WHAT'S CORRECT FOR MY APPLICATION— A CENTRIFUGAL OR RECIPROCATING COMPRESSOR?

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ABSTRACT

This tutorial addresses the question of which compressor type is better suited to a given application—a centrifugal or reciprocating design. The general application map will be presented and discussed, as will the advantages and disadvantages of each type of compressor. The application guidelines will be addressed from the standpoint of reliability, cost, efficiency, size, and other more general application parameters such as molecular weight, compression ratio, and flow range, etc.

The intent of the tutorial will be to provide guidelines and comparative information to be used by contractors and users to determine which type of compressor will be the best fit for their particular application.

INTRODUCTION

The tutorial is organized into four sections. The first, "HOW A RECIPROCATING COMPRESSOR WORKS," will be a short, very basic explanation of how a recip compressor works. The next section, "HOW A CENTRIFUGAL COMPRESSOR WORKS," will do the same for a centrifugal compressor. The goal with these two sections is to serve as a primer for the rest of the tutorial. The third section, and the primary content of the tutorial, will be where the two different machines are compared and contrasted. Finally, the fourth section is entitled "CASE STUDIES." Here 12 different sets of application conditions (four sets of inlet and outlet pressures each at three different gas mole weights) are used to compare the performance of the two machines.

HOW A RECIPROCATING COMPRESSOR WORKS

How a reciprocating compressor works will be explained by discussing pressure versus time (Figure 1) and pressure versus volume (Figure 2) diagrams.

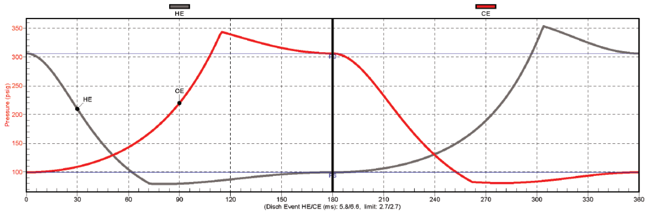

Figure 1. Pressure Versus Time Diagram.

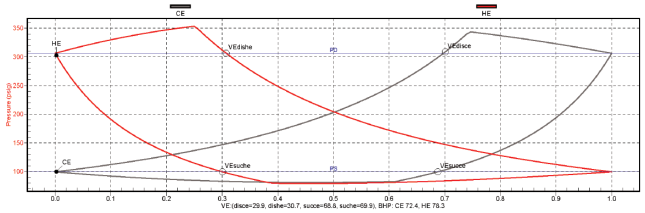

Figure 2. Pressure Versus Volume Diagram.

The P-T diagram (Figure 1) is a plot of the pressure of the gas in the compression chamber versus the angle of crankshaft rotation, which is essentially time because crank angle and time are directly related. Understanding the P-T diagram will help in understanding the P-V diagram, which underlies all the theory of reciprocating gas compressor operation.

The P-V diagram (Figure 2) is a plot of the pressure of the gas trapped in the compression chamber versus the volume of gas trapped in the compression chamber. The volume of gas trapped in the compression chamber is not linearly related to crank angle or time, so the two diagrams have different shapes and purposes.

A reciprocating compressor is a positive displacement machine—meaning a certain volume of gas is drawn in to the compression chamber where it is trapped, compressed, and released.

HOW A CENTRIFUGAL COMPRESSOR WORKS

A centrifugal compressor is a dynamic type of compressor where the pressure rise is accomplished by transfer of dynamic (motion-related) energy from the rotor to the gas.

- The basic aerodynamic components of a centrifugal compressor are the impellers, diffusers, and return channels. (Figure 3)

- Velocity (kinetic energy) is imparted from moving blade to gas in the impeller (Figure 4).

- Velocity (kinetic energy) is converted to pressure (potential energy) in the diffuser.

- For a given pressure ratio, more head is required to compress a low molecular weight gas than for a higher molecular weight gas (Figure 5).

- Increasing speed imparts higher kinetic energy, which converts to higher pressure (potential energy) (Figure 6).

- The head/pressure ratio curve is essentially constant with changing volume flow at fixed speed (Figure 7).

- Centrifugal compressor performance can be estimated using the fan laws. According to the fan laws, capacity is proportional to speed, head is proportional to the square of the speed, and power is proportional to the cube of the speed. Since these laws assume ideal gases with constant k and Z values, they apply with reasonable accuracy to single-stage compressors or multistage compressors with low pressure ratios. For a multi-stage centrifugal compressor with a high pressure ratio, the laws still apply directionally, but the accuracy of performance estimates using the fan laws is insufficient for most calculations.

