APPLICATION MANUAL

WORLD STANDARD COMPRESSORS

ARIEL CORPORATION

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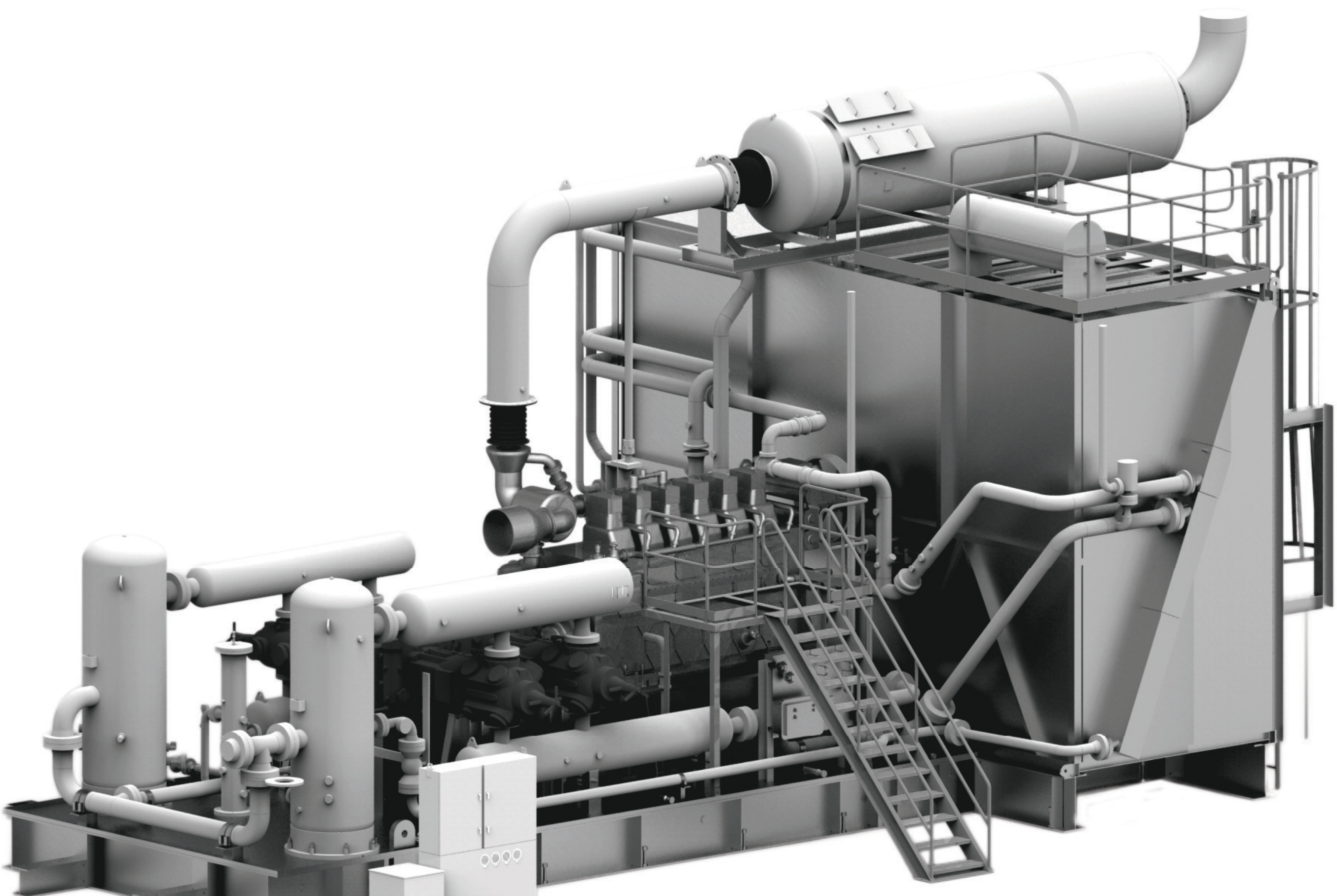

Heavy Duty Balanced Opposed Reciprocating Compressors

Table of Contents

Introduction

Welcome to the Ariel Application Manual. For any questions or comments concerning the DataBook or Application Manual, please contact Ariel Applications Engineering at:

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Disclaimer

Technical information changes all the time. Ariel claims that the information in this document is the latest at the time of publication. In all cases, contact Ariel application engineering for issues regarding specific applications.

Revision History

14 December 2023

- Modified the Sour Gas topic to revise flushing lube recommendations.
- Modified the Electric Motor Drive topic to exclude the Service Factor from the 10% margin between rated driver power and maximum horsepower.

11 January 2022

- Added maximum allowable inertia limit for fan drive shafts
- Converted to Adobe Experience Manager

20 April 2021

- Re-applied the Distance Piece Arrangements topic
- Expanded the Minimum Allowable Pin Reversal to help identify configurations to review closer for acceptable reversal

17 June 2020

- Modified the discharge temperature topic to better define the Application Limit versus the Maximum Shutdown Limit.
- Added a topic on Oxygen.

29 May 2019

- Added information on VVCP stem seal vent, which cylinders have the two seal vent.
- Removed cylinder options / features table, referring to the Performance Software for the list of features and options.

20 February 2019

- Modified water cooled packing and non-lube topics to be more concise that packing cooling requires the water cooling system applied
- Added allowance for non-lubricated cylinder construction for Sour Level 1 service (Non-lube and Sour Gas topics)

19 November 2018

- Added references to EN 10204:2004 to Materials Certifications and Tests topic

8 October 2018

- Included the KBK:T frames.
- Added ability to purge wiper set with purged packing on long single compartment distance pieces for KBK:KBT and KBZ:KBU frames.

31 October 2016

- Added Valve Topic, to include low lift valve discussion.
- Modified Sour Gas topic due to the removal of the "H2S" designation from forged steel cylinders.
- Modified Piston Rod topic for the piston rod surface finish values.
- Modified Tools and Special Tools topics to remove specific components and refer to the Maintenance and Repair Manual.
- Modified Cooled Packing topic to better define when to provide a packing cooling system.

8 July 2016

- Added Auxiliary End Pump Removal topic.
- Added reference within Torsional Vibration Analysis to ER-83.
- Modified Ariel Special Flange topic to provide definition of the Taperlok flange ASME Div 1 design basis.

16 July 2015

- Modified Ariel Special Flange topic to include the alloy steel material designation for the higher pressure 2-5/8x10-FS-HE 10,000 psi cylinder.

9 March 2015

- Modified ISO-9001 topic to refer to the ISO statement on the website.

- Removed unit conversion calculation fields from the unit conversions due to instability with various browsers.

29 September 2014

- Included a low temperature cautionary note to the Suction Temperature and Ambient Temperature topics for o-ring sealing below -15 F.

17 April 2014

- Modified the Sour Gas topic to further stress the importance of safety, changing the recommendations for purged packing, two compartment distance pieces (short or long) and stainless steel piston rod material to required options.
- Modified the Carbon Dioxide Service topic to allow the use of 400 series stainless steel valve body material in CO2 service. 400 series stainless steel material is the supplied standard for the majority of the valves in Ariel cylinders. This allows for the use of standard valve material in CO2 service if the standard material is 400 series stainless steel.

26 July 2013

- Updated to re-organize table of contents and function on greater number of web platforms.
- Added gas properties for some of the more common gasses encountered in compression.
- Added an FPSO topic
- Added a Carbon Monoxide topic
- Simplified the Calculation Method discussions
- Added Project Check List to the Torsional topic
- Added the JGF frame designation to the JGC:D:F frame class

14 September 2012

- Updated to provide changes in links to a fully revised Packager Standards.
- Removed references for Purge and Vent Systems in favor of the Packager Standards Section 8 Packing and Distance Piece Vent Systems.

15 July 2012

- Added Air Service topic.
- Added selection recommendations to the Carbon Dioxide Service topic.
- Added Gas Properties topic.
- Added Crankcase Relief Door topic.
- Added Selection Recommendations to the Sour Gas topic.

11 November 2011

- Better defined those variables impacted by speed range on the Minimum Allowable Rotating Speed topic.
- Added the 19BL:VL:BM:VM cylinder to the Ariel Special Flange list for special peanut type flanges.
- Added a Project Engineering Checklist to the Electric Motor topic.

22 December 2010

- Removed frame lube oil viscosity and temperature information in favor of referencing the Packager's Standards, for a single location of information.

22 October 2009

- Added a watt density limit to the frame lube oil heater topic.

25 October 2008

- Added a Tools topic discussing the hydraulic torque tools and the SAE hand tools as a performance software option.
- Added the discussion of the SG tandem cylinder high clearance valve assemblies to the High Clearance Valve Assembly topic.

7 March 2007

- Modified Capacity and Load Control topic to include a load sequence hierarchy (including notes and links within the Torsional and

Cylinder Single Acting topics to Capacity and Load Control topic).

- Removed Frame Thermal Growth topic. Please refer to the same topic presented in the Packager's Standards, Technical Manuals and Outline Drawings.
- Revised Low Suction Temperature Applications Topic to be Suction Temperature, discussing low suction temperature, high suction temperature and high mean cylinder gas temperature.
- Added Non-Intercooled Topic.
- Modified Ariel Calculation Method to remove critical temperature and pressure references.
- Removed the No Yellow Metals topic from the Sour Gas topic.

23 February 2007

- Corrected Frame Driven Lube Oil Pump discussion for the large frames that have external pressure relief valves downstream of the lube oil filter.

28 December 2006

- Modified Deactivated Stage topic, added clarification for the durations of blowthru and pulling suction valves.
- Added Special Tools topic for Hydraulic torque tools.
- Modified Helium Leak Test topic, added the mole weight and hydrogen content requiring He test.

6 December 2006

- Modified Assembly Inspections and Tests topic, added "prepared for shipment" in last bullet point.
- Modified Cylinder Hydro Test topic, changed ISO reference to match current ISO procedure numbers.
- Modified Helium Leak Test topic, changed ISO reference to match current ISO procedure numbers.
- Packager's Standards topic, added subsection links.

6 November 2006

- Added Gas Method page defining the usage of VMG and Hall gas methods.
- Added the JGJ/4 fan shaft, a new addition to the line of fan shafts, suitable for 50 hp.

2 November 2006

- Various pages: Changed JGB:V frame references to KBB:V frames.
- Modified frame tilt data for the JGB:V and KBB:V frames.
- Sour Gas: Changed recommendations for S2C guides to allow for Long Single guides at lower levels of H2S when the S2C guide is not made available by Ariel (JGU:Z, KBB:V cylinders and some -VS cylinders).

Mission Statement

Vision Statement

Ariel sets the world standard in gas compression, shaping the future of the compression industry – a global company addressing emerging energy and environmental challenges. From wellhead to burner, Ariel = compression.

Mission Statement

In order to achieve our vision, we will apply our compression expertise wherever natural gas is found. We will identify opportunities and capture market share in every viable compression market. We will maintain and expand our market share by offering unparalleled products, service, and innovative engineering. We will maintain our core tradition of supporting our products with a fair and generous warranty policy, with broad technical and educational support, and with fairly-priced, fast response replacement parts.

Quality Policy

Ariel people take pride in the company’s world class manufacturing processes and product designs. Quality is the foundation of our success. Maintaining our reputation as the world standard compression company requires us to design products that can be manufactured, installed, and serviced with ease. Our compressors are designed to match available drivers, offer maximum efficiency and value, and continue to be the most reliable compressors attainable.

We will maintain our core tradition of standing behind our products with fair and generous warranties, with broad technical and educational support, and with fairly-priced, rapid spare parts delivery.

Our key processes incorporate the best aspects of world class manufacturing practices. Our quality system is certified to the requirements of ISO 9001. Key performance metrics supporting continual improvement will be communicated throughout the organization. Yearly objectives will be established for performance metrics and reported at the management review of the quality system.

Alex Wright/CEO

General Contact

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After Hours Support

Ariel 24 Hour, 7 Day a Week, Emergency Help Phone Lines

Ariel has available emergency after hour phone numbers for the Field Service and Spares Departments.

These numbers are in addition to the general numbers that are used during regular business hours. Regular business hours at Ariel are 8:00 a.m. to 5:00 p.m. for office hours, 8:00 a.m. to 8:00 p.m. for Spare Parts office hours and 8:00 a.m. to 7:00 p.m. for Ariel Response Center hours, Eastern time, Monday thru Friday, excluding national holidays.

Emergency Field Service technical assistance and Emergency Spare Parts service are available after hours at (740)397-3602 International and (888)397-7766 North America. Emergency Field Service technical assistance and Spare Parts calls will be handled automatically by an individual responsible for coverage of emergency situations when a detailed message is left on the above phone numbers.

Ariel Response Center

Ariel has developed a staff of experienced personnel who are ready to provide quick, accurate information on topics that you face in compressor design, operation, and maintenance.

Whether you just need a torque value for a fastener or assistance in a total reconfiguration, you can contact this team during our extended business hours of 8:00 am to 7:00 p.m. Eastern Time.

Call now for information concerning:

- Ariel products and data
- Assembly questions
- Reconfiguration assistance
- Balance and lubrication information
- Unit specific as-built information
- Valve selection assistance
- Recommended spare parts
- Product conversions

Phone: 888-397-7766 (North America) / 740-397-3602 (International)

Fax: 740-397-1060
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Packager Standards

Ariel provides guidance and standards on how to build a successful reciprocating compressor package around the Ariel compressor. These are minimum requirements for packager quality and design. Ariel encourages our packagers to exceed these standards with the finest quality packages.

The Ariel Reciprocating Packager Standards can be found through the Ariel website.

Customer Technical Bulletins

Current Customer Technical Bulletins are available through the Internet at www.arielcorp.com

Frame Class Equipment

JGM:JGP Frames

ARIEL balanced/opposed, multi cylinder, gas compressor arranged for clockwise rotation when facing the drive end of the compressor (standing on the driver looking at the compressor). Designed for operation with appropriate engine, electric motor, turbine or other prime mover. Includes the following standard equipment:

- Heavy-duty, horizontal balanced/opposed, moisture and dust-proof compressor frame.
- Forged steel crankshaft
- Precision insert tri-metal bearings.
- Strong, H-beam design ductile iron connecting rods.
- Short close coupled guide is standard and integral with the compressor frame.
- Lubricating oil pump with system relief valve for full pressure lubrication to bearings and crossheads. (See Frame Lube Oil System)
- Manual lube oil priming pump is available as an option
- Frame mounted full-flow lube oil filter with inlet and outlet pressure gauges
- Lube oil strainer and stainless steel lube oil tubing with plated steel fittings
- Crankcase oil breather
- Oil level sightglass
- Force-feed lubricator pump(s) with block distribution system, cycle indicator / and no-flow shutdown(s), and stainless steel tubing with plated steel fittings for cylinders and packing. (See Compressor Cylinder Lube Oil System)
- Special wrenches and tools
- Instruction manual and parts lists in electronic format
- Mechanical running test with cylinders mounted

For cylinder information refer to M, P, SP, JG Cylinders.

JGN:JGQ Frames

ARIEL balanced/opposed, multi cylinder, gas compressor arranged for clockwise rotation when facing the drive end of the compressor (standing on the driver looking at the compressor). Designed for operation with appropriate engine, electric motor, turbine or other prime mover. Includes the following standard equipment:

- Heavy-duty, horizontal balanced/opposed, moisture and dust-proof compressor frame.
- Forged steel crankshaft.
- Precision insert tri-metal bearings.
- Strong, H-beam design forged steel connecting rods.
- Short close coupled guide is standard and integral with the compressor frame.
- Lubricating oil pump with system relief valve for full pressure lubrication to bearings and crossheads. (See Frame Lube Oil System)
- Manual lube oil priming pump is available as an option
- Frame mounted full-flow lube oil filter with inlet and outlet pressure gauges
- Lube oil strainer and stainless steel lube oil tubing with plated steel fittings
- Crankcase oil breather
- Oil level sightglass
- Force-feed lubricator pump(s) with block distribution system, cycle indicator / and no-flow shutdown(s), and stainless steel tubing with plated steel fittings for cylinders and packing. (See Compressor Cylinder Lube Oil System)

- Special wrenches and tools
- Instruction manual and parts lists in electronic format
- Mechanical running test with cylinders mounted

For cylinder information refer to M, P, SP, JG Cylinders.

JG:JGA Frames

ARIEL balanced/opposed, multi cylinder, gas compressor arranged for clockwise rotation when facing the drive end of the compressor (standing on the driver looking at the compressor). Designed for operation with appropriate engine, electric motor, turbine or other prime mover. Includes the following standard equipment:

- Heavy-duty, horizontal balanced/opposed, moisture and dust-proof compressor frame.
- Forged steel crankshaft
- Precision insert tri-metal bearings.
- Strong, H-beam design forged steel connecting rods
- Short close coupled guide standard. Short two compartment and long two compartment distance piece are available as an option
- Built-in crank end cylinder support
- Lubricating oil pump with system relief valve for full pressure lubrication to bearings and crossheads. (See Frame Lube Oil System)
- Manual lube oil priming pump is available as an option
- Frame mounted full-flow lube oil filter with inlet and outlet pressure gauges
- Lube oil strainer and stainless steel lube oil tubing with plated steel fittings
- Crankcase oil breather
- Oil level sightglass
- Force-feed lubricator pump(s) with block distribution system, cycle indicator / and no-flow shutdown(s), and stainless steel tubing with plated steel fittings for cylinders and packing.(See Compressor Cylinder Lube Oil System)
- Special wrenches and tools
- Instruction manual and parts lists in electronic format
- Mechanical run test with cylinders mounted

For cylinder information refer to M, P, SP, JG Cylinders.

JGM:JG:JGSP Cylinders

- Horizontal single or double acting, non-cooled compressor cylinders.
- Plugged indicator cock connections on the head-end and crank-end of most cylinders
- SAE series 4100 steel piston rods, ion-nitrided with rolled threads. 17-4PH stainless steel piston rods available as an option
- Pistons of scuff-resistant gray iron or ductile iron
- Non-metallic piston rings
- Pistons with piston/rider rings standard for 13-1/2JG and 1-3/4M-FS cylinders, and available as an option on all other M, P and JG cylinders. (See Piston Rings, Piston/Rider Rings & Wear Bands)
- Full floating, vented rod and wiper packings
- Profiled plate type valves with non-metallic valve plates.

JGR:JGJ Frames

ARIEL balanced/opposed, multi cylinder, gas compressor arranged for clockwise rotation when facing the drive end of the compressor (standing on the driver looking at the compressor). Designed for operation with appropriate engine, electric motor, turbine or other prime mover. Includes the following standard equipment:

- Heavy-duty, horizontal balanced/opposed, moisture and dust-proof compressor frame

- Forged steel crankshaft
- Precision insert tri-metal bearings
- Strong, H-beam design forged steel connecting rods
- Short close coupled guide standard. Short two compartment distance piece is available as an option. Long two compartment (Ariel design) distance piece, is available for JGW frames with 8-7/8W or R cylinders.
- Full floating, vented rod and wiper packings
- Lubricating oil pump with system relief valve for full pressure lubrication to bearings and crossheads. (See Frame Lube Oil System)
- Manual lube oil priming pump is available as an option
- Frame mounted full-flow lube oil filter with inlet and outlet pressure gauges
- Lube oil strainer and stainless steel lube oil tubing with plated steel fittings
- Crankcase oil breather
- Oil level sightglass
- Force-feed lubricator pump(s) with block distribution system, cycle indicator / and no-flow shutdown(s), and stainless steel tubing with plated steel fittings for cylinders and packing. (See Compressor Cylinder Lube Oil System)
- Special wrenches and tools
- Instruction manual and parts lists in electronic format
- Mechanical run test with cylinders mounted

For cylinder information refer to R, RJ Cylinders.

JGR:JGJ:JGE Cylinders

- Horizontal single or double acting, ion-nitrided, non-cooled compressor cylinders.
- Plugged indicator cock connections on the head-end and crank-end of most cylinders.
- SAE series 4100 steel piston rods, ion-nitrided with rolled threads. 17-4PH stainless steel piston rods available as an option
- Pistons of scuff-resistant gray iron or ductile iron
- Non-metallic piston/rider rings (Piston Rings, Piston/Rider Rings & Wear Bands)
- Full floating, vented rod and wiper packings
- Profiled plate type valves with non-metallic valve plates.

JGH Frame

ARIEL balanced/opposed, multi cylinder, air or gas compressor arranged for clockwise rotation when facing the drive end of the compressor (standing on the driver looking at the compressor). Designed for operation with appropriate engine, electric motor, turbine or other prime mover. Includes the following standard equipment:

- Heavy-duty, horizontal balanced/opposed, moisture and dust-proof compressor frame
- Forged steel crankshaft
- Precision insert tri-metal bearings
- Strong, H-beam design ductile iron connecting rods
- Long single compartment distance piece standard. short two compartment and long, two compartment (API-618 Type C) distance pieces are available as options.
- Lubricating oil pump with system relief valve for full pressure lubrication to bearings and crossheads. (Frame Lube Oil System)
- Manual lube oil priming pump is available as an option
- Frame mounted full-flow lube oil filter with inlet and outlet pressure gauges
- Lube oil strainer and stainless steel lube oil tubing with plated steel fittings
- Crankcase oil breather
- Oil level sightglass
- Force-feed lubricator pump(s) with block distribution system, cycle indicator / and no-flow shutdown(s), and stainless steel tubing with plated steel fittings for cylinders and packing. (Compressor Cylinder Lube Oil System)

- Special wrenches and tools
- Instruction manual and parts lists in electronic format
- Mechanical run test with cylinders mounted

For cylinder information refer to ET Cylinders.

JGE:JGT:JGK Frames

ARIEL balanced/opposed, multi cylinder, air or gas compressor arranged for clockwise rotation when facing the drive end of the compressor (standing on the driver looking at the compressor). Designed for operation with appropriate engine, electric motor, turbine or other prime mover. Includes the following standard equipment:

- Heavy-duty, horizontal balanced/opposed, moisture and dust-proof compressor frame
- Forged steel crankshaft
- Precision insert tri-metal bearings
- Strong, H-beam design forged steel connecting rods
- Long single compartment distance piece standard. short two compartment and long, two compartment (API-618 Type C) distance pieces are available as options.
- Lubricating oil pump with system relief valve for full pressure lubrication to bearings and crossheads. (Frame Lube Oil System)
- Manual lube oil priming pump is available as an option
- Frame mounted full-flow lube oil filter with inlet and outlet pressure gauges
- Lube oil strainer and stainless steel lube oil tubing with plated steel fittings
- Crankcase oil breather
- Oil level sightglass
- Force-feed lubricator pump(s) with block distribution system, cycle indicator / and no-flow shutdown(s), and stainless steel tubing with plated steel fittings for cylinders and packing. (Compressor Cylinder Lube Oil System)
- Special wrenches and tools
- Instruction manual and parts lists in electronic format.
- Mechanical run test with cylinders mounted

For cylinder information refer to ET Cylinders and T, K Cylinders.

KBK:KBT Frames

ARIEL balanced/opposed, multi cylinder, air or gas compressor arranged for clockwise rotation when facing the drive end of the compressor (standing on the driver looking at the compressor). Designed for operation with appropriate engine, electric motor, turbine or other prime mover. Includes the following standard equipment:

- Heavy-duty, horizontal balanced/opposed, moisture and dust-proof compressor frame
- Forged steel crankshaft
- Precision insert tri-metal bearings
- Strong, H-beam design forged steel connecting rods
- Long single compartment distance piece standard. Long, two compartment (API-618 Type C) distance piece is available as an option.
- Lubricating oil pump with system relief valve for full pressure lubrication to bearings and crossheads. (Frame Lube Oil System)
- Frame mounted full-flow lube oil filter with inlet and outlet pressure gauges
- Lube oil thermostatic valve integrally mounted to frame oil filter header
- Lube oil strainer and stainless steel lube oil tubing with plated steel fittings
- Crankcase oil breather
- Oil level sightglass
- Force-feed lubricator pump(s) with block distribution system, cycle indicator / and no-flow shutdown(s), and stainless steel tubing with plated steel fittings for cylinders and

packing. (Compressor Cylinder Lube Oil System)

- Special wrenches and tools
- Instruction manual and parts lists in electronic format.
- Mechanical run test with cylinders mounted

For cylinder information refer to T, K Cylinders.

K:T:C:D:Z:U:B:V Cylinders

- Horizontal single or double acting, ion-nitrided, non-cooled compressor cylinders.
- Plugged indicator cock connections on the head-end and crank-end of most cylinders.
- Standard and pipeline cylinders available.
- SAE series 4100 steel piston rods, ion-nitrided with rolled threads. 17-4PH stainless steel piston rods available as an option
- Pistons of scuff-resistant gray iron or ductile iron
- Non-metallic piston rings
- One-piece, angle cut, non-metallic wear bands. (Piston Rings, Piston/Rider Rings & Wear Bands)
- Full floating, vented rod and wiper packings
- Profiled plate type valves with non-metallic valve plates.

JGC:JGD:JGF Frames

ARIEL balanced/opposed, multi cylinder, gas compressor arranged for clockwise rotation when facing the drive end of the compressor (standing on the driver looking at the compressor). Designed for operation with appropriate engine, electric motor, turbine or other prime mover. Includes the following standard equipment:

- Heavy-duty, horizontal balanced/opposed, moisture and dust-proof compressor frame
- Forged steel crankshaft
- Precision insert tri-metal bearings
- Strong, H-beam design forged steel connecting rods
- Long single compartment distance piece standard. Short two compartment and long, two compartment (API-618 Type C) distance pieces are available as options.
- Lubricating oil pump with system relief valve for full pressure lubrication to bearings and crossheads. (Frame Lube Oil System)
- Frame lube oil priming pump, electric motor driven, supplied by Packager
- Frame mounted lube oil filter with inlet and outlet pressure gauges
- Lube oil strainer and stainless steel lube oil tubing with plated steel fittings
- Crankcase oil breather
- Oil level sightglass
- Force-feed lubricator pump(s) with block distribution system, cycle indicator / and no-flow shutdown(s), and stainless steel tubing with plated steel fittings for cylinders and packing. (Compressor Cylinder Lube Oil System)
- Special wrenches and tools
- Instruction manual and parts lists in electronic format
- Mechanical run test with cylinders mounted

For cylinder information refer to C, D, F Cylinders.

KBZ:KBU Frames

ARIEL balanced/opposed, multi cylinder, gas compressor arranged for clockwise rotation when facing the drive end of the compressor (standing on the driver looking at the compressor). Designed for operation with appropriate engine, electric motor, turbine or other prime mover. Includes the following standard equipment:

- Heavy-duty, horizontal balanced/opposed, moisture and dust-proof compressor frame
- Forged steel crankshaft
- Precision insert tri-metal bearings

- Main bearing temperature devices
- Strong, H-beam design forged steel connecting rods
- Long single compartment distance piece standard. Long two compartment (API-618 Type C) distance pieces are available as an option.
- Lubricating oil pump with system relief valve for full pressure lubrication to bearings and crossheads. (Frame Lube Oil System)
- Frame lube oil priming pump, electric motor driven, supplied by Packager
- Frame mounted lube oil filter with inlet and outlet pressure gauges
- Lube oil strainer and stainless steel lube oil tubing with plated steel fittings
- Crankcase oil breather
- Oil level sightglass
- Force-feed lubricator pump(s) with block distribution system, cycle indicator / and no-flow shutdown(s), and stainless steel tubing with plated steel fittings for cylinders and packing. (Compressor Cylinder Lube Oil System)
- Special wrenches and tools (Hydraulic tools and pumps are required and priced separately)
- Instruction manual and parts lists in electronic format
- Mechanical run test with cylinders mounted

For cylinder information refer to Z, U Cylinders.

KBB:KBV Frames

ARIEL balanced/opposed, multi cylinder, gas compressor arranged for clockwise rotation when facing the drive end of the compressor (standing on the driver looking at the compressor). Designed for operation with the appropriate engine, electric motor, turbine, or other prime mover. Includes the following standard equipment:

- Heavy-duty, horizontal balanced/opposed, moisture and dust-proof compressor frame
- Forged steel crankshaft with integral flanged crankshaft hub
- Precision insert tri-metal bearings
- Main bearing temperature devices
- Strong, H-beam design forged steel connecting rods
- Long single compartment distance piece standard. Long two compartment (API-618 Type C) distance pieces are available as an option.
- Lubricating oil pump with system relief valve for full pressure lubrication to bearings and crossheads. (Frame Lube Oil System)
- Frame lube oil priming pump, electric motor driven, supplied by Packager
- Frame mounted lube oil filter with inlet and outlet pressure gauges
- Lube oil strainer and carbon steel lube oil piping with steel flanges
- Crankcase oil breather
- Oil level sightglass
- Force-feed lubricator pump(s) with block distribution system, cycle indicator / and no-flow shutdown(s), and stainless steel tubing with plated steel fittings for cylinders and packing. (Compressor Cylinder Lube Oil System)
- Special wrenches and tools (Hydraulic tensioning tools and pumps are required and priced separately)
- Instruction manual and parts lists in electronic format
- Mechanical run test with cylinders mounted

For cylinder information refer to B, V Cylinders.

