

# ***CHAPTER 5***

# ***CONCLUSIONS***

## 5-CONCLUSIONS

The aims of the present work are modeling and simulation of Fischer-Tropsch slurry bubble column reactor as well as energy conservation in the FT process. The two- class bubble model of **Van der Lann et al. (1999)** was chosen for simulation. The model equations were solved analytically. An overall executive program that calls different subroutines at request to calculate the hydrodynamic and kinetic parameters and at the same time performs the necessary calculations needed for model solution was developed

The developed software was used to reproduce the performance study of an industrial scale slurry F-T bubble column reactor that uses iron based catalyst which was undertaken by **Van der Laan et al. (1999)**.

The operating conditions were varied so as to study the effect of superficial gas velocity, solids holdup and  $H_2/CO$  feed ratio on synthesis gas conversion and reactor productivity. It was found that synthesis gas conversion decreases with increasing superficial gas velocity, decreasing solids holdup and decreasing  $H_2/CO$  feed ratio. On the other hand reactor productivity increases with increasing all three variables.

The Software results are similar to those obtained by **Van der Laan et al. [1999]**. This confirmed the validity of the proposed method of solution

The same model but with cobalt catalyst based kinetics was used to simulate the performance of the pilot scale slurry reactor of the **FT AFDU** demonstration plant at **Laporte Texas USA**. Simulation studies were performed under different operating conditions.

Conversion of both hydrogen and carbon monoxide are slightly higher than the pilot results. The reason of this discrepancy is thought to be due to diffusivity values necessary to calculate mass transfer coefficients. Diffusivity and hence mass transfer coefficients have strong influence on the reactants concentrations in the bubble column slurry reactor and hence synthesis gas conversion

The parameters of the **ORPDM** of **Van der Laan et al. (1999)** were modified so as to suit selectivity obtained from cobalt catalyst. The model results are in excellent agreement with the reported experimental results for gas holdup and reactor productivity and in fair agreement with the reported conversion and selectivity for light hydrocarbons.

Energy conservation in the pilot scale slurry-phase **FT AFDU** demonstration plant at **Laporte Texas USA** has been attempted in this work. The transshipment model for minimum energy utilization developed at the Egyptian Petroleum Research Institute has been utilized together with **LINDO** linear programming solver to establish minimum energy utilization.

Five assigned minimum temperature differences,  $\Delta T_{\min}$  namely; 10, 20, 30, 40 and 50 °C were utilized. The results indicated that hot utility was not needed until  $\Delta T_{\min} = 30$  °C. Thus a total saving of the hot utility was possible. The minimum cost heat exchanger network was chosen among the designed networks at different minimum temperature differences. That corresponded to,  $\Delta T_{\min} = 10$  °C showed the minimum annualized cost.

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# ***APPENDIX***

## Appendix: A

### Solution of large bubble class differential mass balance equation (2-12)

The large bubble class differential mass balance was represented by Eq. (2-12)

$$\frac{-d y_{i,G}^{large}}{dZ} = \frac{(y_{i,G0} + \alpha y_{i,G}^{large})^2 (k_L a)_i^{large} R T L}{U_{LB0} (y_{i,G0})^2 (1 + \alpha) P} \left[ \frac{P y_{i,G}^{large}}{m_i^*} - C_{i,L} \right] \quad (A-1)$$

let

$$a = \frac{(k_L a)_i^{large} R T L C_{i,L}}{U_{LB0} (y_{i,G0})^2 (1 + \alpha) P}$$

$$b = \frac{(k_L a)_i^{large} R T L}{U_{LB0} (y_{i,G0})^2 (1 + \alpha) m_i^*}$$

$$\frac{d(y_{i,G}^{large})}{dZ} = a(y_{i,G0} + \alpha y_{i,G}^{large})^2 - b(y_{i,G0} + \alpha y_{i,G}^{large})^2 y_{i,G}^{large} \quad (A-2)$$

$$\frac{d(y_{i,G}^{large})}{dZ} = (y_{i,G0} + \alpha y_{i,G}^{large})^2 (a - b y_{i,G}^{large}) \quad (A-3)$$

$$dZ = \frac{d(y_{i,G}^{large})}{(y_{i,G0} + \alpha y_{i,G}^{large})^2 (a - b y_{i,G}^{large})} \quad (A-4)$$

Analyzing the term  $\frac{1}{(y_{i,G0} + \alpha y_{i,G}^{large})^2 (a - b y_{i,G}^{large})}$

Then

$$\frac{1}{(y_{i,G0} + \alpha y_{i,G}^{\prime \text{arg} e})^2 (a - b y_{i,G}^{\prime \text{arg} e})}$$

$$= \frac{\bar{A}}{(y_{i,G0} + \alpha y_{i,G}^{\prime \text{arg} e})^2} + \frac{\bar{B}}{(y_{i,G0} + \alpha y_{i,G}^{\prime \text{arg} e})} + \frac{\bar{C}}{(a - b y_{i,G}^{\prime \text{arg} e})} \quad (\text{A-5})$$

$$= \frac{\bar{A}(a - b y_{i,G}^{\prime \text{arg} e}) + \bar{B}(y_{i,G0} + \alpha y_{i,G}^{\prime \text{arg} e})(a - b y_{i,G}^{\prime \text{arg} e}) + \bar{C}(y_{i,G0} + \alpha y_{i,G}^{\prime \text{arg} e})^2}{(y_{i,G0} + \alpha y_{i,G}^{\prime \text{arg} e})^2 (a - b y_{i,G}^{\prime \text{arg} e})} \quad (\text{A-6})$$

Find the constants  $\bar{A}$ ,  $\bar{B}$  and  $\bar{C}$

$$\bar{A} a - \bar{A} b y_{i,G}^{\prime \text{arg} e} + \bar{B} a y_{i,G0} + \bar{B} a \alpha y_{i,G}^{\prime \text{arg} e} - \bar{B} b y_{i,G0} y_{i,G}^{\prime \text{arg} e} - \bar{B} \alpha b (y_{i,G}^{\prime \text{arg} e})^2$$

$$+ \bar{C} y_{i,G0}^2 + 2 \bar{C} \alpha y_{i,G0} y_{i,G}^{\prime \text{arg} e} + \bar{C} \alpha^2 (y_{i,G}^{\prime \text{arg} e})^2 = 1 \quad (\text{A-7})$$

Then

$$\bar{A} a + \bar{B} a y_{i,G0} + \bar{C} y_{i,G0}^2 = 1 \quad (\text{A-8})$$

$$-\bar{A} b - \bar{B} b y_{i,G0} + \bar{B} a \alpha + 2 \bar{C} \alpha y_{i,G0} = 0 \quad (\text{A-9})$$

$$-\bar{B} \alpha b + \bar{C} \alpha^2 = 0 \quad (\text{A-10})$$

Then

$$\bar{C} = \bar{B} \frac{b}{\alpha} \quad (\text{A-11})$$

By substitution of equation (A-11) in equation (A-9)

$$-\bar{A} b - \bar{B} b y_{i,G0} + \bar{B} a \alpha + 2 \bar{B} \frac{b}{\alpha} \alpha y_{i,G0} = 0 \quad (\text{A-12})$$

$$-\bar{A} b + \bar{B} b y_{i,G0} + \bar{B} a \alpha = 0 \quad (\text{A-13})$$

$$\bar{A} b = -\bar{B} b y_{i,G0} + \bar{B} a \alpha \quad (\text{A-14})$$

$$\bar{A} = \frac{\bar{B} [b y_{i,G0} + a \alpha]}{b} \quad (\text{A-15})$$

By substitution of equation (A-11) and equation (A-15) in equation (A-8)

$$\frac{\bar{B} [b y_{i,G0} + a \alpha]}{b} a + \bar{B} a y_{i,G0} + \bar{B} \frac{b}{\alpha} y_{i,G0}^2 = 1 \quad (\text{A-16})$$

$$\bar{B} \left[ \frac{a}{b} [b y_{i,G0} + a \alpha] + a y_{i,G0} + \frac{b}{\alpha} y_{i,G0}^2 \right] = 1 \quad (\text{A-17})$$

$$\bar{B} = \frac{1}{\left[ \frac{a}{b} [b y_{i,G0} + a \alpha] \right] + a y_{i,G0} + \frac{b}{\alpha} y_{i,G0}^2} \quad (\text{A-18})$$

$$\int_0^1 dZ = \left[ \frac{-\bar{A}}{\alpha (y_{i,G0} + \alpha y_{i,G}^{\text{large}})} + \frac{\bar{B}}{\alpha} \ln(y_{i,G0} + \alpha y_{i,G}^{\text{large}}) + -\frac{\bar{C}}{b} \ln(a - b y_{i,G}^{\text{large}}) \right]_0^1 \quad (\text{A-19})$$

$$\left[ \frac{-\bar{A}}{\alpha (y_{i,G0} + \alpha y_{i,G}^{\text{large}})} \right] = \frac{-\bar{A}}{\alpha (y_{i,G0})(1+\alpha)} + \frac{-\bar{A}}{\alpha (y_{i,G0} + \alpha y_{i,G}^{\text{large}})} \quad (\text{A-20})$$

$$= \frac{-\bar{A}(1+\alpha)(y_{i,G0}) + \bar{A}(y_{i,G0} + \alpha y_{i,G}^{large})}{\alpha(y_{i,G0})(1+\alpha)(y_{i,G0} + \alpha y_{i,G}^{large})} \quad (A-21)$$

$$= \frac{-\bar{A}(y_{i,G0}) - \bar{A}(y_{i,G0})\alpha + \bar{A}(y_{i,G0}) + \alpha \bar{A}(y_{i,G}^{large})}{\alpha(y_{i,G0})(1+\alpha)(y_{i,G0} + \alpha y_{i,G}^{large})} \quad (A-22)$$

$$= \frac{-\bar{A}\alpha(y_{i,G0} - y_{i,G}^{large})}{\alpha(y_{i,G0})(1+\alpha)(y_{i,G0} + \alpha y_{i,G}^{large})} \quad (A-23)$$

$$= \frac{-\bar{A}(y_{i,G0} - y_{i,G}^{large})}{(y_{i,G0})(1+\alpha)(y_{i,G0} + \alpha y_{i,G}^{large})} \quad (A-24)$$

$$\begin{aligned} \left[ \frac{\bar{B}}{\alpha} \ln(y_{i,G0} + \alpha y_{i,G}^{large}) \right]_0^1 &= \frac{\bar{B}}{\alpha} \ln(y_{i,G0} + \alpha y_{i,G}^{large}) - \frac{\bar{B}}{\alpha} \ln(1+\alpha)y_{i,G0} \\ &= \frac{\bar{B}}{\alpha} \ln \frac{(y_{i,G0} + \alpha y_{i,G}^{large})}{(1+\alpha)y_{i,G0}} \end{aligned} \quad (A-25)$$

$$\begin{aligned} \left[ -\frac{\bar{C}}{b} \ln(a - b y_{i,G}^{large}) \right]_0^1 &= -\frac{\bar{C}}{b} \ln(a - b y_{i,G}^{large}) + \frac{\bar{C}}{b} \ln(a - b y_{i,G0}) \\ &= \frac{\bar{C}}{b} \ln \frac{(a - b y_{i,G0})}{(a - b y_{i,G}^{large})} \end{aligned} \quad (A-26)$$

