+YB*CPPN/YN
      CPRT3=0.625+0.000386*T3
      CPIC3=(1.-YB/YN)*CPRT3+YB*CPPT3/YN
      TCA2=0.5*(TC1+TCC)
      XWICB=XF*11.87*(CPICB*TN-CPIC3*T3)/(CPW*(TC1-TCA2)+HV)
      TICBM=T3+(XWICB*CPW*(TC1-TCA2)/(XF*11.87*CPIC3))
      TAVB1=((TICBM-TC1)-(T3-TCA2))/ALOG((TICBM-TC1)/(T3-TCA2))
      TAVB2=((TN-TC1)-(TICBM-TC1))/ALOG((TN-TC1)/(TICBM-TC1))
      UIC=85.*(P0/1064.7)**0.3
      AIC1=XWICB*CPW*(TC1-TCA2)/(UIC*TAVB1)
      AIC2=XWICB*HV/(UIC*TAVB2)
      AI=AIC1+AIC2
      E3=550.*(AI/50.)**0.562*1.40*4.0*CFOP
      E10=0.870.12*(XWICA+XWICB)/6330.
      E11=0.8*0.30*(XWICA+XWICB)/1000.
```

```
      WT=SUMWA+WB+WC
      E4=2.5*WT
      PS=(PNA+PO)/2.
      D=D1
      TH1=(PS-14.7)*D*6.0/(15105.-0.5*(PS-14.7))
      TH=TH1+0.25
      FD=16.15*D/12.
      BI=I-1
      AL=(SUMWA/(DSC*0.487*D**2))+0.5*BI
      E5A=754.37*(AL*((D+TH/12.)**2-D**2)+FD**2*TH/6.)
      PS=(PNB+PNC)/2.
      D=D2
      TH1=(PS-14.7)*D*6.0/(15105.-0.5*(PS-14.7))
      TH=TH1+0.25
      FD=16.15*D/12.
      BL=WB/(DSC*0.487*D**2)
      E5B=754.37*(BL*((D+TH/12.)**2-D**2)+FD**2*TH/6.0)
      PS=(PNC+PN)/2.
      D=D3
      TH1=(PS-14.7)*D*6.0/(15105.-0.5*(PS-14.7))
      TH=TH1+0.25
      FD=16.15*D/12.
      CL=WC/(DSC*0.487*D**2)
      E5C=754.37*(CL*((D+TH/12.)**2-D**2)+FD**2*TH/6.0)
      E5=E5A+E5B+E5C
      E6A=(AL*12./40.)*0.206*(D1+5.0)**3.13*4.0
      E6B=(BL*12./40.)*0.206*(D2+5.0)**3.13*4.0
      E6C=(CL*12./40.)*0.206*(D3+5.0)**3.13*4.0
      E6=E6A+E6B+E6C
      E7=4000.*(BI+1.0)
      XP=X1(M)+X2(M)+X3(M)+X4+X5(M)+X6
      IF(PF-X7(1)) 290,295,295
290   EF=0.00406B*(TF+460.)*XF*((X7(1)/PF)**0.240-1.0)
      E8=598.*EF**0.81
      GO TO 300
295   EF=0.0
      E8=0.0
300   IF(PN-1014.) 305,310,310
305   EP=0.004065*(100.+460.)*XP*((1014./PN)**0.240-1.)
      E9=698.*EP**0.81
      GO TO 315
310   E9=0.0
315   CPW=1.0
      PI=PN-1.0
      PW=PI*(X5(M)/XP)
      IF(TNP-800.) 801,802,803
801   TNP2=TNP
      GO TO 803
802   TNP2=460.
803   TNP3=270.
      PV=1.176*(TNP3-260.)+35.439
      CPF=0.493+0.000444*TF
      CPNP1=0.493+0.000444*TNP
      CPNP2=0.493+0.000444*TNP2
      CPNP3=0.493+0.000444*TNP3
      IF(PV-PW) 805,805,804
805   CC2=XFM**(CPNP2*TNP2-CPNP3*TNP3)
```