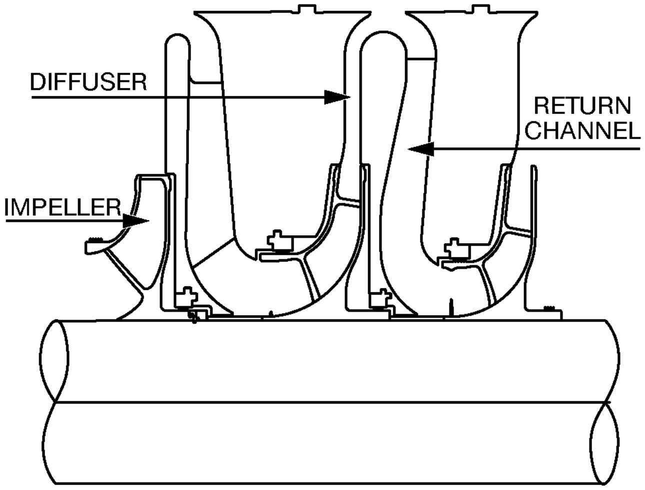

Figure 3. Aerodynamic Parts of a Centrifugal Compressor.

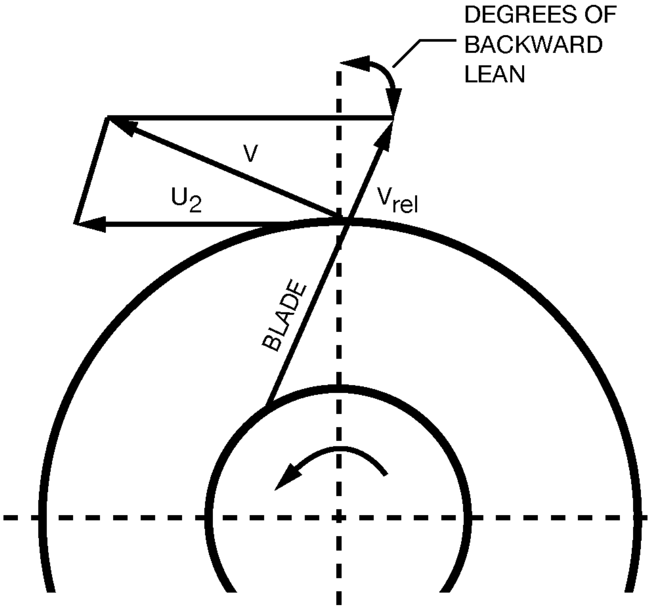

Figure 4. Impeller Discharge Gas Velocity.

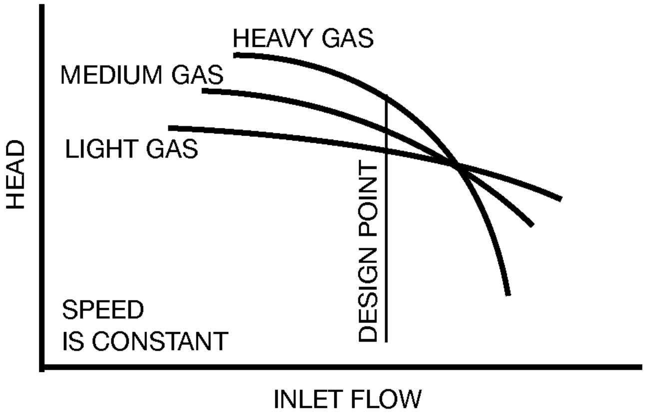

Figure 5. Gas Mole Weight Effect on Head.

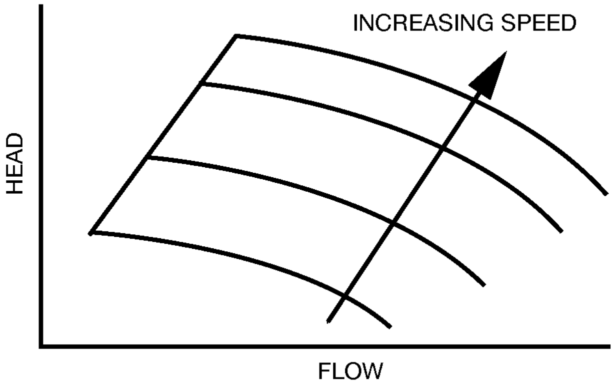

Figure 6. Effect of Speed on Head.

