Definitions and Terms

Adjusted Equivalent Valve Area

Adjusted equivalent valve area is a measure of the effective orifice area of the complete valve assembly. This is a useful term to compare valve designs, as a valve with a higher adjusted equivalent area will generally have a lower pressure drop and better efficiency.

See the compressor theory section for additional information regarding adjusted equivalent valve area as compared to the valve lift area.

Ambient Temperature

Ambient temperature is the surrounding temperature at a compressor installation. The range of ambient temperatures is required for the proper application of gas coolers, drivers, and auxiliary systems.

Ariel does not limit services based upon low ambient temperatures. Please refer to Section 6 of the Packager Standards for frame oil heating requirements for starting and loading purposes.

Also see Suction Temperature topic for information on low gas suction temperatures.

Note: There is a potential for o-rings to lose flexibility while at lower temperatures, at or below -10 F (-23 C). This temporary loss of flexibility may result in potential gas release at the o-ring sealing joints on the cylinders when under pressure. The lower temperatures occur with either low inlet gas temperatures during operation or low ambient temperatures during idle periods. If the gas release is of concern, it is recommended that the unit be allowed to warm up in a relatively unloaded state (low or no gas pressure and start up bypass line fully open) until the equipment reaches warmer temperatures.

Balanced Opposed Design

Ariel compressors (except the JGI) are a horizontal balanced opposed design. This design utilizes throws with equal amounts of reciprocating weight on opposite sides of the frame to minimize horizontal forces. To achieve this balance, a combination of different weight crossheads and crosshead nut weights are used to achieve equal weights on opposing throws with different size / weight pistons. The maximum unbalance of reciprocating weight between opposite throws is:

Frame	Maximum Unbalance of Reciprocating Weight Between Opposite Throws, lbs
JGM, JGP, JGN, JG, JGQ, JGA, JGR, JGJ	1.0
JGH, JGE, JGK, JGT, KBK, KBT, JGC, JGD, JGF	2.5
KBZ, KBU, KBB, KBV	5.0

Some combinations of larger cylinders opposite much smaller cylinders may not balance on opposite throws. The Ariel performance software will provide these limitations.

For balancing opposing throws with the same cylinder size, use the lightest crosshead / nut combination. For balancing opposing throws with different piston sizes, pick the heaviest piston and rod assembly, and use the lightest crosshead / balance nut combination. For the lighter piston and rod assembly, choose the crosshead / balance nut combination that will match the first throws' reciprocating weight within the tolerances in the table above.

For balancing opposite a blank throw a balance crosshead may need to be used if a standard crosshead is not sufficient in weight. It must be noted that a balance crosshead requires a balance crosshead guide which is not suitable for mounting a cylinder.

Reciprocating weights are balanced on opposing throws. Reciprocating weights are not balanced end to end, across adjacent throws.

Contact Ariel Application Engineering for any questions or problems concerning reciprocating weight balance.

Clearance Volume

Cylinder clearance volume is the volume of gas left in the cylinder at the discharge end of the stroke. It includes the space between the piston and cylinder head, the volume of the valves, valve pockets and any added clearance. Clearance volume is generally expressed as a percentage of the swept volume of a given cylinder end.

$$CL\% = \frac{\text{cylinder clearance volume, in}^3}{\text{cylinder swept volume, in}^3} \times 100$$

Changes in the clearance volume of a compressor cylinder will affect the throughput and power requirements of that cylinder. Refer to the compressor theory topic for additional information. Additional clearance can be added to Ariel cylinders using the following devices:

High Clearance Valve Assembly

Variable Volume Clearance Pocket

Pneumatic Fixed Volume Clearance Pocket

Double Deck Volume Clearance Pocket

Compression Ratio

Compression ratio is defined as the discharge pressure divided by the suction pressure of a given stage of compression. Compression ratio is used in the equations for discharge temperature, volumetric efficiency, discharge event, power and rod load.

Compression ratios are typically in the range of 2 to 4 for gathering applications and typically below 2 for pipeline applications.

Higher compression ratios will result in higher discharge temperatures, lower volumetric efficiencies and lower valve discharge events. Typically, the upper end of the compression ratio is limited by reaching a maximum discharge temperature or low volumetric efficiency. Some gasses with lower ratio of specific heat values (k or N) can reach higher compression ratios before being limited by discharge temperature. Some cylinders with lower volumetric clearance can reach higher compression ratios before being limited by volumetric efficiency. This makes limiting the upper end of compression ratio subjective.

