ME 423: FLUIDS ENGINEERING

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Lecture-20-21 (16/11/2024)

Gas Pipeline Hydraulics

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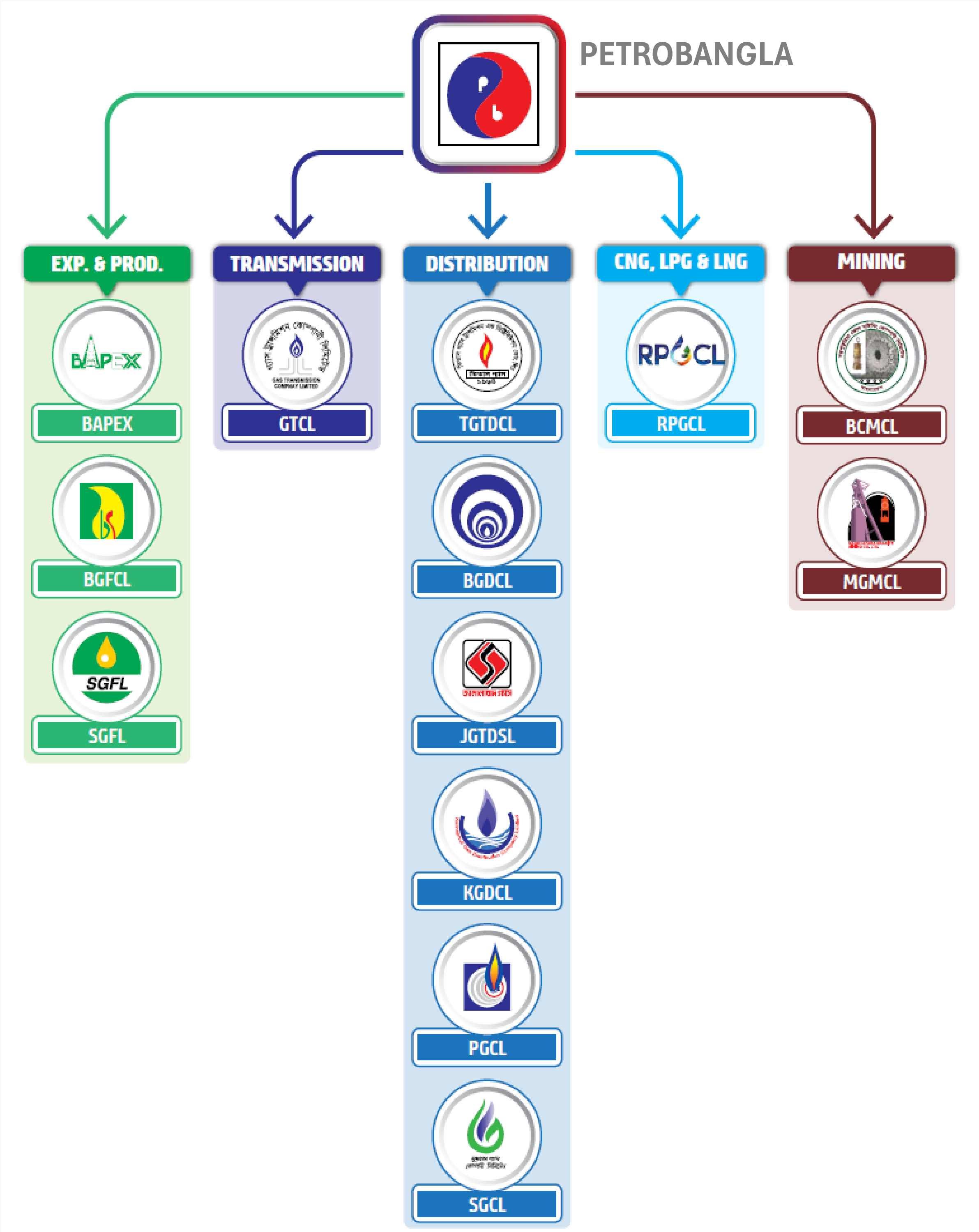
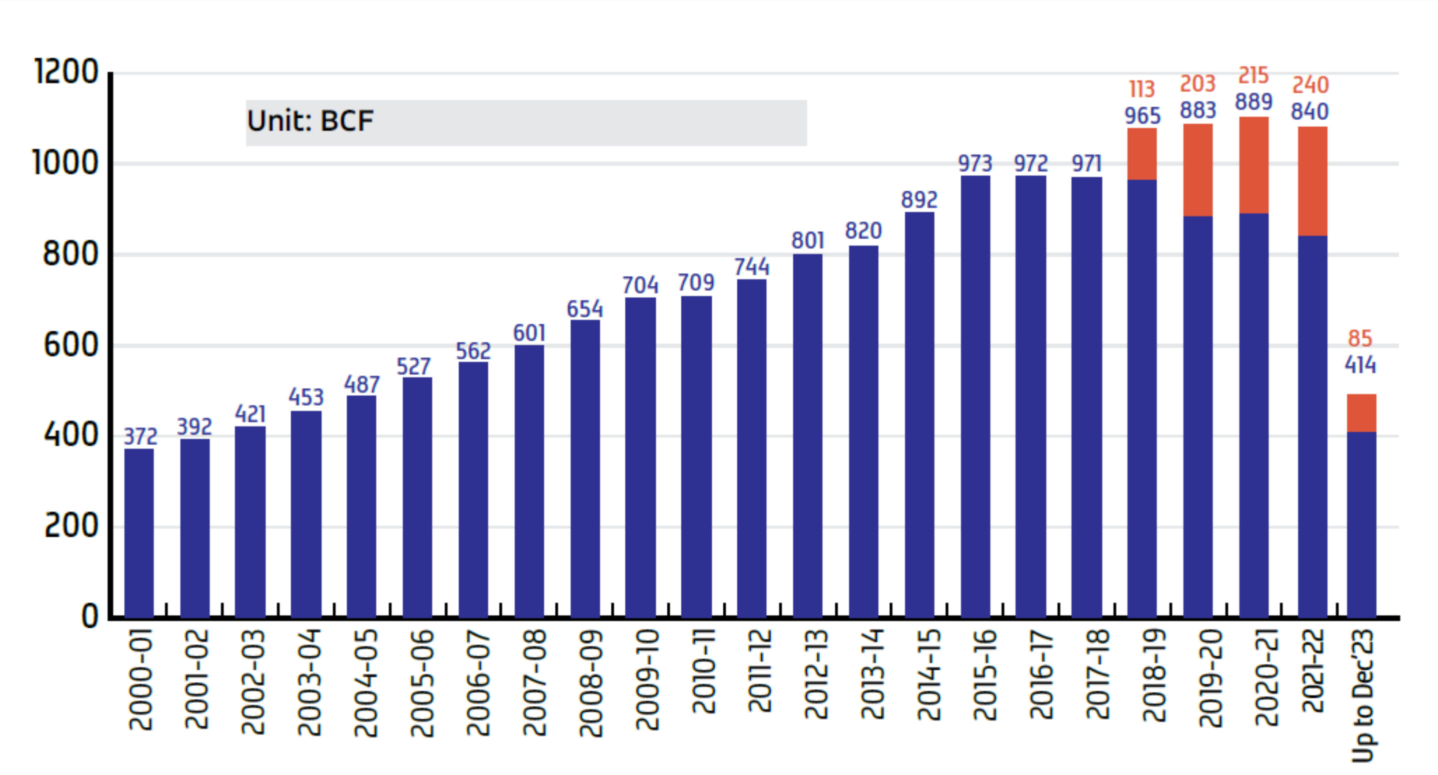


