

COMPRESSORS

STEPS TO COMPRESSOR SELECTION & SIZING

- I Understand the Application
What is the compressor supposed to do?
- II Find Out the Details
Gas, pressures, temperatures, capacities, etc.?
- III Scope of Supply
Who is to supply the motor, switchgear, piping, etc.?
- IV Size the Compressor
- V Select Accessories

When all of the above has been done, this information can be combined with what is known about the customer's 'needs/desires' to generate a successful quotation.

STEP I - Understand the Application

Become familiar with the big picture **before** getting into the details of the application.

1. Form a clear, concise statement describing the purpose of the compressor.
2. Many compressors operate at more than one condition. Determine why and how often the various conditions occur.

Examples:

This compressor is to transfer liquid propane from railcars into a bulk storage tank. After the liquid has been transferred, the remaining vapors will be recovered. The compressor will operate year around, emptying about 2 railcars per week.

This compressor will be used to evacuate a vessel at the end of a batch process. It will be used in a production facility that will perform 6 batch operations in a 16 hour day.

NOTE THAT DETAILS LIKE PRESSURES, TEMPERATURES & FLOW RATES ARE NOT NEEDED OR EVEN WANTED AT THIS STEP.

STEP II - Find Out the Details

In order to determine what type of compressor system will be needed to accomplish the job, a variety of detailed data will need to be discerned.

As a minimum, a precise understanding of the following data is required:

- Gas being handled
- Suction and Discharge Pressure
- Site Elevation (or Local Barometric Pressure)
- Suction Temperature
- Capacity

In addition the following items are needed to help make some subjective decisions when two or more options are available or in the selection of various accessories.

- 'Normal' operating conditions
- Other operating conditions
- Duty Cycle
- Electrical characteristics and area classification
- Availability of cooling water

Here is a sample problem that we will use to work through the steps needed to select a compressor and accessories.

A compressor to be used to draw nitrogen off of a cryogenic storage tank and boost the pressure to feed a number of plant processes. The flow requirement will vary throughout the 8 hour production day, but will average about 15 CFM.

Suction: Nitrogen at 5 psi

Discharge: 65 psi

Site: 1,000 ft. elevation, outdoors, Ambient of 0 to 100°F

Utilities: 460V/3ph/60hz, 80°F fresh water

STEP II - (Details) Gas Being Handled

The gas to be compressed must be precisely identified. Once the gas has been identified the data for most gasses are readily available from published tables. If it isn't, the customer can often provide the needed information.

Gas Name - This may be presented as a chemical formula, a common name or a trade name. For example, dichlorodifluoromethane has a chemical formula of $\text{C Cl}_2 \text{ F}_2$, a DuPont trade name of Freon 12, and a common name of refrigerant 12 or R12.

Each gas has a number of physical data that must be known. For most gasses, these values are easily found if the gas has been precisely identified. (Terms like Freon, LPG, or even natural gas are too generic.)

Data needed for
each gas.

Molecular Weight	Critical Pressure
"n" Value	Critical Temperature

Gas Mixtures - A gas stream containing more than one gas may be presented with the MW, "n" value, and critical values already calculated for the mixture. Alternately, the specification may list the individual gasses and their percentage of the total. The percentages may be expressed on a volume (molar) or weight basis. The basis being used **must** be known! Procedures for calculating average values for the total gas stream will be presented later.

In our example the gas is given as nitrogen from a cryogenic vessel. In this case the gas stream should be 100% N_2 with virtually no measurable contaminants.

MW = 28.01

Critical Pressure = 493 psia

"n" value = 1.40

Critical Temperature = 228°R

STEP II - (Details) **Gas Being Handled**

Molecular Weight - The molecular weight of most gasses is fairly easy to find in published tables. For some gasses (particularly natural gas) the "specific gravity" may be given. The molecular weight can easily be determined from the specific gravity: $MW = SG (28.56)$.

R12 has a $MW = 120.9$ and a $SG = 4.18$.

"n" Value - This is known as the specific heat ratio and is listed in many published tables. If the "n" value is not given, another value called the specific heat at constant pressure (C_p) may be used to calculate the "n" value. The formula is:

$$n = \frac{MW (C_p)}{MW (C_p) - 1.99}$$

Critical Pressure (P_c) and Critical Temperature (T_c) - These two values are used to calculate a value called compressibility (Z). Both P_c and T_c are published for most gasses. Charts or a computer program are used to calculate the Z value from the critical pressure and the critical temperature. For hand calculations or estimating purposes the compressibility factor may usually be ignored when sizing Blackmer compressors. The error introduced in most cases is small and the resulting calculation will size the compressor slightly larger than necessary.