JGI Standard Equipment

Ariel, vertical single throw air or gas compressor arranged for counter-clockwise rotation when facing the drive end of the compressor (looking at the compressor crankshaft stub) and designed for operation with appropriate engine, motor, belt drive arrangement, with standard equipment including:

- Heavy duty, vertical, moisture and dust proof compressor frame
- Gray Iron crankshaft
- Strong, H-beam design connecting rods
- Vertical, single or double acting non-cooled compressor cylinders
- Short, close coupled distance piece
- Lubricating oil pump with system relief valve for full pressure lubrication to bearings and crosshead
- Manual lube oil priming pump is available as an option
- Frame mounted full-flow lubricating oil filter with in and out pressure gages
- Lube oil strainer and stainless steel lube oil tubing with plated steel fittings
- Crankcase oil breather
- Oil level sight glass
- Force feed lubricator with distribution block system, cycle indicator/electric no-flow shut-down switch, and stainless steel tubing with plated steel fittings for cylinders and packing
- Special wrenches and tools
- Instruction manual and parts lists in electronic format
- Mechanical running test with cylinder mounted

JGI Unbalanced Forces and Moments

Based upon 800 rpm operation, largest available cylinder bore:

	Primary	Secondary
Horizontal force, lbs	260	0
Horizontal couple, lbs	0	0
Vertical force, lbs	1520	380
Vertical couple, lb-ft	0	0

Tools

Ariel compressors are provided with special tools, and have a number of optional tools available. All available tools are listed in the Ariel performance software to allow separate purchase. Details on the special tools, and what is included or recommended for each frame or tool option, can be found on the Ariel website within the Maintenance and Repair Manuals.

Ariel compressors are built with some special tool requirements. Special tools that are not available through standard tool suppliers are provided by Ariel with each compressor.

Some compressor frames require (or recommend) the use of hydraulic tensioning devices. As these may be needed for each site, rather than each compressor frame, they are provided as an optional purchase.

Ariel compressors are built using SAE fasteners. As SAE tools are not readily available in all installation locations, an option to provide SAE tools is available in the Ariel performance software.

Further information on Special Tools can be found on the Ariel website within the Maintenance and Repair Manuals.

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.

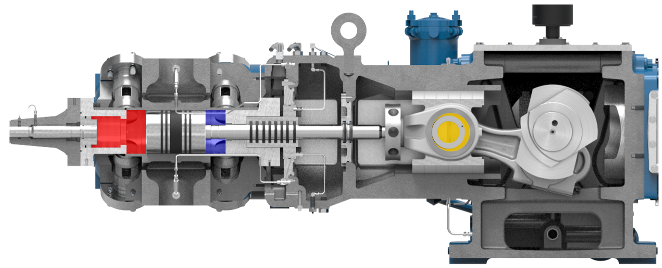
When no other flags exist, a good practical limit for the higher end of the compression ratio range is 4.5 ratios. A warning has been placed in the performance software to flag this ratio to help draw attention to the possible difficulties. When this warning flag occurs, the specific application must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

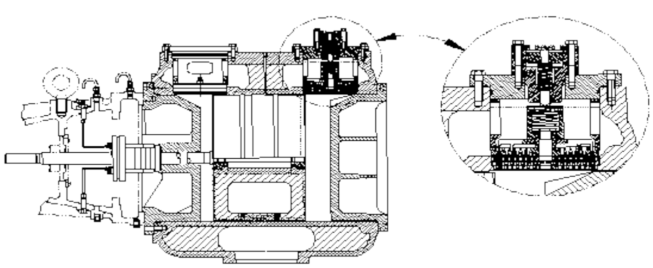
Removing Suction Valves to Single Act

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.

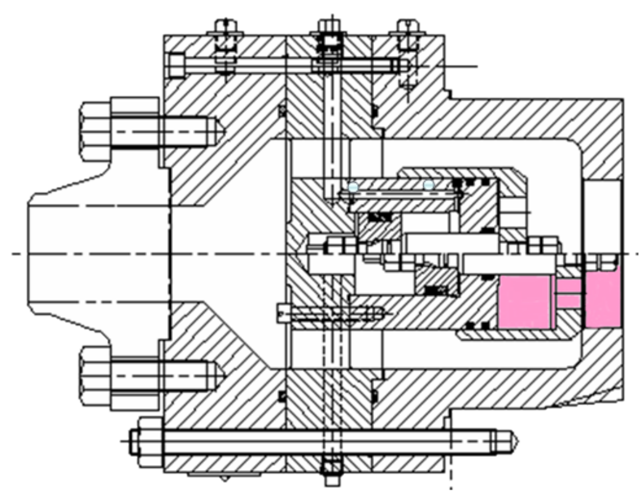


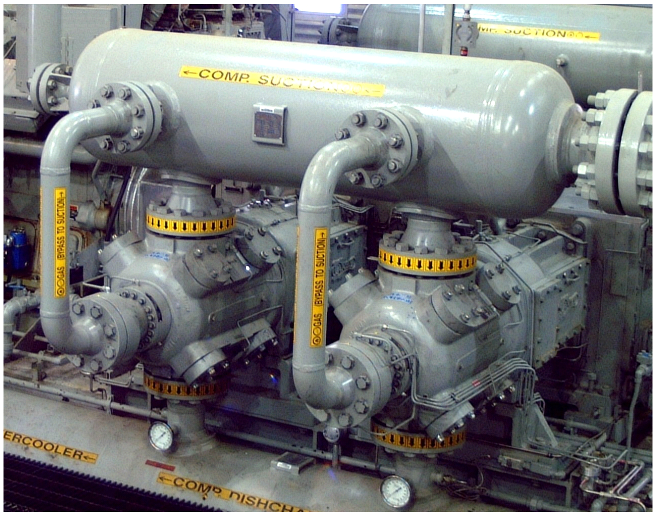
In order to maintain proper rod load reversal, the head end of the cylinder is usually deactivated. This will help maintain rod load reversal due to the differential areas between the crank end and the head end of the cylinder (due to the rod area in the crank end). In some cases it is possible to deactivate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

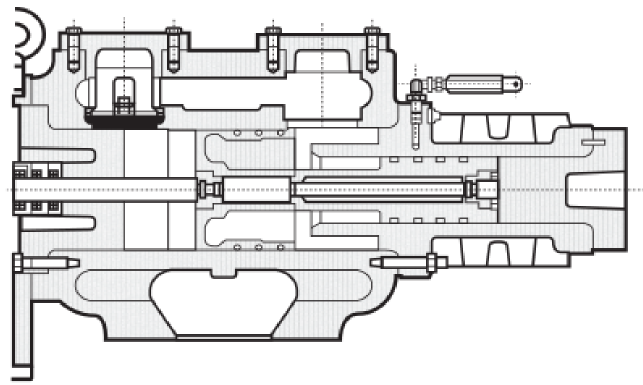
Some restrictions may apply to operating a cylinder single acting at higher speeds. The performance software should flag higher speed single acting conditions that require review and approval.

Cylinder Action, Tandem

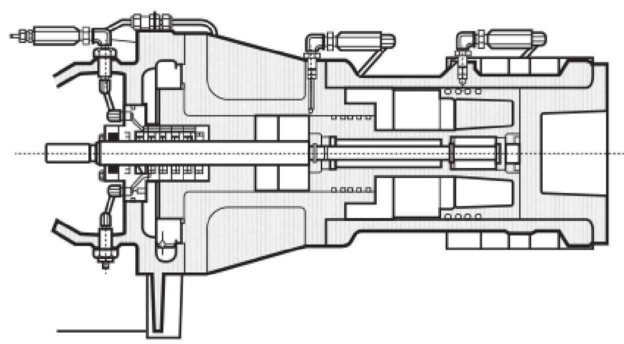
Tandem cylinders are two cylinders on the same throw. The inboard cylinder may be the high pressure or low pressure cylinder, and is single acting on the crank end only. The outboard cylinder may also be the high pressure or low pressure cylinder, and is single acting on the head end only.

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.

Tandem Cylinder, High Pressure Cylinder Outboard



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;

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

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:

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

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. $\frac{P_1 V_1}{Z_1 T_1} = \frac{P_2 V_2}{Z_2 T_2}$

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.

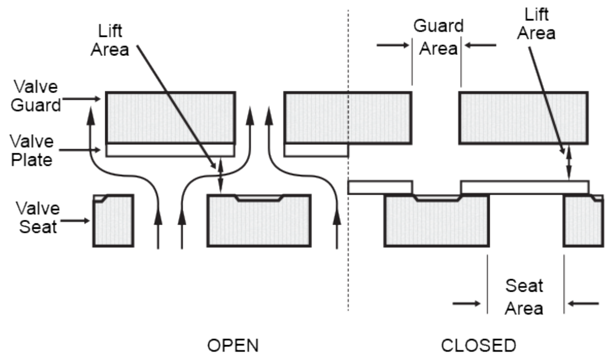
REDUCED PRESSURE is the ratio in absolute units of the actual gas pressure to the critical pressure. Pseudo - reduced pressure is the ratio in absolute units of a gas mixtures actual pressure to its pseudo - critical pressure.

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.

Calculations

Ariel Calculation Method

The Ariel Performance Software includes calculations for predicting the flow, power, temperatures, pressures, gas rod loads, crosshead pin load reversals as well as other values for the predictions and limitations of the compressor applications. The following outlines the general methods and some of the equations applied for Ariel reciprocating compressors.

Pressures:

Operating pressures are calculated allowing user input pressure losses prior to, after and between stages of compression. Ariel includes a typical pressure loss for the interstage and final discharge pressure losses. Typical values are:

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%	

Operating pressures at each stage are expressed in the term Compression Ratio. Depending upon the use of this term, it may be defined at the cylinder flange pressures or the internal pressures. Compression ratio is the discharge pressure divided by the suction pressure (in absolute pressure units).

Interstage flange pressures are determined by balancing the flow of gas through each stage (expressed in standard, not actual volume). Gas added through side streams or removed through side streams or condensate from each stage is considered.

Pressures inside the cylinder consider pressure losses through the cylinder gas passages and valves. Many of the calculations apply the use if internal pressures rather than flange to flange pressures. Cylinder and valve pressure losses are a function of the gas density and gas velocity through the cylinder gas passages and valves.

Temperatures:

Discharge temperature after each stage of compression is a function of the gas properties (k-value, or N-value), internal compression ratio and suction temperature. Suction temperature at each stage is user defined. The internal suction temperature may include a preheat value, depending upon the inlet gas temperature and discharge gas temperature.

- Discharge Temperature (initial estimate using flange ratio): $Tdi = Tsi\,(Ri)^{\frac{k-1}{k}}$
- Suction Temperature Preheat: Tsph = Ts + [(0.02 + (0.002 x Cyl bore)) x (Tdi - Ts)]
- Discharge Temperature: Td = Tsph x (Rint-ernal)^((k-1)/k)

Flow:

Flow is a function of the piston displacement and the volumetric efficiency. The piston displacement is the piston area times the length of stroke times the rpm. Both ends of a double acting cylinder are included in this calculations, with the crank end considering the loss of piston area due to the piston rod. Flow is calculated on a per end basis.

$$Q = VE \times PD \times \left(\frac{Ps}{Zs}\right) \times \text{number of cylinders} \times 10^{-6}$$

As Q is actual flow, it is often converted to be expressed in standard flow units.

Volumetric Efficiency:

Volumetric efficiency includes many factors that help explain the differences between ideal gas behavior and real gas behavior. In general, volumetric efficiency depends upon compression ratio, cylinder clearances, gas compressibility values and the ratio of specific heats (k or N value). A common representation of volumetric efficiency is:

$$VE = \frac{98 - R}{100} - CL\left[\left(\frac{Z_s}{Z_d}\right)R^{\frac{1}{n}} - 1\right]$$

Power:

Power is calculated through a power per unit flow equation, multiplied by the flow. Calculated power will include the power of compression, plus mechanical inefficiencies, plus frame friction power. Internal power of compression equations include:

$$IHP / MM = 43.6\left(\frac{k}{k-1}\right)\left(Rint^{\frac{k-1}{k}} - 1\right) \times Za$$

CHP = Q x (IHP/MM)/ Mech Eff + Friction power.

Mechanical Efficiency is near 0.95, offering a 5% loss for mechanical inefficiencies of the cylinders. Friction power loss is dependent upon the frame size.

Gas Rod Load:

Ariel calculates gas rod load based upon internal cylinder pressures. The equations below are based upon pressures in gauge units. If absolute units are applied, then additional terms for Patm being applied on the piston rod diameter must be included.

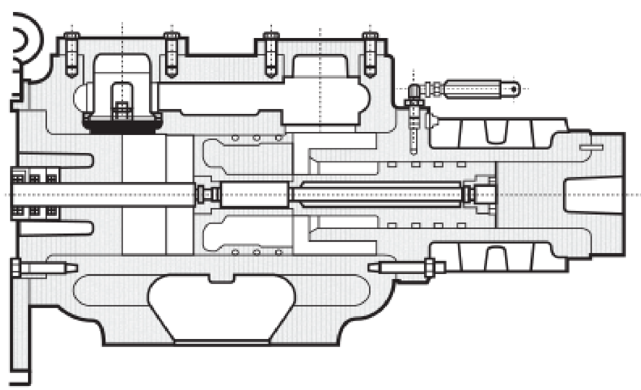
Double Acting Cylinders

- RLc = Ahe x Pdi - Ace x Psi
- RLt = Ace x Pdi - Ahe x Psi

Single Acting Crank-End Cylinders

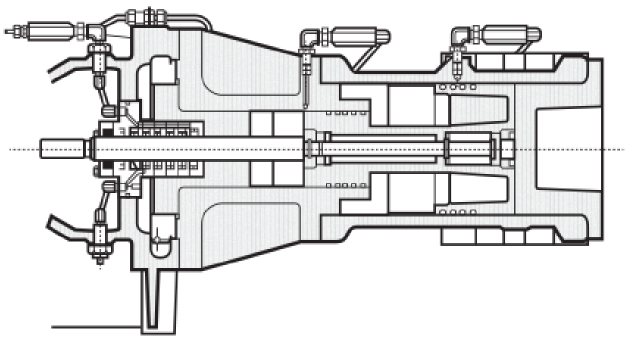
- RLc = Ahe x Pdihe - Ace x Psi
- RLt = Ace x Pdi - Ahe x Psihe

Tandem Cylinders - (High Pressure Cylinder Outboard)



- RLc = Ahe(HP) x Pdi(HP) +[Ahe((LP) - Ahe(HP)] x Psflg(LP) - Ace(LP) x Psi(LP)
- RLt = Ace(LP) x Pdi(LP) - [Ahe(LP) - Ahe(HP)] x Psflg(LP) - Ahe(HP) x Psi(HP)

Tandem Cylinders - (High Pressure Cylinder Inboard)



- RLc = Ahe(LP) x Pdi(LP) - [Ahe(LP) - Ahe(HP)] x Psflg(LP) - Ace(HP) x Psi(HP)
- RLt = Ace(HP) x Pdi(HP) + [Ahe(LP) - Ahe(HP)] x Psflg(LP) - Ahe(LP) x Psi(LP)

Since Gas Rod Load is calculated using internal pressures, the pressure losses through the cylinder gas passages and valves must be applied to the cylinder flange pressures. Pressure losses are calculated using the gas velocity at the suction and discharge. Gas velocities are calculated based upon the flow areas of the gas passages and valves. Flow areas are available through the Performance Software cylinder data sheets.

Psi = Psflg x ((100 - PLs)/100)

Pdi = Pdflg x ((100 + PLd)/100)

Rint = Pdi / Psi

$$PLs = \left[\frac{(GVs)^2}{6.55 \times 10^6}\right] \times \frac{SG}{Zsi} \times \frac{520}{Tsi}$$

$$PLd = \left[\frac{(GVd)^2}{4.55 \times 10^6}\right] \times \frac{SG}{Zd} \times \frac{520}{Td}$$

$$Avc = \left[\frac{1}{(AV)^2} + \frac{1}{(AC)^2}\right]^{-\frac{1}{2}} \text{ (HE or CE Suction or Discharge)}$$

$$\text{GVs or GVd} = \frac{\text{Piston Area, in}^2 \text{ (HE or CE)} \times \text{Piston Speed, fpm}}{\text{Avc, in}^2 \text{ (HE or CE) Suction or Discharge/Corner}}$$

Definitions / Units

Area units are in square inches.

Diameter and stroke units are in inches.

Gas velocity units are in feet per minute

Pressure units are in psia for ratio calculations and psig for rod load calculations.

Temperature units are in Rankine.

Power units are in hp.

Flow units are in MMCFD, actual for Q and standard for Flow.

Clearance values are in percent.

Pressure loss is expressed in percent.

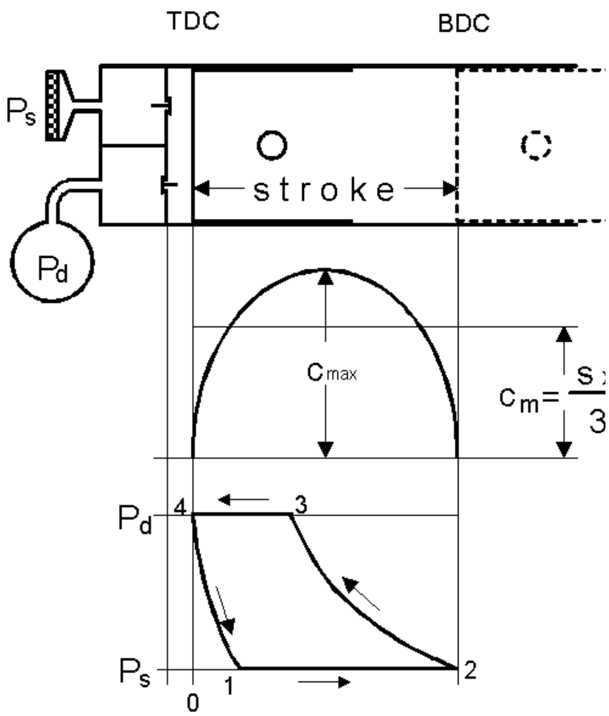
Compressor Theory

Ideal P-V Diagram

Given the laws governing and definitions describing gas behavior, let us look at how they are applied to a typical reciprocating compressor cycle. One of the preferred tools for analyzing compressor performance is the Pressure-Volume (P-V) diagram. The P-V diagram which is to be discussed here depicts the relationship of the pressure and volume of the gas within one end of a cylinder of a reciprocating compressor to the displacement of the piston. To start with we will look at an ideal P-V diagram in which there are no valve losses and the compression is adiabatic.

1. Suction valve opens and gas is drawn into the cylinder (1 - 2).
2. Suction valve closes and gas compression begins (2 - 3).
3. Discharge valve opens and the compressed gas is discharged from the cylinder (3 - 4).

4. Discharge valve closes. Note that a gap is shown in this diagram between zero volume and the volume at position 4. This represents the clearance volume in the cylinder. As the piston begins its return stroke, the gas which remains in this space re-expands (4 - 1).



Effect of Clearance Volume on Capacity

Gas is trapped in the clearance volume after each stroke. This volume of gas must be re-expanded before gas at suction conditions is admitted into the cylinder to be compressed.

Effect of Clearance Volume

The re-expansion of the gas trapped at the end of the discharge cycle does not influence the horsepower losses but has a direct effect on the volumetric efficiency of the cylinder. Figure: Effect of Clearance Volume shows two P-V curves with different clearance volumes superimposed. The opening positions of the valves change dramatically. With the higher clearance volume the volumetric efficiency is considerably lower but so is the horsepower consumption.

$$VE_s = 100 - CL\% \left[\left(\frac{P_d}{P_s} \right)^{\frac{1}{k}} - 1 \right]$$

$$VEd = \frac{VEs}{\left[\frac{Z_s}{Z_d} \left(\frac{P_d}{P_s} \right)^{\frac{1}{k}} \right]}$$

Pd = discharge pressure [psia]

Ps = suction pressure [psia]

CL% = clearance volume in %

k = effective cylinder isentropic exponent

Figure: PV vs Clearance

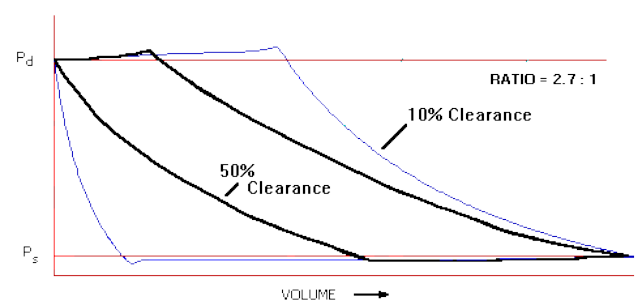
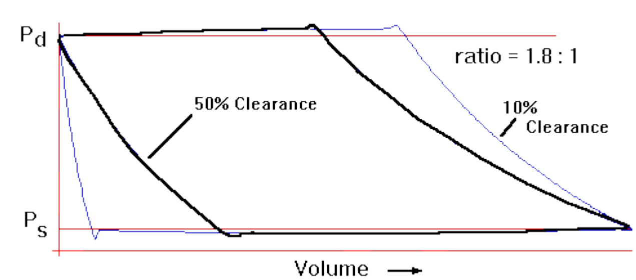


Figure: PV vs Clearance Low Ratio



Clearance Volume - Low Ratio

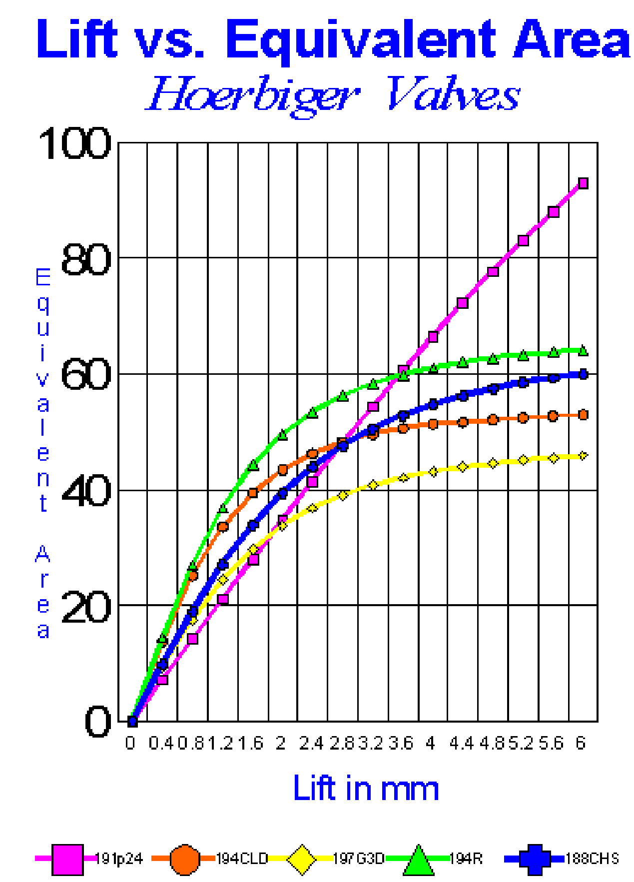
In applications where the compression ratio is relatively small, the extra clearance volume has a lesser effect on the volumetric efficiency. The reason for this is demonstrated in Figure: Effect of Clearance Volume and Figure PV vs Clearance Low Ratio. In Figure: PV vs Clearance Low Ratio an application with a 2.7:1 compression ratio is shown with clearance volumes of 10% and 50%. With more clearance volume, the piston must travel farther in its compression stroke before the cylinder pressure exceeds the discharge line pressure enough to open the discharge valve. The discharge volumetric efficiency (VEd) decreases and can be reduced to a point (especially in high-speed machines) where the compressed gas cannot be discharged quickly enough and the valve is forced to close late. A similar reduction in volumetric efficiency, and therefore incapacity, can be expected on the suction valve when the clearance volume is increased.

Adjusted Equivalent Valve Area

Adjusted equivalent valve area is a measure of the effective orifice area of the complete valve assembly. The equivalent area is a static measure and does not assure good dynamic behavior of the valve. 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.

Equivalent area is a function of valve lift and port area. Increasing lift or port area increases equivalent area. However, higher lift valves generally have a shorter life than lower lift valves--thus the trade-off between efficiency and durability

Below is a comparison of lift vs. equivalent area for several valves.



Piston Rod Root Stress

Piston rod root stress is used to design the appropriate piston rod attachment preload levels. Ariel piston rod to crosshead nut preload levels are 30,000 psi. This is well above 1-1/2 times the root stress potential from inertia and gas loading. Ariel does not publish a limit based upon piston rod root stress.

Root areas for Ariel frames are below:

Frame Model	Rod Diameter (in)	Crosshead Thread Pitch	Thread Root Area (in^2)
JGM:N:P:Q	1-1/8 inch	1"-12	0.625 in^2
JG / JGA	1-1/8 inch	1"-12	0.625 in^2
JGW:R:J	1-1/2 inch	1-3/8"-12	1.260 in^2
JGH:E:K:T KBK:T	2 inch	1-3/4"-12	2.120 in^2
JGC:D:F	2-1/2 inch	2-1/4"-8	3.420 in^2
KBZ:U	2-7/8 inch	2-5/8"-8	4.76 in^2
KBB:V	3-1/8 inch	2-7/8"-8	5.780 in^2

Unit Conversions -Flow

Multiply units in left column by proper factor below.

Units of Flow	MMSCFD	Sm^3/hr	Nm^3/hr
1 MMSCFD @14.7 psia & 60oF	1	1179.87	1116.28
1 Sm^3/hr @1.0135 BarA & 15oC	0.0008476	1	0.9461
1 Nm^3/hr @1.0135 BarA & 0oC	0.0008958	1.0569	1

Flow Units: CFM -Cubic feet per minute.

ACFM -Actual cubic feet per minute (pressure and temperature condition must also be stated)

ICFM -Inlet cubic feet per minute based upon the inlet pressure and temperature at the cylinder flange.

SCFM -Standard cubic feet per minute is gas flow measured at standard conditions (14.7 psia & 60 °F).

MMSCFD -Million standard cubic feet per day is million cubic feet of gas per day measured at standard conditions (14.7 psia & 60 °F). (not to be confused with MSCFD, 1000 SCFD)

Sm^3/hr -Standard cubic meters per hour, measured at standard metric conditions(1 Atm & 15 °C). Used primarily in Canada, South America, and New Zealand

Nm^3/hr -Normal cubic meters per hour, measured at normal metric conditions (1 Atm & 0 °C). Used primarily in Europe.

Unit Conversions - Volume

Multiply units in left column by proper factor below.

Units of Volume	cu.in.	cu.ft.	cu.meter	liter	US.gal	Imp. gal
1 cu.inch	1	0.00058	0.0000164	0.0164	0.0043	0.0036
1 cu.foot	1728	1	0.0283	28.32	7.481	6.229
1 cu.meter	61,023	35.31	1	1000	264.2	220
1 liter	61.025	0.0353	0.0010	1	0.2642	0.220
1 US. gal	231	0.1337	0.0038	3.785	1	0.8327
1 Imp. gal	277.4	0.1605	0.0045	4.546	1.201	1

Unit Conversions - Power

Multiply units in left column by proper factor below.

Units of Power	hp	kw
1 horsepower	1	0.7457
1 kilowatt	1.3410	1

Unit Conversions - Pressure

Multiply units in left column by proper factor below.

Units of Pressure	psi	atm	kg/sq.cm.	kPa	bar
1 pound/sq.in.	1	0.06805	0.0703	6.89476	0.06895
1 atmosphere	14.696	1	1.0332	101.325	1.01325
1 kilogram/sq. cm.	14.223	0.9678	1	98.066	0.98066
1 kilopascal	0.14504	0.009869	0.010197	1	0.01
1 bar	14.504	0.9869	1.0197	100	1

Unit Conversions - Length

Multiply units in left column by proper factor below.

Units of Length	in	ft	mm	cm	m
1 inch	1	0.0833	25.4	2.54	0.0254
1 foot	12	1	304.8	30.48	0.3048
1 millimeter	0.394	0.00328	1	0.1	0.001
1 centimeter	0.3937	0.03281	10	1	0.01
1 meter	39.37	3.281	1000	100	1

Unit Conversions - Weight

Multiply units in left column by proper factor below.

Units of Weight	lbs	ton	kg	metric ton
1 pound	1	0.0005	0.4535	0.00045
1 ton	2000	1	907	0.907
1 kilogram	2.205	0.0011	1	0.001
1 metric ton	2205	1.102	1000	1

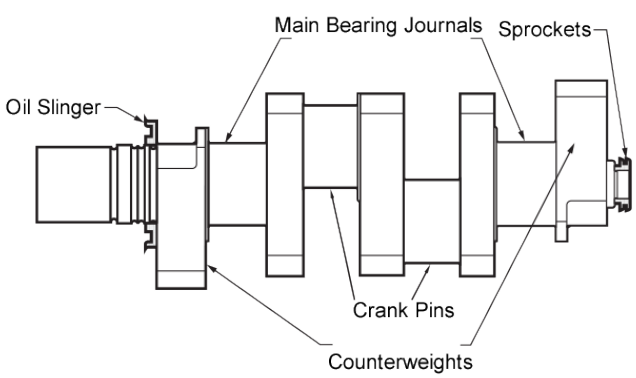
Compressor

A compressor is the combination of a frame and cylinders. A complete compressor is provided with a properly sized cylinder lube distribution system and balance components.