Finally equation (A-1) becomes:

$$Z = \frac{-\bar{A}(y_{i,G0} - y_{i,G}^{large})}{(y_{i,G0})(1+\alpha)(y_{i,G0} + \alpha y_{i,G}^{large})} + \frac{\bar{B}}{\alpha} \ln \frac{(y_{i,G0} + \alpha y_{i,G}^{large})}{(1+\alpha)y_{i,G0}} + \frac{\bar{C}}{b} \ln \frac{(a - b y_{i,G0})}{(a - b y_{i,G}^{large})} \quad (A-27)$$

```

DECLARE SUB TIME ()
DECLARE SUB READATA ()
DECLARE SUB CARBONUM ()
DECLARE SUB HENER ()
DECLARE SUB ALFA ()
DECLARE SUB HeatCof ()
DECLARE SUB EngBL ()
DECLARE SUB RNX ()
DECLARE SUB PhyProp ()
DECLARE SUB HydPra ()
DECLARE SUB Results ()
DECLARE SUB SaveData ()
DECLARE SUB PrintData ()
DECLARE SUB READDATA ()
DECLARE SUB InputData ()

```

### \*\*\* MODEL CALCULATIONS \*\*\*

```

DIM SHARED TR, TR$, TRI, TRI$, TC, TC$, P, P$, L, L$, D1, D1$, DHR, DHR$
DIM SHARED RG, RG$, RGO, RGO$, ES, ES$, CF, CF$, UO, UO$, UG, UG$, G$, UGO$
DIM SHARED US, US$, RL, RL$, VL$, TCL$, EDO$, CpL$, DLO$, TCC$, CpC$, G, XI(50)
DIM SHARED VL, TCL, EDO, CpL, DLO, TCC, CpC, RP, RP$, RSK, RSK$, NC, UGO
DIM SHARED YS(50), YL(50), YSI(50), ya(50), YO(50), C$(10), HC(50), LRT
DIM SHARED DL(50), VD, EDF, UDF, ULB, EL, EG, RX, KLaL(40), KLaS(40), KC2
DIM SHARED Z(150), Z1(20), Z2(20), Z3(20), KA, RSL, DR(20), CpS, HE, F(20)
DIM SHARED V, adb(50), ED, edd, RFT, TCS, VS, ACC, RT(30), X1E, X2E, R$
DIM SHARED AC1(10), B(150), K, m, Q, SUM, DTitle$, HE1, UG1, ZI(100), MTOP(50)
DIM SHARED Tcat, CC(150), BC(150), AC(120), R, CLM1(10), CLM2(10), CLM3(10)
DIM SHARED DT$, DM$, CL1(10), CL2(10), CL3(10), CLM(50), DFileName$, ZO(50)
DIM SHARED MO(50), MP(50), WO(50), WP(50), WW1(50), MWT(20), WCO(50), WCP(50)
DIM SHARED XA(10), ELB, NC$, YLI(100), IT, YLO(50), A(150), KK, YG(20), KCO
DIM SHARED MC1, MC2P, MC2O, KC1, KC24, KC26, XO(60), XP(60), YP(60), KH, KN2
DIM SHARED INTG(50), SUM(50), X1E(50), X2E(50), Q(50), CL(50), PF1$, N, TT7
DIM SHARED T0, PP, KR, ALF2, ALF(50), CT1, TP1, TP2, C, MC(50), KC36, KC38,
DIM SHARED TT1$, TT2, TT2$, TT3, TT4, TT5, TT6, TT1, X1(50), X2(50), Y1(50),
DIM SHARED MCNP(50), MCNO(50), SUMT, KI(50), FY(50), SUMP, SUMO, SUM1, SUMT2
DIM SHARED MCOP(50), MC2T, MTOT(50), Y2(50)
PRINT "DATE "; DATE$, "TIME "; TIME$

```

#### 'CALCULATIONS CONSTANTS

```

'-----
MH$ = "MOL. WEIGHT OF H2;MH(g/mol):"
MCO$ = "MOL. WEIGHT OF CO;MCO(g/mol):"
R$ = "GAS CONST.;R(pa.m^3/(mole.k):"
G$ = "GRAVITY ; G, (m^2/s)"
R = 8.314: G = 9.8
PF1$ = "###.####"
PF5$ = "####.####"
PRINT " REACTOR CONDITIONS"
PRINT " _____"
TR$ = "Reactor Temperature (K):"
TRI$ = "Inlet Reactor Temperature ;TRI,(K):"
TC$ = "Cooling Temperature ;TC,(K):"
P$ = "Reactor Pressure ;P,(pa):"
L$ = "Reactor Length ;L,(m):"
D1$ = "Reactor Length ;D1,(m):"
DHR$ = "Reaction Enthalpy ;DHR,(J/mol):"
RG$ = "Density of Gas at Reactor Condition ;RG,(kg/m^3):"
RGO$ = "Density of Gas at Ambient Condition ;RGO,(kg/m^3):"

```

```

TR$ = "Reactor Temperature (K):"
TRI$ = "Inlet Reactor Temperature ;TRI, (K):"
TC$ = "Cooling Temperature ;TC, (K):"
P$ = "Reactor Pressure ;P, (pa):"
L$ = "Reactor Length ;L, (m):"
D1$ = "Reactor Length ;D1, (m):"
DHR$ = "Reaction Enthalpy ;DHR, (J/mol):"
RG$ = "Density of Gas at Reactor Condition ;RG, (kg/m^3):"
RGO$ = "Density of Gas at Ambient Condition ;RGO, (kg/m^3):"
ES$ = "Slurry Hold up ;ES, (m^3l/m^3r):"
CF$ = "Contraction Factor ;CF:"
UO$ = "Rise Vel. of the Small Bubbles at 0 Solids ;UO, (m/s):"
UG$ = "Inlet Superfacial Velocity ;UG, (m/s):"
US$ = "Slurry Velocity ;US, (m/s):"
PRINT " LIQUID PROPERTIES"
RL$ = "Liquid Density ;RL, (kg/m^3):"
VL$ = "Liquid Viscosity ;VL, (pa-s):"
TCL$ = "Thermal Conductivity of Liquid ;TCL, (w/m.K):"
EDO$ = "Refrence Hold up at Pure Liquid ;EDO:"
CpL$ = "Heat Capacity of Liquid ;CpL, (j/kg.K):"
DLO$ = "Diffusivity at Reference Condition ;DLO, (m^2/s):"
PRINT "CATALYST PROPERTIES"
TCC$ = "Thermal Conductivity of Catalyst ;TCC, (w/m.K):"
CpC$ = "Heat Capacity of Catalyst ;CpC, ( j/(kg.K)):"
RP$ = "Catalyst Particle Density ;RP, (kg/m^3):"
RSK$ = "Skelton Density ;RSK, (kg/m^3):"
PRINT "FEED PROPERTIES"
NC$ = "No of Component ;NC:"
'READ &PRINT DATA
'-----
INPUT "Enter 1 if you want to read the data from the keyboard &2 from disk
file;DIN:", DIN
SELECT CASE DIN
CASE 1:
    CALL InputData
CASE 2:
    CALL READDATA
END SELECT
CALL Results
CLS

INPUT "Enter -1 if you want to perform the calcn &0 if not ;CALC", CAL
OPEN "D:LMK.bas" FOR OUTPUT AS #1
PRINT #1, "DATE "; DATE$, "TIME "; TIME$
PRINT #1, TAB(25); "*** INPUT DATA PRINT OUT ***"
PRINT #1, TAB(23); "===== "
PRINT #1, "REACTOR CONDITIONS"
PRINT #1, "Reactor Temperature ;TR, (K)="; TR
PRINT #1, "Reactor Inlet Temperature ;TRI, (K):", TRI
PRINT #1, "Reaction Enthalpy ;DHR, (J/mol)="; DHR
PRINT #1, "Reactor Length ;L, (m)="; L
PRINT #1, "Reactor Diameter ;D, (m)="; D1
PRINT #1, "Reactor Pressure ;P, (pa)="; P
PRINT #1, "Inlet Superfacial Velocity ;UG, (m/s)="; UG
PRINT #1, "Density of Gas at Reactor Condition ;RG, (kg/m^3)="; RG
PRINT #1, "Density of Gas at Ambient Condition ;RGO, (kg/m^3)="; RGO
PRINT #1, "Slurry Hold up ;ES, (m^3l/m^3r)="; ES
PRINT #1, "Rise Vel. of the Small Bubbles at 0 Solids ;UO, (m/s) =:"; UO
PRINT #1, "Cooling Temperature ;TC, (K)="; TC

```

```

PRINT #1, "Slurry Velocity ;US,(m/s)="; US
PRINT #1, "Diffusivity at Reference Condition ;DLO,(m^2/s)="; DLO
PRINT #1, "Gravity ;G,(m/s^2)="; G
PRINT #1,

PRINT #1, "LIQUID PROPERTIES"
PRINT #1, "-----"
PRINT #1, "Liquid Density ;RL,(kg/m^3)="; RL
PRINT #1, "Reference Hold up at Pure Liquid ;EDO="; EDO
PRINT #1, "Liquid Viscosity ;VL,(m/s)="; VL
PRINT #1, "Thermal Conductivity of Liquid ;TCL,( )="; TCL
PRINT #1, "Heat Capacity of Liquid ;CpL,(j/kg.k)="; CpL
PRINT #1,
PRINT #1, "CATALYST PROPERTIES"
PRINT #1, "-----"
PRINT #1, "Catalyst Particle Density ;RP,(kg/m^3) ="; RP
PRINT #1, "Skelton Density ;RSK,(kg/m^3)="; RSK
PRINT #1, "Thermal Conductivity of Catalyst ; TCC,(w/m.K):="; TCC
PRINT #1, "Heat Capacity of Catalyst ;CpC,( j/(kg.k)):="; CpC
PRINT #1, " FEED PROPERTIES "
PRINT #1, "-----"
PRINT #1, "Gas Constant ;R,(pa*m^3/(mol*K))="; R
PRINT #1, "No of Component ;NC="; NC
PRINT #1,
FOR I = 1 TO NC
'-----
PRINT #1, "C$( "; I; ")="; C$(I)
PRINT #1, "The Mol.Fr.of "; C$(I); " in the Feed YO( "; C$(I); ") = "; YO(I)
PRINT #1, "Henry Co. for "; C$(I); ", HC( "; C$(I); ),(Pa.m^3/mol)="; HC(I)
PRINT #1, "Diffusivity for DL ( "; C$(I); ) , (m ^ 2 / s) = "; DL(I); "
NEXT I
'-----
PRINT #1, TAB(27); "*** RESULTS PRINT OUT ***"
PRINT #1, TAB(23); "===== "
'SUB CALCULATIONS
'-----
CALL HydPra
CALL PhyProp
CALL RNX

' Calculation the ( ys ,Small Bubble Mole Fraction & Concentration.
'-----
LRT = L * R * TR
FOR I = 1 TO NC
6 CL1(I) = -P * YO(I) * UDF / (LRT * KLaS(I))
ya(I) = ULB * YO(I) ^ 2 * (1 + CF)
YS(I) = .16 * YO(I) 'ys mole fr. of component i gas in small bubble
CL2(I) = (YO(I) - YS(I)) / (YO(I) + CF * YS(I))
CL3(I) = P * YS(I) / HC(I)

'CALCULATION OF (CAL) RELATED WITH YS= CL(I)
'-----
CL(I) = CL1(I) * CL2(I) + CL3(I)
PRINT #1, "YS( "; C$(I); ")="; YS(I), ";CL1( "; C$(I); ")="; CL1(I)
PRINT #1, "CL2( "; C$(I); ")="; CL2(I), ";CL3( "; C$(I); ")="; CL3(I)
PRINT #1, "CL( "; C$(I); ")="; CL(I)
' Calculation YL ,mole Fraction of H2 in large bubble&relation with Z"
'-----