STEP II - (Details) Pressures

Values for pressure can also be a source of confusion since there are two distinct methods of expressing pressure - "absolute pressure" and "gauge pressure". In order to size a compressor, the pressures must be expressed in "absolute" terms. The relationship between the two systems is:

$$PSIA = PSIG + P_{amb} \quad \text{Bar-a} = \text{Bar-g} + P_{amb}$$

PSIA pounds per square inch, absolute

PSIG pounds per square inch, gauge

P_{amb} local barometric pressure (psia or Bar-a)

Bar-a Bars, absolute

Bar-g Bars, gauge

The use of the term "PSI" or "Bar" without an indication as to whether the value is a gauge reading or an absolute measurement must be resolved.

P_s SUCTION PRESSURE

The pressure at the compressor inlet expressed as psia (or Bar-a).

P_d DISCHARGE PRESSURE

The pressure at the compressor discharge expressed as PSIA (or Bar-a).

In the example, the suction and discharge pressures are given as 5 and 65 psi respectively. As mentioned above, we have to know whether he means 'psia' or 'psig'. In this case the customer advises that he meant 'psig'.

These values will have to be converted to 'absolute' terms, but we can't do it until we know the local barometric pressure.

STEP II - (Details) Site Elevation

Site Elevation is used to determine the local Barometric Pressure, P_{amb})

Many of the formulas shown above require knowledge of the local barometric pressure, P_{amb} . If P_{amb} is not listed in the specifications it can easily be determined from the table below.

Atmospheric Pressure at Different Altitudes			
Altitude above sea level, ft.	Atmospheric pressure, psia.	Altitude above sea level, ft.	Atmospheric pressure, psia.
0	14.69	7,500	11.12
500	14.42	8,000	10.91
1,000	14.16	8,500	10.70
1,500	13.91	9,000	10.50
2,000	13.66	9,500	10.30
2,500	13.41	10,000	10.10
3,000	13.16	10,500	9.90
3,500	12.92	11,000	9.71
4,000	12.68	11,500	9.52
4,500	12.45	12,000	9.34
5,000	12.22	12,500	9.15
5,500	11.99	13,000	8.97
6,000	11.77	13,500	8.80
6,500	11.55	14,000	8.62
7,000	11.33	14,500	8.45

In our example, the site data lists an elevation of 1,000 ft., so the local barometric pressure is 14.16 psia. Now the absolute suction and discharge pressure can be calculated:

$$P_s = 5 \text{ psig} + 14.16 \text{ psia} = 19.16 \text{ psia}$$

$$P_d = 65 \text{ psig} + 14.16 \text{ psia} = 79.16 \text{ psia}$$

STEP II - (Details) Suction Temperature

T_s SUCTION TEMPERATURE

Temperatures are also expressed as absolute ($^{\circ}\text{R}$, $^{\circ}\text{K}$) or gauge ($^{\circ}\text{F}$, $^{\circ}\text{C}$) values. The compressor suction temperature should be expressed in absolute terms ($^{\circ}\text{R}$ or $^{\circ}\text{K}$). Fortunately, most specifications are quite clear as to which scale is being used.

$$^{\circ}\text{R} = ^{\circ}\text{F} + 460$$

$$^{\circ}\text{K} = ^{\circ}\text{C} + 273$$

$^{\circ}\text{R}$ Degrees Rankine, an absolute value

$^{\circ}\text{F}$ Degrees Fahrenheit, a gauge value

$^{\circ}\text{K}$ Degrees Kelvin, an absolute value

$^{\circ}\text{C}$ Degrees Centigrade, a gauge value

In the example, the suction temperature is not given. We do know that the N_2 is being drawn off a cryogenic vessel; this will be much colder than we will allow at the compressor. Discussions with the customer indicates that a heat exchanger will be placed between the storage vessel and the compressor that will heat the gas stream to about 50°F . Therefore:

$$T_s = 50^{\circ}\text{F} + 460 = 510^{\circ}\text{R}$$

STEP II - (Details) Capacity

Properly specifying the capacity required is often the most difficult aspect of sizing a compressor. Many of the terms used to indicate a gas capacity are either vague or often misunderstood. In addition many applications require the compressor to operate under a variety of conditions resulting in a very wide range of capacities.

