Regulator Station Design

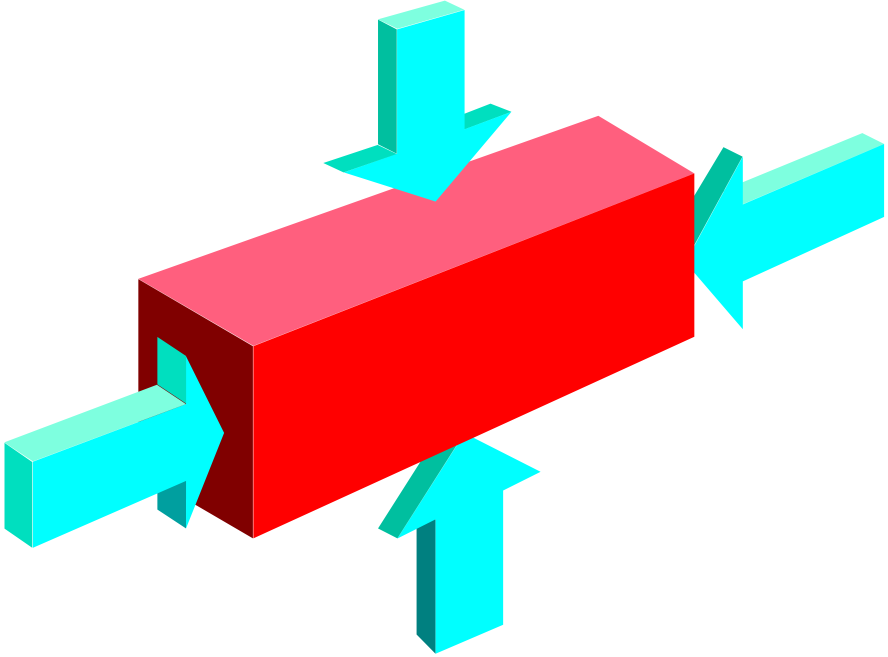
INTRODUCTION OF BASIC GAS LAWS

OGA 2015 Regulator Fundamentals Seminar

Ideal Gas Law

- A *volume* of gas is directly *proportional* to the *absolute temperature* and *inversely proportional* to the *absolute pressure*

Ideal Gas Law



- $V = \dfrac{K \times T}{P}$
- $\dfrac{(V \times P)}{T} = K$
- $\dfrac{(V_1 \times P_1)}{T_1} = \dfrac{(V_2 \times P_2)}{T_2}$
- Where