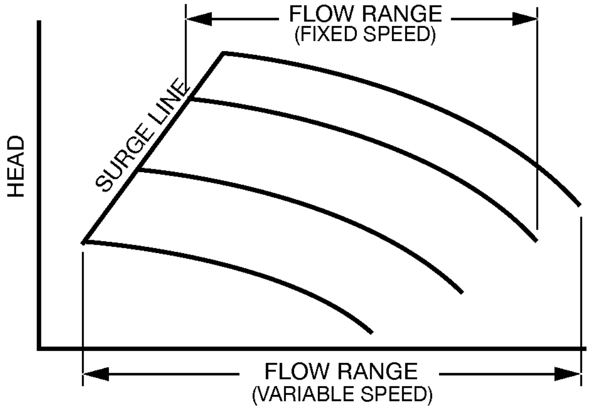

Figure 7. Effect of Speed Range on Overall Flow Range.

CENTRIFUGAL VERSUS RECIPROCATING COMPARISON

The following text is organized by topic with comments for that topic relating to reciprocating and centrifugal compressors.

Maximum Discharge (Outlet) Pressure

- *Reciprocating*—The "typical" reciprocating compressor is used for discharge pressures up to 12,000 psi (828 bar). Special compressors (called hypercompressors) are used in low density polyethylene production and discharge at pressures up to 50,000 psi (3500 bar).
- *Centrifugal*—Discharge pressures to 1450 psi (100 bar) for horizontally split compressors. Discharge pressures up to 15,000 psi (1034 bar) for radially split (barrel) compressors.

Minimum Suction (Inlet) Pressure

- *Reciprocating*—Can be applied with suction pressures at atmospheric or even a slight vacuum. In vacuum applications, precautions must be taken to prevent atmospheric air from leaking into the cylinder through the piston rod packing.
- *Centrifugal*—Inlet pressures to atmospheric or below. For subatmospheric inlet conditions, special seal and buffering designs are employed to keep atmospheric air from being drawn into the compressor.

Maximum Discharge (Outlet) Temperature

- *Reciprocating*—Discharge temperature limits will depend on the application and the seal element materials selected. In hydrogen rich applications, API 618 (1995) limits discharge temperatures to 275°F (135°C). For natural gas service the maximum discharge temperature limit is 350°F (175°C); although in most cases a more practical limit is 300°F (149°C). Air compressors may run at discharge temperatures in excess of 400°F (204°C).
- *Centrifugal*—Maximum temperature based on the compressor design itself is typically 400 to 450°F (204 to 232°C). Higher temperatures are possible but require special designs such as center supported diaphragms, less efficient seal materials, and high temperature O-rings and sealants.

The process may also have discharge temperature limitations due to fouling, temperature limits of downstream components, and process efficiency.

Minimum Suction (Inlet) Temperature

- *Reciprocating*—The common compressor cylinder materials, cast gray iron and cast ductile iron, are acceptable for use at temperatures as low as −40°F (−40°C) which typically occur in refrigeration applications.

The lowest suction temperatures requested typically are in liquefied natural gas boil-off gas applications. These inlet temperatures can be as low as −260°F (−162°C). Compressor cylinders used for this application require very special materials and are not offered by all manufacturers.

- *Centrifugal*—Standard centrifugal compressor materials are typically suitable for −20 to −50°F (−19 to −46°C).

Refrigeration compressors in ethylene service typically have inlet temperatures as low as −155°F (−104°C), which require special low temperature compressor materials.

Similar to reciprocating compressors, the lowest temperature requirement for centrifugal compressors is typically found in liquefied natural gas (LNG) boil-off gas applications. Centrifugal compressor designs and materials for this service can accommodate minimum temperatures down to −275°F (−171°C). Special low temperature stainless steels are typically used for this service. Special low temperature seals and O-rings are also required.

Maximum Flow

- *Reciprocating*—Reciprocating compressors are positive displacement type compressors. Capacity is limited by cylinder size, the number of throws available, and the available driver speeds. A "throw" is a location on the crankcase where acompressor cylinder can be attached.
- *Centrifugal*—Centrifugal compressors can be sized for an inlet flow of 400,000 acfm (680,000 m3/hr) in a single body.

