



Training Services

Crude Unit Design

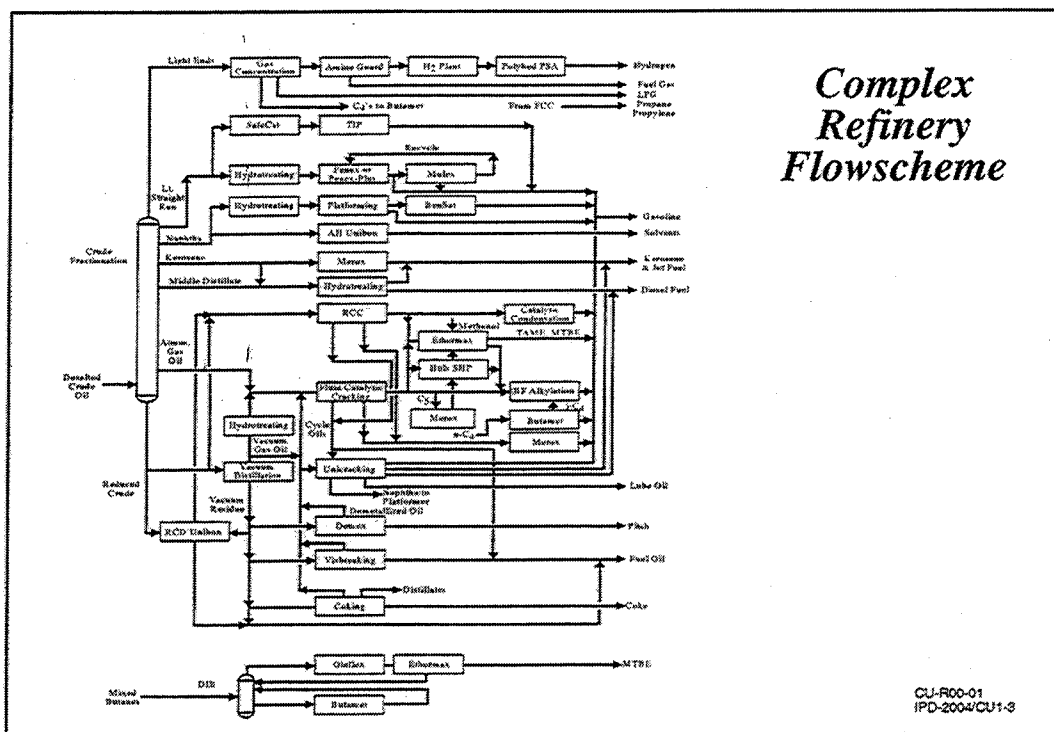
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Introduction

- Crude Unit is a 'Keystone' process in refinery
- Other common refining units have similar fractionator designs
 - Hydrocracking
 - Fluid Catalytic Cracking
 - Coking/Visbreaking

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Complex Refinery Flowscheme



Introduction

■ Terminology

- Desalter
- Preflash Column or Preflash Vessel
- Flash Zone
- Pumparound
- Side Stripper
- Absorber
- Stabilizer (or Debutanizer)
- Splitter
- Heat Exchange Network

Outline

- Design Basis
- Feed System
- Crude Tower
- Sat Gas Plant
- Heat Exchange Network

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Design Basis

- Feed properties - design crude oil and alternate cases
Light Arabian
- Feed quantity - design and turndown rates
100 000 bpd
- Product properties
 - product specifications
 - seasonal variations in specifications
- Product demands
will be reviewed as they become relevant

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Example 1

Plot Pertinent Properties from Light Arabian Crude Assay

— The plot is important to determine the cut point

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Example 2

Input Light Arabian Crude Assay into Simulation

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More on Design Basis

■ Battery Limit Conditions

Consider line pressure drop and tank head

Stream	Pressure (psig)	Temperature to Tankage (°F)	Temperature to Units (°F)
LPG	200		
Naphtha / Kerosene	50	< 120	< 120
Diesel	50	250 - 400	100 - 120
Gas Oils	50	350 - 500	120 - 180
Residues	50	450 - 700	150 - 180
Asphalt		300 - 450	300 - 450

Consider safety (flash point) and evaporative losses at tanks

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More on Design Basis

■ Utilities

Pressure (psig) Temperature (°F)

Design Air Temperature		95
Cooling Water Supply		90
Cooling Water Return		120
MP Steam	150	Saturated
LP Steam	50	Saturated

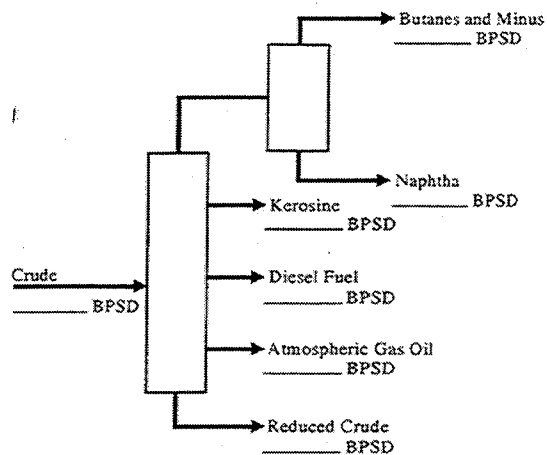
20°F and 10°F design cold end approach for air- and water-cooling services; respectively

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Block Flow Diagram

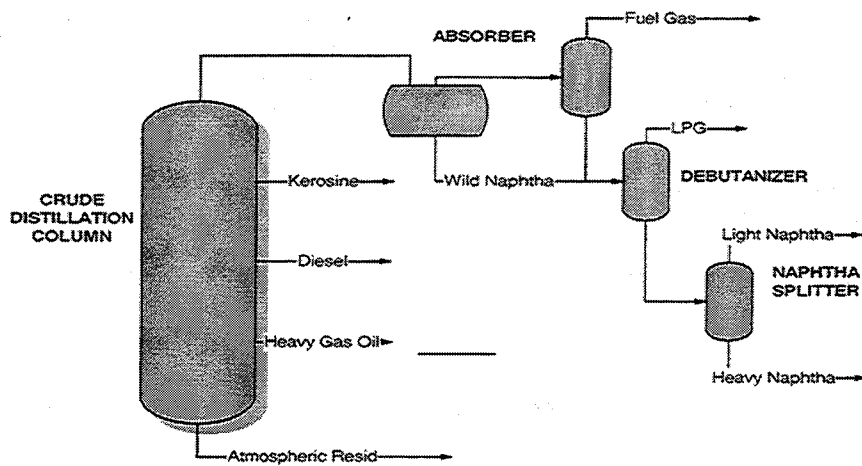
Obtain Product Yields

Enter Product Yields on Block Flow Diagram



CU-R00-02
IPD-2004/CU1-11

More on Block Flow Diagrams



CU-R00-02
IPD-2004/CU1-12

More on Design Philosophy

- Specify, at minimum, two alternate feed cases and one turndown case.
- Use simulation tool to model the full process for each case.
- Specify equipment using process data generated from simulation results.
- Do not use simulation tool to design equipment. Utilize company standards or other best practices to set design margins for equipment.
- Estimate product properties relevant to product specifications using simulation results.

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Desalting

Presentation Slides

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Crude Tower Design Options

- Preflash
- Overhead Configuration
- Fractionation Sections
- Sidecut Stripper Design
- Flash Zone Conditions
- Pumparounds
- Saturated Gas Plant Configuration

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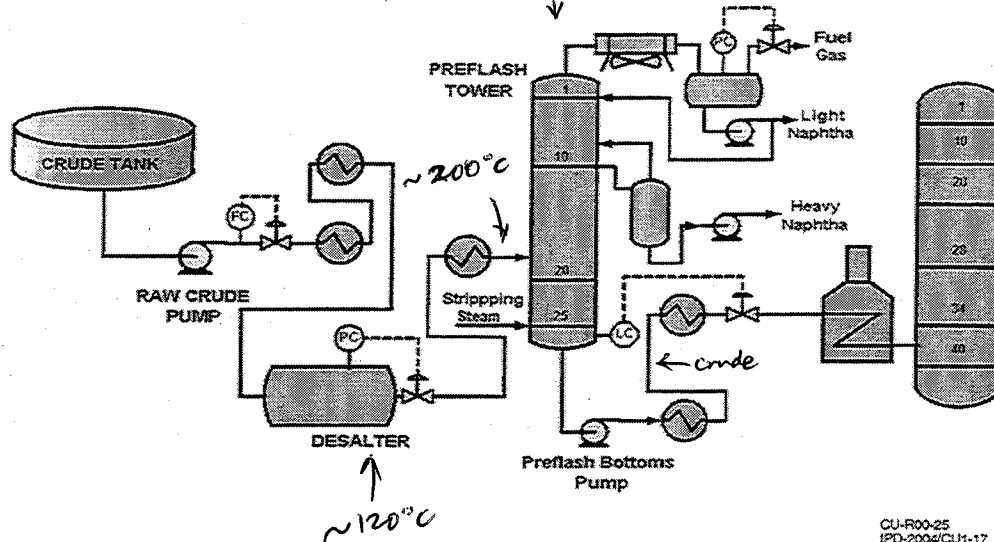
Crude Unit Preflash Column

- Preflash columns might be considered when:
 - design slate contains a high proportion of naphtha
 - energy costs savings outweigh capital costs
 - as revamp to add additional capacity
- Preflash column can provide higher energy efficiency
- Preflash column may not allow a clean split with main tower overhead product

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CDU Configuration with a Preflash Column

Remove naphtha before it goes to crude unit



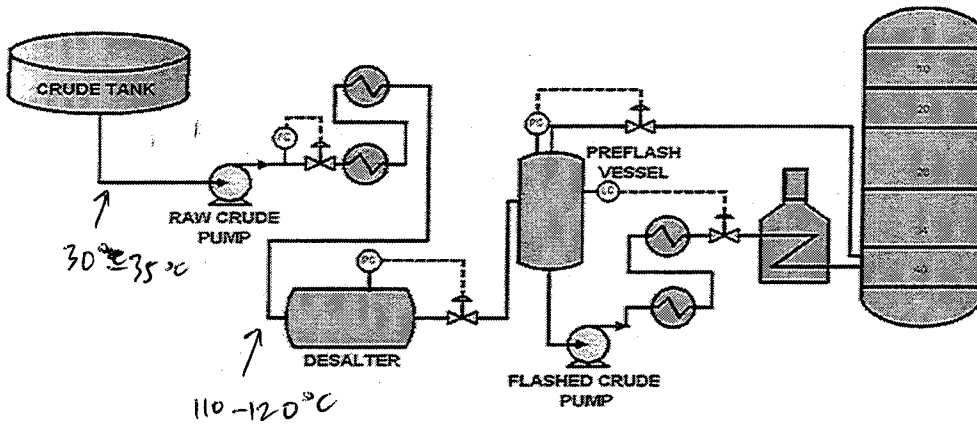
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Crude Unit Preflash Vessel

- Preflash vessels are installed to:
 - prevent flashing in control valves
 - provide surge capacity
 - reduce exchanger fouling
- Energy benefits only realized if vapor is routed above the flash zone.
- Issues with foaming and carry over must be addressed. Possible solutions are reflux system, demister pad, back pressure controller.

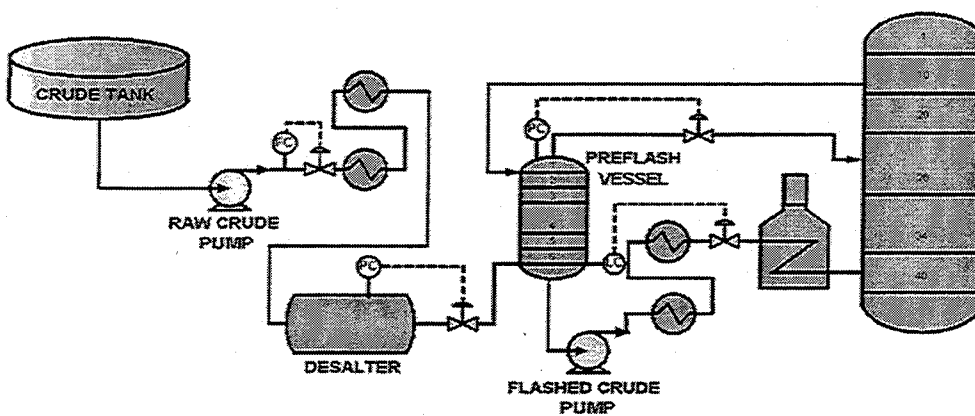
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CDU Configuration with a Preflash Vessel



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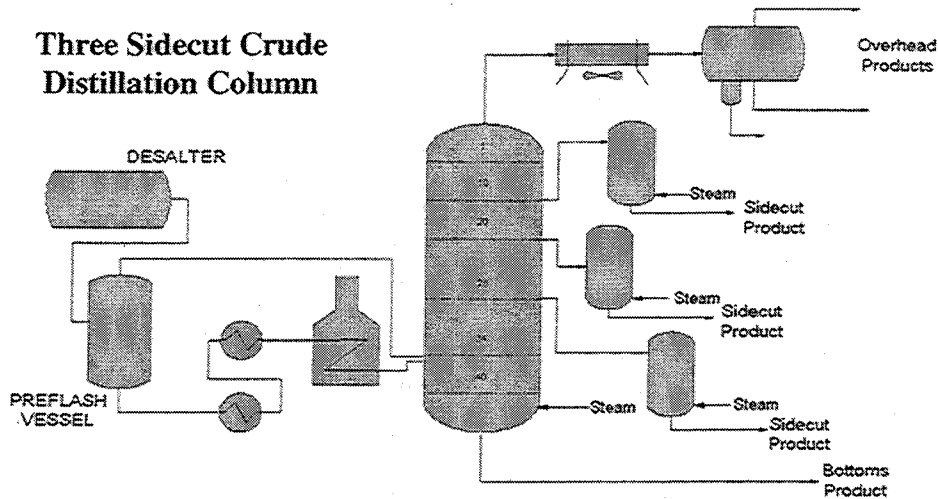
CDU Configuration with a Refluxed Preflash Vessel



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Process Configuration

Three Sidecut Crude Distillation Column

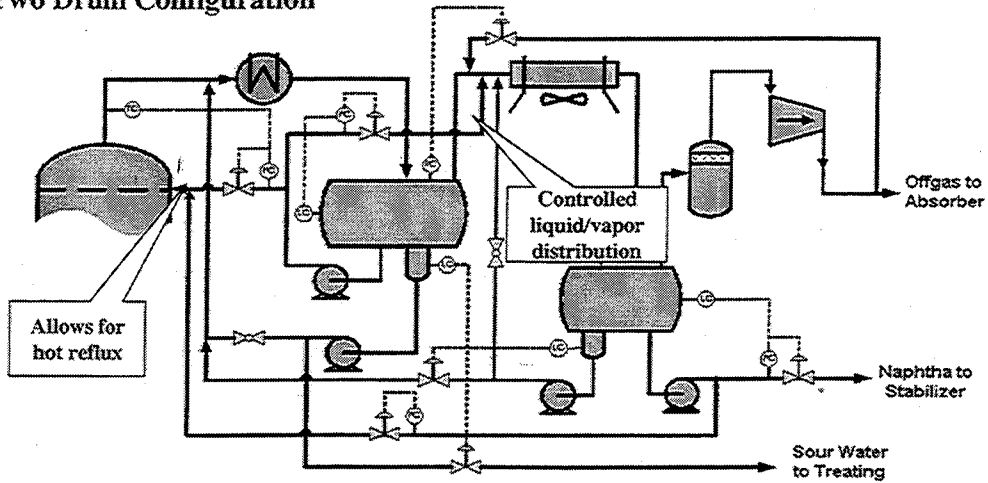


Overhead Configuration Options

- **Single drum configuration**
 - Limited heat recovery
 - Possible corrosion/distribution problems
- **Two drum configuration**
 - Complex control scheme/more equipment
- **Top pumparound with single drum**
 - Eliminates potential for tube leak contamination
 - Must maintain high return temperature
- **Crude overhead off-gas compressor**

Overhead Configuration

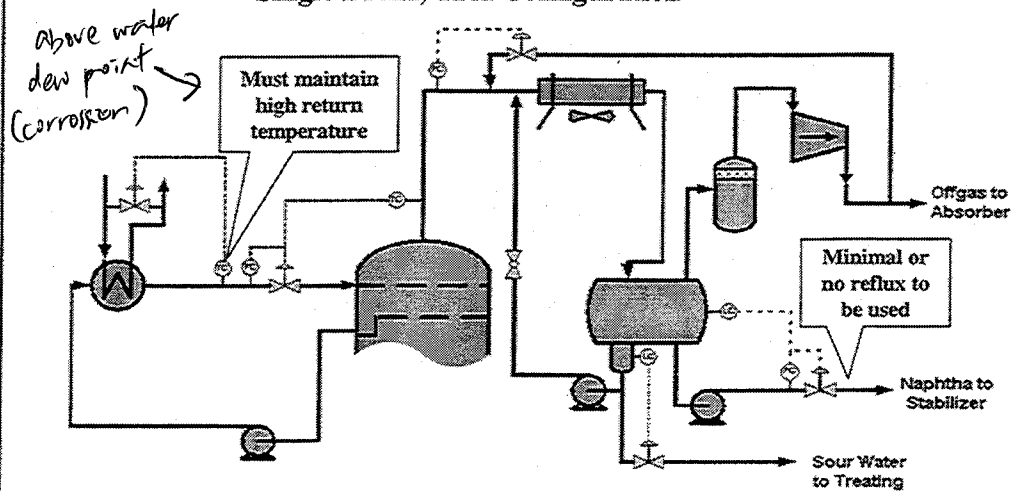
Two Drum Configuration



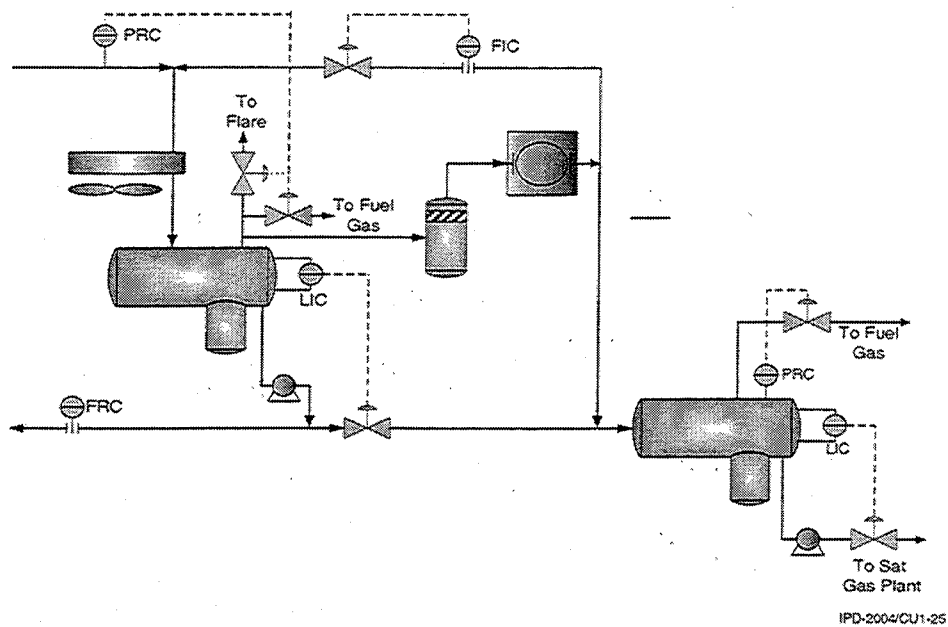
Overhead Configuration

↓ top pumparound

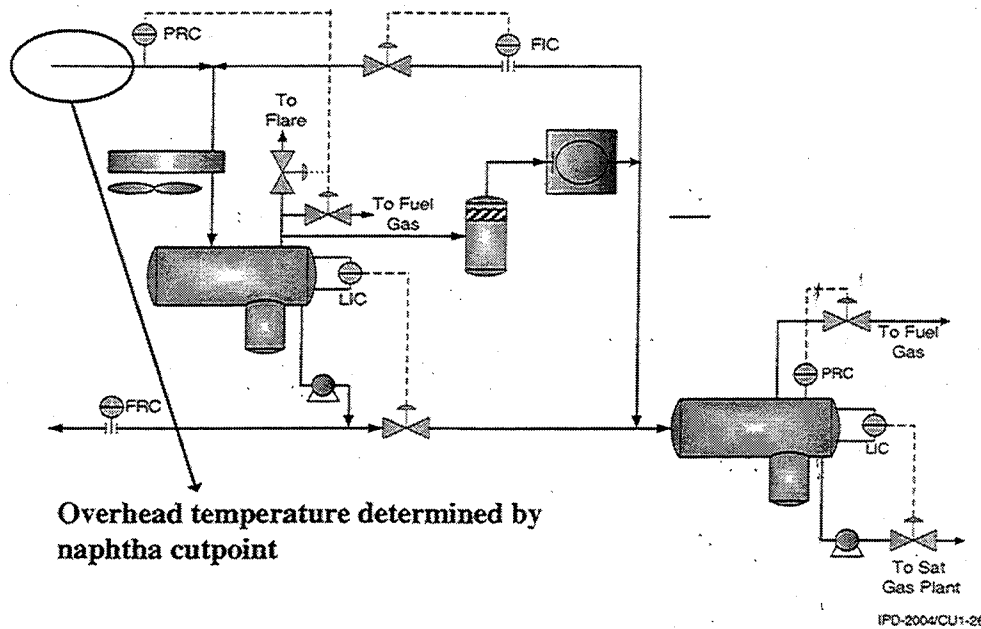
Single Drum, TPA Configuration



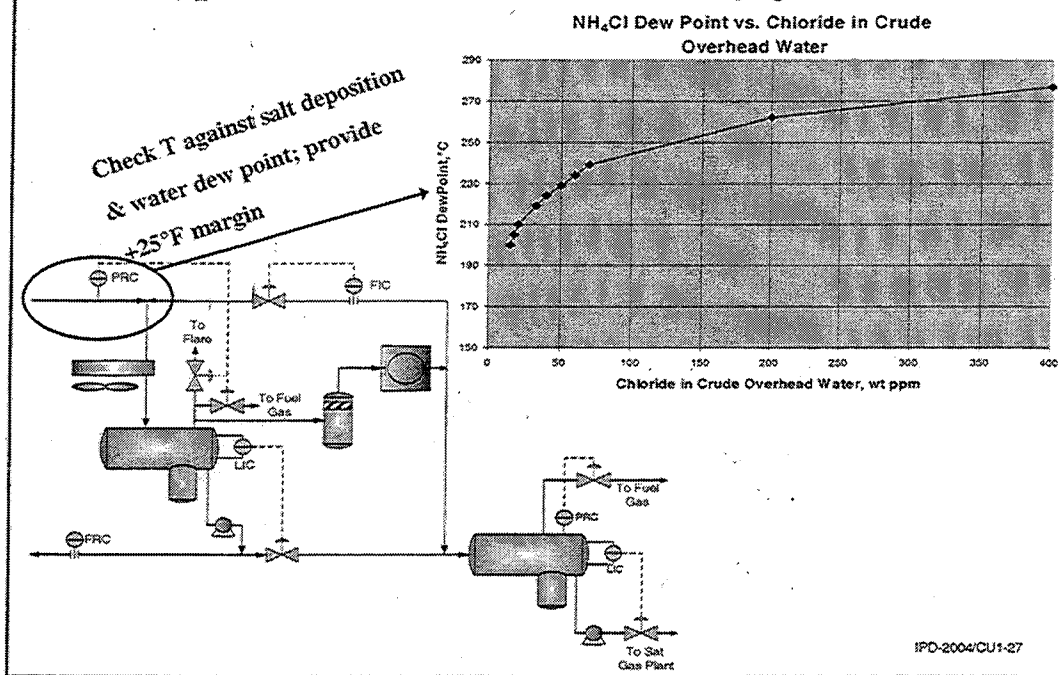
Typical Crude Overhead Configuration



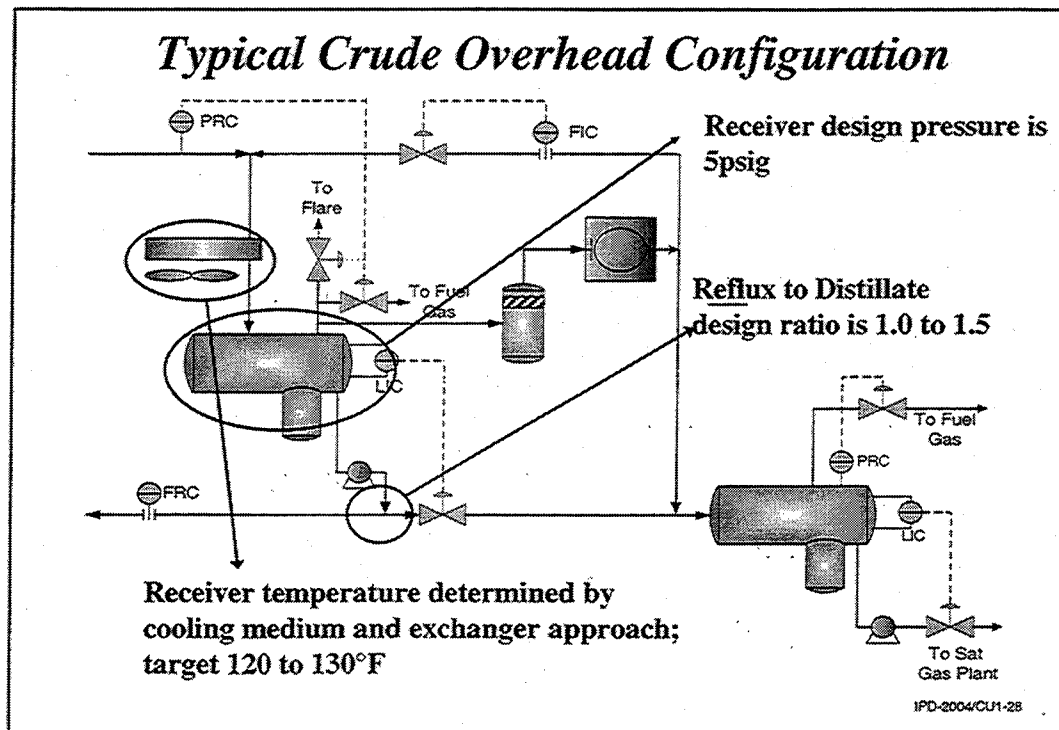
Typical Crude Overhead Configuration



Typical Crude Overhead Configuration



Typical Crude Overhead Configuration



Target 0.51v% off-gas on crude at 5psig and 100°F; add spike if required

Pump and compressor discharge pressure set to condense off-gas

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■ Packing Pro's

- A packed column will be thinner and shorter than a trayed column
- Pressure drop across the column will be less
- Packing gives better performance in low flow sections (e.g. wash section)

■ Packing Con's

- Even with the smaller column, costs will be approximately the same
- Packing gives more maintenance problems

General Rule of Thumb -

“Build with trays, revamp with packing”

Crude Fractionation Trays Selection

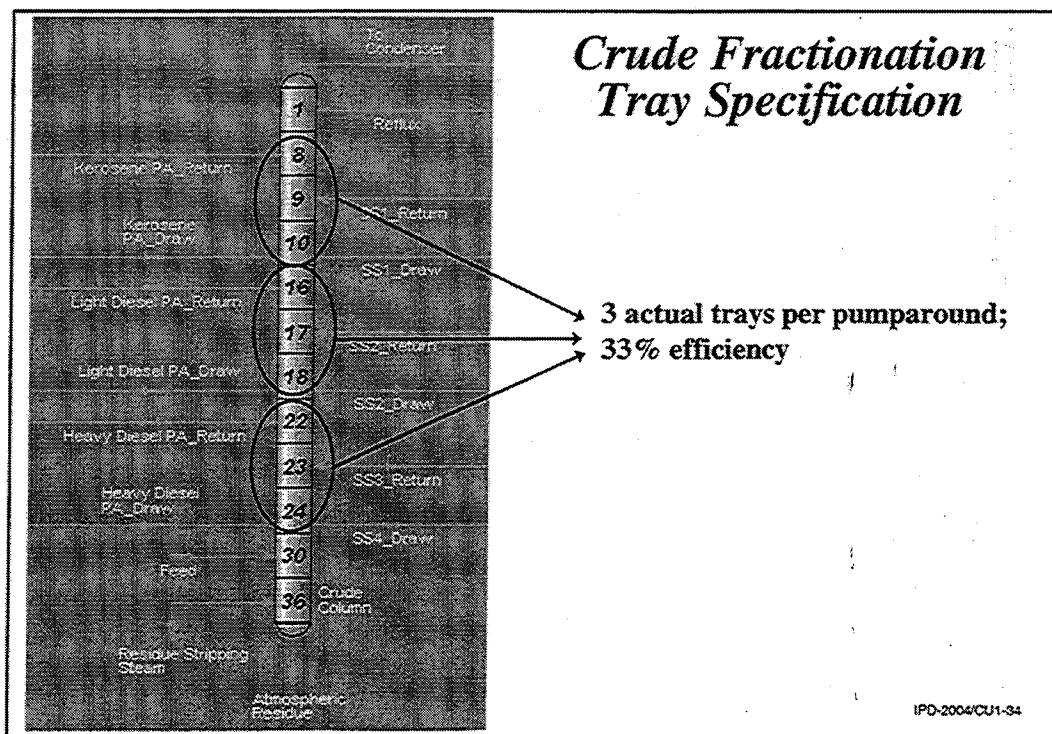
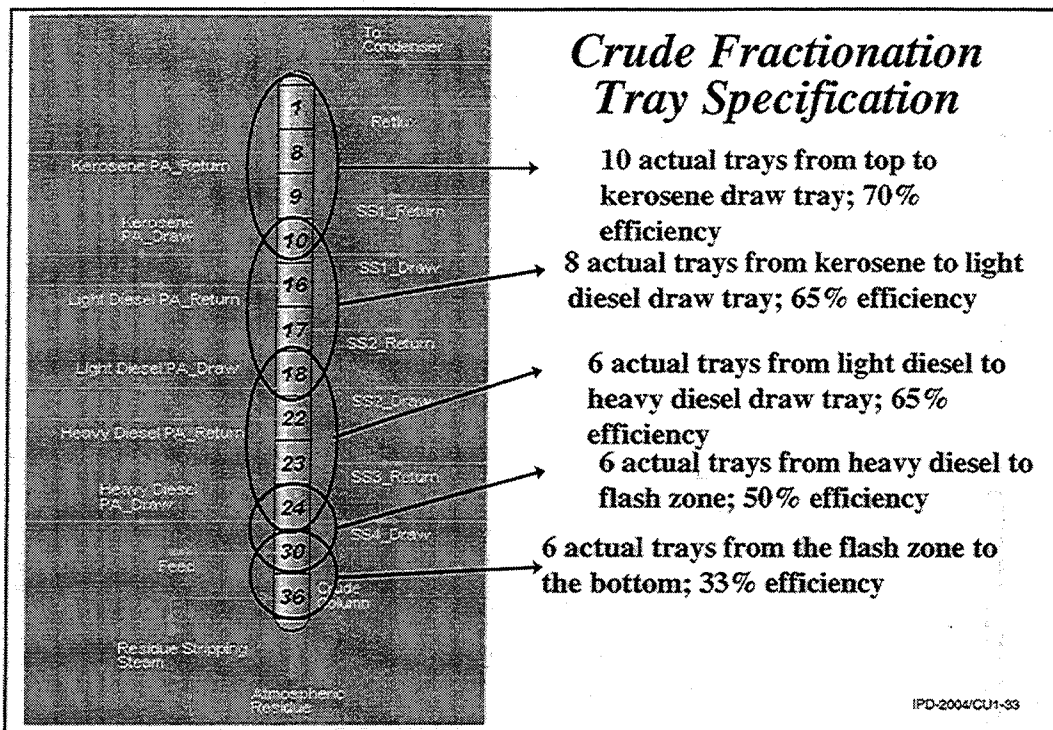
- **Valve Trays**
 - Most commonly used trays
 - Allow better turndown than
 - Less prone to channeling /Better distribution
- **Sieve Decks**
 - Best for cost and maintenance
 - Not Suitable for turndown below 70%
- **Bubble Caps**
 - Rarely used because of high maintenance requirements
 - Best for turndown and low flow zone