13 companies under Petrobangla dealing in oil and gas exploration, production, transmission, distribution, conversion and promotion of LNG as well as the development and marketing of coal and granite.

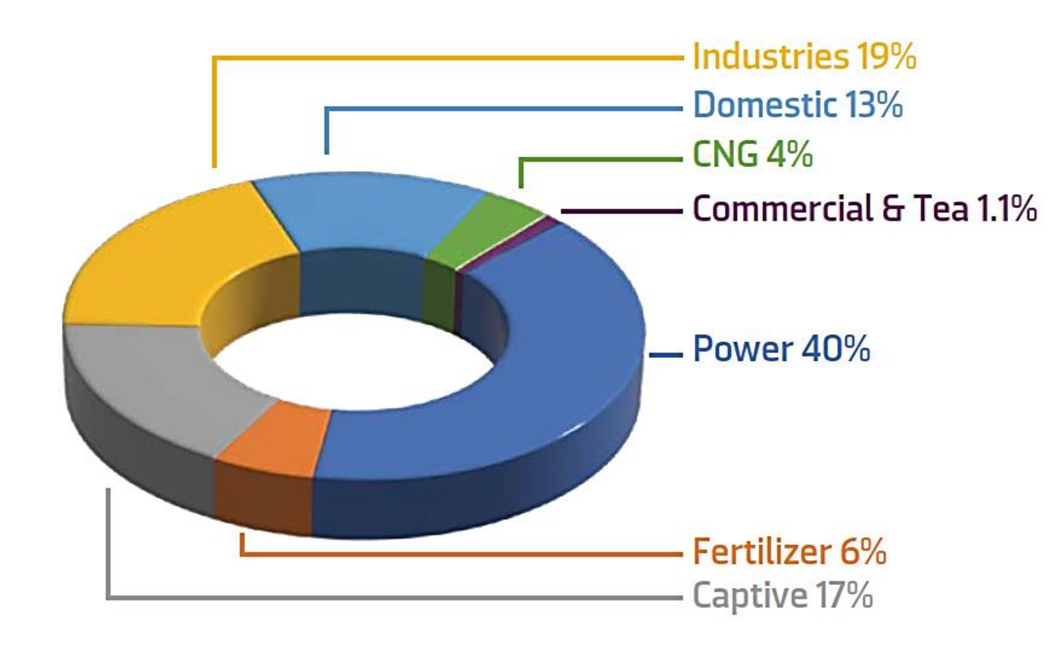
* Petrobangla: Annual Report (2022)

Gas Production & Utilization in Bangladesh



NG (Natural Gas)

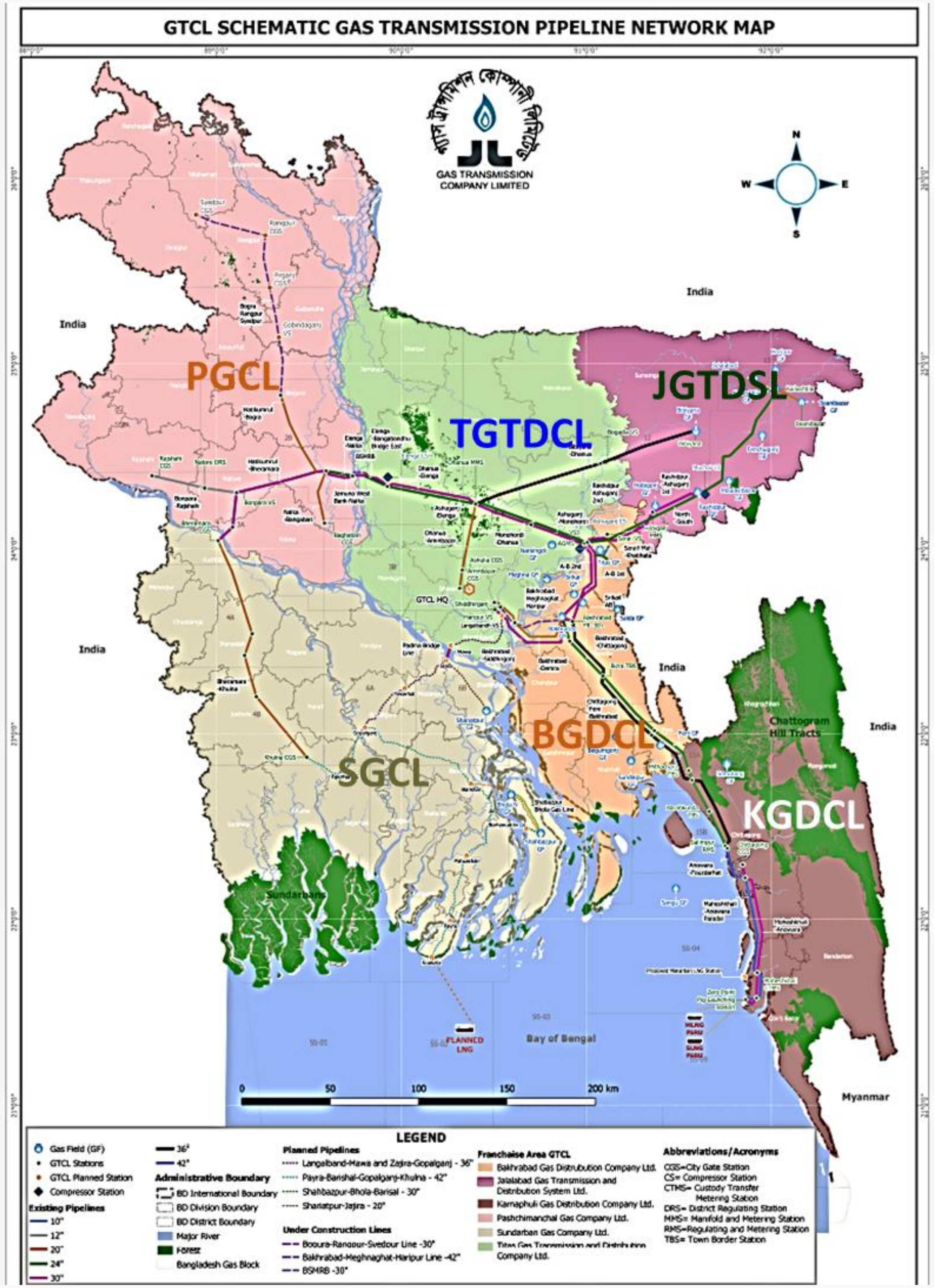
RLNG (Regassified Liquefied Natural Gas)