```

```

'1 - Calculation of Z
'
-----
IT = 0
10 A1 = CL(I) * KLaL(I) * LRT           '"calc. of a const"
   a2 = ya(I) * P
   A(I) = A1 / a2
   B1 = LRT * KLaL(I)                 '"calc. of b const"
   B2 = ya(I) * HC(I)
   B(I) = B1 / B2
   adb(I) = A(I) / B(I)
   BC1(I) = adb(I) * (A(I) * CF + B(I) * YO(I))   '"calc. of BC Const"
   BC2(I) = B(I) / CF * YO(I) ^ 2
   BC3(I) = A(I) * YO(I)
   BC(I) = 1 / (BC1(I) + BC2(I) + BC3(I))
   CC(I) = BC(I) * B(I) / CF           '"calc. of CC Const"
   AC1(I) = A(I) * CF + B(I) * YO(I)   '" calc. of AC Const"
   AC(I) = BC(I) * AC1(I) / B(I)
   W = adb(I)
   Q = W + .03
   SUM = 0
   J = 0
   FOR K = Q TO .9999 * YO(I) STEP .0001
-----
     YL(I) = K
20  Z1N = AC(I) * (YL(I) - YO(I))       ' Z Calculations
     Z1D = (1 + CF) * YO(I) * (YO(I) + CF * YL(I))
     Z1 = Z1N / Z1D
     Z2N = (YO(I) + CF * YL(I))
     Z2D = ((1 + CF) * YO(I))
     Z2 = BC(I) / CF * LOG(Z2N / Z2D)
     Z3N = (A(I) - B(I) * YO(I))
     Z3D = (A(I) - B(I) * YL(I))
     Z3 = CC(I) / B(I) * LOG(Z3N / Z3D)
     Z(I) = Z1 + Z2 + Z3
     IF YL(I) = Q THEN
     ZO(I) = Z(I)
       IF Z(I) > 1 THEN
         GOTO 35
       ELSE
         GOTO 30
       END IF
     END IF
     IF Z(I) > 1 THEN : GOTO 35
     IF ABS(Z(I) - m) <= .0001 THEN 30
     GOTO 40
30  J = J + 1
     YLI(J) = YL(I)
     ZI(J) = Z(I)
34  SUM = SUM + 2 * YL(I)
35  m = Z(I) - .03
40  IF (Z(I) - m) > 0 THEN 60
50  IF (Z(I) - m) < 0 THEN 70
60  KK = YL(I)
     GOTO 80
70  YL(I) = (KK + YL(I)) / 2:           GOTO 20

80 NEXT K
-----
'2 - Calculation of Modified Liquid Concentration ;CLM, (mol/m^3)
'
-----

```

```

SUM = SUM - Q - YL(I)
INTG = (.03 / 2) * SUM
CLM1(I) = KLaL(I) * P * INTG / HC(I)
RT(I) = F(I) * RX
CLM2(I) = KLaS(I) * P * YS(I) / HC(I)
IF C$(I) = "N2" THEN GOTO 81
CLM3(I) = (KLaS(I) + KLaL(I) + US / L) + (RT(I) / CL(I))  ''
GOTO 82
81 CLM3(I) = (KLaS(I) + KLaL(I) + US / L)  ''
82 CLM(I) = (CLM1(I) + CLM2(I)) / CLM3(I)  ''
AE = CF * P
BE = P * YO(I) - (HC(I) * (CL1(I) + CF * CLM(I)))
CE = YO(I) * HC(I) * (CL1(I) - CLM(I))
SRE = SQR(BE * BE - 4 * AE * CE)
X1E = (-BE + SRE) / (2 * AE)
X2E = (-BE - SRE) / (2 * AE)
YSI(I) = CLM(I) * HC(I) / P          'BY HENERY COEF.
IF X1E >= YSI(I) AND X1E <= YO(I) THEN YS(I) = X1E
IF X2E >= YSI(I) AND X2E <= YO(I) THEN YS(I) = X2E
90 IF ABS((CLM(I) - CL(I)) / CLM(I)) <= .0919 THEN 100
CL(I) = CLM(I)
IT = IT + 1
A(IT) = A(I): B(IT) = B(I): adb(IT) = adb(I)
AC(IT) = AC(I): BC(IT) = BC(I): CC(IT) = CC(I)
YS(IT) = YS(I): ZO(IT) = ZO(I): YLO(IT) = Q: CLM(IT) = CLM(I)
YSI(IT) = YSI(I): INTG(IT) = INTG: X1E(IT) = X1E: X2E(IT) = X2E
SUM(IT) = SUM: Z(IT) = Z(I): YL(IT) = YL(I)
GOTO 10
100 'PRINT #1,
PRINT #1, "-----"
'PRINT #1,
'PRINT #1, "NO OF ITERATION="; IT
PRINT #1,
PRINT #1, "FOR COMPONENT OF :"; C$(I)
FOR TT = 2 TO IT
'-----
PRINT #1, TT; TAB(10); a(TT);
PRINT #1, TAB(25); USING PF1$; adb(TT);
PRINT #1, TAB(40); USING PF1$; AC(TT);
PRINT #1, TAB(55); USING PF1$; BC(TT);
PRINT #2, TAB(70); USING PF1$; CC(TT)
NEXT TT
PRINT #1, "-----"
PRINT #1, "IT"; TAB(10); " INTG"; TAB(25); " SUM";
PRINT #1, TAB(40); " X1E"; TAB(55); " YS"; TAB(70); " YSE"
PRINT #1, "-----"
FOR TT = 2 TO IT
'-----
PRINT #1, TT; TAB(10); INTG(TT);
PRINT #1, TAB(25); USING PF1$; SUM(TT);
PRINT #1, TAB(40); USING PF1$; X1E(TT);
PRINT #1, TAB(55); USING PF1$; YS(TT);
PRINT #1, TAB(70); USING PF1$; YSI(TT)
NEXT TT
'-----
PRINT #1, "-----"
PRINT #1, "IT"; TAB(10); " CLM"; TAB(25); " ZO";
PRINT #1, TAB(40); " YLO"; TAB(55); " ZI"; TAB(70); " YLI"
PRINT #1, "-----"

```

```

FOR TT = 2 TO IT
'-----
PRINT #1, TT; TAB(10); USING PF1$; CLM(TT);
PRINT #1, TAB(25); USING PF1$; ZO(TT);
PRINT #1, TAB(40); USING PF1$; YLO(TT);
PRINT #1, TAB(55); USING PF1$; Z(TT);
PRINT #1, TAB(70); USING PF1$; YL(TT)
NEXT TT
PRINT #1, "*****"
PRINT #1, "PROFILE OF GAS OUTLET FROM REACTOR"
PRINT #1, "L"; TAB(20); "YLP("; C$(I); ")"; TAB(45); "ZP("; C$(I); ")
PRINT #1, "-----"
PRINT #1,
FOR KL = 1 TO J
'-----
IF C$(I) = "N2" THEN YLI(KL) = YO(I)
PRINT #1, KL; TAB(20); USING PF1$; YLI(KL);
PRINT #1, TAB(45); USING PF1$; ZI(KL)
NEXT KL
'-----

'Calculation the Gas Conversion of the Component I
'
'-----
' The Mass Balance of the Gas Phase at the Outlet of the Reactor
'
U1 = (ULB * Q * YO(I)) / (YO(I) + CF * Q)
U2 = (UDF * YS(I) * YO(I)) / (YO(I) + CF * YS(I))
U3 = U1 + U2
YG(I) = (U3 * YO(I)) / (UG * YO(I) - (U3 * CF))
IF C$(I) = "N2" THEN YG(I) = YO(I)
XA(I) = (YO(I) - YG(I)) / (YO(I) + CF * YG(I))
UG1 = UG * (1 + CF * XA(I))
XHC(I) = ((UG1 / UG) - 1) / CF
RT = R * TR
UT1 = ((ULB * ELB) + (UDF * EDF)) / (EDF + ELB)
YT(I) = ((YS(I) * EDF) + (YG(I) * ELB)) / (EDF + ELB): CVT = 150
PRINT #1, "-----"
PRINT #1, "Outlet Mole Fr in the L Gas Bubbles of ("; C$(I); ")="; YG(I)
PRINT #1, "Outlet Mole Fr in the S Bubbles of ("; C$(I); ")="; YS(I)
PRINT #1, "Avg.Outlet M.Fr in the (S+L) Gas Bubbles of ("; C$(I); ")="; YT(I)
PRINT #1, "The Liquid Phase Conc., (mole/m3) of ("; C$(I); ")="; CLM(I)
PRINT #1, "V Conc.in the L Gas Bubbles, (mole/m3)of ("; C$(I); ")="; CLM1(I)
PRINT #1, "V Conc.in the S Gas Bubbles, (mole/m3)of ("; C$(I); ")="; CL1(I)
PRINT #1, "The Avg.Vap Phase Conc. in (S+L) Gas Bubbles, (mole/m3) of (";
C$(I); ")="; CVT(I)
PRINT #1, "Total Vapor Phase Conc. in the (Small+Large) Gas Bubbles ,
mole/m3="; CVT
PRINT #1, "Gas Outlet Velocity from krishna calcn ;UG1(m/s)="; UG1
PRINT #1, "Gas Outlet Vel. from (Small + Large) Gas Bubbles, (m/s) ="; UT1
PRINT #1, "Conversion % ;XA("; C$(I); ")="; XA(I)
NEXT I
CALL HeatCof
CALL EngBL
CALL RNX
PRINT #1, TAB(17); "***INDIVIDUAL HYDROCARBON PRODUCT FORMATION RATES***"
PRINT #1, TAB(14); CALL ALFA
PI = 3.14
A1 = D1 ^ 2 * PI / 4
WC1 = L * A1 * 16 * RX * MC1
WC21 = L * A1 * 28 * RX * MC20

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WC22 = L * A1 * 30 * RX * MC2P
WC2 = WC12 + WC22
MTO = 0: MTO = 0: MTP = 0
FOR I = 3 TO 50
  MO(I) = I * 12 + I * 2
  MP(I) = I * 12 + I * 2 + 2
  WCO(I) = A1 * L * MO(I) * RX * MCNO(I)
  WCP(I) = A1 * L * MP(I) * RX * MCNP(I)
  MTOP(I) = WCO(I) + WCP(I)
  MTO = MTO + WCO(I)
  MTP = MTP + WCP(I)
  MTOP = MTOP + MTOP(I)
NEXT I
TOT = MTOP + WC1 + WC21 + WC22
WC2 = WC21 + WC22
MO = MTO + WC21
MP = MTP + WC22
SOP = MO + MP

PRINT #1, "-----"
PRINT #1, "COMP"; TAB(10); "WT Ratio "; TAB(23); " Para /Tot "; TAB(35);
      "Olef/ Tot"; TAB(50); "Olef/Para"
PRINT #1, "-----"
PRINT #1, "C(1)"; USING PF5$; TAB(10); WC1 / TOT
PRINT #1, "C(2)"; USING PF5$; TAB(10); WC2 / TOT; TAB(23); (WC22) / TOT;
      TAB(35); WC21 / TOT; TAB(50); WC21 / WC22
FOR I = 3 TO N
  PRINT #1, "C("; (I); ")"; USING PF5$; TAB(10); MTOP(I) / TOT; TAB(23);
      WCP(I) / TOT; TAB(35); WCO(I) / TOT; TAB(50); WCO(I) / WCP(I)
NEXT I
PRINT #1, "COMP"; TAB(14); "MI"; TAB(30); "Para selec "; TAB(50); "Olef selec"
PRINT #1, "-----"
PRINT #1, "C(1)"; USING PF5$; TAB(10); MC1
PRINT #1, "C(2)"; USING PF5$; TAB(10); MC2T; TAB(30); MC2P; TAB(50); MC2O
FOR I = 3 TO N
  PRINT #1, "C("; (I); ")"; USING PF5$; TAB(10); MCOP(I); TAB(30); MCNP(I);
      TAB(50); MCNO(I)
NEXT I
PRINT #1, "-----"
PRINT #1, "Total production rates of hydrocarbons, kg/hr ="; TOT
PRINT #1, "Oefin /TOT="; MO / SOP
PRINT #1, "Parafin /TOT="; MP / SOP
PRINT #1, "-----"
PRINT #1,
TT2$ = TIME$
PRINT #1, TT1$, TT2$
CALL TIME
PRINT #1, "Operating Time="; TT7; "SEC."

CLOSE #1
END