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Crude Fractionation Trays Selection

- **High Capacity Trays**
 - Consider only for revamps
 - Confirm vendor's past experience with specific service
- **Efficiency**
 - Several equations available for efficiency
 - For refinery services, past experience is generally relied upon
 - Moderate services: 60 to 70% efficiency
 - Heavier services (wash zones): 50 - 60%
 - Bottoms stripping section: 25 - 35%

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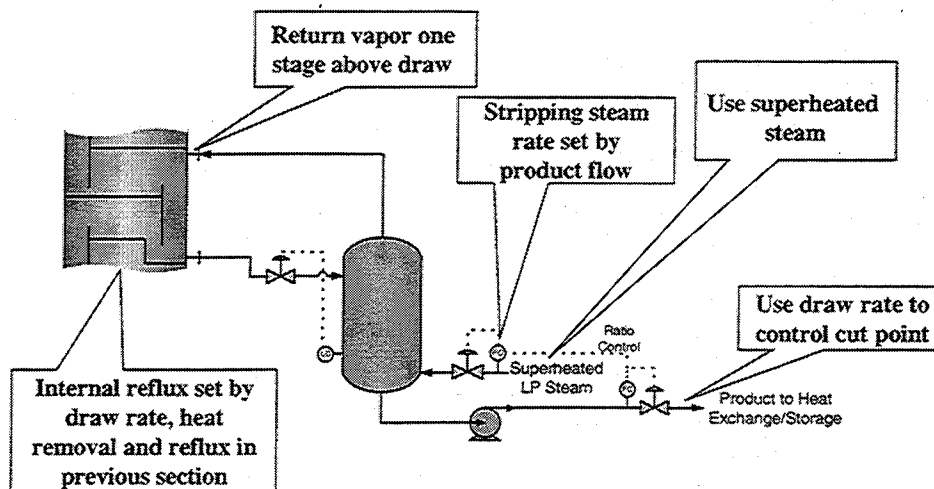


Side Stripper Designs

- Types of side strippers
 - Steam-stripped
 - Side-reboiled
 - Vacuum-educted
- Typically 5 to 10 actual trays - 3 to 6 theoretical trays
- Design steam stripping rates
 - Residue - 8 to 10 lb/bbl (28.5 kg/m^3)
 - Diesel and lighter streams - 5 lb/bbl (15 kg/m^3)
- Target 10% removal of incoming stream for non-steam stripped services

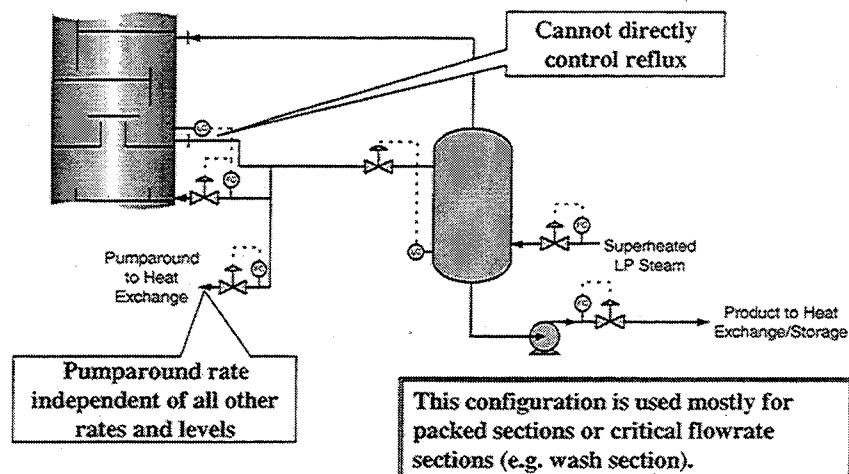
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Side Stripper Configuration - Internal Reflux



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Side Stripper Configuration - External Reflux



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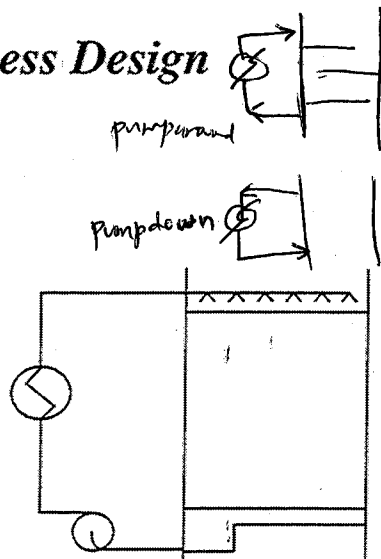
Pumparound Process Design

Pumparounds:

- remove excess heat from distillation column
- keep the column diameter from becoming too large

Design Philosophy

- one pumparound per side draw
- 150°F ΔT
- use excess heat concept to determine heat removal rate at each pumparound
- optimize duty, delta T with network design and column sizing



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Example 3

Configuration of Crude Column in Simulation

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FBP = 100% cut BP at ASTM D86

Example 4

Initial Convergence of Crude Column in Simulation

To get result:

- minimize FBP = 40°C
- ~~Normal~~ FBP = 180°C
- Kerosene FBP $< 360^{\circ}\text{C}$
- Top 95% D86 Heavy Diesel = 360°C

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Furnace and Transfer Line Initial Design Assumptions

- Need HX Network Design to Specify Furnace
- Need Column Design to specify HX Network
- Preliminary Assumptions
 - Target 500°F Inlet Temperature
 - Furnace ΔP 125 psi
 - Transfer line ΔP 2-5 psi
 - HX ΔP from flash drum ~150 psi
 - Furnace outlet temperature - 650 - 725 °F

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Flash Zone Design

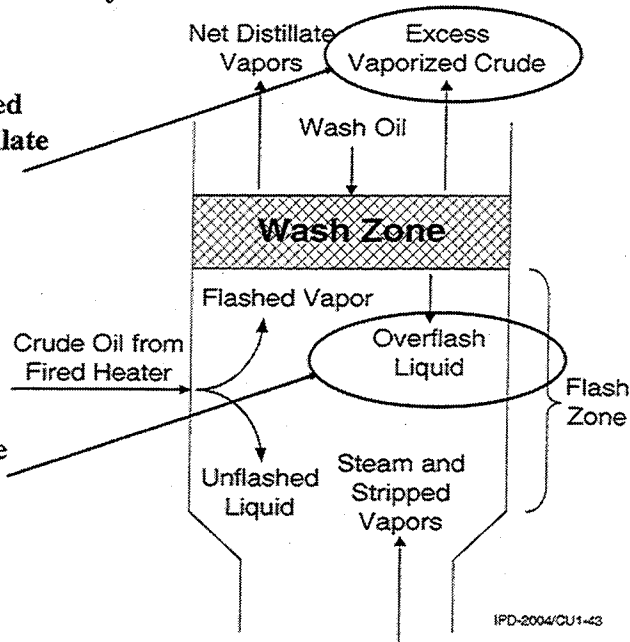
- Minimize pressure and overflash
- Maximize steam stripping to maximize distillate recovery
- Benefits of increased distillate recovery
 - Improved vacuum column operation
 - improved energy performance
- Considerations
 - AGO cutpoint / entrainment
 - maximum allowable furnace outlet temperature
 - transfer line hydraulics - allow 2 to 5 psi ΔP

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Flash Zone Design Parameters Overflash

Definition #1 - Crude feed flashed in excess of distillate yields without stripped vapor

Definition #2 - Liquid leaving wash section to the flash zone including stripped vapors

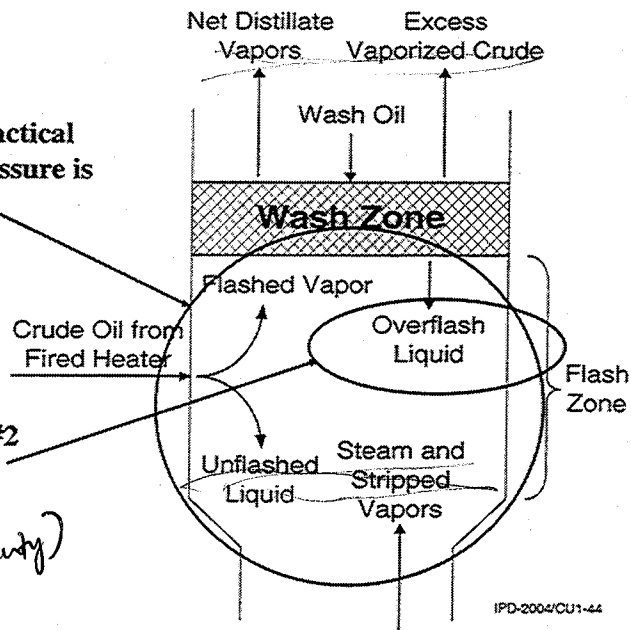


Flash Zone Design Parameters Overflash

Minimum practical operating pressure is 30psig

Target 2 to 5lv% on crude overflash using definition #2

to save energy (reduce reboiler duty)



Example 5

**Estimate Flash Zone Temperature from API
Method**

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Example 6

**Adjust Flash Zone Temperature within a
Simulation to Target Design Parameters**

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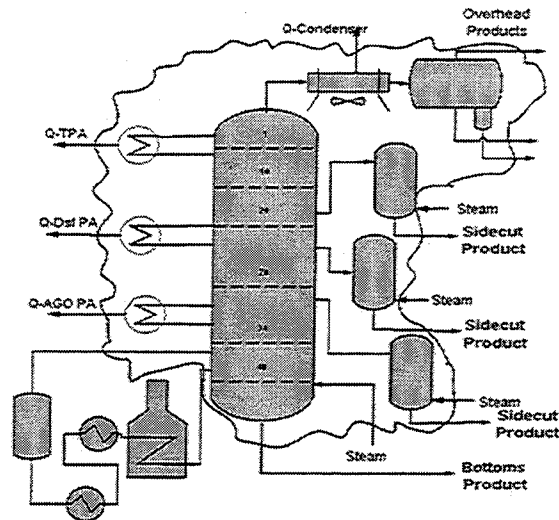
Heat Balance Internal Loading

Heat Inputs

- Feed(s)
- Steam

Heat Outputs

- Bottom Product
- Side draws
- Overhead Draws
- Condenser Duty
- Pumparound Duty



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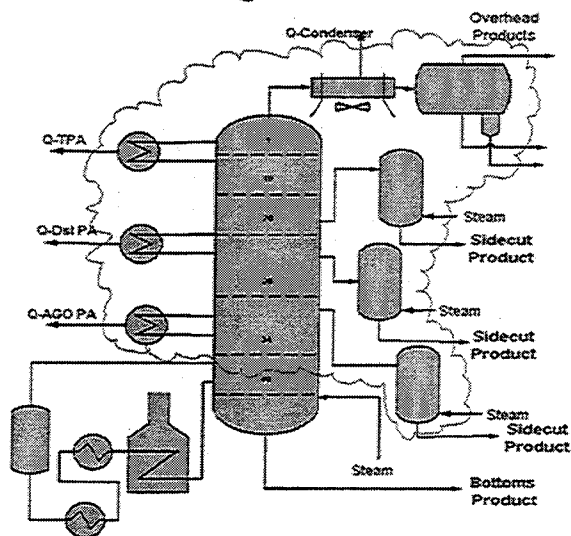
Heat Balance From Flash Zone Internal Loading

■ Heat Inputs

- Flash Zone Vapor
- Steam

■ Heat Outputs

- Overflash
- Side draws
- Overhead Draws
- Condenser Duty
- Pumparound Duty



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Example 7

Determine Pumparound Heat Removal Rates

- Excess heat around 20% , heat to be removed by pumparound.

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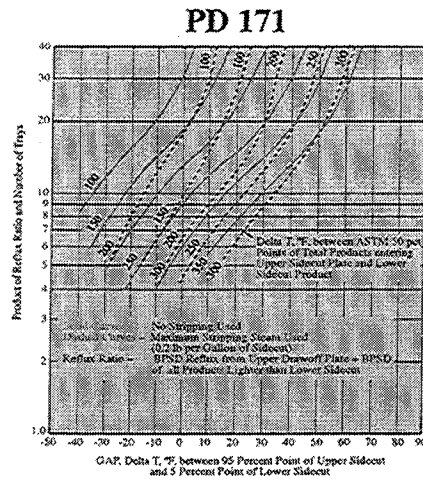
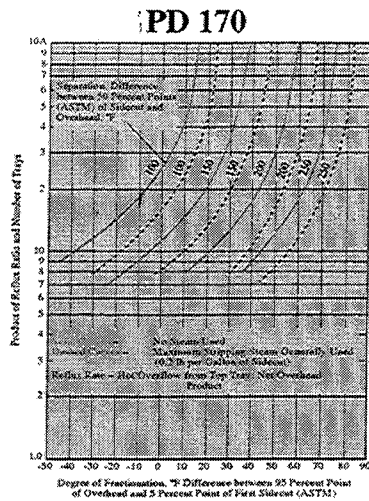
Check Fractionation Efficiency

- Distillation "gap" is defined as the ASTM 5% distillation point of the heavier fraction - ASTM 95% distillation point of the lighter fraction

Cut	Actual Gap (°F)	Recommended Gap (°F)
Light Naphtha - Heavy Naphtha	37	30
Heavy Naphtha - Kerosene	39	20-30
Kerosene - Light Diesel	18	10-15
Light Diesel - Heavy Diesel	-28	0
Heavy Diesel - Atmospheric Residue	-4	

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Degree of Fractionation



CU-R00-16 & 17
IPD-2004/CU1-51

Degree of Fractionation (continued)

Naphtha vs. Kerosene

Net Overhead, BPSD	
Internal Reflux, BPSD	
R - Internal Reflux/Net	
Net Overhead 50 % point	
Sidecut 50 % point	
Delta 50% points	
Number Actual Trays	
N = Number of Fractionation Trays	
R x N	
Calculated Gap (95 - 5) fr PD 170	

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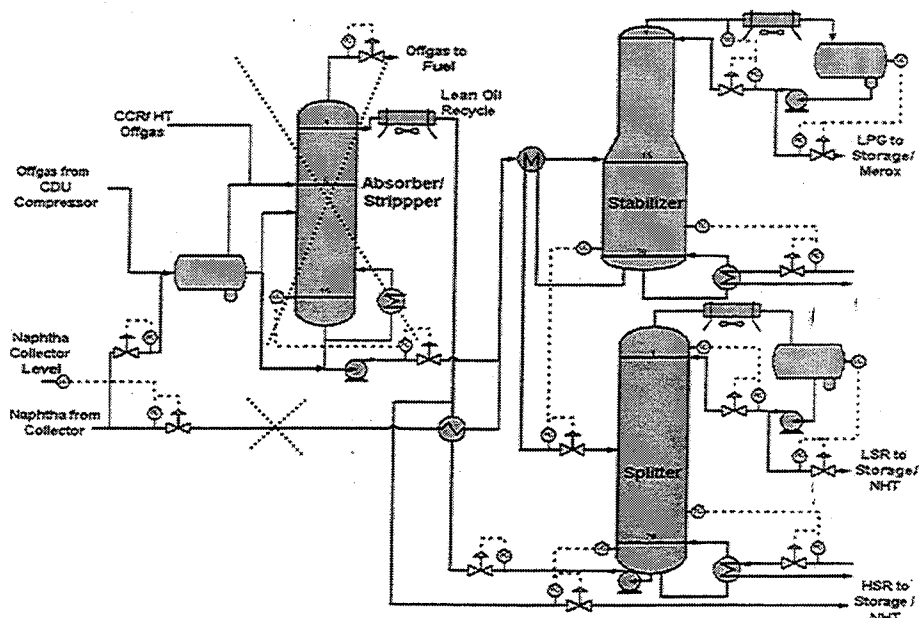
Generate Crude Column Sizing Information

Tray Section	Naphtha-Kerosene	Kerosene-PA	Kerosene-Diesel	Light Diesel-PA	Light Diesel-Heavy Diesel	Heavy Diesel-PA	Heavy Diesel-Residue	Residue Stripping
Tray Numbers	1-7	8-10	11-15	16-18	19-21	22-24	25-30	31-36
Vapor								
Vapor Mass Rate (lb/h)	707011	899878	967924	1081108	1115139	1069182	1003199	90500
Vapor Density (lb/ft ³)	0.31	0.34	0.36	0.38	0.39	0.39	0.39	0.20
Vapor Volume Rate (actual ft ³ /s)	648	729	763	792	797	765	720	124
Liquid								
Liquid Mass Rate (lb/h)	410070	1277697	480303	1052888	532156	464621	321639	661410
Liquid Density (lb/ft ³)	49	50	52	52	54	55	56	59
Liquid Volume Rate (GPM)	1062	3205	1201	2507	1261	1071	732	1406

Where is the maximum column loading?

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Sat Gas Plant Configurations



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Sat Gas Plant Absorber/Stripper

- Feeds are saturated streams
 - CDU off-gas
 - hydroprocessing off-gases
 - catalytic reforming stabilizer off-gas
 - unstabilized naphthas from hydroprocessing units
 - isomerization stabilizer off-gas
- Objectives
 - target >90% C3 recovery
 - meet LPG specifications
- Conditions
 - Pressure dependent upon CDU compressor limits
 - top temperature set by lean oil (preferably naphtha) temperature

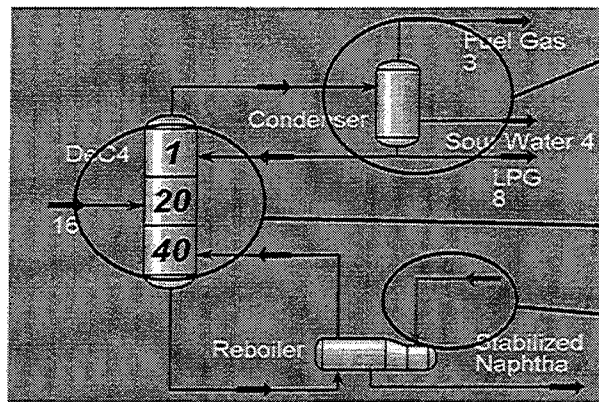
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Some LPG Specifications

Country	India	India	India	U.S.	U.S.	U.S.
Product	Commercial Mixed Propane-Butane	Commercial Butane	Commercial Propane	Commercial Mixed Propane-Butane	Commercial Butane	Commercial Propane
Specification						
Vapor Pressure at:						
65°C (kg/cm ² g), Max.	17	10	26			
37.8°C (kg/cm ² g)				6.00 to 14.75	2.50 to 4.90	12.65 to 14.75
Total Sulfur (ppm), Max.	200	200	200	140	140	185
Cu Strip Corrosion, Max.	No. 1	No. 1	No. 1	No. 1	No. 1	No. 1
95 LV% Off Evaporation Temperature (°C) at 760mmHg, Max.	2	2	-38	2	2	-38
Residual Matter (lv%), Max.				5	5	5
Typical C4 and Heavier (lv%), Max.						2.5
Typical C5 and Heavier (lv%), Max.				2.0	2.0	

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Naphtha Stabilizer (Debutanizer)



Overhead temperature set by cooling utilities exchanger approach; pressure set by off-gas compressor

30 to 40 stages with 75% efficiency

Typically reboiled with hot process stream

Operating Objectives

- Meet LPG specifications
- Light naphtha RVP

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Example 8

Debutanizer Design using Simulation

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Naphtha Splitter

■ Products

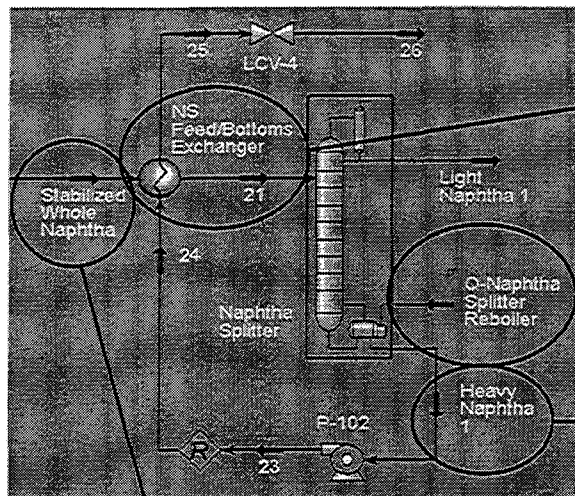
- light straight-run naphtha (LSRN) for gasoline blending or isomerization
- heavy straight-run naphtha (HSRN) for naphtha hydrotreating / catalytic reforming feed

■ Design strategy

- Meet LSR RVP for gasoline blending directly to pool
- Remove C5+ material and benzene precursors from catalytic reforming feed

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Naphtha Splitter



Splitter feed/bottoms exchanger is common; not ideal from HTEX network design perspective

Use hot process stream for reboiling, if possible

Target 221°F ASTM IBP;
30°F gap between LSRN
and HSRN

Many refiners split the whole
range naphtha after
hydrotreating

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Example 9

Naphtha Splitter Design using Simulation

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Crude Unit and Saturated Gas Plant Mass Balance

Stream	Crude	Fuel Gas	LPG	Light Naphtha	Heavy Naphtha	Kerosene	Light Diesel	Heavy Diesel	Residue
Mass Rate (lb/h)	1250900	2010	11164	72934	191190	194140	96999	77309	606170
Volume Rate (Mbpd)	100.034	0.319	1.400	7.424	17.562	16.545	7.829	5.987	43.784
LV% on Crude	100.0	0.3	1.4	7.4	17.6	16.5	7.8	6.0	43.8
Gravity (°API)	34.8		127.5	78.7	58.2	44.5	35.2	28.4	17.7
Composition		(mole%)	(lv%)	(lv%)					
C1		34.2	1.8						
C2		30.6	10.3						
C3		9.7	9.6						
iC4		4.3	10.8	0.1					
nC4		20.4	65.5	1.7					
iC5		1.9	1.5	9.6					
nC5		0.1	0.5	19.7					
CP		0.0	0.0	0.9					
C6+		0.0	0.0	68.1					
ASTM Distillation (°F)									
IBP (1%)				91	225	338	457	520	559
10				119	234	382	511	578	679
30				133	255	400	534	599	786
50				153	278	422	551	614	937
70				172	297	449	567	632	1077
90				185	329	480	591	668	
95				197	343	493	606	683	
FBP (99%)				209	363	519	628	710	

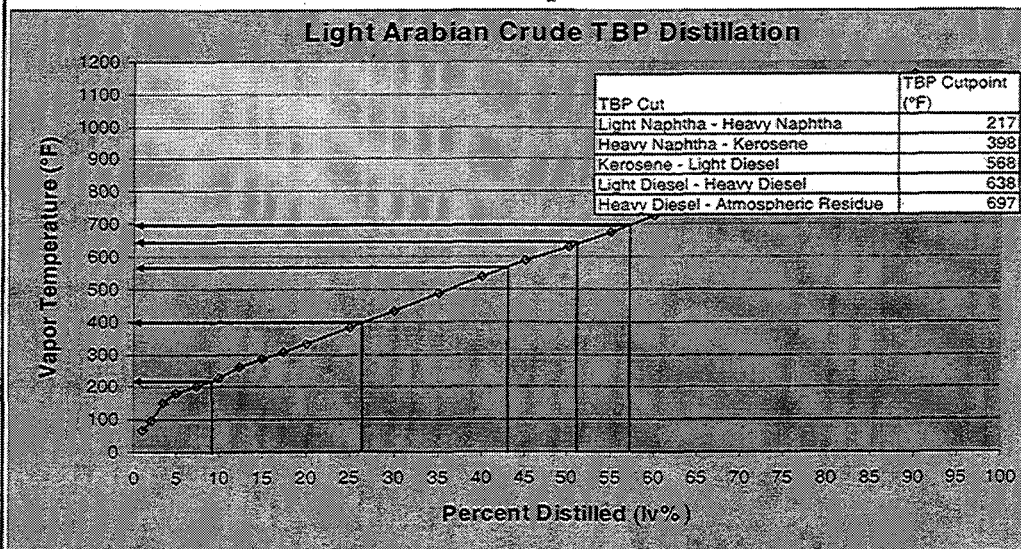
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Crude Unit and Saturated Gas Plant Mass Balance

Stream	Crude	Fuel Gas	LPG	Light Naphtha	Heavy Naphtha	Kerosene	Light Diesel	Heavy Diesel	Residue
Correlated Properties									
UOP K	11.63		14.01	12.54	12.07	11.93	11.83	11.61	11.68
MW	210	34	52	82	116	174	237	269	442
Sulfur (wt%)	1.70	0.0095	0.014	0.021	0.043	0.28	1.01	1.52	3.05
Vapor Pressure / RVP (psi)			215	8.9					
Flash Point (°F)						151			
Freeze Point (°F)						-40			
95% Distillation Point (°F)							606	683	
ASTM D976 C1						49.6	51.5	45.0	

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Crude Unit and Saturated Gas Plant Mass Balance TBP Cutpoints



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Crude Distillation Unit Process Monitoring

Critical Process Monitoring Activities

■ Desalter

- Monitor salt removal
- Monitor water oil content

■ Exchanger Network

- Monitor exchanger fouling
- Monitor pressure drop
- Monitor flow splits

■ Furnace

- Monitor flux
- Monitor draft
- Monitor excess oxygen

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Crude Distillation Unit Process Monitoring

Critical Process Monitoring Activities

■ Columns

- Monitor fractionation
- Monitor loading
- Monitor pumparound duties
- Monitor overhead conditions
- Calculate all reboiler and condenser duties
- Perform routine Heat & Mass Balances
- Identify bottlenecks

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Crude Distillation Unit Test Runs for Equipment Rating

Collect the following information during a test run to be used for rating and simulation...

- All available DCS data including valve positions
- Additional manual temperature points and flow rates for exchanger rating
- Stream suction and discharge pressures, temperatures, flows and driver power draws for pump rating
- Fired heater skin points and crossover temperatures

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Crude Distillation Unit Strategy for Column Rating Simulation

- Achieve mass balance – zero meters, if required, proper flow corrections, use tank levels where possible to verify
- Use redundant data to reconcile flows and temperatures
 - Enthalpy transfer on each side of an exchanger is equal
- What goes out must come in!
 - Back blend net distillation unit streams to create the feed for a simulation
 - Back blend streams from product recovery sections to create net reactor effluents

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Crude Distillation Unit Strategy for Column Rating Simulation

- Model the feed as a mix of all products
- Match known product flow rates (or cutpoints), duties, and refluxes by specification
- Adjust tray efficiencies to match D86 gaps
 - Recommend 5/95 gap - never IBP or EP
 - For gas plant, match light key/heavy key components
 - Check draw temperatures where uncertainty exists
- Check tray loading

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Crude Distillation Unit Troubleshooting

Heat Exchanger

- Possible reasons for poor performance
 - Fouling
 - Open bypass or passing valve
 - Low flow
 - Changes in conditions
- Checks
 - Calculate U-Value / Fouling factor
 - Check LMTD TEMA correction (F_T)
 - Check pressure drop
 - Check thermowells (upstream of bypass return)

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Crude Distillation Unit Troubleshooting

Column

■ Possible reasons for poor performance

- Flooding / Foaming
- Low reflux / Weeping
- Entrainment
- Internal Damage

■ Checks

- Simulate column and check tray loading
- Check section pressure drops
- Compare historical data to current performance
- Gamma scanning

Desalting - What is it?

The commonly referred to process of removing water soluble/dispersible contaminants (salt, solids, & water) from crude oil.

UOP

Why Desalt Raw Crude?