Total 1,001.31 BCF (**B**illion **C**ubic **F**eet)
in FY 2021-2022

* as of 2022 (Petrobangla: Annual Report (2022))

Gas Transmission Network in Bangladesh



Six marketing or distribution companies under Petrobangla are entrusted with the responsibility of marketing of natural gas (NG) to the customers ranging from large power and fertilizer plants to small households:

TGTDCL: Titas Gas Transmission & Distribution Company Ltd. (55%)

JGTDSL: Jalalabad Gas Transmission & Distribution System Ltd. (15%)

KGDCL: Karnaphuli Gas Distribution Company Ltd. (11%)

BGDCL: Bakhrabad Gas Distribution Company Ltd. (10%)

PGCL : Pashchimanchal Gas Company Ltd. (5%)

SGCL: Sundarban Gas Company Ltd. (4%)

Total gas sales during FY 2021-22 was 1,001.3 BCF

* Petrobangla: Annual Report (2022)

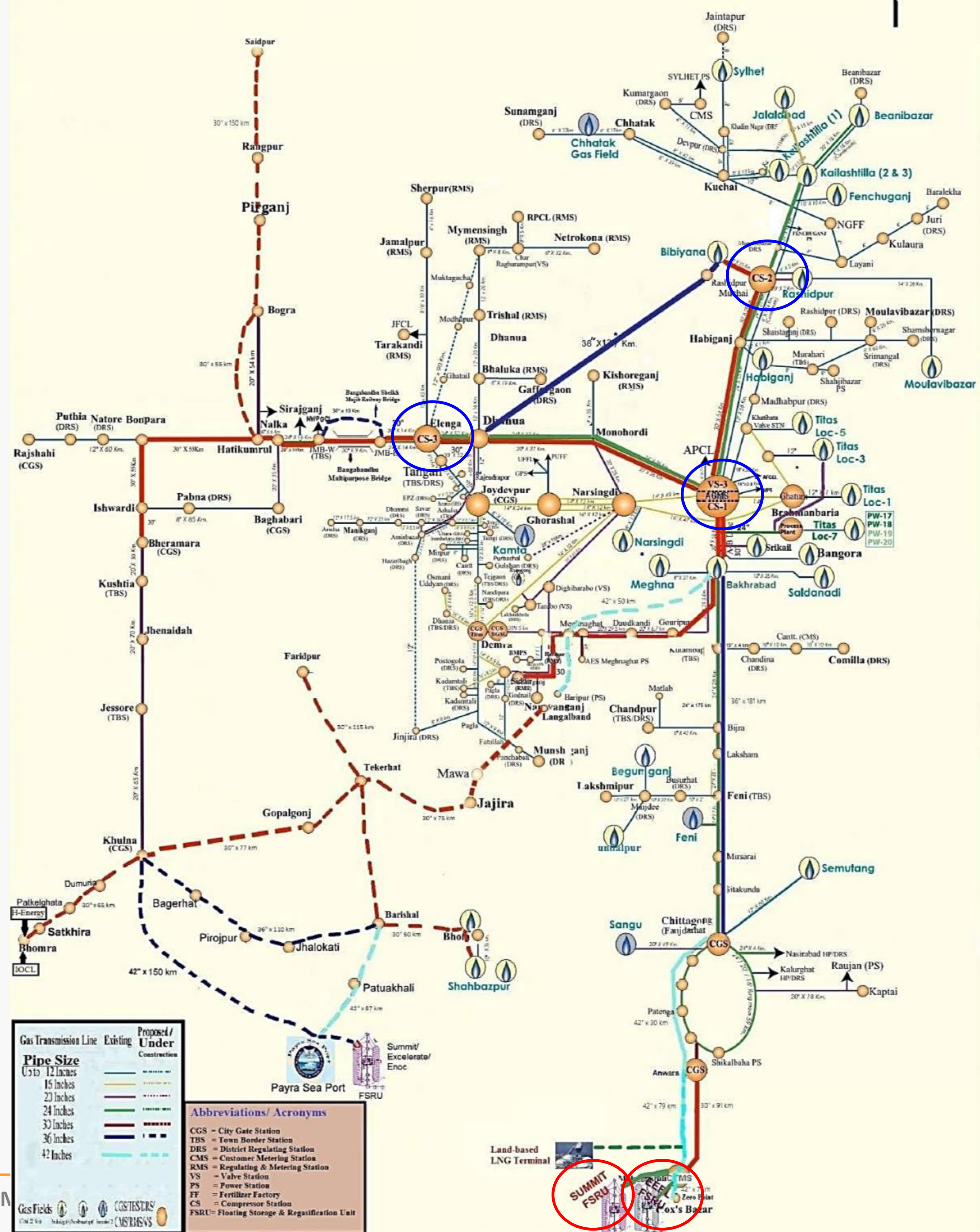
Gas Transmission Network

CS: Compressor station

RMS: Regulating & Metering Station

FSRU: Floating Storage & Regasification Unit

RLNG: Regassified LNG



* Petrobangla: Annual Report (2022)

Gas Transmission Network

মহেশখালী জিরোপয়েন্ট প্ল্যাটফরমে ৪২" সঞ্চালন পাইপলাইনের আন্ত:সংযোগ

Valve Station Under Chattrogram-Feni-Bakhrabad project

1500 million cubic feet capacity metering station constructing under Maheshkhali Zero point project

চট্টগ্রামের আনোয়ারায় নির্মিত ৬০০ এমএমএসসিএফডি সিটিএমএস

Compressor Station

3nos. compressor stations: (1) Ashuganj (CS-1), (2) Rashidpur (CS-2), and (3) Elenga (CS-3)