  T = Absolute Temperature

  P = Absolute Pressure

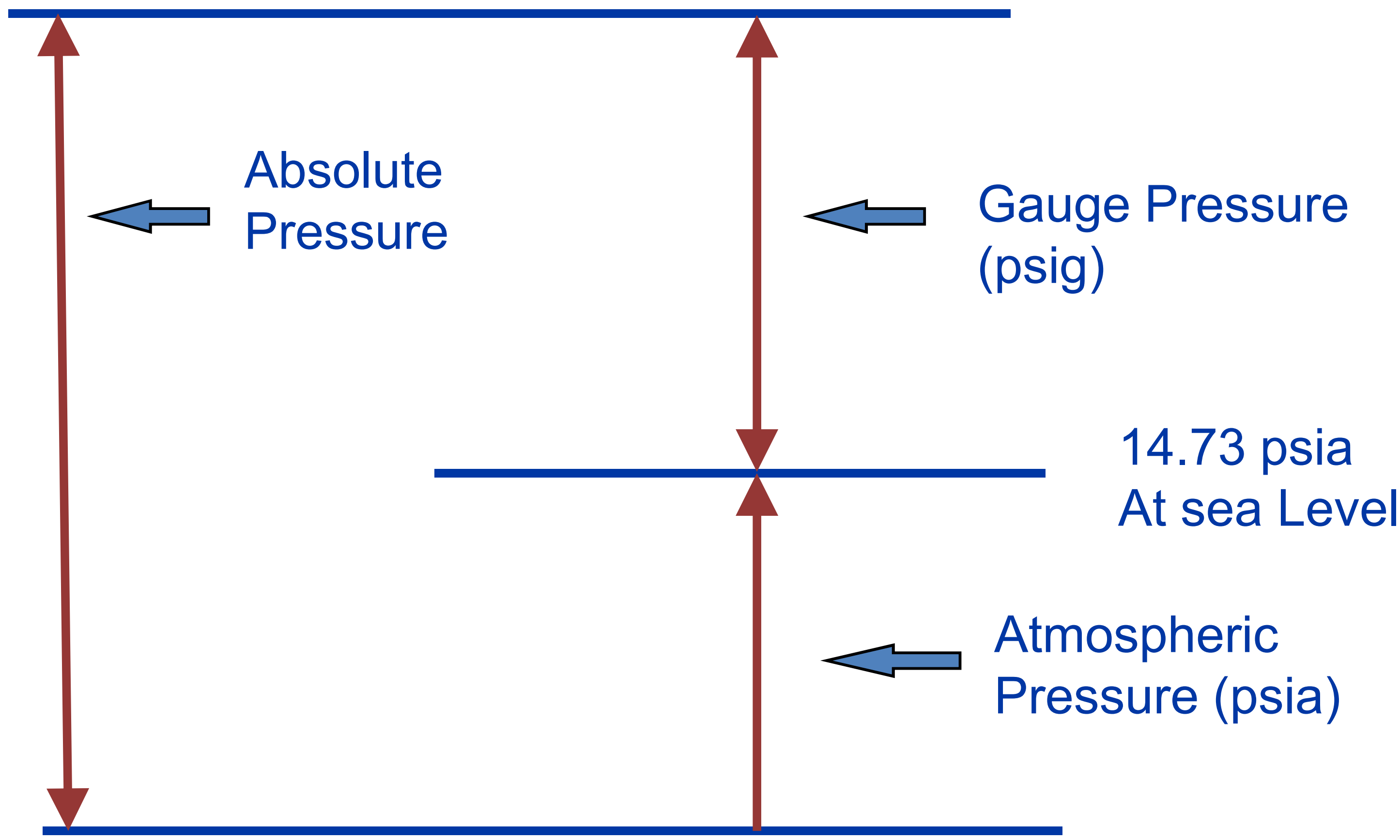
  K = Gas Constant

Gas Law Units and Conversions

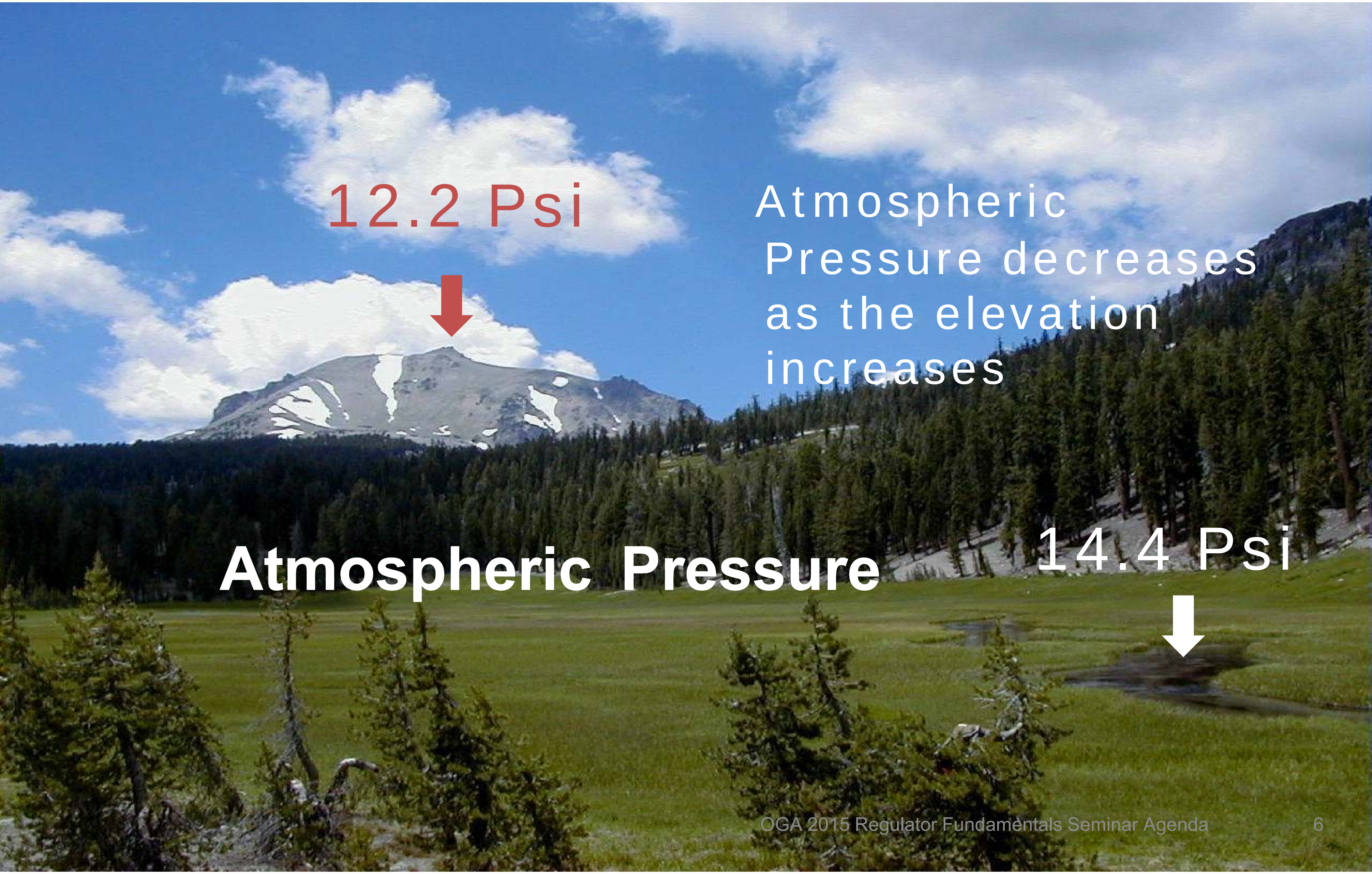
- T = Absolute Temperature
  - Measured in degrees Rankine
- P = Absolute Pressure
  - Measured in psia
- P_{gauge} = Gauge Pressure
  - Measured in psig