Frame

The main components of a compressor frame include the base casting, crankshaft, connecting rods, crossheads, and crosshead guides. An example of a four throw Ariel frame would be a JGK/4.

Crankshafts



Ariel two throw and four throw Compressor frames utilize integral counterweights to minimize horizontal couples.

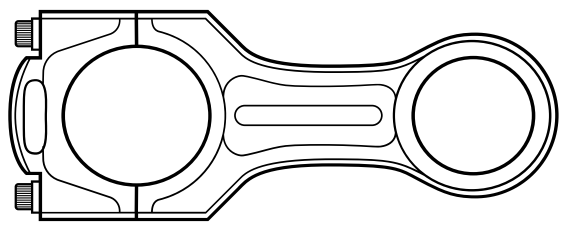
Ariel two throw and four throw Compressor frames utilize integral counterweights to minimize horizontal couples.

Ariel Crankshafts are precision machined of forged steel with a keyless shaft end.

JGE/6, JGK/6, JGT/6, KBB, and KBV frames have integral flanged crankshafts.

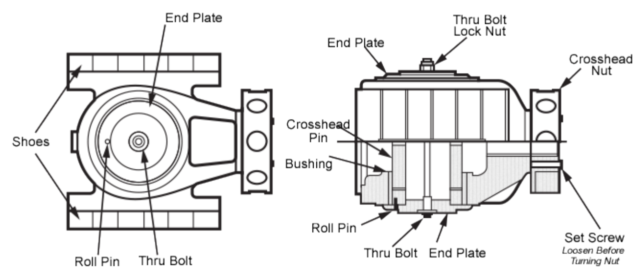
Connecting Rods

Ariel Connecting Rods are machined from forged steel in all frames except for JGM,JGP, and JGH, which are made of ductile iron.



Crossheads

Ariel uses one piece crossheads with full top and bottom lubrication. Crossheads are ductile iron with babbitted sliding surfaces, except for the JGM and JGP which are gray iron without babbitted surfaces. Heavier crossheads, used to balance larger opposing weights, can be provided in bronze.



Full floating alloy steel crosshead pins are used in Ariel frames; all frames except for the JGM, JGP, and JGH have bronze crosshead pin bushings.

Inadequate rod load reversal can result in lack of lubrication to the crosshead pin and consequent failure.

Crossheads and crosshead nuts of varying weight are available to facilitate proper frame balance. Balance crossheads are available to balance opposite blank throws.

Frame Lube Oil System

For frame oil system lubricants, viscosities, temperatures, and recommendations refer to the Ariel Packager Standards Section 6.0.

Frame Driven Lube Oil Pumps

The frame lube oil pump is driven by the chain drive system at the auxiliary end of the frame. The lube oil pump sprocket and the crankshaft sprocket are sized so that the pump is running at the correct speed when the frame is running at rated speed.

Oil pump discharge pressure is held nearly constant by a spring loaded regulating valve within the pump head. Lube system pressure can be raised or lowered by adjusting this valve. Normal pressure on the discharge side of the lube oil filter is set at the factory at 60 PSI when the crankshaft speed is greater than half rated speed. If oil pressure drops below 50 PSI, the reason should be found.

The larger frames, KBU:Z and KBB:V, utilize an external pressure relief valve located downstream of the lube oil filter. The external pressure relief valve is used to set the system pressure. The regulating valve located on the main lube oil pump is to be set fully closed.

If the crankshaft speed is less than 50%, there will not be enough flow through the pump to maintain proper lube oil pressure to the frame - an auxiliary lube oil pump will be needed.

The frame oil pump may require removal due to torsional vibration concerns. Please refer to the Auxiliary End Pump Removal topic for further information.

Aux End Pump Removal

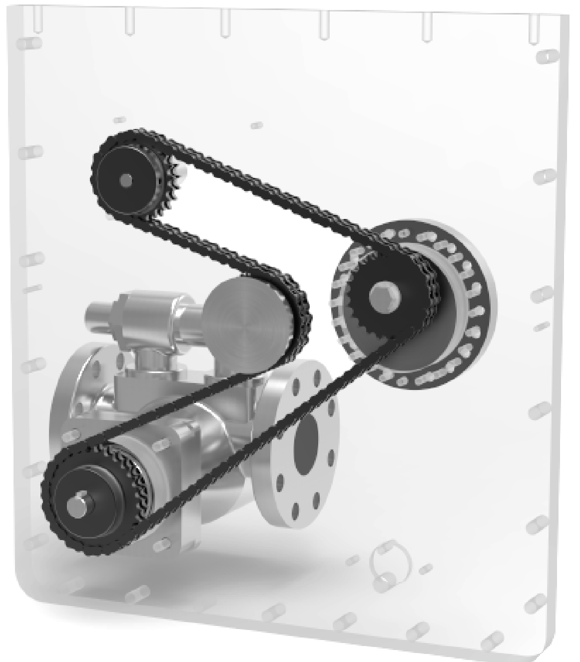
Both the frame oil pump and the cylinder force feed lubricator pump(s) are located on the auxiliary end of the compressor frame. These may be removed, and electric motor driven, for various reasons.

Ariel offers an electric motor driven cylinder force feed lubricator pumps in place of the chain driven cylinder force feed lubricator pumps. This option is for two purposes; for customer preference and for torsional considerations at the auxiliary end of the compressor.

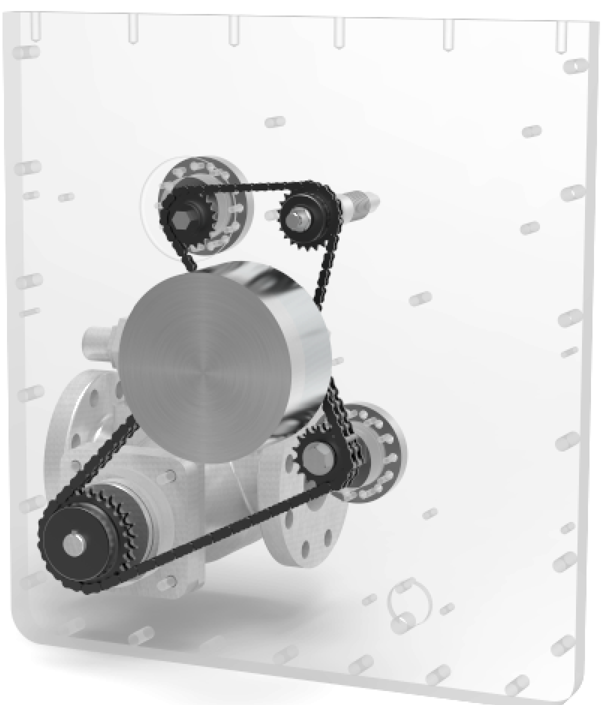
If this is for a torsional consideration, both the cylinder force feed lubricator pump and the frame oil pump must be removed from the auxiliary end.

Some frames utilize a single chain for both the cylinder force feed lubricator pumps and the frame oil pump. Larger frames utilize a dual chain, one for each pump system. When the electric motor drive cylinder force feed lubricator pump option is purchased and the frame uses a single chain system, a fully functional lube box, without lubricator pumps, will remain as a chain idler where the cylinder force feed lubricator pumps were located.

Single Chain Drive



Dual Chain Drive



Frame	Throws	Chain Configuration
JG, JGM:N:P:Q:A:R:J	All	Single
JGH:E:K:T	2,4	Single
JGE:K:T	6	Dual
JGC:D:F	2,4	Single
JGC:D:F	6	Dual
KBZ:U:B:V, JGZ:U:B:V	All	Dual

Ariel offers an option for Pumps Removed, No Chain Drive System. This option is for both customer preference and for torsional considerations. If the chain drive system is removed from the auxiliary end of the compressor, the electric motor driven cylinder force feed lubricator pump option must be purchased. The frame oil pump will be removed along with the chain system and will not be provided (packager must provide electric driven frame oil pump assembly).

Operation below half of the frame max rated speed does not require a separately driven cylinder force feed lubricator pump. When the compressor speed is reduced, the cylinder lubrication demand reduces and matches the cylinder force feed lubricator pump supply at the reduced speeds. Operation below half of the frame max rated speed does require additional frame oil supply flow, through a separate auxiliary frame oil pump, provided by the Packager.

When the cylinder force feed lubricator pumps are electric motor driven and the compressor is driven by a VFD motor, consideration should be given to operating the electric motor driven cylinder force feed lubricator with a VFD. The cylinder lubrication demand varies directly with the operating speed of the compressor.

Pumps can be removed during packaging or after field installation if necessary. Ariel offers blind cover plates for the different pump locations. For a single chain system, both the cylinder force feed lubricator pump and frame oil pump must be removed as idler sprockets are not available.

Pre-lube Requirements

Ariel offers a manual lube oil priming pump for the JGI, JGM, JGP, JGN, JG, JGQ, and JGA frames (unmounted) as an option and the JGW, JGR, JGJ, JGH, JGE, JGK, and JGT frames (mounted) as an option.

JGC, JGD, JGF, KBZ, KBU, KBB, and KBV frames must be equipped with a motor driven pre-lube pump. A priming pump is not provided by Ariel for these frames.

Refer to Section 6 of the Packager Standards for information regarding the sizing of the pre-lube pump.

Lube Oil Filter

All Ariel frames require full flow filtration.

All Ariel frames with exception of KBU:Z/2, JGC:D:F:Z:U:KBB:V/4 and JGE:K:T:C:D:F:KBZ:U:B:V/6 are equipped with simplex, spin-on, pleated paper type filters. These spin on filters have a nominal filtration of 5 micron. The filter headers are equipped with pressure gauges to determine pressure drop across the filter. Ariel recommends replacing the filter element when the differential pressure across the filter reaches 10 psid at normal temperatures or at six month intervals (or 4000 hours, whichever comes first).

The KBU:Z/2, JGC:D:F:KBZ:U:B:V/4 and JGE:K:T:C:D:F:KBZ:U:B:V/6 frames are equipped with a simplex, cartridge style, pleated paper type filters. The nominal filtration is 1 micron. The filter housings are equipped with pressure gauges to determine pressure drop across the filter. Ariel recommends replacing the filter element when the differential pressure across the filter reaches 15 psid at normal temperatures or at six month intervals (or 4000 hours, whichever comes first).

Duplex lube oil filters with continuous flow transfer valves can be provided as an option. Duplex filters are to be mounted separately (not directly attached to the frame by Ariel), the original simplex filter must remain on the frame, operating in series downstream of the duplex filter. Duplex filter nominal filtration levels will match the frame mounted simplex filters noted above (5 micron on the smaller frames and 1 micron on the larger frames)

Lube Oil Cooler

Each lube oil system must be equipped with a lube oil cooler to maintain the proper temperature of the lube oil before it is supplied to the bearings. Maximum allowable oil temperature to the frame is 190°F (88°C). Thermostat temperature should be set at 170°F (77°C). The cooler should be as close as possible to the compressor, and the piping of adequate size to minimize pressure drop below 10 psi.

Ariel offers an unmounted shell and tube lube oil cooler as an option. Based on 140 deg F water in the tube side at a 2:1 oil to water flow ratio the following coolers can be used. Contact Application Engineering for specific cooler applications. Less available water flow may require a larger cooler than specified.

Warmer ambient temperatures, and within enclosed engine rooms, may require a larger cooler to help dissipate the heat load. The compressor frame can account for up to one half of the heat transfer when installed in an open environment. The coolers specified below are based on an open environment.

When the coolers are provided by others, heat load data can be found in the Ariel DataBook or Ariel Performance Program. The heat load numbers are based on an open field environment. Shell and tube, radiator style (oil to air) and plate and frame lube oil cooler types are acceptable.

Frame	Cooler
JG:A:M:N:P:Q:R:J/2/4,JGH:E:K:T/2, KBE:K:T/2	single pass cooler (P/N B-1962)
JGJ/6, JGH:E:K:T/4, JGC:D:F/2/4/6, JGE:K:T/6, KBE/4,KBK:T/4/6, KBU:Z/2	single pass cooler (P/N B-2073)
KBU:Z/4/6, KBB:V/4/6	two pass cooler (P/N B-6250)

Ariel cooler material specifications:

Shell	Steel
Baffles	Steel
Mounting Brackets	Steel
Gaskets	Nitrile Rubber / Cellulose Fiber
Tubes	Copper
Fins	Aluminum
End Caps	Gray Iron
Nameplate	Aluminum
Oil in the Shell side	Water in the tubeside

Maximum Allowable Lube Oil Temperature

The frame lube oil system is designed for a maximum allowable lube oil temperature of 190 F, with a required thermostat setting of 170 F. These temperatures are based upon the viscosity needs as outlined in the Ariel Packager Standards Section 6 Lubrication. Refer to this section for lube oil viscosity chart for some of the common lube oil grades to determine suitability for the compressor frame oil system.

Minimum Allowable Lube Oil Temperature

The frame oil temperature must meet a specific minimum prior to starting the compressor. As well, it must meet a specific minimum temperature prior to loading the compressor. These temperatures are based upon the oil viscosity since there are some differences in similar weight oils that may be suitable for the frame oil system. See the Ariel Packager Standards Section 6, Compressor Frame Lubricants, for viscosity and temperature information.

Dry Sump

Units that are installed on board ships or floating production platforms may require the dry sump option. This option would be required if the roll and yaw of the ship would cause the frame lube oil pump to lose suction of the oil in the sump or any of the running gear to foam the oil from contact with the oil level. Refer to Frame Tilt Limits for Offshore for allowable tilt with a wet sump in offshore applications.

If the dry sump is selected, both frame ends are supplied with drains and an additional oil pump chain oiler is provided. An oil sump strainer is provided by Ariel to be placed in the pump suction line at the outlet of the Packager's wet sump. The packager is responsible to provide a lube oil reservoir sized and located such that the oil pump will have suction regardless of the tilt of the ship or floating platform.

Refer to the Packager Standards Section 6: Lubrication for further information and schematics.

Maximum Frame Tilt for Offshore Applications

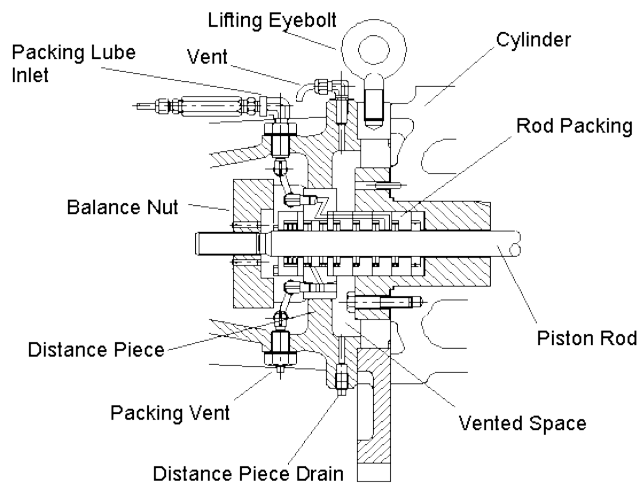
Units that are installed on board ships or floating production platforms may require the use of a dry sump design. This option would be required if the pitch and roll of the ship would cause either the crankshaft counterweights or connecting rods to contact the oil level and froth the oil. Excessive tilt can also cause the oil pick-up tube to lose suction. Serious bearing damage can result from such conditions.

Leveling Limits for Stationary Reciprocating Compressors in the Packager Standards Manual lists the maximum angle from horizontal that each frame can tolerate assuming the motion is transient like the rocking of a boat. There are two lists, applying to stationary installations and transient installations.

Distance Piece Arrangements

Short Single Compartment Distance Piece

A short coupled distance piece, described by ISO-13631 as Type 1, is used when mixing of the cylinder lubricant and the crankcase lubricant is acceptable. Since oil and process gas will enter the crankcase from along the piston rod, the short, single compartment distance piece is recommended for use when compressing non-corrosive gasses. This distance piece will also keep the package arrangement at minimum width.

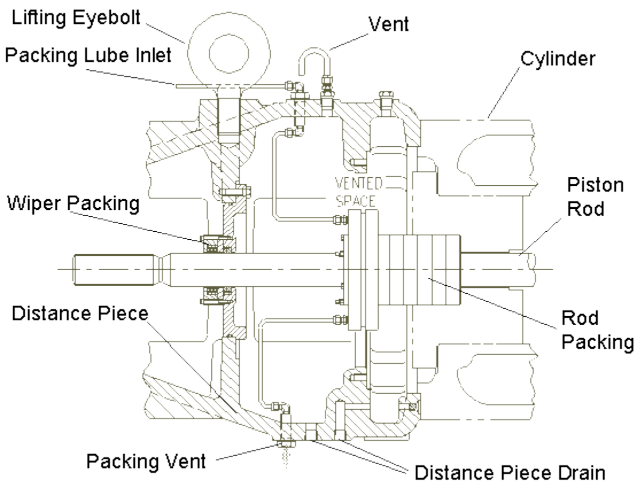


The short coupled distance piece is standard for the JGI, JGM, JGN, JGP, JGQ, JG, JGA, JGW, JGR and JGJ frames.

Long Single Compartment Distance Piece

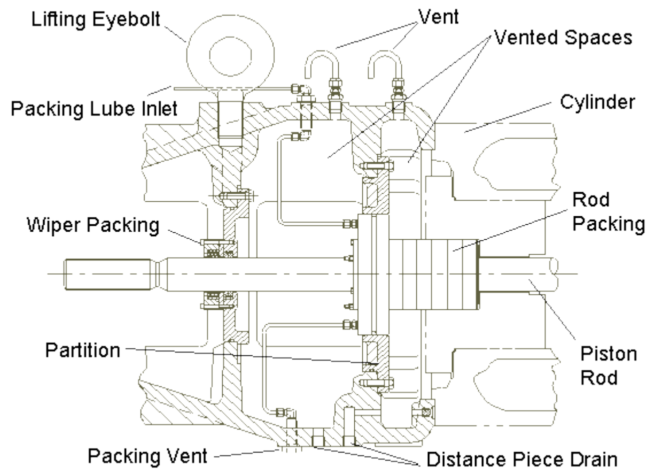
The long single compartment distance piece meets API-618 Type B and ISO-13631 Type 2. It is used for separation of the pressure and wiper packings. With the availability of the two compartment distance piece options, the single compartment distance piece is recommended for non-corrosive gas applications.

The long single compartment distance piece is standard on the JGH, JGE, JGT, JGK, KBE, KBK, KBT, JGC, JGD, JGF, KBZ, KBU, KBB and KBV frames.



Short Two Compartment Distance Piece

The short, two compartment distance piece is recommended for use in corrosive applications, in order to keep sour or corrosive gasses from entering the crankcase. It is a modified long single compartment distance piece. The inboard compartment is suitable for the application of a purge or buffer gas to maintain a positive pressure on the distance piece. This will assist keeping corrosive process gasses out of the crankcase. Ariel recommends either sweet natural gas or nitrogen for purge gas, and the distance piece vents must be piped to a safe area.



The short, two compartment distance piece is available as an option on the JG, JGA, JGW, JGR, JGJ, JGH, JGE, JGT, JGK, JGC, JGD and JGF frames, and not available on the KBE, KBK, KBT, KBU, KBZ, KBB and KBV frames.

The short two compartment distance piece may not be available on all -VS forged steel cylinders. Please refer to the performance program for availability of the short two compartment distance piece.

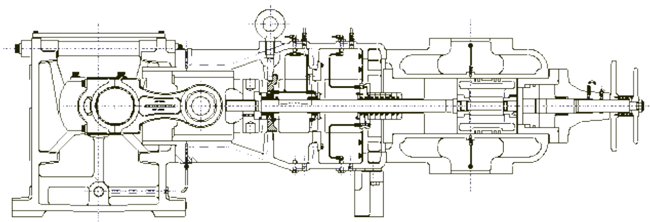
Refer to the Distance Piece Purge and Vent Arrangements for notes on a purge system for sour gas.

Long Two Compartment Distance Piece (Ariel Design)

The 8-7/8W:R cylinder long two compartment distance piece option has a long and a short distance piece, API-618 Type D and ISO-13631 Type 3. The remainder of the Ariel products use a Type C long two compartment distance piece. Ariel recommends either sweet natural gas or nitrogen for purge gas. The distance piece vents must also be piped to a safe area. No part of the piston rod alternately enters the wiper packing and the intermediate seal packing. This distance piece is recommended for use when compressing corrosive gasses.

This long two compartment distance piece is available as an option on all JGR assemblies (with R cylinders), and on JGW assemblies with 8 7/8” W Class or any R Class cylinder(s).

Figure: Long Two Compartment Distance Piece JGR:W (Type D)

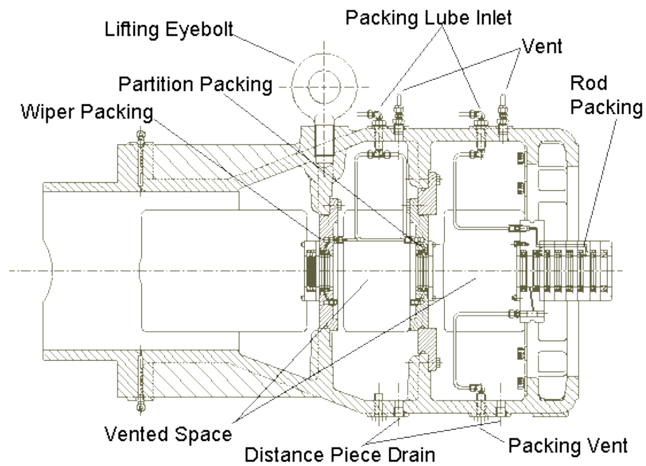


Long Two Compartment Distance Piece (API 618 Type C, API 11P Type 3

The long two compartment distance piece option meets API 618 Type C and ISO-13631 Type 3. There are two long compartments, and each of the three seal sets can be purged (pressure packing, intermediate and wiper seals). This distance piece option provides the maximum amount of protection against flammable, hazardous, toxic and corrosive gasses entering the crankcase. Ariel recommends either sweet natural gas or nitrogen for purge gas. The distance piece vents must be piped to a safe area. No part of the piston rod alternately enters the wiper packing, intermediate partition packing, or pressure packing. When the purged packing option is selected the intermediate, wiper and pressure packing are arranged for purge.

The long two compartment distance piece is available as an option on all JG, JGA, JGJ, JGH, JGE, JGT, JGK, KBT, KBK, JGC, JGD, JGF, KBZ, KBU, KBB and KBV frames.

Figure: Long Two Compartment Distance Piece (API 618 Type C, ISO-13631 Type 3)



Refer to the Distance Piece Purge and Vent Arrangements for notes on a purge system for sour gas.

Balance Crossheads

Balance crossheads are used to balance a blank throw, when standard crossheads and balance nuts are not of sufficient weight; this generally happens when the blank throw is opposite from a larger cylinder.

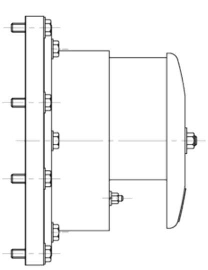
When a balancing crosshead is used a special balance crosshead guide is also required due to the extra length of a balance crosshead. The balance crosshead guide cannot accommodate mounting a cylinder. Conversion to blank a throw or add a cylinder to an already blank throw will require a new crosshead guide when balancing guides are involved.

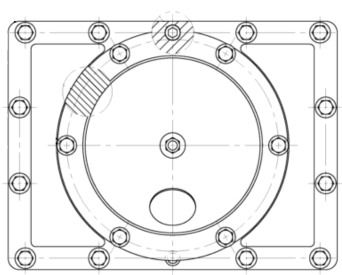
Crankcase Relief Doors

Crankcase over-pressure relief valves are available for all Ariel reciprocating compressors.

Crankcase overpressure relief valves include an internal flame trap and an external downward deflector. They are designed to immediately re-seal to prevent air from rushing back into the crankcase after an uncontrolled expansion of the gas in the crankcase. When using multiple valves on a frame, use valves of the same manufacturer, design valve area, and relief pressure.
Crankcase relief doors are mandatory in Air Service when short coupled distance piece configurations are applied. This includes the standard guide configuration on the JGM:N:P:Q:I, JG:A and JGR:J:W frames. This is due to the higher potential for crankcase over-pressure conditions due to possible auto ignition of lubricants the cylinder, creating escaping gas pressure through the pressure packing.

Ariel offers crankcase relief doors sized per ISO-13631 and API-618.





Fan Shaft

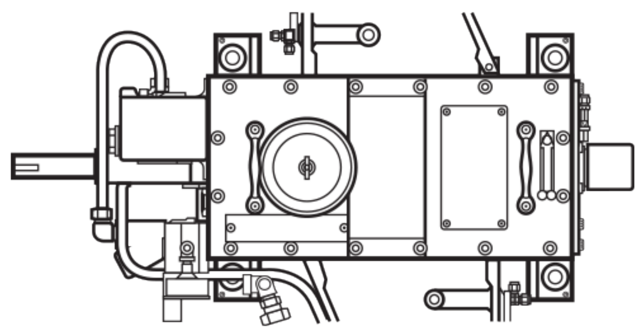
Ariel can provide a fan drive shaft on the auxiliary end of the smaller compressor frames. The fan drive shaft is to be used without a side load. The shaft should be supported with an outboard bearing pillow block pair if used with a side loading similar to a belt drive load. The fan drive shaft can be used up to the power limitations listed below.

The JGJ/2 shaft will require a pillow block arrangement for all applications to limit the axial thrust on the frame bearings.

The JG:A/2 and JGM:P:N:Q fan shafts connect to the crankshaft with a threaded connection. To avoid the threaded fan shaft from backing out due to shutdown deceleration, the fan inertia must be limited.

Frame	Fan Drive Horsepower (Max)	Fan Inertia (Max)
JGM:P:N:Q	15 hp	28 lb-ft2 (4000 lb-in2) (1.18 kg-m2)
JG:A/2	15 hp	28 lb-ft2 (4000 lb-in2) (1.18 kg-m2)
JG:A/4	15 hp	
JGJ/2	30 hp	
JGJ/4	50 hp	

Figure: Fan Drive Shaft Drive End



Frame Lube Oil Heaters

Up to two (2) bayonet style immersion heaters can be installed in Ariel frames. The installation dimensions for the heaters are contained in the frame outline drawing notes.

The watt density of the oil heaters must be low enough to avoid “coking” the crankcase oil, 15 watts per square inch maximum. The oil heater should be interlocked with the compressor instrumentation panel to function only when an oil circulation pump is operating. Refer to the Ariel Packager Standards Section 6.0 for recommendations on heater watt density.

Thermostatic Temperature Valve

Each lube oil system should be equipped with a temperature control valve to regulate the oil temperature into the frame. The valve should be installed in the “mixing” mode.

A thermostatic valve with a cast iron housing is available as an option for all units. The standard temperature setting of the valve is 170 °F. Valves can be provided mounted or unmounted.

Information on particular thermostatic valves can be found within the Ariel website under Vendor Literature. Valve sizing for the various frames is:

- 3/4" NPT Valve - JGM through JGR, JGJ/2-4, JGH/2, JGE/2, JGK/2, JGT/2
- 1-1/2" NPT Valve - JGJ/6, JGH/4, JGE/4, JGK/4, JGT/4, JGC/2, JGD/2, JGF/2
- 2"-125# Flanged Valve - JGE/6, JGK/6, JGT/6, JGC/4-6, JGD/4-6, JGF/4-6
- 3"-125# Flanged Valve - KBZ/2-4-6, KBU/2-4-6, KBB/4-6, KBV/4-6

Cylinder

The main components of a cylinder include the cylinder body, head end head, crank end head, piston rod, piston, packing, suction and discharge valves, valve retainers and valve caps. Cylinders can be double acting or two single acting cylinders can be combined to create a tandem cylinder. An example of a double acting cylinder is an 11K and an example of a tandem cylinder is a 9-5/8K-CE x 5-3/8K-HE-FS.

