TABLE 4.3-1

FISCHER TROPSCH

MAGNITUDE OF VARIABLE DEPENDENCE

DEPENDENT / INDEPENDENT	CO CONVERSION	DEGREE OF POLYMERIZATION	OLEFIN TO PARAFFIN RATIO
K_P ⇑	⇑	↑	—
K_H ⇑	—	⇓	⇓
K_O ⇑	—	⇓	⇑

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TABLE 4.3-2

EFFECT OF TEMPERATURE,
P = 650 psig, H_2/CO = 2.11

PETC Tube-Wall Data

T, °C (°F)	275 (526)	310 (589)	335 (634)
% CO Conversion	30.7	54.8	77.2
Product Distribution, Wt-%:			
$C_1 + C_2$	60.0	67.0	69.7
C_3	9.9	10.3	10.5
Gasoline ($C_3^=$ - 204°C)	24.1	20.6	14.2
Diesel (204 - 316°C)	4.3	1.1	3.4
Fuel Oil (316 - 450°C)	1.7	1.0	2.2
Wax (> 450°C)	0	0	0
Gross Molar Flow Rate, (moles/hr x 10^4)	1.51	3.53	6.62

Values Used for Data Fitting

Degree of Polymerization	2.7	2.2	2.1
Olefin-to-Paraffin Ratio	1.0	1.0	1.0

TABLE 4.3-3

TUBE-WALL REACTOR FITTING

Fresh Feed Rate, moles/hr	0.009608
Composition, mol-%	
H_2O	0.5
H_2	66.2
CO	31.0
CO_2	0.5
CH_4	1.9
J Factor (SCFH FF/ft^2 Cat Surface Area)	23.87
Reactor Dimensions	
Inside Diameter of Tube, ft	0.0402
Outside Diameter of Tube, ft	0.0875
Shell Diameter, ft	0.175
Length, ft	0.5
Catalyst Thickness, ft	0.00208

TABLE 4.3-4

TUBE-WALL FREQUENCY FACTORS

Temp, °C (°F)	275 (526)	310 (589)	335 (634)	Derived Activation Energies (Btu/lb mole)
Frequency Factors				
k_p^o [$(ft^3_{Rx})^2$/lb Cat-hr-mole]	73.3	71.5	73.0	26,400
k_H^o (ft^3_{Rx}/lb Cat-hr)	0.436	0.494	0.465	28,800
k_o^o (ft^3_{Rx}/lb Cat-hr)	0.0180	0.0203	0.0193	27,000
k_{WG}^o [$(ft^3_{Rx})^2$/lb Cat-hr-mole]	169.58	144.38	170.5	33,000

I = Input C = Calculated

	I	C	I	C	I	C
% CO Conversion	30.7	30.7	54.8	54.9	77.2	77.2
Degree of Poly.	2.70	2.71	2.20	2.19	2.10	2.10
Olefin/Paraffin	1.00	1.00	1.00	0.988	1.00	0.981
CO + H_2 Conversion	28.4	27.3	51.1	46.0	66.1	59.2
CO_2 Molar Flow	1.51×10^{-4}	1.50×10^{-4}	3.53×10^{-4}	3.53×10^{-4}	6.62×10^{-4}	6.61×10^{-4}

Note: All frequency factors are based on a reference temperature of 1100°R.

TABLE 4.3-5

EXAMPLE EXPERIMENTAL RESULTS
STEEL LATHE TURNINGS CATALYST (SLTC) FISCHER-TROPSCH RUNS

Item	Experiment 26 Period C
Catalyst Type	SLTC
Synthesis, hours	416 - 488
Reactor Conditions	
Fresh Feed Rate, scfh	1,214
Space Velocity, vol/vol/hr	607
Reactor Pressure, psig	405
Recycle to Fresh Feed:	
Total	27
Hot	25.5
Cold	1.5
CO_2 scrubbed	1.5
Reactor Temperature, °F	
In Gas	552
Out Gas	610
Increment	58
Average Catalyst Temperature, °F	586
Maximum Catalyst Temperature, °F	622
H_2:CO Ratio, Fresh Gas	1.45
Results	
CO_2 Free Contraction, %	74.6
H_2 Conversion, %	73.7
CO Conversion, %	88.7
H_2 + CO Conversion, %	79.8
H_2:CO Ratio:	
Recycle Gas	3.35
Usage	1.21
Water Vapor in Recycle Gas, vol-%	7.0
Tail Gas Composition, vol-%(a)	
H_2	55.2
CO	16.5
N_2	1.2
CO_2	9.6