- Rankine = Fahrenheit + 460
- Absolute Pressure = Gauge Pressure + Atmospheric Pressure

Pressure Scales



Atmospheric Pressure



Atmospheric Pressure

Altitude	Atmospheric Pressure (psia)
0	14.73
500	14.48
1000	14.22
1500	13.95
2000	13.69
2500	13.44
3000	13.19

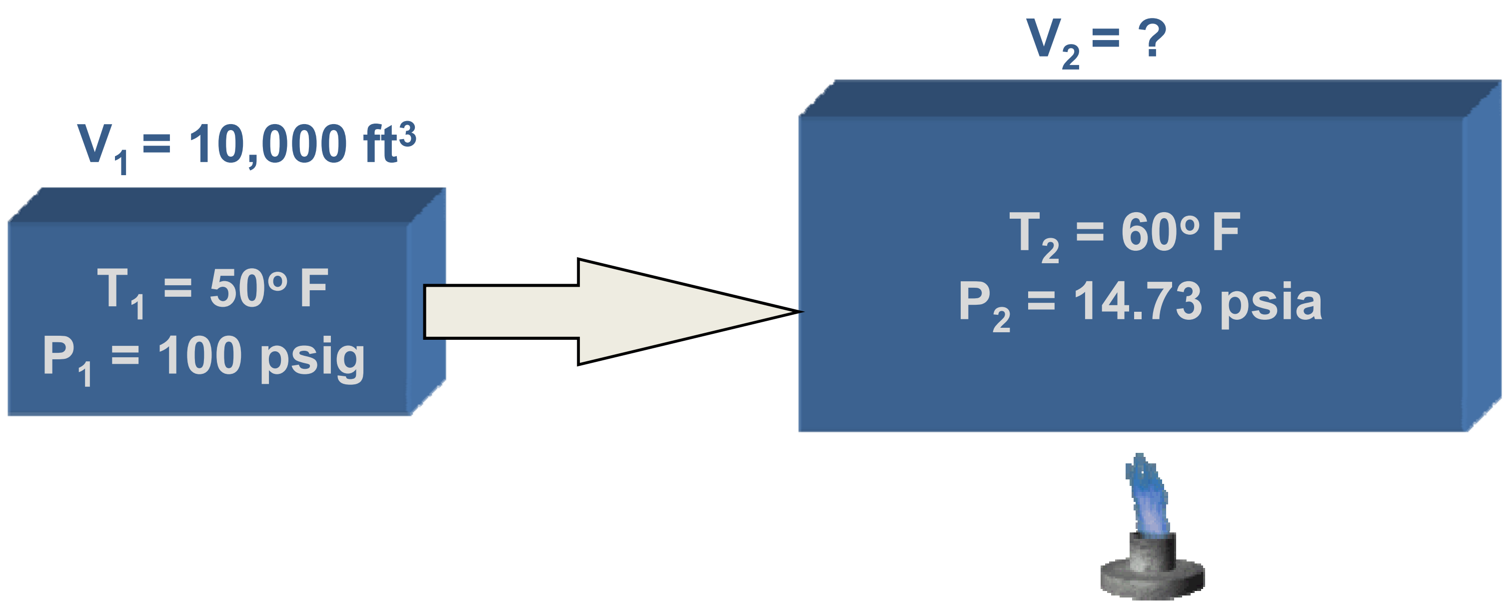
Altitude	Atmospheric Pressure (psia)
3500	12.96
4000	12.72
4500	12.49
5000	12.27
5500	12.05
6000	11.84
6500	11.63

