APPENDIX A

LINEAR REGRESSION ANALYSIS

Estimated equation

$$y = a + bx \qquad (1)$$

b = slope

a = intercep

x = the number of year

y = the demand of nitrogen fertilizer, tons

Year	No. of Year X	Demand of Fertilizer Y	X^2	XY
1965	1	17,917	1	17,917
1966	2	34,774	4	69,548
1967	3	52,013	9	156,039
1968	4	44,013	16	176,025
1969	5	45,725	25	228,625
1970	6	47,245	36	283,470
1971	7	37,288	49	261,016
1972	8	62,723	64	501,784
1973	9	58,580	81	527,220
1974	10	79,845	100	798,450
1975	11	80,852	121	889,372
1976	12	136,552	144	1,638,624
	$\Sigma X = 78$	$\Sigma Y = 695,527$	$\Sigma X^2 = 650$	$\Sigma XY = 5,548,117$

$$b = \frac{\Sigma XY - (\Sigma X \Sigma Y)/N}{\Sigma X^2 - \frac{\Sigma (X)^2}{N}}$$

N = the number of year

by substitution

b = 7092.25

Equation (1) can be rewritten as

$$\bar{Y} = a + b\bar{X}$$

by substitution,

a = 12,027.6

In 1980, the estimated demand of nitrogen fertilizer

Y = 12,027.6 + 7,092.25 (16) = 125,504 tons

In 1985, Y = 12,027.6 + 7,092.25 (21) = 160,965 tons

In 1990, Y = 12,027.6 + 7,092.25 (26) = 196,426 tons

APPENDIX B

SPECIFICATIONS OF MAJOR EQUIPMENTS

Pressure Vessel Design

Use Primary Reformer Unit PR-1

No. of Stream	Flow Rate, lb-mole/hr.	Temp., ^{o}F	Density, lb/ft^3
13	13522	950	0.02
14	17517	1450	0.01

Vessel Construction

Diameter, ft 1/2

Height, ft 30

Design Pressure, psia 550

Design Temperature, ^{o}F 1640

Material High-alloy tubes, type 310, 25 Cr,20Ni, Co.35-0.45

Shell Thickness, inch 1"

Operating Pressure, psia 500

Operating Temperature, ^{o}F 1450

No. of bed in rows, with refractory walls on either side

Catalyst Volume 136.42 ft^3

Catalyst Type Ni-base catalyst

Catalyst density, lb/ft^3

Pressure Vessel Design

Use Methanation Unit ME

No. of Stream	Flow Rate, lb-mole/hr.	Temp., ^{o}F	Density, lb/ft^3
241	13608	500	0.024
25	13351	580	0.024

Vessel Construction

Diameter, ft 8.2

Height, ft 75

Design Pressure, psia 450

Design Temperature, ^{o}F 720

Material Stainless Steel

Shell Thickness, inch 4"

Operating Pressure, psia 400

Operating Temperature, ^{o}F 580

No. of bed 1

Catalyst Volume 3000 ft^3

Catalyst Type Ni-base Catalyst

Catalyst density, lb/ft^3

Pressure Vessel Design

Use High-Temperature Shift Converter - Unit HTS-1

No. of Stream	Flow Rate, lb-mole/hr.	Temp., ^{o}F	Density, lb/ft^3
151	22709	700	1.207
21	22709	780	1.207

Vessel Construction

Diameter, ft 9.22

Height, ft 102

Design Pressure, psia 440

Design Temperature, ^{o}F 900

Material Low alloy Steel, C-0.5 Mo, Cr $1\frac{1}{2}$, $Mo\frac{1}{2}$

Shell Thickness, inch 9.5

Operating Pressure, psia 400

Operating Temperature, ^{o}F 780

No. of bed 1

Catalyst Volume 5100 ft^3

Catalyst Type Cr-oxide promoted Iron oxide

Catalyst density, lb/ft^3

Pressure Vessel Design

Use Low Temp. Shift Conversion Unit LS-1

No. of Stream	Flow Rate, lb-mole/hr.	Temp., °F	Density, lb/ft^3
211	22709	450	0.04
22	22709	450	0.04

Vessel Construction

Diameter, ft 9.5

Height, ft 95

Design Pressure, psia 440

Design Temperature, °F 540

Material Low alloy Steel

Shell Thickness, inch 4.25

Operating Pressure, psia 400

Operating Temperature, °F 450

No. of bed 1

Catalyst Volume 6800

Catalyst Type CuO/Zinc Oxide

Catalyst density, lb/ft^3

Pressure Vessel Design

Use Desulfurrisation of NG feed Unit DS-1

No. of Stream	Flow Rate, lb-mole/hr.	Temp., ^{o}F	Density, lb/ft^3
NG-feet to 10	3005	550	0.045