Continued on Next Page

TABLE 4.3-5 (Continued)

Item	Experiment 26 Period C
Tail Gas Composition, vol-%(a)	
C_1	9.8
$C_2^=$	0.7
C_2	2.3
$C_3^=$	0.3
C_3	1.0
$C_4^=$	0.6
C_4	1.8
$C_5^=$	0.2
C_5	0.8
$C_6^=$	0
C_6	0
Yield, g/m^3 (H_2 + CO) Converted	
C_1	24
$C_2^=$	3
C_2	12
$C_3^=$	2
C_3	7
$C_4^=$	6
C_4	18
$C_5^=$	2
C_5	9
$C_6^=$	0
C_6	0
Oil	0.97
Aqueous	130
C_1 - C_3OH(b)	8
Other Oxygenates(b)	3
Water	119
CO_2 307	
Hydrocarbon Recovery, g/m^3	191
Theoretical Recovery, g/m^3	201
Hydrocarbon Recovery, wt-%	
C_1 + C_2	19.4
C_3	3.5
Gasoline (C_3 = < 400°F)	59.0
Diesel Oil (400 to 600°F)	9.1
Fuel Oil (600 to 842°F)	6.2
Wax (< 842°F)	2.8

(a) Dry basis.
(b) Calculated as hydrocarbons.

TABLE 4.3-6

TUBE-WALL vs. LATHE TURNINGS
FREQUENCY FACTORS

	Tube-Wall	Lathe Turning	Adjusted Lathe Turning
k_p^o [$(ft^3_{Rx})^2$/lb Cat-hr-mole]	73.0	113.0	73.0
k_H^o (ft^3_{Rx}/lb Cat-hr)	0.465	0.108	0.070
k_o^o (ft^3_{Rx}/lb Cat-hr)	0.0193	0.002	0.0013
k_{WG}^o [$(ft^3_{Rx})^2$/lb Cat-hr-mole]	170.0	318.0	205.0

Note: All frequency factors are based on a reference temperature of 1100°R.

TABLE 4.3-7

OPERATING DATA AND RESULTS OF LIQUID-PHASE SYNTHESIS FOR ONE-STEP OPERATION WITH A SINGLE PASSAGE OF THE GAS OVER IRON CATALYSTS

Effective Reaction Space, volume suspension including dispersed gas, (λ)	10,000
Catalyst, kg Fe	800
Synthesis Gas Pressure, bar	12
Synthesis Gas, (volume ratio, $CO:H_2$)	1.5
Quantity of Synthesis Gas, Nm^3/h	2700
Linear Velocity of the Compressed Gases at Operating Temperature Referred to the Free Reactor Cross Section, cm/s	9.5
Total $CO + H_2$ used, Nm^3/h	2300
per m^3 of Reaction Chamber	230
per kg of Fe	2.6
Average Synthesis Temperature, °C	268
CO Conversion, %	91
$CO + H_2$ Conversion, %	89
Synthesis Products Referred to $CO + H_2$ used, g/Nm^3	
Hydrocarbons	
C_1+	178
$C_1 + C_3$	12
C_{3+}	166
O-containing Products in the Synthesis Water, g/Nm^3	3
Space-time Yield of C_3+ Products incl. O-products in 24 hours (kg/m^3 of reaction chamber)	930

Continued on Next Page

TABLE 4.3-7 (Continued)

Composition of a Product from the Demonstration Plant
(Mode of Operation Adjusted for Gasoline Production)

	$CO + H_2$, g/Nm^3	Wt-% of Total Product C_1+	Olefin, %
Methane + Ethane	5.7	3.2	0
Ethylene	613	3.6	100
C_3	40.3	22.6	75-85
C_4	9.1	5.1	70-80
40-180°C Fraction	95.5	53.6	70
180-220°C	7.1	4.0	48
220-320°C	10.7	6.0	37
> 320°C	3.3	1.9	7
Total	178.0	100.0	