Preheat Train

- *salts and solids fouling aggravate hydraulic and thermal limits*
- *affects capacity, run length, maintenance costs*

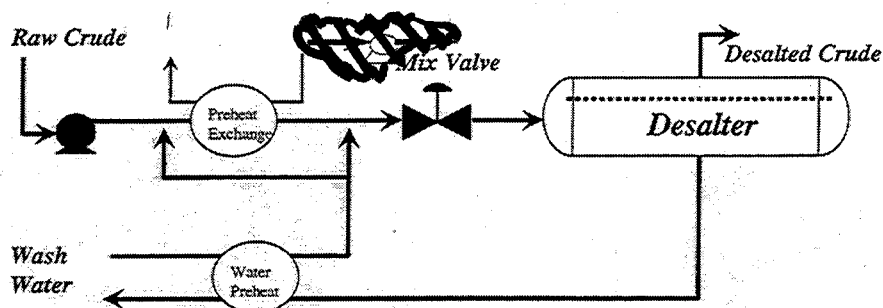
Overhead Corrosion

- *reduces time between turnaround*
- *reduced overhead exchange performance increases load on condenser*
- *possible overhead bundle replacement*
- *increases maintenance cost*

UOP

Basics of Desalting

Crude + Heat
 + Water + Demulsifier
 + Mix Energy
 + Electrostatic Precipitation
 = Desalted Crude + Separated Water



UOP

Typical 2 Stage Setup

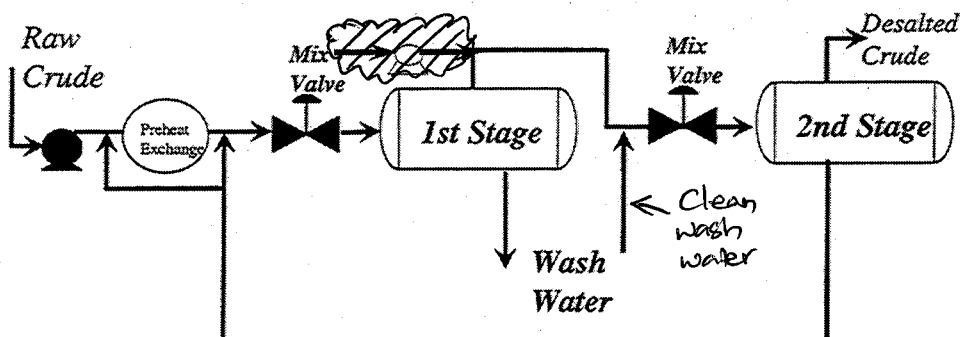
pound per thousand barrel

50 ptb NaCl

Op. T = 120°C max
 Temperature is low enough for sufficient use of carbon steel and crude not vaporise

5.5 ptb NaCl

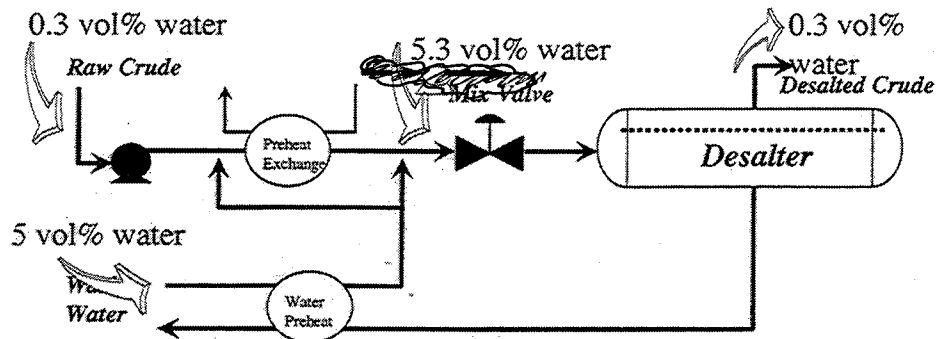
0.8 ptb NaCl



UOP

Basics of Desalting

Dilution - Dehydration



UOP

water hardness
measured by calcium
content

Wash Water

Attributes:

Soft, no hardness

Moderate slightly
acid pH, ~6

Low/no contaminants

To Avoid:

Mineral scaling problems

Rag stabilization particularly with solids
& neutralized organic
acids/naphthenates

H₂S, organic acid etc. drop into effluent

Hidden slop oil loading

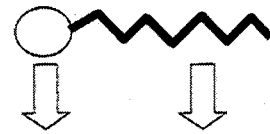
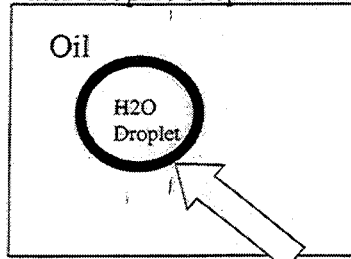
Phenol, ammonia, etc. "lift" to crude unit

Usual sources: Crude and Vacuum unit overhead
water, Saturates units stripped sour water

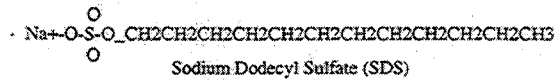
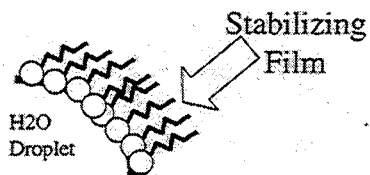
UOP

General Surfactant Structure

Water droplet suspended in oil



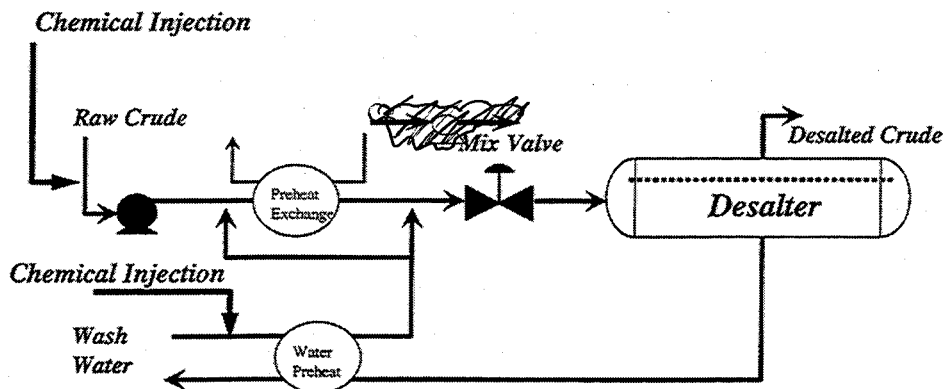
Head Group	Tail Group
Hydrophilic	Lipophilic
Lipophobic	Hydrophilic



Also, anionic, cationic, polymers, flocculants, wetting agents

UOP

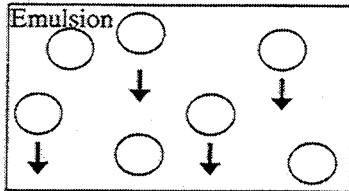
Typical Chemical Injection



UOP

Electrostatic Precipitation Basics

Quiescent Water in Oil



Stokes Law

$$\text{Settling Rate} = k (\rho_{\text{h}_2\text{o}} - \rho_{\text{oil}}) d^2 / \mu_{\text{oil}}$$

Force on droplets within electric field

$$F = KE^2 d^6 / s^4 \quad (s \gg d)$$

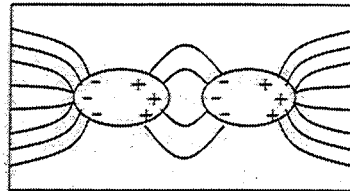
K = System constant

E = Voltage gradient

d = Droplet diameter

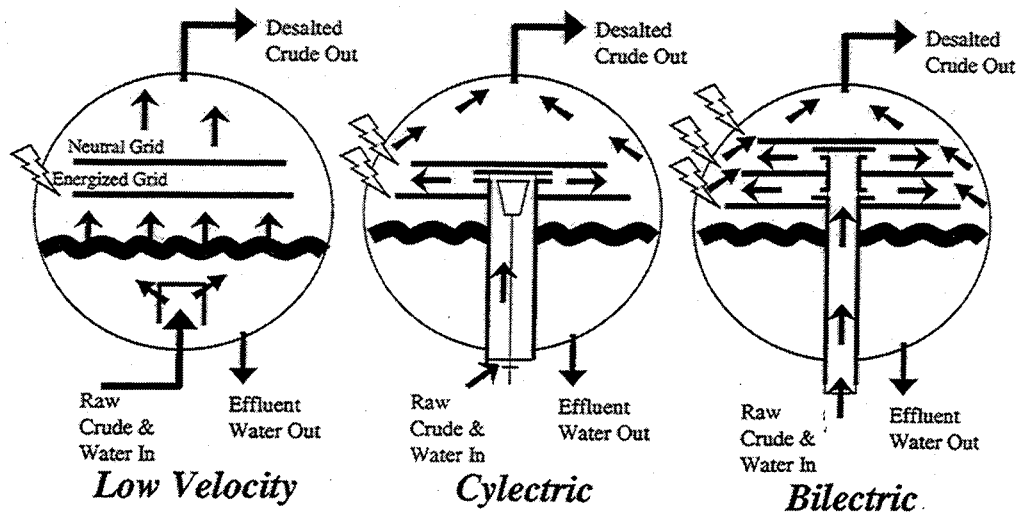
s = Distance between droplet centers

Emulsion in Electric Field



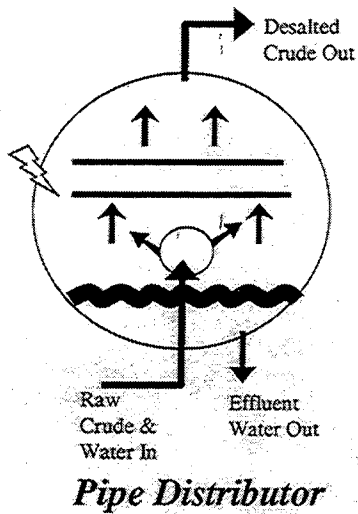
UOP

Desalter Style Schematics - End View



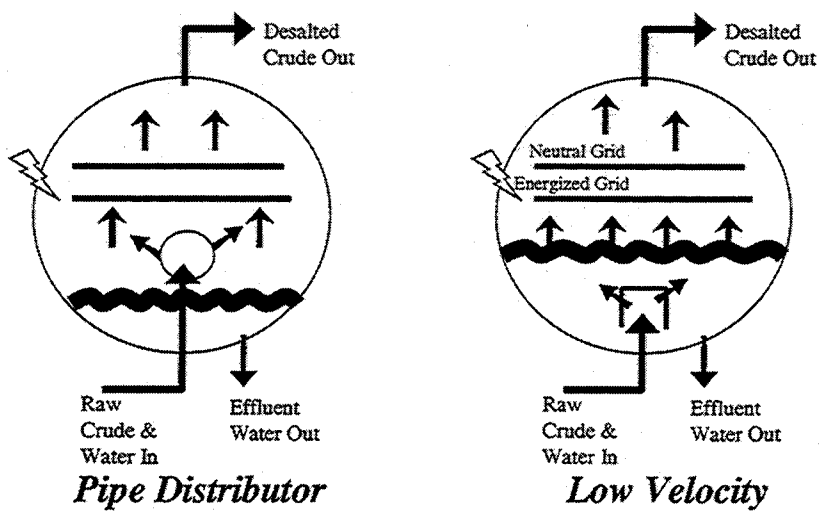
UOP

Desalter Style Schematics - End View



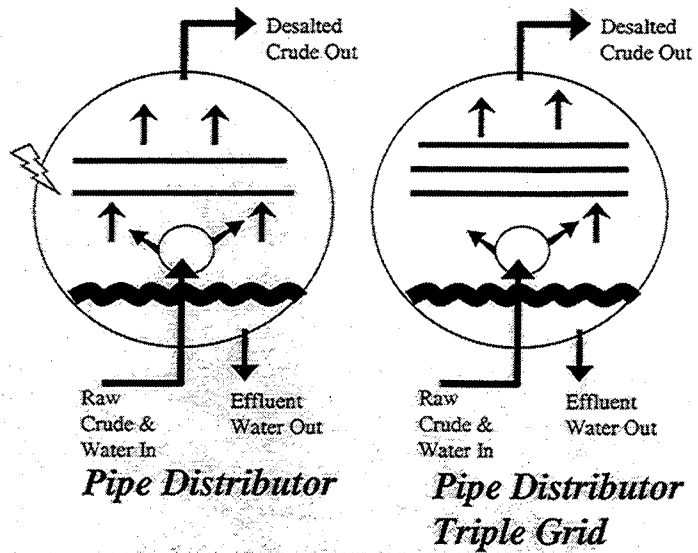
UOP

Desalter Style Schematics - End View



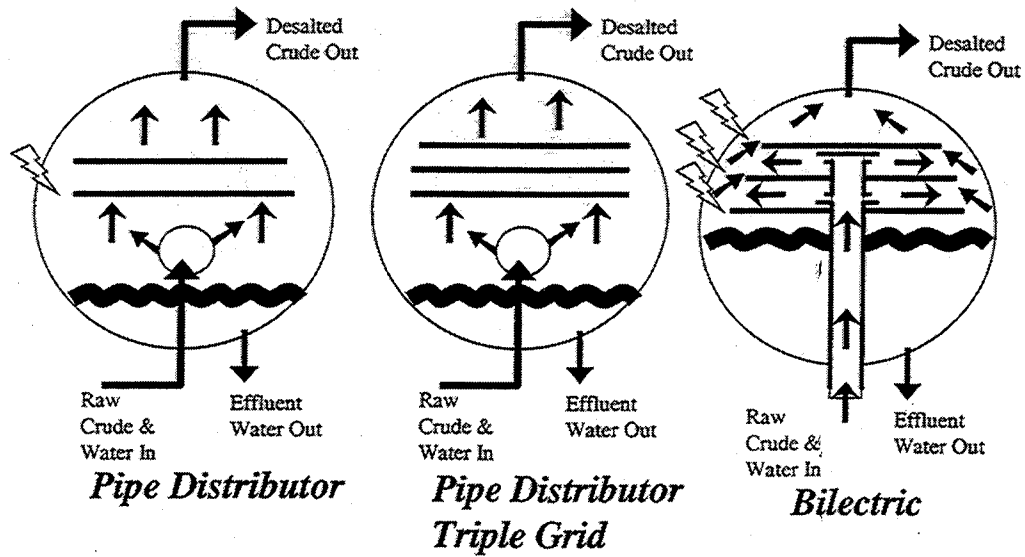
UOP

Desalter Style Schematics - End View



UOP

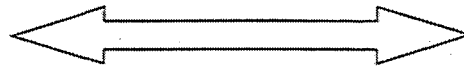
Desalter Style Schematics - End View



UOP

Typical Desalter Operational Variables

Frequently
Varied for
Desalter
Control



Infrequently
Varied for
Desalter
Control

Chemical(s) selection

Chemical addition rate

Chemical addition points

Mix valve pressure
drop/Wash water
injection strategy

Wash water rate

Desalter level control

Wash water quality

Mud-washing
strategy

Desalter temperature

Slop oil addition rates

doesn't impact
too much on desalting
capabilities

Crude type and quality

Crude charge rate

Desalter pressure

Desalter residence time

Desalter design

Equipment limitations

UOP

interfere
level

Desalter pressure always maximise

"Typical**" Single Stage Performance

Raw Crude:

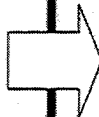
Salt: 50 ptb (pounds / thousand
barrels)

Basic Sediment: 0.1%

Water: 0.2+%

%BS&W: 0.3 %

Filterable solids: 20 ptb



Desalted Crude:

Salt: 5 ptb

Basic Sediment: 0.05%

Water: 0.1+%

%BS&W: 0.15 %

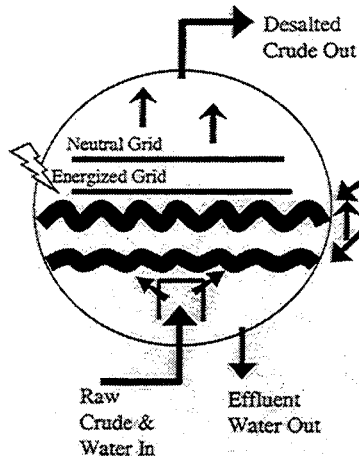
Filterable solids: 10 ptb

Effluent Water: <1000 ppm oil

** Highly Variable

UOP

Optimizing Desalter Level



Maximizing Level:

*Raises water residence significantly:
Improves effluent quality*

Automatically thins rag layer

*Utilizes field between lower grid and
water level*

Too High: Shorts out grid.

UOP

Heavier Crude Operation

Typical Attributes:

*Diminished oil/water gravity
difference*

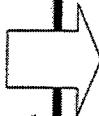
Higher viscosity

Usually less preheat available

Usually higher contaminant levels

More inherent surfactant chemistry

*Lower surface tension, higher
conductivity*



Possible Actions:

*Drop water in tankage/use mixers to smooth
out feed quality*

*Mix difficult crudes with less difficult
crudes*

Reduce slop; don't run blocked out

Raise desalter temp if possible

*Improve wash water quality, drop pH if
possible. Optimize rate.*

Optimize shear

Optimize level

Optimize chemical addition

Design changes

UOP

High Solids Crudes

Typical Attributes:

Solids posses surface wetting properties

Oily effluent water to sewer

Benzene, effluent issues

Thick, stable rag layers particularly with high pH wash water

Generally poorer desalter performance

Possible Actions:

Similar to heavy crude but with emphasis on:

Reduce shear

Maximize water residence time

Also: Optimize mudwash, check for vortexing, check level controls

UOP

Desalting for Other Refinery Applications

- *“Black Oil” services such as vacuum distillation units, visbreaking, delayed coking, residue desulfurization*
- *salt and solids exchanger fouling, overhead corrosion*
- *furnace coking*
- *foaming; silicon antifoam usage*
- *catalyst fouling*
- *sodium poisoning*

UOP

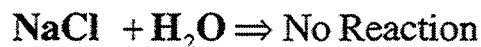
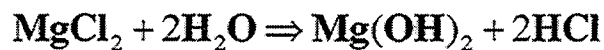
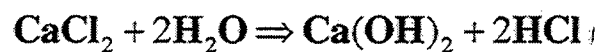
Corrosion Control Overhead System

- Primary corrosion concern is chlorides in Overhead System
- Chloride salts in feed hydrolyze to form Hydrochloric Acid
- Acid must be neutralized to prevent exchanger damage
- Remedies against acid attack are:
 - Desalter / Caustic Injection
 - Overhead Neutralizer / Filmer
 - Water wash / Overhead Temperature Control
 - Metallurgy (monel, duplex steel)

UOP

Chloride Corrosion HCl Evolution

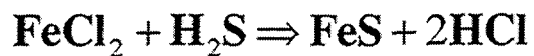
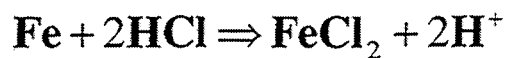
- At high temperatures the following reactions occur:



UOP

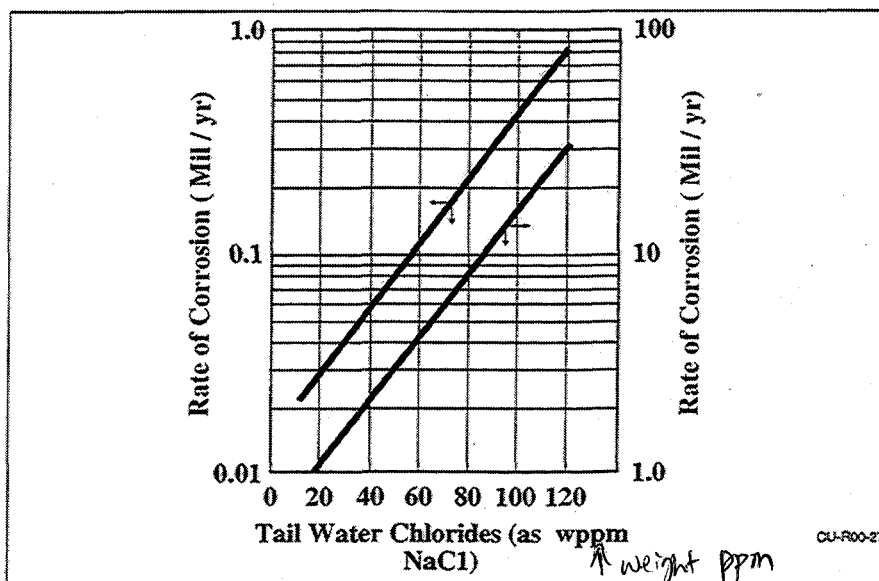
Chloride Corrosion HCl Evolution

- In the overhead system (aqueous phase):



UOP

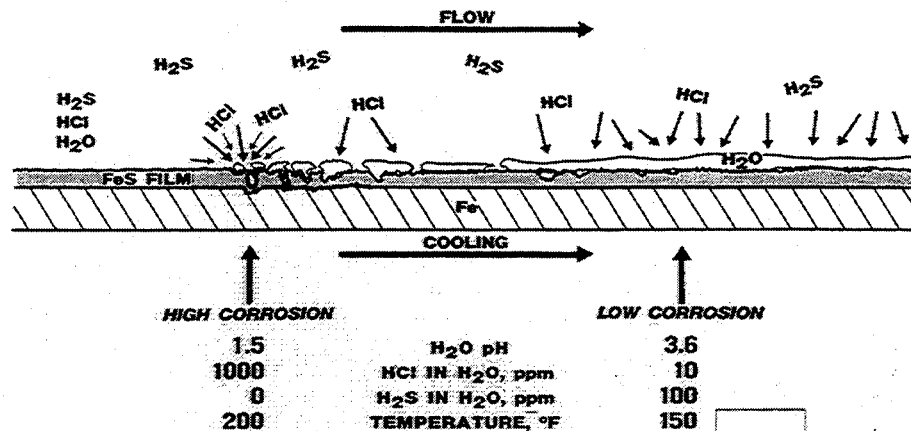
Effect of Chlorides on Corrosion Rate in Crude Unit



UOP

Mechanism of Chloride Corrosion

WATER CONDENSATION IN OVERHEAD PIPE



UOP

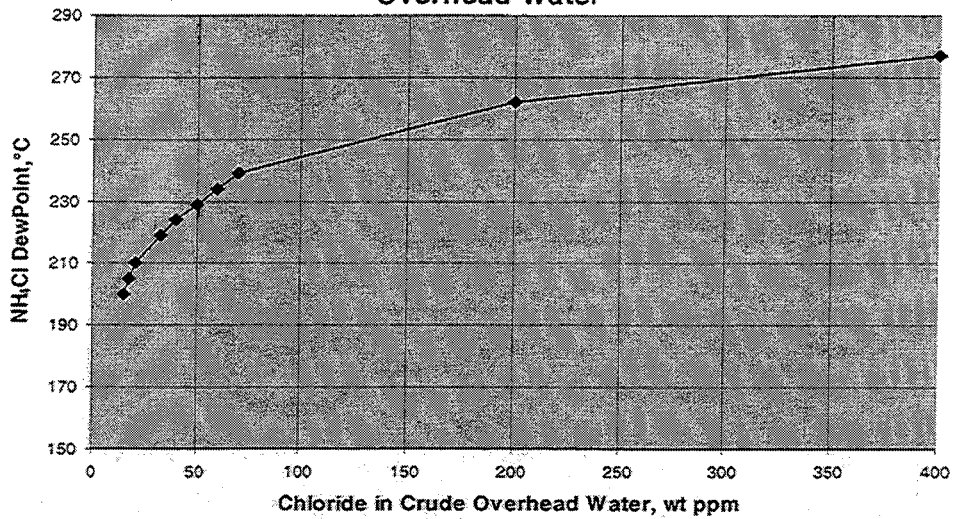
Prevention of Chloride Corrosion

- Remove the salt → Desalting
- Prevent Hydrolysis → Caustic Addition
- Neutralize HCl → Ammonia/Neutralizer
- Protect surfaces → Water Wash/Filmer
- Prevent Condensation → Top Temp/Hot Reflux

UOP

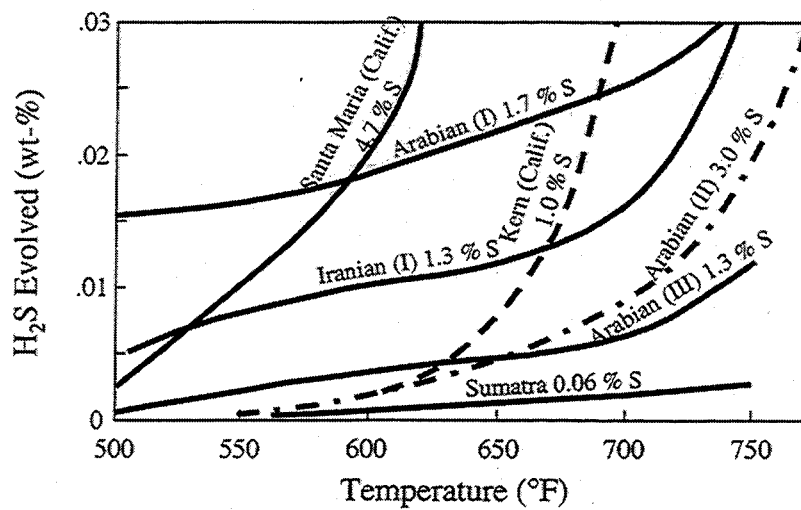
Effect of Chlorides on Corrosion Rate in Crude Unit

NH₄Cl Dew Point vs. Chloride in Crude
Overhead Water



UOP

Hydrogen Sulfide Release from Crude



CU-R00-41

UOP

Corrosion Control in the Feed System

■ Desalter

- Desalter removes feed chlorides through mixing with water
- Even a short desalter upset can cause major overhead damage
- Mixing water upstream of preheat will prevent salt fouling in exchangers
- Preflash required to prevent downstream fouling

■ Caustic Injection

- Prevents chloride hydrolization in the crude furnace
- Not possible in refineries with resid processing

UOP

Corrosion Control Through Overhead Chemical Injection

■ Neutralizer

- Base injected into the overhead system will prevent hydrochloric acid formation
- Ammonia or other amine base typically used
- Target 5.5 to 6.5 overhead pH
- Amine chloride salt precipitation also a corrosion concern

■ Filming amine

- Filmer coats metal to protect from chloride attack
- Can inject some filmers into column or top pumparound

UOP

Corrosion Control - Amine Salt Prevention

■ Water Wash

- Water wash absorbs amine salts, prevents precipitation
- Intent is to create a water phase upstream of exchangers
- Water wash to be distributed to all exchangers and finned bundles

■ Temperature Control

- Keep overhead temperature above amine salt sublimation point
- Keep reflux temperature as high as possible

UOP

Corrosion Control Through Metallurgy

Overhead Chlorides

- Column top trays may require special material
- If corrosion problems persist, exchangers may be changed to more resistant metals

■ Naphthenic Acids

- Naphthenic crudes require special metals in furnace outlet, distillate cuts and bottoms system

