

Upstream Process Engineering Course

1a. Physical Properties

Physical Properties

Accurate physical properties are required for system and equipment design. Errors here will result in a flawed design or perhaps an unsafe design.

CENTRIFUGAL PUMPS (API 610)																					
DATA SHEET																					
1 Facility Name/Location:	Supplier: Sulzer																				
2 Item Name: Cooling Medium Circulating Pumps	Company Project Number: 2200																				
3 Item Tag Number:	Purchase Order Number: 22001-434.0																				
4	Supplier Project Number:																				
• GENERAL Applicable to: <input checked="" type="checkbox"/> Proposal <input type="checkbox"/> Purchase <input type="checkbox"/> As Built Information to be completed by: <input type="checkbox"/> Supplier <input checked="" type="checkbox"/> Supplier if not completed by Company For: <input type="checkbox"/> Unit <input type="checkbox"/> Supplier Site: UK Offshore Service: 35 wt% TEG and Water Qty Req: Two (2) Pump Size: 8 X 10 X 14 Type: OH2 Qty Stages: One (1) Manufacturer: Sulzer Model: CAP8 Serial No.: Pumps to Operate in (Parallel): Qty Motor Driven: Two (2) Qty Turbine Driven: (Series) With: Pump Item No.: PBE-6240/6241 Turbine Item No.: Gear Item No.: Motor Item No.: Turbine Item No.: Gear Provided By: Motor Provided By: Supplier Turbine Provided By: Gear Mounted By: Motor Mounted By: Supplier Turbine Mounted By: Gear Data Sheet No.: Motor D. S. CLR-1-10-EL-DS-6108 Turbine Data Sheet No.:																					
• OPERATING CONDITIONS Capacity: Normal, m ³ /hr 500 Rated m ³ /hr 570 Other: Suction Pressure, BarG: Max: Rated 3.6 Discharge Pressure, BarG: 8.3 Differential Pressure, Bar: 4.7 Differential Head, m: 46.8 NPSHA, m: 20 Process Variation (3.1.2): Starting Conditions (3.1.3): Service: <input checked="" type="checkbox"/> Continuous <input type="checkbox"/> Intermittent <input type="checkbox"/> Parallel Operation Req'd (2.1.11)																					
• SITE AND UTILITY DATA Location: (2.1.2.9) <input type="checkbox"/> Indoor <input type="checkbox"/> Heated <input type="checkbox"/> Under Roof <input checked="" type="checkbox"/> Outdoor <input checked="" type="checkbox"/> Unheated <input type="checkbox"/> Partial Shades <input type="checkbox"/> Grade <input type="checkbox"/> Mezzanine <input checked="" type="checkbox"/> Cellular Deck Electrical Area Classification (2.1.22/3.1.5) <input checked="" type="checkbox"/> IEC Zone 2 <input checked="" type="checkbox"/> IEC Symbol Exn, IIA, T3 <input type="checkbox"/> Winterization Req'd <input type="checkbox"/> Tropicalization Req'd Site Data: (2.1.29) SEE CLR-1-10-ME-SP-2201 Altitude, m: 28 Barometer, BarG: 0 Ambient Temp Range, °C: Min: 16 Max: 22 Relative Humidity, %RH: Min: Max: 100 Unusual Conditions (2.1.23) <input type="checkbox"/> Dust <input type="checkbox"/> Fumes Other: Offshore marine, north sea atmosphere Steam Conditions: Min: BarG °C Max: BarG °C <input type="checkbox"/> Drivers: <input type="checkbox"/> Heating:																					
• LIQUID Type/Name of Liquid: 35 wt% TEG and Water Pumping Temperature: Normal, °C: 49 Max: °C: Min: °C: 18 Vapor Pressure, BarA: 0.14 at °C: 49 Relative Density (Specific Gravity): Normal: 1.04 Max: Min: Specific Heat, (kJ/kg°C): 3.76 Viscosity, cP: 1.5 at °C: 49 Max Viscosity, cP: 3.5 @ 18 deg C Corrosive/Erosive Agents (2.1.11.8): Chloride Concentration, ppm (3.5.2.6): ≤10																					
<table border="1"> <thead> <tr> <th>No</th> <th>Date</th> <th>Revision</th> <th>By</th> <th>Apvd.</th> </tr> </thead> <tbody> <tr> <td>1</td> <td>22/07/02</td> <td>Revised Inc. Comments</td> <td>SB</td> <td>TV</td> </tr> <tr> <td>2</td> <td>11/09/02</td> <td>Revised Inc. Comments</td> <td>SB</td> <td>TV</td> </tr> <tr> <td>4</td> <td>28/03/03</td> <td>As Built</td> <td>SB</td> <td>TV</td> </tr> </tbody> </table>		No	Date	Revision	By	Apvd.	1	22/07/02	Revised Inc. Comments	SB	TV	2	11/09/02	Revised Inc. Comments	SB	TV	4	28/03/03	As Built	SB	TV
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Document Control No.	Project: 2200 Site: CLR-1 Location: 10 Discipline: ME Type: DS Seq. No: 0240 Revision: 0																				