To size a compressor the capacity must be stated as the volume it will occupy at the compressor's suction. This volume is normally referred to as inlet cubic feet per minute (ICFM). The metric equivalent is inlet cubic meters per hour (Im^3/hr). If the term ACFM is used, it must be made clear the volume is measured at suction pressure and temperature and not some other conditions.

The confusion surrounding the measuring of a volume of gas is due to the fact that gasses are compressible. This simply means that a given number of gas molecules may occupy a vastly different volume depending on its pressure and temperature. A 60 gal. vessel contains significantly less gas at 50 psig than at 200 psig even though the size of the vessel remains constant. Specifying a capacity of 15 CFM does little except create confusion unless a reference pressure and temperature are also specified or implied.

There are a variety of common ways to specify a gas volume - lb/hr, SCFM, MCFD, MSCFD, free air ACFM, ICFM. Metric values are usually expressed as kg/hr, Nm^3/hr or Im^3/hr . Additionally, liquefied gas transfer compressors may have the capacity expressed as a liquid transfer rate (GPM or m^3/hr).

Occasionally a specification may have the expressed in words like "capacity to be 80 ACFM delivered at 125 psig". This terminology is confusing since it attempts to specify both capacity and discharge pressure at the same time without clearly stating the reference pressure and temperatures for the capacity value.

The next few pages present the various methods of describing gas capacity.

In our example, the capacity is given as 15 cfm average. This terminology is quite common, but is not precise enough as we do not know if the gas occupies 15 cfm at standard conditions, compressor inlet conditions, or some other condition. After further discussions with the customer, it is determined that he meant 15 SCFM.

Note that the capacity varies, but is 15 SCFM average. This implies that the usage rate will be both under and over 15 SCFM. Further discussions, reveal that the normal maximum flow expected from the compressor will be 20 SCFM. This is what will be used to size the compressor. Now we have enough information to calculate the gas volume at the compressor's inlet:

$$\text{ICFM} = 20 \text{ SCFM} (14.7 \text{ psia} / 19.16 \text{ psia}) (510^\circ\text{R} / 520^\circ\text{R}) = 15.05 \text{ ICFM}$$

STEP II - (Details) Capacity

ICFM - Inlet Cubic Feet per Minute

Im³/hr - Inlet Meters Cubed per Hour

This is the volume the gas will occupy at the compressor's suction. In order to size the compressor the ICFM must be known. If it is not given in this form it can be calculated from one of the formulas presented below.

ACFM Actual Cubic Feet per Minute

Am³/hr Actual Meters Cubed per Hour

This terminology specifies the actual volume the gas will occupy at a given pressure and temperature. If the pressure and temperature referenced match those at the compressor inlet, then ACFM will equal ICFM. If the referenced pressure and temperature are at some other conditions use:

$$\text{ICFM} = \text{ACFM} \left(\frac{P_{\text{ref}}}{P_s} \right) \left(\frac{T_s}{T_{\text{ref}}} \right)$$

$$\text{Im}^3/\text{hr} = \text{Am}^3/\text{hr} \left(\frac{P_{\text{ref}}}{P_s} \right) \left(\frac{T_s}{T_{\text{ref}}} \right)$$

P_{ref} Reference pressure psia (Bar-a)

T_{ref} Reference temperature °R (°K)

P_s Compressor suction pressure psia (Bar-a)

T_s Compressor suction temperature °R (°K)

lb/hr (kg/hr) - Converting to ICFM is requires knowledge of the gas molecular weight, inlet temperature and inlet pressure. This is known as the ideal gas law:

$$\text{ICFM} = \frac{Z (\text{lb/hr}) R_u T_s}{60 \text{ MW } P_s}$$

$$\text{Im}^3/\text{hr} = \frac{Z (\text{kg/hr}) R_u T_s}{\text{MW } P_s}$$

Z Compressibility - Use a value of 1 unless a true value is known.

R_u Universal gas constant $10.7315 \frac{\text{psia ft}^3}{\text{lb-mole } ^\circ\text{R}}$ $0.08319 \frac{\text{Bar m}^3}{\text{kg-mole } ^\circ\text{K}}$

T_s Suction Temperature °R °K

P_s Suction Pressure psia bar-a

MW Molecular Weight

STEP II - (Details) Capacity

SCFM - Standard Cubic Feet per Minute

Nm³/hr - Normal Meters Cubed per Hour

The use of this form of gas volume implies a standard reference value for pressure and temperature. The agreed upon standard references for SCFM are 14.7 psia and 520 °R (Nm³/hr is referenced to 1.014 Bar-a and 273 °K). Notice that the reference temperatures are different in the two systems.