The main difficulty with higher compression ratios is the loss of flexibility of operating conditions. Higher compression ratios result in a greater sensitivity to changes in suction and discharge pressure. This can limit the useful operating range of an application. Higher ratios also have an adverse effect on compressor valve performance and reliability.

Rod load is a function of the suction and discharge pressures within a cylinder, so are also impacted by the compression ratio. High compression ratios generally result in higher rod load values. Small changes in pressures at higher ratios can result in larger changes in rod load.

When compression ratios are in the higher range, any clearance pocket devices should be checked for full range use. With higher ratios, clearance has a much greater effect on the volumetric efficiency. If the clearance pockets cannot be used fully at the higher compression ratios, considerations should be made to either limit the use of the pockets, or to omit clearance pocket devices from the cylinders.

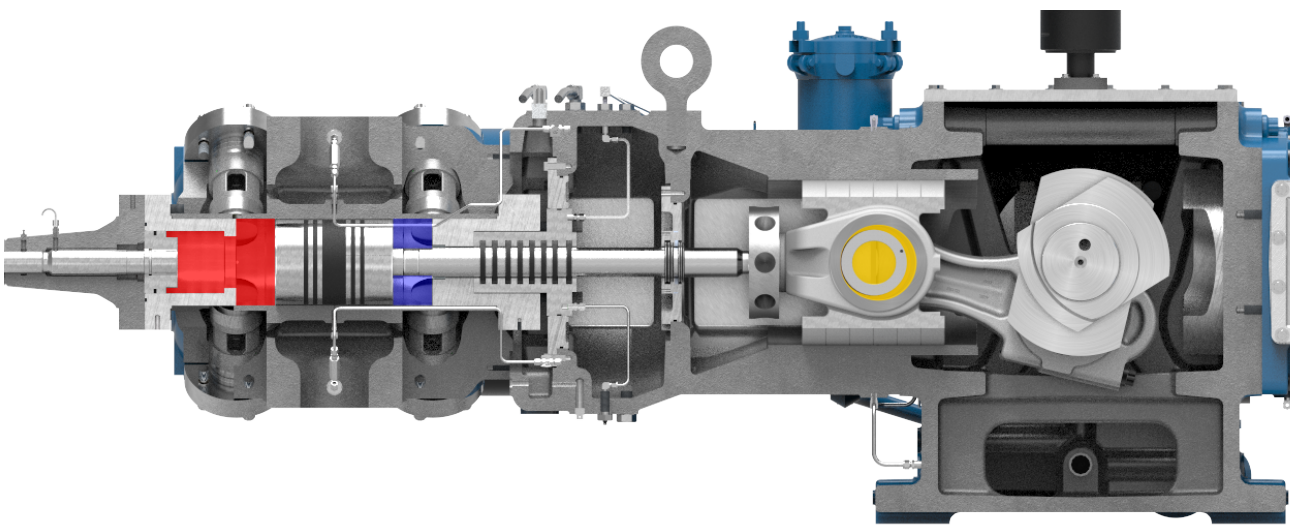
When no other flags exist, a good practical limit for the higher end of the compression ratio range is 4.5 ratios. A warning has been placed in the performance software to flag this ratio to help draw attention to the possible difficulties. When this warning flag occurs, the specific application must be reviewed for the applicability of the compression ratio for the specific operating range.

Cylinder Action, Double Acting

A double acting cylinder compresses gas on the instroke and outstroke of the piston. This requires suction and discharge valves on both ends (head end and crank end) of the cylinder.

As gas is being compressed in the head end on the outstroke, gas is entering the cylinder on the crank end, with the process reversed on the instroke.

Figure: Double Acting Cylinder



Cylinder Action, Single Acting

A single acting cylinder compresses gas on only either the instroke or outstroke of the piston. Double acting cylinders can be operated in a single acting mode by removing the suction valves from one end, by using valve plate depressor type suction valve unloaders, or by using a head end bypass unloader.

All single acting operating cases need special review. Single acting conditions can create low crosshead pin reversal, torsional resonance responses or acoustical resonance responses. A full review of the potential operating conditions in single acting mode must be made. This is to include across the entire pressure range and speed range.