GENERAL INFORMATION	
1 APPLICABLE TO:	T PROPOSAL <input type="checkbox"/> PURCHASE <input type="checkbox"/> AS BUILT
2 Item No.:	HBG-3540
3 Site:	BP Clair Platform / UK Continental Shelf, West of Shetlands
4 Service:	HP Compressor Discharge Cooler Serial Number 32016-1
5 Size:	508-4877 Type: NEN Shells/Unit: One (1)
6 Surface/Unit:	90.4 (m ²) Surface/Shell (Eff): 90.4 (m ²)
7 Manufacturer:	Allards International Ltd Connected In: <input checked="" type="checkbox"/> Series <input type="checkbox"/> Parallel
PERFORMANCE OF ONE UNIT	
8 Fluid Allocation	Shell Side Tube Side
9 Fluid Circulated	Cooling Medium (35% TEG & Water) Hydrocarbon Gas
10 Fluid Quantity, Total	87.273 447.10
11	In Out In Out
12 Vapor (kg/hr)	— — 447.10 447.10
13 Liquid (kg/hr)	87.273 87.273 — —
14 Steam (kg/hr)	— — — —
15 Water (kg/hr)	— — — —
16 Non-condensable (kg/hr)	— — — —
17 Operating Temperature (°C)	24 49 113 54
18 Density, (LV) (kg/m ³)	1059 — 1037 — — 188 — 247
19 Viscosity (LV) (cP)	3.0 — 1.5 — — 0.03 — 0.03
20 Molecular Weight (LV)	26 — 26 — — 21.7 — 21.7
21 Molecular Weight, Non-condensable	— — — —
22 Specific Heat (LV) (kJ/kg°C)	3.78 — 3.81 — — 3.13 — 3.31
23 Thermal Conductivity (LV) (W/m°C)	0.43 — 0.44 — — 0.07 — 0.08
24 Latent Heat (MJ/kg @ °C)	— — — —
25 Inlet Pressure (bar(g))	3.45 242
26 Velocity (m/sec)	0.414 1.809
27 Pressure Drop (Allow/Calc.) (bar)	1 0.3 1 0.1
28 Fouling Resistance (m ² °C/W)	0.00035 0.00018
29 Heat Load: 2300 (kW)	Corrected LMTD: 44.38 (°C)
30 Heat Transfer Rate Service: 573.2 (W/m ² °C)	Clean: 920.5 (W/m ² °C)
CONSTRUCTION	
31 Fluid Allocation	Shell Side Tube Side
32 Pressure Design Test (bar(g))	12 17.16 270 388.1
33 Maximum Allowable Working Pressure (bar(g))	12 270
34 Temperature Design/Minimum (°C)	175 -5 175 -5
35 No. of Passes	1 1
36 Corrosion Allowance (mm)	3.0 3.0
37 Nozzles: (No.) & Size (In/Out)	Note (9) 8" 8" 8" 8"
38 Nozzles: Hange Type & Rating	RF 150# RTJ 2500#
39 Tubes: No.: 389 OD: 16.2 (mm) BWG: 12 min. Length: 4877 (mm) Pitch: 22.23 mm, 30°	
40 Tube Material: SA-789 UNS 31803, Note (1)	Tube Type: <input checked="" type="checkbox"/> Seamless <input type="checkbox"/> Welded
41 Shell: SA-516-70	Impact Plate: CS
42 Shell Cover: —	Channel Cover: —
43 Tubesheets: <input checked="" type="checkbox"/> Stationary <input type="checkbox"/> Floating Impingement Protection: <input checked="" type="checkbox"/> Yes <input type="checkbox"/> No	
44 Tubesheets Material: SA-350-LF2	Impingement Protection Mat: CS Baffle Mat: CS
45 Baffles: CS, Note (7) <input checked="" type="checkbox"/> Cross <input type="checkbox"/> Long Type: Segment <input checked="" type="checkbox"/> Vertical <input type="checkbox"/> Horizontal <input type="checkbox"/> Others	
46 % Cut: 20 (Dia.) Spacing: C/C: 241.1	Inlet: 508 Seal type: Tube Supports: 316L SS, Note (6)
47 Gaskets: Shell Side: RTJ, 316 SS, solid Note (4) <input checked="" type="checkbox"/> Exp. Joint Type: 316L SS, Note (6)	
48 Code Requirements: <input checked="" type="checkbox"/> ASME Sec. VIII, DIV. 1 <input type="checkbox"/> Code Stamp <input checked="" type="checkbox"/> TEMA Class: R <input type="checkbox"/> Others	
49 Weights: Shell (kg) Full of Water: (kg) <input checked="" type="checkbox"/> Insulation Thk. (mm)	
Notes (1) Strength weld tube to tube sheet. (2) 100% RT on channel side. (3) 6" pressure relief connection in shell (4) 316 SS spiral wound gasket, style CGI (w/ inner and outer ring) on shell nozzles; tube nozzle, solid 316 SS for RTJ (5) Expansion joint, flanged and fused, designed for 1000 cycles, with 1/2" plugged vent and drain. The expansion shall be based on: a. Shell fluid flowing at -8 °C and tube fluid entering at 113 °C b. Normal operating condition (6) Both ends of channel require insulation, or personnel protection heat shields. (7) 17 crosspaths shell side (16 baffles) (8) Deleted (9) Two (2) 8" 150# nozzles shall be provided at 1/3 point and 2/3 point on top of shell for rupture pin valve.	

Critical and Reduced Temperature and Pressure

Critical and reduced pressure and temperature are often used as correlating parameters and properties in thermodynamics. For a single compound/element, the vapor–liquid critical point in a pressure–temperature phase diagram is at the high-temperature extreme of the liquid–gas phase boundary. The dotted green line gives the anomalous behaviour of water. As shown in the pure species phase diagram to the right, this is the point at which the phase boundary between liquid and gas terminates. In water, the critical point occurs at around 647 K (374 °C; 705 °F) and 22.064 MPa (3200 PSIA or 218 atm). As the critical temperature is approached, the properties of gas and liquid phases approach one another, resulting in only one phase at the critical point: a homogeneous supercritical fluid. The heat of vaporization is zero at and beyond this critical point, so there is no distinction between the two phases. Above the critical temperature a liquid cannot be formed by an increase in pressure, but with enough pressure a solid may be formed. The critical pressure is the vapor pressure at the critical temperature. On the diagram showing the thermodynamic properties for a given substance, the point at which critical temperature and critical pressure meet is called the critical point of the substance. The critical molar volume is the volume of one mole of material at the critical temperature and pressure.

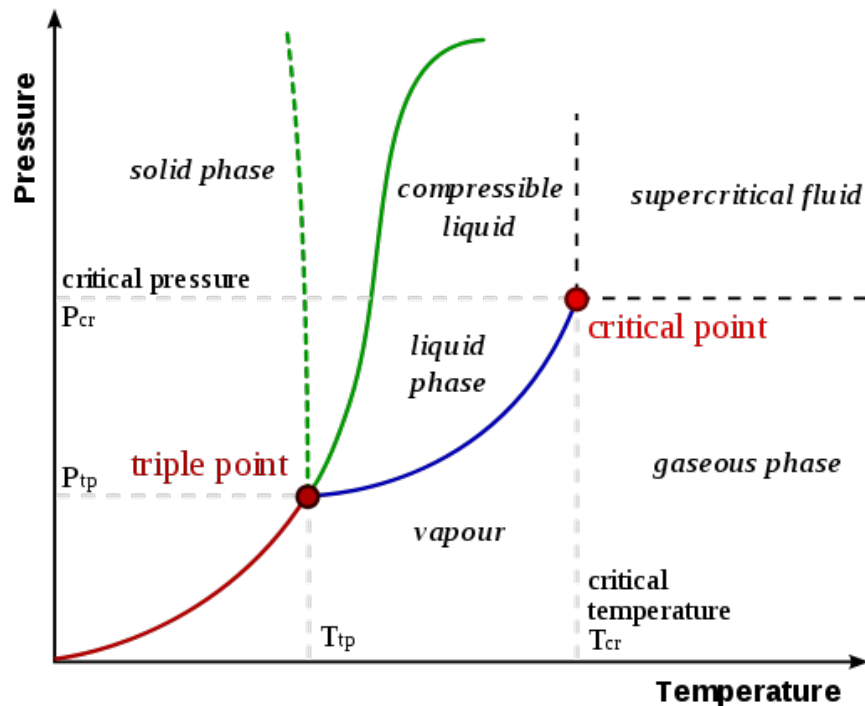
Critical properties vary from material to material, just as is the case for the melting point and boiling point. Critical properties for many pure substances are readily available in the literature. Obtaining critical properties for mixtures is somewhat more problematic.