$$\text{ICFM} = \text{SCFM} \frac{P_{\text{std}}}{P_s} \frac{T_s}{T_{\text{std}}} \qquad \text{Im}^3\text{hr} = \text{Nm}^3/\text{hr} \frac{P_{\text{std}}}{P_s} \frac{T_s}{T_{\text{std}}}$$

$$\text{SCFM} = \text{Nm}^3/\text{hr} \frac{35.31 \text{ ft}^3}{\text{m}^3} \frac{1 \text{ hr}}{60 \text{ min}} \frac{520 \text{ }^\circ\text{R}}{492 \text{ }^\circ\text{R}} = \text{Nm}^3/\text{hr} (0.622)$$

P_{std} Standard barometric pressure 14.7 psia (1.014 Bar-a)

T_{std} Standard temperature 520 °R (273 °K)

P_s Compressor suction pressure psia (Bar-a)

T_s Compressor suction temperature °R (°K)

If the suction temperature and pressure are close to the standard values, then ICFM will be close to SCFM. However, the values for ICFM and SCFM will quickly diverge as P_s and T_s move away from standard values.

Example: $P_s = 75 \text{ psia}$ $T_s = 510 \text{ }^\circ\text{R}$ SCFM = 110 SCFM
 ICFM = 110 (14.7 / 75) (510 / 520) = 21.1

In this case the value for ICFM is less than 1/5 that for SCFM. Obviously, knowing how the capacity is specified can have large effects on compressor sizing.

STEP II - (Details) Capacity

MSCFD: Thousand standard cubic feet per day

This form references the volume of the gas to standard conditions just like SCFM does - only the units of measure differ. This form is often written MCFD (leaving the "S" implied) and is most often used in the natural gas industry.

$$\begin{aligned} \text{ICFM} &= \text{MSCFD} (P_{\text{std}} / P_s) (T_s / T_{\text{std}}) 1000 (1 \text{ day} / 1440 \text{ min}) \\ &= \text{MSCFD} (P_{\text{std}} / P_s) (T_s / T_{\text{std}}) (.694) \end{aligned}$$

P_{std}	Standard barometric pressure	14.7 psia (1.014 Bar-a)
T_{std}	Standard temperature	520 °R (273 °K)
P_s	Compressor suction pressure	psia (Bar-a)
T_s	Compressor suction temperature	°R (°K)

Free Air

This method of specifying a gas volume is typically used in air compressors and is of little use when dealing with gas compressors. In fact, its use in conjunction with gas compressors should be viewed with suspicion. Free Air volume is the volume occupied at the ambient pressure and temperature at the compressor. These two values will vary dependent upon the local weather and elevation above sea level.

$$\text{ICFM} = (\text{Free Air})(P_{\text{amb}} / P_s) (T_s / T_{\text{amb}})$$

P_{amb}	Local barometric pressure	psia (Bar-a)
T_{amb}	Local ambient temperature	°R (°K)
P_s	Compressor suction pressure	psia (Bar-a)
T_s	Compressor suction temperature	°R (°K)

GPM - Gallon per minute

M³/hr - Cubic Meters of liquid per hour.

This measurement of capacity is often used on liquefied gas transfer compressors. Converting this value to an ICFM involves making some additional assumptions or obtaining some additional data about the application.

$$\text{ICFM} = \text{GPM} (P_d / P_s) (1 \text{ ft}^3 / 7.48 \text{ gal}) \quad \text{Im}^3/\text{hr} = \text{m}^3/\text{hr} (P_d / P_s)$$

P_s	Suction pressure psia (Bar-a). Suction pressure will typically be equal to the vapor pressure of the liquefied gas.
P_d	Discharge pressure psia (Bar-a). The discharge pressure in a liquefied gas transfer compressor is dependant on the pressure loss due to the piping friction and elevation differences. Most systems are designed so that P_d will be 20 to 30 psi above P_s .

STEP II - (Details) Summary

At this point we have a clear statement of the compressor application and enough detailed information to start the compressor and accessory selection. Here is a description of the example application:

A compressor to be used to draw nitrogen off of a cryogenic storage tank and boost the pressure to feed a number of plant processes. The flow requirement will vary throughout the 8 hour production day, but will average about 15 SCFM. In order to meet peak demands the compressors should be sized for 20 SCFM. A heat exchanger will be used between the cryogenic storage vessel and the compressor to raise the nitrogen temperature to about 50°F.