TABLE 4.3-8

SLURRY AND ENTRAINED BED INPUT
FOR FITTING PURPOSES

	Slurry	Entrained Bed
Fresh Feed Rate, moles/hr	251.6	86,585.9
Composition, %		
H_2O	3.0	0.01
H_2	38.0	66.51
CO	54.0	27.71
CO_2	5.0	5.77
Recycle Rate, moles/hr	-	192,500.00
Composition		
H_2O		0.37
H_2		4.78
CO		2.83
CO_2		26.82
Cl		16.92
$\underline{n}$-C_2		3.90
$\underline{n}$-C_3		1.19
$\underline{n}$-C_4		0.52
$\underline{n}$-C_5		0.15
$\underline{n}$-C_6		0.03
$\underline{n}$-C_7		0.0081
$\underline{n}$-C_8		0.0017
$\underline{n}$-C_9		0.0005
$\underline{n}$-C_{10}		0.0002
$=C_2$		3.72
$=C_3$		4.50
$=C_4$		2.72
$=C_5$		1.05
$=C_6$		0.33
$=C_7$		0.115
$=C_8$		0.034
$=C_9$		0.0115
$=C_{10}$		0.0038
Pressure, psia	174	380 (inlet)
Temperature, °F	514	599 (inlet)
Space Velocity, $\frac{SCF_{FF}}{hr\text{-}ft^3 \text{ reactor}}$	280	959
Catalyst Concentration (lbs cat/ft^3 slurry)	4.44	-
$\frac{\text{lbs cat circulated}}{\text{sec.}}$	-	26,057

Continued on Next Page

TABLE 4.3-8 (Continued)

Total Reactor Δ T, °F	-	36
% CO Conversion, FF	91	97.8
Degree of Polymerization	4.0	3.3
Olefin-to-Paraffin Ratio	1.0	1.0
Gross CO_2 Molar Flow, moles/hr	73.4	5,133.6

TABLE 4.3-9

FREQUENCY FACTOR COMPARISON

Frequency Factor	Tube-Wall	Lathe Turning	Slurry	Entrained Bed
k_p^o [$(ft^3_{Rx})^2$/lb Cat-hr-mole]	73.0	113.0	2604.0	1821.0
k_H^o (ft^3_{Rx}/lb Cat-hr)	0.465	0.106	3.94	1.11
k_o^o(ft^3_{Rx}/lb Cat-hr)	0.0193	0.002	0.06	0.015
k_{WG}^o [$(ft^3_{Rx})^2$/lb Cat-hr-mole]	170.0	318.0	10,699.0	228.8

NORMALIZED FOR SURFACE AREA PER POUND OF CATALYST DIFFERENCES USING TUBE-WALL AS BASE

Frequency Factor	Tube-Wall	Lathe Turning	Slurry	Entrained Bed
k_p^o [$(ft^3_{Rx})^2$/lb Cat-hr-mole]	73.0	73.0	73.0	73.0
k_H^o (ft^3_{Rx}/lb Cat-hr)	0.465	0.070	0.110	0.045
k_o^o (ft^3_{Rx}/lb Cat-hr)	0.0193	0.00129	0.0016	0.0006
k_{WG}^o [$(ft^3_{Rx})^2$/lb Cat-hr-mole]	170.0	205.0	300.0	9.2

Note: All frequency factors are based on a reference temperature of 1100°R.