The critical point for a multicomponent mixture is referred to as the state of pressure and temperature at which all intensive properties of the gas and liquid phases are equal. The corresponding temperature and pressure at that point are called critical pressure and critical temperature.

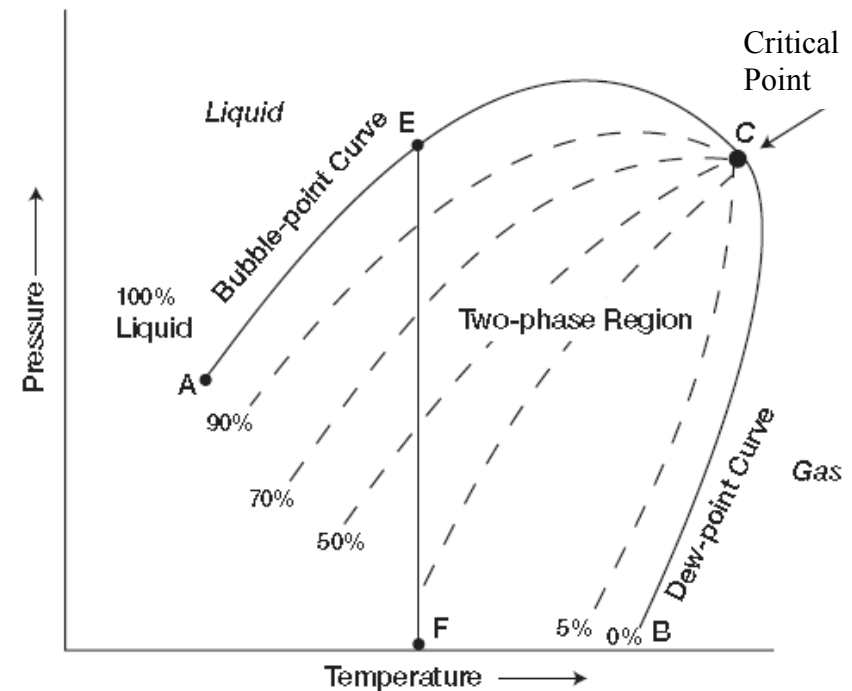
Reduced Properties

Like critical properties, reduced properties are often used as correlating parameters and properties in thermodynamics. Reduced properties are temperature and pressure divided the respective critical property.

Critical and Reduced Temperature and Pressure



Water



Multi-component mixture

Liquid Density

Compound	Density @ 15 °C (kg/m ³)
Water	1000
Ethyl alcohol	785
Butane	563.2
Octane	706.7
Heavy Crude	903
Medium Crude	859
Light Gas Condensate	734
Steel	Approx. 7800
Concrete	Approx. 2300

Calculation of mixture density

One of the simplest methods is the API corresponding states method which uses a correlation to obtain a correction factor that adjusts the density at standard conditions to the actual conditions.

Below are the equations used:

$$v_m = \sum \frac{M_i x_i}{\rho_i}$$

$$M_m = \sum x_i M_i$$

$$\rho_{\text{actual}} = \rho_{\text{standard}} \cdot \left(\frac{C1}{C2} \right)$$

Where: v - Molar Volume (m³/kmol) ρ - density (kg/m³)
 M - Molecular weight (kg/kmol) x - Mole fraction
 $C1$ & $C2$ - Correlation factors for density correction
subscripts: m - mixed compound i - component i

Liquid Density - Example Calculation

Example:

Calculate the liquid density of a saturated mixture of 70% ethane, 20% propane and 10 %butane at 100 bara and 25°C

Working:

Obtain the density of components at standard conditions, here data is given relative to water.

$$\left. \begin{array}{l} C_2 - \gamma = 0.3581 \quad \therefore \rho = 358.1 \text{ kg/m}^3, \quad M = 30.07 \\ C_3 - \gamma = 0.5083 \quad \therefore \rho = 508.3 \text{ kg/m}^3, \quad M = 44.097 \\ C_4 - \gamma = 0.5637 \quad \therefore \rho = 563.7 \text{ kg/m}^3, \quad M = 58.124 \end{array} \right\} \begin{array}{l} \text{Relative density } (\gamma) \text{ at standard conditions and} \\ \text{molecular weight (M) can be found in general databooks} \end{array}$$

Using volume mixing equation

$$v_m = \frac{30.07 \times 0.7}{358.1} + \frac{44.097 \times 0.2}{508.3} + \frac{58.124 \times 0.1}{563.7} = 0.0865 \text{ m}^3 / \text{kmol}$$

$$M_m = (30.07 \times 0.7) + (44.097 \times 0.2) + (58.124 \times 0.1) = 38.69 \text{ kg/kmol}$$

$$\rho_{m \text{ standard}} = \frac{M_m}{v_m} = \frac{38.69}{0.0864} = 412.6 \text{ kg/m}^3 \quad @ \text{Standard Conditions}$$

Now find the correlation factors to adjust the standard density to the actual conditions.

Liquid Density - Example

Taking Critical Properties from standard databooks

$$P_{cm} = \sum x_i P_{ci} = (0.7 \times 48.8) + (0.2 \times 42.49) + (0.1 \times 36.49) = 46.31 \text{ bara}$$

$$T_{cm} = \sum x_i T_{ci} = (0.7 \times 305.43) + (0.2 \times 369.82) + (0.1 \times 408.13) = 328.6 \text{ K}$$

@ Standard Conditions (15 C & 1 bara)

$$P_{r\text{standard}} = \text{Saturated Liquid} \quad T_{r\text{standard}} = \frac{288}{328.6} = 0.876$$

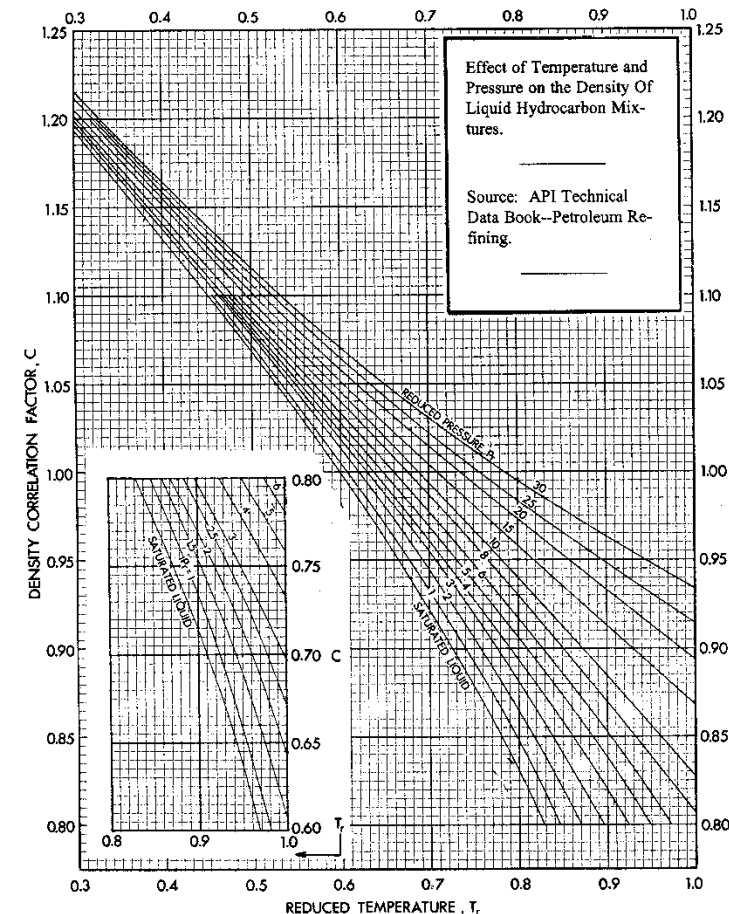
From Correlation chart C1 = 0.745

@ Actual Conditions (25 C & 100 barg)