FSRU

Ship to Ship (STS) LNG Transfer Operation

LNG Terminal at Moheshkhali Off-shore Area

Gas Production

No: 41.01.09/2604.Dec.2014

Petrobangla

Production & Marketing Division 2:14 PM

3, Kawran Bazar, Dhaka-1215

Date : 13-14 Nov, 2024

From 8.00 to 8.00

Units:
Gas in MMCFD
Condensate/ NGL/ MS/ HSD in BBLD
LPG in Kg

Daily Gas & Condensate Production and Distribution Report

I. Production

Company	Gas Fields	No.of Producing Wells	Capacity	Production: Gas	Production: Condensate	Pro.as a % of T.Cap(Gas)	Pro.as a % of T. Prod(Gas)
1. BGFCL	Titas	26	542	363.3	330.0	9.5	12.8
	Habiganj	8	225	112.1	7.2	2.9	1.0
	Bakhrabad	7	43	29.0	34.5	0.8	0.8
	Narsingdi	2	30	22.7	28.0	0.6	0.8
	Meghna	1	11	4.2	4.3	0.1	0.1
	Sub-Total	44	851	531.2	404.0	13.9	18.8
2. SGFL	Sylhet	3	6	11.9	44.8	0.3	0.4
	Kailashtila #1 (Silicagel)	0	0	0.0	0.0	0.0	0.0
	Kailashtila #2 (MSTE)	2	30	40.3	321.3	1.1	1.4
	Rashidpur	7	67	69.9	41.7	1.8	2.5
	Beanibazar	2	15	15.0	222.4	0.4	0.5
	Sub-Total	14	118	137.0	630.1	3.6	4.8
3. BAPEX	Salda	2	3	2.5	0.7	0.1	0.1
	Fenchuganj	2	26	8.6	1.4	0.2	0.3
	Shahbazpur	4	50	72.4	13.2	1.9	2.6
	Semutung	2	3	0.9	0.0	0.0	0.0
	Sundalpur	1	5	3.2	0.0	0.1	0.1
	Srikail	3	40	19.2	80.8	0.5	0.7
	Begumganj	1	10	7.5	1.6	0.2	0.3
	Rupganj	0	8	0.0	0.0	0.0	0.0
	Sub-Total	15	145	114.3	97.7	3.0	4.0
Sub-Total (1+2+3)		73	1114	782.6	1131.8	20.4	27.7
4. IOCs							
CHEVRON	Jalalabad	7	270	146.1	813.8	3.8	5.2
	Maulavibazar	5	42	14.7	1.9	0.4	0.5
	Bibiyana	26	1200	990.9	5636.4	25.9	35.0
TULLOW	Bangora	5	103	37.1	110.0	1.0	1.3
	Sub-Total	43	1615	1188.8	6562.1	31.0	42.0
5. RPGCL (R-LNG)			1100	857.0		22.4	30.3
	Sub-Total	0	1100	857.0	0.0	22.4	30.3
Grand Total (1+2+3+4+5):		116	3829	2828.3	7693.9	73.9	100.0

III. RPGCL Production

Feed Received: NGL	Feed Received: Cond.	Production: LPG	Production: MS	Production: HSD
0.0	0.0	0	0.0	0.0

N-S & RA pipeline
Delivered from N-S pipeline

AB1	0.0
AB2	0.0
BB	144.6
VS3	105.2
AM	554.8
BD	409.5
Total	**1214.0**

Remarks:

Units to be used

In professional practices in gas pipeline hydraulics, the **U.S. Customary System (USCS) units** are most popular than **Systeme International (SI) units**.

Quantity	USCS unit	SI unit
Mass	slug	kg
Weight	lb	N
Mass flow rate	lb/hr	Kg/hr
Pressure	psi	Pa
Temperature	°F	°C
Volume	ft^3	m^3
Volume of gas in gas production/distribution	• **thousand ft^3 (Mft^3)** • **million ft^3** (**MMft^3**)	• thousand m^3 (km^3) • million m^3 (Mm^3)
Volume rate production / distribution of gas	**MMCFD** (Million Cubic Feet per Day) **MMSCFD** (Million Standard Cubic Feet per Day)	

It must be noted that in the USCS units, the practice has been to use **M to represent a thousand**, and therefore **MM refers to a million**. This goes back to the Roman days of numerals, when M represented a thousand.

Units to be used

When referred to standard conditions (also called **base conditions**) of temperature and pressure (**60°F and 14.7 psia in USCS units**), the volume is stated as **standard volume** and, therefore, measured in **standard ft^3 (SCF)** or **million standard ft^3 (MMSCF).**

Volume flow rate of gas is measured per unit time and can be expressed as ft^3/min, ft^3/h, ft^3/day, SCFD, MMSCFD, etc. in USCS units. In SI units, gas flow rate is expressed in m^3/h or Mm^3/day.

Therefore,
500 MSCFD in USCS units refers to 500 thousand standard cubic feet per day (500,000 ft^3/day), whereas 15 Mm^3/day means 15 million cubic meters per day in SI units.

This distinction in the use of the letter **M to denote a thousand in USCS units** and **M for a million in SI units** must be clearly understood.

Text Book (s):

E. Shashi Menon, *Gas Pipeline Hydraulics*, 2005, ISBN: 978-0-8493-2785-8.

Standards:

ASME B31.8 (2010): ASME Code for Gas Transmission and Distribution Piping System

ASME B31.1(2018): ASME Code for Pressure Piping

Gas density & Specific Weight

Density represents the amount of gas that can be packed in a given volume. Therefore, it is measured in terms of mass per unit volume. If 5 lb of a gas is contained in 100 ft^3 of volume at some temperature and pressure, we say that the gas density is 5/100 = 0.05 lb/ft^3.

Strictly speaking, in USCS units density must be expressed as $slug/ft^3$ since mass is customarily referred to in slug.

Thus,

$$\rho = \frac{m}{V} \tag{1.1}$$

where

ρ = density of gas
m = mass of gas
V = volume of gas

Density is expressed in $slug/ft^3$ or lb/ft^3 in USCS units and kg/m^3 in SI units.

USCS : U.S. Customary System

SI : Systeme International

A companion term called *specific weight* is also used when referring to the density of gas. Specific weight, represented by the symbol γ, is the weight of gas per unit volume measured in lb/ft^3 in USCS units, and is, therefore, contrasted with density, which is measured in $slug/ft^3$. In SI units, the specific weight is expressed in Newton per m^3 (N/m^3). Quite often, density is also referred to in lb/ft^3 in USCS units.

$$\gamma = \frac{mg}{V}$$

Specific Gravity of Gas

Specific gravity of a gas, sometimes called *gravity*, is a measure of how heavy the gas is compared to air at a particular temperature. It might also be called *relative density*, expressed as the ratio of the gas density to the density of air. Because specific gravity is a ratio, it is a dimensionless quantity.

$$G = \frac{\rho_g}{\rho_{air}} \qquad (1.2)$$

where

G = gas gravity, dimensionless

ρ_g = density of gas

ρ_{air} = density of air

For example, natural gas has a specific gravity of 0.60 (air = 1.00) at 60°F. This means that the gas is 60% as heavy as air.