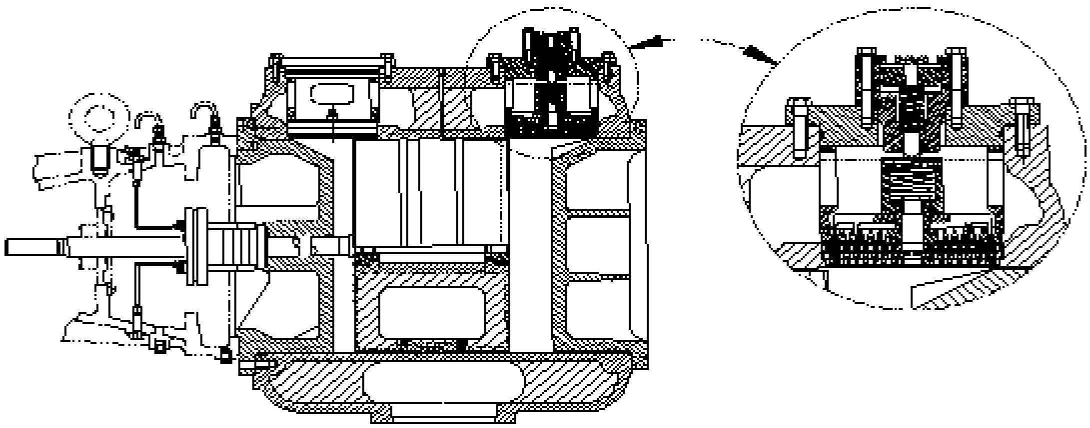
Removing Suction Valves to Single Act

All suction valves on one end of the cylinder can be removed for single acting configuration. Typically head end suction valves are removed, allowing compression on the crank end of the cylinder. Suction valve removal is the most efficient method of single acting, but does require the unit to be shutdown and gas pressure removed to change the configuration. Removal will include the valve, valve seat gasket and retainer. Washers can be installed on all of the cap bolts, under the caps, to allow for easier removal of the valve cap for maintenance, and to indicate that the valve has been removed

Higher pressure forged steel cylinders may require the suction valves to be in place in order for the gas seal at the valve cap to correctly seal. If the gas seal is located between the valve cap and the valve retainer, the valve body must remain in place. Single acting in this instance can be done by removing the valve plates and springs, but reinstalling the "empty" suction valve body in the cylinder. If the valve cap includes a pressure activated seal assembly, the suction valve, seat gasket, and retainer can be removed to single act.

Suction valve Unloader

Suction valve unloaders are typically applied on the head end of the cylinder, allowing compression only on the crank end. Ariel requires installing suction valve unloaders on all suction valves of a cylinder end to be single acted to reduce horsepower losses.

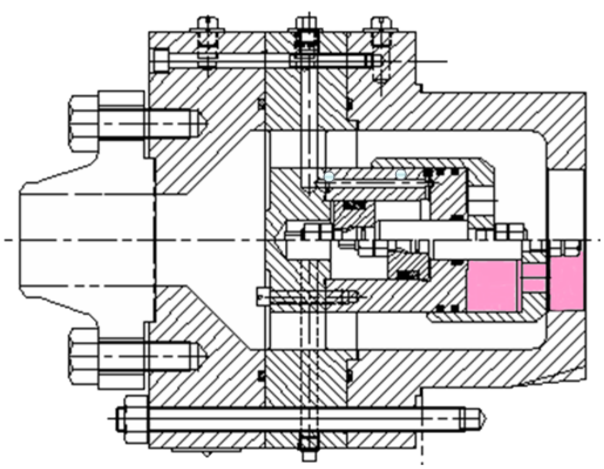


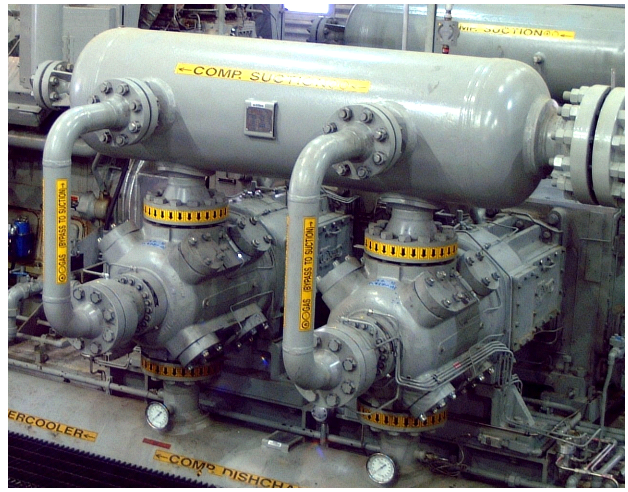
In order to maintain proper rod load reversal, the head end of the cylinder is usually deactivated. This will help maintain rod load reversal due to the differential areas between the crank end and the head end of the cylinder (due to the rod area in the crank end). In some cases it is possible to deactivate the crank end and maintain rod load reversal due to the inertia load.