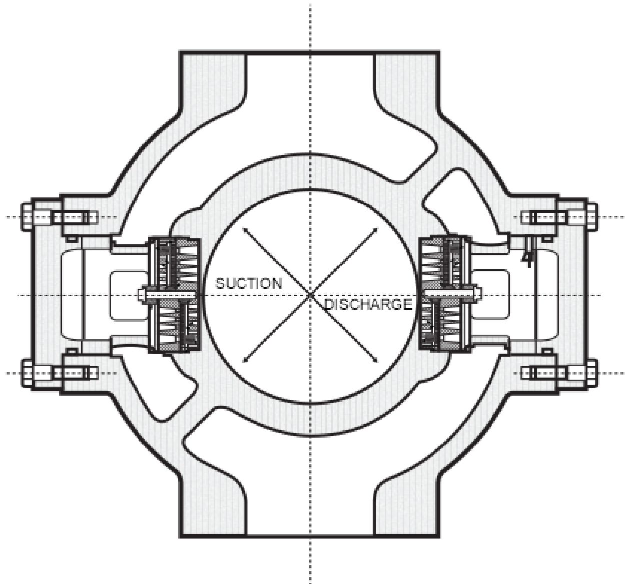
Cylinder, Design Features

Ariel cast cylinders are single and double wall castings. Materials include nodular iron for the greater majority of cylinders, cast iron for a very few of the smaller models and forged steel for the higher pressure ratings. The cylinders on the mid and larger frame classes are ion nitrided to harden the bore for wear resistance. The case cylinders on the smaller frame classes are made from 80-55-06 ductile iron for the harder surface for wear resistance.

Water Jackets

Ariel cylinders are provided without water jackets. Water jackets were originally used to maintain the dimensions of cylinder bores with longer piston strokes and more complicated casting geometry. Shorter stroke cylinder designs combined with casting quality allow the use of non-jacketed cylinders while maintaining stable bore geometry. Despite the misconception, water coursing through the cylinder passages does not have an appreciable effect on the bore temperature and does not impact wearing component life.

Figure: Ariel Cylinder Cross-Section



Cylinder Liners

All ASTM A395 ductile iron cylinder bores are surface hardened with an ion-nitride process to increase cylinder bore wear resistance. Ion nitride surface hardening is provided in lieu of providing a sacrificial wear part (liner). Should a cylinder bore become damaged beyond the re-bore capability, a replacement can be provided. Since Ariel cylinders are non-jacketed (simpler casting geometry), the downtime and cost of a replacement cylinder is generally lower than the downtime and cost of removal and re-installation of a cylinder liner.

ASME Section VIII Pressure Vessel Design

Ariel cast cylinders are designed and pressure rated based on guidelines from Section VIII, Division 1, of the ASME Pressure Vessel Code. Although compressor cylinders categorically cannot be ASME Code stamped, Section VIII, Division 1 of the ASME Pressure Vessel Code provides consistent design and pressure rating methods. Please contact Ariel Design Engineering for a description of the methods applied.

Cylinder Re-Bore Capability

Ariel cylinders may be rebored within limits. A bore restoration guideline is available from Ariel upon request.

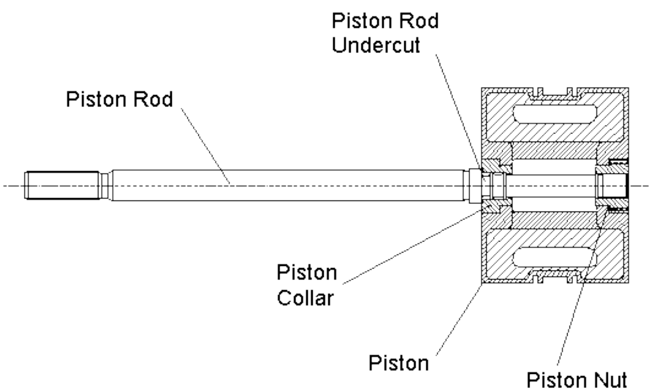
Cylinder, Design Options

Cylinder, Design Options

There are several features and options across the cylinder line. These include features such as number of cylinder lubrication points, piston rod material, piston rod hardening process, wear bands versus rider rings, cylinder bore hardening through ion-nitride process... A full list of the features that are provided, and options that are available, can be found through the Ariel Performance Software.

Piston Rods

Piston rods are designed to resist the loading due to gas and inertia rod loads and wear in the packing travel area. All Ariel piston rods have rolled threads to take advantage of the cold working and reduce the stress concentration of cut threads. The rods are designed with an undercut, or "fail safe" section. It is intended that a failure of the piston rod would fail in this section. A failure at this point allows the piston rod to be supported by the rod packing, and prevents the escape of gas from the compressor cylinder in to the distance piece/crosshead guide, preventing further damage.

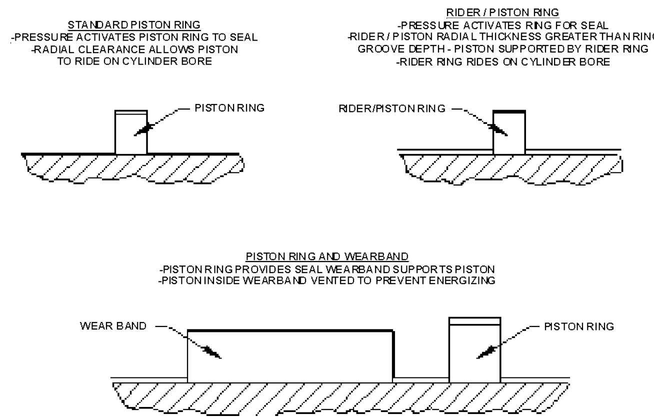


The piston rod material is ETD 150 or 4150 and is Ion-nitrided in the packing travel area. Ion nitride results in a surface hardness range of 57 to 63 Rc from the surface to a base material hardness of 29 Rc at a depth of 0.008 inches. Tungsten carbide coating can be provided as an option.

Gases that contain significant amounts of H_2S or CO_2 will require piston rods machined from 17-4PH stainless steel material to reduce the potential for corrosion, due to the creation of sulfuric or carbonic acids. Piston rods of 17-4PH (UNS S17400) are provided in the double H1150 condition with a base hardness of 33 Rc maximum and chromium nitrided in the packing travel area. Chromium nitride provides a surface hardness of 2500 Vickers. The chromium nitride process has a length limitation due to manufacturing constraints. Longer stainless steel piston rods will be tungsten carbide coated. (When the length of the stainless steel piston rod requires the tungsten carbide coating, the performance software will automatically select the coating.)

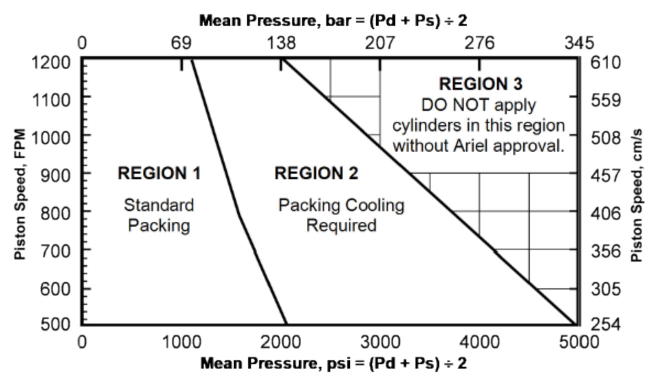
Ariel piston rods have a surface finish of 7-13 micro inches Ra for ion nitride and chromium nitride hardening processes, and 5-10 micro inches Ra for tungsten carbide surface hardening.

Piston Rings, Piston/Rider Rings & Wear Bands



Water Cooled Packings

Figure: Packing Cooling Application Guidelines



Cooled packing cases are required for compressor cylinders based upon the average piston speed and average cylinder pressure. Cooled packing cases are supplied to help remove the heat generated as the piston rod/ packing friction increases with the higher pressures and piston speed.

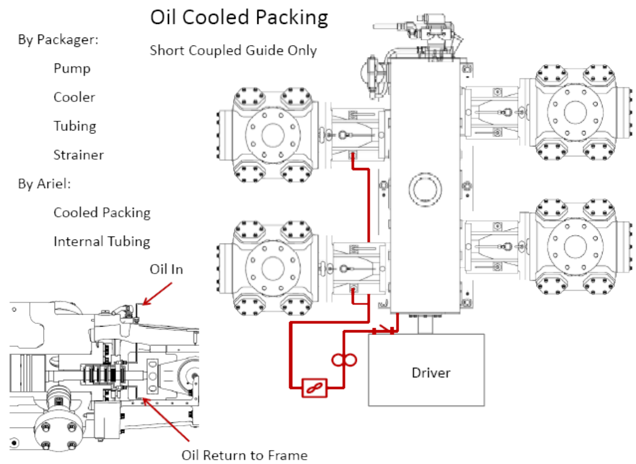
Please refer to the Packager Standards Section 7: Cooled Packing for further information on this topic. The following chart is an excerpt from the Cooled Packing topic:

Notes:

1. The Ariel Performance Software will indicate when operating conditions fall within Region 2 or Region 3.
2. All forged steel cylinders have cooled packing as standard and must be connected to a cooling system.
3. All non lubricated cylinders have cooled packing as standard and must be connected to a cooling system.
4. Any deviation from the packing cooling requirements must be reviewed and approved by Ariel Applications Engineering or Technical Services.

Cooling with oil is not as effective due to the lower heat transfer ability and higher pressure losses due to viscosity. In some circumstances, oil can be used as a coolant in the packing cases. This is limited to lower heat load conditions and smaller compressor frames. The advantage of applying oil cooling in the smaller frames, is the ability to use frame oil, making it possible to cool the packing case with the short coupled distance piece. Oil will be taken from the frame oil system, and returned internally, directly into the crosshead guide.

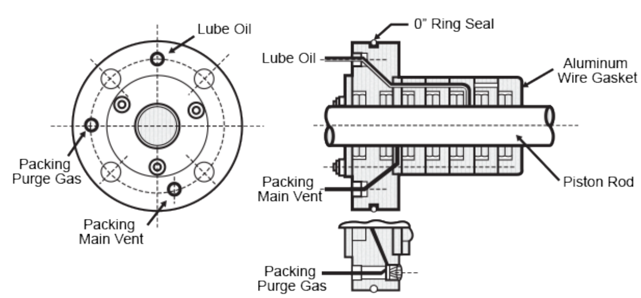
If one packing case is oil cooled on the smaller frames, the oil will be taken from the pressurized frame oil system. This is a closed loop and all tubing provided by Ariel. If more than one packing is oil cooled, a separate oil loop will need to be provided by the packager. Oil can be taken from the sump at the drive end of the frame, through a pump, cooler, and into the packing. The packing return will be internal, directly into the crosshead guide. Below is a schematic showing oil cooling on more than one packing case.



Purged Packings

Purge packing refers to a packing case modified to accept an external purge pressure 15 to 20 psi above the primary packing vent/drain pressure with no more than 5 psi external system back pressure. The purge gas must be sweet natural gas or an inert gas, such as nitrogen. The purpose of purge gas is to block and contain hazardous, toxic, flammable or corrosive gases, and to prevent such from entering the compressor frame where damage to the running gear, or personnel safety hazards can occur.

Figure: Compressor Rod Pack 3500-2000 PSIG with Purge Two Compartment Guides



Packing case materials are cast iron and steel. When steel is used, it is heat treated to be in compliance with NACE. Garter springs are 316 stainless steel, for both sweet and sour applications (acceptable for sour service based upon acceptable field experience).

Please refer to the Packager Standards Section 8 Packing and Distance Piece Vent Systems for further information on this topic.

Compressor Cylinder Lube Oil System

Ariel provides a distribution block cylinder lubrication system. A distribution block system has a single plunger style pump feeding high pressure oil to a distribution block where a combination of specifically sized lube blocks distribute the oil to the individual lube ports, such as cylinder lube ports, packing lubrication, intermediate packing lubrication and flushing lube ports. Some systems require two pumps to be manifolded to a distribution block for higher feed rates. Some distribution block systems require a two tier system, a primary block that divides the oil flow for each cylinder and a secondary block that divides the oil flow for each lube port. A no-flow instrument is located on each primary block to allow a measurement of the lube oil flow (through cycle time) and to ensure a low oil flow shutdown can be provided.

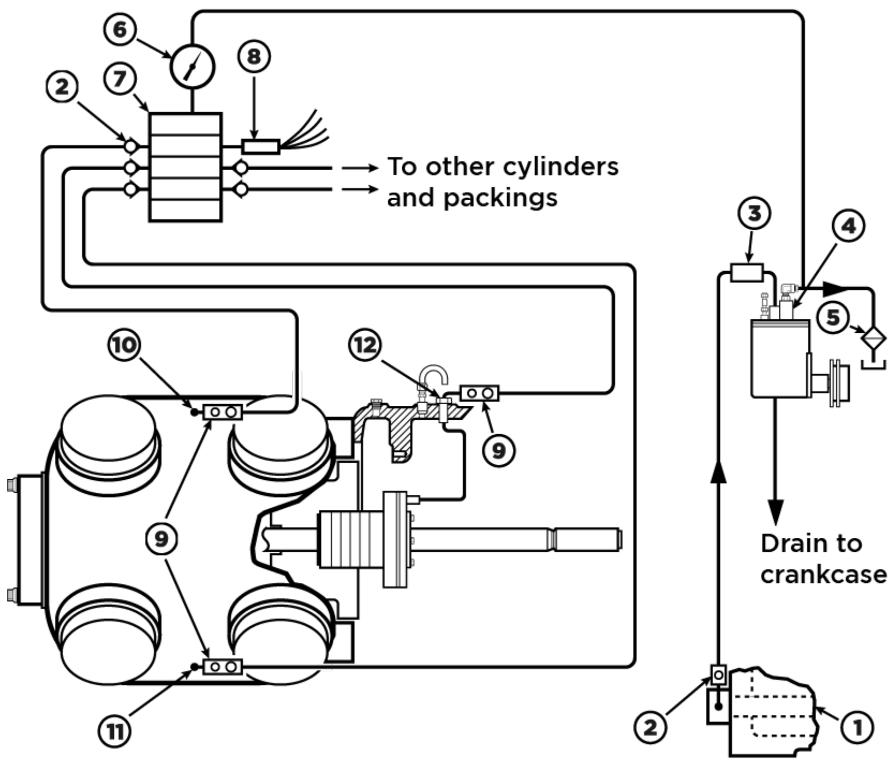
The advantages of the distribution block system over single pump per point systems is the ability to ensure lubrication is provided to all lube points. If one lubrication point is blocked, the no-flow device will trigger a shutdown. Precise lubrication distribution for each point is also ensured.

Cylinder bore and packing oil lubricants and rates, refer to the Ariel Packager Standards Section 6.

Cylinder Lube Oil Supply

Cylinder and packing lube oil is normally supplied from the frame lubrication system at the main oil gallery directly to the suction side of the cylinder force feed lubricator pump. The oil is then pumped through a distribution block system to individual supply points; cylinder lube injection, packing lube, intermediate packing lube, and cylinder flushing points. A lubricator no-flow switch is installed at each primary divider block to ensure appropriate and monitored oil flow.

Figure: Force Feed Lubrication System Common Oil Supply



1 Frame Oil Gallery
2 Single Ball Check Valve
3 Sintered Bronze Filter (if applicable)
4 Force Feed Lubricator Pump
5 ARV or Rupture Disk
6 Pressure Gauge
7 Divider Valves/Distribution Block
8 Fluid Flow Monitor No-Flow Timer Shutdown Switch
9 Double Ball Check Valve
10 Top Cylinder Injection Point
11 Bottom Cylinder Injection Point
12 Packing Injection Point

The cylinder and packing lube can be supplied from a separate system. Generally, separate lube oil for the cylinders and packings is required for applications where the required cylinder and packing lubricant is not compatible with the frame lubricant. These applications include high discharge pressure applications , or when the process gas conditions require an oil heavier than 40 weight, or a synthetic lubricant, such as when heavy hydrocarbons, wet gas or CO2 are present in the gas stream and would dilute a conventional lubricant.

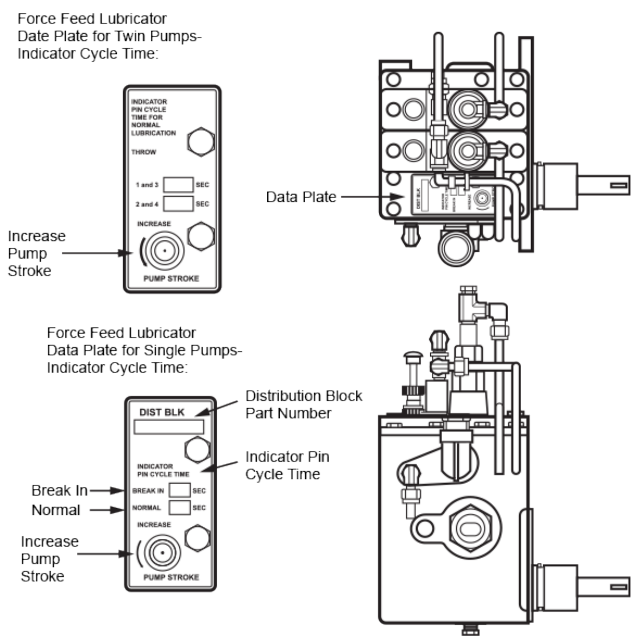
For applications requiring separate frame and cylinder/packing lubricant, the packager is required to provide a separate day tank for the cylinder and packing lubricant. A line filter is recommended between the day tank and the pump inlet. This day tank will need to be elevated to provide the cylinder lube pump oil at a slight positive pressure. Oil filter and piping pressure drop as well as the increased oil viscosity at cold temperatures should be considered when sizing the piping between the day tank and the compressor.

An electric motor driven cylinder force feed lubricator is available upon request. Please refer to the Auxiliary End Pump Removal topic for further information.

See section 6 of the Packager Standards for information on cylinder and packing lubricants and rates.

Force Feed Lubricator Pump

The force feed lubricator provides oil to the cylinder bore for the piston rings and packing case for the piston rod packing seal rings. The lubricator plates provides direction for adjusting the flow of oil. If the plate is missing, please contact the Ariel Response Center and a replacement one can be provided.

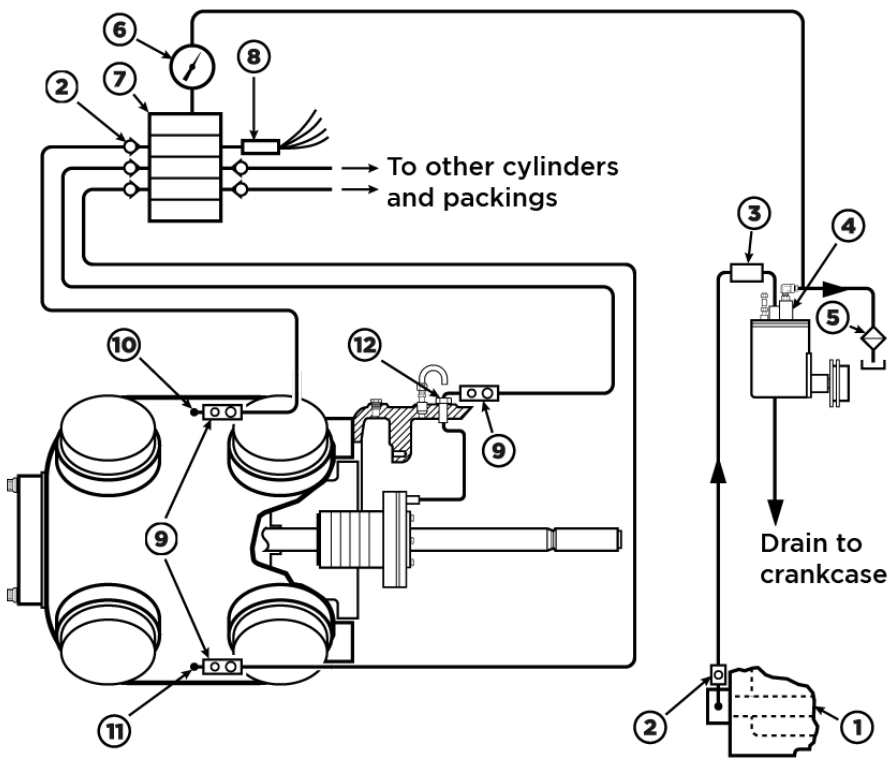


NOTE: The force feed lubricator box contains approximately 1/3 gallons of lubricant. An initial charge to the sight glass must be provided prior to initial start up.

Cylinder, Lube Oil Distribution Block System

The cylinder lube oil distribution blocks system is a series of hydraulic divider valves that distribute lube oil to the various lube points (cylinder bores, packings, wiper / seal sets). The system is applied with predefined divider valves sized to offer various rates of lube flow. Once these blocks are applied to each specific compression application the oil flow proportions insured proper lubrication to each lube point.

Table: Force Feed Lubrication System Common Oil Supply



1	Frame Oil Gallery
2	Single Ball Check Valve
3	Sintered Bronze Filter (if applicable)
4	Force Feed Lubricator Pump
5	ARV or Rupture Disk
6	Pressure Gauge
7	Divider Valves/Distribution Block
8	Fluid Flow Monitor No-Flow Timer Shutdown Switch
9	Double Ball Check Valve
10	Top Cylinder Injection Point
11	Bottom Cylinder Injection Point
12	Packing Injection Point

The advantages of the distribution block system over single pump per point systems is the ability to ensure lubrication is provided to all lube points. If one lubrication point is blocked, the no-flow device will trigger a shutdown. Precise lubrication distribution for each point is also ensured.

Given the nature of the distribution block system to provide a specified quantity of oil per each stroke of the divider valve the oil provided to each point can be monitored by one lubricator no-flow switch per distribution block. In this way all points can be insured appropriate and monitored oil flow.

Cylinder lubricator no-flow Switch

The cylinder lubricator no-flow switch monitors the cycling of the cylinder lube oil distribution block. A magnet in the lubricator no-flow switch monitors the position of a piston in the cylinder lubricant distribution block. If the piston fails to cycle in a predetermined amount of time, indicating a loss of lubrication, the lubricator no-flow switch will send a signal to the control logic of the package to shut down.

There are several lubricator no-flow switch models available. These are listed within the Performance Software as well as in the Packager Standards Section 6: Lubrication. These range from a proximitor that provides a signal to the control panel, allowing shutdown logic and flow calculations to be programmed in the panel, to a no-flow device with on board programming for shutdown timing and flow calculations.

See the Cylinder Lube Oil Supply for the location of a lubricator no-flow switch in the cylinder lubrication system. Please refer to our Vendor Literature on the website for literature on the available lubricator no-flow switches.

Tubing

Tubing and Swagelok fittings are used on both the frame lubrication system and the cylinder lubrication system. On larger frame classes, some of the frame lubrication system includes welded pipe.

Tubing is provided in 304 / 304L stainless steel, ASTM A213/A269/A511. A minimum size of 1/4 inch O.D. with 0.035 wall is applied. 0.065 inch wall tubing is used on higher pressure applications. Fittings are Swagelok zinc plated steel fittings.

An option to apply 316 / 316L stainless steel tubing and 316 / 316L Swagelok fittings is available.When selected, the 316L stainless steel tubing and fittings will be applied to all frame and cylinder lubrication tubing. Tubing is differentiated from welded piping for the stainless steel options.

On larger frames welded pipe is required for the frame oil pump suction pipe (JGC:D:F/4 and larger) or the oil filter to gallery pipe (KBZ:U/2 and larger). The oil filter to gallery pipe is downstream of the oil filter. The material for these piping sections is carbon steel with carbon steel fittings and flanges. A separate option is available for these frame classes to provide 316L welded oil piping.

Items provided in carbon steel despite selecting the stainless steel tubing or stainless steel piping options include the frame suction strainer and the oil gallery pipe. Both of these are internal to the crankcase and below the normal oil level.

Refer to the Ariel Pricebook for these options.

Ion-nitriding

Ion-nitriding is a thermal process by which nitrogen ions are diffused onto the surface of a metal. The process is done in a vessel called an ion-nitrider. The piece to be nitrided is placed inside the vessel. Air in the vessel is pumped out, and replaced with a nitrogen rich atmosphere. A negative charge is applied to the work piece, which causes nitrogen ions to bombard the work piece.

Ariel ion-nitrides cylinders, piston rods in the packing wear area, and variable volume clearance pocket stems.

Ion-nitriding increases the surface hardness of metals to improve wear resistance. The following table outlines the effect of ion-nitriding on the surface hardness of Ariel's piston rods and cylinder bodies.

Material	Component	Base Hardness, Rockwell C	Ion-Nitrided Hardness, Rockwell C	Thickness of Hardened Layer, in
ETD-150	piston rods	29	57-63	0.005-0.006
Gray Iron ASTM A278	cylinder bodies	<20	57	0.006
Ductile Iron 60-40-18	cylinder bodies	<20	57	0.006
416 SST	VVCP stems	<20	70+	0.005

Ductile Iron cylinders of 80-55-06 are not ion-nitrided.

17-4PH Piston Rods are chromium nitrided in the packing travel area to a hardness level of 2500 Vickers.

Tungsten carbide coating can be applied as an option on piston rods for packing travel.

Tungsten Carbide Coating

Tungsten carbide coating can be applied to Ariel's piston rods using a High Pressure High Velocity Oxygen Fuel process, HVOF. The HVOF process is a thermal spray process by which fuel, oxygen and hydrogen are burned to produce a hot high pressure gas stream. A tungsten carbide, cobalt and chromium powder is injected into the high velocity gas stream and is accelerated towards the piston rod. The high energy and hot powder forms a near pore-free density level of tungsten carbide on the surface of the piston rod.

For the Ariel piston rods, the HVOF process creates a final coating thickness after machining of 0.003 to 0.005 inches and a hardness level of 68-73 Rc.

Cylinder, Side-by-Side Clearance

Some compressor cylinders will not fit side-by-side on certain frames. For a listing of such cylinders refer to the Ariel DataBook, or the Ariel Performance Program.

There may be difficulty installing suction valve unloaders on large cylinders installed side-by-side on a frame. Contact Ariel Design Engineering for a determination if suction valve unloaders can be installed on all valves of adjacent cylinders.

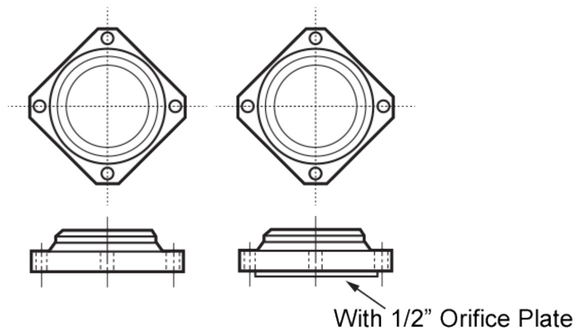
Special Flange

Ariel provides special flanges for all cylinders that do not utilize standard Industry flanges. Ariel's special flanges come in four main types, Dual Nozzle, Racetrack, Peanut, and Taper-Lok. Special flange outline drawings are available in the Ariel Databook listed next to the cylinder outline drawing. These outline drawings show the flange style, size, and use of orifice plates.

Cylinder Class	Flange Type	Sealing	Standard Material	Special Bolting	"For Orifice" Bolting	Orifice Plate Thickness Required
13-1/2JG:J:M	Dual Nozzle	O-ring	SA-105	Fatigue Fighter	Option	1/2" with o-ring groove
17-1/4R:RJ:H:E 19-1/2R:RJ:H:E	Dual Nozzle	O-ring	SA-105	Fatigue Fighter	Option	1/2" with o-ring groove
22-1/2H:E	Racetrack	Gasket	SA-516 Gr70 and SA-53	Fatigue Fighter	Not Avail	Not Applicable
17-7/8K:T:C:D:Z:U 20-1/8K:T:C:D:Z:U 22K:T:C:D:Z:U	Peanut	Flexitallic Gasket	SA-516 Gr70	Fatigue Fighter	Option	3/8"
24-1/8K:T:C:D:Z:U 26-1/2K:T:C:D:Z:U	Peanut	Flexitallic Gasket	SA-516 Gr70	Fatigue Fighter	Option	3/8"
19BL:VL:BM:VM	Peanut	Flexitallic Gasket	SA-516 Gr70	Fatigue Fighter	Included	Included
Higher Pressure Cylinder Class (refer to Databook)	Taper-Lok	Taper-Lok Seal Ring	SA350 LF2	Studs and Nuts	Included	Included
1-3/4SG-FS-HE 2-1/2SG-FS-HE	SAE Straight Thread	O-Ring	Fitting By Packager	None	Not Available	Not Available

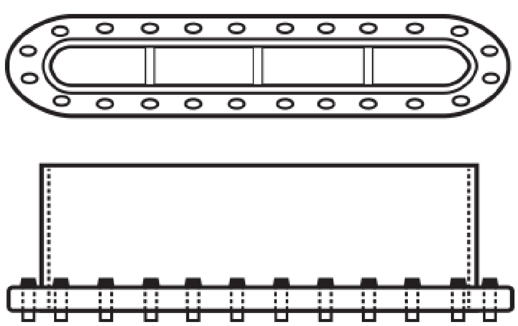
Dual Nozzle Flanges:

Dual nozzle flanges are used on medium sized cylinders where there are two separate nozzles for suction, and two separate nozzles for discharge. These nozzles are weld neck flanges and need to be butt welded to nozzle piping between the flange and the pulsation vessel body. These nozzles are not standard ANSI flange sizes. The bolting is high strength fatigue fighter bolts, and the sealing is accomplished with an o-ring. When orifices are required, Ariel can provide longer bolting and an extra o-ring ("for orifice" option).