TABLE 4.3-10

EXAMPLE EXPERIMENTAL RESULTS
FLAME SPRAYED CATALYST (FSC) FISCHER-TROPSCH RUNS

Item	Experiment No. HGR 33		Experiment No. HGR 34	
Catalyst Type	Coated Plates	Coated Plates	Coated Plates	Coated Plates
Fresh Gas Velocity, vol/vol/hr	600	1000	1000	2000
Fresh Feed Rate, scfh	165	275	275	550
Recycle Ratio Total Recycle:Fresh Feed, vol/vol	51	15.9	20.4	14.4
Reactor Pressure, psig	400	400	400	400
Catalyst Temperature, °F				
Average	516	617	608	617
Differential	36	90	72	90
H_2 Conversion, %	73.4	90.9	90.1	83
CO Conversion, %	80.6	98.8	98.2	94.4
H_2 + CO Conversion, %	76.4	94.4	93.4	87.5
Overall Weight Balance, %	93.6	90.8	87.8	96.6
Hydrocarbons Recovered lb/1,000 scf fresh gas	7.4	9.5	10.3	11.6
Hydrocarbons Recovered, wt-%				
$C_1 + C_2$	59.7	36.5	33.9	29.5
C_3	6.6	14.1	13.3	12.8
Gasoline (C_3= < 400°F)	31.8	43.7	48.5	53.0
Diesel Fuel (400 to 600°F)	1.9	5.0	4.0	3.8
Fuel Oil (600 to 842°F)	0	0.4	0.2	0.5
Wax (> 842°F)	0	0.3	0.1	0.4

TABLE 4.3-11

KEY REACTOR DESIGN BASIS ELEMENTS

Capacity, Btu/day Total Products HHV, billion	500
Pressure, psig	400
Temperature (average), °F	606
Space Velocity Factors	
J, scf/hr/sq ft of catalyst area	10
S_V, scf/hr/cu ft of reaction zone volume	1,330
Catalyst Activity	1.33
Syngas Composition	
Fresh Feed H_2:CO Ratio	1.45
CO + H_2 Conversion, %	80
Reactor Recycle Ratio	
Volume Recycle Gas : Volume (CO + H_2) in Fresh Syngas Feed	1.5
Heat of Reaction at Reactor Conditions	
Btu/scf of (CO + H_2) Converted	72.8

REACTOR PRODUCT COMPOSITION

	Weight Percent
C_1, C_2, C_2^-	19.3
C_3, C_3^-	4.5
C_4, C_4^-	11.9
C_5, C_5^-, C_6	13.6
C_7, C_8, C_9	19.2
C_{10}, C_{11} to 640°F BP	18.8
640 to 940°F BP	7.3
Alcohols and Ketones	4.9
Acids	0.5
Total	100.00

TABLE 4.3-12

CONCEPTUAL FISCHER-TROPSCH REACTOR DESIGN
COMPARED WITH PETC EXPERIMENTAL DATA

Item	Experiment HGR 34		SLTC Experiment 26C	TWR Experiment FT-TW-1	Conceptual Design Basis
"J", scfh/sf Catalyst Surface	8.85	17.7	1.5	30	10.0
H_2:CO Ratio in Feed	1.41	1.41	1.45	3	1.45
Recycle Ratio	20.4	14.4	27.0	-	1.5
(CO + H_2) Conversion, %	93.4	87.5	80.0	52.0	80.0
Total Reaction Heat Calculated, Btu/sf/hr	583.0	1092.0	84.0	1100.0	563.0

TABLE 4.3-13

TUBE-WALL REACTOR DESIGN COMPARISON

OPERATING CONDITIONS	Parsons	UOP Model Prediction	
Case	Study	1	2
Inlet Temperature, °F	571	571	606
Coolant Temperature, °F	606	606	640
Pressure, psia	415	415	415
J Factor (FF), $ft^3/hr\text{-}ft^2$	10.0	10.0	5.38
GHSV (FF), hr^{-1}	1330	1331	716.2
Recycle Ratio	1.5	1.5	1.5
H_2/CO Ratio			
Fresh Feed	1.45	1.45	1.45
Combined Feed	2.17	2.17	2.03
Catalyst	Flame sprayed magnetite	K promoted, flame sprayed taconite	
YIELD INFORMATION			
CO Conversion, mol-%			
Fresh Feed	88.7	34.9	90.0
Combined Feed	55.6	21.9	54.4
Degree of Polymerization	4.30	5.92	4.30
CO + H_2 Conversion, mol-%	53.3	18.8	41.1