$$P_{r\text{actual}} = \frac{100}{46.31} = 2.16 \quad T_{r\text{actual}} = \frac{298}{328.6} = 0.907$$

From Correlation Chart C2 = 0.764

$$\text{So } \rho_{\text{actual}} = \rho_{\text{standard}} \left(\frac{C2}{C1} \right) = 412.6 \left(\frac{0.764}{0.745} \right) = 423.11 \text{ kg/m}^3$$



Liquid Density

The computer simulation Unisim uses an Equation of State by Hawkinson, Brombst & Thomson usually referred to as COSTALD because it uses Corresponding Standard Liquid Tables.

$$\frac{V_s}{V^*} = V_R^0 [1 - \omega_{SRK} V_R^\delta]$$

$$V_R^0 = 1 + a(1 - T_r)^{1/3} + b(1 - T_r)^{2/3} + c(1 - T_r) + d(1 - T_r)^{4/3} \quad 0.25 < T_r < 0.95$$

$$V_R^\delta = [e + fT_r + gT_r^2 + hT_r^3] / (T_r - 1.00001) \quad 0.25 < T_r < 1.0$$

V_s – Saturated Liquid Volume

V_R^0, V_R^δ – Functions of T_r

T_r – Reduced Temperature

V^* – Molar Volume

ω_{SRK} – Acentric factor

} Found in COSTALD tables

Liquid Density - Mixing Rules

The mixing rules for the variables in the previous equations are as follows:

$$T_{cm} = \frac{\sum_{i=1}^n \sum_{j=1}^n x_i x_j V_{ij}^* T_{cij}}{V_m^*}$$

$$V_m^* = \frac{1}{4} \left[\sum x_i V_i^* + 3 \left(\sum x_i V_i^{*2/3} \right) \left(\sum x_i V_i^{*1/3} \right) \right]$$

$$V_{ij}^* T_{cij} = \left(V_i^* T_{ci} V_j^* T_{cj} \right)^{1/2}$$

$$\omega_{SRK_m} = \sum x_i \omega_{SRK_i} \quad \text{Acentric Factor (shape sensitive)}$$

$$P_{cm} = \frac{(0.291 - 0.80 \omega_{SRK_m}) R T_{cm}}{V_m^*}$$

This is a much more complicated method and is not suitable for hand calculations.

Running the liquid density calculation in Unisim returns a density of 456.5 kg/m³.

Using the API method we obtained a value of 423.11 kg/m³.

Gas Compressibility

The term "compressibility" is also used in thermodynamics to describe the deviance in the thermodynamic properties of a real gas from those expected from an ideal gas. The **compressibility factor** is defined as

$$Z = \frac{p\tilde{V}}{RT}$$

where p is the pressure of the gas, T is its temperature, and \tilde{V} is its molar volume. In the case of an ideal gas, the compressibility factor Z is equal to unity, and the familiar ideal gas law is recovered:

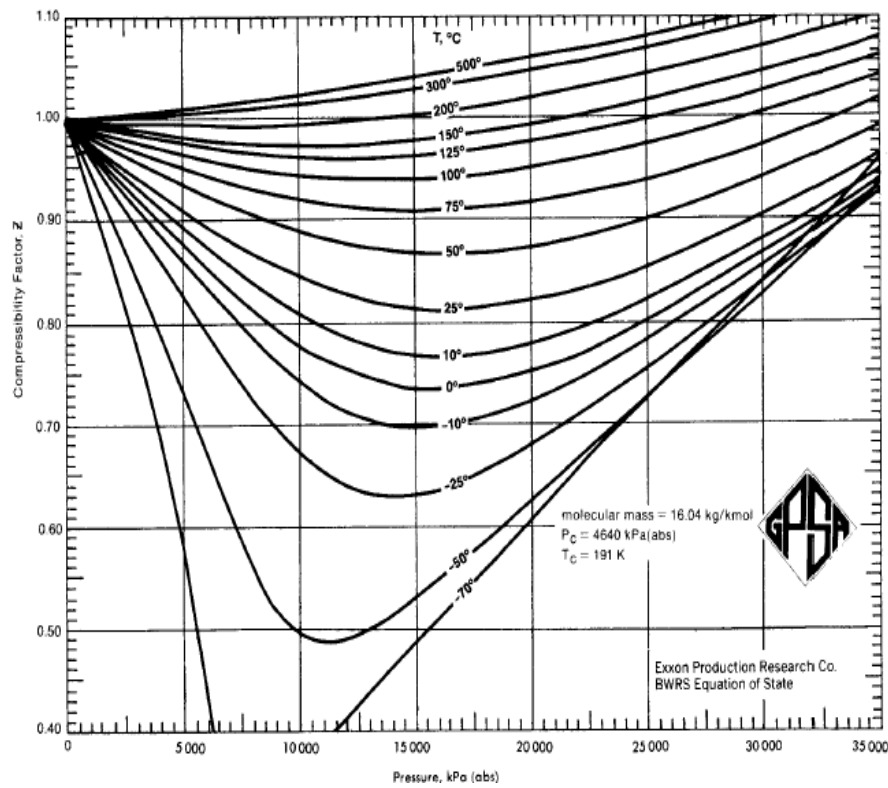
$$p = \frac{RT}{\tilde{V}}$$

Z can, in general, be either greater or less than unity for a real gas.