■ Sulfur in High Temperature Services

- Above 500°F, special (5% chrome) metallurgy required to prevent sulfur attack

UOP



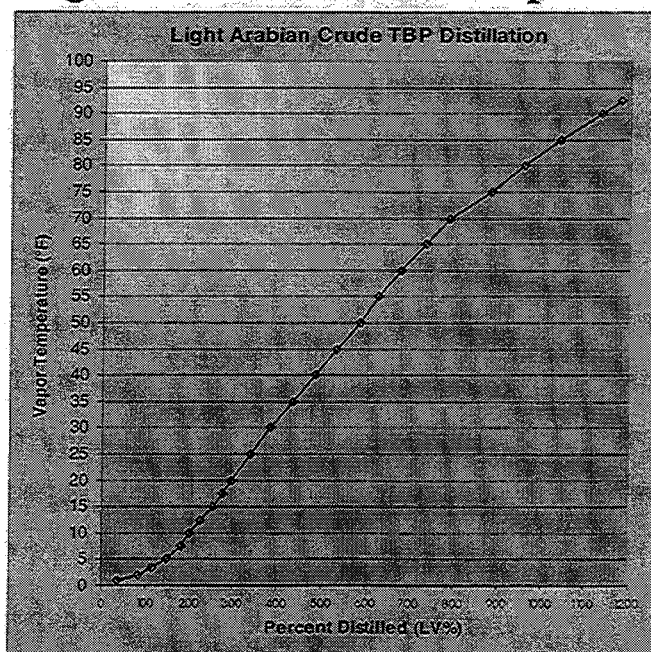
Training Services

Crude Unit Design Example

Plot Pertinent Crude Assay Properties v. Mid-Boiling Points

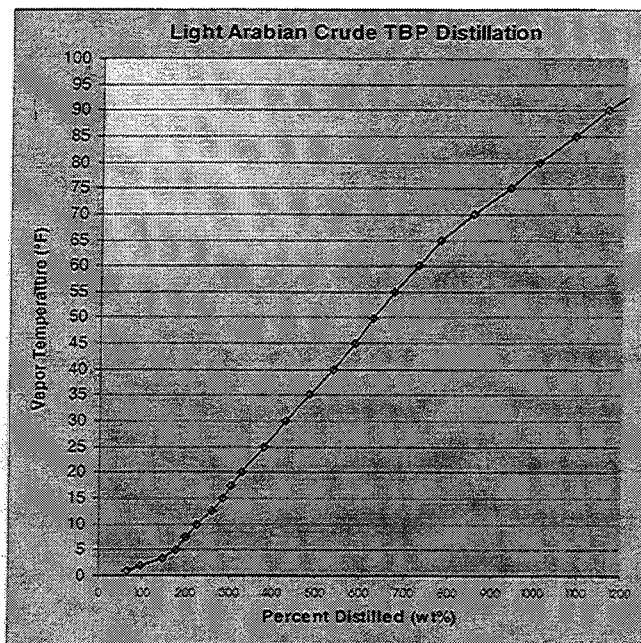
IPD-2004/CU3-1

Light Arabian Crude Properties



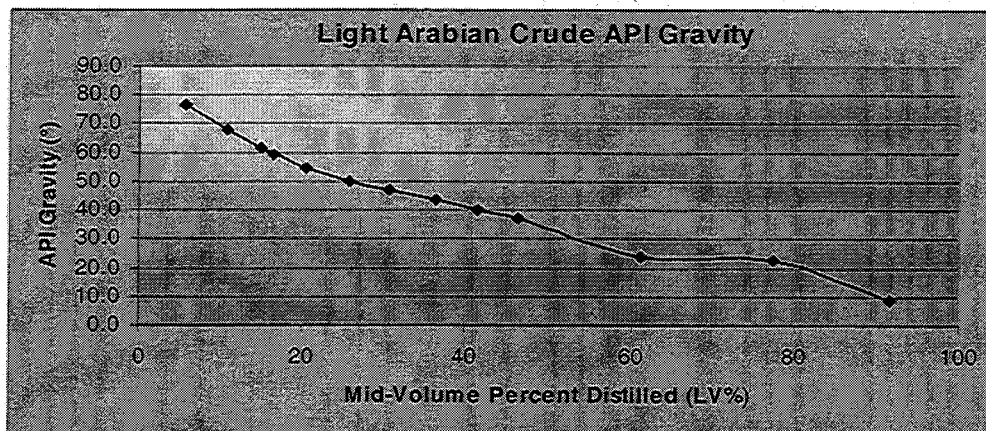
IPD-2004/CU3-2

Light Arabian Crude Properties



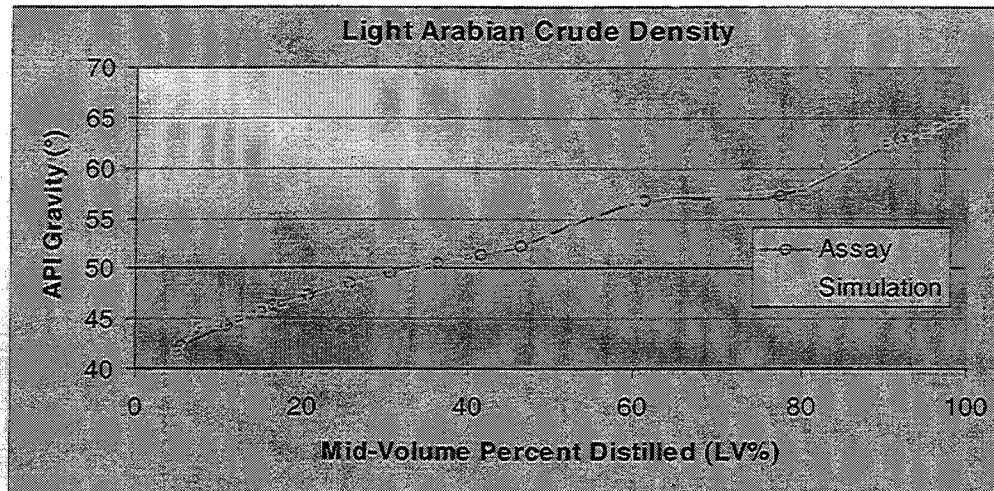
IPD-2004/CUS-3

Light Arabian Crude Properties



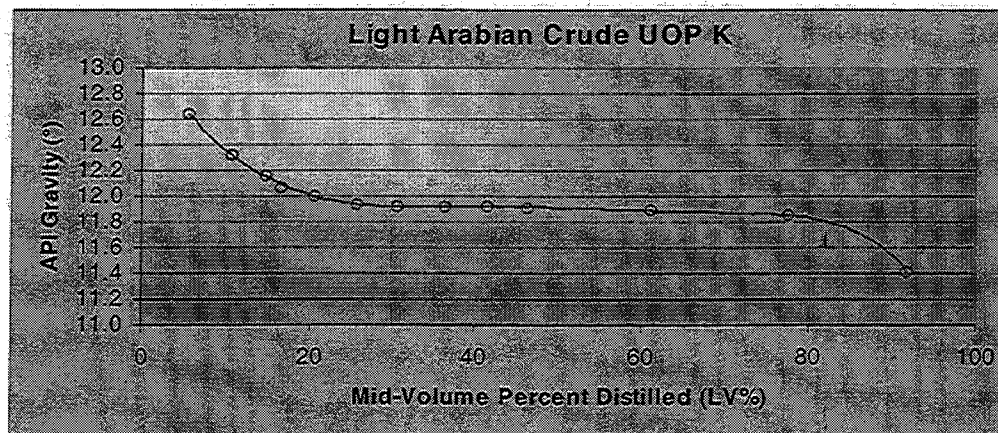
IPD-2004/CUS-4

Light Arabian Crude Properties



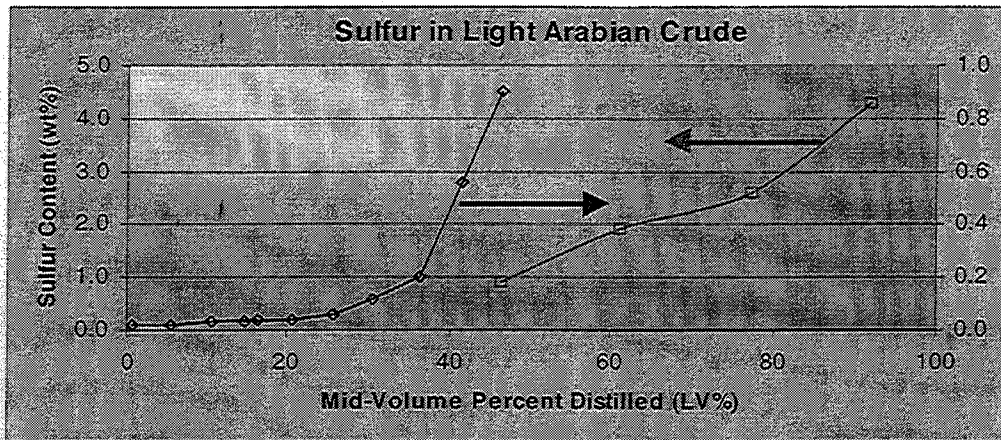
IPD-2004/CUS-5

Light Arabian Crude Properties



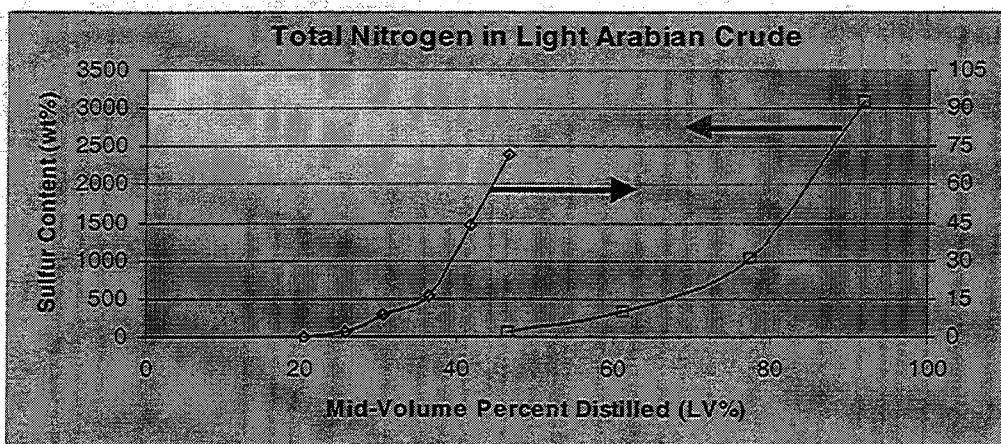
IPD-2004/CUS-6

Light Arabian Crude Properties



IPD-2004/CUS-7

Light Arabian Crude Properties



IPD-2004/CUS-8



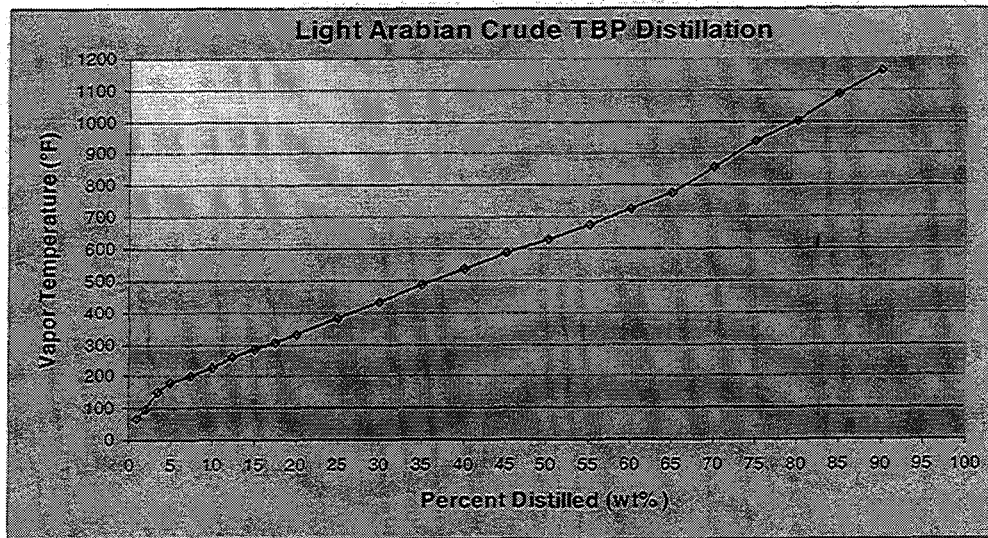
Training Services

Crude Unit Design Example

*Estimate Flash Zone Temperature by API Equilibrium Flash
Vaporization Method*

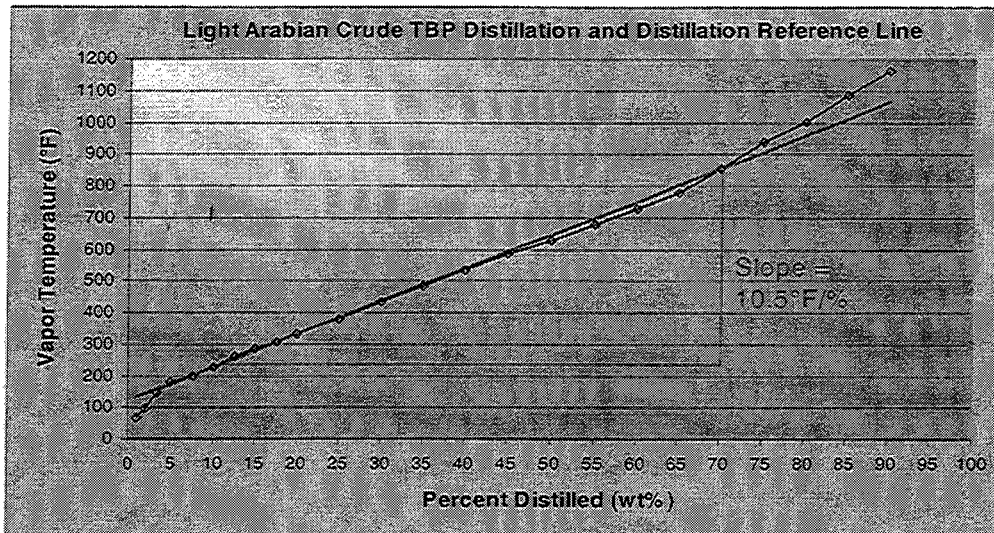
IPD-2004/CU4-1

Construction of Equilibrium Flash Vaporization Curves Plot Crude Assay TBP Curve



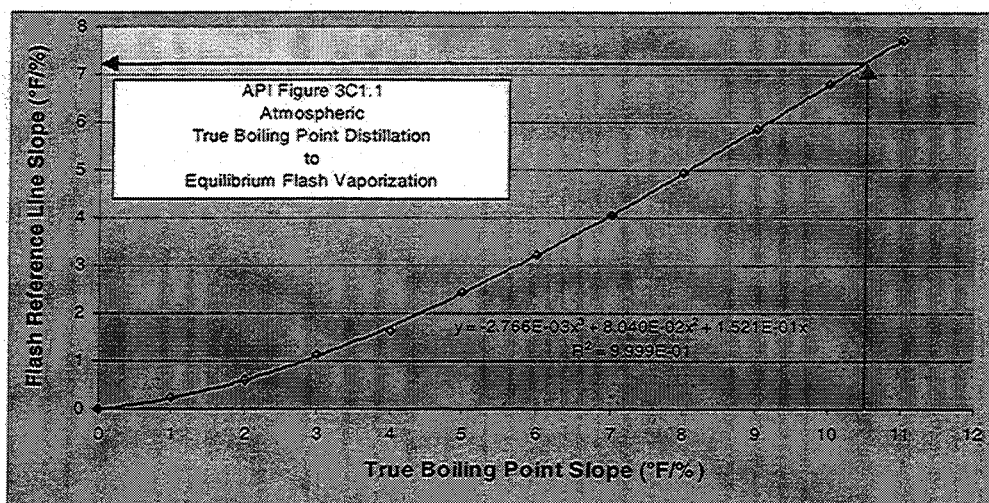
IPD-2004/CU4-2

Construction of Equilibrium Flash Vaporization Curves Plot TBP Distillation Reference Line (DRL)



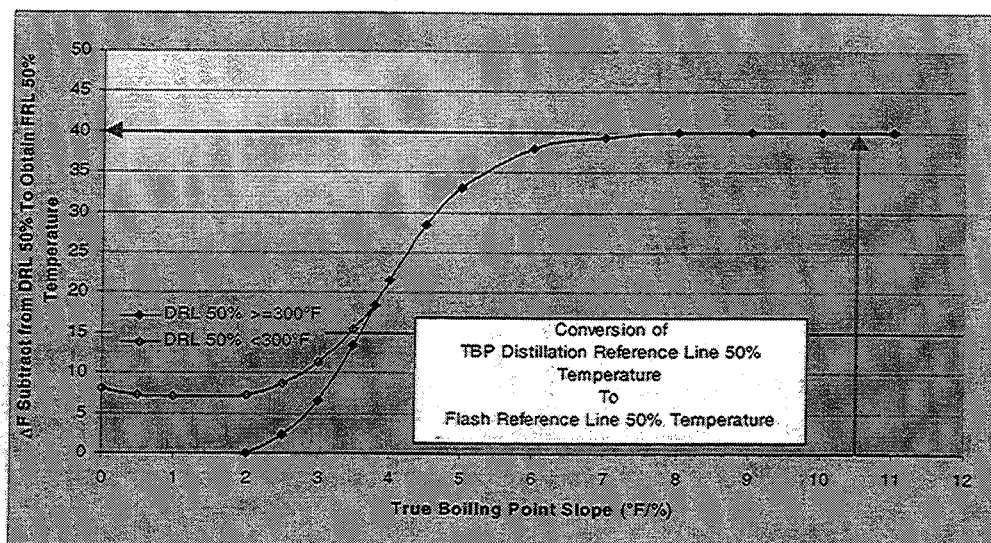
IPD-2004/CU4-3

Construction of Equilibrium Flash Vaporization Curves Determine Flash Reference Line (FRL) Slope



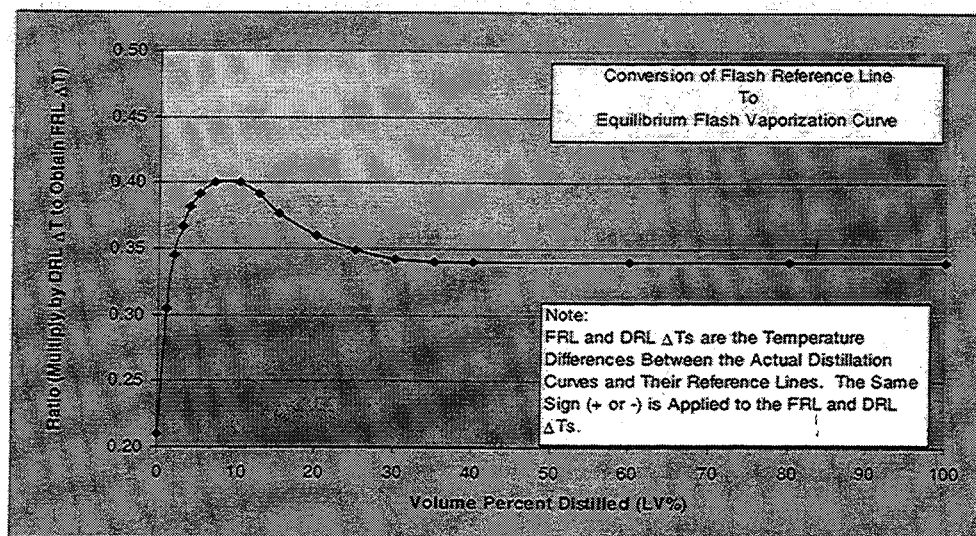
IPD-2004/CU4-4

Construction of Equilibrium Flash Vaporization Curves Determine FRL 50% Point



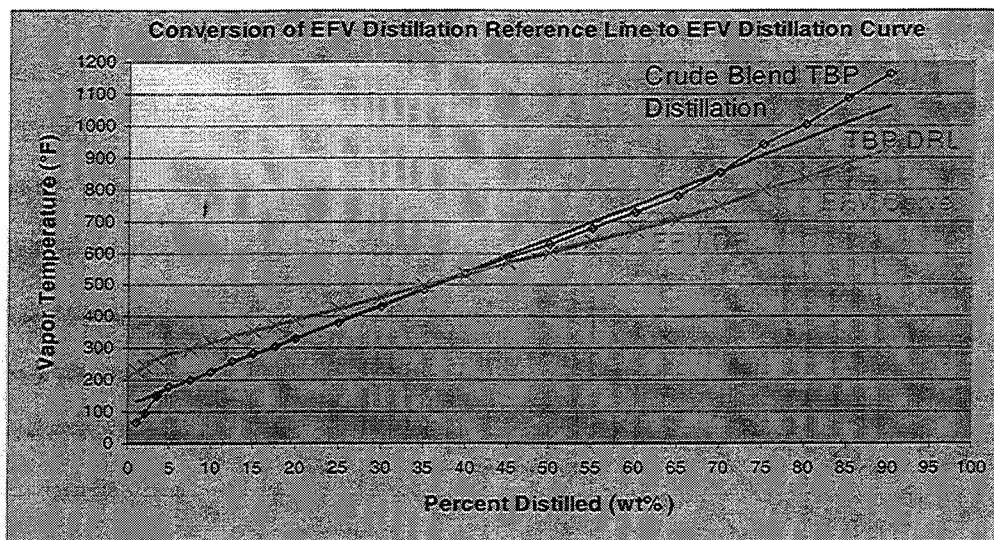
IPD-2004/CU4-5

Construction of Equilibrium Flash Vaporization Curves Conversion of FRL to Equilibrium Flash Vaporization (EFV) Curve



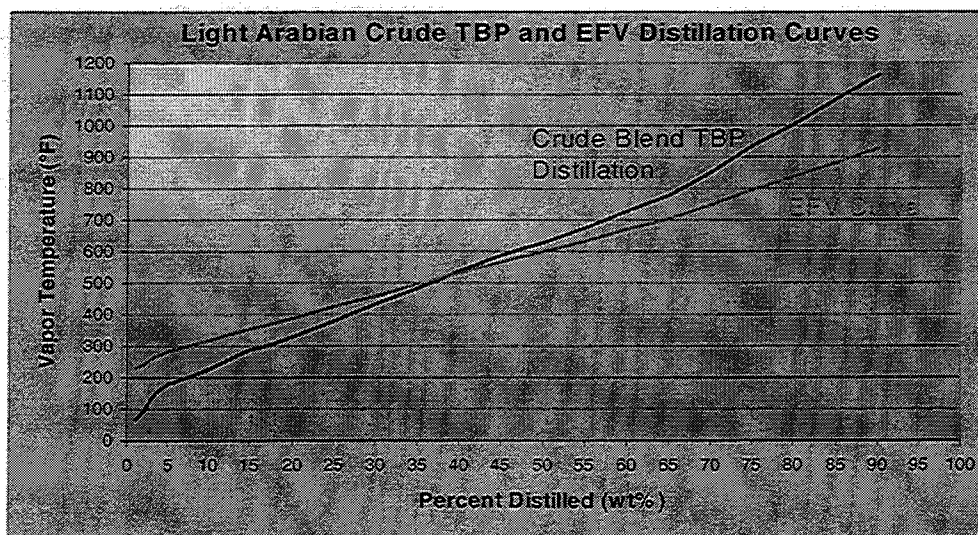
IPD-2004/CU4-6

Construction of Equilibrium Flash Vaporization Curves Construction of EFV Curve



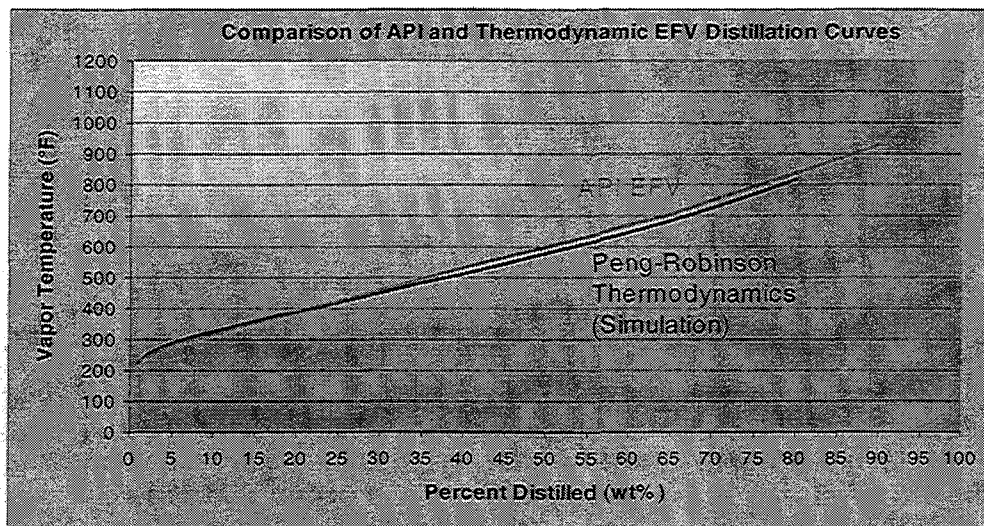
IPD-2004/CU4-7

Construction of Equilibrium Flash Vaporization Curves Comparison of Crude TBP Distillation and EFV Curves



IPD-2004/CU4-8

Construction of Equilibrium Flash Vaporization Curves Comparison of API and Thermodynamic EFV Curves



IPD-2004/CU4-9

LPG Specifications

Country	India	India	India	U.S.	U.S.	U.S.
Product	Commercial Mixed Propane-Butane	Commercial Butane	Commercial Propane	Commercial Mixed Propane-Butane	Commercial Butane	Commercial Propane
Specification						
Vapor Pressure at:						
65°C (kg/cm ² g), Max.	17	10	26			
37.8°C (kg/cm ² g)				6.00 to 14.75	2.50 to 4.90	12.65 to 14.75
Total Sulfur (ppm), Max.	200	200	200	140	140	185
Cu Strip Corrosion, Max.	No. 1	No. 1	No. 1	No. 1	No. 1	No. 1
95 LV% Off Evaporation Temperature (°C) at 760mmHg, Max.	2	2	-38	2	2	-38
Residual Matter (lv%), Max.				5	5	5
Typical C4 and Heavier (lv%), Max.						2.5
Typical C5 and Heavier (lv%), Max.				2.0	2.0	

CRUDE ASSAY

Table A-I
34.5API Arabian Crude Oil - Crude and Residual Properties

	Crude	400°F (204°C)	600°F (315°C)	800°F (427°C)	1000°F (538°C)
Yield from Crude, Vol. %	100	68.6	48.4	29.2	16.0
Yield Range from Crude, Vol. %	0.0-100.0	31.4-100.0	51.6-100.0	70.8-100.0	84.0-100.0
Gravity, API	34.5	24.7	19.4	13.6	8.5
Specific Gravity at 60°F	0.8524	0.9059	0.9377	0.9752	1.017
Sulfur, Wt. %	1.7	2.3	2.9	3.7	4.3
H ₂ S, ppm	2				
Nitrogen, Wt. %	0.08	0.11	0.15	0.23	0.31
Wax, Holde, Wt. %	2.8	3.8	5.2		
Pour Point, °F	-15	+10	+40	+50	+80
Pour Point, °C ¹	-26	-12	+4	+10	+27
Fluidity, °F		-15	+20	+35	+80
Fluidity, °C ¹		-26	-7	+2	+16
Viscosity, cs at 100°F	5.5	28.5	155	2200	
Viscosity, cs at 130°F	4.0	16.5	70	700	14,000
Viscosity, cs at 210°F		5.5	14.5	65	470
UOP K		11.85	11.72	11.55	11.42
Total Acid No., mg KOH/g	0.08				
Saponification No., mg KOH/g	0.34				
Dielectric Constant ²	2.2				
Ramsbottom Carbon, Wt. %	2.6	3.7	5.6	8.7	12.1
Conradson Carbon, Wt. %	3.1	4.4	6.7	10.5	14.5
Ash, ASTM, Wt. %	0.01	0.01	0.02	0.03	0.05
Metals					
Vanadium					66
Nickel					24
Sodium					24
Iron					7
Copper					1.1
Chromium					0.5
Flash, Cleveland Open Cup, °F		230	395	525	610
Flash, Cleveland Open Cup, °C ¹		110	202	274	321
Vapor Pressure, psi Reid	3.5				
ASTM Dist. D 86, °F					
St	115				
10%	220				
20%	302				
30%	395				
40%	477				
50%	558				

¹ Converted from observed, °F.

² Specific inductive capacitance at 23°C (77°F), ASTM D 924

To get 60-200 range
use Yield from Crude (Vol %)

$$\frac{4.8}{8.1} \times 2.1 = 1.244$$

Table A-II

34.5 API Arabian Crude Oil
Light Hydrocarbon Analysis
(Sulfur Free Basis)

TBP Temperature Range, °F TBP Temperature Range, °C		St-60 St-16		60-160 16-71	
Yield from Crude, Vol. %		1.5		4.8	
Yield Range from Crude, Vol. %		0.0-1.5		1.5-6.3	
Light Hydrocarbons, Vol. %	Total In Crude	In Cut	In Crude	In Cut	In Crude
Propane	0.17	11.3	0.17		
Isobutane	0.17	11.4	0.17		
Normal Butane	1.06	64.0	0.96	2.1	0.10
	3.67				
Cyclopentane	0.07	1.3	0.02	1.0	0.05
Isopentane	0.73	8.0	0.12	12.7	0.61
Normal Pentane	1.47	4.0	0.06	29.4	1.41
2-Methylpentane	0.62			12.9	0.62
3-Methylpentane	0.42			8.7	0.42
2,2-Dimethylbutane	0.01			0.2	0.01
2,3-Dimethylbutane	0.06			1.3	0.06
Normal Hexane	1.44			23.8	1.14
Methylcyclopentane	0.22			3.3	0.16
Cyclohexane	0.16			1.5	0.07
Benzene	0.07			0.8	0.04
C ₇ 's and Heavier	93.33			2.3	0.11
Totals	100.00	100.0	1.50	100.0	4.80

60-200

In Cut

1.244

0.593

user curves for total sulfur used plot in Example 1

Table A-III

**34.5 API Arabian Crude Oil
Gasolines and Naphthas**

TBP Temperature Range, °F TBF Temperature Range, °C	St-60 St-16	60-200 16-93	60-300 16-149	60-400 16-204	200-300 93-149	200-400 93-204	300-400 149-204
Yield from Crude Vol % Yield Range from Crude Vol %	1.50 0.0-1.5	8.10 1.5-9.6	18.50 1.5-20.0	29.90 1.5-31.4	10.00 9.6-20.0	21.80 9.6-31.4	11.40 20.0-31.4
Mid Volume % Gravity API Specific Gravity at 60°F		5.60 76.90 0.6693	10.80 67.80 0.7100	16.50 59.00 0.7428	14.80 61.30 0.7339	20.50 54.50 0.7608	25.70 50.20 0.7788
Sulfur Weight % Hydrogen Sulfide ppm Mercaptan Sulfur ppm Doctor Test Corrosion Copper Strip Test		0.02 <5 200 Positive Negative	0.03 <5 180 Positive Negative	0.04 <5 160 Positive Negative	0.03 <5 160 Positive Negative	0.04 <5 150 Positive Negative	0.06 <5 130 Positive Negative
Octanes: F-1 Clear F-1 + 1ml TEL/Gal F-1 + 3ml TEL/Gal F-2 Clear F-2 + 1ml TEL/Gal F-2 + 3ml TEL/Gal		58.00 69.50 79.70 56.70 69.20 79.30	45.30 59.00 70.00 44.30 58.30 69.50	36.10 50.50 62.80 36.20 50.10 62.30	38.30 52.50 64.60 38.10 52.00 64.10	29.50 44.10 57.50 31.50 45.00 57.50	19.50 34.80 49.00 25.00 38.80 51.70
Paraffins Volume % Naphthenes Volume % Aromatics Volume %		87.00 10.00 3.00	75.00 19.00 6.00	67.00 20.00 13.00	70.00 19.00 11.00	65.00 19.00 16.00	61.00 20.00 19.00
Vapor Pressure psi Reid		8.90	4.40	3.50	1.50	1.00	0.50
ASTM Distillation, D 86 °F St 10% 20% 30% 50% 70% 80% 90% End Point		90 112 122 132 148 164 174 184 198	120 152 168 184 211 238 253 272 293	140 185 207 227 263 302 324 351 385	212 224 231 237 250 265 273 283 295	227 249 263 275 299 327 343 362 387	308 318 325 330 343 357 365 377 389
UOP K (From API & Distillation Data)		12.64	12.32	12.07	12.16	12.00	11.94

Table A-IV

**34.5 API Arabian Crude Oil
Kerosines and Gas Oils**

TBP Temperature Range °F TBF Temperature Range °C	300-400 143-204	300-500 149-260	300-600 149-316	400-500 204-260	400-600 204-316	500-600 260-316	600-800 316-427	800-1000 427-553	
Yield from Crude Vol % Yield Range from Crude Vol %	11.40 20.0-31.4	21.20 20.0-41.2	31.60 20.0-51.6	9.80 31.4-41.2	20.20 31.4-51.6	10.40 41.2-51.6	19.20 51.6-70.8	13.20 70.8-84.0	9.50 24.0-33.5
Mid Volume % Gravity API Specific Gravity at 60°F	25.20 50.20 0.7733	30.60 46.80 0.7935	35.80 43.60 0.8061	36.30 43.30 0.8095	41.50 40.30 0.8236	46.40 37.30 0.8383	61.20 23.80 0.8327	77.40 22.70 0.9175	13.80 0.9736
Sulfur Weight % Hydrogen Sulfide ppm Mercaptan Sulfur ppm Nitrogen ppm	0.06 <5 130 2	0.12 115 9	0.39 100 30	0.20 100 16	0.56 90 44	0.90 80 72	1.90 350	2.60 1050	2700
Viscosity: cs at 0°F cs at 100°F cs at 130°F cs at 210°F	2.30 0.97 0.75 0.57	3.60 1.28 0.93 0.64	5.27 1.75 1.23 0.77	5.35 1.77 1.30 0.78	12.00 2.60 1.88 1.00	3.60 2.57 1.25	10.90 7.30 2.68	112.00 40.00 9.80	95.00
Pour Point °F/°C* IP Cold Test °F/°C* Cloud Point °F/°C* Smoke Point mm ASTM/IP Smoke Tendency Lamp mm Naphthalenes (PNA)Vol % Luminosity Number Small Burner Coke ppm Color Saybolt	B-60/6-62 B-60/6-62 26/28 47 0.70 57 1 27	-65/-54 -50/-46 25/27 40 1.60 51 1 24	-30/-34 -17/-27 24/26 3.60 20 7	-40/-40 -26/-32 23/24 38 2.50 46 1 21	-10/-23 +5/-15 +5/-15 20/21 5.00 50 70	+10/-12 +10/-12 17/18 7.50 36 400 Below -16	+65/+22 +65/+22	+110/-57 +105/-41	
Color Stability 16 hrs at 212°F	21	19		16					
Corrosion Cu Strip at 210°F	Negative	Negative	Negative	Negative	Negative	Negative			
Aniline Point °F/°C*	133/56	142/61	143/64	151/65	156/65	161/72	171/77	182/83	
Cetane Number Determined	44	43	51	53	55	57			
Diesel Index	67	66	64	65	63	60	49	41	
Characterization Factor	11.97	11.96	11.97	11.97	11.93	11.97	11.87	12.03	
UOP K:									
(From API & Viscosity Data)	11.85	11.88	11.90	11.90	11.98	11.92	11.80	11.85	
(From API & Distillation Data)	11.94	11.92	11.92	11.92	11.92	11.91	11.89	12.05	

**Table A-IV
(continued)**

**34.5 API Arabian Crude Oil
Kerosines and Gas Oils**

TBP Temperature Range °F	300-400	300-500	300-600	400-500	400-600	500-600	600-800	800-1000	
TBP Temperature Range °C	143-204	149-260	149-316	204-260	204-316	260-316	316-427	427-553	
Paraffins Volume %	61	56	50	59	44	40	34	26	
Naphthenes Volume %	20	23	27	28	32	38	51	54	
Aromatics Volume %	19	21	23	23	24	22	15	20	
Flash Pensky Martens °F/°C*	108/42	116/47	127/53	179/82	190/88	250/121			
Flash Closed Tag °F/°C*	110/43	122/50	134/57	182/83	195/91	252/122			
ASTM Distillation °F	D86	D86	D86	D86	D86	D86	D1160	D1160	
Start	308	318	328	402	415	493	616	814	
10%	318	337	357	412	435	508	627	824	
20%	325	350	377	420	450	515	639	851	
30%	330	350	393	426	460	521	653	885	
50%	343	383	430	437	487	534	692	928	
70%	357	413	477	451	517	549	732	950	
80%	365	430	502	460	532	555	754	973	
90%	377	452	536	470	552	556	776	1000	
End Point	389	480	573	483	576	578	800		