The maximum flow through a centrifugal compressor is limited by the choke point, which is the point at which the flow through some part of the compressor nears a velocity of Mach 1.

Minimum Flow

- *Reciprocating*—Similar to the maximum flow, the minimum flow in a reciprocating compressor is limited by cylinder size, stroke, and speed. Very small reciprocating compressors are available.
- *Centrifugal*—Centrifugal compressors can be sized for flow as low as a few hundred acfm. Unlike a reciprocating compressor where minimum flow is solely a function of compressor geometry and speed, the minimum flow for a centrifugal compressor is limited by an aerodynamic condition known as surge, which is a function of compressor geometry, speed, aerodynamic gas conditions, and system resistance.

Flow Range

- *Reciprocating*—Reciprocating compressors have the ability to change flow (throughput) through speed control, the addition of fixed clearance to a cylinder (fixed or variable volume clearance pockets), cylinder end deactivation, and system recycle. Typical flow range might be 100 percent down to as low as 20 percent, and even lower.

The application will determine what type of capacity control method is required and used. On low compression ratio applications (compression ratio less than 1.6, such as natural gas pipeline gas transmission) adding fixed clearance will have little if any effect on flow. These applications may use speed control or cylinder end deactivation.

In other applications, with higher compression ratios, it is quite common to use clearance pockets and cylinder end deactivation to regulate flow.

- *Centrifugal*—As discussed above, the flow range of a centrifugal compressor is set by the surge and choke points.

Typical turndown for a fixed speed, multistage centrifugal compressor is approximately 20 to 30 percent. With speed variation or adjustable inlet guide vanes, the turndown can be increased to 40 to 50 percent or more (Figure 9).

Weight

- *Reciprocating*—The weight of a reciprocating compressor obviously varies with size, which varies with speed, stroke, and rod load rating.

It is safe to say that on a mass per power basis the centrifugal compressor will be lighter.

- *Centrifugal*—The weight of a centrifugal compressor varies depending on compressor size (refer to “Size” below) and, to a smaller degree, on materials of construction.

The driver, baseplate, and auxiliary systems contribute significantly to the weight of a centrifugal compressor package.

Size

- *Reciprocating*—Reciprocating compressors come in a wide variety of sizes. The size and weight of a reciprocating compressor is directly related to stroke, speed, and rod load rating. Stroke, in turn, can be related to the driver speed. In general, the higher the driver rotating speed, the shorter the stroke and therefore the smaller the compressor. Conversely, a slower speed compressor will typically have a longer stroke and be physically larger.

- *Centrifugal*—The size of a centrifugal compressor is mainly a function of flow capacity (sets the diameter) and number of stages (sets the length).

Casing outer diameters range from as small as 20 inches (500 mm) to as large as 150 inches (3800 mm).

Reliability

- *Reciprocating*—Reciprocating compressors will probably never be as reliable as centrifugal compressors. The recip has many more parts and more rubbing seals (pressure packing, piston rings, and rider rings) that wear and require more frequent replacement than any seal or other part in a centrifugal.

In addition a recip has compressor valves, which though very simple mechanical devices (simple spring-loaded check valves), require considerable maintenance.

Another significant factor affecting the reliability of the recip is the cleanliness of the process gas. Wear life of the seals and the valves will be considerably longer with a process gas that is free of liquid and solid debris.

- *Centrifugal*—Reliability/availability of centrifugal compressors is typically 98 to 99 percent.

Typical Maintenance Intervals

- *Reciprocating*—Maintenance intervals for a reciprocating compressor vary significantly with the application and follow along with the comments made in the reliability section.

Compressor valve and seal element intervals might be as short as a few months and as long as three to five years (some applications may be even longer). This depends so much on the specifics of the application and the cleanliness of the gas.

A major overhaul (typically defined as completely going through the machine to the point of replacing the bearings) may be required only every 10 years or longer.

- *Centrifugal*—Per API 617 (2002), Seventh Edition, a centrifugal compressor has to be designed for at least five years of uninterrupted service. In clean service, a centrifugal compressor can operate continuously for 10 years or longer.

Maintenance requirements are typically limited to replacing bearing pads and seal wearing parts.

Compressed Gas Molecular Weight

- *Reciprocating*—A reciprocating compressor has no limit with regard to molecular weight. Very light and very heavy gases are compressed equally well. Over the range of molecular weight different application configurations may be required. For example, very low molecular weight gases may present some seal challenges and very high molecular weight gases pose issues with efficiency. But nonetheless, the recip handles the whole range quite well.