Vessel Construction

Diameter, ft 5.5

Height, ft 35

Design Pressure, psia 550

Design Temperature, ^{o}F 600

Material Carbon Steel

Shell Thickness, inch 3.5"

Operating Pressure, psia 550

Operating Temperature, ^{o}F 550

No. of bed 2

Catalyst Volume 650 ft^3

Catalyst Type Activated Carbon, CuO promoted

Catalyst density, lb/ft^3 36

Pressure Vessel Design

Use Desulferrisation of Synthesis-Gas Unit DS-2

No. of Stream	Flow Rate, lb-mole/hr.	Temp., ^{o}F	Density, lb/ft^3
21	22709	450	0.044
22	22709	450	0.044

Vessel Construction

Diameter, ft 6.5

Height, ft 27.5

Design Pressure, psia 440

Design Temperature, ^{o}F 800

Material Carbon-low-Alloy Steel

Shell Thickness, inch 3.25

Operating Pressure, psia 400

Operating Temperature, ^{o}F 450

No. of bed 1

Catalyst Volume 750 ft^3

Catalyst Type ZnO

Catalyst density, lb/ft^3 70

Pressure Vessel Design

Use Secondary Reformer Unit SR-1

No. of Stream	Flow Rate, lb-mole/hr.	Temp., ^{o}F	Density, lb/ft^3
141	17517	1450	0.037
142	4109	1200	0.08
150	22709	1750	

Vessel Construction

Diameter, ft 3.5

Height, ft 66

Design Pressure, psia 550

Design Temperature, ^{o}F 1970

Material High-alloy tubes

Shell Thickness, inch 12"

Operating Pressure, psia 500

Operating Temperature, ^{o}F 1750

No. of bed 1

Catalyst Volume 230 ft^3

Catalyst Type Ni-base Catalyst

Catalyst density, lb/ft^3 -

Pressure Vessel Design

Use Synthesis Conversion Unit S-1

No. of Stream	Flow Rate, lb-mole/hr.	Temp., °F	Density, lb/ft^3
28	11812.2	360	8.565
30	11812.2	700	9.485

Vessel Construction

Diameter, ft

Height, ft

Design Pressure, psia 3300

Design Temperature, °F 980

Material Ferritic Stainless Steel, 26% Cr, 1% Mo

Shell Thickness, inch

Operating Pressure, psia 3000

Operating Temperature, °F 850

No. of bed 1

Catalyst Volume 1700 ft^3

Catalyst Type

Catalyst density, lb/ft^3

Flash Drum Specification

Use Separation of Water Unit FD-1

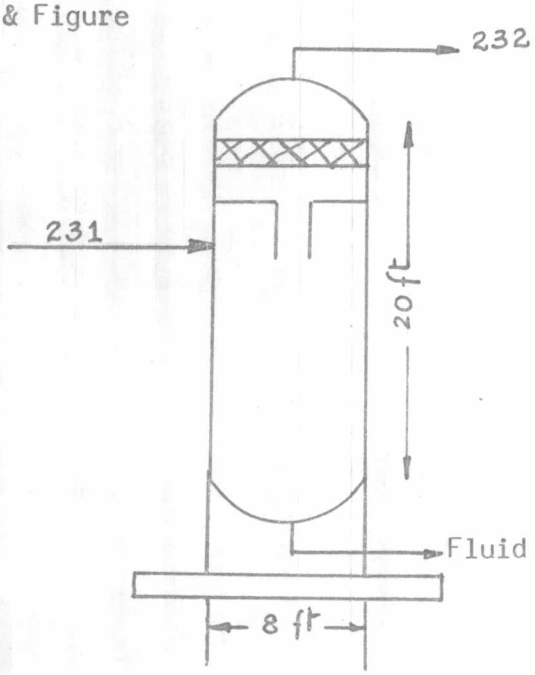
Fluid Designation	Flow Rate, lb-mole/min	Temperature, ^{o}F	Density, lb/ft^3
231	22709	200	0.037
232	16447	200	0.035
Liquid	6262	200	59.93