Specific Gravity of Gas

If we know the molecular weight of a particular gas, we can calculate its gravity by dividing the molecular weight by the molecular weight of air, as follows.

$$G = \frac{M_g}{M_{air}} = \frac{M_g}{28.9625} \qquad (1.3)$$

or

$$G = \frac{M_g}{29} \qquad (1.4)$$

Rounding off the molecular weight of air to 29

where

G = specific gravity of gas

M_g = molecular weight of gas

M_{air} = molecular weight of air = 28.9625

Specific Gravity of Gas

Multi component gas mixture

Since natural gas consists of a mixture of several gases (methane, ethane, etc.), the molecular weight M_g in Equation 1.4 is referred to as the apparent molecular weight of the gas mixture.

When the molecular weight and the percentage or mole fractions of the individual components of a natural gas mixture are known, we can calculate the molecular weight of the gas mixture by using a weighted average method. Thus, a natural gas mixture consisting of 90% methane, 8% ethane, and 2% propane will have a specific gravity of

$$G = \frac{(0.9 \times M1) + (0.08 \times M2) + (0.02 \times M3)}{29}$$

where $M1$, $M2$, and $M3$ are the molecular weights of methane, ethane, and propane, respectively, and 29 represents the molecular weight of air.

Table 1.1 Properties of Hydrocarbon Gases

Gas	Formula	Molecular Weight	Vapor Pressure psia at 100°F	Critical Constants Pressure psia	Critical Constants Temperature °F	Critical Constants Volume ft³/lb	Ideal Gas 14.696 psia, 60°F Spgr (air=1.00)	Ideal Gas 14.696 psia, 60°F ft³/lb-gas	Specific Heat, Btu/lb/°F 14.696 psia, 60°F Ideal Gas
Methane	CH_4 (C_1)	16.0430	5000	666.0	–116.66	0.0988	0.5539	23.654	0.52676
Ethane	C_2H_6 (C_2)	30.0700	800	707.0	90.07	0.0783	1.0382	12.620	0.40789
Propane	C_3H_8 (C_3)	44.0970	188.65	617.0	205.93	0.0727	1.5226	8.6059	0.38847
Isobutane	C_4H_{10} (C_4)	58.1230	72.581	527.9	274.4	0.0714	2.0068	6.5291	0.38669
n-butane	C_4H_{10}	58.1230	51.706	548.8	305.52	0.0703	2.0068	6.5291	0.39500
Iso-pentane	C_5H_{12}	72.1500	20.443	490.4	368.96	0.0684	2.4912	5.2596	0.38448
n-pentane	C_5H_{12}	72.1500	15.575	488.1	385.7	0.0695	2.4912	5.2596	0.38831
Neo-pentane	C_5H_{12}	72.1500	36.72	464.0	321.01	0.0673	2.4912	5.2596	0.39038
n-hexane	C_6H_{14}	86.1770	4.9596	436.9	453.8	0.0688	2.9755	4.4035	0.38631
2-methyl pentane	C_6H_{14}	86.1770	6.769	436.6	435.76	0.0682	2.9755	4.4035	0.38526
3-methyl pentane	C_6H_{14}	86.1770	6.103	452.5	448.2	0.0682	2.9755	4.4035	0.37902
Neo hexane	C_6H_{14}	86.1770	9.859	446.7	419.92	0.0667	2.9755	4.4035	0.38231
2,3-dimethylbutane	C_6H_{14}	86.1770	7.406	454.0	440.08	0.0665	2.9755	4.4035	0.37762
n-Heptane	C_7H_{16}	100.2040	1.621	396.8	512.8	0.0682	3.4598	3.7872	0.38449

- Natural gas, C1-C5+, water, inert gases

- NGL (Natural Gas Liquids), under pressure
- LPG (Liquefied Petroleum Gas), propan+butan, -42 C
- LNG (Liquefied Natural Gas), -162 C, 1 atm
- CNG (Compressed Natural Gas), 180-200 bar

- Condensate (liquid), C4-C7, transition gas-to-oil
- Oil, C6 and heavier fractions

Viscosity

The viscosity of a gas depends on its temperature and pressure. Unlike liquids, the viscosity of a gas increases with increase in temperature. Since viscosity represents resistance to flow, as the gas temperature increases, the quantity of gas flow through a pipeline will decrease; hence, more throughput is possible in a gas pipeline at lower temperatures. This is in sharp contrast to liquid flow, where the throughput increases with temperature due to decrease in viscosity and vice versa. It must be noted that, unlike liquids, pressure also affects the viscosity of a gas. Like temperature, the gas viscosity increases with pressure. Figure 1.1 shows the variation of viscosity with temperature for a gas. Table 1.2 lists the viscosities of common gases.

Viscosity		USCS	SI
	Absolute Viscosity, μ (dynamic viscosity)	lb/ft-s	Pa.s (kg/m-s) Poise, P = 0.1 Pa.s centiPoise, cP = 0.01 P = 0.001 Pa.s Water viscosity = 1 cP
	Kinematic Viscosity, $\nu = \dfrac{\mu}{\rho}$	ft^2/s	m^2/s Stokes, St = 10^{-4} m^2/s