*Converted from Observed °F

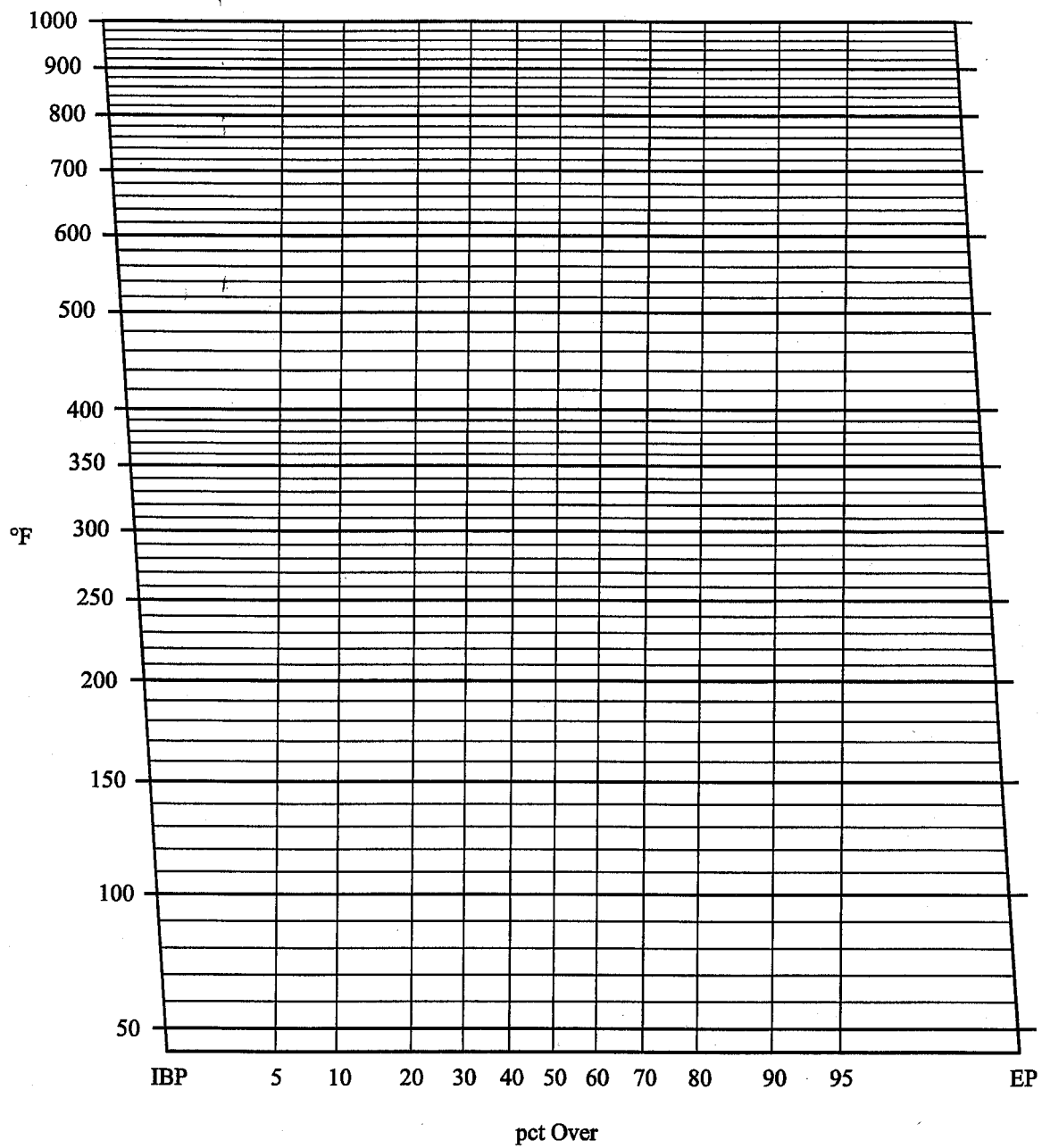
Table A-V

**34.5 API Arabian Crude Oil
Yields in Volume Per Cent Distilled
Versus True Boiling Temperature (Fahrenheit)**

True Temperature °F	0	10	20	30	40	50	60	70	80	90
							1.5	1.8	2.1	2.4
100	2.8	3.2	3.7	4.3	4.9	5.6	6.3	7.1	7.9	8.7
200	9.6	10.5	11.5	12.5	13.5	14.5	15.6	16.7	17.8	18.9
300	20.0	21.1	22.3	23.5	24.7	25.9	27.0	28.1	29.2	30.3
400	31.4	32.4	33.5	34.5	35.5	36.5	37.5	38.4	39.3	40.3
500	41.2	42.2	43.1	44.1	45.2	46.2	47.2	48.3	49.4	50.5
600	51.6	52.7	53.8	54.9	56.0	57.0	58.0	59.0	60.0	61.0
700	61.9	62.9	63.8	64.7	65.6	66.5	67.4	68.2	69.1	70.0
800	70.8	71.7	72.5	73.2	74.0	74.8	75.5	76.2	76.9	77.6
900	78.2	78.9	79.5	80.1	80.7	81.3	81.8	82.4	82.9	83.4
1000	84.0									

**Yields in Weight Per Cent Distilled
Versus True Boiling Temperature (Centigrade)**

True Temperature °C	0	10	20	30	40	50	60	70	80	90
			1.3	1.7	2.3	2.9	3.7	4.7	5.9	7.1
100	8.3	9.8	11.4	13.0	14.7	16.5	18.4	20.4	22.3	24.2
200	26.0	27.7	29.5	31.3	33.0	34.6	36.2	37.9	39.6	41.5
300	43.5	45.4	47.4	49.4	51.3	53.2	54.0	56.8	58.6	60.4
400	62.0	63.7	65.3	66.9	68.5	69.9	71.4	72.8	74.1	75.4
500	76.7	77.9	79.0	80.1	81.2					



EDS-R00-0817.

Crude Fractionation Tray Specification

Use the following number of trays which is representative of crude unit designs:

	Actual Trays	Theoretical Trays
Top to Kerosene Draw Tray	10	7
Kerosene to Diesel Draw Tray	8	5
Diesel to AGO Draw Tray	6	4
AGO to Flash Zone	6	3
Flash Zone to Bottoms	6	2
Pumparounds	3	2

Estimating separation efficiency

Part 1—Introduction

Part 2—Plate columns

Part 3—Packed columns

T. J. Vital,* S. S. Grossel and P. I. Olsen, Hoffmann-La Roche, Inc., Nutley, N.J.

EMPIRICAL AND theoretical methods are suggested for estimating plate efficiencies. Also, an extensive array of efficiency data is included for comparative purposes. Both the suggested methods and the data are the results of an extensive review of the literature and a summary of the findings pertaining to plate columns is appended.

Based upon published empirical validations, the O'Connell method of 1946 and the MacFarland, Sigmund and VanWinkle method of 1972 were selected as the preferred empirical relationships. The AIChE method of 1958 is the preferred theoretical procedure.

The recommended procedure is as follows:

- Estimate plate efficiency by three methods—O'Connell Method; MacFarland, Sigmund, VanWinkle Method and the American Institute of Chemical Engineers' Method.
- Deduct an error band from the estimated values for a safety margin.
- Compare the resulting values with literature values for the same or similar systems (Table 1).
- Select the most conservative calculated efficiency or the efficiency closest to the experimental literature values.

Careful comparison of various published methods indicates this recommended procedure includes relationships

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TABLE 1—Survey of tray efficiencies

System	Col. dia., m	Press., kPa	Temp., °K	Weir height, m	Tray efficiency, %			Remarks	Ref.
					E_{OG}	E_{mv}	E_o		
Bubble-cap									
Ethanol/Water	0.46				98				35
	—				70		95		36, 37
	0.11				64.6				38
	0.46	101			80–90	90–130		with splash baffle	39
	—				95				40
	—			81				± 11%	41
	0.48			0.81	85			± 5%	42
	0.15				99.8			Carey (1934)	43
	0.196	101			80				44
	0.11				64.6				38
Methylcyclohexane/toluene									
Air/water	1.52		290				83		45
Carbon dioxide/water	0.076				80		125	no mixing	46
	—						100	50% mixing	
Acetic acid/water	0.46	101			65				47
	0.59	58			54			± 5%	48
Deuterium/hydrogen	0.027		20		50		44	± 3%	49
Oxygen/nitrogen	—						76	± 9%	49
Acetone/water	5.49				91				47
	—				83			± 2%	50
Ethylene dichloride/toluene	—			0.032		95			40
Sugar/water	1.52					80			51
CHCl ₃ /CCl ₄	—				90			± 5%	52
Ammonia/water	0.305	101	283			77			53
Methanol/water	1.0					90			54
	—					70			55

Continued

TABLE 1—Survey of tray efficiencies, continued

System	Col. dia., m	Press., kPa	Temp., °K	Weir height, m	Tray efficiency, %			Remarks	Ref.
					E_{OG}	E_{mv}	E_o		
Bubble-cap, cont.									
Acetone/benzene	—				79			± 1%	50
Methanol/isopropanol/ water	0.45				68	68			55
	—				70				
	—				68				
Acetone/methanol/water	0.45				60				55
	—				60				
	—				80				
Gasoline stabilizers	1.44	1,820			75	100		Brown (1936)	43
Benzene/toluene	0.2					60		Lewis (1930)	43
	0.2					70		Carey (1934)	43
	0.15					58		Carey (1934)	43
Aniline/water	0.2					58		Carey (1934)	43
Naphtha/water	2.74					65		Lewis (1928)	43
Isopropanol/water	0.45					78			55
Methanol/isopropanol	0.45					64			55
Acetone/methanol	0.45					61			55
Benzene/toluene/xylene	0.2					75		Lewis (1930)	43
Naphtha/pinene/aniline	0.2					90		Lewis (1930)	43
Sieve									
Ethanol/Water	0.076	101			45.5				56
	0.127					85			57
	0.196	101				90			44
	—					71.4		CA-100455C (1970)	91
	Lab						120	Brown (1936)	43
Methylethylketone/Water	0.08				41				56
Acetone/water	0.05	101			25.5				56
	0.11				43.5			± 11.5%	58
	0.15		373			80			59
Benzene/water	0.05	101			9.6				56
Toluene/water	0.05	101			7.1				56
n-Heptane/ methylcyclohexane	0.04					77.6		± 2.07%	60, 61
n-Heptane/cyclohexane	1.2	165		0.05			85		62
	2.44	165		0.05			75		62
	1.2	164		0.05		90		60% flood	63
Toluene/ methylcyclohexane	0.15	101					54.6	± 15%	64
	—	27					55.5	± 5%	64
Methylcyclohexane/ toluene	0.05	101					91		65
	—					88			66
Propane/butane	—						100	± 5%	67
Carbon dioxide/water	0.08					80	125	no mixing	3
	—						100	50% mixing	
	0.15	111	298			89.7			34
n-Octane/toluene	0.15	101		0.025			38		7
Air/water/ammonia	0.08		298	0.08	85.7	96.4		± 0.1	22
	—			0.03	70				51
	—					65	50		32
Oxygen/water/ammonia	0.15					75		± 7%	59
Ammonia/water	0.3	101	283			89			68
Methylisobutylketone/ water	0.08		298	0.08	41.5	64		± 1.7	22
Ethylene dichloride/ toluene	0.05	101					75		65
Methylethylketone/toluene	0.15			0.05			88		69
Air/ethanol	—			0.1	80			± 20%	51
Air/propanol	—			0.03	77			± 5%	51
Methanol/CCl ₄	0.11				25.7			± 0.8	58
Methanol/water	0.11				56			± 13%	58
	—				79.2				70
	1.0					93			54
	—					90		CA-100455C (1970)	91
Acetone/CCl ₄	0.11				50			± 9%	58
Isopropanol/water	—						72.9	CA-100455C (1970)	91
Benzene/toluene	0.127					75			57
	—				76.5			± 7.1%	70
	10.7	101	353	0.08		80.5		1 pass	71
	—					80.5		2 pass	
	—			0.14		85.2		4 pass	
Benzene/methanol	0.18	690		0.05	86.4	94.2	85		72
Cyclohexane/toluene	2.4	103					70		62
Ethylbenzene/styrene	—	13							33
	0.5	13		0.038		75			73

Continued

TABLE 1—Survey of tray efficiencies, continued

System	Col. dia., m	Press., kPa	Temp., °K	Weir height, m	Tray efficiency, %			Remarks	Ref.
					E_{OG}	E_{mv}	E_o		
Sieve, cont.									
Helium/ methylisobutylketone	—			0.038	90		± 5%		52
Nitrogen/isobutanol	—			80					52
Nitrogen/cyclohexanol	—			0.051	70		± 20%		52
Acetic acid/water	0.46	101				75			74
Benzene/propanol	0.46					58.6	96.6% flood		75
Cyclohexane/n-heptane/ toluene	0.038				78				76
	—				110				
	—				93				
n-Heptane/toluene	—			0.02		45			77
	—					62			74
n-Heptane/benzene	—			0.02		55			77
	—					68			74
CCl ₄ /benzene	0.032						71	no vapor pulsing	78
	—						73	vapor pulsing	
Isobutane/n-butane	—	2,068				110			63
Ethanol/water/furfural	—					80		CA-165714Y (1980)	91
n-Hexane/ethanol/ methylcyclopentane	0.1	101	333		70		+ 0.9		39, 79
	—				70.3		- 2.5		
	—				71		- 4.4		
n-Hexane/ethanol/ methylcyclopentane/ benzene	0.1	101	333		55		+ 14.3		39, 79
	—				60		- 1.5		
	—				6		- 1.9		
Benzene/n-propanol	0.46	101	366	0.08		54		± 5%, 60% flood	16
	0.03	101	366			57		± 5%, 60% flood	16
Toluene/n-propanol	0.46	101	366	0.08		61		± 5%, 60% flood	16
	0.03	101	366			57		± 8%, 60% flood	16
Beer/water	Comm.						120	Brown (1936)	43
Air/water triethyleneglycol	—	101	297	0.05		62			80
APV-West									
Methanol/water	1.0					81			54
Kascade									
Ethanol/water	0.2					54.1			38
	0.2						70		67
Methylcyclohexane/toluene	0.2					44.6			38
							72		67
Oxygen/water	0.2					84			67
Tunnel									
Furfural/isobutane & butylene	4.0	593	318			25		± 4%, ΔP = 12.5	81
Furfural/n-butane & butylene	4.0	593	318			25		± 7%, ΔP = 12.5	81
Turbogrid									
Ammonia/water	0.3	101	283			75			53
Ethanol/water	—	0.24				85			82
	—	101					85	± 11%	23
Methanol/water	—					87		± 2%	70
	0.1	101	298			95		± 3.9%	83
	Small					86			84
Methanol/isopropanol/ water	0.15					66.4			85
Methanol/isopropanol	Small					65			84
V-Grid									
Air/water/ammonia	—					70	60		32
Combination valve-sieve									
Benzene/propanol	0.46				32				86
Ethylenebenzene/styrene	—	13					80		33
Wyatt Perfavalve									
Propanol/toluene	0.46					76.7		74.7% flood	75
Propanol/benzene	0.46					55.5		44.4% flood	75
Valve									
Benzene/toluene/xylene	2.43					69		± 3%	86
Ethanol/water	0.032						70		87
	0.06					56		CA-107562W (1975)	91
n-Propanol/benzene	0.46					73		± 5%, 60% flood	16
n-Propanol/toluene	0.46					51		± 5%, 60% flood	16
Ethylbenzene/styrene	0.5	13				85			73
Benzene/C ₈ aromatics	2.43				44		88	top	88
					66			bottom	

Continued

TABLE 1—Survey of tray efficiencies, continued

System	Col. dia., m	Press., kPa	Temp., °K	Weir height, m	Tray efficiency, %			Remarks	Ref.
					E_{OG}	E_{mv}	E_o		
Round valve									
Ethanol/water	0.196	101			92				44
L-Type valve									
Ethanol/water	0.196	101			68				44
Nutter valve									
C_6/C_7	—	165					96	float valve	14
iC_4/nC_4		1,131					121	float valve	14
Propanol/benzene	0.5				63.8			29.6% flood	75
Propanol/toluene	0.5		303		75.3				75
Cyclohexane/heptane	1.2						96	20% flood	75
Koch valve									
Cyclohexane/heptane	1.2						93.8	50% flood	75
Benzene/toluene/xylene	2.43	92	346	0.08	48		88		89
Glitsch									
n-Butane/isobutane	1.3	1,138		0.05			122	V-1 Ballast	15
Cyclohexane/n-heptane	1.3	165		0.05	99.5			V-1 Ballast	15
	1.2						97	21% flood, Valve	75
Methanol/water	0.1	101						High A-1 Ballast CA-31366g (1967)	91
	—			0.05	88			± 2%, Valve (downcomers)	70
Ripple									
Methanol/water	1.0				73				54
Ammonia/water	0.3	101			82				53
Light gasoline	2.0						48	CA-68739C (1968)	91
Uniflex									
Methanol/water	1.0				87				54
Baffle									
Toluene/methylcyclohexane	—	101			87				90
Angle									
Methanol/water	—	101					70	CA-18097g (1972)	91
Crossflow plate									
Benzene/toluene	—				60				42
Ethanol/water	—				70				42
Jet									
Air/water/ triethyleneglycol	—	101	297	0.05	65				80
Methylethylketone/toluene	0.15			0.03			93		69

that have been widely used and tested. The results are reasonable for a variety of tray types, e.g., sieve, valve and bubble-cap trays.^{5,7,8,18-22,34}

O'Connell Method (1946). The O'Connell correlations can be readily applied to hydrocarbon and nonhydrocarbon systems, fractionators and absorbers. The tray efficiencies can be predicted from Fig. 1, ± 10% for 90% of the data.^{18,19} O'Connell's correlation for absorption has been further substantiated by Williams (1950) and found to be 90% accurate.⁵

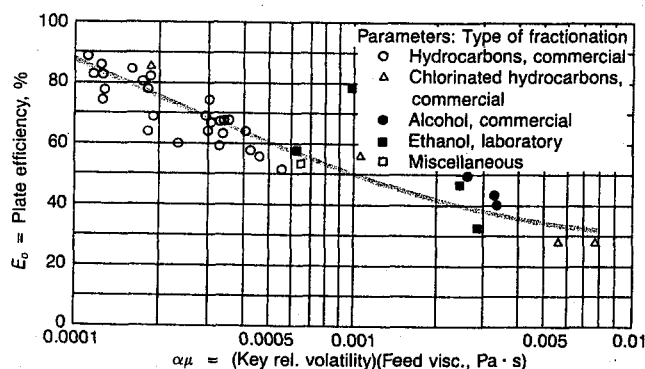


Fig. 1—Relative volatility of the key component and viscosity of the feed are taken at average column conditions. Multiply centipoise time 10^{-3} to get Pascal-seconds.¹⁹

MacFarland, Sigmund and VanWinkle Method (1972).

Studies of binary systems using sieve and bubble-cap trays were made by MacFarland, Sigmund and VanWinkle.²⁰ The data collected were in the range of normal operations, that is above the weep point and below the flood point.

The Murphree vapor plate efficiency was calculated using the following equation:

$$E_{mv} = 6.8 (N_{Re} N_{Sc})^{0.1} (N_{Dg} N_{Sc})^{0.115}$$

The absolute average deviation from experimental values was found to be ± 10.6%. The dimensionless groups used in this correlation are as follows:

Modified Reynold's number,

$$N_{Re} = \frac{h_w U_{vs} \rho_v}{\mu_t (FA)} = \frac{h_w G}{\mu_t (FA)}$$

Liquid Schmidt number,

$$N_{Sc} = \frac{\mu_t}{\rho_t D_{ik}}$$

Surface tension number,

$$N_{Dg} = \frac{\sigma_t}{\mu_t U_{vs}}$$

American Institute of Chemical Engineer's Method (1958).

The Distillation Subcommittee of the American Institute of Chemical Engineers recommended the following method for

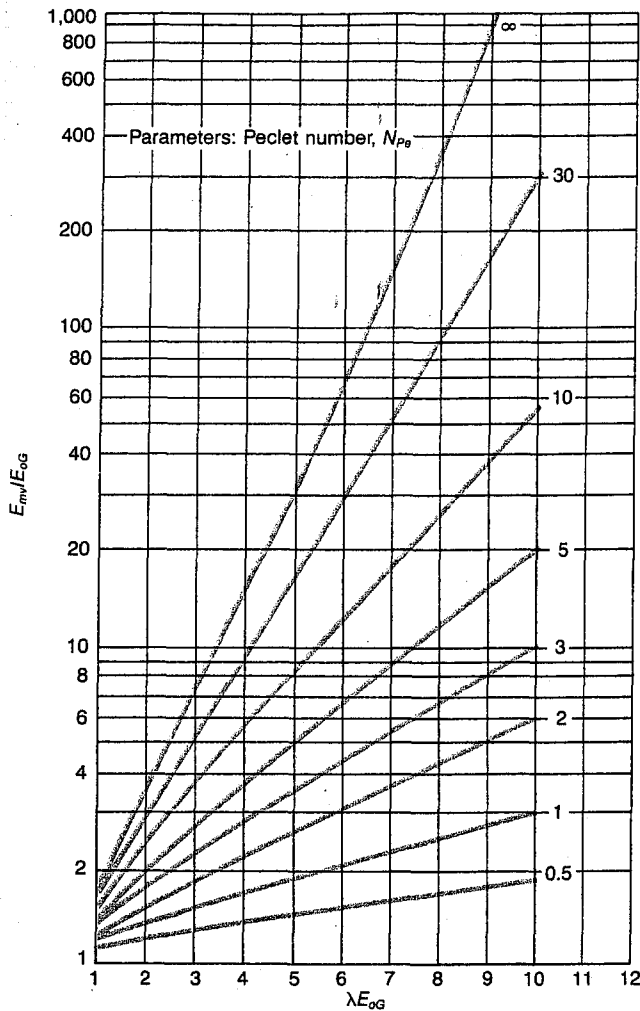


Fig. 2—Mixing curve used in Step 15.²⁴

tray efficiency. The method consists of fixing a plate design and calculating or fixing the operating variables and the system variables. The variables are total pressure, tray temperature, total vapor load, total liquid load, vapor and liquid densities, vapor and liquid viscosities, vapor and liquid molecular weights, vapor and liquid molar diffusivity, and liquid surface tension.^{7,19} The AIChE method was found to be 90% accurate.

The AIChE method of calculation is as follows:¹⁷

Step 1. Calculate the vapor load Q_v and the liquid load Q_l in cubic meters per second.

Step 2. Determine the vapor velocity based on bubbling area in meters per second:

$$U_{VA} = \frac{Q_v}{A_A}$$

Step 3. Calculate F_{VA} :

$$F_{VA} = \left(\frac{U_{VA}}{0.3048} \right) \left(\frac{\rho_v}{16.0185} \right)^{0.5}$$

Step 4. Calculate liquid rate per average flow width, Q_l/W_a .

Step 5. Calculate the absorption factor $\lambda = mG_m/L_m$:

$$\lambda = \frac{mQ_v\rho_v M_l C}{Q_l \rho_l M_v}$$

Step 6. Calculate the foam height:

$$h_f = 2.53 F_{VA}^2 + 74.41 h_w - 1.6$$

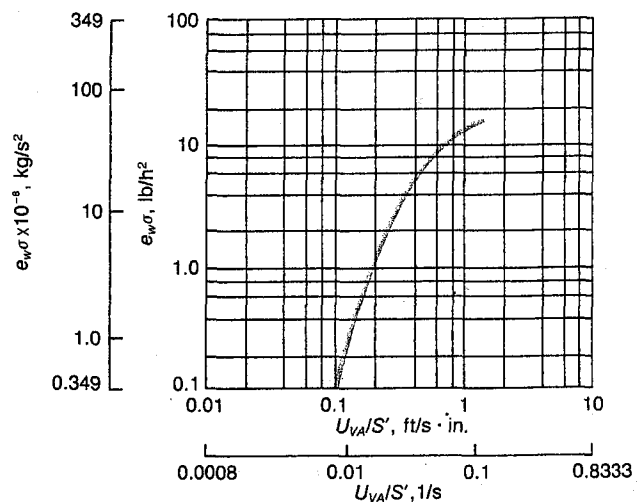


Fig. 3—Entrainment relation.²⁴

Step 7. Calculate the clear liquid height:

$$h_c = \frac{103 + 464.57 h_w - 40.5 F_{VA} + 6038.69 Q_l/W_a}{(\rho_l/16.0185)}$$

Step 8. Calculate the liquid contact time in seconds:

$$\theta_l = \frac{0.95 h_c A_A}{Q_l}$$

Step 9. Determine the number of liquid-phase transfer units:

$$N_l = 103 (38750.078 D_l)^{0.5} (0.26 F_{VA} + 0.15) \theta_l$$

Step 10. Calculate the number of gas-phase transfer units:

$$N_G = [\rho_v D_v / \mu_v]^{0.5} [0.776 + 4.57 h_w - 0.29 F_{VA} + 104.84 Q_l/W_a + 7.874 \Delta]$$

Step 11. Evaluate the overall gas-phase efficiency, E_{oG} :

$$-\log(1 - E_{oG}) = 0.434 \frac{N_l N_G}{N_l + \lambda N_G}$$

Step 12. Determine the percent liquid-phase resistance:

$$\% R_l = \frac{\lambda N_G}{N_l + \lambda N_G} 100$$

Step 13. Calculate the eddy diffusion coefficient:

$$D_e = [1.0 + 0.044 ((d_c^*/0.0254) - 3)]^2 \\ [0.0124 + 0.591 h_w + 0.056 U_{FA} + 12.078 Q_t/W_a]$$

where: d_c^* = 0.0762 meters, approaches sieve and valve tray operation.²⁴

Step 14. Evaluate the Peclet number:

$$P_e = \frac{(Z_t/0.0929)^2}{D_e \theta_t}$$

Step 15. Evaluate the term λE_{OG} so that Fig. 2 can be used to determine E_{mv}/E_{OG} .

Step 16. Evaluate E_{mv} .

Step 17. Calculate the effective plate spacing:

$$S' = S - 0.0254 h_f$$

Step 18. Using the value of U_{FA}/S' , determine $e_w \rho$ from Fig. 3.

Step 19. Calculate the net fraction of liquid entrained:

$$r_e = \frac{449 e_w Q_o \rho_o}{Q_t \rho_t}$$

Step 20. Determine the wet-plate efficiency

$$E_w = \frac{E_{mv}}{1 + r_e E_{mv}}$$

and the overall efficiency:

$$E_o = \frac{\log 1 + E_w (\lambda - 1)}{\log \lambda}$$

LITERATURE REVIEW

Empirical and theoretical methods for the determination of efficiency in tray columns for the past fifty years were extensively reviewed. In general, correlations derived from binary system studies apply equally well to multicomponent systems, and correlations derived for individual types of trays, i.e., bubble-cap, sieve and valve, can be used interchangeably.

In general, the tray efficiency decreases as the flowrate of vapor through the holes is reduced to the dump point, and for open tray areas greater than 30 percent. The tray efficiency increases as the tray spacing increases for a given throughput. The highest efficiencies are in the 20-25 percent open hole areas and are obtained for operating conditions within 85-95 percent of the tray flood point.¹⁷

Empirical methods. Walter and Sherwood (1941) developed a correlation for absorption systems.^{1,25} Drickamer and Bradford (1943) derived an accurate method for narrow boiling hydrocarbons.^{18,19} O'Connell (1946) extended Drickamer and Bradford's method to systems with high relative volatility and a wider range of systems and operating conditions.^{18,19} Williams (1950) further substantiated O'Connell's method.⁵ Gerster, Colburn, Bonnett and Carmody (1949) developed a more theoretical model using estimated values of transfer units.^{5,9} Robinson and Gilliland (1950) extended this work of Walter and Sherwood to span a wider range of applications.⁵ Zuideweg (1960) developed a generalized correlation for both tray and packed towers.²⁰ Chariyarech and VanWinkle (1961) derived an expression for the separation of binary mixtures in bubble-cap and sieve trays.¹⁷ English and VanWinkle (1963) proposed a correlation for binary systems in bubble-cap and sieve trays, but later studies found some of this data to be in error.^{18,20,26} Fair (1965) summarized FRI data and suggested a correlation for bubble-cap and sieve plate columns, and Billet and Raichle (1966), Standart (1967) and Krischbaum (1969) developed additional correlations.¹⁸ Onda, Sada, Tahahaski and Mukhtar (1971) used least squares analysis to correlate plate efficiencies.²⁷ Tarat and Simakov (1972) suggested a correlation based on the separation of propane and butane.²⁸ Later,

MacFarland, Sigmund and VanWinkle (1972) re-examined and repeated the study of English and VanWinkle (1963) of binary systems using bubble-cap and sieve trays, and obtained successful results.²⁰

Theoretical methods. Geddes (1949) developed a correlation for point efficiency in which he attempted to calculate the resistance of the two phases in distillation from basic mass transfer information. Good agreement was found between Geddes' equation and the data obtained by Walter in 1941.²⁵ However, some authors report that Geddes' assumptions diverge from the actual conditions in the column, i.e., he assumes small size bubbles moving at low velocities, therefore his equation should be used with caution.¹⁰

Chu (1951) suggested an approach that produced results a little low due to the assumption of too large a size bubble in the bubble size correlation. This method has not been reported to be experimentally verified.⁵

Bakowski (1952) developed an equation for point efficiency based on the mechanism of bubble formation at submerged slots. The vapor was regarded as flowing through channels rather than in the form of streams of separate bubbles.¹⁰ Good agreement was found between this equation and the data collected by Carey (1933); however, the equation did not work well at extremes of concentration ranges and near azeotropic mixtures.

Gautreaux and O'Connell (1953) developed a method for large or small columns using bubble-cap trays.^{29,30} Anderson (1955) derived a correlation for point efficiency based on adding the resistance of two phases. The film theory mechanism was used for the gas phase and the unsteady-state prediction theory was used for the liquid phase. This equation gave values of the same order of magnitude as those obtained in commercial towers.²⁵

The American Institute of Chemical Engineers (1958) recommended a method based on a two-film model for mass transfer and relates all efficiencies to gas-phase concentrations—for convenience only, since it could have been done for liquid-phase concentration as well. A suitable correction for the Murphree plate efficiency is also included for entrainment effects.¹⁹ This method was based on small columns with bubble-cap trays in the froth regime. It may not be good for large diameter columns, where efficiency decreases due to incomplete liquid mixing can be large. This method is not good for cross-flow trays due to the complexity of the hydrodynamic design involved.^{19,21} The AIChE method is not good for liquid phase controlling systems such as absorption or stripping columns.⁷ The correlation is unsatisfactory for unusual combinations of system properties, and vapor and liquid flows. It does not provide a means for assessing the effects of liquid and/or vapor bypassing, which is important for unusual K values, particularly in combination with extreme V/L conditions.²¹ The method should not be used for systems operating near the flooding point, or where there is a lot of empirical data available.¹⁹ The method gives reasonable results for sieve trays with downpipes, and has been validated for valve and bubble-cap trays.^{8,22} However, Garrett (1975) observed that the AIChE method does not predict valve tray efficiencies well.¹⁶

Foldes and Evangelidi (1968) derived a correlation for Turbogrid-trays (non-crossflow trays without downcomers) used in distillation. This method assumes a high degree of turbulence will assure that mass transfer is not materially affected by the physico-chemical parameters of the system.²³

Kastanek (1969) developed a method analogous to the AIChE method (1958), but simpler to use and extended the application to Turbogrid and Glitch valve trays, and Nutter valve trays (trays with downcomers and oblong movable elements).³¹ It is based on a relationship between NTU and the vapor phase residence time for a given binary mixture, regardless of the plate characteristics. Using this method and data by Nutter³², Fair³³ obtained good results for sieve trays.