```

SUB ALFA

```

FOR CT1 = .02 TO .125 STEP .0001
  F1 = .4: F2 = .6: P1 = 3 " PRESSURE MPA" P * 10 ^ -6 'F1,F2 FEED RATIO
  KR = .17: TP1 = 6.5: TP2 = 1.7: C = .35: N = 50':CT1 = .10E39
  T0 = 3.71 * ((P1 * F1) ^ -.5) 'T0,PC,KR CONST
  T0 = 5.6
  PP = 14 * ((P1 * F1) ^ -.26) * ((P1 * F2) ^ .4)
  PP = 17.4

```

```

MC1 = CT1 * TP1 ': KR = 0
KR2 = 17.6 * KR * EXP(2 * C)           'Calc of ALF2
T2 = T0 ^ 2 / (1 + KR2)
ALF2 = PP / (T2 + TP2 + PP)
MC2P = TP2 * ALF2 * CT1                'Cal of C2 in Paraffin Molar Selec
MC2O = ALF2 * CT1 * T2                 'Calc. of C2 in Olefin in Molar Selec
CTN = CT1 * ALF2
SUM = 0: SUMP = 0
SUMT1 = 0: SUMT2 = 0
PRINT #1, "MC1="; MC1
PRINT #1, "-----"
PRINT #1, "N"; TAB(10); "MCNP(N)"; TAB(20); "SUMP"; TAB(30); "SUMP1";
      TAB(40); "MCNO(I)"; TAB(50); "SUMO"; TAB(60); "SUMO1"
PRINT #1, "-----"
PRINT #1,

FOR I = 3 TO N
'-----
  T3 = T0 / (1 + KR * EXP(I * C))
  ALF(I) = PP / (T3 + 1 + PP)
  CTN = CTN * ALF(I)
  MCNP(I) = CTN                        'Calc. of Paraffin in Molar Selec
  MCNO(I) = MCNP(I) * T3              'Calc. of Olefin in Molar Selec
  SUMP = SUMP + MCNP(I)
  SUMP1 = SUMP1 + MCNP(I) * I
  SUMO = SUMO + MCNO(I)
  SUMO1 = SUMO1 + MCNO(I) * I
  SUMT = SUMO1 + SUMP1
  MCOP(I) = MCNP(I) + MCNO(I)
  PRINT #1, I; TAB(10); USING PF1$; MCNP(I); TAB(20); SUMP; TAB(30);
    SUMP1; TAB(40); MCNO(I); TAB(50); SUMO; TAB(60); SUMO1
NEXT I
'-----
  SUM1 = MC1 + MC2P * 2 + MC2O * 2
  SUM = SUMP + SUMO + MC1 + MC2P + MC2O
  MC2T = MC2P + MC2O
  IF SUM - .001 >= 1 THEN GOTO 333
NEXT CT1
333 PRINT #1, "-----"
PRINT #1, "Sum mi Selectivity =" ; SUM; CT1
PRINT #1, "Sum mi Selectivity * No of carbon =" ; SUMT + SUM1
PRINT #1, "-----"
  END SUB

SUB EngBL
'-----
PRINT #1, "-----"

'Energy Balance Calculation ;ENG,(j/m^3.s)
'-----
ENG1 = ES * EL * RP * DHR * RFT
ENG2 = US / L * ((RSL * CpS * TRI) - (RSL * CpS * TR))
ENG3 = HE * (TR - TC)
'Calculation of Specific Cooling Area ;ACC,(1/m)
'-----
ACC = (ENG1 + ENG2) / ENG3
PRINT #1, "Specific Cooling Area ;ACC,(1/m)=" ; ACC
END SUB

```

```

'-----
ACC = (ENG1 + ENG2) / ENG3
PRINT #1, "Specific Cooling Area ;ACC,(1/m)="; ACC
PRINT #1, "*****"

END SUB

SUB HeatCof
'-----
' "Calculation of Heat Transfer Coef ,HE ;(w.m^2/K)"
'-----

HE1 = .1 * RSL * CpS * UG1
HE2 = UG1 ^ 3 * RSL / (G * VS)
HE3 = (VS * CpS / TCS) ^ 2
HE = HE1 * ((HE2 * HE3) ^ -.25)
PRINT #1,
PRINT #1, "Heat Transfer Coef.;HE(w.m^2/K)="; HE
PRINT #1, "-----"

END SUB

SUB HydPra
'-----
' "Calculation of Gas Hold up (Small &Large Bubble)"
'-----

VD = UO * (1 + .8 * ES / UO)
EDF = EDO * (RG / RGO) ^ .48 * (1 - .7 * ES / EDO)
UDF = EDF * VD      'Superficial Velocity of Small Bubbles,(m/s)
ULB = UG - UDF      'Superficial Velocity of Large Bubbles,(m/s)
ELB = .3 * (ULB ^ .58) * ((RG / RGO) ^ .5)
EG = ELB + EDF * (1 - ELB)      ' total gas hold up
EL = 1 - ES - EG      ' liquid hold up
PRINT #1, "Superficial Velocity of Small Bubbles,UDF,(m/s)="; UDF
PRINT #1, "Superficial Velocity of Large Bubbles,ULB,(m/s) = "; ULB
PRINT #1, "Small Gas Hold up ;EDF="; EDF
PRINT #1, "Large Gas Hold up ;ELB="; ELB
PRINT #1, "Solid Hold up ;ES="; ES
PRINT #1, "Liquid Hold up ;EL="; EL
PRINT #1, "Total Gas Hold up ;EG="; EG
PRINT #1, "-----"
' Calculation of Volumetric Mass Transfer Coef.,1/s"
'-----

FOR I = 1 TO NC
'-----
KLaS(I) = EDF * (DL(I) / DLO) ^ .5
KLaL(I) = .5 * ELB * ((DL(I) / DLO) ^ .5)
PRINT #1, "-----"
PRINT #1, "Vol. Mass Trans Coef.for S Bubble(1/S):KLaS("; C$(I); ")=";
KLaS(I)
PRINT #1, "Vol. Mass Trans Co.for L Bubble(1/S):KLaL("; C$(I); ")="; KLaL(I)
NEXT I
'-----
END SUB

```

SUB InputData

```
'-----  
  
PRINT "DATE "; DATE$, "TIME "; TIME$  
PRINT "===== "  
PRINT : INPUT "enter the data D_title;D_title$:", DTitle$  
PRINT " REACTOR CONDITION"  
PRINT "-----"  
PRINT TR$; : INPUT TR  
PRINT TRI$; : INPUT TRI  
PRINT TC$; : INPUT TC  
PRINT P$; : INPUT P  
PRINT L$; : INPUT L  
PRINT D1$; : INPUT D1  
PRINT DHR$; : INPUT DHR  
PRINT RG$; : INPUT RG  
PRINT RGO$; : INPUT RGO  
PRINT ES$; : INPUT ES  
PRINT CF$; : INPUT CF  
PRINT UO$; : INPUT UO  
PRINT UG$; : INPUT UG  
PRINT US$; : INPUT US  
PRINT "LIQUID PROPERTIES"  
PRINT "  
PRINT RL$; : INPUT RL  
PRINT VL$; : INPUT VL  
PRINT TCL$; : INPUT TCL  
PRINT EDO$; : INPUT EDO  
PRINT CpL$; : INPUT CpL  
PRINT DLO$; : INPUT DLO  
PRINT "CATALYST PROPERTIER"  
PRINT "  
PRINT TCC$; : INPUT TCC  
PRINT CpC$; : INPUT CpC  
PRINT RP$; : INPUT RP  
PRINT RSK$; : INPUT RSK  
PRINT "FEED PROPERTIES"  
PRINT "-----"  
PRINT NC$; : INPUT NC  
FOR I = 1 TO NC  
  
PRINT "Input the Name of the Components in the Feed:C$( "; I; ")=";  
INPUT C$(I)  
PRINT "Input the M.WT. of "; C$(I); " in the Feed M.WT( "; C$(I); ")=";  
INPUT MWT(I)  
PRINT "Input the Mole fr. of "; C$(I); " in the Feed YO( "; C$(I); ")=";  
INPUT YO(I)  
PRINT "Input Henryy Coff. of "; C$(I); ",pa.m3/mol: HC( "; C$(I); ") = "  
INPUT HC(I)  
PRINT "Input the Diffusivity. of "; C$(I); ", (m/s^2), :DL( "; C$(I); ")=";  
INPUT DL(I)  
PRINT " Input the Feed Ratio of the Component :F( "; C$(I); ") = "  
INPUT F(I)  
NEXT I  
  
INPUT "Enter -1 if you want to save the data &0 if not ;dts:", DTS  
IF DTS THEN CALL SaveData
```

END SUB

SUB PhyProp

```
'
-----
'Calculation of Slurry Density,rsl, kg/m^3"
-----
RSL = RL * (1 - RL * ES / RSK) + (RP * ES)
PRINT #1, "Slurry Dinsity: RSL(kg/m^3)="; RSL
PRINT #1,

'"Calculation of Slurry Viscosity,:VS,(pa.s)"
-----
VS = VL * (1 + 4.5 * ES)
PRINT #1, "Slurry Viscosity:vs(pa.s)="; VS
PRINT #1,

'"Calculation of Slurry Heat Capacity ,CpS ;(J/m3R)"
-----
CpS = ES * RP / RL * CpC + (1 - (ES * RP / RL)) * CpL
PRINT #1, "Slurry Heat Capacity:CpS(j/m3R)="; CpS

'"Thermal Conductivity of Slurry ;TCS ,(w/m.K)
-----

TCS1 = TCC + 2 * TCL - 2 * ES * (TCL - TCC)
TCS2 = 2 * TCL + TCC + ES * (TCL - TCC)
TCS = TCL * TCS1 / TCS2          '"Thermal Conductivity of slurr
PRINT #1, "Thermal Conductivity of Slurry;TCS(w/m.K)="; TCS
END SUB
```