Viscosity

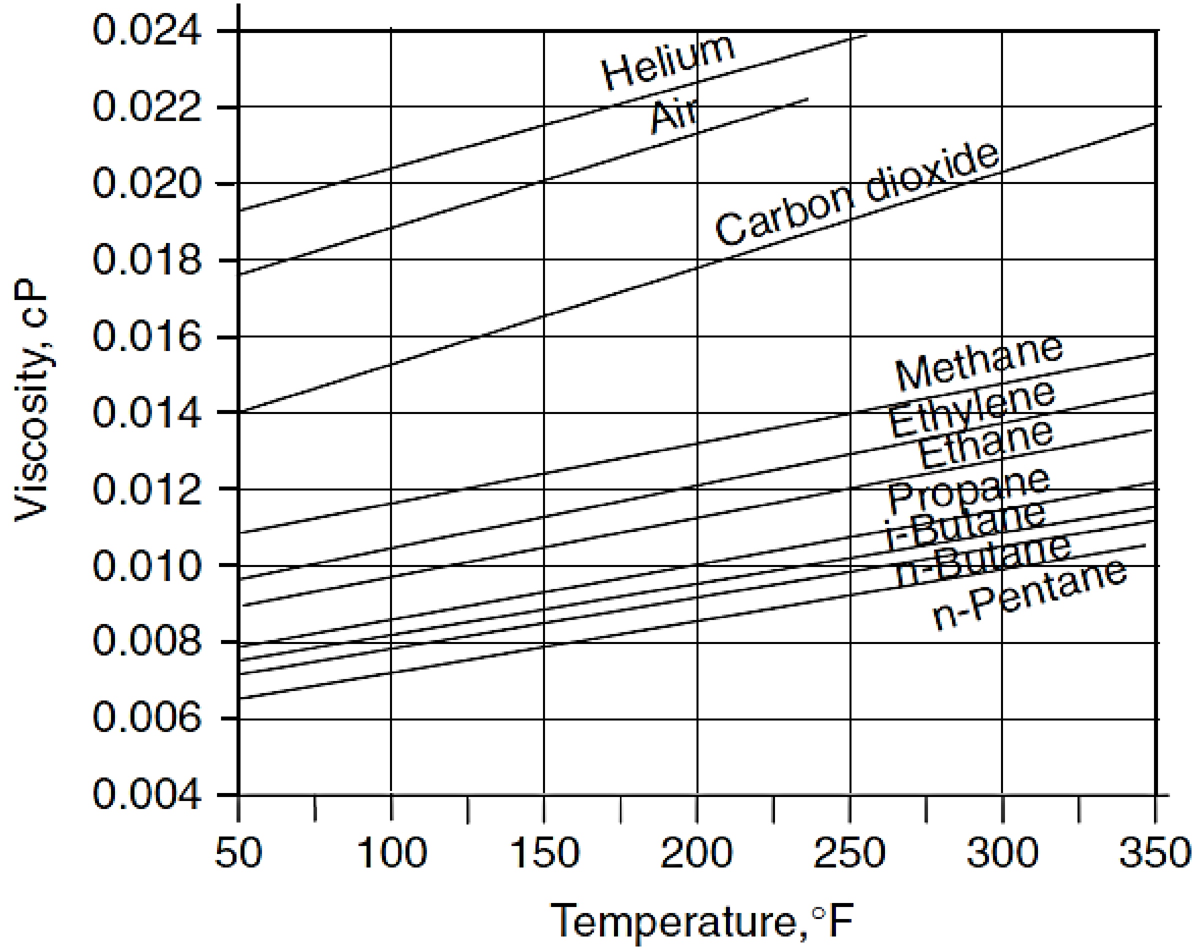


Figure 1.1 Variation of gas viscosity with temperature.

$$1\,cP = 10^{-3}\ Pa.s$$

Table 1.2 Viscosities of Common Gases

Gas	Viscosity (cP)
Methane	0.0107
Ethane	0.0089
Propane	0.0075
i-Butane	0.0071
n-Butane	0.0073
i-Pentane	0.0066
n-Pentane	0.0066
Hexane	0.0063
Heptane	0.0059
Octane	0.0050
Nonane	0.0048
Decane	0.0045
Ethylene	0.0098
Carbon Monoxide	0.0184
Carbon Dioxide	0.0147
Hydrogen Sulphide	0.0122
Air	0.0178
Nitrogen	0.0173
Helium	0.0193

Viscosity

Since natural gas is a mixture of pure gases such as methane and ethane, the following formula is used to calculate the viscosity from the viscosities of component gases:

$$\mu = \frac{\Sigma\left(\mu_i y_i \sqrt{M_i}\right)}{\Sigma\left(y_i \sqrt{M_i}\right)} \tag{1.6}$$

According to kinetic theory of gases

where

μ = dynamic viscosity of gas mixture

μ_i = dynamic viscosity of gas component i

y_i = mole fraction or percent of gas component i

M_i = molecular weight of gas component i

It must be noted that all viscosities must be measured at the same temperature and pressure.

Example 1

A natural gas mixture consists of four components C_1, C_2, C_3, and nC_4. Their mole fractions and viscosities at a particular temperature and pressure are indicated below, along with their molecular weights.

Component	Mole Fraction *y*	Viscosity, cP	Molecular Weight
C_1	0.8200	0.0130	16.04
C_2	0.1000	0.0112	30.07
C_3	0.0500	0.0098	44.10
nC_4	0.0300	0.0091	58.12
Total	1.000		

Calculate the viscosity of the gas mixture.

Ans: 0.0123 cP

Ideal Gases

An **ideal gas** is defined as a fluid in which the volume of the gas molecules is negligible when compared to the volume occupied by the gas. Also, the attraction or repulsion between the individual gas molecules and the container is negligible.

Further, in an ideal gas, the molecules are considered to be perfectly elastic, and there is no internal energy loss resulting from collision between the molecules. Such ideal gases are said to obey several gas laws, such as **Boyle's law, Charles's law, and the ideal gas law** or the perfect gas equation.

If M represents the molecular weight of a gas and the mass of a certain quantity of gas is m, the number of moles, n is given by

$$n = \frac{m}{M} \tag{1.7}$$

For example the molecular weight of methane is 16.043. Therefore, 50 lb of methane will contain approximately 3 moles.

Ideal Gases

The ideal gas law, sometimes referred to as the perfect gas equation, simply states that the pressure, volume, and temperature of the gas are related to the number of moles by the following equation:

$$PV = nRT \quad \text{(USCS units)} \tag{1.8}$$

where

P = absolute pressure, pounds per square inch absolute (psia)
V = gas volume, ft^3
n = number of lb moles as defined in Equation 1.7
R = universal gas constant, psia ft^3/lb mole °R
T = absolute temperature of gas, °R (°F + 460)

The universal gas constant R has a value of 10.73 psia ft^3/lb mole °R in USCS units. We can combine Equation 1.7 with Equation 1.8 and express the ideal gas equation as follows:

$$PV = \frac{mRT}{M} \tag{1.9}$$

All symbols are as defined previously.

It should be noted that the constant R is the same for all ideal gases and, hence, it is called the universal gas constant.

Ideal Gases

It has been found that the ideal gas equation is correct only at low pressures close to the atmospheric pressure. Since gas pipelines generally operate at pressures higher than atmospheric pressures, we must modify Equation 1.9 to take into account the **effect of compressibility.**

The effect of compressibility is accounted for by using a term called the **compressibility factor** or **gas deviation factor, Z**.

Real Gases

When dealing with real gases, we can apply the ideal gas equation and get reasonably accurate results only when the pressures are close to the atmospheric pressure. When pressures are higher, the ideal gas equation will not be accurate for most real gases. The error in calculations at high pressures using the ideal gas equation may be as high as 500% in some instances. This compares with errors of 2 to 3% at low pressures.