SYMBOLS USED

- A = Cross-sectional area of column, sq m
 A_d = Bubbling area, sq m = $A - 2A_d$
 A_d = Area of downcomer, sq m
 D_t = Tower diameter, m
 D_e = Longitudinal effy diffusivity, sq ft/sec
 D_l = Volumetric liquid diffusion coefficient, sq m/sec
 D_v = Volumetric vapor diffusion coefficient, sq m/sec
 D_{lk} = Molecular diffusion coefficient of light key, sq m/sec
 d_c = Cap diameter, m
 E_{mv} = Murphree vapor efficiency
 E_{OG} = Overall vapor phase efficiency
 E_o = Overall plate efficiency
 E_w = Actual efficiency corrected for entrainment
 e_w = Entrainment ratio, kg/kg_g
 FA = Fractional free area
 F_{VA} = F factor based on active area
 G = Mass velocity based on column cross section, kg_m/sec m²
 G_m = Molar vapor velocity, moles/sec m²
 h_c = Clear liquid height, in.
 h_f = Height of foam, in.
 h_w = Weir height, m
 l_m = Length of weir, m
 L = Liquid flow rate, kg/(sec)(sq m of area)
 L_m = Molar liquid velocity, moles/sec m²
 M = Molecular weight, kg/kg-mole
 m = Slope of equilibrium curve, y/x
 N_G = Number of vapor-phase transfer units
 N_L = Number of liquid-phase transfer units
 Q_l = Liquid flow rate, m³/sec
 Q_v = Vapor load, m³/sec
 r_e = Net fraction of liquid entrained
 S = Tray spacing, m
 S' = Corrected tray spacing, m, $S' = 0.0254 h_f$
 U_{vs} = Velocity of vapor based on superficial area, m/sec
 U_{VA} = Vapor velocity based on active area, m/sec
 V = Vapor flow rate, kg/(sec)(sq m of area)
 W_a = $(D_l + l_w)/2$, average width of liquid flow across plate, m
 Z_e = Distance between weirs, m

Subscripts:

- l = Liquid
 lk = Liquid light key
 v = Vapor
 w = Water

Greek Letters:

- Δ = Liquid gradient, m
 λ = $m G_m/L_m$, absorption factor
 μ_v = Viscosity of vapor, kg/m sec
 μ_l = Viscosity of liquid, kg/m sec
 ρ_l = Density of liquid, kg/m³
 ρ_v = Density of vapor, kg/m³
 σ = Surface tension, kg_m/sec²
 θ_l = Liquid contact time, sec

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FIG. 23-2
Physical Constants

*See the Table of Notes and References.

Number	See Note No. ->	Compound	Formula	A. Molar mass (molecular weight)	B. Boiling point, °F 14.696 psia	C. Vapor pressure, psia 100 °F	D. Freezing point, °F 14.696 psia	Refractive index, n_D 60 °F	Critical constants			Number
									Pressure, psia	Temperature, °F	Volume, ft^3/lbm	
1		Methane	CH_4	16.043	-258.73	(5000)*	-296.44*	1.00042*	666.4	-116.67	0.0988	1
2		Ethane	C_2H_6	30.070	-127.49	(800)*	-297.04*	1.20971*	706.5	89.92	0.0783	2
3		Propane	C_3H_8	44.097	-43.75	188.64	-305.73*	1.29480*	616.0	206.06	0.0727	3
4		Isobutane	C_4H_{10}	58.123	10.78	72.581	-255.28	1.3245*	527.9	274.46	0.0714	4
5		n-Butane	C_4H_{10}	58.123	31.08	51.706	-217.05	1.33588*	550.8	305.62	0.0703	5
6		Isopentane	C_5H_{12}	72.150	82.12	20.445	-255.82	1.35831	490.4	369.10	0.0679	6
7		n-Pentane	C_5H_{12}	72.150	96.92	15.574	-201.51	1.35992	488.6	385.8	0.0675	7
8		Neopentane	C_5H_{12}	72.150	49.10	36.69	2.17	1.342*	464.0	321.13	0.0673	8
9		n-Hexane	C_6H_{14}	86.177	155.72	4.9597	-139.58	1.37708	436.9	453.6	0.0688	9
10		2-Methylpentane	C_6H_{14}	86.177	140.47	6.769	-244.62	1.37387	436.8	435.83	0.0682	10
11		3-Methylpentane	C_6H_{14}	86.177	145.89	6.103	—	1.37888	453.1	448.4	0.0682	11
12		Neohexane	C_6H_{14}	86.177	121.52	9.859	-147.72	1.37126	446.8	420.13	0.0687	12
13		2,3-Dimethylbutane	C_6H_{14}	86.177	136.36	7.406	-199.38	1.37730	453.5	440.29	0.0665	13
14		n-Heptane	C_7H_{16}	100.204	209.16	1.620	-131.05	1.38989	396.8	512.7	0.0691	14
15		2-Methylhexane	C_7H_{16}	100.204	194.09	2.272	-180.89	1.38714	396.5	495.00	0.0673	15
16		3-Methylhexane	C_7H_{16}	100.204	197.33	2.131	—	1.39091	408.1	503.80	0.0646	16
17		3-Ethylpentane	C_7H_{16}	100.204	200.25	2.013	-181.48	1.39566	419.3	513.39	0.0665	17
18		2,2-Dimethylpentane	C_7H_{16}	100.204	174.54	3.494	-190.86	1.38446	402.2	477.23	0.0665	18
19		2,4-Dimethylpentane	C_7H_{16}	100.204	176.89	3.293	-182.63	1.38379	396.9	475.95	0.0668	19
20		3,3-Dimethylpentane	C_7H_{16}	100.204	186.91	2.774	-210.01	1.38564	427.2	505.87	0.0662	20
21		Triptane	C_7H_{16}	100.204	177.58	3.375	-12.81	1.39168	428.4	496.44	0.0636	21
22		n-Octane	C_8H_{18}	114.231	258.21	0.53694	-70.18	1.39956	360.7	564.22	0.0690	22
23		Diisobutyl	C_8H_{18}	114.231	228.39	1.102	-132.11	1.39461	360.6	530.44	0.0676	23
24		Isooctane	C_8H_{18}	114.231	210.63	1.709	-181.27	1.38624	372.4	519.46	0.0656	24
25		n-Nonane	C_9H_{20}	128.258	303.47	0.17953	-64.28	1.40746	331.8	610.68	0.0684	25
26		n-Decane	$\text{C}_{10}\text{H}_{22}$	142.285	345.48	0.06088	-21.36	1.41385	305.2	652.0	0.0679	26
27		Cyclopentane	C_5H_{10}	70.134	120.65	9.915	-136.91	1.40896	653.8	461.2	0.0594	27
28		Methylcyclopentane	C_6H_{12}	84.161	181.25	4.503	-224.40	1.41210	548.9	499.35	0.0607	28
29		Cyclohexane	C_6H_{12}	84.161	177.29	3.266	43.77	1.42862	590.8	536.6	0.0586	29
30		Methylcyclohexane	C_7H_{14}	98.188	213.68	1.609	-195.87	1.42538	503.5	570.27	0.0600	30
31		Ethene (Ethylene)	C_2H_4	28.054	-154.73	(1400)*	-272.47*	(1.228)*	731.0	48.54	0.0746	31
32		Propene (Propylene)	C_3H_6	42.081	-53.84	227.7	-301.45*	1.3130*	668.6	197.17	0.0689	32
33		1-Butene (Butylene)	C_4H_8	56.108	20.79	62.10	-301.63*	1.3494*	583.5	295.48	0.0685	33
34		cis-2-Butene	C_4H_8	56.108	38.69	45.95	-218.06	1.3665*	612.1	324.37	0.0668	34
35		trans-2-Butene	C_4H_8	56.108	33.58	49.87	-157.96	1.3563*	587.4	311.86	0.0679	35
36		Isobutene	C_4H_8	56.108	19.59	63.02	-220.65	1.3512*	580.2	292.55	0.0682	36
37		1-Pentene	C_5H_{10}	70.134	85.93	19.12	-265.39	1.37426	511.8	376.93	0.0676	37
38		1,2-Butadiene	C_4H_6	54.092	51.53	36.53	-213.16	—	(653.)*	(340.)*	(0.065)*	38
39		1,3-Butadiene	C_4H_6	54.092	24.06	59.46	-164.02	1.3975*	627.5	305.	0.0654	39
40		Isoprene	C_5H_8	68.119	93.31	16.68	-230.73	1.42498	(558.)*	(412.)*	(0.065)*	40
41		Acetylene	C_2H_2	26.038	-120.49*	—	-114.5*	—	890.4	95.34	0.0695	41
42		Benzene	C_6H_6	78.114	176.18	3.225	41.95	1.50396	710.4	552.22	0.0531	42
43		Toluene	C_7H_8	92.141	231.13	1.033	-139.00	1.49942	595.5	605.57	0.0550	43
44		Ethylbenzene	C_8H_{10}	106.167	277.16	0.3716	-138.966	1.49826	523.0	651.29	0.0565	44
45		o-Xylene	C_8H_{10}	106.167	291.97	0.2643	-13.59	1.50767	541.6	674.82	0.0557	45
46		m-Xylene	C_8H_{10}	106.167	282.41	0.3265	-54.18	1.49951	512.9	651.02	0.0567	46
47		p-Xylene	C_8H_{10}	106.167	281.07	0.3424	55.83	1.49810	509.2	649.54	0.0570	47
48		Styrene	C_8H_8	104.152	293.25	0.2582	-23.10	1.54937	587.8	(703.)*	0.0534	48
49		Isopropylbenzene	C_9H_{12}	120.194	306.34	0.1884	-140.814	1.49372	465.4	676.3	0.0572	49
50		Methyl alcohol	CH_3O	32.042	148.44	4.629	-143.79	1.33034	1174.	463.08	0.0590	50
51		Ethyl alcohol	$\text{C}_2\text{H}_5\text{O}$	46.069	172.90	2.312	-173.4	1.36346	890.1	485.39	0.0581	51
52		Carbon monoxide	CO	28.010	-312.68	—	-337.00*	1.00036*	507.5	-220.43	0.0532	52
53		Carbon dioxide	CO_2	44.010	-109.257*	—	-69.83*	1.00048*	1071.	87.91	0.0344	53
54		Hydrogen sulfide	H_2S	34.08	-76.497	394.59	-121.88*	1.00060*	1300.	212.45	0.0461	54
55		Sulfur dioxide	SO_2	64.06	14.11	85.46	-103.86*	1.00062*	1143.	315.8	0.0305	55
56		Ammonia	NH_3	17.0305	-27.99	211.9	-107.88*	1.00036*	1646.	270.2	0.0681	56
57		Air	N_2+O_2	28.9625	-317.8	—	—	1.00028*	546.9	-221.31	0.0517	57
58		Hydrogen	H_2	2.0159	-422.955*	—	-435.26*	1.00013*	188.1	-399.9	0.5165	58
59		Oxygen	O_2	31.9988	-297.332*	—	-361.820*	1.00027*	731.4	-181.43	0.0367	59
60		Nitrogen	N_2	28.0134	-320.451	—	-346.00*	1.00028*	493.1	-232.51	0.0510	60
61		Chlorine	Cl_2	70.906	-29.13	157.3	-149.73*	1.3878*	1157.	290.75	0.0280	61
62		Water	H_2O	18.0153	212.000*	0.9501	32.00	1.33335	3198.8	705.16	0.0497*	62
63		Helium	He	4.0026	-452.09	—	—	1.00003*	32.99	-450.31	0.2300	63
64		Hydrogen chloride	HCl	36.461	-121.27	906.71	-173.52*	1.00042*	1205.	124.77	0.0356	64

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NOTE: Numbers in this table do not have accuracies greater than 1 part in 1000; in some cases extra digits have been added to calculated values to achieve consistency or to permit recalculation of experimental values.

FIG. 23-2 (Cont'd)

Physical Constants

*See the Table of Notes and References.

Number	E.			F.	G.	H.	I.			J.		Number
	Density of liquid 14.696 psia, 60°F						Ideal gas 14.696 psia, 60°F			Specific Heat 60°F 14.696 psia Btu/(lbm·°F)		
	Relative density (specific gravity) 60°F/60°F	lbm/gal.	gal./lb mole				Relative density (specific gravity) Air = 1	ft ³ gas/lbm	ft ³ gas/gal. liquid	C _p , Ideal gas	C _p , Liquid	
1	(0.3)*	(2.5)*	(8.4172)*	—	0.0104	0.9980	0.5539	23.654	(59.135)*	0.52669	—	1
2	0.35619*	2.9696*	10.126*	—	0.0979	0.9919	1.0382	12.620	37.476*	0.40782	0.97225	2
3	0.50699*	4.2268*	10.433*	-0.00162*	0.1522	0.9825	1.5226	8.6059	36.375*	0.38852	0.61996	3
4	0.56287*	4.6927*	12.386*	-0.00119*	0.1852	0.9711	2.0068	6.5291	30.639*	0.38669	0.57066	4
5	0.58401*	4.8690*	11.937*	-0.00106*	0.1995	0.9667	2.0068	6.5291	31.790*	0.39499	0.57272	5
6	0.62470	5.2082	13.853	-0.00090	0.2280	—	2.4912	5.2596	27.393	0.38440	0.53331	6
7	0.63112	5.2617	13.712	-0.00086	0.2514	—	2.4912	5.2596	27.674	0.38825	0.54363	7
8	0.59666*	4.9744*	14.504*	-0.00106*	0.1963	0.9582	2.4912	5.2596	26.163*	0.39038	0.55021	8
9	0.66383	5.5344	15.571	-0.00075	0.2994	—	2.9755	4.4035	24.371	0.38628	0.53327	9
10	0.65785	5.4846	15.713	-0.00076	0.2780	—	2.9755	4.4035	24.152	0.38526	0.52732	10
11	0.66901	5.5776	15.451	-0.00076	0.2732	—	2.9755	4.4035	24.561	0.37902	0.51876	11
12	0.65385	5.4512	15.809	-0.00076	0.2326	—	2.9755	4.4035	24.005	0.38231	0.51367	12
13	0.66631	5.5551	15.513	-0.00076	0.2469	—	2.9755	4.4035	24.462	0.37762	0.51308	13
14	0.68820	5.7376	17.464	-0.00068	0.3494	—	3.4598	3.7872	21.729	0.38447	0.52802	14
15	0.68310	5.6951	17.595	-0.00070	0.3298	—	3.4598	3.7872	21.568	0.38041	0.52199	15
16	0.69165	5.7664	17.377	-0.00070	0.3232	—	3.4598	3.7872	21.838	0.37882	0.51019	16
17	0.70276	5.8590	17.103	-0.00069	0.3105	—	3.4598	3.7872	22.189	0.38646	0.51410	17
18	0.67829	5.6550	17.720	-0.00070	0.2871	—	3.4598	3.7872	21.416	0.38594	0.51678	18
19	0.67733	5.6470	17.745	-0.00073	0.3026	—	3.4598	3.7872	21.386	0.39414	0.52440	19
20	0.69772	5.8170	17.226	-0.00067	0.2674	—	3.4598	3.7872	22.030	0.38306	0.50138	20
21	0.69457	5.7907	17.304	-0.00068	0.2503	—	3.4598	3.7872	21.930	0.37724	0.49920	21
22	0.70696	5.8940	19.381	-0.00064	0.3977	—	3.9441	3.3220	19.580	0.38331	0.52406	22
23	0.69793	5.8187	19.632	-0.00067	0.3564	—	3.9441	3.3220	19.330	0.37571	0.51130	23
24	0.69624	5.8046	19.679	-0.00065	0.3035	—	3.9441	3.3220	19.283	0.38222	0.48951	24
25	0.72187	6.0183	21.311	-0.00061	0.4445	—	4.4284	2.9588	17.807	0.38246	0.52244	25
26	0.73421	6.1212	23.245	-0.00057	0.4898	—	4.9127	2.6671	16.326	0.38179	0.52103	26
27	0.75050	6.2570	11.209	-0.00073	0.1950	—	2.4215	5.4110	33.856	0.27199	0.42182	27
28	0.75349	6.2819	13.397	-0.00069	0.2302	—	2.9059	4.5090	28.325	0.30100	0.44126	28
29	0.78347	6.5319	12.885	-0.00065	0.2096	—	2.9059	4.5090	29.452	0.28817	0.43584	29
30	0.77400	6.4529	15.216	-0.00062	0.2358	—	3.3902	3.8649	24.940	0.31700	0.44012	30
31	—	—	—	—	0.0865	0.9936	0.9686	13.527	—	0.35697	—	31
32	0.52095*	4.3432*	9.6889*	-0.00173*	0.1356	0.9844	1.4529	9.0179	39.167*	0.35714	0.57116	32
33	0.60107*	5.0112*	11.197*	-0.00112*	0.1941	0.9699	1.9373	6.7636	33.894*	0.35446	0.54533	33
34	0.62717*	5.2288*	10.731*	-0.00105*	0.2029	0.9665	1.9373	6.7636	35.366*	0.33754	0.52980	34
35	0.60996*	5.0853*	11.033*	-0.00106*	0.2128	0.9667	1.9373	6.7636	34.395*	0.35574	0.54215	35
36	0.60040*	5.0056*	11.209*	-0.00117*	0.1999	0.9700	1.9373	6.7636	33.856*	0.37690	0.54839	36
37	0.64571	5.3834	13.028	-0.00089	0.2333	—	2.4215	5.4110	29.129	0.36351	0.51782	37
38	0.65799*	5.4857*	9.8605*	-0.00101*	0.2540	(0.969)	1.8677	7.0156	38.485*	0.34347	0.54029	38
39	0.62723*	5.2293*	10.344*	-0.00110*	0.2007	(0.965)	1.8677	7.0156	36.687*	0.34120	0.53447	39
40	0.68615	5.7205	11.908	-0.00082	0.1568	—	2.3520	5.5710	31.869	0.35072	0.51933	40
41	(0.41796)	(3.4842)	(7.473)	—	0.1949	0.9930	0.8990	14.574	—	0.39754	—	41
42	0.88448	7.3740	10.593	-0.00067	0.2093	—	2.6971	4.8581	35.824	0.24296	0.40989	42
43	0.87190	7.2691	12.676	-0.00059	0.2633	—	3.1814	4.1184	29.937	0.25370	0.40095	43
44	0.87168	7.2673	14.609	-0.00056	0.3027	—	3.6657	3.5744	25.976	0.27792	0.41139	44
45	0.88467	7.3756	14.394	-0.00052	0.3942	—	3.6657	3.5744	26.363	0.28964	0.41620	45
46	0.86875	7.2429	14.658	-0.00053	0.3257	—	3.6657	3.5744	25.889	0.27427	0.40545	46
47	0.86578	7.2181	14.708	-0.00056	0.3216	—	3.6657	3.5744	25.800	0.27471	0.40255	47
48	0.91108	7.5958	13.712	-0.00053	(0.2412)	—	3.5961	3.6435	27.675	0.27110	0.41220	48
49	0.86634	7.2228	16.641	-0.00055	0.3260	—	4.1500	3.1573	22.804	0.29170	0.42053	49
50	0.79626	6.6385	4.8267	-0.00066	0.5649	—	1.1063	11.843	78.622	0.32316	0.59187	50
51	0.79399	6.6196	6.9595	-0.00058	0.6438	—	1.5906	8.2372	54.527	0.33222	0.56610	51
52	0.78939*	6.5812*	4.2561*	—	0.0484	0.9959	0.9671	13.548	89.163*	0.24847	—	52
53	0.81802*	6.8199*	6.4532*	-0.00583*	0.2667	0.9943	1.5196	8.6229	58.807*	0.19911	—	53
54	0.80144*	6.6817*	5.1005*	-0.00157*	0.0948	0.9846	1.1767	11.135	74.401*	0.23827	0.50418	54
55	1.3974*	11.650*	5.4987*	—	0.2548	0.9802	2.2118	5.9238	69.012*	0.14804	0.32460	55
56	0.61832*	5.1550*	3.3037*	—	0.2557	0.9877	0.5880	22.283	114.87*	0.49677	1.1209	56
57	0.87476*	7.2930*	3.9713*	—	—	1.0000	1.0000	13.103	95.557*	0.23988	—	57
58	0.071070*	0.59252*	3.4022*	—	-0.2202	1.0006	0.06960	188.25	111.54*	3.4038	—	58
59	1.1421*	9.5221*	3.3605*	—	0.0216	0.9992	1.1048	11.859	112.93*	0.21892	—	59
60	0.80940*	6.7481*	4.1513*	—	0.0372	0.9997	0.9672	13.546	91.413*	0.24828	—	60
61	1.4244*	11.875*	5.9710*	—	0.0878	(0.9875)	2.4482	5.3519	63.554*	0.11377	—	61
62	1.00000	8.33712	2.1609	-0.00009	0.3443	—	0.62202	21.065	175.62	0.44457	0.99974	62
63	0.12510*	1.0430*	3.8376*	—	0.	1.0006	0.1382	94.814	98.891*	1.2404	—	63
64	0.85129*	7.0973*	5.1373*	-0.00300*	0.1259	0.9923	1.2589	10.408	73.869*	0.19086	—	64

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NOTE: Numbers in this table do not have accuracies greater than 1 part in 1000; in some cases extra digits have been added to calculated values to achieve consistency or to permit recalculation of experimental values.

FIG. 23-2 (Cont'd)

Physical Constants

*See the Table of Notes and References.

Number	Compound	K.					L.	M.	Flammability limits, vol %		ASTM octane number		Number
		Heating value, 60°F							in air mixture				
		Net		Gross					Lower	Higher	Motor method D-357	Research method D-908	
		Btu/ft ³ Ideal gas, 14.696 psia	Btu/lbm Liquid	Btu/ft ³ Ideal gas, 14.696 psia	Btu/lbm Liquid	Btu/gal. Liquid							
Heat of vaporization 14.696 psia at boiling point, Btu/lbm	Air required for combustion ideal gas ft ³ (air)/ft ³ (gas)												
1	Methane	909.4	—	1010.0	—	—	219.45	9.548	5.0	15.0	—	—	1
2	Ethane	1618.7	20277.*	1769.6	22181.*	65869.*	211.14	18.710	2.9	13.0	+0.05	+1.6*	2
3	Propane	2314.9	19757.*	2516.1	21489.*	90830.*	183.01	23.871	2.0	9.5	97.1	+1.8*	3
4	Isobutane	3000.4	19437.*	3251.9	21079.*	98917.*	157.23	31.032	1.8	8.5	97.6	+0.1*	4
5	n-Butane	3010.8	19494.*	3262.3	21136.*	102911.*	165.93	31.032	1.5	9.0	89.6*	93.8*	5
6	Isopentane	3699.0	19303.	4000.9	20891.	108805.	147.12	38.193	1.3	8.0	90.3	92.3	6
7	n-Pentane	3706.9	19335.	4008.9	20923.	110091.	153.57	38.193	1.4	8.3	82.6*	81.7*	7
8	Neopentane	3682.9	19235.*	3984.7	20822.*	103577.*	135.58	38.193	1.3	7.5	80.2	85.5	8
9	n-Hexane	4403.8	19232.	4755.9	20783.	115021.	143.94	45.355	1.1	7.7	26.0	24.8	9
10	2-Methylpentane	4395.2	19202.	4747.3	20753.	113822.	138.45	45.355	1.18	7.0	73.5	73.4	10
11	3-Methylpentane	4398.2	19213.	4750.3	20764.	115813.	140.05	45.355	1.2	7.7	74.3	74.5	11
12	Neohexane	4384.0	19163.	4736.2	20714.	112916.	131.23	45.355	1.2	7.0	93.4	91.8	12
13	2,3-Dimethylbutane	4392.9	19195.	4745.0	20746.	115246.	136.07	45.355	1.2	7.0	94.3	+0.3	13
14	n-Heptane	5100.0	19155.	5502.5	20679.	118648.	136.00	52.516	1.0	7.0	0.0	0.0	14
15	2-Methylhexane	5092.2	19133.	5494.6	20657.	117644.	131.58	52.516	1.0	7.0	46.4	42.4	15
16	3-Methylhexane	5096.0	19146.	5498.6	20671.	119197.	132.10	52.516	(1.01)	(6.6)	55.8	52.0	16
17	3-Ethylpentane	5098.3	19154.	5500.7	20679.	121158.	132.82	52.516	(1.00)	(6.5)	69.3	65.0	17
18	2,2-Dimethylpentane	5079.6	19095.	5481.9	20620.	116806.	125.12	52.516	(1.09)	(6.8)	95.6	92.8	18
19	2,4-Dimethylpentane	5084.2	19111.	5486.7	20635.	116526.	126.57	52.516	(1.08)	(6.8)	83.8	83.1	19
20	3,3-Dimethylpentane	5086.4	19119.	5488.8	20643.	120080.	127.20	52.516	(1.04)	(7.0)	86.6	80.8	20
21	Triptane	5081.2	19103.	5483.5	20628.	119451.	124.21	52.516	(1.08)	(6.8)	+0.1	+1.8	21
22	n-Octane	5796.1	19096.	6248.9	20601.	121422.	129.52	59.677	0.8	6.5	—	—	22
23	Diisobutyl	5780.5	19047.	6233.5	20552.	119586.	122.83	59.677	(0.92)	(6.3)	55.7	55.2	23
24	Isooctane	5778.8	19063.	6231.7	20568.	119389.	112.94	59.677	0.95	6.0	100.0	100.0	24
25	n-Nonane	6493.2	19054.	6996.5	20543.	123634.	124.36	66.839	0.7	5.6	—	—	25
26	n-Decane	7189.6	19018.	7742.9	20494.	125448.	119.65	74.000	0.7	5.4	—	—	26
27	Cyclopentane	3512.1	18825.	3763.7	20186.	126304.	167.33	35.806	(1.48)	(8.3)	84.9*	+0.1	27
28	Methylcyclopentane	4199.4	18771.	4501.2	20132.	126467.	148.54	42.968	1.0	8.35	80.0	91.3	28
29	Cyclohexane	4179.7	18675.	4481.7	20036.	130873.	153.03	42.968	1.2	8.35	77.2	83.0	29
30	Methylcyclohexane	4863.6	18640.	5215.9	20002.	129071.	136.30	50.129	1.1	6.7	71.1	74.8	30
31	Ethene(Ethylene)	1499.1	—	1599.8	—	—	207.41	14.323	2.7	36.0	75.6	+0.03	31
32	Propene(Propylene)	2181.8	(19858.)	2332.7	(21208.)	(92113.)	188.19	21.484	2.0	11.7	84.8	+0.2	32
33	1-Butene(Butylene)	2878.7	19309.*	3079.9	20670.*	103582.*	167.96	28.645	1.6	10.	80.8*	97.4	33
34	cis-2-Butene	2871.0	19241.*	3072.2	20602.*	107724.*	178.89	28.645	1.6	10.	83.5	100.0	34
35	trans-2-Butene	2866.8	19221.*	3068.0	20582.*	104666.*	174.37	28.645	1.6	10.	—	—	35
36	Isobutene	2859.9	19182.*	3061.1	20543.*	102830.*	169.47	28.645	1.6	10.	—	—	36
37	1-Pentene	3575.0	19184.	3826.5	20545.	110802.	154.48	35.806	1.3	10.	77.1	90.9	37
38	1,2-Butadiene	2789.0	19378.*	2939.9	20437.*	112111.*	191.88	26.258	(1.62)	(10.3)	—	—	38
39	1,3-Butadiene	2729.0	18967.*	2879.9	20025.*	104717.*	185.29	26.258	2.0	12.5	—	—	39
40	Isoprene	3410.8	18832.	3612.1	19953.	114141.	163.48	33.419	(1.12)	(8.5)	81.0	99.1	40
41	Acetylene	1423.2	(20887.)	1473.5	(21613.)	(75204.)	151.90	11.935	1.5	100.	—	—	41
42	Benzene	3590.9	17256.	3741.8	17989.	132651.	169.24	35.806	1.2	8.0	+2.8	—	42
43	Toluene	4273.6	17421.	4475.0	18250.	132661.	154.83	42.968	1.2	7.1	+0.3	+5.8	43
44	Ethylbenzene	4970.5	17593.	5222.2	18492.	134387.	144.02	50.129	1.0	8.0	97.9	+0.8	44
45	o-Xylene	4958.2	17544.	5209.9	18444.	136036.	149.10	50.129	1.0	7.6	100.0	—	45
46	m-Xylene	4956.3	17541.	5207.9	18440.	133559.	147.24	50.129	1.0	7.0	+2.8	+4.0	46
47	p-Xylene	4957.1	17545.	5208.8	18444.	133131.	145.71	50.129	1.0	7.0	+1.2	+3.4	47
48	Styrene	4829.8	17414.	5031.1	18147.	137841.	152.85	47.742	1.1	8.0	+0.2	+3.3*	48
49	Isopropylbenzene	5660.9	17709.	5962.8	18662.	134792.	134.24	57.290	0.8	6.5	99.3	+2.1	49
50	Methyl alcohol	766.1	8559.	866.7	9751.	64731.	462.58	7.161	5.5	44.0	—	—	50
51	Ethyl alcohol	1448.1	11530.	1599.1	12770.	84539.	359.07	14.323	3.28	19.0	—	—	51
52	Carbon monoxide	320.5	—	320.5	—	—	92.77	2.387	12.50	74.20	—	—	52
53	Carbon dioxide	0.0	—	0.0	—	—	246.47*	—	—	—	—	—	53
54	Hydrogen sulfide	586.8	6337.*	637.1	6897.*	46086.*	235.63	7.161	4.30	45.50	—	—	54
55	Sulfur dioxide	0.0	—	0.0	—	—	167.22	—	—	—	—	—	55
56	Ammonia	359.0	—	434.4	—	—	589.48	3.581	15.50	27.00	—	—	56
57	Air	0.0	—	0.0	—	—	88.20	—	—	—	—	—	57
58	Hydrogen	273.8	—	324.2	—	—	192.74	2.387	4.00	74.20	—	—	58
59	Oxygen	0.0	—	0.0	—	—	91.59	—	—	—	—	—	59
60	Nitrogen	0.0	—	0.0	—	—	85.59	—	—	—	—	—	60
61	Chlorine	—	—	—	—	—	123.75	—	—	—	—	—	61
62	Water	0.0	*	*	0.0	0.0	970.18	—	—	—	—	—	62
63	Helium	0.0	—	0.0	—	—	—	—	—	—	—	—	63
64	Hydrogen chloride	—	—	—	—	—	190.43	—	—	—	—	—	64

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NOTE: Numbers in this table do not have accuracies greater than 1 part in 1000; in some cases extra digits have been added to calculated values to achieve consistency or to permit recalculation of experimental values.

PROPERTY DATA

Equation for liquid density

Saturated liquid densities for organic chemicals are given as functions of temperature using a modified Rackett equation

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SATURATED LIQUID DENSITIES are presented for approximately 700 major organic chemicals including hydrocarbons, oxygen, nitrogen, halogen and sulfur compounds. The densities are reported as functions of temperature by using a modified form of the Rackett equation:

$$DEN = A \cdot B^{-(1 - TR)^{2/7}} \quad (1)$$

where

DEN = saturated liquid density, g/ml
 A, B = correlation constants for each compound
 TR = reduced temperature, T/TC

The correlation constants, A and B , are given in Table 1 along with densities (experimental data) reported in the literature.¹⁻²¹ Some values in Table 1 are estimated and are noted with an asterisk, *.