SUB PrintData

```
CLS : PRINT "the data title:"; titles
PRINT " REACTOR CONDITION"
PRINT "DATE "; DATE$, "TIME "; TIME$
PRINT "INPUT DATA PRINT OUT"
PRINT "REACTOR CONDITIONS"
PRINT "Reactor Temperature ;TR,(K)="; TR
PRINT "Reactor Inlet Temperature ;TRI,(K):", TRI
PRINT " Reaction Enthalpy ;DHR,(J/mol)="; DHR
PRINT "Reactor Length ;L,(m)="; L
PRINT "Reactor Length ;Dl,(m)="; Dl
PRINT "Reactor Pressure ;P,(pa)="; P
PRINT "Inlet Superfacial Velocity ;UG,(m/s)="; UG
PRINT "Density of Gas at Reactor Condition ;RG,(kg/m^3)="; RG
PRINT "Density of Gas at Ambient Condition ;RGO,(kg/m^3)="; RGO
PRINT "Slurry Hold up ;ES,(m^3l/m^3r)="; ES
PRINT "Rise Vel. of the Small Bubbles at 0 Solids ;UO,(m/s)="; UO
PRINT "Cooling Temperature ;TC,(K)="; TC
PRINT "Contraction Factor ;CF="; CF
PRINT "Slurry Velocity ;US,(m/s)="; US
PRINT "Diffusivity at Reference Condition ;DLO,(m^2/s)="; DLO
PRINT "Gravity ;G,(m/s^2)="; G
PRINT "LIQUID PROPERTIES"
PRINT "Liquid Density ;RL,(kg/m^3)="; RL
PRINT "Refrence Hold up at Pure Liquid ;EDO="; EDO
PRINT "Liquid Viscosity ;VL,(m/s)="; VL
PRINT "Thermal Conductivity of Liquid ;TCL,( )="; TCL
```

```

PRINT "Heat Capacity of Liquid    ;CpL, (j/kg.k))="; CpL
PRINT "CATALYST PROPERTIES"
PRINT "Catalyst Particle Density  ;RP, (kg/m^3) ="; RP
PRINT "Skelton Density    ;RSK, (kg/m^3)="; RSK
PRINT "Thermal Conductivity of Catalyst  ; TCC, (w/m.K):="; TCC
PRINT "Heat Capacity of Catalyst    ;CpC, ( j/(kg.k)):="; CpC
PRINT " FEED PROPERTIES "
PRINT "Gas Constant    ;R, (pa*m^3/(mol*K))="; R
PRINT "No of Component    ;NC="; NC
FOR I = 1 TO NC
'-----
PRINT "C$( "; I; ")="; C$(I)
PRINT "The Mol.WT.of "; C$(I); " in the Feed M.WT( "; C$(I); ") = "; MWT(I)
PRINT "The Mol.Fr.of "; C$(I); " in the Feed YO( "; C$(I); ") = "; YO(I)
PRINT "The Diffusivity for "; C$(I); ", dl( "; C$(I); "), (m^2/s)="; DL(I)
PRINT "Henery Co. for "; C$(I); ", HC( "; C$(I); "), (Pa.m^3/mol)="; HC(I)
NEXT I
'-----
END SUB

SUB READDATA
'-----
INPUT "Enter the drive name (drive:\)&file name to read the data:", DFileName$
OPEN DFileName$ FOR INPUT AS #4
INPUT #4, DT$, TMS$
INPUT #4, DTitle$
INPUT #4, TR, TRI, TC, P, L, DL, DHR, RG, RGO
INPUT #4, ES, CF, UO, UG, US
INPUT #4, RL, VL, TCL, EDO, CpL, DLO
INPUT #4, TCC, CpC, RP, RSK, NC
FOR I = 1 TO NC
'-----
INPUT #4, C$(I)
INPUT #4, MWT(I)
INPUT #4, YO(I)
INPUT #4, HC(I)
INPUT #4, DL(I)
INPUT #4, F(I)
NEXT I
'-----
CLOSE #4
END SUB

SUB Results
'-----
INPUT "Enter The Drive Name (Drive :\ ) &File name to Save Results(<=8chs.<=3"
RFilename$
INPUT "Enter the results titles:", RTITLE$
OPEN RFilename$ FOR OUTPUT AS #5
WRITE #5, "DATE ", DATE$, "TIME ", TIME$
WRITE #5, "===== "
WRITE #5, "The Data Used for Calculations"
WRITE #5,
WRITE #5, TR$, TR
WRITE #5, TRI$, TRI
WRITE #5, TC$, TC
WRITE #5, P$, P

```

```

WRITE #5, CpL$, CpL
WRITE #5, DLO$, DLO
WRITE #5, TCC$, TCC
WRITE #5, CpC$, CpC
WRITE #5, RP$, RP
WRITE #5, RSK$, RSK
WRITE #5, NC$, NC
FOR I = 1 TO NC
'
WRITE #5, "The Name of Component in the Feed ;C$(I) ", C$(I)
WRITE #5, "The Mole Weight ;M.WT(", C$(I), " )", MWT(I)
WRITE #5, "The Mole Fraction in the Feed ;YO(", C$(I), " )", YO(I)
WRITE #5, "The Henry Coef. ,(pa.m3/mol) ;HC(", C$(I), ")", HC(I)
WRITE #5, "The Diffusivity Coef of the Comp. ;(m2/s) ;DL(", C$(I), ")", DL(I)
WRITE #5, "The Diffusivity Coef of the Comp. ;(m2/s) ;F(", C$(I), ")", F(I)
NEXT I
'
CLOSE #5
END SUB

```

SUB RNX

```

' "Calculation of Kinetic Rate ;RFT ,(mol/kg/s)
PH2 = .4 * P * 10 ^ -5 ' partial pressure of H2, (pa)
PCO = .6 * P * 10 ^ -5 ' " " " CO, (pa)
PH2O = .00006 * P * 10 ^ -5 ' partial pressure of H2O, (pa)
PCO2 = .05 * P * 10 ^ -5 ' " " " CO2, (pa)
K1 = .0339: A = 1.185: B = .656: KW = .0292: K3 = 3.07: KP = 86
PR1 = (1 + A * PCO + B * PCO2)
RFT = K1 * (PH2 ^ .5) * PCO / (PR1 ^ 2) ' kinetic rate, ( mol/kg/s)
PR2 = (PCO2 * PH2) / KP
PR3 = (PCO + K3 * PH2O)
RWGS = KW * (PCO * PH2O - PR2) / (PR3 ^ 2) ' kinetic rate, ( mol/kg/s)
AL = .69: JM = .25
MN = (1 - AL) ^ 2 + (JM * AL * (1 - AL))
VHC1 = (1 - AL) / (3 + MN)
VHC2 = (1 - AL) / (3 + MN)
RX = (RFT + RWGS) * ES * EL * RP
PRINT #1, "Kinetic Rate;RFT,(mol/kg/s)="; RFT
PRINT #1, "Kinetic Rate;RWGS,(mol/kg/s)="; RWGS
PRINT #1, "Kinetic Rate;RX="; RX
PRINT #1, "Kinetic VHC1="; VHC1

```

END SUB

SUB SaveData

```

'-----
INPUT "enter the drive (drive:\)&file name to save the data<=8chs.<=3):",
DFileName$
OPEN DFileName$ FOR OUTPUT AS #3
WRITE #3, DT$, TM$
WRITE #3, DTitle$
WRITE #3, TR, TRI, TC, P, L, D1, DHR, RG, RGO
WRITE #3, ES, CF, UO, UG, US
WRITE #3, RL, VL, TCL, EDO, CpL, DLO
WRITE #3, TCC, CpC, RP, RSK, NC
FOR I = 1 TO NC
'
WRITE #3, C$(I)
WRITE #3, MWT(I)
WRITE #3, YO(I)

```

```
PRINT #1, "Kinetic Rate;RWGS,(mol/kg/s)="; RWGS
PRINT #1, "Kinetic Rate;RX="; RX
PRINT #1, "Kinetic VHC1="; VHC1
```

```
END SUB
```

```
SUB SaveData
```

```
CLS
```

```
INPUT "enter the drive (drive:\)&file name to save the data<=8chs.<=3):",
DFileName$
```

```
OPEN DFileName$ FOR OUTPUT AS #3
WRITE #3, DT$, TM$
WRITE #3, DTitle$
WRITE #3, TR, TRI, TC, P, L, D1, DHR, RG, RGO
WRITE #3, ES, CF, UO, UG, US
WRITE #3, RL, VL, TCL, EDO, CpL, DLO
WRITE #3, TCC, CpC, RP, RSK, NC
FOR I = 1 TO NC
```

```
WRITE #3, C$(I)
WRITE #3, MWT(I)
WRITE #3, YO(I)
WRITE #3, HC(I)
WRITE #3, DL(I)
WRITE #3, F(I)
```

```
NEXT I
```

```
CLOSE #3
```

```
END SUB
```

```
SUB TIME
```

```
REM time subroutine
```

```
REM -----
```

```
TT1 = VAL(LEFT$(TT1$, 2))
```

```
TT2 = VAL(MID$(TT1$, 4, 2))
```

```
TT3 = VAL(RIGHT$(TT1$, 2))
```

```
TT4 = VAL(LEFT$(TT2$, 2))
```

```
TT5 = VAL(MID$(TT2$, 4, 2))
```

```
TT6 = VAL(RIGHT$(TT2$, 2))
```

```
TT7 = TT6 + 60 * TT5 + 60 * 60 * TT4 - (TT3 + 60 * TT2 + 60 * 60 * TT1)
```

```
END SUB
```

Start Date / Time	10/17/1996	12.00
End Date / Time	10/18/1996	12.00

<b>On-stream Time From Start-up (hr)</b>	
Start	64.00
End	88.00

<b>Reaction Conditions:</b>					
Temperature	average	deg F	440.1	deg C	226.7
Pressure	PIC-201	psig	710.0	bara	49.97
Space Velocity		sL/kg-hr	7612		
Superficial Gas Vel. - Inlet		ft/sec	0.43	cm/sec	13.18
(based on average reactor temp)					
Recycle Ratio			3.20		

<b>Slurry Data:</b>					
Catalyst Oxide Wt (Reactor)	lbs	860	kg	390.1	
Slurry Concentration by NDG	wt%	42.4			
Slurry Concentration by DP	wt%	39.9			
Slurry Level by NDG	% NDG Span	95.2			
Slurry Height	ft	20.57	meters	6.27	
Average Gas Holdup by NDG	Vol%	41.4			
Average Gas Holdup by DP	Vol%	35.8			

<b>Performance Results</b>	
CO Conversion per pass, mole %	9.1
H2 Conversion per pass, mole %	15.8
CO + H2 Conversion per pass, mole %	13.0
Plant CO Conversion, mole%	36.8
Plant H2 Conversion, mole%	54.7
Plant CO+H2 Conversion, mole%	48.4
CO Conversion Rate,	11.6
gmole CO converted/kg cat oxide-hr	
HC Production Rate,	163.4
grams of HC (CH2.1) produced/kg cat oxide-hr	
Reactor Productivity (STY)	43.85
grams of H C (CH2.1)/lit of reactor vol. - hr	
H2/CO in Fresh Feed, mole/mole	1.82
H2/CO in Reactor Feed, mole/mole	1.41
H2/CO Usage Ratio, mole/mole	2.43
H2/CO in Outlet, mole/mole	1.30
CO2 Selectivity, mole %	0.41
<b>HC Selectivity (CO2 free) wt%:</b>	
CH4	13.88
C2H6	1.50
C2H4	1.01
C3H8	1.90
C3H6	3.57
SUM C4H10	2.57
SUM C4H8	3.40
SUM C5H11	5.47