The **critical temperature, T_c** of a pure gas is defined as the temperature above which a gas cannot be compressed to form a liquid, regardless of the pressure. The **critical pressure, P_c** is defined as the minimum pressure that is required at the **critical temperature** to compress a gas into a liquid.

Real gases can be considered to follow a modified form of the ideal gas law. The modifying factor is included in the gas property known as the **compressibility factor, Z**. This is also called the **gas deviation factor**.

Real Gases

The **compressibility factor, *Z*** can be defined as the ratio of the gas volume at a given temperature and pressure to the volume the gas would occupy if it were an ideal gas at the same temperature and pressure.

Z is a dimensionless number less than 1.0 and it varies with temperature, pressure, and composition of the gas. Using the **compressibility factor *Z***, the ideal gas equation is modified for real gas as follows:

$$PV = ZnRT \quad \text{(USCS units)} \qquad (1.16)$$

where

P = absolute pressure of gas, psia
V = volume of gas, ft^3
Z = gas compressibility factor, dimensionless
T = absolute temperature of gas, °R
n = number of lb moles as defined in Equation 1.7
R = universal gas constant, 10.73 psia ft^3/lb mole °R

Real Gases

The theorem known as **corresponding states** says that the extent of deviation of a real gas from the ideal gas equation is the same for all real gases when the gases are at the same corresponding state.

The corresponding state can be represented by the two parameters called **reduced temperature, T_r** and **reduced pressure, P_r**.

The **reduced temperature, T_r** is the ratio of the temperature of the gas to its **critical temperature, T_c**. Similarly, the **reduced pressure, P_r** is the ratio of the gas pressure to its **critical pressure, P_c** as indicated in the following equations:

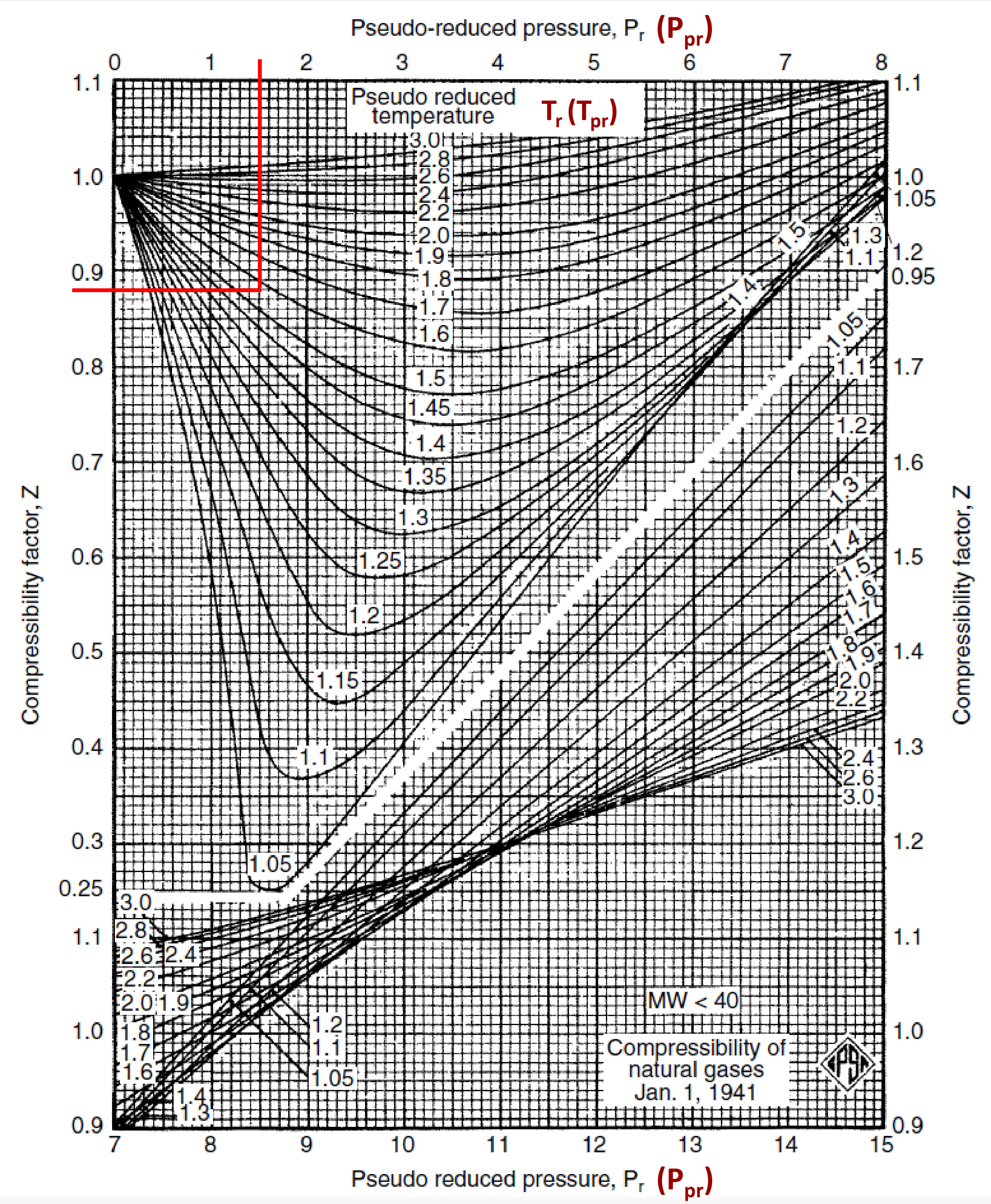
$$T_r = \frac{T}{T_c} \qquad (1.17)$$

$$P_r = \frac{P}{P_c} \qquad (1.18)$$

where

P = absolute pressure of gas, psia
T = absolute temperature of gas, °R
T_r = reduced temperature, dimensionless
P_r = reduced pressure, dimensionless
T_c = critical temperature, °R
P_c = critical pressure, psia

Compressibility factor chart (Standing-Katz chart)



For example, suppose the critical temperature and critical pressure of methane are 343°R and 666 psia, respectively; the ~~reduced~~ temperature and pressure of the gas at 80°F and 1000 psia pressure are as follows:

$$T_r = \frac{80+460}{343} = 1.57$$

and

$$P_r = \frac{1000}{666} = 1.50$$

$$Z = 0.88$$

Natural Gas Mixtures

When the gas consists of a mixture of different components, the critical temperature and critical pressure are called the ***pseudo-critical temperature, T_{pc}*** and ***pseudo-critical pressure, P_{pc}*** ,respectively.