Suction: Nitrogen at 5 psig and 50°F (19.16 psia and 510°R)
MW = 28.01 Critical Pressure = 493 psia
"n" value = 1.40 Critical Temperature = 228°R

Discharge: 65 psig (79.16 psia)

Capacity: 20 SCFM 15.05 ICFM

Site: 1,000 ft. elevation (Barometric pressure = 14.16 psia)
Outdoors, Ambient of 0 to 100°F
Non-Hazardous

Utilities: 460V/3ph/60hz, 80°F fresh water

STEP III - Scope of Supply

The term 'compressor' will have different meanings depending on your frame of reference. As a manufacturer, Blackmer usually views a 'compressor' as meaning the compressor block only. The Blackmer catalog lists a wide variety of basic compressors and also lists configurations that include closely related compressor accessories that are common to almost every installation.

A user generally has a plant or product that is his primary concern. Within the plant will be a process that requires a 'compressor' to accomplish its task. In this context, the 'compressor' is everything that is needed to take the gas at some point in the system and place it at another point in the system at a higher pressure. Such a 'compressor' is actually a process or system in itself and almost always consists of a number of common items or systems:

The compressor	Driver
Gauges	Drive System
Relief Devices	Protective Switches
Cooling Systems	Control Switches
Vessels	Motor Starter and Logic Circuits
Piping	Capacity Control System
Filtration	Liquid Condensate Handling System
Valving	Foundations

For the example, the customer indicates that we should offer the following items:

- Compressor with drive system
- Needed gauges
- Needed protective and control switches
- Capacity Control

STEP IV - Selecting the Proper Compressor

Knowledge of the gas, required capacity, suction pressure, suction temperature, and discharge pressure will enable the proper compressor to be sized. The basics steps involved are:

1. Calculate the compression ratio.
2. Choose between a single-stage or two-stage compressor.
3. Calculate the discharge temperature.
4. Determine the volumetric efficiency.
5. Determine the required piston displacement.
6. Select the compressor model.
7. Determine the minimum RPM required of the selected compressor.
8. Select an actual RPM.
9. Calculate the actual piston displacement.
10. Calculate the power required.
11. Select appropriate options.

A computer is generally used to perform steps 1 to 10, but hand calculations are often adequate.

STEP IV - Selecting the Proper Compressor

Part 1 CALCULATE THE COMPRESSION RATIO

Compression ratio (R) is the ratio of discharge pressure to suction pressure:

$$R = P_d/P_s \quad (\text{remember } P_d \text{ and } P_s \text{ must be "absolute" values!})$$

A single-stage compressor has only a single R value.

A two-stage compressor has three R values.

R = total compression ratio for the compressor

R₁ = compression ratio for the first stage

R₂ = compression ratio for the second stage

$$R = P_d/P_s \quad R_1 = P_i/P_s \quad R_2 = P_d/P_i$$

P_s Suction pressure

P_d Discharge pressure

P_i Interstage pressure - the pressure between the 1st and 2nd stage of the compressor.

For the example P_s = 19.16 psia and P_d = 79.16 psia, therefore:

$$R = 79.16 / 19.16 \text{ psia} = 4.13$$

STEP IV - Selecting the Proper Compressor

Part 2 CHOOSING A ONE-STAGE OR TWO-STAGE COMPRESSOR

The choice of the proper number of compression stages is largely based on the compression ratio. Discharge temperatures and the duty cycle could also be considered when determining the number of stages to use. Here are some guidelines for choosing the proper number of stages:

R value	# stages
1 - 3	single-stage
3 - 5	normally single-stage, occasionally two-stage
5 - 7	normally two-stage, occasionally single-stage
7 - 10	two-stage
10 - 15	usually two-stage, occasionally three-stage
15 +	three-stage

Comparison of a single-stage and two-stage compressor both installed to do the same application (same capacity, gas and pressures):

	Single-Stage	Two-Stage
Discharge Temperature	higher	lower
BHP	higher	lower
Initial Cost	lower	higher
Overall System Complexity	lower	higher

As with many engineering decisions, a suitable compromise between initial cost and operating/maintenance costs must be found.

In the example problem $R = 4.13$. From the chart above, it appears that a single-stage unit is most likely.