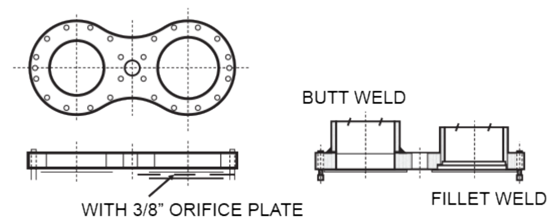
Racetrack Flanges:

Racetrack flanges are used on the larger low pressure cylinders, 22-1/2H and E. The bolting is high strength fatigue fighter bolts, and the sealing is accomplished with a gasket. The flange nozzle is designed to weld directly to the pulsation vessel body or to a transition piece.



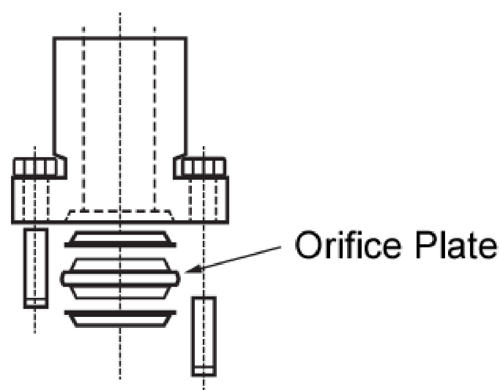
Peanut Flanges:

Peanut flanges are used on the larger cylinder classes. These cylinders have two separate flow areas like the dual nozzle cylinders, but the flanges are connected together resembling the shape of a peanut. The flanges are plate material ready for welding the pulsation vessel nozzle piping, two nozzles per flange. The bolting is high strength fatigue fighter bolts, and the sealing is accomplished with flexitallic gaskets. When orifices are required, Ariel can provide longer bolting and an extra flexitallic gasket ("for orifice" option). The flanges need to be welded to the nozzle piping between the flange and the pulsation vessel body. The Customer must specify either butt or fillet weld style flanges at time of order.



Taper-Lok:

Taper-Lok flanges are used on higher pressure cylinders. Ariel provides the flange, seal rings, orifice plate and bolting. The orifice plates ship with a minimum bore and require drilling to the required orifice bore by the Packager.



Taper-Lok flanges are designed to ASME Boiler and Pressure Vessel code Section VIII Div 1. If design and calculations are required to Div 2, the packager can procure the flanges, seal rings and orifice plates directly from Taper-Lok.

When stainless steel Taper-Lok flanges are required by the Client or Packager (such as on carbon dioxide applications) Ariel will provide the studs and nuts and a deduct for the carbon steel flange parts. The Packager can procure the stainless steel flange, two seal rings and the orifice plate directly from Taper-Lok.

Taper-Lok flanges include an orifice plate with minimum bore. Final bore dimensions for all orifice plates to be machined by the Packager. Refer to the outline drawings for maximum bore limits.

SAE Straight Thread (Fitting Provided by Packager)

The 1-3/4SG-FS-HE and 2-1/2SG-FS-HE cylinder classes utilize an SAE o-ring style connection at the cylinder for gas inlet and discharge. These cylinders are most commonly fit up with tubing. The SAE o-ring fittings for tubing fitting can be found at a local Parker Hannifin distributor, Parker Seal-Lok O-Ring Face Seal Tube Fitting part number 16 F5OLO.

If piping will be utilized rather than tubing, a Grayloc hub to SAE adapter can be found at a local Grayloc distributor, drawing number H600307-1310. Care must be taken that an understanding of the use of Grayloc hubs is known prior to incorporating a Grayloc hub pipe system.

Code Calculations:

Code calculations for the special flanges are available on the Ariel website.

Materials:

Standard materials of construction for these special flanges are carbon steel. Flange materials are suitable for NACE construction once suitable bolting is provided.

Flanges are designed to ASME Boiler and Pressure Vessel code Section VIII Div 1. Division IIfor Ariel supplied flanges are not available. See Taper-Lok above for special notes on the high pressure flanges.

Dual Nozzle Flange SA-105

Racetrack Flange SA-516 Gr 70 and SA-53

Peanut Flange SA-516 Gr 70

Taper-Lok SA-350 LF2 suitable for -50 F

304L and 316L stainless steel materials are available options for the dual nozzle flanges and peanut flanges.

17-4PH bolting may lower available MAWP on some cylinders, specifically the 17-7/8K,T,C,D,Z,U Class cylinders and some KBB:V cylinders. Refer to the Ariel Databook.

Orifices:

Steel orifice plates for suction or discharge are commonly used for pulsation attenuation. Orifices are to be provided by the Packager. Longer bolts and extra o-rings / gaskets are available as a "for orifice" option when orifice plates are used (not applicable to welded in orifice plates).

Ariel encourages the use of orifice plates of specific thickness due to the special bolting types and lengths used in the "for orifice" bolting option provided by Ariel. The dual nozzle flanges require the use of o-rings rather than gaskets. The o-ring groove dimensions for the orifice plates are defined in the special flange outline drawings.

Dual Nozzle Flanges 1/2" orifice plate with o-ring groove

Peanut Flanges 3/8" orifice plate and gasket

Taper-Lok flanges include an orifice plate with minimum bore. Final bore dimensions for all orifice plates to be machined by the Packager. Refer to the outline drawings for maximum bore limits.

Valves

Compressor valves are finely tuned check valves, cycling up to 1800 times per minute. The variations in operating pressures, gas composition, gas density, operating speed, and load steps are all designed into the specific valve configuration for a given application. The valve design consists of the proper size, plate mass, plate lift, spring force, and plate and spring materials.

The valve selection is optimized for the specific operating conditions provided within each compressor application. When operating conditions vary outside the original parameters, the valve selection should be reviewed to confirm appropriate plate motion. This may mean a change in valve springs, plates, or sometimes entire valve.

Operating across a wide speed range, as with a variable speed electric motor driver (VFD), will require special consideration in the valve selection. The speed range will depend upon several variables. Generally the valve selection will not tolerate a speed range greater than a 2:1 turndown. Further consideration may be needed below half frame rated speed, as this may impact valve reliability.

Commissioning and Operation of the Compressor

Once the compressor is installed and the operating conditions confirmed, the valve configuration should be reviewed. If the current operating pressures are much different than the expected operating conditions, contact the Ariel Response Center (ARC) to confirm the valve configuration. Different springs may be necessary to ensure proper valve dynamic motion.

If the valve life proves shorter than expected, contact Ariel with the unit serial numbers, current valve part numbers and current operating conditions. The valve configuration can be confirmed, or altered as necessary.

Valve Analyses

A valve dynamic motion analysis can be provided for the valve design condition upon request. This is a mass spring damped motion review of the plate motion, including impact velocities and motion analysis. Response to the acoustical pulsations is not included in the valve motion study.

Valve Lift

The current CP valve type is offered in one valve lift. This lower lift offers improved valve reliability, while maintaining or improving upon valve efficiency (flow area).

Older valve styles were offered in varying lift configurations to accommodate wider, or varying operating conditions. Low lift valves improved reliability by reducing impact stresses or improving closing timing. However, this also increased power usage, rod loads and discharge temperatures. The increase may be slight in most cases, but should be reviewed and considered.

Low lift valves were required when suction pressure, discharge pressure, and / or operating speed vary greater than 25%. Contact Ariel with the full range of operating conditions for review of valve type and lift.

See Also:

- Valve Lift
- Pseudo-q Value
- Suction Valve Unloaders
- High Clearance Valve Assembly
- Adjusted Equivalent Valve Area

Special Tools

KBB:V & KBU:Z frames require special hydraulic torque tools for disassembly & re-assembly. These special tools are available as an option and should be included as an option in the proposal. Special tools are priced and scoped separately to allow the purchase of these based upon having one set per location. A list of special tools is made available in the Ariel performance software.

These special tools include:

- Hydraulic Piston Nut torque tool
- Hydraulic Balance Nut torque tool
- Hydraulic Main / Conn Rod torque tool
- Hydraulic Stud tensioner (optional)
- Hydraulic pumps, manual, electric or pneumatic

Hydraulic tools can be used on the smaller frames, but are considered optional as manual hand tools can be used. A full list of the optional, recommended and required tools are listed in the Ariel performance software for each frame.

We encourage the review and inclusion of any necessary special tools in the initial purchase of larger compressor frames.

Further information on Special Tools can be found on the Ariel website within the Maintenance and Repair Manuals.

Hand Tools

Ariel compressors are provided with special tools, and have a number of optional tools available. All available tools are listed in the Ariel performance software to allow separate purchase. Details on the special tools, and what is included or recommended for each frame or tool option, can be found on the Ariel website within the Maintenance and Repair Manuals.

Ariel compressors are built with some special tool requirements. Special tools that are not available through standard tool suppliers are provided by Ariel with each compressor.

Some compressor frames require (or recommend) the use of hydraulic tensioning devices. As these may be needed for each site, rather than each compressor frame, they are provided as an optional purchase.

Ariel compressors are built using SAE fasteners. As SAE tools are not readily available in all installation locations, an option to provide SAE tools is available in the Ariel performance software.

Further information on Special Tools can be found on the Ariel website within the Maintenance and Repair Manuals.

Industry Specification Comments and Exceptions

The Ariel Corporation Electronic DataBook and Ariel Performance Program provides Ariel's comments and exceptions to the industry specifications. These can be accessed by selecting the frame of interest, then right clicking on the frame.

The industry standard comments include comments to:

- API 618 Fifth Edition, December 2007
- ISO-13631
- API-11P
- NACE MR0175/ISO 15156-1,-2,-3

Applications

Air Service

Air service can include applications for underbalanced drilling, air feed for air separation, and seismic applications. Many air services have high discharge pressures. Air compression has a few technical details for consideration when sizing an air application.

The k-value for air is relatively high, resulting in gas discharge temperatures being higher at lower compression ratios. The higher k-value will also result in faster discharge temperature rises with changes in pressures. Off conditions need to be reviewed to confirm maximum operational temperatures are within the Ariel discharge temperature limits. Refer to the Packager Standards for information on Instrumentation.

Mineral oil auto ignition temperatures in Air service are relatively low at higher pressures and drop significantly as pressures and temperatures increase. An ester based lubricant must be used in air service. The lube oil auto ignition temperature must exceed the compressor discharge temperatures at discharge pressure. The user must confirm the lube oil auto ignition temperature is well above potential discharge temperatures. Ariel limits air applications to no more than 5000 psi. Above this pressure, nitrogen can be applied, with no more than 5% oxygen content.

Refer to the Packager Standards for information on Cylinder and Packing Lubrication.

Due to the potential for auto ignition of the lube oil in air service crank case relief doors are mandatory on JGJ frames with cylinder working pressures greater than 1500 and short coupled distance pieces are provided. Crank case relief doors are highly recommended on all other short coupled guide arrangements, such as on JGM:N:P:Q:I, JG:A and JGR:J:W frames.

When selecting a compressor for air service, lower piston speeds may be necessary in order to allow the heavier gas to flow through the valves with proper valve dynamics. The lower piston speeds will lower the pseudo-q values as well as improve the efficiency of the unit (lowering the power per unit flow value).

Package and Operational Recommendations:

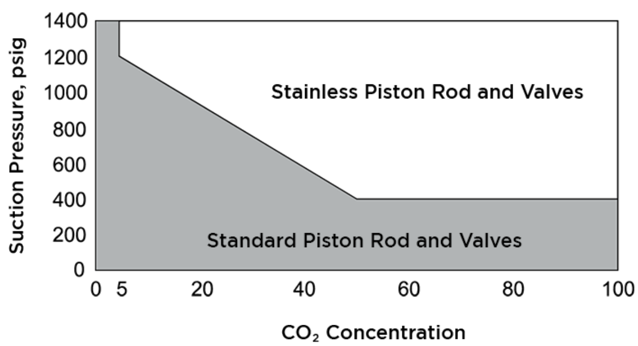
1. Ariel recommends discharge valve temperature sensors to detect higher temperatures due to leaking or failed valves.
2. Deactivation of cylinder ends is discouraged due to the potential for higher heat build up. Discharge temperature devices will not measure internal heat build-up due to end deactivation.
3. Where available, provide water cooling to packing cases to reduce packing heat.
4. Gas piping systems must be designed to eliminate low points where lube oil can accumulate. Any low point must be set up for continuous draining, including (but not limited to) low points at each elbow-up and gas cooler sections.
5. Separators are to be configured for continuous draining.

Carbon Dioxide

Carbon Dioxide (CO_2) may combine with water to form carbonic acid. Carbonic acid is mildly corrosive and at higher pressures can condense into a liquid which will act as a solvent and dilute the cylinder lubrication. The gas properties of the CO_2 mixture should be reviewed at the required operating conditions. Gas properties of CO_2 can be found under the Gas Properties topic.

See the chart below for recommended materials of construction for piston rods and valves based on suction pressure and CO_2 concentration.

Figure: Suction Pressure vs. CO_2 Concentration



Standard or Stainless Piston Rod and Valves Chart

When the standard valve body materials are 416 stainless steel, these are suitable and meet the recommendations of the above chart for CO_2 service. Some valves have carbon steel body material, and would not meet the recommendations for the above chart. The valve material can be found on the cylinder data sheets.

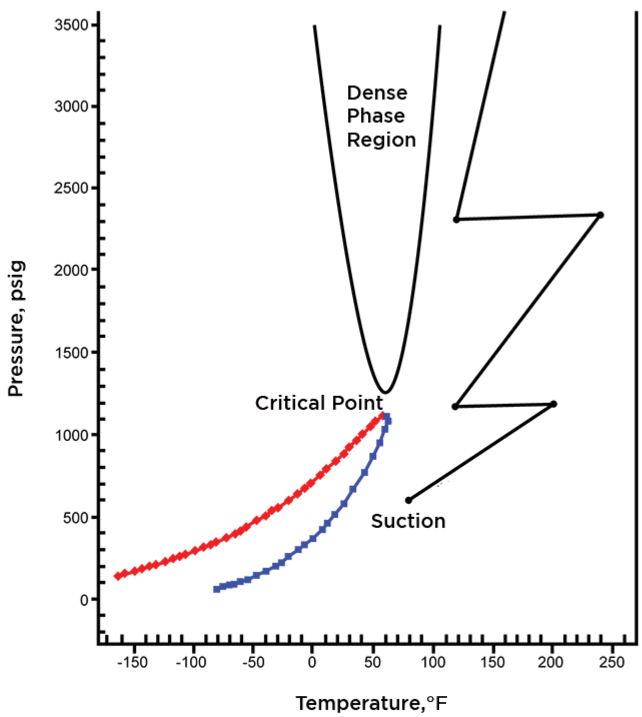
The recommendations for compressor piston rod and valve materials are:

For sweet natural gas with a carbon dioxide concentration less than 5%, or at 5% with a suction pressure less than 1200 psig, or with a carbon dioxide concentration up to 50% with a suction pressure less than 400 psig, or with any suction pressure lower than 400 psig, use standard piston rod and valve materials.

For sweet natural gas with a carbon dioxide concentration outside the above limits, use 17-4PH stainless steel piston rods and stainless steel compressor valves. Most valve bodies are 416 stainless steel material and will meet the recommendations for stainless steel in CO_2 service. When the standard valve body material is carbon steel, the 17-4PH stainless steel valve option should be chosen. (When changing to the 17-4PH valve material option, it is recommended that standard valves be used for unit start-up. Once the system is confirmed clean, the stainless steel valves should be installed).

CO_2 is soluble in mineral oils, thereby reducing the oil / gas mixture viscosity. Mineral oils are completely miscible into CO_2, which reduces the effectiveness of the oil. Compounding mineral oils or PAG (poly-alkaline-glycol) synthetic lubricants are commonly used. See Cylinder and Packing Lubrication Requirements in the Ariel Packager Standards and contact Ariel in Mount Vernon for a recommendation.

Compression of carbon dioxide often involves operating conditions that are near or above the critical point of the gas. The gas properties will be very sensitive to small changes in pressures and temperatures when near and above the critical point. When a stage suction pressure is near the critical pressure, allow a greater margin from the critical temperature for more stable gas properties. This may mean operating at a suction temperature of 40 to 50 F (20 to 30 C) above the critical temperature. When a stage suction pressure is above the critical pressure, allow enough suction temperature to maintain proper gas properties. Proper gas properties means maintaining a suction compressibility (Z) value above 0.4, and preferably above 0.5. In this "dense phase" region above the critical pressure the gas can have properties of either a gas or a liquid and the density of the gas will fluctuate greatly with small changes in pressure or temperature.



Due to the sensitivity of the gas properties to small changes in pressure and temperature in this "dense phase" region, near and above the critical point, the interstage temperature may need to be controlled. If the gas suction temperature is allowed to vary, the gas density will fluctuate widely and can cause large changes in the acoustical response of the gas piping system. This can lead to acoustic force driven shaking of the equipment.

Critical pressure and temperature are provided on the phase envelope within the Ariel Performance Program.

A controlled temperature system can be accommodated during higher ambient temperature swings through gas cooler louvers and fan control. If this is not enough to control the gas temperature out of the cooler, hot air recirculation or heaters may need to be provided in the cooler design. Controlling with a bypass around the gas cooler with a temperature control valve allowing mixing of hot and cold gas may not be suitable, if the cooled gas condenses in the cooler.

When selecting a compressor for carbon dioxide service, lower piston speeds may be necessary in order to allow the heavier gas to flow through the valves with proper valve dynamics. The lower piston speeds will lower the pseudo-q values as well as improve the efficiency of the unit (lowering the power per unit flow value).

Carbon Monoxide

Gas properties of CO can be found under the Gas Properties topic.

Carbon Monoxide presence in the gas stream will require a lubricated cylinder construction. Non-lubricated applications should be avoided. This is due to the increased risk of Carbon Dissociation. Carbon Dissociation may cause the formation of hard carbon deposits and CO_2. This process can also result in carbon dust accumulating in the piping. This dust may be pyrophoric, combusting when coming in contact with air.

Discharge temperatures should be limited to 255° F (124° C).

When the combined content of carbon monoxide and hydrogen approaches 50%, PRC guidelines will govern the selection of equipment.

Ariel does not provide non-lubricated cylinder construction for carbon monoxide applications.

Gas Storage Service

Gas Storage service includes applications where gas is injected at relatively high pressures into formations, wells, caverns for future use or sale. Gas storage applications may also include the compression for withdrawal from these storage sites during periods of demand for the gas. Discharge gas pressures will swing widely during the injection process, while suction pressure will remain relatively stable. Suction gas pressures will swing widely during the withdrawal process, while the discharge pressure will remain relatively stable.

Due to the wide range of pressures, compressor valves are often required to be low lift for proper dynamics.

The elevated storage pressures often require two stages of compression as the storage sites fill. However, much of the injection process and most of the withdrawal process can be done with a single stage of compression. Many gas storage applications are designed to operate all cylinders in parallel for a single stage of compression during the early phase of injection and during withdrawal. The gas piping is then reconfigured through valving to operate with two stages of compression at the final phase of injection. This one stage / two stage operation allows for much greater use of the installed power and much more flow during the lower ratio phase of the processes.

Gas storage compressors are often installed in highly automated systems. Capacity control devices are often pneumatically operated rather than manually operated. This would include pneumatic actuated fixed volume clearance pockets and suction valve unloaders.

High Gas Molecular Weight

It is always recommended to use a gas analysis for the highest accuracy for predicted performance. For the normal natural gas mixtures with .56 to .80 specific gravity a specific gravity entered for performance predictions is acceptable. If the gas contains gas constituents outside the normal pipeline gas mixtures (ie., carbon dioxide, nitrogen, hydrogen sulfide, hydrogen...) a gas analysis will provide more accurate performance results.

When gas mixtures are lighter than .35 specific gravity (10 mole weight) or heavier than 1.35 specific gravity (39 mole weight) it is recommended to contact Ariel Applications Engineering. The VMG gas method should be used for gasses outside the use of natural gas.

When only a specific gravity is specified, the gas properties (K value and compressibility) are based upon a generalized hydrocarbon mixture. This could lead to inaccurate compressor performance predictions when other gas constituents are present outside the normal natural gas mixture. Air should never be entered by a specific gravity.

Heavier gasses will create higher pressure losses through the valves. This pressure loss is calculated through the pseudo-Q values. When the pseudo-Q values are high, reaching or exceeding 15, a slower piston speed will be necessary.

Often times heavy gas applications are also wet gas or low suction pressure applications.

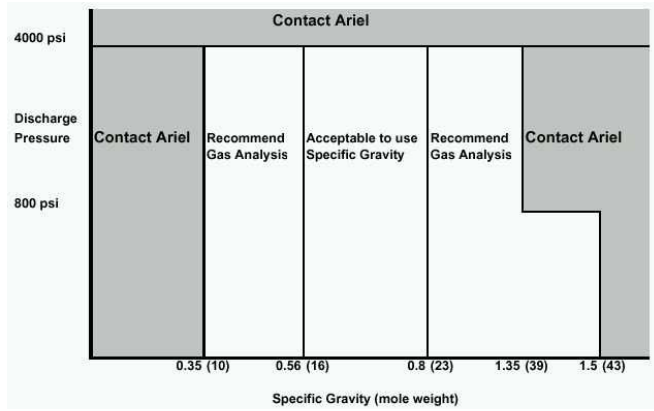
See the Packager Standards Section 6: Lubrication for information on applying the appropriate cylinder lubricant and rates for high gas molecular weight applications.

Heavier gasses may approach the dew point at the higher pressure interstages. If so, temperature controls for the interstage may be necessary to avoid gas product condensates.

Light gasses, molecular weight less than 12 (specific gravity less than 0.4), are considered low molecular weight applications and must be reviewed by Ariel Application Engineering. A valid gas analysis must be provided for these applications. The VMG gas method should be used for light molecular weight gasses.

Special attention will be paid to the selection of compressor valves for low molecular weight applications. The pseudo-Q-value must exceed 1.0 for all operating conditions. The application will be reviewed with the valve supplier to select the proper compressor valve. Ariel will also adjust the expected compressor capacity to account for higher piston ring blow by. It must be noted that any changes to the compressor valves that may be required to increase the pseudo-Q-value and any capacity adjustments may result in an increased HP (kW) requirement.

Applications that involve higher than 50% by volume of hydrogen shall be sized to limit the internal discharge temperature to 275 °F. Cylinders in these applications must have a helium leak test and packing cases with lapped cups.



Hydrogen Service

Hydrogen is a diatomic gas used in a number of refining and petrochemical processes.

Hydrogen has a high ratio of specific heats, therefore will increase in discharge temperature with smaller increases in compression ratio. Temperature limitations are 250 F (121 C) for selection purposes and no greater than 275 F (135 C) in operation. Shutdown setting should be no greater than 300 F (149 C). Additional stages of compression may be necessary to maintain these lower discharge temperatures.

PRC cylinders and application guidelines are necessary for hydrogen applications. The application guidelines include lower discharge temperatures and lower piston speeds. Helium leak testing is required for cylinders used in Hydrogen service.

Non Lube Compressor Cylinders

Please refer all non-lube applications to the Ariel Application Engineering Department.

Non lube applications will be limited to the following compressor frame and cylinder classes:

- Frames – JGA, JGJ, JGK, JGT, KBK, KBT, JGD, JGF, KBU and KBB
- Cylinders - JG, RJ, JGK, JGT, KBK, KBT, JGD, JGF, KBU and KBB

Non-lube applications will require that the following application guidelines be strictly adhered to:

- Use a long two compartment distance piece (API – 618 Fourth edition Type C) with oil slingers in both compartments;
- Piston rod materials for non lube service will be as follows:
    - For non-corrosive applications – ETD 150 with a Tungsten Carbide coating.
    - For corrosive applications – 17-4 PH Stainless Steel with a Tungsten Carbide coating.
- Limit cylinder internal discharge temperature to 275°F (135°C) for selection, 325°F (163°C) for maximum shutdown limit
- Limit cylinder discharge pressure to 1500 psig (103 barG)
- All non lube cylinders are provided with water cooled packing and must be connected to a packing cooling system.
- Compressor valves, pistons (and piston trim) are specifically designed for non-lube service.

Non lubricated cylinder construction can be applied for sour gas services, but is limited to sour level 1, less than 2% H_2S content by volume. NACE Stainless Steel Valves are required along with the Sour Level 1 trim (stainless steel piston rods, purged packing, proper purge / vent system, long two compartment distance piece).

Internal piston ring blow-by is accounted for in the Ariel performance program as a relation to the gas mole weight.

Rubbing speed is a factor that must be considered for all Non-Lube applications. The piston speed limit for Non-Lube applications is 750 feet per minute (3.81 meters per second). Refer to Process Rotative Speeds for maximum allowable rotative speeds for each frame model.

Offshore Applications

Offshore production applications carry additional considerations for compressor selection, packaging and analytical studies. A conservative approach to the selection will offer the benefit of longer time between maintenance, for less maintenance work and replacement parts in this remote environment. This would include reduced speeds, lower discharge temperatures and conservative rod load usage.

Offshore structures do not carry the immense mass of earth and concrete to absorb the many forces and couples associated with reciprocating compressors. Therefore, selecting a compressor for offshore installation must keep this in mind. When possible, a four throw compressor will carry lower forces and couples than a two throw compressor. A six throw compressor will carry even lower forces and couples.

The forces and couples associated with reciprocating compressors can come from a number of sources. The offset distance along the crank centerline between opposing throws creates a couple. Different reciprocating weights on opposing throws, or between pairs of opposing throws creates forces and couples. Ariel balances the reciprocating weight on opposing throws to a very tight margin to limit the unbalance forces. The reaction to the conversion from rotating to reciprocating motion at the crosshead guide creates vertical forces at the crosshead guides. Torsional vibration forces can resolve into lateral vibration forces on some configurations.

A heavier skid structure will be necessary for greater rigidity with offshore packages. This includes a "full pedestal width" construction, tying the structure under the crosshead guide support to the frame supporting structure.

Along with the torsional and acoustical analyses, a full mechanical analysis of the skid and surrounding supporting structure is necessary.

Gathering, vapor recovery, gas lift, gas re-injection and fuel gas booster for gas turbine generator are most common FPSO applications.

Dry sump is recommended for vessel pitch, roll and yaw. Most often, 316SST tubing and fittings as well as duplex oil filter are specified by end user customers for offshore environments.

Third party certification is often required for FPSO, or offshore applications. These would include:

- FPSO - Floating, Production, Storage, Offloading Vessels
- FSO - Floating, Storage, Offloading vessels, without the processing facilities
- FSRU – Floating, Storage, re-gasification and offloading vessels
- FLNG – Floating Liquid Natural Gas Production vessels
- FDPSO – Floating, Drilling, Production, Storage and Offloading vessels

The third party certification requirements for FPSO applications are specified by FPSO Classification Organizations as listed here.

- ABS (American Bureau of Shipping) in USA
- DNV (Det Norsk Veritas) in Norway
- Lloyd's Register of Shipping in United Kingdom
- Bureau Veritas in France

FPSO documentation as required by all the third party certification is termed Design Review by the classification organization.

1. For each compressor, an affidavit is required from the manufacturer stating that design and fabrication have fully complied with an applicable API standard, except as noted. All exceptions shall be listed and if no exceptions are taken to the specifications, then the affidavit should indicate as such.
2. Compressor performance runs information shall be provided indicating maximum allowable suction and discharge pressures and corresponding temperatures (both maximum and minimum), as well as maximum rated discharge pressure.
3. For compressors handling hydrocarbons, casing (cylinder) drawings and casing (cylinder) strength calculations may be required. The casing strength calculation shall include cylinder thickness calculation and inlet/outlet nozzle reinforcement calculation. If casing drawings cannot be submitted due to confidentiality, a sketch of casing drawing including diameter and thickness and inlet/outlet diameter and thickness information is acceptable.

- Ariel requirements to FPSO documentation are compilation and documentation of
- Compressor configuration with serial numbers and general model ratings
- Compressor frame and cylinders outline drawings
- Compressor frame and cylinders data sheets
- Cylinder casing design data
- Compressor performance data sheets
- Comments and exceptions to API-618 and 11-P Specifications

- ASME Code Calculations for Special Flanges

Offshore environments can be corrosive due to salt water spray. Cylinder and valve cap bolts can be provided in 17-4PH stainless steel if salt water corrosion is a concern. The NACE Cylinder Bolting option will apply 17-4PH bolting and studs for the cylinder heads and valve caps.

Oxygen

Oxygen service requires special cleaning processes during manufacturing of the compression equipment. Ariel does not provide compression for oxygen service.

Oxygen in a hydrocarbon based gas stream can be a concern for combustion. Ariel limits the oxygen content in a hydrocarbon service to 5% to ensure the lower explosion limit is not reached.

Oxygen can be introduced into the gas stream when suction pressures are near or below atmospheric pressure. When considering suction pressures near atmospheric pressure, an oxygen sensor downstream of the first stage of compression is recommended. Oxygen content will be limited by either the 5% listed above, or the limits by the gas composition requirements by the client, whichever is lower.