<b>Reactor Heat Balance</b>		
	<b>Btu/hr</b>	<b>kW</b>
Chemical Heat Production by Reaction	708882	207.75
Sensible Gas Heat	-114281	-33.49
Sensible Oil Heat	-453176	-132.81
Sensible Wax Heat	-80173	-23.50
Estimate of Heat Loss from Catalyst Drying Data	-35000	-10.26
% Heat Balance based on Reaction Heat	96.30	

<b>Mass Balance</b>	<b>Reactor</b>	<b>Plant</b>	<b>Feed</b>	<b>Prod Gas</b>
	<b>lb/hr</b>	<b>lb/hr</b>	<b>lb/hr</b>	<b>lb/hr</b>
Fresh Feed		823	823	
HP H2 Feed				
Recycle Feed			3317	3317
Reactor Feed	4162		4162	
Total In	4162	823		
Prod Gas	3839			3839
Main Purge		541		541
22.11 Purge	45.7	45.7		
HC Phase	36.9	36.9		
AQ Phase	200.1	200.1		
Heavy Wax	34.0	34.0		
Light Wax				
Total Out	4156	857		
Mass Balance, %	99.8	104.2	100.5	100.5

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Compositions (mole%):		LP FRESH FEED	HP FRESH FEED (H2)	RECYCLE FEED	REACTOR FEED GAS	PRODUCT GAS	MAIN (22.10) PURGE	22.11 PURGE	REACTOR OUTLET (estimated)
Components									
1	H2	62.08	100.00	50.14	52.89	50.14	50.14	48.34	48.04
2	N2	3.71	0.00	7.12	6.32	7.12	7.12	6.93	6.82
3	CO	34.20	0.00	38.47	37.62	38.47	38.47	38.24	36.85
4	CH4	0.00	0.00	2.93	2.18	2.93	2.93	3.12	2.81
5	CO2	0.00	0.00	0.12	0.09	0.12	0.12	0.16	0.11
6	ETHANE	0.00	0.00	0.17	0.13	0.17	0.17	0.23	0.16
7	ETHYLENE	0.00	0.00	0.02	0.00	0.02	0.02	0.03	0.02
8	PROPANE	0.00	0.00	0.15	0.11	0.15	0.15	0.29	0.14
9	PROPYLENE	0.00	0.00	0.27	0.20	0.27	0.27	0.51	0.26
10	ISOBUTANE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	N-BUTANE	0.00	0.00	0.13	0.10	0.13	0.13	0.38	0.13
12	T-BUTENE-2	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
13	BUTENE-1	0.00	0.00	0.15	0.12	0.15	0.15	0.20	0.15
14	ISOBUTYLENE	0.00	0.00	0.00	0.00	0.00	0.00	0.24	0.00
15	C-BUTENE-2	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00
16	SUM C5	0.00	0.00	0.19	0.13	0.19	0.19	0.63	0.18
17	SUM C6	0.00	0.00	0.08	0.08	0.08	0.08	0.51	0.08
18	SUM C7	0.00	0.00	0.04	0.03	0.04	0.04	0.14	0.04
19	SUM C8	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01
20	SUM C9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21	SUM C10	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
	H2O								4.11
	HC								0.10
	LIGHT WAX								0.000
	TOTAL	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Mole Wt	lb/lb mole	11.87	2.02	14.96	14.26	14.96	14.96	16.15	15.21
Flows	SCFH	26798.58	0.00	85721.03	112858.42	99218.39	13971.76	1093.39	103576.37
	lb mole/hr	69.31	0.00	221.70	291.89	256.61	36.14	2.83	267.88
	lb/hr	823.03	0.00	3316.81	4162.20	3839.06	540.61	45.68	4074.36
	Nm3/hr	705.24	0.00	2255.85	2970.01	2611.05	367.68	28.77	2725.74
	kgmol/hr	31.44	0.00	100.56	132.40	116.40	16.39	1.28	121.51
	kg/hr	373.32	0.00	1504.49	1887.96	1741.39	245.22	20.72	1848.12
Temperature	deg F	277.9	86.7	124.9	247.0	85.0	83.2	79.3	
	deg C	136.6	30.4	51.6	119.5	29.4	28.5	26.3	
Pressure	psig	762.5	780.5	818.1	749.6	662.2	671.6	26.9	
	bara	53.59	54.83	57.42	52.69	46.67	47.32	2.86	

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RUNNO.: AF-R16.1B

TITLE: LIQUID PHASE FISCHER-TROPSCH (IV) SYNTHESIS IN LAPORTE AFDU

Start Date / Time	04/03/1998	12.00
End Date / Time	04/04/1998	8.00

<b>On-stream Time From Start-up (hr)</b>	
Start	142.00
End	162.00

<b>Reaction Conditions:</b>					
Temperature	average	deg F	498.1	deg C	259.0
Pressure	PIC-201	psig	710.0	bara	49.97
Space Velocity		sL/kg-hr	14925		
Superficial Gas Vel. - Inlet		ft/sec	0.41	cm/sec	12.48
(based on average reactor temp)					
Recycle Ratio			1.14		

<b>Slurry Data:</b>				
Catalyst Oxide Wt (Reactor)	lbs	390	kg	176.9
Slurry Concentration by NDG	wt%	28.8		
Slurry Concentration by DP	wt%	27.7		
Slurry Level by NDG	% NDG Span	96.5		
Slurry Height	ft	20.77	meters	6.33
Average Gas Holdup by NDG	Vol%	50.5		
Average Gas Holdup by DP	Vol%	47.3		

<b>Performance Results</b>	
CO Conversion per pass, mole %	33.1
H2 Conversion per pass, mole %	59.9
CO + H2 Conversion per pass, mole %	47.6
Plant CO Conversion, mole%	76.8
Plant H2 Conversion, mole%	91.3
Plant CO+H2 Conversion, mole%	86.3
CO Conversion Rate,	83.0
gmole CO converted/kg cat oxide-hr	
HC Production Rate,	1155.1
grams of HC (CH2.1) produced/kg cat oxide-hr	
Reactor Productivity (STY)	139.23
grams of H C (CH2.1)/lit of reactor vol. - hr	
H2/CO in Fresh Feed, mole/mole	1.88
H2/CO in Reactor Feed, mole/mole	1.17
H2/CO Usage Ratio, mole/mole	2.13
H2/CO in Outlet, mole/mole	0.70
CO2 Selectivity, mole %	1.33
<b>HC Selectivity (CO2 free) wt%:</b>	
CH4	13.95
C2H6	2.05
C2H4	0.08
C3H8	2.40
C3H6	1.46
SUM C4H10	1.89
SUM C4H8	1.24

<b>Reactor Heat Balance</b>		
	<b>Btu/hr</b>	<b>kW</b>
Chemical Heat Production by Reaction	2277851	667.57
Sensible Gas Heat	-118507	-34.73
Sensible Oil Heat	-1781173	-522.01
Sensible Wax Heat	-244482	-71.65
Estimate of Heat Loss from Catalyst Drying Data	-50000	-14.65
% Heat Balance based on Reaction Heat	96.33	

<b>Mass Balance</b>	<b>Reactor</b>	<b>Plant</b>	<b>Feed</b>	<b>Prod Gas</b>
	<b>lb/hr</b>	<b>lb/hr</b>	<b>lb/hr</b>	<b>lb/hr</b>
Fresh Feed		1300	1300	
HP H2 Feed		89	89	
Recycle Feed			2790	2790
Reactor Feed	4202		4202	
Total In	4202	1390		
Prod Gas	3266			3266
Main Purge		481		481
22.11 Purge	0.0	0.0		
HC Phase	287.8	287.8		
AQ Phase	554.0	554.0		
Heavy Wax	59.2	59.2		
Light Wax				
Total Out	4167	1382		
Mass Balance, %	99.2	99.5	100.5	100.2

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Compositions (mole%):		LP FRESH FEED	HP FRESH FEED (H2)	RECYCLE FEED	REACTOR FEED GAS	PRODUCT GAS	MAIN (22.10) PURGE	22.11 PURGE	REACTOR OUTLET (estimated)
Components									
1	H2	43.59	100.00	28.14	44.25	28.14	28.14	8.18	23.35
2	N2	3.04	0.00	9.83	6.20	9.83	9.83	4.82	8.15
3	CO	53.37	0.00	40.06	37.72	40.06	40.06	24.11	33.24
4	CH4	0.00	0.00	15.62	8.33	15.62	15.62	23.27	12.96
5	CO2	0.00	0.00	1.83	0.99	1.83	1.83	7.57	1.52
6	ETHANE	0.00	0.00	1.39	0.76	1.39	1.39	7.11	1.16
7	ETHYLENE	0.00	0.00	0.02	0.01	0.02	0.02	0.10	0.02
8	PROPANE	0.00	0.00	1.02	0.55	1.02	1.02	7.96	0.84
9	PROPYLENE	0.00	0.00	0.67	0.36	0.67	0.67	5.27	0.56
10	ISOBUTANE	0.00	0.00	0.01	0.00	0.01	0.01	0.09	0.01
11	N-BUTANE	0.00	0.00	0.46	0.24	0.46	0.46	4.03	0.38
12	T-BUTENE-2	0.00	0.00	0.04	0.02	0.04	0.04	0.31	0.03
13	BUTENE-1	0.00	0.00	0.26	0.12	0.26	0.26	2.33	0.22
14	ISOBUTYLENE	0.00	0.00	0.03	0.04	0.03	0.03	0.26	0.02
15	C-BUTENE-2	0.00	0.00	0.05	0.02	0.05	0.05	0.40	0.04
16	SUM C5	0.00	0.00	0.32	0.18	0.32	0.32	2.69	0.27
17	SUM C6	0.00	0.00	0.11	0.06	0.11	0.11	0.85	0.09
18	SUM C7	0.00	0.00	0.11	0.12	0.11	0.11	0.62	0.09
19	SUM C8	0.00	0.00	0.04	0.04	0.04	0.04	0.01	0.03
20	SUM C9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21	SUM C10	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
	H2O								15.98
	HC								1.04
	LIGHT WAX								0.000
	TOTAL	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Mole Wt	lb/lb mole	16.68	2.02	19.97	16.19	19.97	19.97	30.75	20.92
Flows	SCFH	30138.70	17101.00	54031.22	100355.33	63249.80	9314.22	0.00	76219.29
	lb mole/hr	77.95	44.23	139.74	259.55	163.59	24.09	0.00	197.13
	lb/hr	1300.26	89.34	2790.32	4201.68	3266.39	481.01	0.00	4123.30
	Nm3/hr	793.14	450.03	1421.90	2640.97	1664.49	245.11	0.00	2005.80
	kgmol/hr	35.36	20.06	63.39	117.73	74.20	10.93	0.00	89.42
	kg/hr	589.79	40.53	1265.68	1905.87	1481.62	218.19	0.00	1870.32
Temperature	deg F	266.7	82.5	98.2	238.1	75.5	74.4	73.4	
	deg C	130.4	28.0	36.8	114.5	24.2	23.5	23.0	
Pressure	psig	768.1	779.2	760.3	734.4	686.4	682.3	33.5	
	bara	53.97	54.74	53.43	51.65	48.34	48.06	3.32	