STEP IV - Selecting the Proper Compressor

Part 3 CALCULATE THE DISCHARGE TEMPERATURE (T_d)

The compressor's discharge temperature directly affects the life of the piston rings and valves. Here is the formula to calculate the discharge temperature for an air cooled single-staged compressor:

$$T_d = T_s (P_d/P_s)^{(n-1)/n} = T_s R^{(n-1)/n}$$

T_s Suction temperature °R (°K)

P_s Suction pressure PSIA (Bar-a)

P_d Discharge pressure PSIA (Bar-a)

R Compression Ratio (P_d/P_s)

n specific heat ratio of the gas.

Continuous duty applications should be limited to about 300°F (149°C) maximum. The published maximum allowable temperature for Blackmer compressors is 350°F (177°C). Applications with temperatures higher than 350°F (177°C) should be closely reviewed. Unless extremely short duty cycles are involved, additional stages of compression or a water cooled unit should be considered.

In the example problem $T_d = 510^\circ\text{R} (4.13)^{(1.40-1)/1.40} = 765^\circ\text{R} (305^\circ\text{F})$

In this case an air-cooled single-stage model should work fine. If the calculated temperature had been higher, we might consider a water-cooled unit or a two-stage model.

STEP IV - Selecting the Proper Compressor

Part 4 DETERMINE THE VOLUMETRIC EFFICIENCY.

Volumetric efficiency is the ratio of the amount of gas compressed versus the physical size of the compressor's cylinder volume. For estimating purposes, the following formulas can be used:

$$\text{Single-stage compressors} \quad \text{VE\%} = 93 - R - 8(R^{1/n} - 1)$$

$$\text{Two-stage compressors} \quad \text{VE\%} = 89 - R - 7.8(R^{1/2n} - 1)$$

R Compression ratio (P_d/P_s)

n Gas specific heat ratio

In the example problem $\text{VE\%} = 93 - 4.13 - 8(4.13^{1/1.40} - 1) = 75\%$

STEP IV - Selecting the Proper Compressor

Part 5 DETERMINE THE REQUIRED PISTON DISPLACEMENT. (PD_R)

Piston displacement (PD) is a measure of the compressor's size and is dependant on the size, number and type of cylinders, and compressor RPM. Required piston displacement (PD_R) is a calculated number that will determine how large a compressor will be required to handle the specified capacity.

$$PD_R = ICFM / VE \quad PD_R = (Im^3/hr) / VE$$

PD_R Required piston displacement (CFM or m^3/hr)

ICFM Capacity (inlet cubic feet per minute)

VE Volumetric Efficiency

Im^3/hr Capacity (inlet meters cubed per hour)

In the example problem $PD_R = 15.05 \text{ ICFM} / .75 = 20.07 \text{ CFM}$ required

STEP IV - Selecting the Proper Compressor

Part 6 SELECT THE COMPRESSOR SIZE.

Once the choice of single-stage or two-stage and the calculation of required piston displacement have been made, the compressor can be sized.

	Size	Piston Displacement
Single-stage	161, 162, 163	7.16 - 16.9 CFM (12.2 - 28.7 m ³ /hr)
	342, 343	6.89 - 16.25 CFM (11.7 - 27.6 m ³ /hr)
	361, 362, 363	15.3 - 36.0 CFM (26.0 - 61.2 m ³ /hr)
	642, 643	13.4 - 31.7 CFM (22.8 - 53.8 m ³ /hr)
	601, 602, 603	27.2 - 64.2 CFM (46.3 - 109.0 m ³ /hr)
	942	52.5 - 125.2 CFM (89 - 212 m ³ /hr)
Two-stage	172, 173	3.6 - 8.4 CFM (6.1 - 14.3 m ³ /hr)
	372, 373	10.2 - 26.1 CFM (17.3 - 40.8 m ³ /hr)
	612, 613	22.9 - 53.7 CFM (38.9 - 91.2 m ³ /hr)

Often, a choice between a larger size compressor at slow speed versus a smaller compressor at a faster speed must be made. Both discharge temperature and duty cycle should be considered in making this choice.

In the example problem we are looking for a single-stage compressor with a Piston Displacement of 20.07 CFM. From the above, it can be seen that a size 360 compressor will work.