In inert gas based compositions, such as nitrogen, oxygen content will impact the auto ignition temperature and pressure for the lubricating oil. Any composition of inert gas and oxygen above the oxygen content of air (21% oxygen) should be reviewed for auto ignition temperature and pressure, and lubricating oil selection.

Propane

Propane (C_3H_8) applications will typically be classified under the application guidelines for High gas molecular weight, low suction temperature applications or low gas suction pressure (The most stringent of these criteria shall apply).

There are several special application considerations for propane service. The minimum suction temperature for gray and ductile iron is -40°F (-40°C). Ariel Application Engineering should review all applications with suction temperatures below 0 degrees F (-18 degrees C).

Some applications utilize propane in a closed loop refrigeration service. These applications must be reviewed to insure that the settle out pressure of the system is less than the MAWP of the system or that adequate controls and protection are provided to protect the compressor cylinders. In closed loop refrigeration service, cylinder lube rates should be monitored and may require adjustment.

High Pseudo-q values are common in Propane applications. Valve selection is critical in these applications, therefore a valid gas analysis is required.

Gases with high propane content tend to dilute standard compressor cylinder lube oils, thereby reducing the gas/oil mixture viscosity. Propane is oil soluble and tends to wash the lubrication film away.

Refer to the Propane Gas Properties for information on propane gas.

See Cylinder and Packing Lubrication Requirements--6 in the Ariel Packager Standards for guidelines regarding cylinder and packing lubrication for Propane service.

Sour Gas

Hydrogen sulfide is considered corrosive, toxic, and lethal. As such, Ariel has specific recommendations as to the materials and compressor configuration options when compressing gas that contains H_2S. Hydrogen Sulfide (H_2S) can embrittle high strength, high hardness carbon steels, and most martensitic stainless steels (for a full and specific list of material compatibility with H_2S refer to NACE MR-0175, ISO-15156).

Ariel's equipment configuration recommendations for sour gas service are based upon field experience and the NACE guidelines for the protection of the equipment.

It is the End Users responsibility to be aware of the level of H_2S present, and to take all necessary precautions for the protection of personnel from harmful leakages of gas to the atmosphere.

Selection Recommendations / Requirements for Sour Gas Service

Several considerations should be made when selecting compressors in sour gas service. As the gas is both corrosive and toxic, special safety requirements are necessary for the maintenance of the equipment. It may be suitable to provide a more conservative selection to lengthen the time between maintenance. This would include operating at slower piston speeds and allowing for lower discharge temperatures.

The toxic and lethal nature of the gas dictates the use of an appropriate purge and vent system to ensure the gas leakage at the packing case and distance pieces is not vented to the atmosphere. Please refer to the Packager Standards Section 8 Packing and Distance Piece Vent Systems for this topic..

With higher percentages of H_2S in the gas stream, a review of the phase envelope and dew point of the gas constituents (not including water vapor) is recommended. At higher levels of H_2S and higher pressures, the interstage cooling can easily reach the dew point for the H_2S in the gas stream. Most often, condensation of the H_2S is to be avoided.

Sour Gas service, Level 1, can be applied with non-lubricated cylinder construction. NACE SS Valves will be required along with the requirements and recommendations of Sour Level 1 trim below.

Recommendations / Requirements for Sour Gas Service:

	100 ppm to 2% H_2S Sour Level 1	> 2% H_2S Sour Level 2
Distance Piece Arrangement (Requirement)	S2C / L2C / Single with purge wiper	L2C (Recommend)
Piston Rod Material (Requirement)	Stainless Steel	Stainless Steel
Purge Packing (Requirement)	Purged	Purged
Flushing Lube	N/A	Flushing Lube on Stage 1 (Recommend)
Stainless Steel Valves	Standard Valves	Stainless Steel
Forged Steel (-VS) Cylinders (Requirement)	Use lower strength 22Rc cylinder bodies, or stainless bodies even as low as 5-10 ppm of H_2S content	

Optional Equipment:

- Cylinder Bolting Material
- Cylinder Body Material
- Lubrication Tubing and Fitting Materials
- Separate Lube Supply

Distance Pieces Arrangement

A two compartment distance piece, or a long single distance piece with wiper seal purge are required for sour gas service. These configurations offer the ability to create a purge and vent system which segregates the crankcase and operator atmosphere from the packing leakage.

Long two compartment distance piece, "L2C", is recommended above 2% H_2S content as this provides better containment of the gas leakage. S2C distance piece and long single compartment distance piece with purged wiper seal can be used above 2% H_2S content, but do not offer the same level of protection and flexibility for the vent / purge system design.

Two compartment distance pieces are available for all units except for the JGM:N:P:Q and KBE frames.

The long single compartment distance piece with wiper purge is available on the KBE:K:T, KBU:Z and KBB:V frames.

Refer to Packager Standards Section 8 Packing and Distance Piece Vent Systems for notes on a purge system for sour gas.

Piston Rod Material

Ariel standard piston rod material is 4100 series carbon steel heat treated for strength. These are not suitable for sour gas service as defined by NACE MR-0175. For sour gas service with 100 ppm and greater H_2S content stainless steel piston rods are required. Ariel stainless steel piston rod material is 17-4PH in the double H1150 condition, UNS S17400, (per NACE MR-0175), Rc 33 maximum, chromium-nitrided in the packing travel area for a surface hardness of 2500 Vickers. The chromium nitride process has a length limitation due to manufacturing constraints. Longer stainless steel piston rods will be tungsten carbide coated.

Purge Packing

Ariel requires the use of "Purge packing" for sour gas services with 100 ppm and greater H_2S content. The purpose of purge gas is to block and contain hazardous, toxic, flammable or corrosive gases, and to prevent such from entering the compressor frame where damage to the running gear, or personnel safety hazards can occur. The purge gas must be sweet natural gas or an inert gas, such as nitrogen. Purge packing refers to a packing case modified to accept an external purge pressure 15 to 20 psi above the primary packing vent/drain pressure with no more than 5 psi external system back pressure. Refer to Ariel's recommendations in Packager Standards Section 8 Packing and Distance Piece Vent Systems for a purge system for sour gas. See also "Packing Leakage".

When the purged packing option is selected on a long two compartment distance piece, the intermediate and wiper seal sets will be configured for purge along with the pressure packing case. When the purge packing option is selected on a long single compartment for the KBE:K:T, KBU:Z or KBB:V frames, the wiper seal will be configured for purge along with the pressure packing case.

Flushing Lube

Ariel recommends the use of cylinder flushing lube for first stage cylinders for sour gas services with 2% and greater H_2S content. An atomizer for flushing lube injection can be constructed of tubing inserted into the gas stream at the suction pulsation cylinder nozzle with the end opened with a diagonal cut. The Packager would provide the lube lines from the end of the guide to the suction pulsation vessels cylinder nozzle. Flushing lube lines will be tubed to the end of the crosshead guide from the distribution block. Flushing oil is used to ensure corrosion protection for the suction valves, both the valve bodies and springs. Flushing oil is available as an option on all units. If the first stage flushing recommendation for Sour Level 2 is not taken, provisions for flushing on the pulsation vessel nozzle are recommended.

Some cylinders have two nozzles at the suction (dual nozzle and peanut flange). Flushing lube for these two nozzle cylinders is configured for one flushing lube point per cylinder. This is sufficient, considering the flushing lube connection is in the suction pulsation vessel nozzle. If a client wants to apply flushing to both pulsation vessel nozzles, the packager can install a pipe tee to split the single line provided.

Stainless Steel Valves

Ariel standard valve body material is 400 series stainless steel and 1040 carbon steel. These are not suitable for sour gas applications per NACE-MR0175. Ariel recommends the use of NACE compliant stainless steel valves for sour gas services with 2% and greater H_2S content.Stainless steel valves generally consist of:

- Seats and guards: 17-4PH - H1150
- Plates: Nylon, MT or PEEK. 17-7PH or 15-7PH if metallic plates
- Coil springs: Nimonic 90
- Spring plates: stainless steel (equivalent to 420)

It could be prudent to start up a unit with standard valves and replace those with the stainless steel valves after any start up problems have been solved and piping debris has passed through the unit.

NACE Stainless Steel valves are required for Sour Level 1 service in non-lubricated cylinder construction.

Optional Equipment for Sour Gas Service

Cylinder bolting

Standard cylinder bolting for sweet and sour gas services consists of Grade 8 valve cap, head end head, crank end head and packing case cap screws. Cylinder bolts are outside the gas containment and not considered "wetted".Ariel provides an option to replace these bolts with 17-4PH stainless steel bolts for the valve caps, head end head, crank end head and packing case bolting.The 17-4PH fasteners for the heads and packing case are bolts. The 17-4PH fasteners for the valve caps are studs.

Cylinder Body Materials

Standard cylinder body materials are:

- ASTM A278 Grade 40 gray iron
- ASTM A536 Ductile iron 80-55-06
- ASTM A395 Ductile iron 60-40-18
- AISI 4340 Forged steel
- ASTM A668 Class J forged steel

Forged Steel Cylinder Body Materials

Attention must be paid to forged steel cylinder selections for hydrogen sulfide content. The NACE MR-0175 Stress Cracking Region will be used to determine how much H_2S is allowed for AISI 4340 cylinder bodies.Most Ariel forged steel cylinder bodies are manufactured from AISI 4340 high strength carbon steel.This material is not suitable for H_2S content, even as low as 5 to 10 ppm. When even small amounts of H_2S is present, forged steel cylinders will need to be either softened to 22 RC or manufactured of 17-4PH Stainless steel.This will impact most Ariel double acting forged steel cylinders.

Double acting forged steel cylinders that are not suitable for sour gas service, will be flagged in red in the performance software when H_2S is entered into the gas analysis. Most forged steel tandem cylinder arrangements are suitable for H_2S content due to the controlled hardness of 22 RC maximum.

Lube Tubing

Ariel standard cylinder and frame oil system is 304 / 304L stainless steel tubing with zinc plated carbon steel fittings. An option is available to use 316 / 316L stainless steel tubing and 316 stainless steel fittings. This would encompass the frame and cylinder tubing and fittings on a unit. A separate option is available for upgrading welded frame oil piping from carbon steel to 316L stainless steel, both on the pump suction and downstream of the filter on larger units. Fittings and plugs outside the frame and cylinder oil flow are not included in these stainless steel options.

Separate Lube Supply

Provision is made on all units to use a separate oil source for the cylinder bores and packing cases. Ariel standard is to tube from the main frame oil header to the inlet of the cylinder lubricator pumps. The packager can remove this tube, plug the connection at the main frame oil header and connect the separate supply to the inlet of the lubricator pumps. Sour gas services typically require a special lubricant through this separate lube supply. Refer to Section 6 of the Packager Standards for lubrication recommendations.

Wet Gas

Wet Gas is any gas or gas mixture in which one or more of the constituents is at or very close to it's saturated vapor pressure. The constituent may or may not be water vapor. A valid gas analysis is required to verify gas properties.

Special attention must be paid to the gas separation and piping upstream of the compressor. They must be designed such that no free liquids are permitted to enter the compressor or accumulate in the piping or bottles, causing "slugs" of liquid to carry over.

Consideration should be taken for two-phase flow between the gas cooler and the stage inlet separator, if liquids are dropping out between stages. Gas flow rate between stages will also be lowered by the gas equivalent amount of liquids dropping out due to interstage cooling.

When gas condensates are to be avoided, it is appropriate to raise the interstage temperature to create a separation between the interstage temperature and the dew point of the gas. A 20 to 30 F (10 to 15 C) separation is recommended.

Wet gas will tend to dilute the cylinder lube oil. See Cylinder and Packing Lubrication Requirements--6 in the Ariel Packager Standards for guidelines regarding cylinder and packing lubrication in wet gas service.

Gas Method

The gas method refers to the equations of state used to calculate the gas properties such as the ratio of specific heats, or N-value, and the compressibility values, or Z-values.

The Ariel performance software allows the use of either the Hall equation of state (developed by the Chemical Engineering department at Texas A&M University), or the VMG thermal software (developed by Virtual Materials Group). The VMG software uses an APR, Advanced Peng Robinson, equation of state. The VMG software includes a larger number of available gas components and the ability to perform liquid drop-out flash calculations.

The Hall method can be used when running "natural gas" based applications. The advantage of Hall equation of state is its speed when running larger multi-run calculations with natural gas where the speed of the multi-run may be hampered by the VMG calculation method. The HALL method includes water condensate calculations. The Hall equation of state supports 30 gas components.

The VMG method can be used for all applications. The advantage of VMG is its accuracy and condensate flash calculations when running performance on heavy gasses or non-hydrocarbon based gasses. The VMG method performs hydrocarbon liquid drop-out flash calculations as well as water condensate calculations. The VMG equation of state supports thousands of gas components.

Ariel performance software will flag the user if the Hall option is used when the VMG option should be used due to the potential of non-water liquid dropout.

For assistance or questions regarding either gas property calculation method please contact The Ariel Application Engineering Department.

Gas Properties - Air

Gas Name	Chemical Formula	Chemical Family
Air	Air	Non-Flammable Gases
Synonym(s)	Breathing Air, Compressed Air and Medical Air	

Molecular Weight	Critical Pressure (psia)	Critical Temperature (R)	Ratio of Specific Heats
28.975	547	239	1.406
Physical Characteristics		**Solubility**	
Colorless, Odorless		Slightly soluble, but main components are higher soluble.	
Applications or Uses			
Many uses - Combustion, Life Support and Source of Power. Underbalanced Drilling, De-watering.			
Hazards			
Supports Combustion. Exposure at higher pressure can cause physical problems.			
Material Requirements			
Slightly oxidizing characteristics. Can be contaminated by corrosive components (CO_2, NH_3, H_2S etc.). Many applications require non-lube construction. Materials will be designed for continuous duty at 400 F (204 C), however, applications are to be limited to 350 F (177 C) discharge shutdown temperature.			
Lubrication			
Standard guidelines for lube or non-lube service. Special lubricants for greater than 500 psi. Typically use mineral oils when less than 500 psi and a diester when greater than 500 psi. Special precautions should be taken to prevent oil accumulation in piping and heat exchangers, minimize drops or low points. Prevent excessive lubrication. When synthetic oils are to be used, they must also be used during the mechanical run test.			
Comments (see also Air Service topic)			
Proper temperatures must be maintained to prevent carbon build-up (leads to explosive situations) and proper materials for applicable operating pressure must be used. Materials will be designed for 400 F (204 C) continuous duty, however discharge temperatures will be limited to 350 F (177 C) max. Standard performance runs are used, however humidity must be accounted for and when applicable, the inlet filter pressure drops must be accounted for. Sizing must be based on an entire range of operating conditions. Always request all operating conditions.			

Gas Properties - Carbon Monoxide

Gas Name	Chemical Formula	Chemical Family
Carbon Monoxide	CO	Non-Metal Oxide Gas
Synonym(s)	Carbonic Oxide, Carbon Oxide	

Molecular Weight	Critical Pressure (psia)	Critical Temperature (R)	Ratio of Specific Heats
28.010	515	242	1.404
Physical Characteristics		**Solubility**	
Colorless gas with metallic taste and odor		Practically insoluble in water. Soluble in organic solvents containing Benzene	
Applications or Uses			
Fuel. Metallurgy. Chemical Processes. Synthesis Processes.			
Hazards			
Extremely Toxic. Asphyxiant. Extremely Flammable.			
Material Requirements			
Incompatible with strong oxidizers (Chlorine, Bromine...). At temperatures above 900 F, cast iron is attacked by CO. Nickel and Cobalt should be avoided due to corrosion. Natural rubber and neoprene are chemically attacked by CO.			
Lubrication			
Standard lubricating practice recommended for pressures up to 2000 psig. Non-lube applications should be avoided (see notes below).			
Comments			
Due to toxicity of gas, purged packing is always required. Two compartment distance pieces are highly recommended, or long single compartment with a nitrogen buffered packing and purged distance piece. Limit discharge temperature to 255 F(121 C) if possible. Non-lubricated applications should be avoided. Cylinders tend to develop "hot spots" which result in Carbon Monoxide Dissociation. Hard carbon deposits my be formed and CO2 produced. Limit discharge temperatures to 225 F (107 C). Ariel does not quote carbon monoxide applications non-lubricated.			

Gas Properties - Carbon Dioxide

Gas Name	Chemical Formula	Chemical Family
Carbon Dioxide	CO_2	Acid Anhydride
Synonym(s)	Carbon Anhydride, Carbonic Acid, Dry Ice	

Molecular Weight	Critical Pressure (psia)	Critical Temperature (R)	Ratio of Specific Heats
44.010	1073	548	1.300
Physical Characteristics		**Solubility**	
Colorless, Odorless		Soluble in water, alcohol and alkalis	
Applications or Uses			
Urea Plants, Carbonation, Chilling and Freezing, Fire Protection, Chemical and Synthesis Processes, Re-Injection.			
Hazards			
Asphyxiant. When mixed with water, produces Carbonic Acid.			
Material Requirements			
Dependent on operating conditions is be corrosive. Please review the guidelines of the Ariel Applications Manual.			
Lubrication			
Standard guidelines for lube or non-lube service. CO_2 may combine with water to produce Carbonic Acid. This acts as a solvent and tends to dilute cylinder lubricating oil. CO_2 is soluble in mineral oils, which reduces oil/gas mix viscosity. In addition, mineral oils are completely miscible into CO_2, thereby reducing the quantity of lubricant at the lube site. Compounding or PAG synthetics are commonly used. Follow guidelines of Ariel Packager Standards.			
Comments (see also Carbon Dioxide Service topic)			
When used in Re-injection or Urea plants, the gas is compressed to higher pressures and may reach critical point or dense phase region at interstage pressures. Due to the critical temperature (88 degrees F) and pressure of 1073 psia, it is imperative to monitor interstage pressures and temperatures. If interstage pressures are near critical or above, it may be necessary to control temperatures out of the intercooler to ensure there is a margin above critical temperature or dense regions.			

Gas Properties - Ethylene

Gas Name	Chemical Formula	Chemical Family
Ethylene	C_2H_4	Alkenes, Aliphatic Hydrocarbons
Synonym(s)	Bicarburated Hydrogen, Acetene, Elayl, Etherin	

Molecular Weight	Critical Pressure (psia)	Critical Temperature (R)	Ratio of Specific Heats
28.050	748	509.5	1.255
Physical Characteristics		**Solubility**	
Flammable, Colorless, Slightly sweet odor		Soluble in water and alcohol. Dilutes lube oil.	
Applications or Uses			
Manufacture of Ethylene Glycol. Plastics at higher pressures. Food Processing. Also used as an illuminant with other gasses for lighting. Generally used at relatively higher pressures. .			
Hazards			

Molecular Weight	Critical Pressure (psia)	Critical Temperature (R)	Ratio of Specific Heats
Asphyxiant. Dispersible over a large area and does not dissipate into atmosphere. Long range ignition possible. Handle in well ventilated area.			
Material Requirements			
Non-corrosive. Standard materials apply.			
Lubrication			
Standard guidelines for lube or non-lube service. Has a tendency to dissolve into lube oil, thereby reducing oil viscosity.			
Comments			
No special problems with compression. However, in the event ethylene oxide can be formed, extreme care is required. In certain cases, Ethylene Oxide and copper can combine to form Acetylene. If Ethylene Oxide is present, do not use yellow metals.			

Gas Properties - Helium

Gas Name	Chemical Formula	Chemical Family
Helium	He	Inert Gas
Synonym(s)	Helium USP	

Molecular Weight	Critical Pressure (psia)	Critical Temperature (R)	Ratio of Specific Heats
4.003	33.2	9.47	1.666
Physical Characteristics		**Solubility**	
Colorless, Odorless, Tasteless		Slightly soluble in water. Readily absorbed by oil.	
Applications or Uses			
Leak Testing, Zeppelins, Mixed with oxygen for diver breathing tanks. Typically higher pressure applications, greater than 1000 psi.			
Hazards			
Asphyxiant. Handle in well ventilated area. Lighter than air, collects in overhead pockets. Difficult to detect leakage.			
Material Requirements			
Non-corrosive. Standard materials. Piston rings, riders and packing ring materials need to be reviewed.			
Lubrication			
Standard guidelines for lube or non-lube service.			
Comments			
Requires Helium leak test. Follow guidelines for Low Molecular Weight as detailed in Ariel Applications Manual. Due to the extremely high Ratio of Specific Heats, closely monitor discharge temperatures. Even though Helium has twice the molecular weight of Hydrogen, it tends to be more difficult to seal. Elastomer seals are prone to leakage. Special seals may be required and a double seal arrangement is quite common, if not required.			

Gas Properties - Hydrogen

Gas Name	Chemical Formula	Chemical Family
Hydrogen	H_2	Flammable Gasses
Synonym(s)	Molecular Hydrogen	

Molecular Weight	Critical Pressure (psia)	Critical Temperature (R)	Ratio of Specific Heats
2.016	188	61	1.410
Physical Characteristics		**Solubility**	
Colorless, Odorless, Lighter than air		Slightly soluble in water. Higher solubility in oil.	
Applications or Uses			
Hydro-cracking, Hydro-treating and various other industrial uses. General operating ranges: 800 to 1000 PSI for pipelines and approx. 2500 PSI for Hydrocracking.			
Hazards			
Explosive, Flammable. Difficult to detect. Lighter than air therefore accumulates in overhead pockets. Asphyxiant. Should be handled in well ventilated areas. Difficult to detect, flame is invisible in daylight. Leak test by soap bubble.			
Material Requirements			
Non-corrosive. Standard materials are commonly used. Cast iron cylinders are acceptable. At higher pressures >1000 PSI generally use ductile iron or steel. Piston rings, riders and packing ring materials need to be reviewed.			
Lubrication			
Standard guidelines for lube or non-lube service.			
Comments			
Requires Helium Leak Test. Follow guidelines for low molecular weight as detailed in Ariel Applications Manual. Limit discharge temperature to 275 degrees F or less.			

Gas Properties - Methane

Gas Name	Chemical Formula	Chemical Family
Methane	CH_4	Alkane
Synonym(s)	Marsh Gas, Natural Gas, Methyl Hydride	

Molecular Weight	Critical Pressure (psia)	Critical Temperature (R)	Ratio of Specific Heats
16.040	673	343.7	1.310
Physical Characteristics		**Solubility**	
Colorless, Odorless, Tasteless		Slightly soluble in water. Soluble in alcohol and most petroleum products.	
Applications or Uses			
Fuel or Chemical use			
Hazards			
Flammable. Explosive. Asphyxiant. Lighter than air so collects in overhead pockets. Handle in well-ventilated areas.			
Material Requirements			
Standard materials of construction			
Lubrication			
Standard guidelines for lube or non-lube service.			
Comments			
No special considerations for compression.			

Gas Properties - Natural Gas

Gas Name	Chemical Formula	Chemical Family
Natural Gas	CH_4 + HC's	Alkane
Synonym(s)	Sweet Gas, Marsh Gas, Natural Gas, Methyl Hydride	

Molecular Weight	Critical Pressure (psia)	Critical Temperature (R)	Ratio of Specific Heats
18.910	670	382	1.288
Physical Characteristics		**Solubility**	
Colorless, Odorless, Tasteless (See Comments)		Slightly soluble in water. Soluble in alcohol and most petroleum products.	
Applications or Uses			
Fuel or Chemical use			
Hazards			
Flammable. Explosive. Asphyxiant. Lighter than air so collects in overhead pockets. Handle in well-ventilated areas.			

Molecular Weight	Critical Pressure (psia)	Critical Temperature (R)	Ratio of Specific Heats
Material Requirements			
Standard materials of construction			
Lubrication			
Standard guidelines for lube or non-lube service.			
Comments			
Natural Gas mixtures vary dependent on the where and how it is produced. The mixture used for Physical Properties shown is a clean, dry, "sweet natural gas" with the following composition: 85% Methane, 10% Ethane, 3% Propane, 1% Butane, 0.5% Nitrogen and 0.5% CO_2. The information is to be used as a guideline. Special care must be taken to determine the presence of water, H_2S and debris. Residential (and some commercially applied) Natural Gas has an odorant added to aid in leak detection.			

Gas Properties - Nitrogen

Gas Name	Chemical Formula	Chemical Family
Nitrogen	N_2	Inert Gas
Synonym(s)	Nitrogen NF	

Molecular Weight	Critical Pressure (psia)	Critical Temperature (R)	Ratio of Specific Heats
28.010	493	227	1.404
Physical Characteristics		**Solubility**	
Colorless, Odorless		Slightly soluble in water and alcohol.	
Applications or Uses			
Fertilizer Production, Purge Gas, Injection			
Hazards			
Asphyxiant. Titanium will burn in the presence of pure nitrogen.			
Material Requirements			
Non-corrosive. Standard materials of construction. Piston rings, riders and packing rings need to be reviewed.			
Lubrication			
Standard guidelines for air apply.			
Comments			
Closely monitor discharge temperature. Bone dry nitrogen can cause problems with packing, rings, and wear bands. Ensure that materials are selected for the specific moisture content.			

Gas Properties - Propane

Gas Name	Chemical Formula	Chemical Family
Propane	C_3H_8	Alkane - Hydrocarbon
Synonym(s)	Dimethylmethane, LP-Gas, LPG	

Molecular Weight	Critical Pressure (psia)	Critical Temperature (R)	Ratio of Specific Heats
44.090	661	666	1.14
Physical Characteristics		**Solubility**	
Colorless. Liquefied, flammable gas with a Natural Gas odor. Turns gaseous at atmospheric pressure and temperature.		Almost insoluble in water, but highly soluble in alcohol and petroleum products.	
Applications or Uses			
Fuels. Used as a solvent. Refrigerant Applications. Food additive. Aerosol propellant.			
Hazards			
Asphyxiant. Very heavy gas, collects in low level areas. Dispersible over a large area and does not dissipate into atmosphere. Long range ignition possible. Handle in well ventilated areas.			
Material Requirements			
Standard materials of construction. Due to typical low temperatures in many applications, must ensure all materials are acceptable for temperature.			
Lubrication			
Has a tendency to dissolve into lube oil, thereby reducing oil viscosity.			
Comments (see also Propane Service topic)			
In propane applications, it is very important to analyze gas mixture to verify properties at actual operating conditions. In lower suction temperature applications, like refrigeration service, the first interstage may not require cooling.			

Performance Application Limits

Critical Projects

Critical Projects are those projects that are more complex and have a greater potential for operational issues if special attention is not applied early in the project. Ariel would like to assist in the review of critical projects and therefore has included a flag in the performance software identifying the projects that fall in this category.

Critical Projects are defined by a review of:

Application Type:

- Gas Transmission
    - Wide Range of Operating Conditions
    - Wide Range of Capacity Control Steps including Single Acting Cylinders
    - Large drivers
    - Difficult Valve Selection due to the Wide Operating Range
    - Complex Acoustic Responses
- Storage Injection and Withdrawal
    - Higher Pressures
    - Attention to Cylinder Lubrication
    - Water cooled packing cases
    - Wide Range of Operating Conditions
    - Difficult Valve Selection due to the Wide Operating Range
- PRC (Petroleum / Refinery / Chemical)
    - Industrial Gasses
    - More Stringent Specification Limitations
    - New Customer base

Equipment Type:

- Large Frames
    - KBU, KBZ, KBB and KBV
    - Some JGC, JGD and JGF
    - Large Two Throw Frames
    - Requiring Special Tools for Maintenance
- Pipeline Cylinders
    - High Flows with Large Piping
    - High Frequency Components
    - Large, Low Natural Frequency Cylinders
- VS Forged Steel Cylinders
    - High Pressure
    - Lubrication
    - Water Cooled Packings
    - Available Tailrods

Driver Type;

- Electric Motor
    - Unique Installations
    - Shaft Sizing Restrictions (see Packager's Standards)
    - Always Requiring Torsional
    - Often Requiring Torsional Detuning Devices (flywheels, detuners, special couplings...)
- VFD (Variable Frequency Drive)
    - Unique Installations
    - Shaft sizing restrictions
    - Always Requiring Torsional
    - Often Requiring Torsional Detuning Devices (flywheels, detuners, special couplings...)
    - Wide range of speeds, often with blackout ranges due to torsional response
- Large Gas Engines
    - High horsepower - high excitation forces
    - Longer drive trains
    - Often Requiring Torsional Detuning Devices (flywheels, detuners, special couplings...)
    - Some larger engines designed for power generation may require special couplings and attention to torsional results
- Gear Boxes

- Difficult to detune torsionally
- Most often requiring special couplings
- Axial and Lateral Alignment Concerns including Thrust Limitations

Location:

- Offshore and FPSO
  - Limited Access
  - Limited Space for Maintenance
  - High Visibility
- International Destinations
  - Less Support Infrastructure in some Regions

Other:

- Sour Gas
  - Proper Materials
  - Purge and Vent Systems
- Pneumatic Fixed Volume Clearance Pockets
  - Supply and vent lines
  - Complex controls

Project Reviews

Many Critical Projects can be successful with a comprehensive review of the system during different phases of the project:

1. Budget and Quotation Phase
   - Regional Sales Managers and Applications Engineering can provide assistance in selection
2. Order Phase
   - Order Entry can provide assistance with scope of supply
   - Applications Engineering can provide assistance with documentation, including torsional data
   - Tech Services can provide assistance with packaging design for maintenance support and vibration avoidance
3. Installation and Start-Up Phase
   - Tech Services can provide assistance with installation review, start-up checklist review, review of vibration concerns

Torsional Providers

The success of the torsional analysis depends heavily on the modeling of the equipment and operating range of the compressor. A torsional provider must be familiar with moderate to high speed reciprocating compressors and must be provided with the full range of operation of the compressor. The operating range is to include part load cases, cases with single acting cylinders and speed variations. Familiarity with Ariel compressors is quite helpful in understanding aux end amplitudes, the availability of the torsional data (mass elastic data, torque effort data and fourier coefficient data) and availability of specific flywheels, detuners and internal flywheels.