RUN NO.: AF-R16.1C

TITLE: LIQUID PHASE FISCHER-TROPSCH (IV) SYNTHESIS IN LAPORTE AFDU

Start Date / Time	04/04/1998	8.00
End Date / Time	04/05/1998	4.00

<b>Reaction Conditions:</b>					
Temperature	average	deg F	498.0	deg C	258.9
Pressure	PIC-201	psig	710.0	bara	49.97
Space Velocity		sL/kg-hr	14975		
Superficial Gas Vel. - Inlet		ft/sec	0.41	cm/sec	12.45
(based on average reactor temp)					
Recycle Ratio			1.11		

<b>Performance Results</b>	
CO Conversion per pass, mole %	33.2
H2 Conversion per pass, mole %	60.5
CO + H2 Conversion per pass, mole %	48.4
Plant CO Conversion, mole%	75.7
Plant H2 Conversion, mole%	90.4
Plant CO+H2 Conversion, mole%	85.3
CO Conversion Rate, gmole CO converted/kg cat oxide-hr	81.5
HC Production Rate, grams of HC (CH2.1) produced/kg cat oxide-hr	1132.6
Reactor Productivity (STY) grams of H C (CH2.1)/lit of reactor vol. - hr	135.79
H2/CO in Fresh Feed, mole/mole	1.88
H2/CO in Reactor Feed, mole/mole	1.26
H2/CO Usage Ratio, mole/mole	2.30
H2/CO in Outlet, mole/mole	0.75
CO2 Selectivity, mole %	1.41
HC Selectivity (CO2 free) wt%:	
CH4	14.61
C2H6	2.42
C2H4	0.15
C3H8	2.51
C3H6	1.69
SUM C4H10	1.90
SUM C4H8	1.21

<b>On-stream Time From Start-up (hr)</b>	
Start	162.00
End	182.00

<b>Slurry Data:</b>			
Catalyst Oxide Wt (Reactor)	lbs	388	kg 176.0
Slurry Concentration by NDG	wt%	28.6	
Slurry Concentration by DP	wt%	27.6	
Slurry Level by NDG	% NDG Span	96.5	
Slurry Height	ft	20.77	meters 6.33
Average Gas Holdup by NDG	Vol%	50.1	
Average Gas Holdup by DP	Vol%	47.3	

<b>Reactor Heat Balance</b>		
	Btu/hr	kW
Chemical Heat Production by Reaction		
Sensible Gas Heat		
Sensible Oil Heat		
Sensible Wax Heat		
Estimate of Heat Loss from Catalyst Drying Data		
% Heat Balance based on Reaction Heat		

<b>Mass Balance</b>	<b>Reactor</b>	<b>Plant</b>	<b>Feed</b>	<b>Prod Gas</b>
	lb/hr	lb/hr	lb/hr	lb/hr
Fresh Feed		1301	1301	
HP H2 Feed		89	89	
Recycle Feed			2641	2641
Reactor Feed	4039		4039	
Total In	4039	1390		
Prod Gas	3138			3138
Main Purge		498		498
22.11 Purge	0.0	0.0		
HC Phase	275.8	275.8		
AQ Phase	531.0	531.0		
Heavy Wax	52.7	52.7		
Light Wax				
Total Out	3997	1357		
Mass Balance, %	99.0	97.6	100.2	100.0

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RUN NO.: AF-R16.1C

TITLE: LIQUID PHASE FISCHER-TROPSCH (IV) SYNTHESIS IN LAPORTE AFDU

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Compositions (mole%):		LP FRESH FEED	HP FRESH FEED (H2)	RECYCLE FEED	REACTOR FEED GAS	PRODUCT GAS	MAIN (22.10) PURGE	22.11 PURGE	REACTOR OUTLET (estimated)
Components									
1	H2	43.54	100.00	29.59	46.37	29.59	29.59	9.41	24.58
2	N2	3.07	0.00	9.39	5.82	9.39	9.39	4.57	7.80
3	CO	53.39	0.00	39.71	36.78	39.71	39.71	25.39	32.99
4	CH4	0.00	0.00	15.15	7.81	15.15	15.15	21.44	12.59
5	CO2	0.00	0.00	1.73	0.90	1.73	1.73	6.67	1.44
6	ETHANE	0.00	0.00	1.38	0.71	1.38	1.38	7.24	1.15
7	ETHYLENE	0.00	0.00	0.02	0.00	0.02	0.02	0.11	0.02
8	PROPANE	0.00	0.00	1.01	0.53	1.01	1.01	8.18	0.84
9	PROPYLENE	0.00	0.00	0.67	0.34	0.67	0.67	5.28	0.55
10	ISOBUTANE	0.00	0.00	0.01	0.00	0.01	0.01	0.10	0.01
11	N-BUTANE	0.00	0.00	0.47	0.24	0.47	0.47	4.31	0.39
12	T-BUTENE-2	0.00	0.00	0.04	0.02	0.04	0.04	0.31	0.03
13	BUTENE-1	0.00	0.00	0.26	0.13	0.26	0.26	2.38	0.22
14	ISOBUTYLENE	0.00	0.00	0.03	0.02	0.03	0.03	0.28	0.03
15	C-BUTENE-2	0.00	0.00	0.05	0.02	0.05	0.05	0.41	0.04
16	sum C5	0.00	0.00	0.33	0.18	0.33	0.33	2.88	0.28
17	SUM C6	0.00	0.00	0.12	0.07	0.12	0.12	0.90	0.10
18	SUM C7	0.00	0.00	0.02	0.02	0.02	0.02	0.14	0.02
19	SUM C8	0.00	0.00	0.01	0.02	0.01	0.01	0.02	0.01
20	SUM C9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21	SUM C10	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
	H2O								15.90
	HC								1.01
	LIGHT WAX								0.000
	TOTAL	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Mole Wt	lb/lb mole	16.69	2.02	19.56	15.59	19.56	19.56	30.43	20.55
Flows	SCFH	30132.03	17104.10	52207.22	100178.56	62030.75	9842.83	0.00	74659.86
	lb mole/hr	77.93	44.24	135.03	259.10	160.43	25.46	0.00	193.10
	lb/hr	1301.01	89.36	2640.99	4039.26	3137.93	497.92	0.00	3968.45
	Nm3/hr	792.96	450.12	1373.90	2636.32	1632.41	259.03	0.00	1964.76
	kgmol/hr	35.35	20.07	61.25	117.53	72.77	11.55	0.00	87.59
	kg/hr	590.13	40.53	1197.94	1832.20	1423.36	225.85	0.00	1800.08
Temperature	deg F	272.0	85.2	104.2	238.7	83.8	81.3	69.3	
	deg C	133.4	29.6	40.1	114.8	28.8	27.4	20.7	
Pressure	psig	766.0	792.3	758.4	733.1	685.8	682.0	33.4	

RUN NO.: AF-R16.3A

TITLE: LIQUID PHASE FISCHER-TROPSCH (IV) SYNTHESIS IN LAPORTE AFDU

Start Date / Time	0/06/1998	23.00
End Date / Time	04/07/1998	8.00

<b>On-stream Time From Start-up (hr)</b>	
Start	225.00
End	234.00

<b>Reaction Conditions:</b>					
Temperature	average	deg F	502.2	deg C	261.2
Pressure	PIC-201	psig	710.1	bara	49.98
Space Velocity		sL/kg-hr	22223		
Superficial Gas Vel. - Inlet		ft/sec	0.60	cm/sec	18.32
(based on average reactor temp)					
Recycle Ratio			2.12		

<b>Slurry Data:</b>				
Catalyst Oxide Wt (Reactor)	lbs	383	kg	173.7
Slurry Concentration by NDG	wt%	28.6		
Slurry Concentration by DP	wt%	27.3		
Slurry Level by NDG	% NDG Span	96.8		
Slurry Height	ft	20.81	meters	6.34
Average Gas Holdup by NDG	Vol%	50.2		
Average Gas Holdup by DP	Vol%	47.2		

<b>Performance Results</b>	
CO Conversion per pass, mole %	20.2
H2 Conversion per pass, mole %	43.0
CO + H2 Conversion per pass, mole %	32.2
Plant CO Conversion, mole%	70.2
Plant H2 Conversion, mole%	87.2
Plant CO+H2 Conversion, mole%	81.2
CO Conversion Rate,	76.9
gmole CO converted/kg cat oxide-hr	
HC Production Rate,	1067.3
grams of HC (CH2.1) produced/kg cat oxide-hr	
Reactor Productivity (STY)	126.07
grams of H C (CH2.1)/lit of reactor vol. - hr	
H2/CO in Fresh Feed, mole/mole	1.82
H2/CO in Reactor Feed, mole/mole	1.10
H2/CO Usage Ratio, mole/mole	2.34
H2/CO in Outlet, mole/mole	0.78
CO2 Selectivity, mole %	1.55
HC Selectivity (CO2 free) wt%:	
CH4	17.67
C2H6	2.48
C2H4	-0.05
C3H8	2.64
C3H6	1.73
SUM C4H10	1.55
SUM C4H8	1.45

<b>Reactor Heat Balance</b>		
	<b>Btu/hr</b>	<b>kW</b>
Chemical Heat Production by Reaction	2068071	606.09
Sensible Gas Heat	-178235	-52.24
Sensible Oil Heat	-1608608	-471.43
Sensible Wax Heat	-222668	-65.26
Estimate of Heat Loss from Catalyst Drying Data	-50000	-14.65
% Heat Balance based on Reaction Heat	99.59	

<b>Mass Balance</b>	<b>Reactor</b>	<b>Plant</b>	<b>Feed</b>	<b>Prod Gas</b>
	<b>lb/hr</b>	<b>lb/hr</b>	<b>lb/hr</b>	<b>lb/hr</b>
Fresh Feed		1312	1312	
HP H2 Feed		86	86	
Recycle Feed			4882	4882
Reactor Feed	6296		6296	
Total In	6296	1398		
Prod Gas	5472			5472
Main Purge		590		590
22.11 Purge	0.0	0.0		
HC Phase	274.0	274.0		
AQ Phase	527.4	527.4		
Heavy Wax	8.6	8.6		
Light Wax				
Total Out	6282	1400		
Mass Balance, %	99.8	100.1	100.3	100.0