- *Centrifugal*—Compression ratio is highly dependent on molecular weight. Head is developed by increasing gas velocity to create kinetic energy and then converting the kinetic energy to pressure in the diffuser. The amount of kinetic energy is a function of gas velocity and mass or molecular weight.

Centrifugal compressors are used for a broad range of molecular weight including low molecular weight applications such as hydrogen recycle and high molecular weight applications using refrigerant gases with molecular weights over 100.

Compression Ratio

- *Reciprocating*—The maximum compression ratio that a reciprocating can handle in one stage is limited mostly by compressed gas discharge temperature. The piston rod load generated by the compression ratio may also be a limit.

Typical compression ratios are 1.2 to 4.0.

- *Centrifugal*—Compression ratio is a function of gas molecular weight, compressibility, stage geometry, compressor speed, and the number of compressor stages.

For a specific gas, the limits to compression ratio are the mechanical and rotordynamic limitations on speed and the number of stages that can be accommodated in a single body. Discharge temperatures resulting from high compression ratios can usually be controlled by intercooling.

Materials

- *Reciprocating*—Reciprocating compressors are made of very common materials such as gray iron, ductile iron, carbon steel, alloy steel, and stainless steel, in cast, forging, or bar stock form.

Some compressor pistons and covers may be made of aluminum. For corrosive applications it is common to see stainless steel, typically 17-4PH or a 400 series, used for piston rods and compressor valve seats and guards.

- *Centrifugal*—Materials for major components such as casings, nozzles, shafts, impellers, etc., are primarily carbon, alloy, and/or stainless steels. Components may be cast, forged, or fabricated. Some cast or nodular iron may be used for stationary components.

Material selection is primarily dependent on temperature, stress (pressure, torque), and gas composition (corrosive, erosive, etc).

Multiservice Capability

- *Reciprocating*—It is very easy to have a multiservice reciprocating compressor. The number of different services on a given compressor crankcase (frame) is only limited by the number of throws available and the number of stages required for each service. Eight, 10, and even 12 throw frames are not uncommon.

- *Centrifugal*—While it is possible to have a multisection centrifugal compressor with different services/gases in each section, this is not typical.

Efficiency

- *Reciprocating*—Reciprocating compressors have a very characteristic adiabatic efficiency curve (Figure 8). As compression ratio drops, adiabatic efficiency drops. Efficiency changes with molecular weight. Efficiency will also vary with several other factors, most significantly the compressor cylinder's ratio of valve flow area to main bore diameter and piston speed.

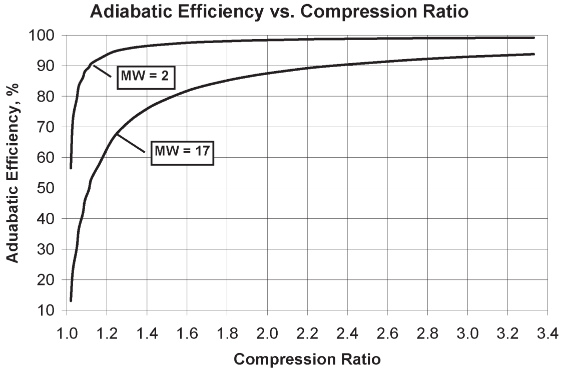

Figure 8. Reciprocating Compressor Efficiency.

- *Centrifugal*—Polytropic efficiency is typically used for centrifugal compressors rather than adiabatic. Adiabatic is commonly used for air compressors.

Typical polytropic efficiencies range from 70 percent to 85 percent. Efficiencies approaching 90 percent are possible. In a centrifugal compressor, efficiency is primarily affected by the internal leakage and mechanical losses.

Cost: Capital and Operating

- *Reciprocating*—Generally a reciprocating compressor will have a lower capital cost but a higher operating cost compared to a centrifugal. The lower capital cost is a direct result of the machine consisting of smaller parts that cost less and are easier to manufacture. Higher operating cost results from the recip containing more wearing parts requiring more maintenance and downtime—most specifically compressor valves, which do not exist in a centrifugal.

- *Centrifugal*—The capital cost of a centrifugal compressor is typically higher than a reciprocating compressor operating at the same conditions. This is primarily due to the fact that centrifugal compressors require parts with more complex geometry such as impellers and diaphragms. However, a centrifugal compressor has fewer wearing parts, resulting in lower operating costs in terms of replacement parts, repairs, and downtime.