An earlier paper²² by the authors provides critical constants for the organic chemicals. The critical compressibility factor, ZC , is used to determine the correlation constant, B ; i.e.,

$$B = ZC \quad (2)$$

For experimental density values, the correlation constants, A , are determined by rearranging Eq. 1 as follows:

$$A = DEN \cdot B^{(1 - TR)^{2/7}} \quad (3)$$

For estimated density values, the correlation constants, A , is the critical density as defined in the original Rackett equation.

Table 1 also gives the temperature range for which the equation may be used to predict liquid density. $TMIN$ is the minimum (freezing point) temperature and TC is the maximum (critical point) temperature.

An example. The value of A in Table 1 for chloromethane (CH_3Cl , compound No. 23) was obtained from the reported density ($DEN = 0.915$) at the given temperature ($T = 20^\circ C$, or $293.16^\circ K$). Then, $TR = T/TC = 293.16/416.2 = 0.7044$, and $B = ZC = 0.268$. By Eq. 3, $A = 0.3610$ as shown in Table 1.

Then the liquid density for chloromethane at $T = 100^\circ C$, or $373.16^\circ K$, is predicted by Eq. 1 as follows:

$$DEN = 0.3610 \cdot 0.268^{-(1 - 373.16/416.2)^{2/7}} = 0.719 \text{ g/ml}$$

The literature value is 0.725 so that the predicted value has a deviation of $(0.719 - 0.725)/0.725$, or 0.83%. Fig. 1 shows the correlation line for chloromethane is in good agreement with literature values (data points).

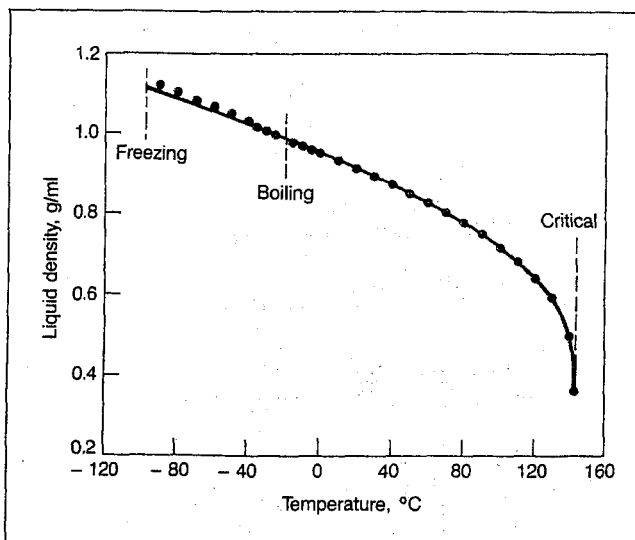


Fig. 1—Data points for chloromethane compared with predicted line.

A computer program of the reported constants, A and B , is available in ASCII on a floppy disk. For details, contact: C. L. Yaws, Dept. of Chemical Engineering, Lamar University, P.O. Box 10053, Beaumont, Texas 77710, U.S.A.

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TABLE 1—Saturated liquid density, $DEN = A * B^{(1 - T/TC)}$ (2.7)

NO.	FORMULA	NAME	A	B	TMIN, K	TC, K	DEN@T, g/cm ³	T, °C
1	CCL4	CARBON-TETRACHLORIDE	0.5566	0.272	250.0	556.5	1.584	25
2	CCL3F	TRICHLOROFLUOROMETHANE	0.5670	0.280	162.0	471.2	1.494	17
3	CCL2F2	DICHLOROFLUOROMETHANE	0.5731	0.273	115.4	384.8	1.750	-115
4	CCLF3	CHLOROTRIFLUOROMETHANE	0.5816	0.278	92.0	302.0	1.298	-30
5	CF4	CARBON-TETRAFLUORIDE	0.6276	0.276	86.4	227.5	1.330	-80
6	CO	CARBON-MONOXIDE	0.3145	0.294	68.1	133.4	0.803	-192
7	CO2	CARBON-DIOXIDE	0.4664	0.275	216.6	304.2	0.713	25
8	COS	CARBONYL-SULFIDE	0.4369	0.279	134.3	378.0	1.274	-99
9	CS2	CARBON-DISULFIDE	0.4483	0.276	161.3	552.0	1.293	0
10	CHCL3	CHLOROFORM	0.5594	0.293	209.6	535.5	1.489	20
11	CHCL2F	DICHLOROFLUOROMETHANE	0.5143	0.271	138.0	451.6	1.380	9
12	CHCLF2	CHLOROFLUOROMETHANE	0.5224	0.266	113.0	369.3	1.230	16
13	CHF3	TRIFLUOROMETHANE	0.5304	0.259	110.0	299.1	1.246	-34
14	CH3	TRICHOLOMETHANE	1.1266	0.281	396.2	794.6	3.194	123
15	CHNS	ISOTHIOCYANIC-ACID	-	-	-	-	-	-
16	CH2CL2	DICHLOROMETHANE	0.4274	0.235	178.1	508.3	1.317	25
17	CH2CLF	CHLOROFLUOROMETHANE	0.4438	0.230	140.2	424.9	1.271	20
18	CH2F2	DIFLUOROMETHANE	0.4296	0.241	101.7	351.5	0.986	25
19	CH2I2	DI-IODOMETHANE	0.9487	0.235	279.3	740.9	3.325	20
20	CH2O	FORMALDEHYDE	0.2395	0.197	156.0	402.7	0.815	-20
21	CH2O2	FORMIC-ACID	0.2606	0.152	281.5	580.0	1.226	15
22	CH3BR	BROMOMETHANE	0.6096	0.262	179.5	464.0	1.737	-5
23	CH3CL	CHLOROMETHANE	0.3610	0.268	175.4	416.2	0.915	20
24	CH3F	FLUOROMETHANE	0.3080	0.251	131.4	317.9	0.843	-60
25	CH3I	IODOMETHANE	0.7125	0.231	206.7	528.0	2.279	20
26	CH3NO2	NITROMETHANE	0.3331	0.224	244.6	588.0	1.138	20
27	CH3NO3	METHYL-NITRATE	-	-	-	-	-	-
28	CH3NO3	METHYL-NITRATE	-	-	-	-	-	-
29	CH4	METHANE	0.1616	0.288	90.7	190.7	0.425	-161
30	CH4O	METHANOL	0.2444	0.224	175.5	513.0	0.791	20
31	CH4S	METHANETHIOL	0.3199	0.268	150.0	469.7	0.866	20
32	CH5N	METHYLAMINE	0.2148	0.213	179.7	429.6	0.703	-13
33	CH2CL4	TETRACHLOROETHENE	0.5105	0.250	251.0	620.2	1.620	20
34	CH2CL6	HEXACHLOROETHANE	0.5643	0.282	458.2	704.4	1.441	185
35	CH2CL3F3	1,1,2,2,3,3-HEXACHLORO-1,1,2,2,3,3-HEXACHLOROFLUOROMETHANE	0.5605	0.274	238.2	487.3	1.580	16
36	CH2CL2F2	1,1,2,2,3,3-HEXACHLORO-1,1,2,2,3,3-HEXACHLOROFLUOROMETHANE	0.5738	0.275	179.0	418.9	1.480	4
37	CH2CLF5	CHLORO-PENTAFLUOROETHANE	0.6041	0.277	167.0	352.2	1.260	30
38	CH2F4	TETRAFLUOROETHANE	0.5479	0.267	130.7	306.4	1.519	-76
39	CH2F6	HEXAFLUOROETHANE	0.6389	0.288	172.4	292.9	1.590	-78
40	C2H2	CYANOGEN	0.5063	0.431	265.3	399.9	0.954	-21
41	C2HCL3	TRICHLOROETHENE	0.4956	0.265	186.8	572.0	1.462	20
42	C2HCL5	PENTACHLOROETHANE	0.5681	0.276	244.0	646.0	1.671	25
43	C2H2F3	TRIFLUOROETHENE	0.4495	0.266	94.5	347.2	0.920	25
44	C2H2	ACETYLENE (ETHYNE)	0.2306	0.274	192.4	309.2	0.615	-81
45	C2H2CL2	1,1-DICHLOROETHENE	0.4427	0.252	155.9	489.0	1.270	20
46	C2H2CL2	CIS-1,2-DICHLOROETHENE	0.4254	0.249	192.7	537.0	1.282	25
47	C2H2CL2	TRANS-1,2-DICHLOROETHENE	0.4332	0.258	223.0	513.0	1.255	20
48	C2H2CL4	1,1,2,2-TETRACHLOROETHANE	0.3891	0.188	237.0	661.2	1.600	20
49	C2H2F2	1,1-DIFLUOROETHENE	0.4040	0.273	129.0	303.0	0.617	24
50	C2H2F2	CIS-1,2-DIFLUOROETHENE	0.3917	0.238	107.9	394.7	1.023	25
51	C2H2F2	TRANS-1,2-DIFLUOROETHENE	0.3917	0.238	107.9	394.7	1.023	25
52	C2H2O	KETENE	0.2899	0.300	138.0	380.0	0.630	25
53	C2H3BR	BROMOETHYLENE	0.5575	0.274	133.7	470.1	1.473	25
54	C2H3CL	CHLOROETHYLENE	0.3470	0.261	119.4	425.0	0.969	-14
55	C2H3CL3	1,1,2-TRICHLOROETHANE	0.4618	0.253	235.8	606.0	1.441	20
56	C2H3CLO	ACETYL-CHLORIDE	0.4079	0.280	160.2	508.0	1.104	20
57	C2H3F	FLUOROETHYLENE	0.3036	0.277	130.0	327.8	0.681	-10
58	C2H3F3	1,1,1-TRIFLUOROETHANE	0.4336	0.253	161.9	346.2	0.948	25
59	C2H3N	ACETONITRILE	0.2006	0.184	229.3	547.9	0.782	20
60	C2H4	ETHYLENE	0.2131	0.280	104.0	282.8	0.577	-110
61	C2H4BR2	1,2-DIBROMOETHANE	0.8358	0.320	283.3	646.0	2.180	20
62	C2H4CL2	1,1-DICHLOROETHANE	0.4234	0.275	176.2	523.2	1.168	25
63	C2H4CL2	1,2-DICHLOROETHANE	0.4155	0.259	237.5	566.1	1.250	16
64	C2H4F2	1,1-DIFLUOROETHANE	0.3623	0.253	156.2	386.6	1.012	-26
65	C2H4I2	1,2-DI-IODOETHANE	0.8713	0.245	356.2	749.9	2.807	83
66	C2H4O	ETHYLENE-OXIDE	0.3137	0.259	161.0	468.9	0.899	0
67	C2H4O	ACETALDEHYDE	0.2501	0.220	150.2	461.1	0.778	20
68	C2H4O2	ACETIC-ACID	0.2798	0.201	289.8	594.4	1.049	20
69	C2H4O3	METHYL-FORMATE	0.3408	0.235	174.2	486.7	0.974	20
70	C2H4O3	THIOACETIC-ACID	0.4163	0.317	150.2	577.3	1.064	20
71	C2H4S	THIACYCLOPROPANE	0.2923	0.214	165.4	555.0	1.008	25
72	C2H5BR	BROMOETHANE	0.5997	0.320	154.6	505.7	1.451	25
73	C2H5CL	CHLOROETHANE	0.3398	0.272	136.8	460.4	0.896	20
74	C2H5F	FLUOROETHANE	0.2844	0.274	129.9	375.3	0.632	25
75	C2H5I	IODOETHANE	0.6334	0.248	165.0	554.0	1.950	20
76	C2H5N	ETHYLENIMINE	0.3022	0.215	195.2	524.0	1.012	25
77	C2H5NO2	NITROETHANE	0.3220	0.238	223.2	595.0	1.045	25
78	C2H5NO3	ETHYL-NITRATE	-	-	-	-	-	-
79	C2H6	ETHANE	0.2084	0.285	89.9	305.4	0.548	-90
80	C2H6O	METHYL-ETHER	0.2966	0.307	131.7	400.1	0.667	20
81	C2H6O	ETHYL-ALCOHOL	0.2567	0.240	159.1	515.8	0.789	20
82	C2H6O2	ETHYLENE-GLYCOL	0.3074	0.230	260.2	790.0	1.114	20
83	C2H6S	METHYL-SULFIDE	0.3021	0.266	174.9	503.3	0.848	20
84	C2H6S	ETHANETHIOL	0.3071	0.274	125.3	498.6	0.839	20
85	C2H6S2	METHYL-DISULFIDE	0.3572	0.268	188.4	605.0	1.057	25
86	C2H7N	ETHYLAMINE	0.2573	0.270	192.0	456.3	0.683	20
87	C2H7N	DIMETHYLAMINE	0.2430	0.256	181.0	437.8	0.656	20
88	C3H3N	ACRYLONITRILE	0.2321	0.210	189.5	536.0	0.806	20
89	C3H4	ALLENE (PROPADIENE)	0.2440	0.271	136.9	385.4	0.658	-35
90	C3H4	PROPYLENE (METHYLACETYLENE)	0.2537	0.275	170.5	401.0	0.706	-50
91	C3H4O2	ACRYLIC-ACID	0.3098	0.230	285.0	615.0	1.051	20
92	C3H5BR	3-BROMO-1-PROPENE	0.5079	0.282	153.8	540.2	1.398	20
93	C3H5CL	3-CHLORO-1-PROPENE	0.3252	0.260	138.7	513.8	0.937	20
94	C3H5CL3	1,2,3-TRICHLOROPROPANE	0.4317	0.250	258.5	651.0	1.389	20
95	C3H5I	3-IODO-1-PROPENE	0.5880	0.249	173.9	595.8	1.849	20
96	C3H5N	PROPIONITRILE	0.2165	0.205	180.3	562.5	0.782	20
97	C3H6	PROPENE	0.2328	0.282	87.9	365.0	0.612	-50
98	C3H6	CYCLOPROPANE	0.2285	0.272	145.7	398.0	0.563	15
99	C3H6BR2	1,2-DIBROMOPROPANE	0.7634	0.330	218.0	634.1	1.932	20
100	C3H6CL2	1,2-DICHLOROPROPANE	0.3215	0.210	172.7	577.0	1.150	20
101	C3H6CL2	1,3-DICHLOROPROPANE	0.3664	0.241	173.7	602.7	1.182	25
102	C3H6CL2	2,2-DICHLOROPROPANE	0.3663	0.266	239.4	539.5	1.114	20
103	C3H6I2	1,2-DI-IODOPROPANE	0.7451	0.242	253.2	780.5	2.576	20
104	C3H6O	PROPYLENE-OXIDE	0.2683	0.229	161.0	482.2	0.829	20
105	C3H6O	ALLYL-ALCOHOL	0.2704	0.240	144.0	515.3	0.797	20
106	C3H6O	PROPIONALDEHYDE	0.2763	0.260	193.0	515.3	0.797	20
107	C3H6O	ACETONE	0.2519	0.232	178.2	508.4	0.790	20
108	C3H6S	THIACYCLOPROPANE	0.3004	0.228	200.0	603.0	1.020	20
109	C3H7BR	1-BROMOPROPANE	0.5031	0.289	163.2	535.5	1.354	20
110	C3H7BR	2-BROMOPROPANE	0.4979	0.293	184.2	522.5	1.314	20
111	C3H7CL	1-CHLOROPROPANE	0.3286	0.278	150.4	503.1	0.891	20
112	C3H7CL	2-CHLOROPROPANE	0.3122	0.269	156.0	494.1	0.862	20
113	C3H7F	1-FLUOROPROPANE	0.3071	0.263	114.2	422.0	0.796	20
114	C3H7F	2-FLUOROPROPANE	0.2881	0.262	139.8	415.7	0.733	25
115	C3H7I	1-IODOPROPANE	0.5690	0.255	172.2	589.4	1.749	20
116	C3H7O	2-1000PROPANE	0.5659	0.259	183.1	574.6	1.703	20
117	C3H7O2	1-NITROPROPANE	0.3255	0.254	165.2	606.0	1.008	24
118	C3H7O2	2-NITROPROPANE	0.3211	0.256	180.2	597.0	0.988	20
119	C3H7O3	PROPYL-NITRATE	-	-	-	-	-	-
120	C3H7O3	ISOPROPYL-NITRATE	-	-	-	-	-	-
121	C3H8	PROPANE	0.2218	0.279	85.5	369.7	0.582	-42
122	C3H8O	ETHYL-METHYL-ETHER	0.2673	0.267	134.0	437.8	0.700	20
123	C3H8O	PROPYL-ALCOHOL	0.2684	0.253	146.9	536.9	0.804	20
124	C3H8O	ISOPROPYL-ALCOHOL	0.2623	0.248	184.7	516.6	0.786	20
125	C3H8S	ETHYL-METHYL-SULFIDE	0.2882	0.262	167.2	532.8	0.837	20
126	C3H8S	1-PROPANETHIOL	0.3030	0.278	160.0	536.0	0.836	25
127	C3H8S	2-PROPANETHIOL	0.3032	0.284	142.6	512.0	0.809	25
128	C3H9N	PROPYLAMINE	0.2607	0.271	190.0	496.1	0.717	20
129	C3H9N	TRIMETHYLAMINE	0.2568	0.288	156.0	433.4	0.633	20
130	C4F8	OCTAFLUOROOCYCLOBUTANE	0.6414	0.278	232.2	388.4	1.654	-20
131	C4H2	BUTADIENE (BIACETYLENE)	0.2640	0.271	237.2	478.0	0.736	0
132	C4H4	1,3-BUTADIENE	0.2518	0.260	227.6	455.0	0.710	0
133	C4H4O	FURAN	0.3583	0.286	187.5	487.0	0.938	20
134	C4H4S	THIOPHENE	0.3532	0.259	234.9	580.0	1.071	16
135	C4H6	1,2-BUTADIENE	0.2472	0.267	137.0	500.0	0.652	20
136	C4H6	1,3-BUTADIENE	0.2432	0.2				

NO.	FORMULA NAME	A	B	TMIN,K	TC,K	DENGT	T,C
231	C6H4CC2 M-DICHLOROBENZENE	0.4174	0.266	248.5	679.4	1.288	20
232	C6H4CL2 P-DICHLOROBENZENE	0.4067	0.265	226.3	680.9	1.224*	53
233	C6H4F2 M-DIFLUOROBENZENE	0.4007	0.265	249.2	552.9	1.169	20
234	C6H4F2 O-DIFLUOROBENZENE	0.3952	0.264	239.2	554.5	1.160	18
235	C6H4F2 P-DIFLUOROBENZENE	0.4012	0.266	260.2	556.0	1.169	20
236	C6H5BR BROMOBENZENE	0.4814	0.263	242.3	670.1	1.495	20
237	C6H5CL CHLOROBENZENE	0.3638	0.265	227.6	632.6	1.106	20
238	C6H5F FLUOROBENZENE	0.3475	0.263	234.0	559.8	1.024	20
239	C6H5I IODOBENZENE	0.5837	0.265	241.8	721.1	1.855	4
240	C6H6 BENZENE	0.3041	0.269	278.7	562.0	0.885	16
241	C6H6O PHENOL	0.4104	0.244	314.0	692.9	1.345	41
242	C6H6S BENZENETHIOL	0.3648	0.281	258.4	685.0	1.072	25
243	C6H7N 2-PICOLINE	0.3439	0.297	207.0	621.1	0.950	15
244	C6H7N 3-PICOLINE	0.3201	0.272	254.9	644.8	0.961	15
245	C6H7N ANILINE	0.3119	0.250	267.0	698.9	1.022	20
246	C6H10 1-HEXYNE	0.2602	0.280	141.3	529.0	0.711	25
247	C6H10 CYCLOHEXENE	0.2823	0.271	169.7	560.4	0.816	16
248	C6H10 1-METHYLCYCLOPENTENE	0.2760	0.273	146.0	542.0	0.785	15
249	C6H10 3-METHYLCYCLOPENTENE	0.2679	0.269	130.2	535.7	0.759	25
250	C6H10 4-METHYLCYCLOPENTENE	0.2649	0.265	112.3	543.8	0.763	25

251	C6H10O CYCLOHEXANONE	0.2950	0.248	242.0	629.1	0.951	15
252	C6H12 1-HEXENE	0.2416	0.270	133.3	508.5	0.673	20
253	C6H12 2-HEXENE,CIS	0.2448	0.270	132.0	518.0	0.687	20
254	C6H12 2-HEXENE,TRANS	0.2420	0.270	140.0	516.0	0.678	20
255	C6H12 3-HEXENE,CIS	0.2425	0.270	135.3	517.0	0.680	20
256	C6H12 3-HEXENE,TRANS	0.2339	0.260	159.7	519.9	0.677	20
257	C6H12 2-METHYL-1-PENTENE	0.2479	0.275	137.4	506.5	0.675	25
258	C6H12 3-METHYL-1-PENTENE	0.2471	0.277	120.2	495.3	0.663	25
259	C6H12 4-METHYL-1-PENTENE	0.2457	0.277	119.5	494.8	0.659	25
260	C6H12 2-METHYL-2-PENTENE	0.2450	0.270	138.1	518.0	0.691	16
261	C6H12 3-METHYL-2-PENTENE,CIS	0.2473	0.270	138.3	518.0	0.694	20
262	C6H12 3-METHYL-2-PENTENE,TRANS	0.2482	0.270	134.7	521.0	0.698	20
263	C6H12 4-METHYL-2-PENTENE,CIS	0.2439	0.270	139.0	490.0	0.669	20
264	C6H12 4-METHYL-2-PENTENE,TRANS	0.2432	0.270	132.0	493.0	0.669	20
265	C6H12 2-ETHYL-1-BUTENE	0.2493	0.273	141.6	510.4	0.685	25
266	C6H12 2,3-DIMETHYL-1-BUTENE	0.2448	0.270	115.9	501.0	0.673	20
267	C6H12 3,3-DIMETHYL-1-BUTENE	0.2380	0.270	158.0	490.0	0.658	20
268	C6H12 2,3-DIMETHYL-2-BUTENE	0.2512	0.270	198.9	524.0	0.708	20
269	C6H12 CYCLOHEXANE	0.2735	0.273	279.6	553.5	0.779	20
270	C6H12 METHYLCYCLOPENTANE	0.2669	0.273	130.7	533.2	0.754	16
271	C6H12O CYCLOHEXANOL	0.3276	0.279	298.0	625.1	0.942	30
272	C6H12O HEXANAL	0.2669	0.256	217.2	581.1	0.814	20
273	C6H12S THIAICYCLOHEPTANE	0.2969	0.322	292.1	640.1	0.766*	25
274	C6H14 HEXANE	0.2325	0.264	177.8	507.9	0.659	20
275	C6H14 2-METHYLPENTANE	0.2343	0.267	119.5	498.5	0.653	20
276	C6H14 3-METHYLPENTANE	0.2412	0.272	155.0	504.4	0.664	20
277	C6H14 2,2-DIMETHYLBUTANE	0.2383	0.273	173.3	488.2	0.649	20
278	C6H14 2,3-DIMETHYLBUTANE	0.2385	0.269	144.6	500.3	0.662	20
279	C6H14O PROPYL-ETHER	0.2599	0.262	187.7	500.2	0.724	20
280	C6H14O ISOPROPYL-ETHER	0.2556	0.260	187.7	500.2	0.724	20
281	C6H14O HEXYL-ALCOHOL	0.2697	0.262	229.2	610.0	0.819	20
282	C6H14S BUTYL-ETHYL-SULFIDE	0.2785	0.265	178.0	609.0	0.833	25
283	C6H14S ISOPROPYL-SULFIDE	0.2859	0.274	170.5	585.7	0.823	25
284	C6H14S METHYL-PENTYL-SULFIDE	0.2930	0.276	179.2	588.0	0.839	25
285	C6H14S PROPYL-SULFIDE	0.2792	0.266	170.5	609.7	0.833	25
286	C6H14S 1-HEXANETHIOL	0.2853	0.273	192.7	622.0	0.838	25
287	C6H14S2 PROPYL-DISULFIDE	0.3223	0.277	187.7	673.0	0.955	25
288	C6H15N TRIETHYLAMINE	0.2556	0.269	158.4	535.2	0.728	20
289	C7H5F3 A,A,A-TRIFLUOROTOLUENE	0.4187	0.276	244.1	562.6	1.188	20
290	C7H5N BENZONITRILE	0.2974	0.241	260.0	699.4	1.010	15
291	C7H6O2 BENZOIC-ACID	0.3531	0.250	395.6	752.0	1.075	130
292	C7H7F P-FLUOROTOLUENE	0.3313	0.262	216.4	590.5	1.001	16
293	C7H8 TOLUENE	0.2906	0.265	178.0	593.1	0.867	20
294	C7H8 1,3,5-CYCLOHEPTATRIENE	0.2980	0.266	193.7	593.9	0.888	19
295	C7H8O M-CRESOL	0.3040	0.240	285.4	705.4	1.034	20
296	C7H8O O-CRESOL	0.3131	0.244	304.1	695.3	1.028	40
297	C7H8O P-CRESOL	0.3092	0.244	307.9	704.5	1.019	40
298	C7H12 1-HEPTYNE	0.2584	0.276	192.3	559.7	0.728	25
299	C7H14 1-HEPTENE	0.2523	0.280	154.3	537.2	0.697	20
300	C7H14 CYCLOHEPTANE	0.2736	0.269	265.0	602.0	0.810	20

301	C7H14 ETHYLCYCLOPENTANE	0.2638	0.269	134.7	569.3	0.771	16
302	C7H14 1,1-DIMETHYLCYCLOPENTANE	0.2633	0.270	203.4	550.0	0.759	16
303	C7H14 C-1,2-DIMETHYLCYCLOPENTANE	0.2673	0.270	219.3	565.0	0.777	16
304	C7H14 C-1,3-DIMETHYLCYCLOPENTANE	0.2619	0.270	155.6	553.0	0.756	16
305	C7H14 C-1,4-DIMETHYLCYCLOPENTANE	0.2595	0.270	139.5	551.0	0.744	25
306	C7H14 T-1,3-DIMETHYLCYCLOPENTANE	0.2606	0.270	139.2	553.0	0.744	25
307	C7H14 METHYLCYCLOHEXANE	0.2596	0.263	166.6	572.3	0.774	10
308	C7H14O HEPTANAL	0.2655	0.250	229.9	638.5	0.850	20
309	C7H16 HEPTANE	0.2343	0.262	182.6	540.1	0.684	20
310	C7H16 2-METHYLHEXANE	0.2334	0.261	154.9	531.0	0.679	20
311	C7H16 3-METHYLHEXANE	0.2311	0.255	100.0	535.4	0.687	20
312	C7H16 3-ETHYLPENTANE	0.2434	0.266	145.6	540.7	0.698	20
313	C7H16 2,2-DIMETHYLPENTANE	0.2370	0.268	149.4	520.4	0.674	20
314	C7H16 2,3-DIMETHYLPENTANE	0.2341	0.256	149.4	537.6	0.695	20
315	C7H16 2,4-DIMETHYLPENTANE	0.2351	0.264	154.0	520.8	0.673	20
316	C7H16 3,3-DIMETHYLPENTANE	0.2460	0.273	138.7	536.3	0.693	20
317	C7H16 2,2,3-TRIMETHYLBUTANE	0.2409	0.266	248.3	530.4	0.690	20
318	C7H16O ISOPROPYL-TERT-BUTYL-ETHER	0.2548	0.261	177.8	558.2	0.755	20
319	C7H16O HEPTYL-ALCOHOL	0.2679	0.262	239.2	631.9	0.822	20
320	C7H16S BUTYL-PROPYL-SULFIDE	0.2697	0.259	206.7	653.5	0.839	25
321	C7H16S ETHYL-PENTYL-SULFIDE	0.2715	0.259	206.7	638.4	0.839	25
322	C7H16S HEXYL-METHYL-SULFIDE	0.2715	0.259	206.7	638.4	0.839	25
323	C7H16S 1-HEPTANETHIOL	0.2775	0.267	229.9	645.0	0.839	25
324	C8H6 ETHYLBENZENE	0.3025	0.273	242.5	655.4	0.901	25
325	C8H8 STYRENE	0.2992	0.264	242.5	617.1	0.906	20
326	C8H8 1,3,5,7-CYCLOOCTATETRAENE	0.3015	0.268	266.2	642.6	0.908*	25
327	C8H10 ETHYLBENZENE	0.2898	0.268	178.2	617.9	0.867	20
328	C8H10 M-XYLENE	0.2806	0.259	225.3	619.0	0.864	20
329	C8H10 O-XYLENE	0.2869	0.262	248.0	631.1	0.880	20
330	C8H10 P-XYLENE	0.2807	0.260	286.4	617.4	0.861	20
331	C8H14 1-OCTYNE	0.2547	0.270	193.9	586.9	0.742	25
332	C8H16 1-OCTENE	0.2535	0.280	171.4	571.7	0.715	20
333	C8H16 CYCLOOCTANE	0.2779	0.271	287.6	647.2	0.834	20
334	C8H16 PROPYLCYCLOPENTANE	0.2472	0.250	155.8	603.0	0.781	16
335	C8H16 ETHYLCYCLOHEXANE	0.2661	0.270	161.8	609.0	0.798	20
336	C8H16 1,1-DIMETHYLCYCLOHEXANE	0.2664	0.270	239.7	591.0	0.785	16
337	C8H16 C-1,2-DIMETHYLCYCLOHEXANE	0.2692	0.270	225.1	606.0	0.796	20
338	C8H16 T-1,2-DIMETHYLCYCLOHEXANE	0.2637	0.270	185.0	596.0	0.776	20
339	C8H16 C-1,3-DIMETHYLCYCLOHEXANE	0.2610	0.270	197.6	591.0	0.766	20
340	C8H16 T-1,3-DIMETHYLCYCLOHEXANE	0.2534	0.254	183.0	598.0	0.785	20
341	C8H16 C-1,4-DIMETHYLCYCLOHEXANE	0.2658	0.270	185.7	598.0	0.783	20
342	C8H16 T-1,4-DIMETHYLCYCLOHEXANE	0.2604	0.270	236.2	587.7	0.763	20
343	C8H16O OCTANAL	0.2635	0.256	245.9	621.1	0.816	25
344	C8H18 OCTANE	0.2343	0.259	216.4	569.1	0.703	20
345	C8H18 2-METHYLHEPTANE	0.2355	0.261	164.0	560.6	0.702	16
346	C8H18 3-METHYLHEPTANE	0.2308	0.252	152.7	564.1	0.706	20
347	C8H18 4-METHYLHEPTANE	0.2359	0.259	152.2	562.2	0.705	20

NO.	FORMULA NAME	A	B	TMIN,K	TC,K	DENGT	T,C
348	C8H18 3-ETHYLHEXANE	0.2334	0.252	152.2	566.1	0.718	16
349	C8H18 2,2-DIMETHYLHEXANE	0.2380	0.264	152.0	549.9	0.695	20
350	C8H18 2,3-DIMETHYLHEXANE	0.2409	0.263	172.0	564.5	0.712	20