Type Cyclone Number used 1

Diameter, ft 8

Height, ft 20

Shape & Figure



Flash Drum Specification

Use Separation of Water Unit FD-2

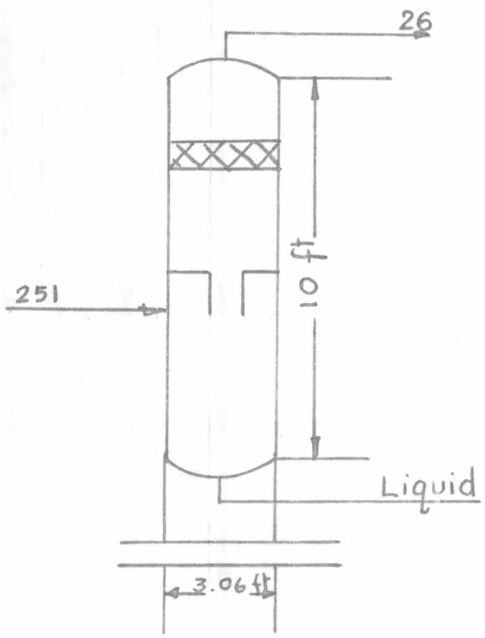
Fluid Designation	Flow Rate, lb-mole/min	Temperature, ^{o}F	Density, lb/ft^3
251	13351	100 ^{o}F	0.024
26	13043	100 ^{o}F	0.024
Liquid	308	100 ^{o}F	61.864

Type Cyclone Number used 1

Diameter, ft 3.06 '

Length, ft 10'

Shape & Figure



Flash Drum Specification

Use Separation of Products Unit FD-3

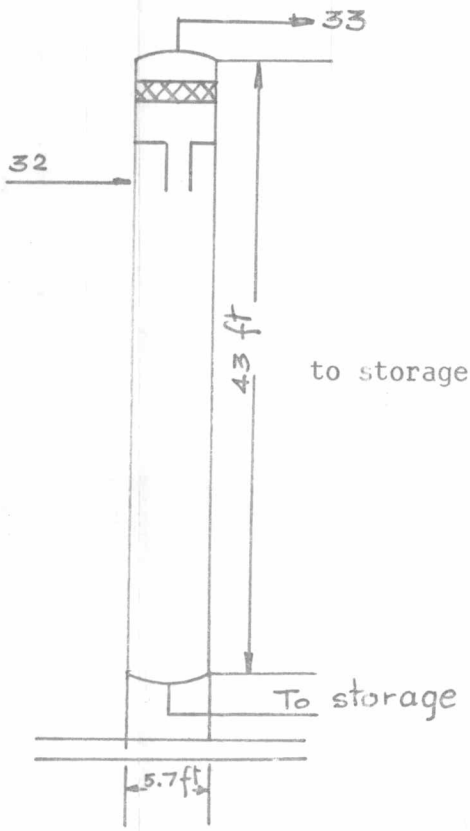
Fluid Designation	Flow Rate, lb-mole/min	Temperature, ^{o}F	Density, lb/ft^3
32	43618	- 10	0.030
33	38028	- 10	0.030
Storage	5590	- 10	38.50

Type Cyclone Number used 1

Diameter, ft 5.7

Height, ft 43

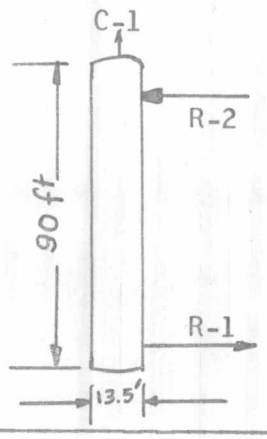
Shape & Figure



Column Design

Use Regenerator Unit R G

No. of Stream	Flow Rate, lb/min	Temp., ^{o}F	Density, lb/ft^3
R-2	73433	250	77.36
R-1	71351	250	74.76
C-1	2082	250	0.102



Column Specifications

Parameter	Top	Bottom
Liquid Rate, lb/min	73433	71351
Vapor Rate, lb/min	2094	-
Liquid Density, lb/ft^3	77.36	74.76
Vapor Density, lb/ft^3	0.102	-