Minimum/Maximum Power

- *Reciprocating*—Reciprocating compressors vary in size from the very small, under 10 hp (7.5 kW), to very large at 12,000 hp (9.0 MW). Even higher horsepower compressors are available from some manufacturers for some very specialized applications, like very high pressure ethylene compression ("hyper" compressors).

- *Centrifugal*—Power developed is dependent on the mass flow of the gas compressed, the head required, and the efficiency. The power required to drive a centrifugal compressor can be as low as 100 hp (75 kW) and as high as 130,000 hp (97 MW) or more.

Lead Time

- *Reciprocating*—Today, reciprocating compressor lead time is quite long due to the increased demand from the natural gas industry. Lead time for a bare compressor will vary from 14 to 40 weeks depending on size and manufacturer. Quite often, electric motor driven compressor lead time is driven by the lead time of the motor—again depending on size (horsepower).

- *Centrifugal*—Typical lead times for a centrifugal compressor train are in the range of 35 to 75 weeks. Lead time is most significantly affected by the original equipment manufacturer (OEM)/subvendor shop loading, availability of any special materials required (low temperature, corrosion resistant, etc.), special/unique design requirements, and testing/inspection requirements.

Installation Time and Complexity

- *Reciprocating*—Installation time for a reciprocating compressor varies significantly with size and location, and whether or not the compressor is packaged. Packaged compressors are common today up to 5000 hp (3.4 MW) of a high speed short stroke design. Installation time for these might vary from a few days to a couple of weeks. Larger slow speed long stroke compressors assembled at site might require three to four weeks to install.

- *Centrifugal*—Similar to a reciprocating compressor, the installation time varies widely depending on the size of the compressor. The number of main casing nozzle connections and the type of driver also affect installation time.

The location can be a factor as well. Remote or offshore locations can add to the installation time.

The compressor and driver are typically packaged on a base plate complete with oil piping and wiring to junction boxes. Process equipment such as coolers and scrubbers and process control valves are typically installed at site. Auxiliary systems such as lube oil consoles, control panels, and seal buffer systems may also be installed separately. Piping and wiring from these auxiliary systems and process equipment to the compressor train are typically done at site.

Installation time for a typical motor/gear driven compressor package is two to three weeks. For a very large compressor or a gas turbine driven compressor the installation time could be three to six weeks.

CASE STUDIES

APPENDIX A contains tables where the performance data for reciprocating and centrifugal compressors are compared for four different sets of pressure conditions, each for three different mole weight gases, for a total of 12 case study points. The purpose of these case studies is to compare performance and to help explain why a certain design compressor fits a certain application better than the other—from a performance perspective. Figure 9 is a chart showing discharge pressure versus inlet flow intending to compare and contrast where each type of compressor fits best in this map. The case study points have been selected from this map.

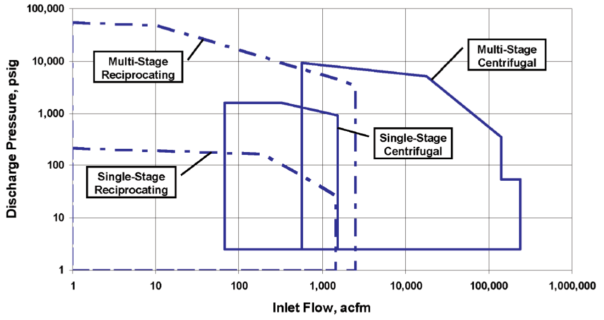

Figure 9. NGPSA Compressor Coverage Chart. (Courtesy, NGPSA Engineering Data Book, 1994)

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APPENDIX A

Table A-1. Case Study Performance Data, A.