Suction valve unloaders are limited to suction pressures below 1000 psi. Above this level, valve removal or head end bypass unloaders may be applied.

Head End Bypass Unloader

Head end bypass unloaders are pneumatically actuated ports on the head end of the cylinder that allows the head end compression to be open to the suction gas pressure. This fully deactivates the head end of the cylinder for single acting configuration. The pneumatic actuator is smaller, to fit within the unloader, so requires a higher actuation pressure, often in the few to several hundred psi level. Each application and cylinder size will require a specific actuation pressure. These can be found in the Ariel performance software on the device datasheet. Most often, process gas can be regulated to the appropriate pressure and applied as the actuation gas. Clean, dry actuation gas is required. Sour actuation gas (greater than 100 ppm H_2S) is NOT to be used as the actuation gas. If the process gas contains hydrogen sulfide, nitrogen may be used for the actuation.





Single acting cylinder operating cases should be included in the analyses for torsional responses and acoustical pulsation responses. Single Acting cylinders can present the worst case scenario for a torsional analysis due to a more dynamic torque effort curve and for an acoustical pulsation analysis due to a change in the number of pulses per cycle. High torsional vibration and / or high acoustically driven vibration can result from single acting cylinder operation when not considered in these analyses.

Some restrictions may apply to operating a cylinder single acting at higher speeds. The performance software should flag higher speed single acting conditions that require review and approval.

Cylinder Action, Tandem

Tandem cylinders are two cylinders on the same throw. The inboard cylinder may be the high pressure or low pressure cylinder, and is single acting on the crank end only. The outboard cylinder may also be the high pressure or low pressure cylinder, and is single acting on the head end only.

Tandem cylinders are used to allow two stages of compression on a single throw. Since they are two single acting cylinders, flow rates are smaller than double acting cylinders.

Figure: Tandem Cylinder, High Pressure Cylinder Outboard

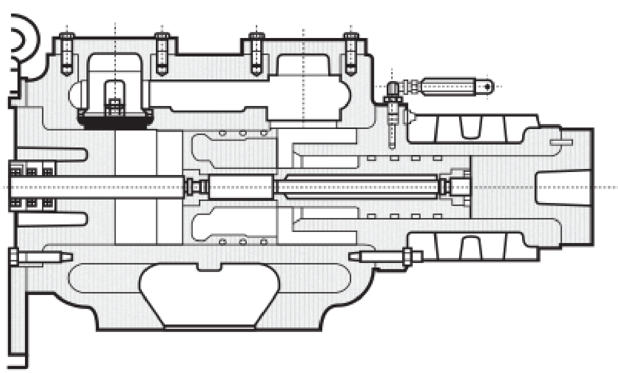
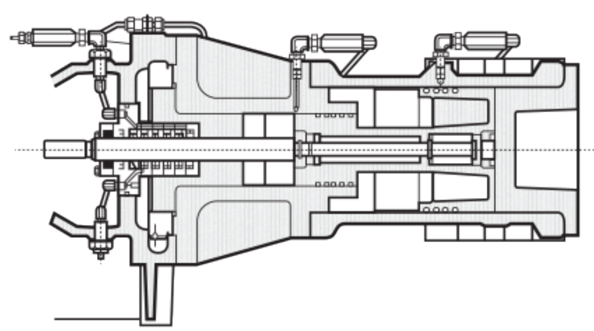


Figure: Tandem Cylinder, High Pressure Cylinder Inboard



Cylinder Hydro Test

All Compressor cylinders are hydrostatically tested prior to shipment. The cylinders are tested at a minimum of 1 hour at 1.5 times the rated MAWP of the cylinder (Maximum Allowable Working Pressure). The hydrostatic test pressure is recorded on a pressure test recorder vs time and retained with the permanent unit file.

Cylinder hydrotests may be observed by the client if required. Requests for witness must be included at the time of order for scheduling purposes.