351	C8H18 2,4-DIMETHYLHEXANE	0.2376	0.262	172.0	554.1	0.700	20
352	C8H18 2,5-DIMETHYLHEXANE	0.2359	0.262	181.9	549.9	0.693	20
353	C8H18 3,3-DIMETHYLHEXANE	0.2323	0.252	147.0	562.8	0.710	20
354	C8H18 3,4-DIMETHYLHEXANE	0.2433	0.264	147.1	569.7	0.719	20
355	C8H18 3-ETHYL-2-METHYLPENTANE	0.2348	0.254	158.2	567.0	0.718	20
356	C8H18 3-ETHYL-3-METHYLPENTANE	0.2466	0.266	182.3	576.5	0.727	20
357	C8H18 2,2,3-TRIMETHYLPENTANE	0.2357	0.254	160.9	563.5	0.716	20
358	C8H18 2,2,4-TRIMETHYLPENTANE	0.2394	0.266	165.8	563.8	0.692	20
359	C8H18 2,3,3-TRIMETHYLPENTANE	0.2469	0.269	172.5	573.5	0.726	20
360	C8H18 2,3,6-TRIMETHYLPENTANE	0.2445	0.265	163.9	566.4	0.719	20
361	C8H18 2,2,3,3-TETRAMETHYLBUTANE	0.2474	0.280	172.5	567.8	0.692*	25
362	C8H18O BUTYL-ETHER	0.2544	0.259	175.0	580.0	0.768	20
363	C8H18O SEC-BUTYL-ETHER	0.2601	0.266	171.7	562.0	0.756	25
364	C8H18O TERT-BUTYL-ETHER	0.2716	0.268	206.5	550.0	0.779*	25
365	C8H18O OCTYL-ALCOHOL	0.2635	0.258	257.7	652.5	0.826	20
366	C8H18S BUTYL-SULFIDE	0.2711	0.260	209.9	650.0	0.840	25

NO.	FORMULA	NAME	A	B	TMIN, K	TC, K	DENST, T, C
465	C10H22	3,5-DIMETHYLOCTANE	0.2268	0.241	219.2	606.3	0.733 25
466	C10H22	3,6-DIMETHYLOCTANE	0.2280	0.243	219.2	608.3	0.732 25
467	C10H22	4,4-DIMETHYLOCTANE	0.2254	0.240	219.2	606.9	0.731 25
468	C10H22	4,5-DIMETHYLOCTANE	0.2285	0.240	219.2	612.2	0.743 25
469	C10H22	4-PROPYLHEPTANE	0.2249	0.238	219.2	601.0	0.732 25
470	C10H22	4-ISOPROPYLHEPTANE	0.2243	0.237	219.2	607.6	0.735 25
471	C10H22	3-ETHYL-2-METHYLHEPTANE	0.2268	0.239	219.2	610.9	0.740 25
472	C10H22	4-ETHYL-2-METHYLHEPTANE	0.2248	0.238	219.2	601.8	0.732 25
473	C10H22	5-ETHYL-2-METHYLHEPTANE	0.2264	0.241	219.2	606.7	0.732 25
474	C10H22	5-ETHYL-3-METHYLHEPTANE	0.2269	0.238	219.2	620.0	0.746 25
475	C10H22	4-ETHYL-3-METHYLHEPTANE	0.2269	0.237	219.2	614.3	0.747 25
476	C10H22	3-ETHYL-4-METHYLHEPTANE	0.2264	0.239	219.2	606.6	0.737 25
477	C10H22	4-ETHYL-4-METHYLHEPTANE	0.2268	0.237	219.2	615.5	0.747 25
478	C10H22	4-ETHYL-5-METHYLHEPTANE	0.2269	0.237	219.2	615.7	0.747 25
479	C10H22	2,2,3-TRIMETHYLHEPTANE	0.2302	0.244	219.2	611.7	0.739 25
480	C10H22	2,2,4-TRIMETHYLHEPTANE	0.2262	0.242	219.2	594.5	0.724 25
481	C10H22	2,2,5-TRIMETHYLHEPTANE	0.2275	0.244	219.2	598.0	0.724 25
482	C10H22	2,2,6-TRIMETHYLHEPTANE	0.2290	0.247	219.2	593.4	0.720 25
483	C10H22	2,3,3-TRIMETHYLHEPTANE	0.2308	0.243	219.2	617.5	0.745 25
484	C10H22	2,3,4-TRIMETHYLHEPTANE	0.2296	0.241	219.2	613.7	0.745 25
485	C10H22	2,3,5-TRIMETHYLHEPTANE	0.2278	0.240	219.2	612.8	0.741 25
486	C10H22	2,3,6-TRIMETHYLHEPTANE	0.2288	0.244	219.2	606.1	0.731 25
487	C10H22	2,4,4-TRIMETHYLHEPTANE	0.2269	0.241	219.2	600.3	0.731 25
488	C10H22	2,4,5-TRIMETHYLHEPTANE	0.2281	0.241	219.2	606.9	0.737 25
489	C10H22	2,4,6-TRIMETHYLHEPTANE	0.2275	0.245	219.2	590.3	0.719 25
490	C10H22	2,5,5-TRIMETHYLHEPTANE	0.2298	0.243	219.2	602.9	0.736 25
491	C10H22	3,3,4-TRIMETHYLHEPTANE	0.2310	0.241	219.2	622.1	0.753 25
492	C10H22	3,3,5-TRIMETHYLHEPTANE	0.2338	0.248	219.2	609.5	0.739 25
493	C10H22	3,4,4-TRIMETHYLHEPTANE	0.2314	0.241	219.2	620.9	0.754 25
494	C10H22	3,4,5-TRIMETHYLHEPTANE	0.2311	0.240	219.2	612.8	0.752 25
495	C10H22	3-ISOPROPYL-2-METHYLHEXANE	0.2226	0.234	219.2	623.4	0.744 25
496	C10H22	3-DIETHYLHEXANE	0.2278	0.236	219.2	627.8	0.758 25
497	C10H22	3,4-DIETHYLHEXANE	0.2250	0.235	219.2	618.8	0.747 25
498	C10H22	3-ETHYL-2,2-DIMETHYLHEXANE	0.2282	0.239	219.2	615.7	0.745 25
499	C10H22	4-ETHYL-2,2-DIMETHYLHEXANE	0.2282	0.242	219.2	594.6	0.730 25
500	C10H22	3-ETHYL-2,3-DIMETHYLHEXANE	0.2319	0.240	219.2	626.8	0.760 25

501	C10H22	4-ETHYL-2,3-DIMETHYLHEXANE	0.2297	0.239	219.2	617.3	0.752 25
502	C10H22	3-ETHYL-2,4-DIMETHYLHEXANE	0.2297	0.239	219.2	616.1	0.751 25
503	C10H22	3-ETHYL-2,4-DIMETHYLHEXANE	0.2311	0.241	219.2	620.9	0.753 25
504	C10H22	3-ETHYL-2,5-DIMETHYLHEXANE	0.2276	0.240	219.2	603.5	0.737 25
505	C10H22	4-ETHYL-3,3-DIMETHYLHEXANE	0.2312	0.239	219.2	625.7	0.760 25
506	C10H22	3-ETHYL-3,4-DIMETHYLHEXANE	0.2305	0.238	219.2	624.5	0.760 25
507	C10H22	2,2,3,3-TETRAMETHYLHEXANE	0.2342	0.242	219.2	623.0	0.761 25
508	C10H22	2,2,3,4-TETRAMETHYLHEXANE	0.2308	0.241	219.2	620.4	0.751 25
509	C10H22	2,2,3,5-TETRAMETHYLHEXANE	0.2307	0.245	219.2	601.3	0.734 25
510	C10H22	2,2,4,4-TETRAMETHYLHEXANE	0.2261	0.237	219.2	610.2	0.742 25
511	C10H22	2,2,4,5-TETRAMETHYLHEXANE	0.2289	0.243	219.2	598.5	0.732 25
512	C10H22	2,2,5,5-TETRAMETHYLHEXANE	0.2356	0.256	260.6	581.4	0.715 25
513	C10H22	2,3,3,4-TETRAMETHYLHEXANE	0.2345	0.242	260.6	633.1	0.766 25
514	C10H22	2,3,3,5-TETRAMETHYLHEXANE	0.2316	0.243	260.6	610.1	0.745 25
515	C10H22	2,3,4,4-TETRAMETHYLHEXANE	0.2385	0.241	260.6	626.6	0.779 25
516	C10H22	2,3,4,5-TETRAMETHYLHEXANE	0.2315	0.243	260.6	613.2	0.746 25
517	C10H22	3,3,4,4-TETRAMETHYLHEXANE	0.2371	0.242	260.6	646.7	0.779 25
518	C10H22	2,4-DIMETHYL-3-ISOPROPYLPENTANE	0.2309	0.239	191.5	614.4	0.755 25
519	C10H22	3,3-DIETHYL-2-METHYLPENTANE	0.2344	0.239	191.5	639.9	0.776 25
520	C10H22	3-ETHYL-2,2,3-TRIMETHYLPENTANE	0.2361	0.241	191.5	646.0	0.778 25
521	C10H22	3-ETHYL-2,2,4-TRIMETHYLPENTANE	0.2312	0.240	191.5	615.3	0.753 25
522	C10H22	3-ETHYL-2,3,4-TRIMETHYLPENTANE	0.2351	0.241	191.5	642.3	0.774 25
523	C10H22	2,2,3,4-PENTAMETHYLPENTANE	0.2392	0.245	236.7	643.8	0.777 25
524	C10H22	2,2,3,4-PENTAMETHYLPENTANE	0.2330	0.240	234.4	627.3	0.764 25
525	C10H22	DECYL-ALCOHOL	0.2561	0.252	280.1	687.0	0.830 20
526	C10H22S	BUTYL-HEXYL-SULFIDE	0.2478	0.239	238.2	701.0	0.841 25
527	C10H22S	ETHYL-OCTYL-SULFIDE	0.2478	0.239	238.2	701.0	0.841 25
528	C10H22S	HEPTYL-PROPYL-SULFIDE	0.2478	0.239	238.2	701.0	0.841 25
529	C10H22S	METHYL-NONYL-SULFIDE	0.2478	0.239	238.2	701.0	0.841 25
530	C10H22S	PENTYL-SULFIDE	0.2544	0.249	247.6	702.2	0.841 25
531	C10H22S	1-DECANETHIOL	0.2816	0.254	214.2	726.9	0.918 25
532	C10H22S	2-PENTYL-1-DIETHYLBENZENE	0.2872	0.234	242.7	702.0	0.918 25
533	C11H10	1-METHYLNAPHTHALENE	0.3107	0.260	307.7	764.3	0.990 40
534	C11H10	2-METHYLNAPHTHALENE	0.3107	0.260	307.7	764.3	0.990 40
535	C11H16	PENTYLBENZENE	0.2727	0.260	198.2	679.9	0.855 25
536	C11H16	PENTAMETHYLBENZENE	0.2728	0.228	327.5	719.0	0.945* 55
537	C11H20	1-UNDECYNE	0.2409	0.251	248.2	651.0	0.769 25
538	C11H22	1-UNDECENE	0.2269	0.240	224.0	637.0	0.751 20
539	C11H22	1-CYCLOPENTYLHEXANE	0.2400	0.243	200.2	667.7	0.793 25
540	C11H22	PENTYLCYCLOHEXANE	0.2425	0.244	215.7	674.0	0.800 25
541	C11H24	UNDECANE	0.2241	0.241	247.6	640.1	0.740 20
542	C11H24O	UNDECYL-ALCOHOL	0.2598	0.254	292.2	666.3	0.830 30
543	C11H24S	BUTYL-HEPTYL-SULFIDE	0.2402	0.232	254.7	717.9	0.841 25
544	C11H24S	DECYL-METHYL-SULFIDE	0.2402	0.232	254.7	717.9	0.841 25
545	C11H24S	ETHYL-NONYL-SULFIDE	0.2402	0.232	254.7	717.9	0.841 25
546	C11H24S	OCTYL-PROPYL-SULFIDE	0.2402	0.232	254.7	717.9	0.841 25
547	C11H24S	1-UNDECANETHIOL	0.2491	0.242	270.4	716.5	0.841 25
548	C12H10	BIPHENYL	0.3508	0.294	342.4	789.3	0.990 74
549	C12H12	1-ETHYLNAPHTHALENE	0.3036	0.253	259.4	774.9	0.904 25
550	C12H12	2-ETHYLNAPHTHALENE	0.2997	0.254	265.8	774.9	0.988 25

551	C12H12	1,2-DIMETHYLNAPHTHALENE	0.2960	0.243	272.2	775.3	1.014 25
552	C12H12	1,3-DIMETHYLNAPHTHALENE	0.2958	0.244	269.2	773.8	1.003 25
553	C12H12	1,4-DIMETHYLNAPHTHALENE	0.2956	0.243	280.8	776.8	1.013 25
554	C12H12	1,5-DIMETHYLNAPHTHALENE	0.2996	0.244	355.2	775.5	0.978* 82
555	C12H12	1,6-DIMETHYLNAPHTHALENE	0.2940	0.245	259.2	770.6	0.999 25
556	C12H12	1,7-DIMETHYLNAPHTHALENE	0.2940	0.245	260.2	770.6	0.999 25
557	C12H12	2,3-DIMETHYLNAPHTHALENE	0.2996	0.242	378.2	777.8	0.968* 105
558	C12H12	2,6-DIMETHYLNAPHTHALENE	0.2996	0.245	385.2	769.2	0.949* 112
559	C12H12	2,7-DIMETHYLNAPHTHALENE	0.2996	0.245	371.2	770.6	0.961* 98
560	C12H18	HEXYLBENZENE	0.2706	0.260	212.2	697.5	0.854 25
561	C12H18	1,2,3-TRIETHYLBENZENE	0.2644	0.246	206.7	684.4	0.874 20
562	C12H18	1,2,4-TRIETHYLBENZENE	0.2644	0.246	206.7	684.4	0.874 20
563	C12H18	1,3,5-TRIETHYLBENZENE	0.2707	0.247	206.7	682.3	0.887* 25
564	C12H18	HEXAMETHYLBENZENE	0.2707	0.216	438.7	758.0	0.896* 166
565	C12H22	1-DODECENE	0.2354	0.244	254.2	668.2	0.775 25
566	C12H24	1-DODECANE	0.2214	0.233	238.0	657.0	0.758 20
567	C12H24	1-CYCLOPENTYLHEPTANE	0.2379	0.237	220.0	679.0	0.810 20
568	C12H24	1-CYCLOHEXYLHEXANE	0.2628	0.238	263.6	691.8	0.892* 25
569	C12H26	DODECANE	0.2222	0.238	263.6	659.5	0.748 20
570	C12H26O	DODECYL-ALCOHOL	0.2474	0.240	297.1	679.0	0.830 25
571	C12H26S	BUTYL-OCTYL-SULFIDE	0.2328	0.225	259.2	733.7	0.842 25
572	C12H26S	DECYL-ETHYL-SULFIDE	0.2328	0.225	259.2	733.7	0.842 25
573	C12H26S	HEXYL-SULFIDE	0.2328	0.225	259.2	733.7	0.842 25
574	C12H26S	METHYL-UNDECYL-SULFIDE	0.2328	0.225	259.2	733.7	0.842 25
575	C12H26S	NONYL-PROPYL-SULFIDE	0.2328	0.225	259.2	733.7	0.842 25
576	C12H26S	1-DODECANETHIOL	0.2429	0.236	265.4	729.8	0.842 25
577	C12H26S	2-ETHYLNAPHTHALENE	0.2653	0.241	225.2	747.1	0.908 25
578	C13H14	1-PROPYLNAPHTHALENE	0.2934	0.248	264.7	771.5	0.987 25
579	C13H14	2-PROPYLNAPHTHALENE	0.2893	0.248	270.2	772.4	0.973 25
580	C13H14	3-ETHYL-6-METHYLNAPHTHALENE	0.2948	0.243	344.2	776.4	0.976* 71
581	C13H14	2-ETHYL-6-METHYLNAPHTHALENE	0.2948	0.246	318.2	766.6	0.982* 43
582	C13H14	2-ETHYL-7-METHYLNAPHTHALENE	0.2948	0.246	318.2	766.6	0.982* 43

NO.	FORMULA	NAME	A	B	TMIN, K	TC, K	DENST	T, C
583	C13H20	1-PHENYLHEPTANE	0.2601	0.250	225.2	713.5	0.853	25
584	C13H24	1-TRIDECYNE	0.2299	0.237	268.2	684.1	0.781	25
585	C13H26	1-TRIDECENE	0.2165	0.226	250.1	674.0	0.766	20
586	C13H26	1-CYCLOPENTYLOCTANE	0.2292	0.231	229.2	702.7	0.801	25
587	C13H26	1-CYCLOHEXYLHEPTANE	0.2305	0.231	242.7	708.6	0.808	25
588	C13H28	TRIDECANE	0.2237	0.239	267.8	678.4	0.756	20
589	C13H28O	1-TRIDECANOL	0.2561	0.241	304.2	693.7	0.856*	31
590	C13H28S	BUTYL-NONYL-SULFIDE	0.2265	0.219	271.2	748.4	0.842	25
591	C13H28S	DECYL-PROPYL-SULFIDE	0.2265	0.219	271.2	748.4	0.842	25
592	C13H28S	DODECYL-METHYL-SULFIDE	0.2265	0.219	271.2	748.4	0.842	25
593	C13H28S	ETHYL-UNDECYL-SULFIDE	0.2265	0.219	271.2	748.4	0.842	25
594	C13H28S	1-TRIDECANETHIOL	0.2367	0.230	282.0	742.1	0.842	25
595	C14H16	1-BUTYLNAPHTHALENE	0.2845	0.244	253.4	781.5	0.973	25
596	C14H16	2-BUTYLNAPHTHALENE	0.2812	0.244	268.2	781.0	0.962	25
597	C14H22	1-PHENYLOCTANE	0.2587	0.250	237.2	728.0	0.853	25
598	C14H22	1,2,3,4,5-TETRAETHYLBENZENE	0.2541	0.233	285.0	708.2	0.888	20
599	C14H22	1,2,3,5-TETRAETHYLBENZENE	0.2535	0.234	284.2	707.5	0.882	20
600	C14H22	1,2,4,5-TETRAETHYLBENZENE	0.2527	0.234	285.2	706.9	0.879	20

FIGURE 1

$$I. VCF = EXP \left[- \left(\frac{K_0 + K_1 \cdot \rho_T}{\rho_T^2} \right) \cdot \Delta t \left\{ 1.0 + 0.8 \left(\frac{K_0 + K_1 \cdot \rho_T}{\rho_T^2} \right) \cdot \Delta t \right\} \right]$$

A) CRUDE OIL $K_0 = 341.0957 \text{ (Kg/m}^3\text{)}^2/\text{°F}$ (Table 6A)
 $K_1 = 0.0$
 Range: 0 - 100°API

B) FUEL OIL $K_0 = 103.8720$
 $K_1 = 0.2701$
 Range: 0 - 37°API

LPG $\begin{cases} K_0 = 876.5 \\ K_1 = 0.868 \end{cases}$

C) JET GROUP $K_0 = 330.3010$
 $K_1 = 0.0$
 Range: 37.1 - 47.9°API

D) GASOLINES $K_0 = 192.4571$
 $K_1 = 0.2438$
 Range: 52.1 - 85°API

1.63 -
1.75 -

For Segment Between Jet and Gasoline Group, i.e. 48 - 52°API

$$II. VCF = EXP \left[- \left(\frac{A + \frac{B}{\rho_T^2}}{\rho_T^2} \right) \cdot \Delta t \left\{ 1.0 + 0.8 \left(\frac{A + \frac{B}{\rho_T^2}}{\rho_T^2} \right) \cdot \Delta t \right\} \right]$$

Volume correction factor

A = -0.00186840
 B = 1489.0670

$\Delta t = t - T$

t = Any Temp., °F

T = Base Temp., 60°F

ρ_T = Density at Base Temp., Kg/m³

α_T = Co-efficient of Thermal Expansion at Base Temp.

ρ_T = sg.gr. 60/60°F x 999.012 Kg/m³

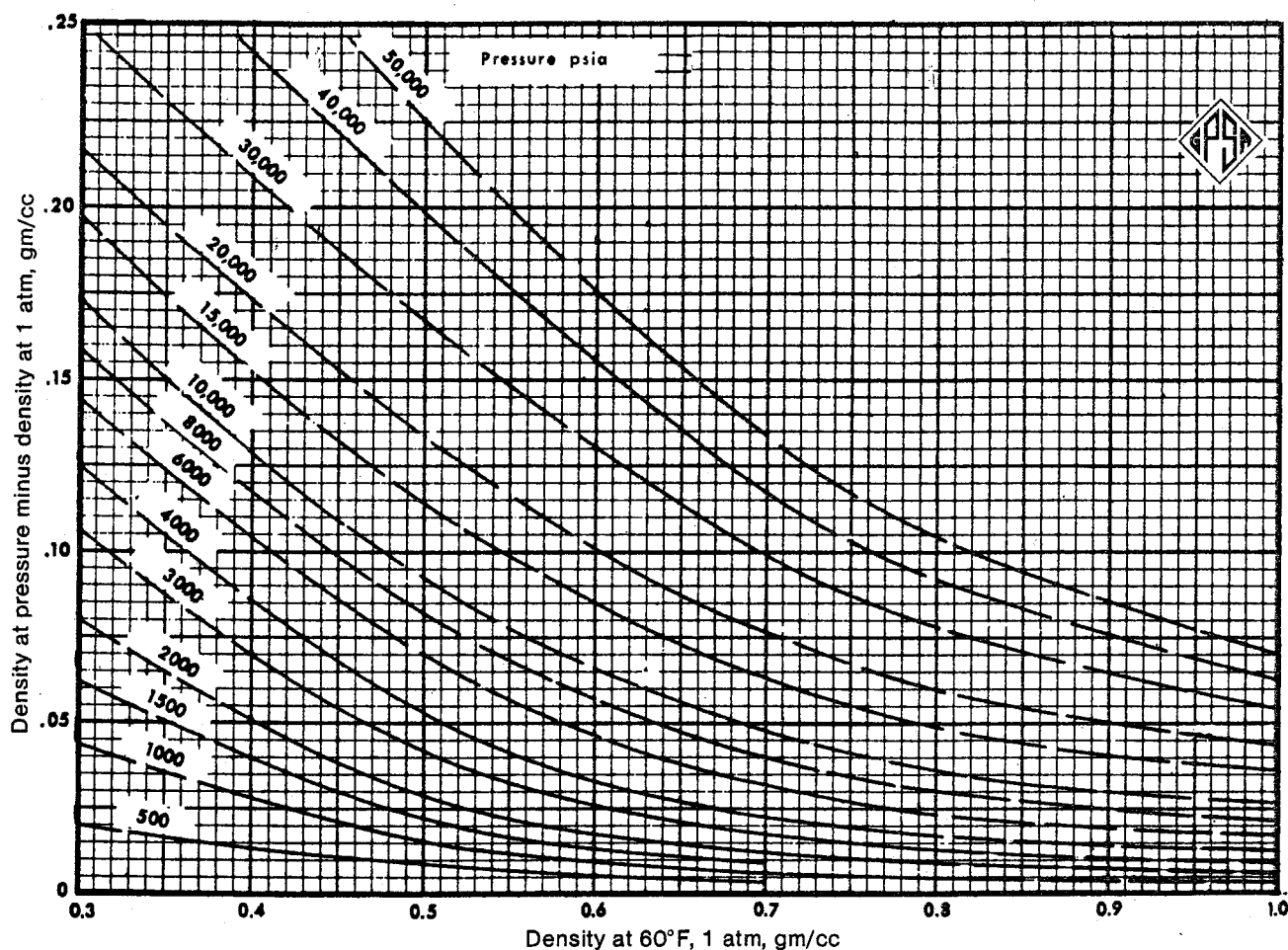
where 999.012 = Density of H₂O @ 60°F, Kg/m³

$$\text{water} = 999.012 \frac{\text{kg}}{\text{m}^3} \left(\frac{2.20462 \text{ lb}}{\text{kg}} \right) \left(\frac{\text{m}^3}{35.3147 \text{ ft}^3} \right) = 62.366 \frac{\text{lb}}{\text{ft}^3} \text{ H}_2\text{O @ 60°F.}$$

$$\frac{3.785 \text{ gal}}{\text{gal}} \left(\frac{\text{m}^3}{1000 \text{ L}} \right) \left(\frac{35.3147 \text{ ft}^3}{\text{m}^3} \right) = 0.13368 \frac{\text{ft}^3}{\text{gal}}$$

$$1.88 \text{ L} \left(\frac{4.2 \text{ gal}}{\text{BBL}} \right) \left(\frac{0.13368 \text{ ft}^3}{\text{gal}} \right) = 5.6146 \frac{\text{ft}^3}{\text{BBL}}$$

FIG. 23-20
Effect of Pressure on Hydrocarbon Liquid Densities¹¹



Specific gravities of petroleum fractions are given in Fig. 23-18 where temperature ranges from 0° to 1,000°F and pressures from atmospheric to 1,500 psia. The petroleum fraction is identified within the center grid by two of three characteristics: API gravity at 60°F, the characterization factor, K_w , or the mean-average boiling point. The mean average boiling point can be determined from Fig. 23-25 together with the API gravity and an ASTM distillation of the petroleum fraction. The characterization factor, K_w , is defined in the example shown in Fig. 23-18.

The specific gravity of paraffinic hydrocarbons at their boiling point or bubble point pressure and temperature can be obtained from Fig. 23-19. The nomograph applies to mixtures as well as to single components. Alignment points for paraffinic mixtures and pure components are located according to molecular weight.

Fig. 23-19 generally predicts specific gravities within 3% of measured values for paraffinic mixtures. However, the accuracy is somewhat less for mixtures having:

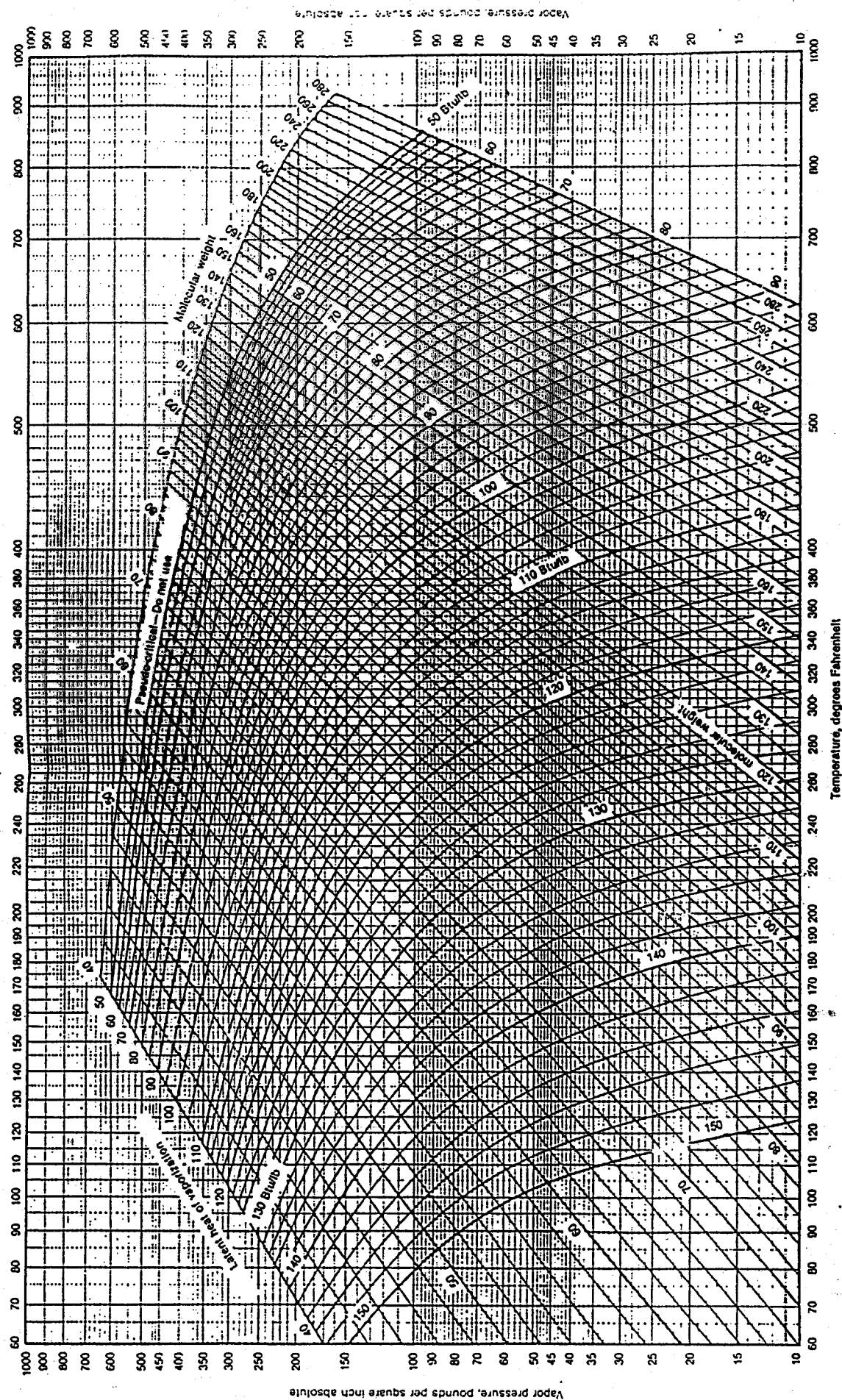
- Reduced temperatures above 0.9.
- Molecular weights less than 30 (low temperature region) and where methane is a significant part of the liquid.

Density of Saturated and Subcooled Liquid Mixtures

A versatile, manual procedure for calculating the density of gas saturated and subcooled hydrocarbon liquid mixtures is that of Standing and Katz.¹ The basic method proposed used the additive volume approach for propane and heavier components at standard conditions, then corrected this ideal volume using apparent densities for the gaseous components ethane and methane. The resulting pseudodensity at 60°F and 14.7 psia was corrected for pressure using a hydrocarbon liquid compressibility chart, then for temperature using a thermal expansion chart for hydrocarbon liquids. Experience with crude oils and rich absorber oils shows this correlation will predict densities within 1 to 4% of experimental data.

The original correlation did not have a procedure for handling significant amounts of nonhydrocarbons and had a fairly narrow temperature range of 60°F to 240°F. The following procedures and charts are recommended for general applicability to liquids containing components heavier than pentanes (gas saturated or subcooled) at pressures up to 10,000 psia and temperatures from -100°F to 600°F. Significant amounts of nonhydrocarbons can be handled by this procedure (up to 20% N_2 , 80% CO_2 , and 30% H_2S).

Temperature, degrees Fahrenheit



Temperature, degrees Fahrenheit

Figure D-3—Vapor Pressure and Heat of Vaporization of Pure Single-Component Paraffin Hydrocarbon Liquids

(°F)

COX
CHART

PD-850