STEP IV - Selecting the Proper Compressor

Part 7 DETERMINE THE MINIMUM RPM REQUIRED. (RPM_{min})

With the compressor model and Required Piston Displacement known, the minimum RPM required can be calculated.

$$RPM_{min} = 100 PD_R / PD_{100}$$

PD_R Required Piston Displacement

PD_{100} Piston Displacement per 100 RPM

	Compressor Size	PD per 100 RPM (PD_{100})	
Single-Stage	161, 162, 163	2.05 ft ³	3.48 m ³
	342, 343	1.97 ft ³	3.34 m ³
	361, 362, 363	4.36 ft ³	7.41 m ³
	642, 643	3.84 ft ³	6.52 m ³
	601, 602, 603	7.78 ft ³	13.2 m ³
	942	14.99 ft ³	25.5 m ³
Two-Stage	172, 173	1.02 ft ³	1.73 m ³
	372, 373	2.92 ft ³	4.96 m ³
	612, 613	6.54 ft ³	11.1 m ³

In the example problem we selected a size 360 compressor with a required Piston Displacement of 20.07 CFM. Therefore:

$$RPM_{min} = 100 (20.07 \text{ CFM} / 4.36 \text{ ft}^3/100\text{rpm}) = 460 \text{ RPM minimum}$$

STEP IV - Selecting the Proper Compressor

Part 8 SELECT AN ACTUAL RPM (RPM)

Using the sheave and V-belt selection tables, pick an RPM slightly above the minimum RPM required just calculated.

In the example problem we selected a size 360 compressor at a minimum speed of 460 RPM. From a list of available V-belt sheaves, the next higher available speed is 470 RPM.

Part 9 CALCULATE THE COMPRESSOR'S ACTUAL PISTON DISPLACEMENT (PD)

After Determining the compressor's actual speed, the actual piston displacement can be calculated.

$$PD = \text{RPM} * (PD_{100}) / 100$$

In the example problem we selected a size 360 compressor at a speed of 470 RPM. Therefore, the actual Piston Displacement will be:

$$PD = 470 \text{ RPM} * (4.36 \text{ ft}^3) / 100 = 20.49 \text{ CFM}$$

STEP IV - Selecting the Proper Compressor

Part 10 CALCULATE THE POWER REQUIRED BHP (KW)

For estimating purposes, the following formulas may be used:

$$\text{Single-Stage Models} \quad \text{BHP} = .00528 \left(\frac{n}{n-1} \right) (P_s) \text{PD} (R^{(n-1)/n} - 1)$$

$$\text{Two-Stage Models} \quad \text{BHP} = .00528 \left(\frac{2n}{n-1} \right) (P_s) \text{PD} (R^{(n-1)/2n} - 1)$$

n	Specific heat ratio of the gas
P_s	Suction Pressure (psia)
PD	Actual Piston Displacement (CFM)
R	Compression Ratio (P_d / P_s)

If the calculated BHP is greater than the rating for the selected model, use a larger size compressor.

In the example problem:

n	= 1.40
P_s	= 19.16 psia
PD	= 20.49 CFM
R	= 4.13

$$\begin{aligned} \text{BHP} &= .00528 \left(\frac{1.40}{1.40-1} \right) (19.16) 20.49 (4.13^{(1.40-1)/1.40} - 1) \\ &= 3.6 \text{ BHP} \end{aligned}$$

STEP IV - Selecting the Proper Compressor

Part 11 OPTIONS

Once the compressor model, RPM and required power have been determined, various compressor options and accessories will need to be considered. The primary concerns are:

Material Compatibility

O-rings and piston ring materials need to be reviewed to ensure compatibility with the gas stream being handled. Although Blackmer compressors use ductile iron as the primary material, a Teflon-Nickel treatment (TNT-12) is available to enhance its corrosion and wear resistance capabilities. Also, a variety of valve materials are available.

Suction Valve Unloaders

Many compressors will need some type of capacity control system. Suction valve unloaders are one method.

Seal (Piston Rod Packing) Configuration

This will depend on degree of leakage control desired and the pressures involved.

External Oil Filter

For dirty or dusty locations.

Extended Crankshaft

If a direct drive is to be used.

In the example the gas being handled is Nitrogen, a non-corrosive gas. Standard materials of construction (ductile iron with Buna-N O-rings) could be used. However, Nitrogen is a very dry gas, so the Poly-filled piston rings and a TNT-12 treated cylinder should be considered.

Since the usage rate will vary, a capacity control system will be needed. Suction valve unloaders will be used. The double-seal model (HD362) with Type 1 packing will be used. Neither the external oil filter nor an extended crankshaft is needed in this case.

STEP IV - Selecting the Proper Compressor

SUMMARY

HD362-B Single-stage, nonlube, ductile iron gas compressor fitted with Buna-N O-rings and iron valve gaskets. Each rod is fitted with two sets of packing to separate the cylinder area from the crankcase to seal the compressed product in and prevent oil contamination. Valves feature PEEK valve plates and include Stainless Steel piston type suction valve unloaders. Complete with liquid filled suction and discharge pressure gauges, steel baseplate, motor slide base, flywheel, V-belts, sheaves, beltguard, and oil pressure gauge. Entire unit to be coated with gray enamel primer and a top coat of Dover Blue enamel.