Case Study Number 1A – Low Flow, Low Pressure, Medium Molecular Weight		
Capacity = 600 acfm (1019.4 m^3/hr) Suction Pressure = 5 psig (0.34 BarG) Suction Temperature = 80° F (27° C) Discharge Pressure = 45 psig (3.1 BarG) Molecular Weight = 18.83 (S.G. = 0.65)	Reciprocating	Centrifugal
Power, hp (kW)	79 (59)	150 (112)
Flow, scfm (Nm^3/hr)	774 (1,244)	774 (1,244)
Power per flow, hp/scfm (kW/Nm^3/hr)	0.102 (0.047)	0.193 (0.090)
Number of Stages	1	7
Equivalent Head, ft (m)	54,869 (16724)	59,230 (18,053)
Case Study Number 1B – Low Flow, Low Pressure, Low Molecular Weight		
Capacity = 600 acfm (1019.4 m^3/hr) Suction Pressure = 5 psig (0.34 BarG) Suction Temperature = 80° F (27° C) Discharge Pressure = 45 psig (3.1 BarG) Molecular Weight = 2.02 (S.G. = 0.07)	Reciprocating	Centrifugal
Power, hp (kW)	78 (58)	This case is too small for a centrifugal compressor.
Flow, scfm (Nm^3/hr)	773 (1243)	
Power per flow, hp/scfm (kW/Nm^3/hr)	0.101 (0.047)	
Number of Stages	2	
Equivalent Head, ft (m)	540,746 (164,819)	
Case Study Number 1C – Low Flow, Low Pressure, High Molecular Weight		
Capacity = 600 acfm (1019.4 m^3/hr) Suction Pressure = 5 psig (0.34 BarG) Suction Temperature = 80° F (27° C) Discharge Pressure = 45 psig (3.1 BarG) Molecular Weight = 28.05	Reciprocating	Centrifugal
Power, hp (kW)	85 (63)	151 (113)
Flow, scfm (Nm^3/hr)	774 (1,245)	774 (1,245)
Power per flow, hp/scfm (kW/Nm^3/hr)	0.110 (0.050)	0.192 (0.089)
Number of Stages	2	5
Equivalent Head, ft (m)	36,702 (11,187)	38,578 (11,759)
Case Study Number 2A, High Flow, Medium Pressure, Medium Molecular Weight		
Capacity = 10,000 acfm (16,990.1 m^3/hr) Suction Pressure = 200 psig (13.8 BarG) Suction Temperature = 80° F (27° C) Discharge Pressure = 1000 psig (68.95 BarG) Molecular Weight = 18.83	Reciprocating	Centrifugal

Table A-2. Case Study Performance Data, B.

Power, hp (kW)	18,909 (14,100)	21850 (16.306)
Flow, scfm (Nm^3/hr)	145,830 (234,522)	145,830 (234,522)
Power per flow, hp/scfm (kW/Nm^3/hr)	0.130 (0.060)	0.150 (0.070)
Number of Stages	2	6
Equivalent Head, ft (m)	78,822 (24,025)	81,400 (24,811)
Case Study Number 2B, High Flow, Medium Pressure, Low Molecular Weight		
Capacity = 10,000 acfm (16,990.1 m^3/hr) Suction Pressure = 200 psig (13.8 BarG) Suction Temperature = 80^{o} F (27^{o} C) Discharge Pressure = 1000 psig (68.95 BarG) Molecular Weight = 2.02	Reciprocating	Centrifugal
Power, hp (kW)	14,295 (10,660)	This case can not be accomplished with a reasonable number of centrifugal compressor bodies/stages.
Flow, scfm (Nm^3/hr)	145,830 (225,430)	
Power per flow, hp/scfm (kW/Nm^3/hr)	0.098 (0.047)	
Number of Stages	2	
Equivalent Head, ft (m)	813,384	
Case Study Number 2C, High Flow, Medium Pressure, High Molecular Weight		
Capacity = 10,000 acfm (16,990.1 m^3/hr) Suction Pressure = 200 psig (13.8 BarG) Suction Temperature = 80^{o} F (27^{o} C) Discharge Pressure = 1000 psig (68.95 BarG) Molecular Weight = 28.05	Reciprocating	Centrifugal
Power, hp (kW)	21,102 (10,660)	20,960 (15,642)
Flow, scfm (Nm^3/hr)	154,014 (225,430)	154,014 (225,430)
Power per flow, hp/scfm (kW/Nm^3/hr)	0.137 (0.047)	0.136 (0.063)
Number of Stages	2	4
Equivalent Head, ft (m)	53,211 (16,219)	49,700 (15,149)
Case Study Number 3A, Medium Flow, Medium Pressure, Medium Molecular Weight		
Capacity = 3,000 acfm (5,097 Nm^3/hr) Suction Pressure = 200 psig (13.79 BarG) Suction Temperature = 80^{o} F (27^{o} C) Discharge Pressure = 600 psig (41.37 BarG) Molecular Weight = 18.83	Reciprocating	Centrifugal
Power, hp (kW)	3,945 (2,948)	4,252 (3,173)
Flow, scfm (Nm^3/hr)	43,867 (70,537)	43,867 (70,537)
HP per flow, hp/scfm (kW/Nm^3/hr)	0.090 (0.042)	0.097 (0.045)
Number of Stages	2	6
Equivalent Head, ft (m)	50,545 (15,406)	51,700 (15,758)

Table A-3 .Case Study Performance Data, C.