TABLE 4.3-14

INFLUENCE OF RECYCLE TO FEED RATIO ON COMPONENT CONCENTRATIONS IN COMBINED FEED

RUN	1-T	5	32
Recycle/Feed	0	1.0	2.5
Mole Fraction in Combined Feed			
H_2	0.645	0.69	0.69
CO	0.323	0.23	0.21
Total Olefins	0	0.008	0.016
% CO Conversion (on Fresh Feed)	89.5	86.7	86.2
Degree of Polymerization	4.78	4.23	4.24

TABLE 4.3-15

SLURRY OPERATING CONDITIONS

	Koelbel	Base Case
GHSV (Hr^{-1})	262	453
Pressure (psia)	174	300
H_2/CO Ratio	0.7	0.7
Temperature (°F)	514	514
CO Conversion (%)	91	91

TABLE 4.3-16

COMPARISON OF SINGLE-STAGE
AND TWO-STAGE SLURRY REACTOR

	Single-Stage	Two-Stage 1st Length	Two-Stage Total
Reactor Length (Ft)	26.0	15.0	26.0
Reactor Diameter (Ft)	4.22	4.22	4.22
GHSV (Hr^{-1}) (FF)	262.4	453.2	262.4
Temperature (°F)	514	514	514
Pressure (psia)	174	174	174
H_2/CO (Product)	1.8	1.20	2.02
CO Conversion (%)	91	78	95
Degree of Polymerization	4.0	5.4	4.7

TABLE 4.3-17

YIELDS VERSUS REACTOR LENGTH

Tube-Wall Reactor		H_2/CO, FF = 2.0		
Once Through		Temperature, °F = 640		
CO Conversion = 98.3%		Pressure, psig = 415		
Relative Reactor Position	0	0.2	0.8	1.0
Yields				
H_2 (Mole Fraction)	0.645	0.522	0.406	0.374
CO (Mole Fraction)	0.323	0.133	0.012	0.010
Total Olefins	0	0.017	0.029	0.030
Degree of Polymerization	6.01	4.70	4.32	4.32

TABLE 4.3-18

REACTOR BASE COMPARISON

	Tube-Wall		Slurry	Entrained Bed
J Factor	5	10	1.9	1.2
GHSV (hr^{-1})	103	241	280	959
B (SCF/lb Cat/Hr)	10	20	90	58
Temp (°F)	590	660	514	616*
Pressure (psig)	400	400	159	365**
H_2/CO mol ratio (FF)	2.0	2.0	0.7	2.4
H_2/CO mol ratio (CF)	-	-	-	4.23
Recycle Ratio	-	-	-	2.36
% CO Conv (FF)	89.5	89	91	97.8
% CO Conv (CF)	-	-	-	79.7
DP	4.78	4.4	4.0	3.3

* Mean Temperature [(Inlet + Outlet)/2]

** Inlet Pressure

TABLE 4.3-19

REACTOR COMPARISON

	Base			Per Mole $CO + H_2$ Used			
	Tube-Wall	Entrained Bed	Slurry		Tube-Wall	Entrained Bed	Slurry
$\frac{\text{Moles } H_2 \text{ Converted}}{\text{Mole FF}}$	0.35	0.60	0.29	$\frac{\text{Moles } H_2}{\text{Mole } CO + H_2 \text{ Used}}$	0.55	0.69	0.37
$\frac{\text{Moles CO Converted}}{\text{Moles FF}}$	0.29	0.27	0.49	$\frac{\text{Moles CO}}{\text{Mole } CO + H_2 \text{ Used}}$	0.45	0.31	0.63
$\frac{\text{Mole } H_2O \text{ Produced}}{\text{Mole FF}}$	0.12	0.27	0.0084	$\frac{\text{Moles } H_2O}{\text{Mole } CO + H_2 \text{ Used}}$	0.19	0.31	0.011
$\frac{\text{Moles } CO_2 \text{ Produced}}{\text{Mole FF}}$	0.09	0.0	0.24	$\frac{\text{Moles } CO_2}{\text{Mole } CO + H_2 \text{ Used}}$	0.14	0.0	0.31
$\frac{\text{Lbs HC Produced}}{\text{Mole FF}}$	2.90	3.92	3.56	$\frac{\text{Lbs HC}}{\text{Mole } CO + H_2 \text{ Used}}$	4.53	4.51	4.56