Options:

Poly filled piston rings for extended life in dry gas service.

TNT-12 Teflon/Nickel impregnated cylinder to provide extended piston ring life.

ASME code Relief valve mounted on the compressor discharge.

Low oil pressure switch, NEMA 4 with startup lockout timer

High Discharge Temperature Switch . NEMA 4 w/ Stainless Steel Thermowell

High Discharge Pressure Switch . NEMA 4

3-Way solenoid valve to control the suction valve unloaders. NEMA 7

	MW	N	CRITICAL TEMP & PRESS		Std.Z
NITROGEN	28.0	1.40	228°R	493 PSIA	1.00

MODEL	RPM	BORE IN.	STROKE IN.	# OF CYL.	MAWP PSIA	CLEAR. %	DISPL. CFM	ATMOSPHERIC PRESSURE PSIA
HD362	470	4.00	3.0	2	350	7.0	20.5	14.2 PSIA

PRESSURE (INLET/OUTLET) 5.0 / 65.0 PSIG

COMPRESSION RATIO 4.13

TEMPERATURE (IN/OUT) 50 / 305°F

COMPRESSIBILITY (IN/OUT) 1.00 / 1.00

CAPACITY

@ INLET 15.9 ACFM

@ STD. COND 21.2 SCFM 30.5 MSCFD

BY WEIGHT 94 LBS/HR

EFFICIENCIES

VOLUMETRIC 78%

COMPRESSION 85%

MECHANICAL 72%

ROD LOADS (COMPRESSION / TENSION)

DEG REVERSAL 310 / 50

GAS LOADS 820 / 9 LB

INERTIAL LOADS 75 / 114 LB

TOTAL LOAD 782 / 85 LB

HORSEPOWER REQUIRED 4.0 BHP

STEP IV - Selecting the Proper Compressor

SUMMARY (Metric Units)

HD362-B Single-stage, nonlube, ductile iron gas compressor fitted with Buna-N O-rings and iron valve gaskets. Each rod is fitted with two sets of packing to separate the cylinder area from the crankcase to seal the compressed product in and prevent oil contamination. Valves feature PEEK valve plates and include Stainless Steel piston type suction valve unloaders. Complete with liquid filled suction and discharge pressure gauges, steel baseplate, motor slide base, flywheel, V-belts, sheaves, beltguard, and oil pressure gauge. Entire unit to be coated with gray enamel primer and a top coat of Dover Blue enamel.

Options:

Poly filled piston rings for extended life in dry gas service.

TNT-12 Teflon/Nickel impregnated cylinder to provide extended piston ring life.

ASME code Relief valve mounted on the compressor discharge.

Low oil pressure switch, NEMA 4 with startup lockout timer

High Discharge Temperature Switch . NEMA 4 w/ Stainless Steel Thermowell

High Discharge Pressure Switch . NEMA 4

3-Way solenoid valve to control the suction valve unloaders. NEMA 7

	MW	N	CRITICAL	TEMP &	PRESS	Std.Z		
NITROGEN	28.0	1.40	127°K	34.0	BARa	1.00		
MODEL	RPM	BORE	STROKE	# OF	MAWP	CLEAR.	DISPL.	ATMOSPHERIC
		cm	cm	CYL.	BARa	%	M3/hr	PRESSURE
HD362	470	10.16	7.6	2	24.1	7.0	34.8	0.98 BARa
PRESSURE (INLET/OUTLET)					0.34 /	4.48	BARg	
COMPRESSION RATIO					4.13			
TEMPERATURE (IN/OUT)					10 /	152°	C	
COMPRESSIBILITY (IN/OUT)					1.00 /	1.00		
CAPACITY								
@ INLET					27.1	AM3/hr		
@ STD. COND					34.1	NM3/hr		
BY WEIGHT					43	KG/hr		
EFFICIENCIES								
VOLUMETRIC					78%			
COMPRESSION					85%			
MECHANICAL					72%			
ROD LOADS (COMPRESSION / TENSION)								
DEG REVERSAL					310 /	50		
GAS LOADS					372 /	4	KG	
INERTIAL LOADS					34 /	52	KG	
TOTAL LOAD					355 /	38	KG	
POWER REQUIRED					3.0	KW		