For lighter gasses, mole weights below 12 or hydrogen content above 50%, cylinders will be leak tested with helium. Once the cylinder has been hydrotested , the cylinder is submerged in a water tank and pressurized with Helium to the cylinder MAWP or 2000 psig , whichever is lower. Pressure must be maintained and no leaks observed for a period of thirty (30) minutes. Helium leak tests of compressor cylinders is available as an option.

Helium testing is required for gasses 12 mole weight and below as well as gasses with 50% or more hydrogen by volume.

Discharge Event

Discharge event refers to the time interval in milliseconds for the discharge valve plates to open, stabilize and close. Should this time window become too short, higher valve impact velocities will result, and consequently reduced valve reliability.

Ariel has set the limit for the discharge event to be 2.7 milliseconds. Discharge event times of between 4.5 and 2.7 milliseconds should be reviewed by Ariel Valve Engineering to select proper valves for the application. Low lift valves may be necessary in this discharge event range, decreasing valve impact velocity.

Discharge event values can be increased by lowering compressor speed, decreasing the compression ratio or decreasing cylinder clearance. If discharge event values cannot be improved upon, low lift valves may be necessary in order to decrease valve impact velocity.

Elevation

The elevation is the distance of a compressor above mean sea level. Elevation affects atmospheric pressure and therefore absolute pressure. This becomes important in the performance calculations in the Ariel Performance Software. Elevation can change the inlet pressure conversion from gauge to absolute by anywhere up to 30%, greatly affecting flow and power calculations. This is especially true with lower suction pressures and higher elevations.

Internal Rod Load, Gas

Internal Gas Rod Load is the force imposed on the rod, caused by pressure inside the cylinder against the head end and crank end piston areas. Ariel's gas rod load equations apply internal cylinder pressure, accounting for pressure losses through valves and cylinder passages.

Ariel uses internal gas rod loads for a compressor frame rating. Combined gas and inertia loads are not part of the frame rating, but are used for determining the crosshead pin load reversal.

For Internal Gas Rod Load equations, please refer to the Ariel Calculation Method topic.

Piston Displacement

Piston displacement is expressed in cubic feet per minute and is the product of the swept volume and compressor speed in revolutions per minute. The following formula would be used to calculate the displacement of a cylinder;

$$\text{Piston Displacement (CFM)} = \frac{\text{Swept Volume (in3) x RPM}}{1728}$$

Pressure, Absolute

The absolute pressure is the sum of the atmospheric pressure and the gauge pressure. It is abbreviated "psia".

Pressure, Atmospheric

Atmospheric pressure exerted by the earth's atmosphere. The normal pressure measured by a barometer at sea level is equivalent to a column of mercury 29.92 inches high or 14.696 psia.

The following formula can be used to calculate the atmospheric pressure for a given elevation:

For elevation greater than 50 feet:

$$P_{atm} = -5.385001 \times 10^{-4} \times (Elev) + 8 \times 10^{-9} \times (Elev^{2}) + 14.69595$$

For elevation < 50 ft, use Patm = 14.696 psia

Pressure Drop

Ariel performance program utilizes inputs for the pressure at the customer line connection, inlet, and outlet. Pressure drops for suction, interstage, and discharge equipment should be considered while defining the pressures in the performance program.

Typical suction and discharge pressures are defined at the customer's line connections. Any pulsation vessels, knock out drums or coolers should be accounted for in the pressure loss section of the performance input.

The Ariel performance program will assume average values for these pressure losses for each interstage and final discharge pressure, as shown in the table below. These values can be manually input if known. The first stage suction pressure loss is initially set at 0 psi, any equipment upstream of the cylinder flange should be input.

Flange Pressure	Pressure Loss	Not To Exceed
35 psia and below	5%	1 psi
36 psia to 250 psia	3%	5 psi
251 psia to 1000 psia	2%	10 psi
1001 psia and above	1%	

Reference Ariel Calculation Method.

Pressure, Gauge

Gauge pressure is the pressure above atmospheric pressure as shown by a pressure gauge. It is generally expressed in pounds per square inch and abbreviated "psig".

Pressure, Rated Discharge (RDP)

ISO-13631 and API-618 define the Rated Discharge Pressure as the "highest pressure required to meet the conditions specified by the purchaser for the intended service".

Rated Discharge Pressure is conditional upon the Maximum Allowable Working Pressure based on the guidelines in ISO-13631 and API-618. The maximum allowable working pressure shall exceed the RDP by at least 10% or 25 psi (1.7 bar), whichever is greater.