If the composition of the gas mixture is known, we can calculate these pseudo-critical values of the mixture, using the critical pressure and temperature values of the pure components that constitute the gas mixture. The ***pseudo-reduced temperature , T_{pr}*** and ***pseudo-reduced pressure , P_{pr}*** for a gas mixture can be calculated as:

$$T_{pr} = \frac{T}{T_{pc}} \tag{1.19}$$

$$P_{pr} = \frac{P}{P_{pc}} \tag{1.20}$$

where

P = absolute pressure of gas mixture, psia
T = absolute temperature of gas mixture, °R
T_{pr} = pseudo-reduced temperature, dimensionless
P_{pr} = pseudo-reduced pressure, dimensionless
T_{pc} = pseudo-critical temperature, °R
P_{pc} = pseudo-critical pressure, psia

Natural Gas Mixtures

A natural gas mixture that consists of components such as C_1, C_2, C_3, and so forth is said to have an **apparent molecular weight, *M_a*** as defined by the equation:

$$M_a = \Sigma y_i M_i \qquad (1.21)$$

where

M_a = apparent molecular weight of gas mixture
y_i = mole fraction of gas component i
M_i = molecular weight of gas component i

In a similar manner, from the given mole fractions of the gas components, we use Kay's rule to calculate the ***average pseudo-critical properties*** of the gas mixture.

$$T_{pc} = \Sigma y_i T_c \qquad (1.22)$$

$$P_{pc} = \Sigma y_i P_c \qquad (1.23)$$

where T_c and P_c are the critical temperature and pressure, respectively, of the pure component (C_1, C_2, etc.) and y_i refers to the mole fraction of the component. T_{pc} and P_{pc} are the average pseudo-critical temperature and pseudo-critical pressure, respectively, of the gas mixture.

Natural Gas Mixtures

Example 5

Calculate the apparent molecular weight of a natural gas mixture that has 85% methane, 9% ethane, 4% propane, and 2% normal butane as shown below:

Component	Percent	Molecular Weight
C_1	85	16.01
C_2	9	30.10
C_3	4	44.10
$n\text{-}C_4$	2	58.10
Total	100	

Ans. 19.24

Example 6

Calculate the pseudo-critical temperature and the pseudo-critical pressure of a natural gas mixture consisting of 83% methane, 12% ethane, and 5% propane.

The critical properties of C_1, C_2, and C_3 components are as follows:

Components	Critical Temperature, °R	Critical Pressure, psia
C_1	343	666
C_2	550	707
C_3	666	617

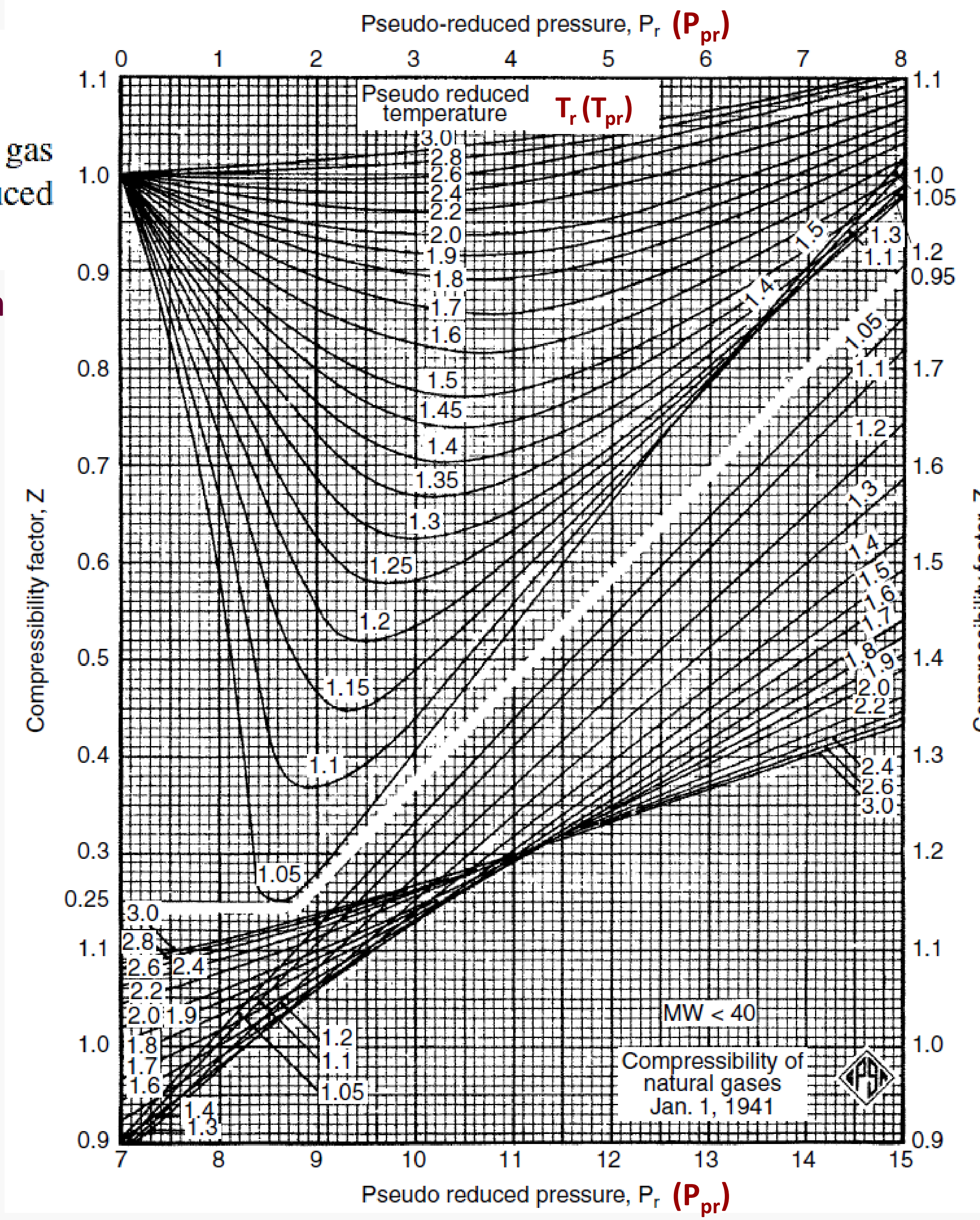
Ans. 383.99°R and 668.47 psia

Natural Gas Mixtures

Example 7

If the temperature of the gas in the previous example is 70°F and the average gas pressure is 1200 psig, what are the pseudo-reduced temperature and pseudo-reduced pressure of this gas? Use 14.7 psia for base pressure.

Also determine the compressibility factor of gas mixture at this condition



$$T_{pr} = \frac{70+460}{383.99} = 1.38$$

$$P_{pr} = \frac{1200+14.7}{668.47} = 1.82$$