Heat Exchanger Specification

Use Heat Recovery Unit HE-3

Duty, BTU/hr 112.64×10^6 Outside Tube Area, ft^2 11800

Overall Transfer Coefficiency, BTU/hr-ft^2-^oF, Clean 17.14

Overall Fouling Resistance, $1/h_f$ 0.006

Corrected Mean Temperature Difference, ^oF 616

Heat Exchanger Construction

Style Shell & Tube Number of Shell 2

Outside Tube Area per Shell, ft^2 5900

Number of passes per shell: Tube side 1 Shell 1

Design Pressure, psia: Tube Side 550 Shell Side 300

Tube OD, inch 3/4 Length, ft 25 Gauge -

Tube arrangement, pitch inch 1 " Type Triangular

Shell ID, inch 54 Number of Tube 1200

Fluid Properties

Characteristics	Shell side	Tube Side
Fluid designation	150-151	BFW
Flow Rate, lb-mole/hr.	22709	-
Temperature in/out, ^oF	1750/700	200/1000
Density, lb/ft^3 ave.		
Thermal conductivity, BTU/hr-ft ^oF		
Viscosity, lb/ft-hr		
Heat Capacity, BTU/lb ^oF		

BFW = Boiler Feed Water

Heat Exchanger Specification

Use Cooling Unit HE-4

Duty, BTU/hr 33.8×10^6 Outside Tube Area, ft^2 4908

Overall Transfer Coefficiency, BTU/hr-ft^2-^oF, Clean 17

Overall Fouling Resistance, $1/h_f$ 0.005

Corrected Mean Temperature Difference, ^oF 434

Heat Exchanger Construction

Style Shell & Tube Number of Shell 1

Outside Tube Area per Shell, ft^2 4908

Number of passes per shell: Tube side 1 Shell 1

Design Pressure, psia: Tube Side 400 Shell Side 450

Tube OD, inch 3/4 Length, ft 25 Gauge -

Tube arrangement, pitch inch 1" Type Triangular

Shell ID, inch 48 Number of Tube 1000

Fluid Properties

Characteristics	Shell side	Tube Side
Fluid designation	BFW	21-211
Flow Rate, lb-mole/hr.	-	22709
Temperature in/out, ^oF	100-250	780-450
Density, lb/ft^3 ave.		
Thermal conductivity, BTU/hr-ft ^oF		
Viscosity, lb/ft-hr		
Heat Capacity, BTU/lb ^oF		

BFW = Boiler Feed Water

Heat Exchanger Specification

Use Cooling Unit HE-5

Duty, BTU/hr 134.33×10^6 Outside Tube Area, ft^2 2945

Overall Transfer Coefficiency, BTU/hr-ft^2-^oF, Clean 525

Overall Fouling Resistance, $1/h_f$ 0.0003

Corrected Mean Temperature Difference, ^oF 100

Heat Exchanger Construction

Style Shell & Tube Number of Shell 1

Outside Tube Area per Shell, ft^2 2945

Number of passes per shell: Tube side 1 Shell 1

Design Pressure, psia: Tube Side 450 Shell Side 200

Tube OD, inch 3/4 Length, ft 16' Gauge -

Tube arrangement, pitch inch 1" Type Triangular

Shell ID, inch 48 Number of Tube 600

Fluid Properties

Characteristics	Shell side	Tube Side
Fluid designation	Water	23-231
Flow Rate, lb-mole/hr.	-	22709
Temperature in/out, ^oF	100/200	450/200
Density, lb/ft^3 ave.	100/350	
Thermal conductivity, BTU/hr-ft ^oF		
Viscosity, lb/ft-hr		
Heat Capacity, BTU/lb ^oF		

Heat Exchanger Specification

Use Cooling Unit HE-6

Duty, BTU/hr 15.57×10^6 Outside Tube Area, ft^2 19630

Overall Transfer Coefficiency, BTU/hr-ft^2-^oF, Clean 10.5

Overall Fouling Resistance, $1/h_f$ 0.006

Corrected Mean Temperature Difference, ^oF 80

Heat Exchanger Construction

Style Finned- Tube Number of Shell 2

Outside Tube Area per Shell, ft^2 9815

Number of passes per shell: Tube side 1 Shell 1

Design Pressure, psia: Tube Side 440 Shell Side 440

Tube OD, inch 3/4 Length, ft 25 Gauge -

Tube arrangement, pitch inch 1" Type Triangular

Shell ID, inch 60 Number of Tube 4000

Fluid Properties

Characteristics	Shell side	Tube Side
Fluid designation	25/251	24/241
Flow Rate, lb-mole/hr.	13351	13608
Temperature in/out, ^oF	580/280	500/200
Density, lb/ft^3 ave.		
Thermal conductivity, BTU/hr-ft ^oF		
Viscosity, lb/ft-hr		
Heat Capacity, BTU/lb ^oF		