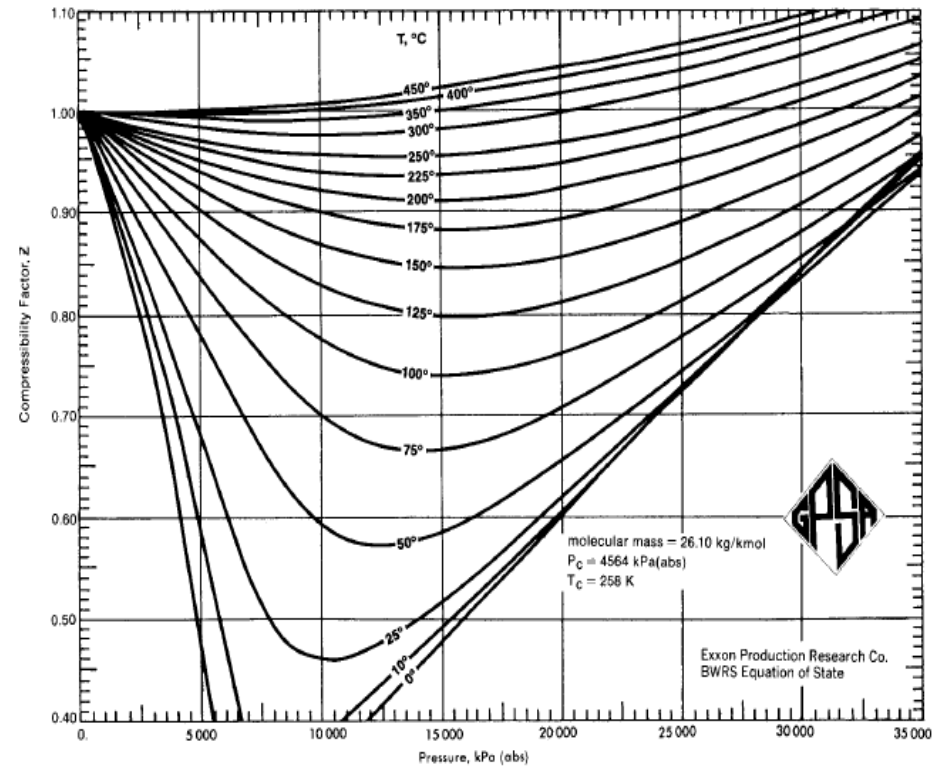
The deviation from ideal gas behavior tends to become particularly significant near the critical point, or in the case of high pressure or low temperature. In these cases, a generalized Compressibility chart or an alternative equation of state better suited to the problem must be utilized to produce accurate results.

Gas Compressibility Charts

Methane



Ethane



Ethane much higher compressibility at higher pressures

Vapour Density

Example Gas Densities:
@15°C, 1 bara

Compound	Vapour Density (kg/m ³)
Air	1.21
Oxygen	1.335
Carbon dioxide	1.873
Methane	0.6784
Propane	1.865

The main parameter in calculating vapour density is the compressibility. This can be calculated by either the appropriate equation of state or activity model, or by generalised compressibility charts.

Calculation using compressibility charts is as follows:

Mixed critical properties are calculated using Kay's rule and databook tables :

$$P_{cm} = \sum y_i P_{ci} \quad , \quad T_{cm} = \sum y_i T_{ci} \quad \text{where } y_i \text{ is mole fraction of vapour component}$$

Reduced properties (Pr, Tr) are calculated

$$P_{rm} = \frac{P}{P_{cm}} \quad , \quad T_{rm} = \frac{T}{T_{cm}}$$

Use the reduced properties with a compressibility chart to obtain the compressibility, Z.

The Mean molecular mass is then calculated $M_m = \sum y_i M_i$

and Density is calculated

$$\rho_m = M_m P / ZRT$$

Vapour Density - Example Calculation

Calculate the density of vapour at 15 bara pressure and 25 C temperature. At these conditions the mixture is single phase gas.

Component	Yi	Tci (K)	YTci	Pci (MPa)	YPci	M	Myi		
C2	0.7	305	213.5	4.88	3.416	30.07	21.049		
C3	0.2	370	74	4.25	0.85	44.097	8.8194		
C4	0.1	408	40.8	3.65	0.365	58.124	5.8124		
Sum			328.3		4.631		35.681		