Ariel does allow for operation above the cylinder RDP provided there is ample room for the pressure relief valve range and for a high pressure shutdown device. Typically, when the operating pressure is above the RDP, a pilot operated relief valve must be used (rather than a spring operated relief valve). The relief valve must be set no higher than the cylinder MAWP.

Rod Load, Inertia

Inertia rod load is the force derived from the acceleration and deceleration of the mass of the reciprocating components; piston and rod assembly and crosshead assembly. The inertia rod load is a direct function of the amount of reciprocating mass and the square of the rotating speed. Inertia rod load always reverses.

Inertia rod load is important for calculating crosshead pin reversal. Ariel calculates inertia rod load solely for the purposes of calculating crosshead pin reversal.

Separable Compressor

A separable compressor package has separate crankshafts for the compressor and driver connected with a flexible coupling. The compressor must be packaged with a driver, cooler, and associated liquid separation equipment and gas and utility piping.

Suction Temperature

Ariel Compressor Performance Software flags suction temperatures at the following levels:

- Low Suction Temperatures below -40 F (-40 C)
- High Suction Temperatures above 250 F (121 C)
- Mean Gas Temperature (suction plus discharge / 2) above 285 F (140 C)

Ariel compressor applications with suction temperatures below 0 °F (-18°C) should be reviewed by Ariel Applications Engineering. Ariel will review these selections to confirm the gas properties.

Ariel does not limit services based upon low ambient temperatures.

Please refer to the Packager Standards Section 6, Lubrication, for frame oil heating requirements for starting and loading purposes.

All low suction temperature applications should be reviewed for gas condensates. Refer to Gas Method. High suction temperature and mean gas temperature limitations are applied due to limitations on the non-metallic wear materials within the cylinder.

> **NOTE:**
>
> There is a potential for o-rings to lose flexibility while at lower temperatures, at or below -10 F (-23 C). This temporary loss of flexibility may result in potential gas release at the o-ring sealing joints on the cylinders when under pressure. The lower temperatures occur with either low inlet gas temperatures during operation or low ambient temperatures during idle periods. If the gas release is of concern, it is recommended that the unit be allowed to warm up in a relatively unloaded state (low or no gas pressure and start up bypass line fully open) until the equipment reaches warmer temperatures.

Swept Volume

Swept volume is the volume swept by a compressor piston during a complete stroke. Swept volume is expressed in cubic inches and calculated as follows:

Head End = Area Piston (in^2) * Stroke (in)

Crank End = (Area Piston (in^2) - Area Rod (in^2)) * Stroke (in)

Total = [2 x Area Piston (in^2) - Area Rod (in^2)] * Stroke (in)

Thermodynamic Terms

Some definitions given here are not as all-inclusive as general thermodynamics might require, but cover the ground necessary for reciprocating compressor applications. There are some items where "authorities" differ in definition and approach. In such cases, a certain amount of judgment has been applied.

SPT means standard pressure and temperature. As used herein it is 14.696 psia and 60° F in the English system of units.

STANDARD Conditions, in the SI System, are 1.01325 barA and 15 C. These conditions are used in Canada, South America, and New Zealand

NORMAL Conditions, in the SI System, are 1.01325 barA and 0 C. These conditions are used primarily in Europe.

DENSITY is the weight of a given volume of gas, usually expressed in lb/cu.ft. at SPT conditions.

SPECIFIC VOLUME is the volume of a given weight of the gas, usually expressed as cu. ft./lb at SPT conditions.

SPECIFIC GRAVITY is the ratio of the molecular weight of a given gas to the molecular weight of dry air, both measured at the same specified conditions of temperature and pressure usually 14.696 psia and 60° F. It should also take into account any compressibility deviation from a perfect gas.

BOYLE'S LAW states that if the temperature of a gas remains constant, its volume varies inversely with the absolute pressure. It is expressed by the formula: $P_1V_1 = P_2V_2$

CHARLES' LAW states that if the pressure of a gas remains constant, its volume varies directly with the absolute temperature. It is expressed by the formula: $\frac{V_1}{T_1} = \frac{V_2}{T_2}$

IDEAL GAS LAW is created by combining Boyle's and Charles' Laws. It is expressed by the formula: $\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$

COMPRESSIBILITY is a volume ratio that indicates the deviation (as a multiplier) of the actual volume from that as determined by the perfect or ideal gas laws. When compressibility is applied, the equation is the real gas law. Compressibility is designated by the term “z”, and is a function of pressure, temperature, and gas composition.

$$\frac{P_1V_1}{z_1T_1} = \frac{P_2V_2}{z_2T_2}$$

TEMPERATURE is the property of a substance that gauges the potential or driving force for the flow of heat.