Altitude & Atmospheric Pressure

City	Alt.	Atm. Pressure	City	Alt.	Atm. Pressure
Santa Fe	7013	11.33	Kansas City	963	14.24
Cheyenne	6141	11.71	Minneapolis	919	14.24
Lander	5352	12.10	Des Moines	860	14.29
Denver	5292	12.14	Pittsburgh	842	14.31
Salt Lake	4357	12.58	Buffalo	706	14.37
Amarillo	3676	12.84	Chicago	673	14.39
Spokane	1929	13.74	Austin	605	14.42
Las Vegas	1869	13.74	St. Louis	568	14.45
Lincoln	1189	14.07	Dallas	512	14.47
Phoenix	1107	14.12	New York	314	14.58
Omaha	1105	14.16	Houston	138	14.68
Atlanta	1010	14.17	Boston	125	14.67
Topica	986	14.22	Philadelphia	114	14.70

Example of Ideal Gas Law

- ***10,000 ft^3*** of gas is metered at ***100 psig @ 50^{O}F***. What would be its volume at a pressure of 14.73 psia and a temperature of 60^{O}F? Assume atmospheric pressure is 14.4 psia



Solution - Ideal Gas Law

- Ideal Gas Law: $\left(\frac{P_1 \times V_1}{T_1}\right) = \left(\frac{P_2 \times V_2}{T_2}\right)$

Solving for V_2: $$V_2 = V_1 \times \left(\frac{P_1}{P_2}\right) \times \left(\frac{T_2}{T_1}\right)$$

Where:

V_1 = 10,000 ft^3

P_1 = 100 psig + 14.4 psia = 114.4 psia

T_1 = 460ºF + 50ºF = 510R

P_2 = 14.73 psia

T_2 = 460ºF + 60ºF = 520R

Solving for V_2 (continued):

- $$V_2 = 10{,}000 \times \left(\frac{114.4}{14.73}\right) \times \left(\frac{520}{510}\right)$$
- $$V_2 = 10{,}000 \times 7.77 \times 1.019$$
- **V_2 = 79,176 ft^3**

Solution - Ideal Gas Law

- Ideal Gas Law: $$\left(\frac{P_1 \times V_1}{T_1}\right) = \left(\frac{P_2 \times V_2}{T_2}\right)$$

Solving for V_2: $$V_2 = V_1 \times \left(\frac{p_1}{P_2}\right) \times \left(\frac{T_2}{T_1}\right)$$

Where:

V_1 = 10,000 ft^3

P_1 = 100 psig + 12.2 psia = 112.2 psia

T_1 = 460ºF + 50ºF = 510R

P_2 = 14.73 psia

T_2 = 460ºF + 60ºF = 520R

Solving for V_2 (continued):

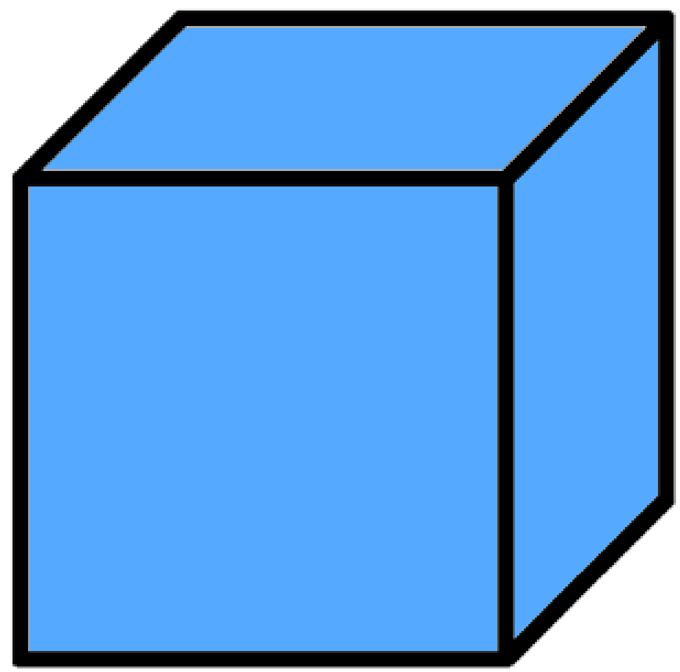
- $$V_2 = 10{,}000 \times \left(\frac{112.2}{14.73}\right) \times \left(\frac{520}{510}\right)$$
- $$V_2 = 10{,}000 \times 7.62 \times 1.019$$
- $$\mathbf{V_2 = 77{,}647\ ft^3}$$
- An Atmospheric Pressure Difference of 14.4 & 12.2 Psia