Case Study Number 3B, Medium Flow, Medium Pressure, Low Molecular Weight		
Capacity = 3000 acfm (5,097 Nm^3/hr) Suction Pressure = 200 psig (13.8 BarG) Suction Temperature = 80^o F (27^o C) Discharge Pressure = 1000 psig (69 BarG) Molecular Weight = 2.02	Reciprocating	Centrifugal
Power, hp (kW)	3,775 (2,815)	This case can not be accomplished with a reasonable number of centrifugal compressor bodies/stages.
Flow, scfm (Nm^3/hr)	41,861 (67,610)	
Power per flow, hp/scfm (kW/Nm^3/hr)	0.090 (0.041)	
Number of Stages	2	
Equivalent Head, ft (m)	511,799 (155,996)	
Case Study Number 3C, Medium Flow, Medium Pressure, High Molecular Weight		
Capacity = 3000 acfm (5,097 Nm^3/hr) Suction Pressure – 200 psig (13.8 BarG) Suction Temperature = 80^o F (27^o C) Discharge Pressure = 1000 psig (69 BarG) Molecular Weight = 28.05	Reciprocating	Centrifugal
Power, hp (kW)	3,927 (2,928)	4,062 (3,031)
Flow, scfm (Nm^3/hr)	45,477 (73,125)	45,477 (73,125)
HP per flow, hp/scfm (kW/Nm^3/hr)	0.086 (0.040)	0.089 (0.041)
Number of Stages	1	4
Equivalent Head, ft (m)	33,937 (10,344)	31,161 (9,498)
Case Study Number 4A, Medium Flow, High Pressure, Medium Molecular Weight		
Capacity = 2000 acfm (3,398 Nm^3/hr) Suction Pressure = 200 psig (13.8 BarG) Suction Temperature = 80^o F (27^o C) Discharge Pressure = 3500 psig (241.4 BarG) Molecular Weight = 18.83	Reciprocating	Centrifugal
Power, hp (kW)	7,012 (5,229)	9,732 (7,263)
Flow, scfm (Nm^3/hr)	29,027 (46,675)	29,027 (46,675)
Power per flow, hp/scfm (kW/Nm^3/hr)	0.241 (0.180)	0.335 (0.156)
Number of Stages	3	16 (2 bodies)
Equivalent Head, ft (m)	163,227 (49,752)	147,763 (45,038)
Case Study Number 4B, Medium Flow, High Pressure, Low Molecular Weight		
Capacity = 2000 acfm (3,398 Nm^3/hr) Suction Pressure = 200 psig (13.8 BarG) Suction Temperature = 80^o F (27^o C) Discharge Pressure = 3500 psig (241.4 BarG) Molecular Weight = 2.02	Reciprocating	Centrifugal

Table A-4. Case Study Performance Data, D.

Power, hp (kW)	6,844 (5,134)	This case can not be accomplished with a reasonable number of centrifugal compressor bodies/stages.
Flow, scfm (Nm^3/hr)	27,908 (44,880)	
Power per flow, hp/scfm (kW/Nm^3/hr)	0.245 (0.114)	
Number of Stages	4	
Equivalent Head, ft (m)	1,788,446	
Case Study Number 4C, Medium Flow, High Pressure, High Molecular Weight		
Capacity = 2000 acfm (3,398 Nm^3/hr) Suction Pressure = 200 psig (13.8 BarG) Suction Temperature = 80^o F (27^o C) Discharge Pressure = 3500 psig (241.4 BarG) Molecular Weight = 28.05	Reciprocating	Centrifugal
Power, hp (kW)	5,890 (4,392)	7,811 (5,829)
Flow, scfm (Nm^3/hr)	30,318 (48,750)	30,318 (48,750)
Power per flow, hp/scfm (kW/Nm^3/hr)	0.194 (0.090)	0.258 (0.120)
Number of Stages	3	10
Equivalent Head, ft (m)	105,164 (32,054)	76,779 (23,408)

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