ABSOLUTE TEMPERATURE is a temperature measurement relative to an absolute scale. The absolute scale in English units is degrees Rankine; Temp Rankine = T F +460. The absolute temperature scale in SI units is degrees Kelvin Temp Kelvin = T C +273. Zero degrees in both absolute temperature scales reference the temperature when a substance contains no heat.

ISOTHERMAL PROCESS is one during which there is no change in the temperature. This is impractical, as it would require all heat to be continuously removed from the process.

ISENTROPIC (ADIABATIC) PROCESS is one during which there is no heat added to or removed from the system. All the heat of compression is contained in the gas and shown as a temperature increase. Although not attained in practice, adiabatic compression is a good model for most positive displacement compression.

ADIABATIC HORSEPOWER is the power required to adiabatically compress a gas delivered from one pressure to a higher one. The power is calculated at the face of the compressor piston.

ADIABATIC EFFICIENCY is the ratio of the adiabatic horsepower required to compress a given amount of gas to the actual horsepower expended in the compressor cylinder The adiabatic efficiency is dependent upon factors such as gas preheat and valve horsepower losses.

MECHANICAL EFFICIENCY is the measure of the power lost due to mechanical friction of the piston rings, packings, and bearings. A value of 95% mechanical efficiency is used for the compressor cylinders in addition to specific frame losses that include bearing and oil pump losses.

BRAKE HORSEPOWER is the measured horsepower input to the compressor. It is the adiabatic horsepower divided by the adiabatic efficiency and the mechanical efficiency.

POLYTROPIC PROCESS is one in which changes in gas characteristics and properties are allowed for throughout the process.

HEAT is energy transferred because of a temperature difference. There is no transfer of mass.

WORK is energy in transition and is defined as Force times Distance. Work cannot be done unless there is motion.

ENTHALPY (Heat Content) is the sum of the Internal and External energies.

ENTROPY is a measure of the unavailability of energy in a substance.

SPECIFIC HEAT (Heat Capacity) is the rate of change in Enthalpy with temperature. It may be measured at constant pressure or at constant volume. The values are different and are known as cp, and cv respectively. For a perfect gas, Cp= Cv + R. R is the universal gas constant.

RATIO OF SPECIFIC HEATS (k) is the ratio of Cp over Cv. It may vary considerably with temperature and pressure levels.

SATURATED VAPOR PRESSURE is the pressure existing at a given temperature in a closed vessel containing a liquid and the vapor from that liquid after equilibrium conditions have been reached. It is dependent only on temperature and must be determined experimentally.

SATURATED PRESSURE is another term for Saturated Vapor Pressure.

SATURATED TEMPERATURE is the temperature corresponding to a given saturated vapor pressure for a given vapor.

DEW POINT of a gas is the temperature at which the vapor (at a given pressure) will start to condense (or form dew). Dew point of a gas mixture is the temperature at which the highest boiling point constituent will start to condense.

BUBBLE POINTof a gas is the temperature at which the liquid (at a given pressure) will start to boil (or form vapor). Bubble point of a gas mixture is the temperature at which the lowest boiling point constituent will start to boil.

RELATIVE HUMIDITYis the amount of water vapor entrained in a gas, expressed as % of saturation.

PARTIAL PRESSURE of a constituent in a mixture is the absolute pressure exerted by that portion of the mixture. Calculated by multiplying the absolute pressure of the system by the mole fraction of the constituent in the mixture.

DRY GAS is any gas or gas mixture which contains no water vapor and also in which all of the constituents are substantially above their respective saturated vapor pressures at the existing temperature. Note: In commercial compressor work a gas may be considered dry (even though it contains water vapor) if its dew point is low at the inlet condition (say -50° F to -60° F.) Note: In commercial compressor work a gas may be considered dry (even though it contains water vapor) if its dew point is low at the inlet condition (say -50° F to -60° F.)

WET GAS is any gas or gas mixture in which one or more of the constituents is at or very close to its saturated vapor pressure. The constituent at saturation pressure may or may not be water vapor.

CRITICAL TEMPERATURE is the highest temperature at which a gas can be liquefied.