We have the mixtures critical properties, next calculate the reduced properties

$$P_r = \frac{P}{P_c}$$

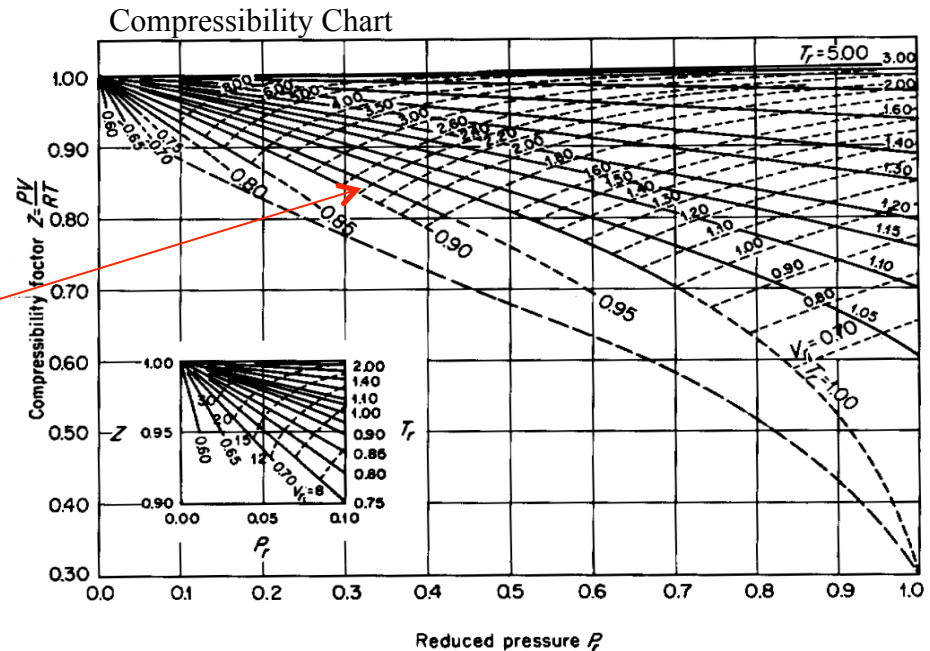
$$T_r = \frac{T}{T_c}$$

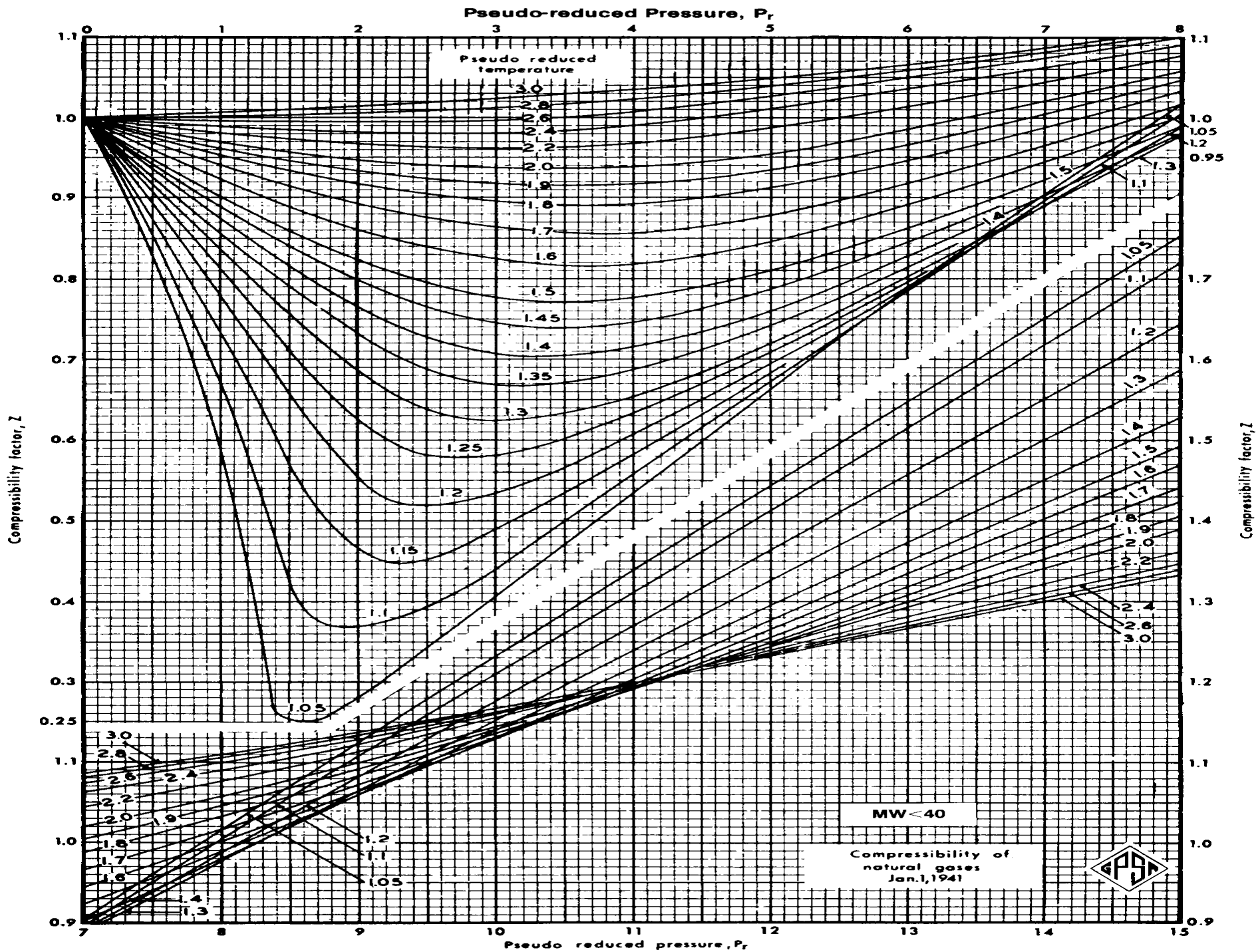
$$P_r = 15 / 46.3 = 0.324$$

$$T_r = 298.15 / 328.3 = 0.907$$

From generalised compressibility charts $Z = 0.84$

$$\begin{aligned}\rho_m &= M_m \cdot P / ZRT \\ &= 35.68 \times 1500 / (0.84 \times 8.314 \times 298.15) \\ &= 25.7 \text{ kg/m}^3\end{aligned}$$





Viscosity

Example Viscosities:

Gas Compounds	Viscosity (cP)	Liquid Compounds	Viscosity (cP)
Air @ 5 °C	.017	Octane @ 5°C	0.75
Methane @ 5 °C	0.01	Water @ 5°C	1.4
Steam @ 100 °C	0.012	Heavy crude @ 15°C	24
		Medium crude @ 15°C	5
		Light gas condensate @ 15°C	1

Accurate prediction of viscosity is very difficult due to the number and type of variables.

Nearly all methods rely on critical data developed from the equation of state and accuracy is greatly affected by the equations chosen.

Unisim uses the following methods for viscosity calculation.

System	Vapour Phase	Liquid Phase
Light Hydrocarbons NBP < 155°F	Modified Ely & Hanley	Modified Ely & Hanley
Heavy Hydrocarbons NBP > 155°F	Modified Ely & Hanley	Twu
Non Hydrocarbon Systems	Modified Ely & Hanley	Modified Letsou-stiel

Viscosity

Component viscosities can be found by using viscosity charts.
These can be found in data books along with co-ordinates which relate to different compounds. There are separate charts for gases and liquids.

For viscosity estimation of liquid mixtures the following rule can be used

$$\mu_m = \left[\sum x_i (\mu_i)^{1/3} \right]^3$$

where

μ_m – mixture viscosity,

x_i – component mole fraction

μ_i – component viscosity

Example:

Estimate the viscosity of a mixture of 30% Pentane and 70% Octane at 25 °C and 1 bar.

Find the co-ordinates for Pentane and Octane to be used with the chart.

Pentane - X=14.9, Y=5.2 Octane - X=13.7, Y=10

from the chart μ (mPas) = 0.23 for pentane

= 0.54 for octane note: cP = mPas

$$\begin{aligned} \mu_m &= \left[\left(0.3 * (0.23)^{1/3} \right) + \left(0.7 * (0.54)^{1/3} \right) \right]^3 \\ &= [0.1838 + 0.5700]^3 \\ &= 0.428 \text{ cP} \end{aligned}$$

Unisim returns a liquid viscosity of 0.416 (cP)

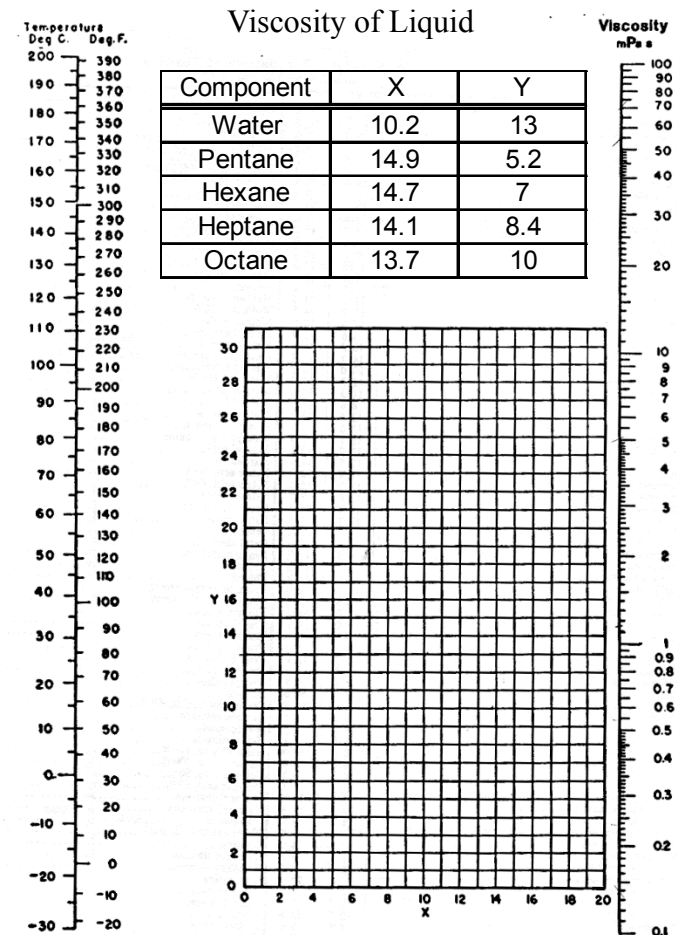


FIG. 3-43. Viscosities of liquids at 1 atm. For coordinates, see Table 3-266.