Acoustical and Mechanical Providers

Familiarity to moderate and high speed reciprocating compressors will aid in the successful acoustical and mechanical analysis. Some larger skids and many platform mounted skids may require a skid analysis to ensure vibration levels and stress levels of skid, piping and vessels are acceptable.

Torsional and Acoustical analyses may have interfering recommendations. More complex the operating ranges have a greater chance of interference between the torsional, acoustical and mechanical systems.

High Discharge Pressure

Applications with high discharge pressures (greater than 1500 psig) have several design details to consider:

Higher pressure applications will require special review of the cylinder lubrication oil selection as well as lubrication rates. Separate lube oil supply and heavier lube oils will be required. Refer to Packager Standards Section 6: Lubrication.

Higher pressure applications may have gas condensates between stages, or operate close to critical points or dense phase regions. This will require special considerations for interstage temperature controls. The Heavy Gas, CO2 and Sour Gas topics can provide further information on this topic.

Higher pressures may require water cooled packing cases, or limitations on piston speed. The Packager Standards and the performance software will help guide the application for water cooled packings and pressure versus speed limitations.

Much higher pressure applications will utilize forged steel cylinders. A closer review for crosshead pin reversal across the operating speed range must be made to ensure sufficient reversal.

The use of the higher pressure forged steel cylinders will require a closer review of hydrogen sulfide content. Not all of the forged steel cylinders are suitable for operation with hydrogen sulfide content.

Low Suction Pressure

At suction pressures below 10 psig it is difficult for the end user to predict what the actual supply pressure will be within 1 to 2 psi and/or for the packager to predict pressure drops within a fraction of a psi. These variations in inlet pressure and pressure drops can result in a significant change in horsepower and flow, either upward or downward, depending upon the actual suction pressure.

Ariel recommends that compressor cylinders in this application be oversized between 5 to 10% and equipped with variable volume clearance pockets or high clearance valve assemblies to produce the desired flow. The effect of the actual suction pressure being 1 to 2 psi higher or lower should be considered when selecting the driver horsepower rating.

Vacuum Suction Pressure

Vacuum suction pressures can be applied to Ariel cylinders. The sensitivity of changes in suction pressure should be reviewed, as in the above Low Suction Pressure paragraph. Additionally, the mean cylinder pressure should be maintained above atmospheric pressure. If the mean cylinder pressure is less than 5 to 10 psig, air may be pulled into the cylinder and into the gas stream through the packing cases. If operating below 5 to 10 psig mean cylinder pressure, a purged packing can be applied, using sweet gas for the purge gas. This provides process or fuel gas to be drawn into the cylinder across the packing, rather than air. Consider installing an oxygen sensor downstream of any negative suction pressure equipment.

Maximum Allowable Discharge Temperature

The discharge temperature limits are presented as both an application limit and a maximum discharge temperature shutdown set point. The Ariel Performance Software provides a blue and red flag on discharge temperature. The blue flag represents a guideline for applying a selection. The red flag represents the maximum discharge temperature shutdown set point. The maximum discharge temperature shutdown set point is listed in the instrumentation section of the Packager Standards.

Table: Discharge Temperature Flags and Limits by Service

Service	Application Limit	Max Shutdown
Lubricated	330 °F (165 °C)	350 °F (177 °C)
Non-Lubricated	275 °F (135 °C)	325 °F (163 °C)
PRC	275 °F (135 °C)	325 °F (163 °C)
Hydrogen Rich	275 °F (135 °C)	300 °F (149 °C)

The Ariel performance software will provide a red flag if the discharge temperature exceeds the maximum allowable discharge temperature shutdown limit. A blue flag will be provided when the discharge temperature exceeds the application guideline, a warning as the discharge temperature approaches the maximum allowable level. A warning will also be displayed when the average of the suction temperature and discharge temperature exceeds 285 F (140 C).

The discharge temperature calculated by current version of the Ariel Reciprocating Performance Program, is based on suction temperature plus cylinder pre-heat and internal compression ratio. The equation is as follows:

$$T_D = \left[\left(T_S + 460\right) x\, R^{\frac{(k-1)}{k}}\right] - 460$$

or

$$T_D = \left[\left(T_S + 273\right) x\, R^{\frac{(k-1)}{k}}\right] - 273$$

for metric units

TD = Discharge Temperature, °F or °C

TS = Internal Suction Temperature, °F or °C

R = Internal Compression Ratio , pressure discharge / pressure suction

k = Ratio of Specific Heats

High discharge gas temperature shutdowns should be set as close as practical to the operating temperature.

Maximum Allowable Working Pressure

The maximum allowable working pressure is the maximum continuous pressure for which Ariel has designed the cylinder when handling the specified fluid at the maximum temperature. Relief valves shall be provided and set to operate at no more than the Maximum Allowable Working Pressure. The MAWP is based upon the minimum of the following considerations:

- Burst test pressure (adjusted by a safety factor which is dependent on cylinder body material)
- Allowable bolt loading
- Flange rating
- Alternate cylinder bolting (17-4PH bolting). Current cylinder MAWP are not reduced in

most cases when "Sour Gas" bolting is used. The NACE MAWP are listed in the DataBook for the exceptions (17-7/8K:T:C:D:Z:U Class cylinders).

The Ariel DataBook lists only current MAWP ratings. Many cylinders have been uprated over time. Always check the cylinder nameplate for the MAWP when calculating compressor performance for existing equipment.

Maximum Allowable Internal Gas Rod Load

Ariel gas rod load ratings are based upon calculated internal gas rod loads. The maximum allowable gas rod load of a given frame shall not be exceeded at any operating point. Refer to Ariel Calculation Method for internal gas rod load equations.

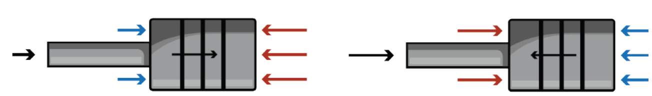
Gas rod load is best monitored for alarm and shutdown with the use of a differential pressure switch across each cylinder at the flange (cylinder discharge pressure minus cylinder suction pressure). The performance software and the rod load charts from the DataBook are available to assist in determining the differential pressure settings.

If the operating conditions are to include the relief valve set pressure, the compressor gas rod load must be maintained within the gas rod load limit, either by not exceeding the gas rod load limit at relief valve set pressure or by applying a shutdown switch on differential pressure across the cylinder. The relief valve is meant to protect the pressure equipment from exceeding system pressure ratings. Relief valve set pressures are discussed in the Packager Standards Section 4.

The Ariel DataBook lists gas rod load ratings for both current and inactive frames. Always check the frame nameplate or contact the Ariel Response Center for the maximum allowable internal gas rod load when calculating compressor performance for existing equipment.

Minimum Allowable Pin Load Reversal

Crosshead pin reversal is a reversal of compression and tension loads at the crosshead pin to connecting rod bushing. Without proper reversing loads, the bushing will not be provided with sufficient lubrication and bushing failure will occur. Pin reversal is defined by two components, degrees and percent. These represent the duration of the reversal and the magnitude of the reversal. Both of these values must meet or exceed minimum values. Ariel's requirements for reversal are 30 degrees of crank rotation, and 25% magnitude. The percent magnitude is defined by the smaller of the tension or compression force divided by the larger of the two. The combined gas plus inertia loading at the crosshead pin is used for the reversal calculations. The inertia load component includes the weights of the piston and rod assembly, balance nut and crosshead with crosshead bushings.



Some smaller frames are rated for lower reversal values, 30 degrees and 15%.

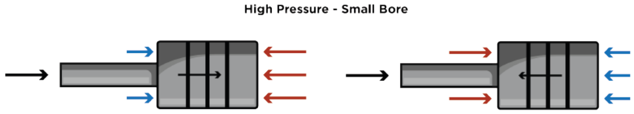
Ariel’s Reciprocating Compressor Performance Program provides the reversal values and will flag upon insufficient reversal. A full review for reversal will need to include the range of speed, pressure and any single acting conditions. The multi-run function is an invaluable tool in reviewing reversal values.

The ratio of compression to tension gas rod load can indicate reversal may be of concern. If compression gas rod load is much higher than the tension gas rod load, reversal may be a concern and should be reviewed.

There are several specific situations and configurations that should be reviewed in the multi-run function across the full range of speed, pressure, and load steps for sufficient reversal. These include:

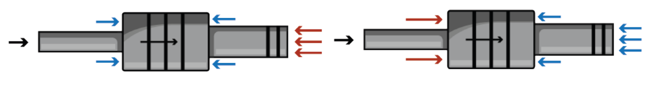
High Pressure Service:

High pressure on smaller bore cylinders operating at lower compression ratios can see a notably higher compression gas rod load than that in tension. Possible solutions include selecting a larger cylinder bore, selecting a tail rod cylinder configuration, or increasing the balance weight (crosshead and balance nut).



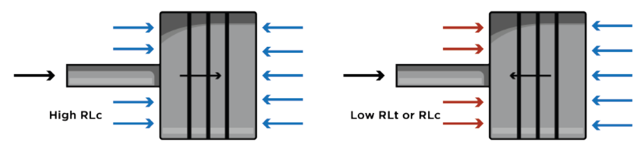
Tandem cylinders:

Tandem cylinders may see sufficient reversal at the maximum and minimum speed, while insufficient reversal somewhere in between. Adding balance weight will move this dip in the reversal curve, but not often completely out of the operating speed range. Possible solutions include selecting a larger crank end cylinder bore (then add clearance if needed), increasing the balance weight, or limiting operating speed.



Single acting cylinders:

Single acting at lower compression ratios results in longer periods of gas rod load in compression. At lower speeds reversal can be insufficient to offset the gas compression load. Possible solutions include increasing the balance weight or limiting the lower end of the speed range.



Maximum Allowable Reciprocating Weight

Each compressor frame has a maximum allowable reciprocating weight limit. This weight is based upon the total combined weight of the connecting rod assembly, crosshead assembly, crosshead nut and piston / rod assembly. The maximum allowable reciprocating weight limits are included in the limitations set within the Ariel performance program.

Reciprocating weight will affect the inertia load, and therefore the combined rod load. Ariel publishes internal gas rod load limits, and maximum allowable reciprocating weights, rather than combined rod load limits.

Ariel's performance program will monitor maximum reciprocating weights versus rotative speed and provide application limitations within the weight balance section.

Refer to Ariel Corporation Electronic DataBook Cylinder Details for rotative speed limitations for the various frames and cylinder classes.

Rated Speed (Maximum Allowable Rotating Speed)

Each frame has a rated (maximum allowable rotating) speed. This is the highest allowable rotating speed for continuous operation. The driver overspeed shutdown must be set no higher than 10% over the rated speed of the compressor.

Some large bore cylinders are limited to a maximum operating speed that is less than the frame rated speed. See the Ariel Corporation DataBook cylinder details for rotative speed limitations.

See Also Rated Speed (Minimum Allowable Rotating Speed)

Rated Speed (Minimum Allowable Rotating Speed)

Many factors affect how slow the compressor can be operated. These include oil supply pressure to the frame, crosshead pin load reversal, valve dynamics, and torsional / acoustical considerations.

Ariel Compressor frames are designed to have adequate frame oil supply pressure down to one half their rated rotating speed. If operation at less than half speed is desired, the addition of a motor driven auxiliary lube oil pump is required to maintain adequate lube oil pressure and flow. The additional flow of the auxiliary oil pump will maintain the frame oil pressure required for proper operation. Removal of the main frame oil pump is not necessary.

Lack of adequate crosshead pin load reversal can limit the minimum operating speed. An analysis of the crosshead pin forces must also be performed to ensure that the proper amount of pin force reversal is present at all operating speeds and load steps.

Compressor valves are selected for a specific operating condition with some flexibility for variations for speed and operating conditions. A general rule of thumb for valve selection is that a single selection can be operated within a 2:1 maximum speed range. Varying suction pressures, discharge pressures and gas analyses can further limit this speed range. Low lift valves may be necessary for speed ranges outside a 25% variation.

Speed ranges must be considered in the torsional and acoustical analyses. Wider speed ranges in combination with wide ranges in operating conditions and load steps may result in black out speeds due to natural frequency interferences.

All applications requiring rotative speeds that are lower than one half the rated speed of the frame, must be reviewed by Ariel Corporation Applications Engineering.

Also See:

Frame Driven Lube Oil Pumps

Rated Speed (Maximum Allowable Rotating Speed)

Maximum Allowable Piston Speed

Ariel compressors are designed to be operated at full speed for most natural gas applications. Slower piston speeds may be necessary based upon the application. Factors that affect lowering the operating piston speed include gas mole weight, higher discharge pressures, desire for better efficiency and client preferences.

Piston speed can be calculated with the following equation:

$$PS = \frac{2 \text{ x } Stroke \text{ x } RPM}{12}$$

PS = Average Piston Speed, feet per minute

This equation calculates average piston speed, which is the basis for piston speed related ratings. Instantaneous piston speed is different, since the piston accelerates from zero velocity at the end of the stroke, and obtains a maximum velocity during the stroke.

Some larger bore cylinders have limited piston speeds due to the higher inertia. For maximum piston speed see individual cylinders in the DataBook.

For non-lube applications, allowable piston speeds are reduced. See application guidelines for non-lube applications for more information.

Frame Horsepower Limits

Ariel Compressor frames are not horsepower limited. Ariel compressor frames are limited by internal gas rod load. The published horsepower ratings are guidelines to be used in applying each compressor frame. The horsepower ratings may be exceeded, as long as other application limits are not exceeded. A torsional analysis should be performed to confirm vibratory torque limits are not exceeded.

Some frames carry a power limit on each throw. This limit is flagged separately, and is speed dependent. The KBK:T frame includes a power per throw limit.

Minimum Volumetric Efficiency

Volumetric Efficiency (VE) is the ratio of the actual delivered gas volume to the swept volume of the cylinder. For additional information refer to the compressor theory

The minimum allowable suction volumetric efficiency for any cylinder end at a proposed operating point is 15%. These limits are set to allow proper valve dynamics.

It is recommended to allow a usable margin to this minimum VE for operation outside normal operating conditions. A 30% VE at normal operating conditions will allow some margin for unforeseen operating conditions or clearance pocket usage.

Low volumetric efficiencies will result in higher than expected discharge temperatures, higher than expected horsepower per million and lower than expected capacity. Low volumetric efficiencies will result in poor valve dynamics leading to possible early valve failure.

Discharge volumetric efficiency must be measured in time rather than percent. Refer to Discharge Event

for information and limits on discharge volumetric efficiencies.

Pseudo-Q Value

(Courtesy Hoerbiger Corporation of America)

The "pseudo-Q value" is a term used at Hoerbiger which is an indicator of the "adequacy" of a valve. In other words, is there enough or too little valve for the application?

The pseudo-Q value is a dimensionless value developed by Hoerbiger and Ariel to indicate the adequacy of a compressor valve. It is defined as the average pressure drop through the valve divided by flange pressure, expressed as a percentage. The pseudo-Q value must be between 1% and 15%. With high and low pseudo-Q values the compressor calculation model is not able to accurately predict the horsepower losses, preheating of the gas during the intake event or the volumetric efficiency (capacity).

On the suction valves the Q - value is the pressure drop across the valve in percent of line pressure:

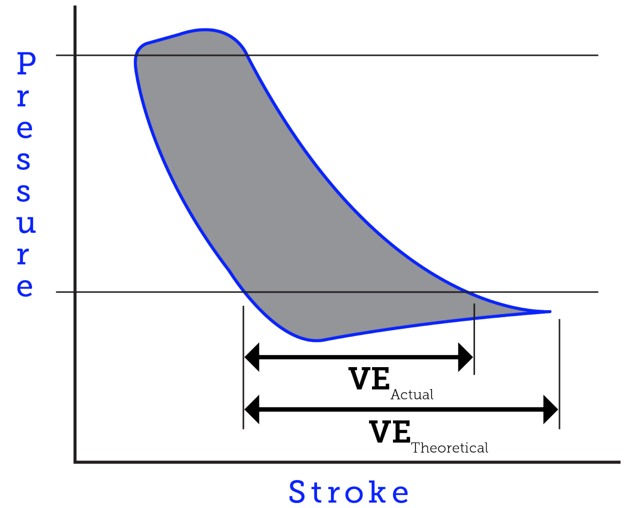
$$q = \frac{\pi^2 \rho_s V^2}{8 P_s} = \frac{\Delta P}{P_s}$$

where *Ps* = gas density

Ps = suction pressure

V = mean valve velocity (calculated with equivalent area)

Figure: Theoretical vs. Actual VE

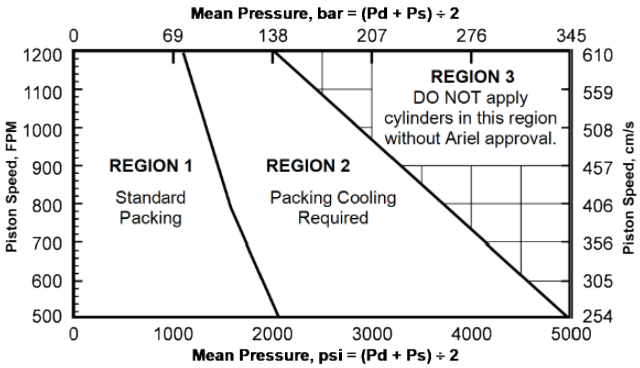


Ariel and Hoerbiger require Pseudo-Q values between 1% and 15%

- Pseudo-Q value less than 1%
  If Q drops below 1%, it becomes difficult to achieve good valve dynamics, since the pressure drop which the valve springs work against is too low and a tendency towards valve flutter is great. This is what is commonly referred to as having "too much valve". This can happen when compressing low molecular weight gases (hydrogen, helium, etc.). The solution is to lower the valve lift, lowering lift area and equivalent area, and creating a larger pressure drop across the valve.
- Pseudo-Q value greater than 15%
  If Q is 15% or higher, the pressure drop across the valve is too high for the cylinder pressure to recover to line pressure at the end of the suction stroke. The valve does not close at the end of the stroke as designed. Gas backflows through the valve as the piston is beginning the compression stroke, which slams the valve closed. Volumetric efficiency is also reduced since the cylinder does not have a full charge of gas (due to a backflow out of the cylinder bore), in addition to the high horsepower losses associated with the large pressure drop across the valve. High q-values can occur when compressing high molecular weight gases(CO_2, propane, etc.). In most cases, lift cannot be added to valve without sacrificing durability. Slower rotating speeds will lower q-values by decreasing piston speed and gas velocity through the valve. Selecting a different cylinder may result in lowering the pseudo-Q value due to valve flow areas differences., etc.).

Cooled Packings

Figure: Packing Cooling Application Guidelines



Cooled packing cases are required for compressor cylinders based upon the average piston speed and average cylinder pressure. Cooled packing cases are supplied to help remove the heat generated as the piston rod/ packing friction increases with the higher pressures and piston speed.

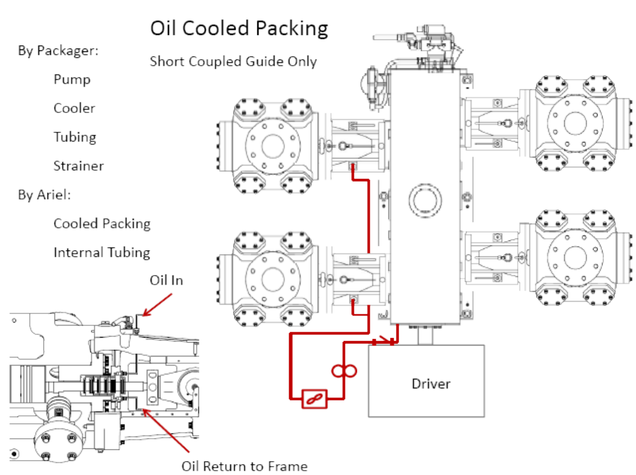
Please refer to the Packager Standards Section 7: Cooled Packing for further information on this topic. The following chart is an excerpt from the Cooled Packing topic:

Notes:

1. The Ariel Performance Software will indicate when operating conditions fall within Region 2 or Region 3.
2. All forged steel cylinders have cooled packing as standard and must be connected to a cooling system.
3. All non lubricated cylinders have cooled packing as standard and must be connected to a cooling system.
4. Any deviation from the packing cooling requirements must be reviewed and approved by Ariel Applications Engineering or Technical Services.

Cooling with oil is not as effective due to the lower heat transfer ability and higher pressure losses due to viscosity. In some circumstances, oil can be used as a coolant in the packing cases. This is limited to lower heat load conditions and smaller compressor frames. The advantage of applying oil cooling in the smaller frames, is the ability to use frame oil, making it possible to cool the packing case with the short coupled distance piece. Oil will be taken from the frame oil system, and returned internally, directly into the crosshead guide.

If one packing case is oil cooled on the smaller frames, the oil will be taken from the pressurized frame oil system. This is a closed loop and all tubing provided by Ariel. If more than one packing is oil cooled, a separate oil loop will need to be provided by the packager. Oil can be taken from the sump at the drive end of the frame, through a pump, cooler, and into the packing. The packing return will be internal, directly into the crosshead guide. Below is a schematic showing oil cooling on more than one packing case.



Non Intercooled

At times, more commonly with refrigeration units, interstage gas cooling may not be necessary due to low discharge temperatures from the low gas k-value. Operating without an interstage gas cooler can be done with special considerations.

The suction temperatures to each stage, and mean cylinder gas temperatures must be limited as noted in the Suction Temperature topic.

All considerations for condensation must be reviewed and confirmed to avoid condensation at the interstage. Condensate considerations include periods of shutdown / cool down and compressor cylinder lube oil carry over. Interstage liquid removal should be considered.

A bottom suction cylinder arrangement may be possible on some applications to allow interstage piping routing from the top of one stage to the top of the next stage, avoiding areas that can trap liquids on the interstage.

All non-intercooled applications must be reviewed and approved by Ariel Mount Vernon prior to quotation.

Capacity and Load Control

The pressure and flow conditions for which the compressor is designed and/or operated can vary across a wide range. The three primary reasons for changing the capacity of a compressor are process flow requirements, suction or discharge pressure management, or load management due to changing pressure conditions and driver power limitations. Several methods can be used to reduce the effective capacity of a compressor. The "best practice" order of the unloading method is included in the table below.

Preferred Order of Unloading Method	
Required Action	**Method Of Unloading**
Reduce Flow	1 Reduce Speed 2 Add Clearance 3 Single Acting Cylinders 4 Bypass to Suction 5 Throttle Suction Pressure
Reduce Torque	1 Add Clearance 2 Single Acting Cylinders (speed dependent) 3 Throttle Suction Pressure
Maintain Suction or Discharge Pressure	1 Reduce Speed 2 Add Clearance 3 Bypass to Suction 4 Single Acting Cylinders 5 Throttle Suction Pressure

1. The use of driver speed for control can be one of the most effective methods for capacity reduction and suction and/or discharge pressure management. The available power of the driver will decrease as the speed is decreased. The compressor power efficiency increases as the speed decreases due to lower gas velocities creating lower valve and cylinder losses.
2. The addition of clearance will reduce capacity and required power through a decrease in the volumetric efficiency of the cylinder. Methods of adding clearance are the following:
   - High Clearance Valve Assembly
   - Variable Volume Clearance Pockets
   - Pneumatic Fixed Volume Clearance Pockets
   - Double Deck Valve Volume Pockets
3. Single acting cylinder operation will reduce capacity through cylinder end deactivation. Cylinder head end deactivation can be accomplished by removing the head end suction valves, installing head end Suction Valve Unloaders, or installing a head end bypass unloader. Refer to Single Acting Cylinder configuration for further information.
4. Bypass to suction is the recycling (bypassing) of gas from the discharge back to suction. This reduces the downstream capacity. Bypassing gas from discharge back to suction does not reduce the power consumption (unless fully bypasses for zero flow downstream).
5. Suction throttling (artificially lowering the suction pressure) reduces the capacity by lowering the actual flow into the first stage cylinder. Suction throttling can reduce power consumption, but may have an impact on the discharge temperatures and rod loads generated by the higher compression ratio.

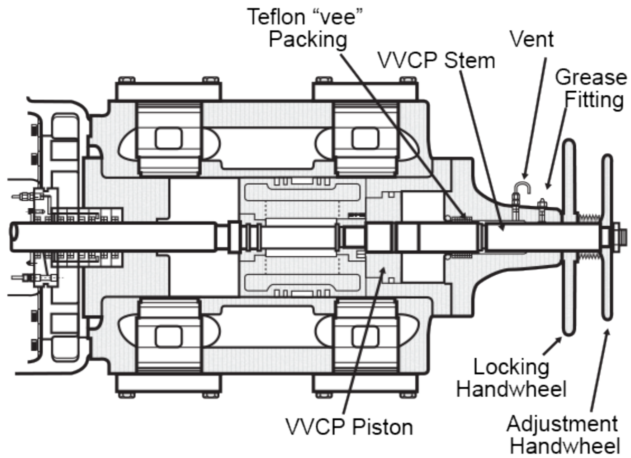
Capacity control methods can have an impact on various performance characteristics besides flow and power. Partial load conditions should be reviewed for acceptable performance including valve lift selection and dynamics, volumetric efficiency, discharge temperatures, rod reversal, gas rod loads, torsional and acoustical response.

Automated capacity control sequences must be communicated so that the same set of loading steps is considered in the acoustical analysis, torsional analysis and control panel logic.

Compressor valves are selected to have optimum dynamic motion at one operating condition, and have some flexibility for off conditions. A general rule of thumb for speed impacts on valve dynamics is that a single valve selection can be operated with a 2:1 maximum speed range. This may be limited with a minimum speed. Operation below half frame rated speed may see reduced valve life. Varying suction pressures, discharge pressures and gas analyses can further limit this speed range. Low lift valves may be necessary for speed ranges outside a 25% variation. When applying variations in speed and single acting cylinder configurations the torsional and acoustical response analysis will be much simplified by applying single acting configuration only at one given speed.

Variable Volume Clearance Pockets

A VVCP is used to change the clearance volume of the head end of a cylinder. The amount of clearance will vary depending upon the position of the clearance pocket piston. Clearance is added to the cylinder by turning the piston / stem assembly counter clockwise (CCW).

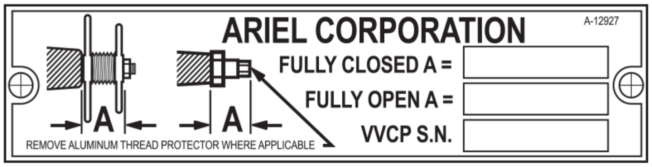


Most compressor cylinders can be equipped with variable volume clearance pockets. The VVCP is mounted in place of the head end cylinder head. The VVCP includes an adapter, piston, seal ring, stem, Teflon vee packing, turning handle and locking wheel.

The expected change in compressor flow and absorbed power will depend upon the application compression ratio and the properties of the gas being compressed. Always check to see that the head end suction volumetric efficiency or discharge event are within limit when setting the pocket.

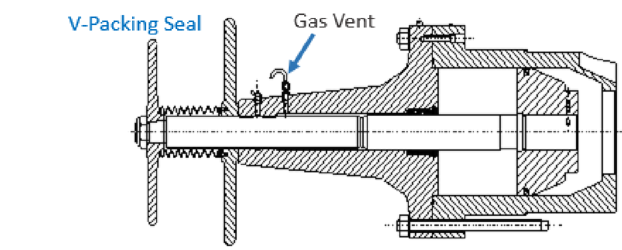
To set the VVCP at the desired percentage open, fully close the VVCP, and then fully open it, counting the number of turns to the full open position. Fully close the VVCP. Multiply the number of turns by the desired percentage open, and turn the VVCP open the resulting number of turns.