$$V_2 = 79{,}176\ ft^3 - 77{,}647\ ft^3 = \mathbf{1{,}529\ ft^3}$$

Standard Cubic Foot

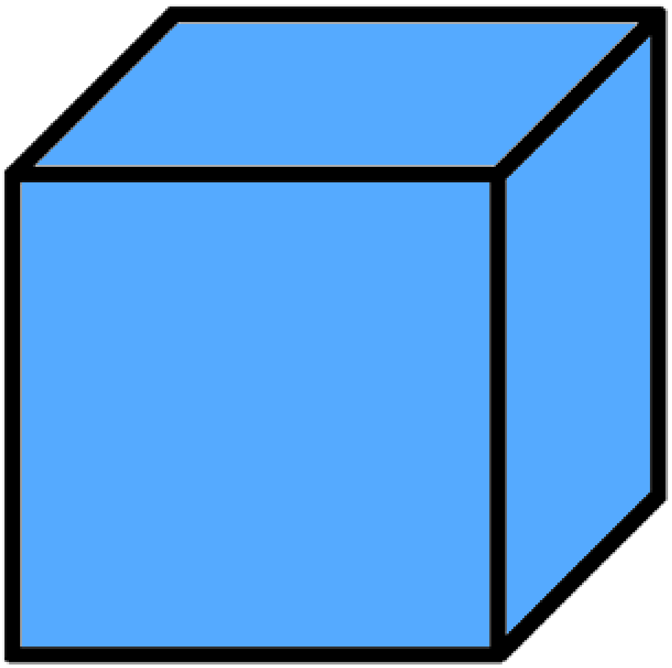
Standard Cubic Foot is Defined As:

1 ft^3 of gas at **60°F** and **14.73 psia (**pounds of pressure per square inch *absolute*)



Units of Gas Measurement

- Gas Volume
  - Cubic Feet (ft^3)
    - CCF – 100 ft^3
    - MCF – 1000 ft^3
    - DMCF – 10,000 ft^3
    - MMCF – 1,000,000 ft^3



Units of Gas Measurement

- Pressure
  - **psi** = pounds per square inch
  - **psig** = pounds per square inch **gauge**
  - **psia** = pounds per square inch **absolute**
  - P_{ATM} = atmospheric pressure
  - in. of w.c. = inches of water column
    - (27.7 inches of water column = 1 psig)
  - oz = ounces per square inch

Actual Cubic Foot

- Actual Cubic Foot
  - One cubic foot of gas at any temperature or pressure
  - A volume of gas measured in actual cubic feet represents the actual volume of the gas under the current conditions (pressure and temperature)
- Positive displacement meters calculate the volume of gas by measuring the actual cubic feet passing
  - e.g. diaphragm meters, rotary meters

Standard Cubic Foot

- Standard Cubic Foot
  - One cubic foot of gas at base temperature or base pressure
    - Base pressure = 14.73 psia
    - Base temperature = 60°F
  - A volume of gas measured in standard cubic feet represents the same volume of gas as if it were subject to base pressure and base temperature
  - The standard cubic foot is the standard form of measurement of gas in the industry
    - It does not vary from location to location, or by pressure or temperature, since it is relative to base conditions

Pressure

- Pressure is:

  The measure of the force per unit area exerted by a gas on all surfaces of a container

- Gage Pressure is:

  A comparison of the pressure in a container against atmospheric pressure

- Atmospheric Pressure is:

  The force of the column of air above a certain area

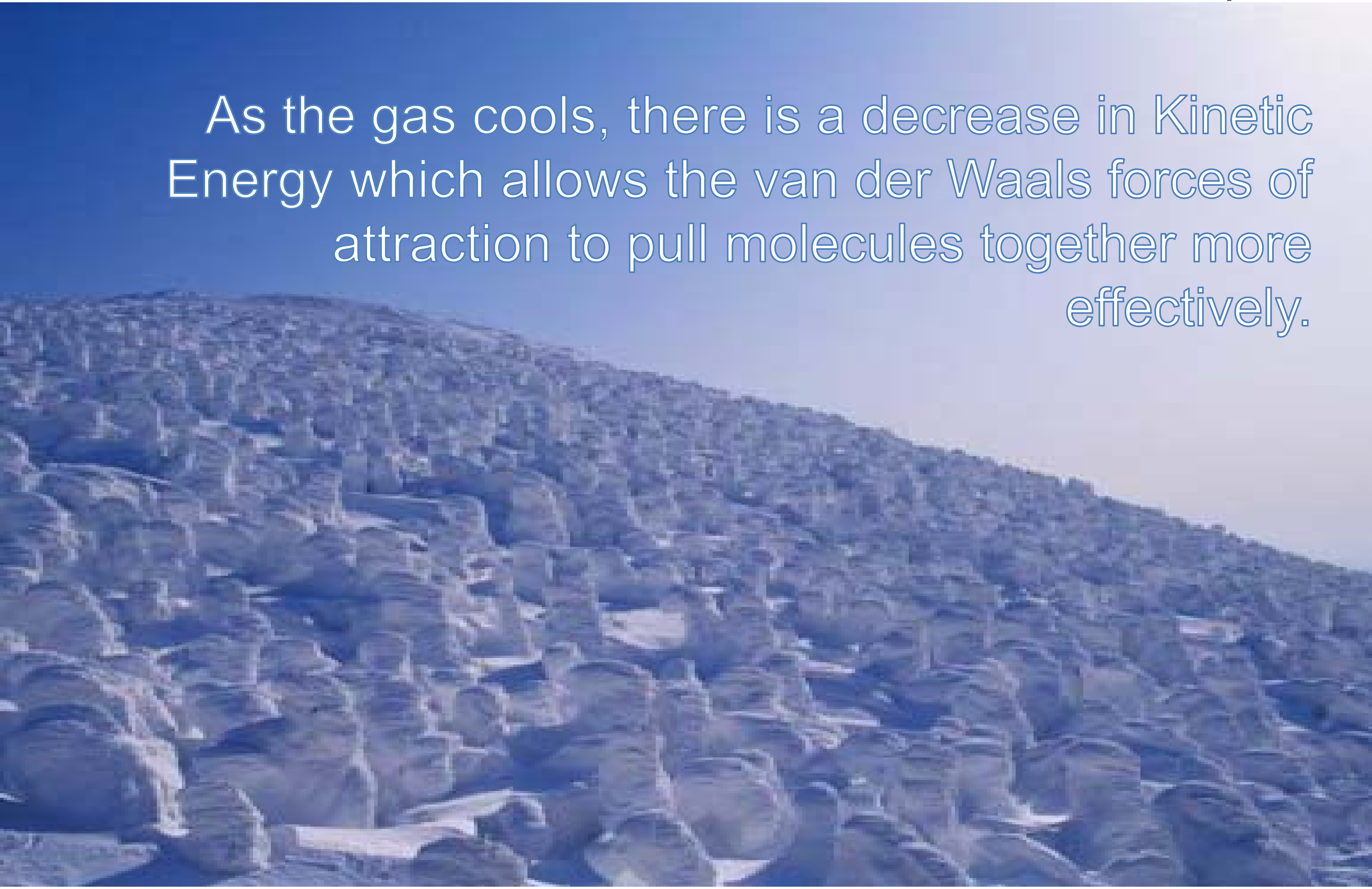
Units of Gas Measurement

- **Temperature**
  - The degree of hotness or coldness of a body or environment.
- **Absolute Temperature**
  - The specific temperature of a material as referenced to the coldest temperature physically possible,
  - Absolute Zero -459.67°F ≈ 0R

Real Gas vs. Ideal Gas

- At pressures up to approximately 2,000 psig, attractive forces bring the molecules closer together
  - Referred to as the van der Waals effect
  - A volume of gas subject to the van der Waals effect occupies a smaller volume than the ideal gas law predicts