Heat Exchanger Specification

Use Heat Exchanger Unit HE-61

Duty, BTU/hr 9.34×10^6 Outside Tube Area, ft^2 11778

Overall Transfer Coefficiency, BTU/hr-ft^2-^oF, Clean 19.81

Overall Fouling Resistance, $1/h_f$ 0.004

Corrected Mean Temperature Difference, ^oF 43.28

Heat Exchanger Construction

Style Shell & Tube Number of Shell 2

Outside Tube Area per Shell, ft^2 5889

Number of passes per shell: Tube side 1 Shell 1

Design Pressure, psia: Tube Side 440 Shell Side 200

Tube OD, inch 3/4 Length, ft 25 Gauge -

Tube arrangement, pitch inch 1" Type Triangular

Shell ID, inch 54 Number of Tube 1200

Fluid Properties

Characteristics	Shell side	Tube Side
Fluid designation	Water	25/251
Flow Rate, lb-mole/hr.		13351
Temperature in/out, ^oF	80/200	100/280
Density, lb/ft^3 ave.		
Thermal conductivity, BTU/hr-ft ^oF		
Viscosity, lb/ft-hr		
Heat Capacity, BTU/lb ^oF		

Heat Exchanger Specification

Use Cooling Unit HE-7

Duty, BTU/hr 35.95×10^6 Outside Tube Area, ft^2 39260

Overall Transfer Coefficiency, BTU/hr-ft^2-^oF, Clean 25

Overall Fouling Resistance, $1/h_f$

Corrected Mean Temperature Difference, ^oF 74.56

Heat Exchanger Construction

Style Shell & Tube Number of Shell 4

Outside Tube Area per Shell, ft^2 9815

Number of passes per shell: Tube side 1 Shell 1

Design Pressure, psia: Tube Side 3300 psi Shell Side 100 psi

Tube OD, inch 3/4" Length, ft 25' Gauge -

Tube arrangement, pitch inch 1" Type Triangular

Shell ID, inch 54 Number of Tube 2000

Fluid Properties

Characteristics	Shell side	Tube Side
Fluid designation	Water	270-271
Flow Rate, lb-mole/hr.		43618
Temperature in/out, ^oF	80/200	300/100
Density, lb/ft^3 ave.		
Thermal conductivity, BTU/hr-ft ^oF		
Viscosity, lb/ft-hr		
Heat Capacity, BTU/lb ^oF		

Heat Exchanger Specification

Use Steam Production Unit HE-8

Duty, BTU/hr 213.2×10^6 Outside Tube Area, ft^2 49075

Overall Transfer Coefficiency, BTU/hr-ft^2-^oF, Clean 20.5

Overall Fouling Resistance, $1/h_f$ 0.009

Corrected Mean Temperature Difference, ^oF 250

Heat Exchanger Construction

Style Shell & Tube Number of Shell 5

Outside Tube Area per Shell, ft^2 9815

Number of passes per shell: Tube side 1 Shell 1

Design Pressure, psia: Tube Side 605 Shell Side 200

Tube OD, inch 3/4 Length, ft 25' Gauge -

Tube arrangement, pitch inch 1" Type Triangular

Shell ID, inch 54 Number of Tube 5306

Fluid Properties

Characteristics	Shell side	Tube Side
Fluid designation	Flue Gas	11
Flow Rate, lb-mole/hr.	-	10522
Temperature in/out, ^oF	750/1000	200/450
Density, lb/ft^3 ave.		
Thermal conductivity, BTU/hr-ft ^oF		
Viscosity, lb/ft-hr		
Heat Capacity, BTU/lb ^oF		

BFW = Boiler feed water

Heat Exchanger Specification

Use Heat Exchanger Unit HE-9

Duty, BTU/hr 61×10^8 Outside Tube Area, ft^2 19630

Overall Transfer Coefficiency, BTU/hr-ft^2-^oF, Clean 10.5

Overall Fouling Resistance, $1/h_f$ 0.012

Corrected Mean Temperature Difference, ^oF 333

Heat Exchanger Construction

Style Finned Tube Number of Shell 2

Outside Tube Area per Shell, ft^2 9815

Number of passes per shell: Tube side 1 Shell 1

Design Pressure, psia: Tube Side 3300 Shell Side 3300

Tube OD, inch 3/4 Length, ft 25 Gauge -

Tube arrangement, pitch inch 1" Type Triangular

Shell ID, inch 54 Number of Tube 2000

Fluid Properties

Characteristics	Shell side	Tube Side
Fluid designation	35/36	33/34
Flow Rate, lb-mole/hr.	32065	38028
Temperature in/out, ^oF	300/700	-10/360
Density, lb/ft^3 ave.		
Thermal conductivity, BTU/hr-ft ^oF		
Viscosity, lb/ft-hr		
Heat Capacity, BTU/lb ^oF		