Compositions (mole%):		LP FRESH FEED	HP FRESH FEED (H2)	RECYCLE FEED	REACTOR FEED GAS	PRODUCT GAS	MAIN (22.10) PURGE	22.11 PURGE	REACTOR OUTLET (estimated)
<b>Components</b>									
1	H2	43.25	100.00	31.65	42.08	31.65	31.65	10.91	28.62
2	N2	3.06	0.00	7.73	5.86	7.73	7.73	4.08	6.99
3	CO	53.69	0.00	40.33	38.30	40.33	40.33	27.97	36.47
4	CH4	0.00	0.00	14.57	9.83	14.57	14.57	19.11	13.18
5	CO2	0.00	0.00	1.45	0.98	1.45	1.45	5.05	1.31
6	ETHANE	0.00	0.00	1.30	0.90	1.30	1.30	7.26	1.18
7	ETHYLENE	0.00	0.00	0.02	0.02	0.02	0.02	0.10	0.02
8	PROPANE	0.00	0.00	0.98	0.88	0.98	0.98	8.24	0.89
9	PROPYLENE	0.00	0.00	0.59	0.40	0.59	0.59	4.84	0.54
10	ISOBUTANE	0.00	0.00	0.01	0.01	0.01	0.01	0.10	0.01
11	N-BUTANE	0.00	0.00	0.48	0.33	0.48	0.48	4.53	0.44
12	T-BUTENE-2	0.00	0.00	0.05	0.03	0.05	0.05	0.42	0.04
13	BUTENE-1	0.00	0.00	0.24	0.16	0.24	0.24	2.20	0.22
14	ISOBUTYLENE	0.00	0.00	0.03	0.02	0.03	0.03	0.30	0.03
15	C-BUTENE-2	0.00	0.00	0.08	0.04	0.06	0.06	0.52	0.05
16	SUM C5	0.00	0.00	0.36	0.25	0.36	0.36	3.16	0.33
17	SUM C6	0.00	0.00	0.13	0.09	0.13	0.13	1.05	0.11
18	SUM C7	0.00	0.00	0.02	0.01	0.02	0.02	0.15	0.01
19	SUM C8	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00
20	SUM C9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21	SUM C10	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
	H2O								8.97
	HC								0.61
	LIGHT WAX								0.000
	TOTAL	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Mole Wt	lb/lb mole	16.77	2.02	19.04	16.59	19.04	19.04	30.30	19.65
Flows	SCFH	30245.09	16504.40	99154.37	148743.26	111147.37	11978.68	0.00	122926.70
	lb mole/hr	78.22	42.69	256.45	379.53	287.47	30.98	0.00	317.93
	lb/hr	1311.76	86.23	4881.66	6296.36	5472.11	589.75	0.00	6261.44
	Nm3/hr	795.94	434.33	2609.37	3861.73	2924.98	315.23	0.00	3234.96
	kgmol/hr	35.48	19.36	116.32	172.15	130.39	14.05	0.00	144.21
	kg/hr	595.01	39.11	2214.31	2856.01	2482.13	267.51	0.00	2840.17
Temperature	deg F	279.1	80.1	122.8	295.2	85.2	82.7	73.2	
	deg C	137.3	26.7	50.4	146.2	29.6	28.2	22.9	
Pressure	psig	815.1	812.4	824.8	770.9	640.5	633.4	33.3	
	bara	57.21	57.02	57.88	54.17	45.17	44.68	3.31	

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جامعة المنيا  
كلية الهندسة  
قسم الهندسة الكيميائية

ترشيد الطاقة والنمذجة لتحويل الغاز الطبيعي إلى وقود سائل  
باستخدام تكنولوجيا فيشر وتربش

دراسة مقدمة من

**المهندس / حسين عبد الموجود محمد السيد**

للحصول على درجة الدكتوراه

فى

الهندسة الكيميائية

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أستاذ هندسة تطوير العمليات - معهد بحوث البترول

## الملخص العربي

هذه الدراسة نتناول طرق توفير الطاقة في المراحل المختلفة لتحويل الغاز الطبيعي الى وقود سائل

(GTL) والمعروفة بتكنولوجيا فيشر وتريشر. وكذلك يتم تناول عملية النمذجة لنفس التكنولوجيا.

١- في مرحلة تحضير غاز التخليق تعتبر فكرة التخليق ذاتي الحرارة (Autothermal) وفيها يتم الجمع بين التخليق البخاري [Steam reforming] والأكسدة الجزئية ( Partial Oxidation ) خطوة هامة لتوفير الطاقة في هذه المرحلة، حيث يتم الاستفادة من الحرارة الناتجة من عملية الأكسدة الجزئية (وهو تفاعل طارد للحرارة) لامداد الحرارة اللازمة لعملية التخليق البخاري (وهو تفاعل ماص للحرارة) ، وفي نفس الوقت يمكن إنتاج غاز التخليق بالنسبة المطلوبة ( هيدروجين /أول أكسيد الكربون) اللازمة لعملية الفيشر و تريشر.

عملية التكامل بين الثلاث خطوات اللازمة لعملية الفيشر وتريشر يمكن ان ينتج عنها توفير في الغاز الطبيعي ومن ثم الطاقة . كذلك فإن عملية الفيشر وتريشر ذات الاتجاه الواحد بدون دوران للغازات التي لم تتفاعل يمكن ان ينتج عنها الطاقة البخارية اللازمة للعمليات الصناعية بالإضافة الى الطاقة الكهربائية حيث يمكن استخدام التوربينات الغازية الى جانب التوربينات البخارية في عملية الدورة المشتركة (Combined Cycle) لتوليد الكهرباء والتي تحسن من اقتصاديات العملية.

وقد تم تناول عملية توفير الطاقة في وحدة تجارب نصف صناعية لعملية الفيشر وتريشر والتي اجريت في وحدة تطوير انتاج الوقود البديل (AFDU) في Laporte تكساس بأمريكا وذلك باستخدام برنامج تم تصميمه بمعهد بحوث البترول وهو برنامج (AMU) الذي يقوم بالاستعانة بدرجات الحرارة الخاصة بالمسارات الباردة والساخنة في تقسيم النطاق الحراري الى مراحل مستقلة ثم يقوم البرنامج بكتابة معادلات التوازن الحراري لكل مرحلة بطريقة البرمجة الخطية وتحل هذه المعادلات بالبرنامج القياسي (LINDO) للحصول على اقل كميات من الطاقة المطلوبة سواء للتبريد او التسخين عند فرق معين من درجة حرارة التقارب ( $\Delta T_{min}$ ) .

وقد تم اخذ خمس فروق لدرجات حرارة تقارب  $\Delta T_{min}$  وهي ( ١٠ ، ٢٠ ، ٣٠ ، ٤٠ ، ٥٠ ° م )

لتحديد فرق درجة الحرارة المثلى ( optimum  $\Delta T_{min}$  ) الذى يصاحب اقل تكلفة كلية. وقد أوضحت النتائج ان الطاقة اللازمة للتسخين يمكن الاستغناء عنها كلية حتى فروق درجات حرارة ٣٠ ° م ، حيث أتضح ان المحتوى الحراري للمسارات الساخنة كافياً لى يعوض النقص فى المحتوى الحراري للمسارات الباردة ونحتاج فقط للطاقة اللازمة للتبريد وتم تصميم شبكة المبادلات الحرارية لكل حالة وحساب تكلفة المبادلات الحرارية عند نفس فروق درجات الحرارة . وأدت النتائج الى انه عند فرق درجات حرارة ١٠ ° م (  $\Delta T_{min} = 10 \text{ }^\circ\text{C}$  ) يتم توفير أقصى طاقة وتحقيق اقل تكلفة.

٢- يمثل مفاعل المعلق ذو الفقاعات الانبوبي الاختيار الامثل لمعظم التكنولوجيات الحديثة بوجه عام فى عمليات تحويل الغاز الطبيعي الى وقود سائل (فيشر وتربش) وكذلك فى اكبر شركتين فى هذا المجال وهما [ExxonMobil , Saso] .

وتناولت الرسالة تصميم برنامج [نمذجة] لعملية الفيشر تربش حيث ان المفاعلات المعلقة ذات الفقاعات الأنبوبية معقدة ومتشابكة وتحتوى على اطوار المادة الثلاث التى تتمثل فى الطور الغازى [غاز التخليق ] والطور السائل ( السائل الناتج من التفاعل ) والطور الصلب ( العامل الحفاز ) .

وعمل نموذج لهذا المفاعل يتطلب معرفة كيناتيكية التفاعل (Kinetics) والحالة الحركية والهيدروديناميكية (Hydrodynamics) لهذه الأطوار الثلاثة داخل المفاعل ، ومعرفة توزيع المنتجات الناتجة من التفاعل (Product selectivity) .

وقد تم اختيار نموذج [Shah et al. , 1985] والذى تم تعديله بواسطة [ Van der Laan , 1999] وهو يتميز بوجود نوعين من الفقاعات [ الصغيرة والكبيرة ] ، وتكون فيه الفقاعات الصغيرة مختلطة تماماً ( Completely mixed ) والفقاعات الكبيرة غير مختلطة ( حالة سريان الدفعة- Plug flow ) اما السائل الناتج وحبيبات العامل الحفاز فيكونا فى حالة مختلطة تماماً ( Completely mixed ) .

تم حل معادلات النموذج بالطريقة التحليلية وبشكل عام فإن البرنامج الرئيسي الذى تم تصميمه ( Software ) ينادى البرامج الفرعية (Subroutines) اللازمة لحساب الحالة الهيدروديناميكية وكيناتيكا التفاعل وفى نفس الوقت يقوم بالحسابات الرئيسية لحل النموذج المطلوب .

نم استخدام البرنامج (Software) الذي تم تصميمه وتطويره في استرجاع نتائج البحث الذي قام به (Van der Laan , 1999) على مفاعل صناعي لمعرفة مدى صحة طريقة الحل التي تم استنباطها لحل المعادلات حيث استخدام الحديد كعامل حفاز . وذلك تحت تأثير عوامل تشغيلية مختلفة. وقد تم دراسة تأثير سرعة الغاز [Superficial gas velocity] وتركيز العامل الحفاز (Solid hold up) ونسبة الهيدروجين / أول أكسيد الكربون (Feed ratio) على نسبة تحويل الهيدروجين أول أكسيد الكربون ألي مواد هيدروكربونية وكمية المنتج من التفاعل (Hydrocarbons productivity) . ووجد أن تحويل غاز التخليق ألي مواد هيدروكربونية يتناقص بزيادة سرعة الغاز الداخل ألي المفاعل وتقليل نسبة هيدروجين/أول أكسيد الكربون ، وكذلك تقليل تركيز العامل الحفاز أما كمية المنتج من التفاعل فتزيد بزيادة المتغيرات السابقة . وقد وجد أن النتائج متشابهة مع التي حصل عليها (Van der Laan , 1999) وكذلك تم حساب توزيع المنتجات (product selectivity) باستخدام نموذج (OPDRM) (Van der Laan , 1999) وذلك مع تغيير نسبة ( $H_2/CO$ ) في غاز التخليق وقد أعطى البرنامج نتائج مشابهة لتلك التي حصل عليه (Vander Laan, 1999) مما يعزز صحة البرنامج وطريقة الحل المقترحة.

٣- وقد استخدم نفس النموذج (البرنامج) ولكن باستخدام الكوبلت كعامل حفاز بدلاً من الحديد وذلك لتطبيقه على التجارب النصف صناعية بوحدة (AFDU) المشار اليها سلفاً. وقد قورنت نتائج البرنامج مع النتائج التجريبية تحت ظروف تشغيلية مختلفة وتم استخدام نموذج (OPDRM) بعد إجراء بعض التعديلات عليه وقد حصلنا من البرنامج على نتائج متوافقة مع تلك الموجودة والناجمة من التجارب المعملية من حيث كمية الغاز المحتجز ، وتوزيع المنتجات ونسبة تحويل كل من  $H_2$  ،  $CO$  ، وكمية الناتج من التفاعل في كل حالة.