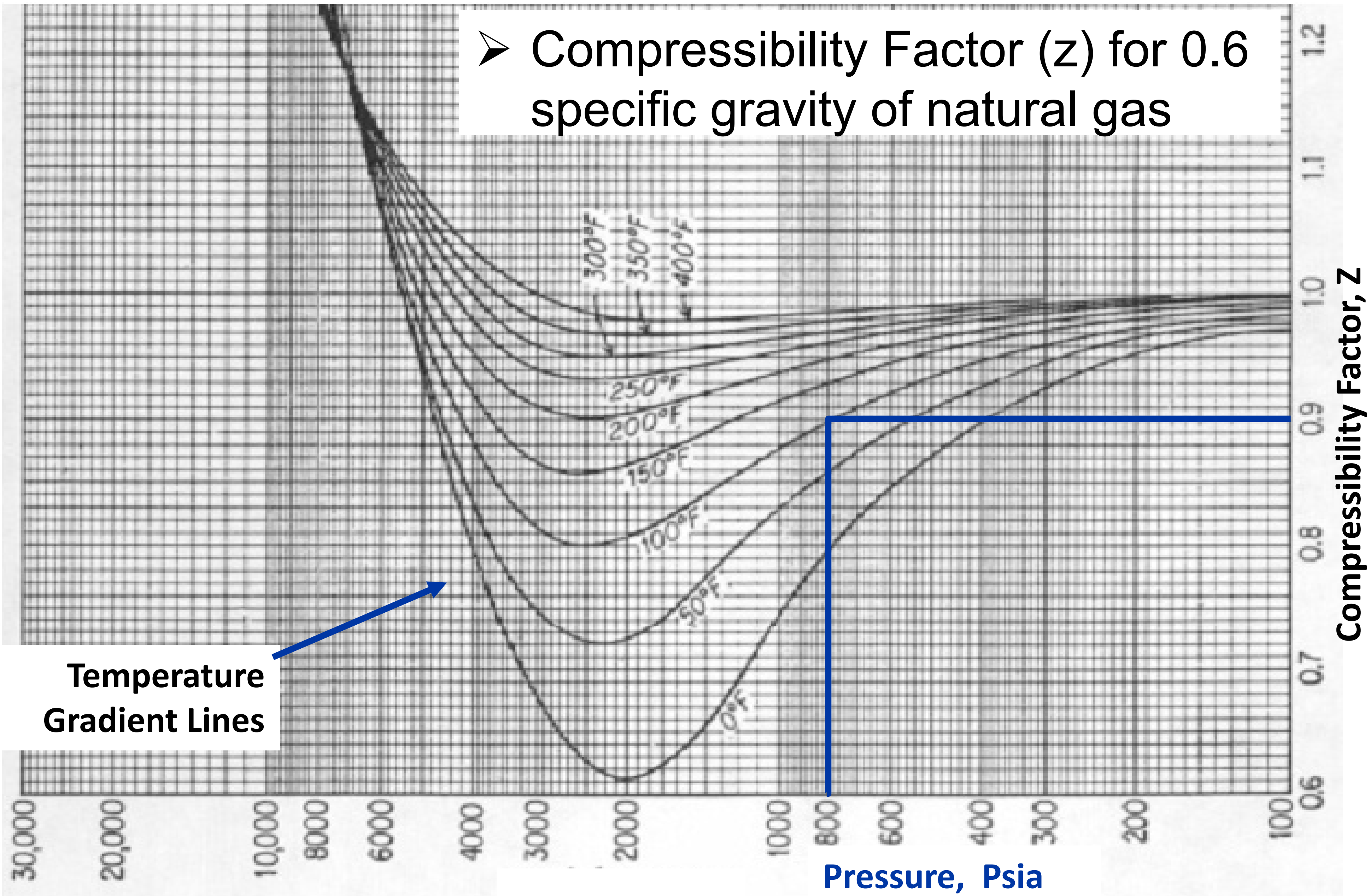
Real Gas vs. Ideal Gas



Real Gas vs. Ideal Gas

- The volume of real gas can be accurately calculated by utilizing the compressibility factor (Z)
- The compressibility factor is a function of pressure (P), temperature (T), and gas composition

Real Gas vs. Ideal Gas



Real Gas Law

Real Gas Law may be written as: $$\frac{P \times V}{T} = Z \times K$$

Solving for *K*, we find: $$K = \frac{P \times V}{T \times Z}$$

Therefore: $$\frac{P_1 \times V_1}{T_1 \times Z_1} = \frac{P_2 \times V_2}{T_2 \times Z_2}$$

Solving for V_2, we find: $$V_2 = \frac{P_1}{P_2} \times \frac{T_2}{T_1} \times \frac{Z_2}{Z_1}$$

Real Gas Law

$$V_2 = \frac{P_1}{P_2} \times \frac{T_2}{T_1} \times \frac{Z_2}{Z_1}$$

The ratio of compressibility factors can be described as:

$$Sc = \frac{Z_2}{Z_1}$$

where *Sc* is known as the *supercompressibility ratio*.

The *supercompressibility ratio* can further be described as the more commonly known *supercompressibility factor*:

$$F_{pv} = \sqrt{\frac{Z_2}{Z_1}}$$

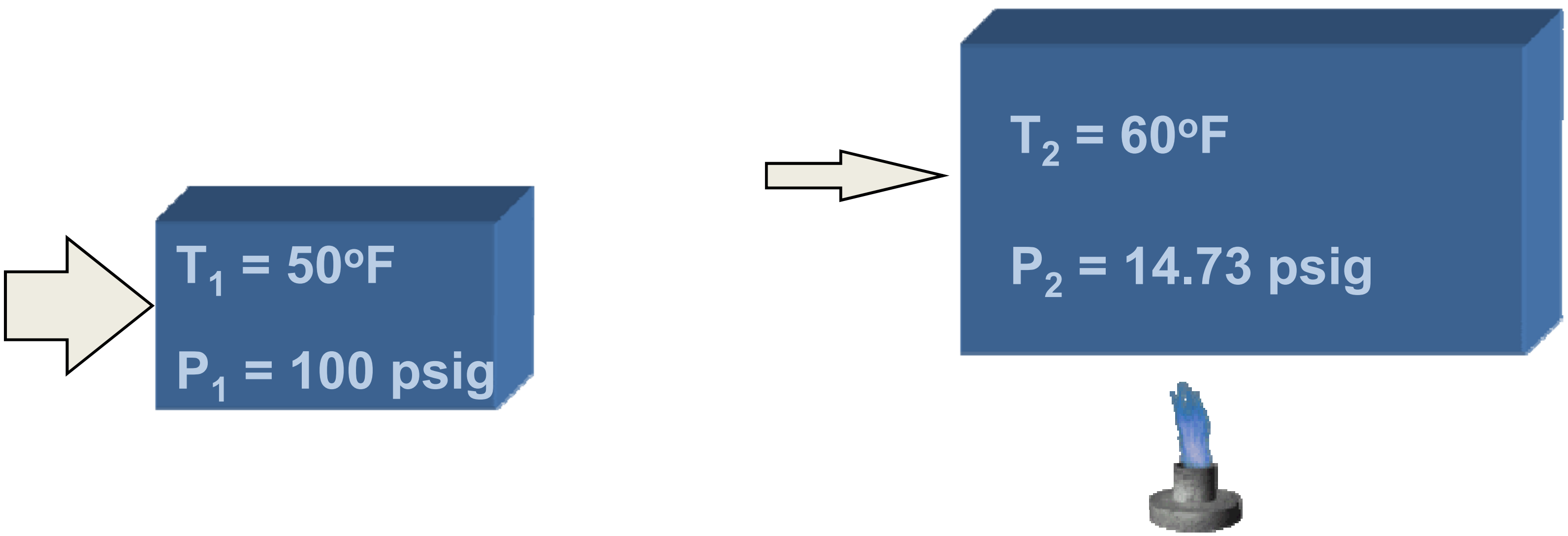
Real Gas Law

Therefore, the real gas law may be rewritten as:

$$V_2 = \frac{P_1}{P_2} \times \frac{T_2}{T_1} \times F_{pv}^2$$

Example of Real Gas Law

- ***10,000 Ft^3*** of gas is metered at **100 psig @ 50^{O}F**
- What would be the volume considering compressibility at a pressure of 14.73 psia and temperature = **60^{O}F?**
- Assume atmospheric pressure is 14.4 psia and a specific gravity of 0.60



Supercompressibility Factor F_{pv}

0.6 Specific Gravity Hydrocarbon Gas

Pressure	Temperature (ºF)					
(psig)	40	45	50	55	60	65
0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
20	1.0018	1.0017	1.0016	1.0016	1.0016	1.0015
40	1.0037	1.0036	1.0034	1.0033	1.0032	1.0031
60	1.0054	1.0053	1.0051	1.0049	1.0047	1.0046
80	1.0073	1.0070	1.0068	1.0066	1.0064	1.0062
100	1.0091	1.0088	1.0085	1.0083	1.0080	1.0078
120	1.0110	1.0106	1.0103	1.0100	1.0097	1.0094
140	1.0128	1.0124	1.0120	1.0116	1.0112	1.0109
160	1.0147	1.0142	1.0138	1.0133	1.0129	1.0125

Solution - Real Gas Law (cont'd)

- Real Gas Law: $\dfrac{(P_1 \times V_1)}{(Z_1 \times T_1)} = \dfrac{(P_2 \times V_2)}{(Z_2 \times T_2)}$

$$V_2 = V_1 \times \frac{(P_1)}{(P_2)} \times \frac{(T_2)}{(T_1)} \times F_{pv}^2$$

$V_1 = 10{,}000\ ft^3$

$P_1 = 100$ psig + 14.4 psia = 114.4 psia

$T_1 = 460ºF + 50ºF = 510R$

$P_2 = 14.73$ psia

$T_2 = 460ºF + 60ºF = 520R$

$F_{pv} = 1.0085$

Solution - Real Gas Law

- $V_2 = 10{,}000 \times \frac{114.4}{14.73} \times \frac{520}{510} \times (1.0085)^2$

- $V_2 = 10{,}000 \times 7.766 \times 1.0196 \times 1.0170$

- $V_2 = 80{,}528 \text{ ft}^3$

QUESTIONS ?