CRITICAL PRESSURE is the saturation pressure at the critical temperature. It is the highest vapor pressure the liquid can exert. Note: Critical conditions must be experimentally determined for each pure gas. When calculated for a mixture, they are called pseudo critical conditions. Pseudo critical conditions are a mole % (volume %) weighted average of critical conditions for each constituent of a mixture.

REDUCED TEMPERATURE is the ratio in absolute units of the actual gas temperature to the critical temperature. Pseudo - reduced temperature is the ratio in absolute units of a gas mixtures actual temperature to pseudo - critical temperature.

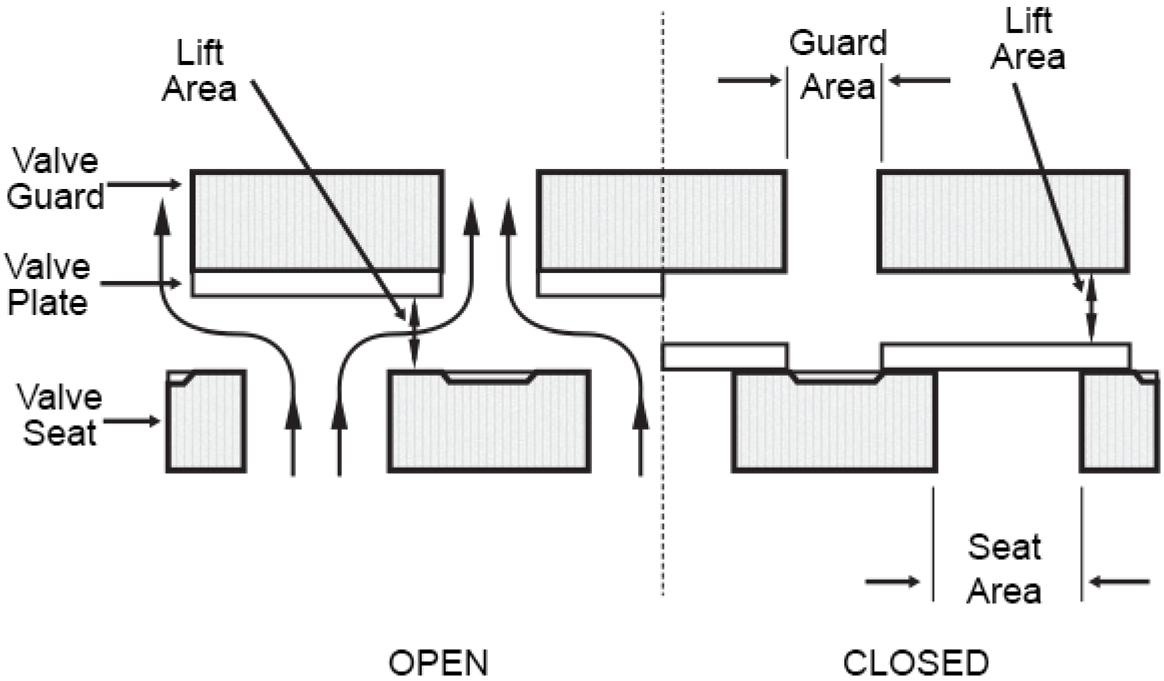
REDUCED PRESSURE is the ratio in absolute units of the actual gas pressure to the critical pressure. Pseudo - reduced pressure is the ratio in absolute units of a gas mixtures actual pressure to its pseudo - critical pressure.

Valve Lift

Valve lift is the distance between the top of the valve plate and the bottom of the valve guard when the valve plate is seated against the valve seat. Valve lift effects lift area, and adjusted equivalent area. Higher lift valves are more efficient (larger equivalent flow areas), but are not as durable as lower lift valves due to the higher impact forces (more time for acceleration of the valve plate).

The maximum valve lift for metallic valve plates is 0.063 inches. The maximum valve lift for non-metallic valve plates (PEEK, Nylon, MT) is 0.112 inches. Non-metallic valve plates are lighter weight, and therefore do not generate as much impact force at higher lift as metallic valve plates.

Figure: Valve Cross Section



Valve Velocity

Average valve velocity is calculated as follows:

$$V = \frac{288 \times D}{A}$$

V = Valve velocity, ft/min

D = Piston displacement, cfm

A = Product of lift and valve opening periphery, total for all valves in the cylinder

Velocities calculated by this method should be treated only as a general indication of valve performance.