Viscosity

Component viscosities can be found by using viscosity charts.

These can be found in data books along with co-ordinates which relate to different compounds. There are separate charts for gases and liquids.

For viscosity estimation of liquid mixtures the following rule can be used

$$\mu_m = \left[\sum x_i (\mu_i)^{1/3} \right]^3$$

where μ_m – mixture viscosity, x_i – component mole fraction

μ_i – component viscosity

Example:

Estimate the viscosity of a mixture of 30% Pentane and 70% Octane at 25 °C and 1 bar.

Working:

Find the co-ordinates for Pentane and Octane to be used with the chart.

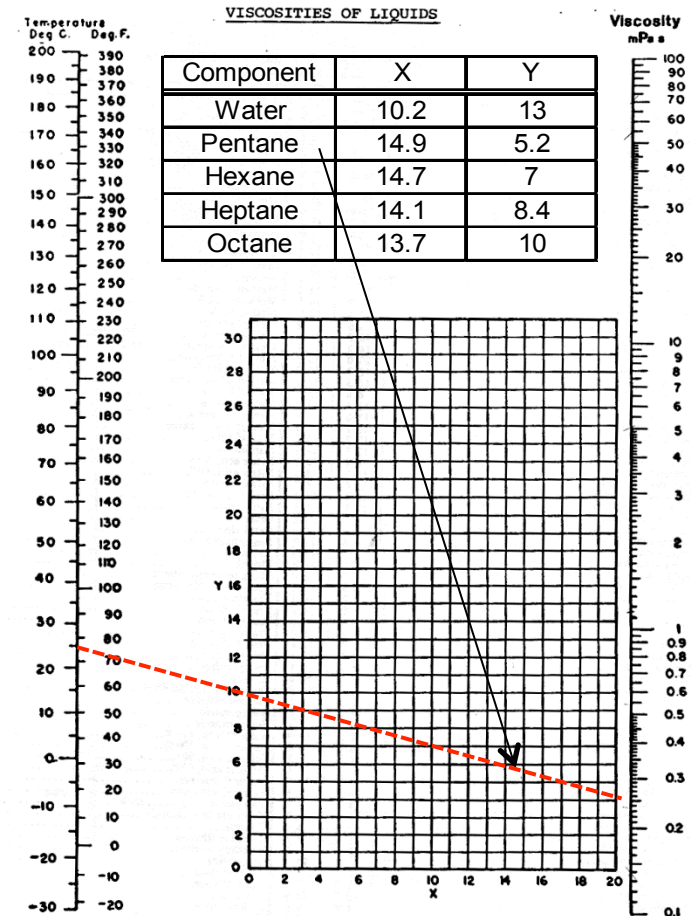
Pentane - X=14.9, Y=5.2 Octane - X=13.7, Y=10

from the chart μ (mPas) = 0.23 for pentane

= 0.54 for octane note: cP = mPas

$$\begin{aligned} \mu_m &= \left[\left(0.3 * (0.23)^{1/3} \right) + \left(0.7 * (0.54)^{1/3} \right) \right]^3 \\ &= [0.1838 + 0.5700]^3 \\ &= 0.428 \text{ (cP)} \end{aligned}$$

Unisim returns a liquid viscosity of 0.416 (cP)



Gas Viscosity

For viscosity estimation of gases the following rule can be used

$$\mu_m = \frac{\sum \mu_i y_i \sqrt{M_i}}{\sum y_i \sqrt{M_i}}$$

where;

μ_m - Mixture viscosity,

μ_i - Component viscosity

y_i - Mole fraction of component

M_i - Component molecular weight

Viscosities are found from viscosity charts. The charts give the viscosity at 1 atmosphere and the required temperature. Correction for pressure and temperature can be made by using a viscosity correction chart. This requires the reduced P & T from Kay's rule.

Example:

Estimate the viscosity of a gas with composition 40% methane & 60% propane at 25°C and 5 bara pressure.

Working:

Calculated the viscosity of the gas at 1 atmosphere and the required temperature
Using co-ordinates: methane - X= 9.9, Y= 15.5 propane - X= 9.7, Y= 12.9
from chart μ (mPas) = 0.011 for methane
= 0.0084 for propane

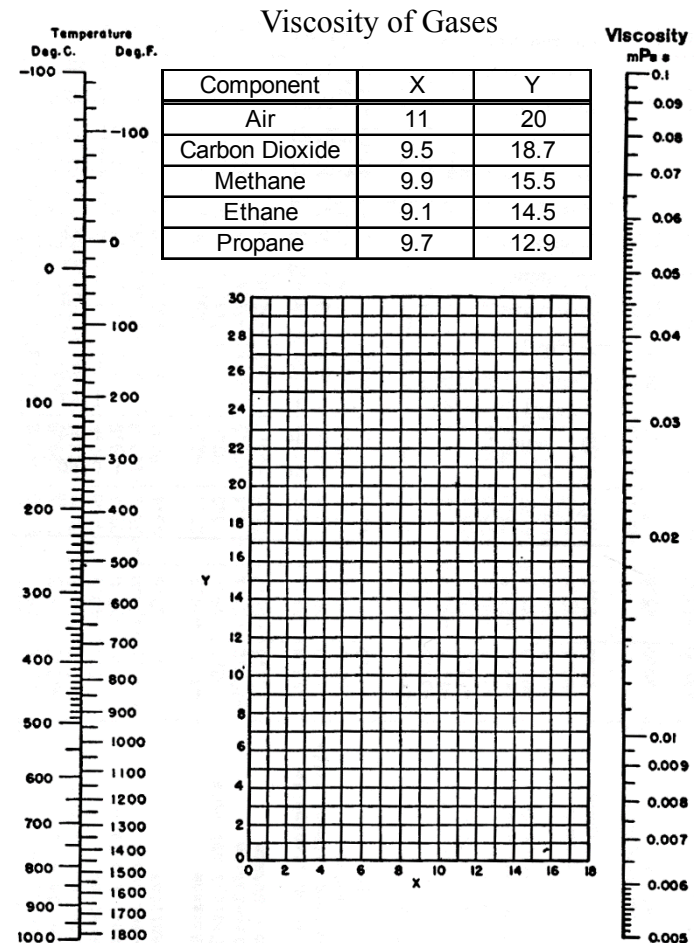


FIG. 3-42. Viscosities of gases at 1 atm. For coordinates, see Table 3-263.