```
      XW2=QC2/(CPW*(TC2-TCC)+     HV)
      TW2=TNP3+(XW2*CPW/(XFW*CPNP3))*(TC2-TCC)
      GO TO 807
  806 QC2=XFW*(CPNP2*TNP2-CPNP3*TNP3)+HZ*((PW-PV)/PI)*18.*XP
      XW2=QC2/(CPW*(TC2-TCC)+     HV)
      RTW2=TNP3+2.
  816 RTW2=RTW2+3.0
      PVM=1.176*(RTW2-350.)+35.429
      IF(PVM-PW) 818,818,817
  817 PVM=PW
  818 TW2=TNP3+ (XW2*CPW*(TC2-TCC)-HZ*((PVM-PV)/PI)*18.*XP)/(XFW*CPNP3)
      IF(ABS(TW2-RTW2)-6.)  807,807,816
  807 IF(TNP-500.) 804,810,810
  804 A1=0.0
      H11=0.0
      H12=0.0
      H13=0.0
      GO TO 821
  810 QC1=XFW*(CPNP1*TNP-CPNP2*TNP2)
      TCC1=(0.5*XW2*(CPW*TC1+     HV)*(TC2-TCC)+0.5*QC1*(TC1-TCC))/(QC1+0
     1.5*XW2*(TC2-TCC))
      TRC1=(TC1+TC2)/2.0
      IF(TCC1-TRC1) 823,822,822
  822 XW1A=0.0
      TCC1=TRC1
      XW1=QC1/(CPW*(TC1-TCC1)+      HV)
      GO TO 824
  823 XW1=QC1/(CPW*(TC1-TCC1)+      HV)
      XW1A=0.5*(XW1-XW2)
  824 TW1=TNP2+(XW1*CPW*(TC1-TCC1)/(XFW*CPNP2))
      IF(TW1-TC1)  320,320,814
  814 TAV1A=((TW1-TC1)-(TNP2-TCC1))/ALOG((TW1-TC1)/(TNP2-TCC1))
      TAV1B=((TNP-TC1)-(TW1-TC1))/ALOG((TNP-TC1)/(TW1-TC1))
      A1A=(XW1*CPW*(TC1-TCC1))/(QC1*TAV1A)
      A1B=(      HV*XW1)/(QC1*TAV1B)
      A1=A1A+A1B
      H11=850.*(A1/50.)**0.562*1.40*4.*CFCP
      H12=CPW*XW1A
      H13=CONS*2.50*XW1
  821 IF(TW2-TC2)  320,320,815
  815 TAV2A=((TW2-TC2)-(TNP3-TCC))/ALOG((TW2-TC2)/(TNP3-TCC))
      TAV2B=((TNP2-TC2)-(TW2-TC2))/ALOG((TNP2-TC2)/(TW2-TC2))
      A2A=XW2*CPW*(TC2-TCC)/(QC2*TAV2A)
      A2B=     HV*XW2/(QC2*TAV2B)
      A2=A2A+A2B
      H21=850.*(A2/50.)**0.562*1.40*4.*CFCP
      H22=CPW*XW2
      H23=1.50*CONS*XW2
      IF(PV-PW)  309,309,308
  308 PV=PW
  309 QC3=XFW*(CPNP2*TNP3-CPPF*TF)+(PV/PI)*HZ*18.*XP
      TAV3=((TNP3-TC3)-(TF-TCC))/ALOG((TNP3-TC3)/(TF-TCC))
      A3=QC3/(QC3*TAV3)
      XW3=QC3*(CPW*(TC3-TCC))
      H31=850.*(A3/50.)**0.562*1.40*4.0*CFCP
      H32=CPW*XW3
      G=1000.*0.7*(P2/1564.7)**0.5
```

```
      HDI=(HPL*XM**XP)/(G*HCA*HDS)
      HNT=130.894*HDI**2
      HL=(A1+A2+A3)/(3.1416*HDO*HNT)
      HN1=HL/HDS
      HS=0.197E-05*XM**P1
      HFF=0.012/(HMR**3/VI)**0.189
      PDROP=(HFF*G**2/0.522E+11)*(HDI*HN1/(HHR*HD))
      ET=E1+E2+E3+E4+E5+E6+E7+E8+E9+H11+H21+H31
      WRITE(6,9003) D1,D2,D3,E1,E2,E3,E4,E5A,E5B,E5C,E5,E6A,E6B,E6C,E6,E
     17,E8,E9,E10,E11,H11,H12,H13,H21,H22,H23,H31,H32,PNA,PNB,PN,PDROP,
     2ET ,GF(1)
  320 IF(D3-7.60) 8,325,325
  325 IF(D2-7.00) 7,330,330
  330 IF(D1-6.40) 6,335,335
  335 STOP
      END
$IBFTC RATE
      SUBROUTINE RATE (S1,S2,S3,S4,S5,S6)
      R=1.987
      EA=8700.
      C1=120.
      IF(S6-600.) 300,305,305
  300 A=C1*EXP(-EA/(R*(S6+460.)/1.8))
      GO TO 310
  305 A=C1*EXP(-EA/(R*1060./1.8))
  310 S1=A*(64/(14.7*S5))*(S3)**0.3*(S2)**0.7
      RETURN
      END
```

```
C       INPUT DATA
    .0516       .0625       .0834       .0208       .0792      4.0
 0.144E-04 0.600E-05 0.180E-03 0.300E-03
.41383E+00.13877E+00.42183E+00.00301E+00.00100E+00.01500E+00.13453E+00
.47654E+00.59337E-01.13014E+00.81000E+03.10000E+03.11870E+02
 85.    44.    200.    150.     85.     85.     60.     85.     70.    390.2
780.4    13.8    90.       .38 600.      .02083    .0484     .08333  1.626564
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