Heat Exchanger Specification

Use Heat Recovery Unit HE 1

Duty, BTU/hr 28.3×10^6 Outside Tube Area, ft^2 7066

Overall Transfer Coefficiency, BTU/hr-ft^2-^oF, Clean 10.5

Overall Fouling Resistance, $1/h_f$ .003

Corrected Mean Temperature Difference, ^oF 393

Heat Exchanger Construction

Style Finned tube Number of Shell 1

Outside Tube Area per Shell, ft^2 7066

Number of passes per shell: Tube side 1 Shell 1

Design Pressure, psia: Tube Side 550 Shell Side 200

Tube OD, inch 3/4 Length, ft 16 Gauge -

Tube arrangement, pitch inch 1" Type Triangular

Shell ID, inch 60 Number of Tube 2250

Fluid Properties

Characteristics	Shell side	Tube Side
Fluid designation	Flue Gas	12-13
Flow Rate, lb-mole/hr.	-	13522
Temperature in/out, ^oF	1300/1000	560/950
Density, lb/ft^3 ave.		
Thermal conductivity, BTU/hr-ft ^oF		
Viscosity, lb/ft-hr		
Heat Capacity, BTU/lb ^oF		

Heat Exchanger Specification

Use Heat Recovery Unit HE-2

Duty, BTU/hr 14.756×10^6 Outside Tube Area, ft^2 2945

Overall Transfer Coefficiency, BTU/hr-$ft^2{}^oF$, Clean 10.5

Overall Fouling Resistance, $1/h_f$ 0.017

Corrected Mean Temperature Difference, ^oF 564

Heat Exchanger Construction

Style Finned tube Number of Shell 1

Outside Tube Area per Shell, ft^2 2945

Number of passes per shell: Tube side 1 Shell 1

Design Pressure, psia: Tube Side 550 Shell Side 200

Tube OD, inch 3/4 Length, ft 20 Gauge -

Tube arrangement, pitch inch 1 Type Triangular

Shell ID, inch 36 Number of Tube 750

Fluid Properties

Characteristics	Shell side	Tube Side
Fluid designation	Flue Gas	141-142
Flow Rate, lb-mole/hr.	-	4109
Temperature in/out, ^oF	1300-1500	350-1200
Density, lb/ft^3 ave.		
Thermal conductivity, BTU/hr-ft ^oF		
Viscosity, lb/ft-hr		
Heat Capacity, BTU/lb ^oF		

APPENDIX C

NOMENCLATURE

c_p = heat capacity at constant pressure, BTU/lb-mole ^oF

c_v = heat capacity at constant temperature, BTU/lb-mole ^oF

C = corrosion allowance, inch

D = internal diameter, inch

D_i = nominal impeller diameter, inch

E = welding joint efficiency, usually 0.8-0.95

e_l = density of vapor, lb/cu. ft.

e_v = density of liquid, lb/cu.ft.

H_{poly} = polytropic heat, ft-lb/lb

$HP_{g(poly)}$ = polytropic heat horsepower, hp

h_i, h_d = heat transfer film coefficient, BTU/hr-ft^2-^oF

k = specific heat ratio

MW = molecular weight

N_{st} = number of stages

n_{poly} = polytropic efficiency

P = designed pressure, psi

R = gas constant

r_c = ratio of compression

S = allowable working stress, psi

T_s = suction temperature, ^oR

5 = wall thickness, inch

U = maximum impeller tip speed, ft/s

U_a = Acoustic velocity at inlet, ft/s

U_c = approximate overall efficiency, BTU/hr-ft^2-$^\circ$F

U_n = vapor velocity based on net area, ft/s

W = weight flow, lb/min

$\bar{z}$ = average compressibility

z_s = compressibility at suction condition

AUTOBIOGRAPHY

Mr. Somsak Chamnanthongpaivanh was born on June 1, 1953 in Bangkok, Thailand. He attended Aksorn Withaya School in 1958, Bangkok Withaya School in 1963, the Assumption Commercial College in 1969, and the Chulalongkorn University in 1974. He received his Bachelor Degree in Chemical Engineering from the Chulalongkorn University, Thailand in 1978. He furthers his study in Chemical Engineering in 1978 and was granted the Master Degree in 1981. Now he is working at the Exxon Chemicals (Thailand) Ltd., Bangkok.