Gas Viscosity

$$\begin{aligned}\mu_m &= \frac{0.011 * 0.4 * \sqrt{16.043} + 0.0084 * 0.6 * \sqrt{44.097}}{0.4 * \sqrt{16.043} + 0.6 * \sqrt{44.097}} \\ &= \frac{0.0176 + 0.0335}{1.602 + 3.984} = 0.00915 \text{ (cP)}\end{aligned}$$

Specific Heat Capacity

Example Heat Capacity values:

Gas / solid Compound	Isobaric Heat Capacity, C_p (J/kgK)	Liquid Compound	Isobaric Heat Capacity, C_p (kJ/kgK)
Air	0.996	Water	4.187
Propane	2.467	Octane	2.177
		Decane	1.758
Steel	0.502	Heavy Crude	1.718
		Medium Crude	1.750
		Gas Condensate	2.077

The AIChemE method can be applied for both gases and liquids. A correction factor is used to adjust the ideal value. A simple Kays Rule weight fraction can be used as a first approximation

Thermal Conductivity

Example Conductivities

Gas / solid Compound	Thermal Conductivity (W/m ² K)	Liquid Compound	Thermal Conductivity (W/m ² K)
Methane	0.0286	Water	0.569
Propane	0.1181	Octane	0.144
		Heavy crude	0.164
Carbon steel	51.9	Medium crude	0.146
Stainless steel	16.3	Gas condensate	0.132

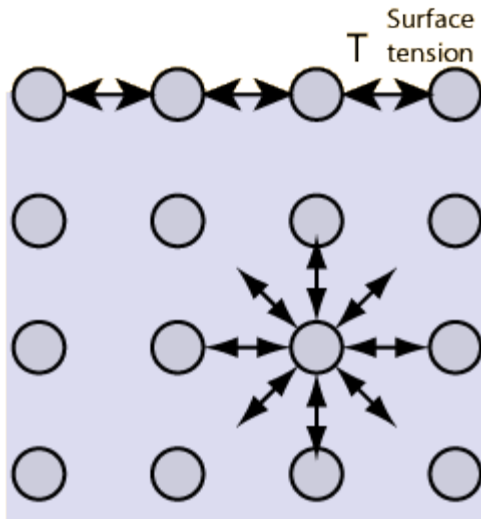
Most simulators use the general guidelines of Reid, Prausnitz & Poling to determine which model best suits each class of component.

- Hydrocarbon systems use the corresponding states method of Ely & Hanley
- Glycols & Acids are calculated by Sato-Reidel method
- Esters, alcohols and light hydrocarbons by Latini

Surface Tension

A molecule on the surface of a liquid is subject to an inward force as a result of the attraction between molecules. This surface molecule tends to adjust itself to a minimum surface area causing the droplet to assume a spherical shape. Work is required to extend this surface or to bring molecules from the bulk of the liquid into the surface.

The units of surface tension are therefore force/unit length – N/m. However, most surface tension values are presented as dyne/cm – where 1 dyne – 10^{-5} Newtons.



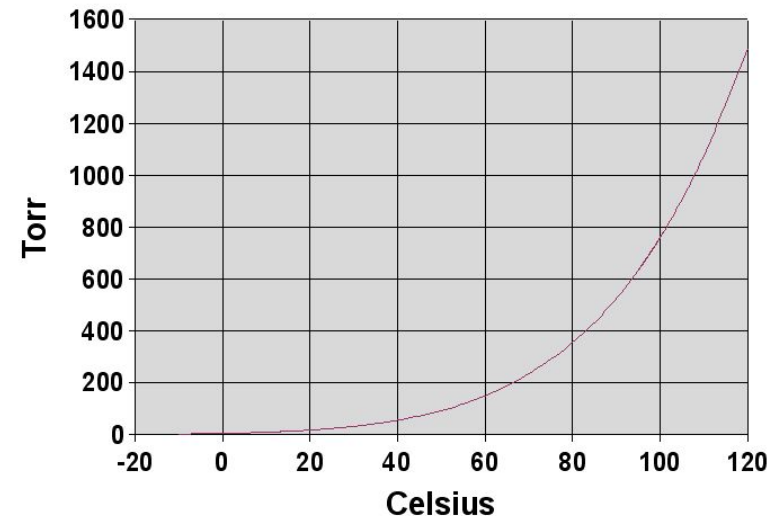
Surface Tension

Component	Surface Tension (dyne/cm)
Water	73.82
Octane	25.05
Heavy crude	30.27
Medium crude	27.32
Gas condensate	23.39

Reference Unit	is equal to	Conversion Factor	Unit
dyne/centimeter	=	1	dyne/centimeter
	=	1	erg/square centimeter
	=	0.01	erg/square millimeter
	=	0.001019716213	gram force/centimeter
	=	1	millinewton/meter
	=	0.001	newton/meter
	=	5.71014709756E-006	pound force/inch
	=	0.000183718550066	poundal/inch

Vapour Pressure

The vapor pressure of a liquid, is the pressure exerted by its vapor when the liquid and vapor are in dynamic equilibrium. Vapor pressure is the pressure of a vapor in equilibrium with its non-vapor phases. All solids and liquids have a tendency to evaporate to a gaseous form, and all gases have a tendency to condense back. At any given temperature, for a particular substance, there is a partial pressure at which the gas of that substance is in dynamic equilibrium with its liquid or solid forms. This is the vapor pressure of that substance at that temperature. In meteorology, the term vapor pressure is used to mean the partial pressure of water vapor in the atmosphere, even if it is not equilibrium, and the equilibrium vapor pressure is specified as such.

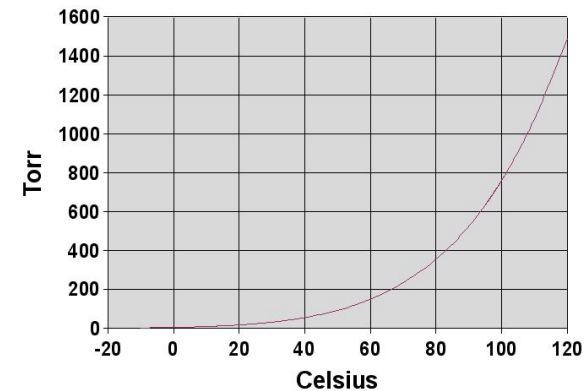


Water Vapour
Pressure

Vapour Pressure

Vapor pressure is an indication of a liquid's evaporation rate. It relates to the tendency of molecules and atoms to escape from a liquid or a solid. A substance with a high vapor pressure at normal temperatures is often referred to as volatile. The higher the vapor pressure of a material at a given temperature, the lower the boiling point.

The vapor pressure of any substance increases non-linearly with temperature according to the Clausius-Clapeyron relation. The boiling point of a liquid is the temperature where the vapor pressure equals the ambient atmospheric pressure. At the boiling temperature, the vapor pressure becomes sufficient to overcome atmospheric pressure and the liquid forms bubbles inside the bulk of the substance.



Water Vapour
Pressure

Substance Vapour Pressures