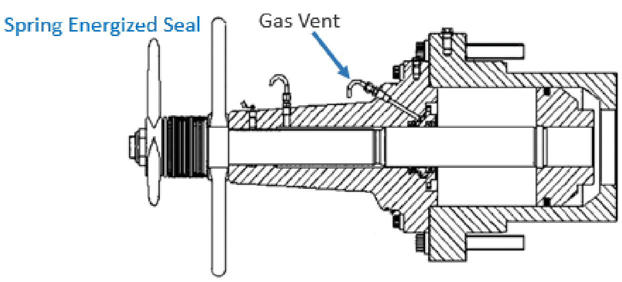
The pocket position can be measured with a ruler on site. A pocket position nameplate is attached to newer pockets showing the measurements for open and closed. This data can also be found in the Ariel Performance Software.



Refer to the compressor cylinder DataBook for available VVCP for each cylinder.

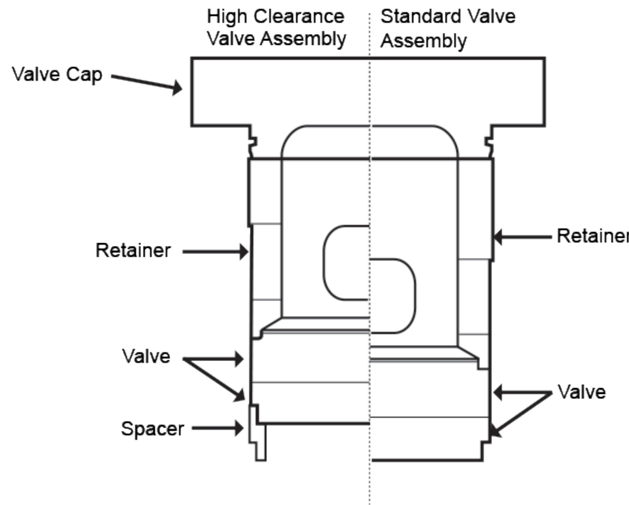
The vent on the VVCP will be one of two configurations. K, T, C, D, F, U, Z cylinder classes with models 8-3/8 and larger, will have two seals on the stem with a vent between. All other cylinder classes will have a vee packing for the stem seal and a vent downstream. Refer to the Packager Standards for information on routing these vents.





High Clearance Valve Assembly

A high clearance valve assembly is used to increase the fixed clearance volume of a cylinder end. A high clearance assembly is comprised of a valve spacer, a special retainer, and a gasket. The spacer is placed between the cylinder valve seat and the valve body.

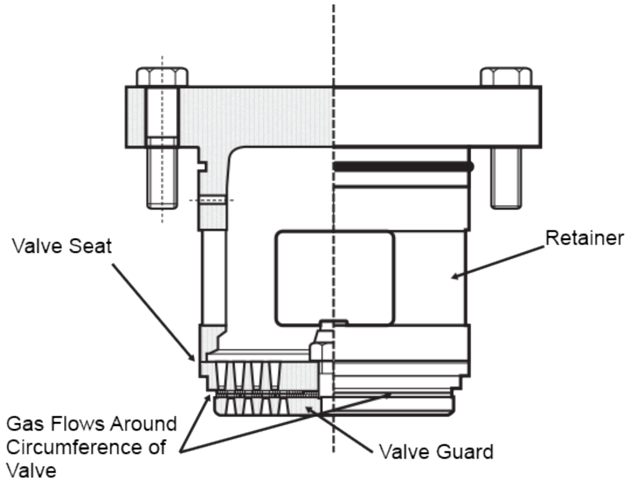


The cylinder DataBook lists the number of high clearance assemblies that can be provided with each cylinder and the percent of added fixed clearance for each assembly. A new cylinder purchased with high clearance assemblies will also be supplied with standard valve retainers.

Cylinders of the class 3SG-CE and 3-5/8SG-CE show the availability of high clearance valve assemblies in the performance software. These cylinder classes do not use the traditional spacers as shown above, but utilize high clearance crank end head designs to add the clearance. The clearance defined for these cylinder classes are machined as part of the cranks end head and are not removable valve spacers.

Hanging guard design valves cannot be outfitted with high clearance valve assemblies. Gas flows around the circumference of these valves. Installing a spacer would block the gas flow.

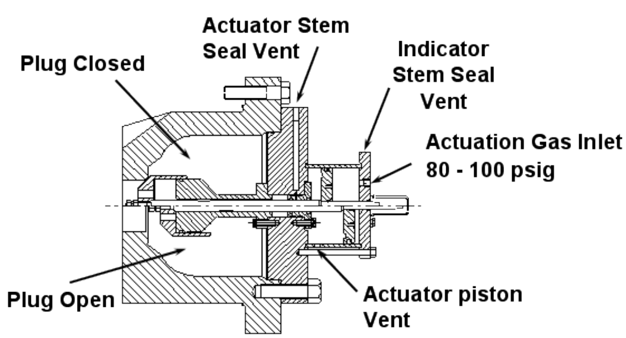
Below is a drawing of a hanging guard design valve.



Also see: Clearance Volume

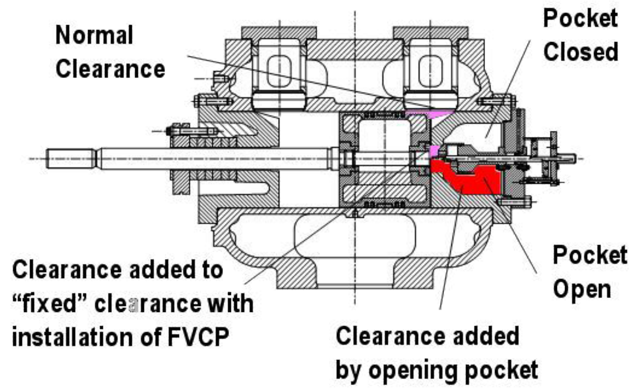
Pneumatic Fixed Volume Clearance Pockets

A FVCP is used to add clearance volume to the head end of a cylinder. A plug is pneumatically actuated to either fully open or fully close the pocket. The FVCP assembly is mounted in the head end of a cylinder.



The FVCP requires 80-100 psi of air or gas pressure to operate. Actuation of the pocket can be performed by the PLC controlling a solenoid valve. In most cases, the FVCP is normally unloaded (FVCP open), requiring air or gas pressure to load (FVCP closed).

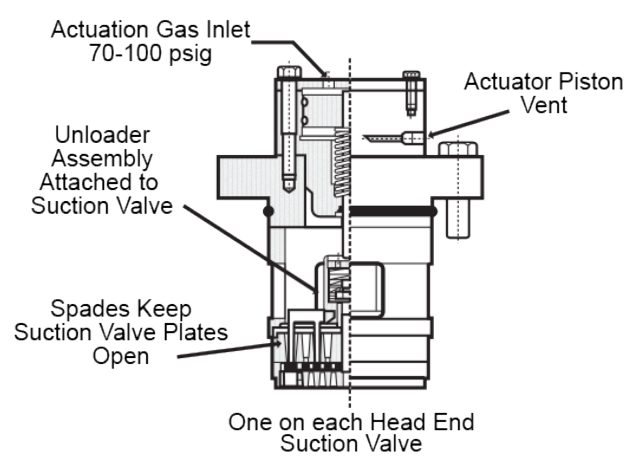
Data regarding FVCP designs and availability for each compressor cylinder is available in the Ariel Electronic Databook.



Suction Valve Unloaders

See Cylinder Action, Single Acting for a drawing of a suction valve unloader installed on a cylinder.

A valve plate depressor type suction valve unloader will depress the suction valve plate against the valve guard to hold the valve open, therefore deactivating the end of the cylinder by allowing gas to pass through the valve during both intake and compression stroke. A valve plate depressor type suction valve unloader is actuated using air or natural gas as actuation gas (usually 70 to 100 psig). In most cases, the suction valve unloaders are normally loaded, with air or gas actuation pressure required to unload the cylinder end. Suction valve unloaders may be used only on plate or ring valves (not poppets).



Applications that require suction valve unloaders must be reviewed by Ariel / Hoerbiger before quoting. The valve depressors are always in the seat flow passages. This will reduce the valve equivalent area and increase the horsepower losses of the valve. Temperatures may also be increased due to a recirculation of the gas on the deactivated end preheating the active end. It is important that data regarding the entire range of suction pressures and gas compositions be submitted for review. The review will specify the valve plate materials, lifts and valve equivalent flow areas to be used for the application. Suction valve unloaders must be installed on all suction valves of the end being deactivated.

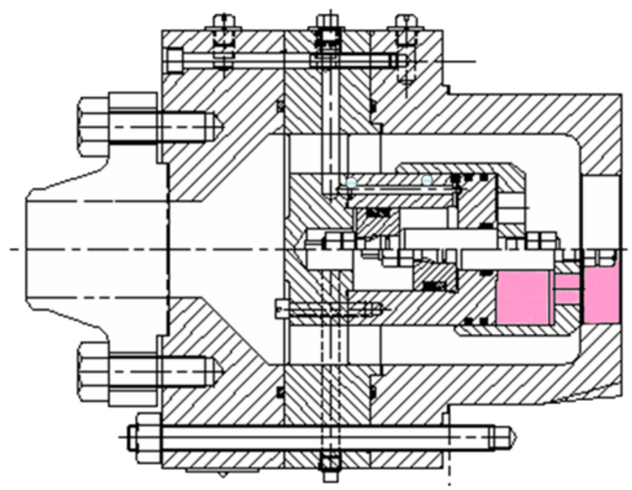
Ariel recommends using suction valve unloaders on the head end of cylinders only. Crank end deactivation may result in a non-rod load reversal situation. All deactivation configurations should be analyzed at all conditions to verify adequate rod load reversal.

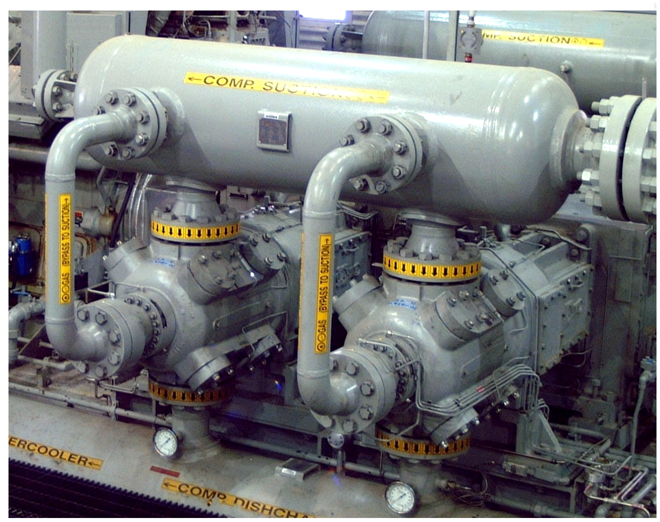
Single acting cylinder operating cases should be considered when analyzing torsional responses and acoustical pulsation responses. Single Acting cylinders can present the worst case scenario for a torsional analysis due to a more dynamic torque effort curve and for an acoustical pulsation analysis due 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.

High torsional vibrations can increase coupling and shaft stresses, driver functionality and auxiliary driven equipment integrity. High acoustical pulsations can increase frame, cylinder, gas piping and equipment vibrations.

An alternate method of single acting a cylinder is by removing the head end suction valves on one cylinder end. Suction valve removal will result in less horsepower loss as the unloading flow area is greater. Cylinders with suction pressures above 750 psi and or small valve sizes may not be suitable for suction valve unloaders.

Head End Bypass Unloaders





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. Head end bypass unloaders are most often applied when the suction pressure is higher than suction valve unloaders can be applied (near 1000 psi and higher).

The pneumatic actuator is smaller, to fit within the unloader, so requires a higher actuation pressure, often in the few to several hundred psi range. 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 from a higher pressure stage discharge to the appropriate pressure and applied as the actuation gas. The actuation gas must be clean and dry. Sour gas cannot be used as actuation gas (greater than 100 ppm H_2S) for safety reasons. If the process gas contains hydrogen sulfide, nitrogen may be used for the actuation gas.

Actuation gas must be clean and dry. When regulating the higher pressure supply stream to the required actuation pressure, a liquid collection / separator device must be installed directly downstream of the regulator.

Head end bypass unloaders may not be as efficient as suction valve unloaders, but can be applied at higher suction pressures.

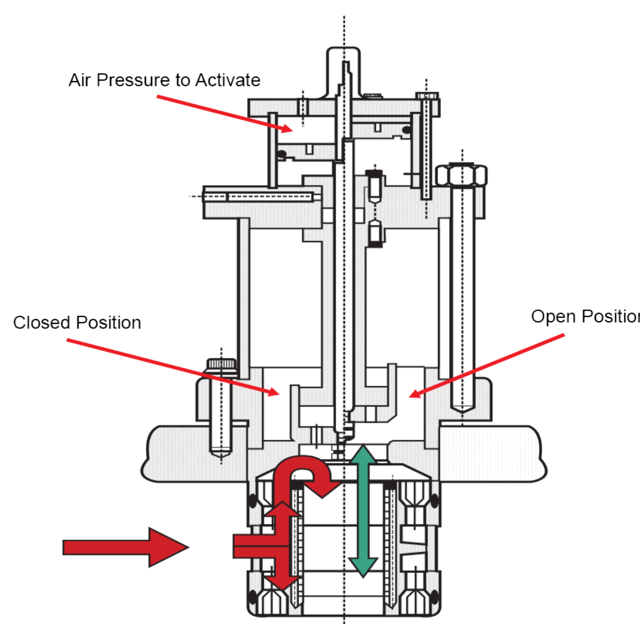
All deactivation configurations should be analyzed at all conditions to verify adequate rod load reversal.

Single acting cylinder operating cases should be considered when analyzing 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.

High torsional vibrations can increase coupling and shaft stresses, and affect driver functionality or auxiliary driven equipment integrity. High acoustical pulsations can increase frame, cylinder, gas piping and equipment vibrations.

An alternate method of single acting a cylinder is by removing the head end suction valves on one cylinder end. Suction valve removal will result in less horsepower loss as the unloaded flow area is greater. Cylinders with suction pressures above 1000 psi and or small valve sizes may not be suitable for suction valve unloaders.

Double Deck Volume Pockets



A double deck volume pocket is used to add clearance volume to the end of a pipeline cylinder through the valve port. An unloader assembly is pneumatically actuated to either fully open or fully close the pocket. The volume pocket assembly is mounted in the valve port of the cylinder.

The unloader requires 80-100 psi of air or gas pressure to operate. Using a solenoid valve, it can be operated by electronic signals from a flow computer or PLC. In most cases, the pocket is normally unloaded with air or gas pressure required to load (close the pocket) the cylinder.

Contact Ariel Corporation for availability and data regarding double deck volume pocket applications.

Deactivated Stage

Every now and then a service changes to lower pressure ratios and requires fewer stages of compression on existing equipment. Deactivating a stage can be accomplished with allowing blowthru or by physically deactivating a stage. Deactivated stage methods are not to be confused with deactivating a cylinder within a multi cylinder stage (see Deactivated Cylinder below).

Blowthru occurs when the compression ratio across the compressor is not high enough to accommodate compression in all the available stages. The gas is compressed to full discharge pressure in the first several stages and physically blows thru the last stage without further compression. This blowthru gas flow holds the suction and discharge valves open. If the unit is close to allowing full compression on the last stage the valves can flutter during this blowthru condition. Blowthru is acceptable if the unit will not operate at extended periods of time at this condition.

If the unit will operate at this lower ratio for extended periods a stage of compression can be deactivated, or taken out of service. For shorter durations the cylinder can be deactivated by removing all suction and discharge valves from both ends of all cylinders on the deactivated stage. Extremely short durations may see only all suction valves removed to lower valve removal time, but will result in more power usage and higher temperatures. For longer periods the stage can be deactivated by removing all valves, removing the piston and rod, rerouting the cylinder and packing lubrication to the frame, replacing the packing with a solid plug and rebalancing the reciprocating weights.

Any changes in operating conditions warrants a review of performance to ensure proper operation within allowable limits is maintained. Changes in conditions requiring deactivating a stage can have impacts to rod reversal, rod loads, discharge pressure versus MAWP and potentially torsional responses.

These "extended periods of time" should be defined by the user based upon frequency of re-activating the stage, acceptable maintenance and the availability of manpower to change the unit configuration. In general, blowthru can be tolerated for days to a few weeks. Deactivating by pulling the suction valves can be tolerated for months. Deactivating by removing the piston and rod can be used for longer durations in the terms of half a year and up. The duration of deactivation by the blowthru and pulling suction valves are discussed due to the likelihood of higher maintenance if the durations are longer.

Blowthru conditions can cause the valves to open and close, without preferable dynamics, resulting in possible broken valves before the next loading of the stage. Pulling the suction valves and leaving the piston and discharge valves in place can also result in failure of the discharge valves over time and will result in continued wear of the piston rings, wearbands and packing sealing rings.

Deactivated Cylinder

Deactivating a cylinder that is part of a stage is handled differently than deactivating an entire stage. An example would be if there are two first stage cylinders and typical unloading methods are not enough, one first stage cylinder can be deactivated while the other first stage cylinder continues to compress. If an entire cylinder within a stage needs to be deactivated, this can be done in one of two ways; Removal of the piston and rod, or non-acting the cylinder.

Removal of the piston and rod is the preferred method to deactivate a cylinder. This is accomplished by removing the piston and rod, installing blank flange blinds between the cylinder and pulsation vessels (suction and discharge), installing a plug in place of the packing case, rebalancing and removing the cylinder lubrication from the deactivated cylinder. Removing the suction valves from both ends of the cylinder can be done rather than installing flange blinds.

An entire single cylinder, when part of a multiple cylinder stage using a manifolded suction pulsation vessel, can be deactivated by removing the suction valves from both ends of the cylinder. This method is not recommended by Ariel, but has been performed successfully on specific installations. If this method is successful, it can save down time for shorter term deactivation. In this method, the gas will be recycled from head end to crank end through the suction gas passages and will heat up. In most cases, the heat generated will be greater than the maximum allowable average cylinder temperature of 285 F (140 C). If this methods is used, cylinder temperature measurements must be taken at the suction gas passages. The discharge temperature measurement location will not read the cylinder gas temperature.

Non-Acting Cylinders

A non-acting cylinder is a cylinder that is installed, but is not compressing gas. There are several ways a cylinder would be non-acting.

- Blowthru
- All Valves Removed
- All Suction Valves Removed
- Piston and Rod Removed
- Blank Throw
- Non-Acting for Startup

Blowthru occurs when the compression ratio across the compressor is not high enough to accommodate compression in all the available stages. The gas is compressed to full discharge pressure in the first several stages and physically blows thru the last stage without further compression. This blowthru gas flow holds the suction and discharge valves open. If the unit is close to allowing full compression on the last stage the valves can flutter during this blowthru condition. Blowthru is acceptable for short durations. Longer durations can lead to premature valve failure in the stage with blowthru.

All of the cylinder valves can be removed if a stage of compression will need to be disabled for an extended period of time. This allows a larger flow area for the gas to pass through the cylinder valve ports, reducing the pressure losses in the stage. This also removes the valves from the wear life equation. Removing all of the cylinder valves must be limited to deactivating an entire stage, not just one cylinder of a mutli-cylinder stage.

All Suction valves can be removed from a cylinder to disable a stage for much shorter periods. Some of the benefits of lower pressure loss are attained, while having a shorter downtime to remove valves.

All Suction valves can be removed if a single cylinder of a mutli-cylinder stage needs to be disabled. Though this method is not recommended by Ariel, it may be possible to non-act a single cylinder within a stage. In most cases, non-acting a cylinder within a stage will result in overheating the cylinder beyond the capabilities of the non-metallic components within the cylinder. If this method is to be used for non-acting a cylinder within a stage, the cylinder nozzle temperatures on the suction side (since suction valves are removed) must be closely monitored so as not to exceed 285 F (140 C). This method has been known to work in some specific circumstances, while in the greater majority is not successful. The cylinder to be non-acting must be part of a manifolded suction vessel with the other cylinder(s) active.

Removal of the piston and rod to disable a stage can be done when the unit will operate with a disabled stage for extended periods of time. Removal of the piston and rod allows the wearing components to be removed and the cylinder lubrication to be shutdown for the cylinder. This is accomplished by removing the piston and rod, installing blank flange blinds between the cylinder and pulsation vessels (suction and discharge), installing a plug in place of the packing case, rebalancing and removing the cylinder lubrication from the deactivated cylinder. Removing the suction valves from both ends of the cylinder can be done rather than installing flange blinds. The definition of "extended period" is determined by the end user and is a balanced of the time and equipment it takes to accomplish the removal of the piston and rod against the savings for wear parts and lubrication.

Removal of the piston and rod is the preferred method to non-act a cylinder within a stage.

Blank throws are locations on the frame that can accommodate a cylinder, but are not mounted with cylinders, ie., placing three cylinders on a four throw compressor. There are two different balancing configurations for a blank throw, an active crosshead guide and a balancing crosshead guide. An active crosshead guide is a guide that can accommodate the mounting of a cylinder and has standard crossheads and balance nuts installed. A balancing crosshead guide, also referred to as a dummy guide, is a special guide with added length to accommodate larger, special, balancing crossheads. Cylinders cannot be mounted on balancing guides. When applying a blank throw, the reciprocating weight is not offset by gas loads from compression. Therefore, the weight of the blank throw should be minimized by mounting the smaller of the cylinders on the opposing throw. Throws are locations on the frame that can accommodate a cylinder, but are not mounted with cylinders, ie., placing three cylinders on a four throw compressor.

Cylinders can be non-acting for start up purposes. When the available starting torque is not available for a fully bypassed compressor start, unloading ends of the cylinders will help reduce some of the starting torque. This will require the use of suction valve unloaders or head end bypass devices. Actuating suction valve unloaders on the head end can help reduce the staring torque. In some cases, the motor inrush current must be further limited; suction valve unloaders can be applied to both the head end and crank end to further reduce the starting torque. When both ends are non-acting for start up, a time limit of five (5) minutes should be applied for the non-acting duration.

Distance Piece Purge and Vent Arrangements for Sour, Corrosive and Hazardous Gasses

Ariel provides suitable materials options and configuration options for a successful packing vent system. Much of the success of a packing vent system falls on the End User and Packager for design of the packing vent system and the End User for operations and maintenance of the system.

Options

Materials options are available for key components in the gas stream for sour and corrosive gasses. Materials options for components such as piston rods, valves, cylinder bolting, bearings, tubing and tube fittings are discussed in the Ariel Sour Gas topic.

Configuration options are available including purged pressure packing cases, short and long two compartment distance piece arrangements, flushing oil system and separate lube oil arrangements for the cylinders. These are discussed in the Ariel Sour Gas topic.

When a long two compartment distance piece and purge packing is purchased the intermediate and wiper packing cases come with purge rings and purge gas connections. These are available for incorporation into the system design.

The KBE:K:T and KBZ:U are not offered with a short two compartment option. The long single compartment design incorporates a purged wiper seal set when purged packing is purchased.

Refer to the Packager Standards Section 8 Packing and Distance Piece Vent Systems for further information and schematics on this topic.

Packing Leakage

Piston rod packing is designed to seal against cylinder pressure, but are dynamic seals and will have some leakage. This leakage will increase over time due to wear of the non-metallic sealing rings. The packing case is made up of several seal sets, each seal breaking down the pressure further than the last. In the new and broken in condition packing rings will leak some gas. The leakage rate will depend upon the condition of the packing and to some extent the use of a purge gas (see purge packing).

Packing in the new and broken in condition will leak 5-10 SCFH through the vent with 2-3 SCFH entering the distance piece. Prior to break in leakage will be higher.

When purged packings are employed the packing will leak 8-13 SCFH through the vent due to the addition of the purge gas and 3-5 SCFH of purge gas entering the distance piece. The purge gas demand will be roughly 5 SCFH.

As the packing wears out vent leakage will increase to as high as 120-180 SCFH (2-3 SCFM) and purge gas may increase up to 30 SCFH to maintain a positive pressure over the vent pressure. Likewise, distance piece flows will increase respectively.

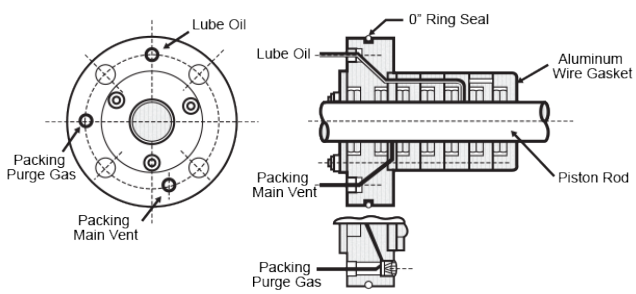
Upon shutdown of the compressor packing leakage will continue, and increase, unless cylinder pressures are relieved.

Refer to the Packager Standards Section 8 Packing and Distance Piece Vent Systems for further information on vent systems.

Purged Pressure Packing Cases

Purge packing refers to a packing case modified to accept an external purge pressure 15 to 20 psi above the primary packing vent/drain pressure with no more than 5 psi external system back pressure. The purge gas must be sweet natural gas or an inert gas, such as nitrogen. The purpose of purge gas is to block and contain hazardous, toxic, flammable or corrosive gases, and to prevent such from entering the compressor frame where damage to the running gear, or personnel safety hazards can occur.

Figure: Compressor Rod Pack 3500-2000 PSIG with Purge Two Compartment Guides



Packing case materials are cast iron and steel. When steel is used, it is heat treated to be in compliance with NACE. Garter springs are 316 stainless steel, for both sweet and sour applications (acceptable for sour service based upon acceptable field experience).

Please refer to the Packager Standards Section 8 Packing and Distance Piece Vent Systems for further information on this topic.

Purge and Vent Arrangements

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Materials options are available for key components in the gas stream for sour and corrosive gasses. Materials options for components such as piston rods, valves, cylinder bolting, bearings, tubing and tube fittings are discussed in the Ariel Sour Gas topic.

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The KBE:K:T and KBZ:U are not offered with a short two compartment option. The long single compartment design incorporates a purged wiper seal set when purged packing is purchased.

Refer to the Packager Standards Section 8 Packing and Distance Piece Vent Systems for further information and schematics on this topic.

Drivers

Electric Motor Drive

Electric motors, direct connected through a flexible coupling can be utilized to drive Ariel compressors. Electric motors are available at various speed depending upon the frequency of the power supply and the number of motor poles.

When the selection permits, it can be beneficial to match an electric driver with the compressor frame that will provide a lower piston speed. Slower piston speeds can provide higher efficiencies and a longer time between scheduled maintenance. For example, if a JGC or a JGD frame could be used for an application were 60Hz electricity is available, an electric driver could run the JGD at 1200 RPM for a piston speed of 1100 fpm, or run the JGC at 900 RPM for a piston speed of 975 fpm. The JGC selection would be more efficient and would have longer times between scheduled maintenance due to the slower piston speed. The JGC will also have slightly larger cylinders. Common motor speeds:

- Synchronous rpm = Power Frequency (hz) x 120 / number of motor poles
- Induction motor rpm = synchronous rpm x 0.985 (accounts for 1.5% slip)
- Induction motors will operate at less than the rated synchronous speed because of “slip”. A typical motor slip is 1.5%. This must be accounted for in the compressor selection.

Number of Motor Poles	Synch	Induction	Synch	Induction
	50 hz	50 hz	60 hz	60 hz
4	1500	1475	1800	1775
6	1000	985	1200	1185
8	750	740	900	885
10	600	590	720	710
12	500	492	600	590
14	428	422	514	506

Electric motor drives will require a review of starting torques to ensure the motor has enough torque to start the rotation of the compressor. This will most often require a full bypass for start-up and may require special motor torques. Variable speed drivers have other details to consider, see Minimum Allowable Rotating Speed topic.

Ariel requires an additional 10% margin for selection purposes to be included in the Rated power of the motor. Service factor is not to be considered to cover this 10% margin. This is a selection and sizing criteria; once installed the full available driver power may be applied. The 10% sizing margin is intended to cover Ariel's prediction tolerances (+/-3% or +/-6%), acoustical resonance impacts, motor efficiencies, power supply cleanliness, and a small portion of differences in operating condition (winter gas temperatures, etc). This conservative sizing approach is to avoid a package that may be restricted due to higher than expected electric motor power usage.

Refer to the Ariel Packager Standards Section 5 for more details on the drive system.

Ariel Performance Software provides the necessary information for motor sizing, such as start up torque, torque effort curve, compressor inertia, and power demand.

Common Project information for motor driven applications include:

Quotation

- Start up torque curve (at highest suction pressure) with estimated bypass line pressure losses
- Full horsepower torque effort curve
- Part load torque effort curves (highest power of each single acting step)
- +10% of max horsepower for nameplate power (Service Factor is not to be used to meet this 10% margin requirement.)
- The motor stub shaft and the section through the drive end bearing should equal or exceed the compressor drive stub diameter. JGE:K:T/6 and KBB:V frames have flanged drive end connections on the crankshaft, use the crankshaft journal diameter for the minimum motor shaft diameter. Crankshaft diameters can be found in ER-83, Frame Data Sheets and Torsional Supporting Documents.

Purchase (confirming quotation data)

- *Start up torque curve (at highest suction pressure) with actual bypass line pressure losses
- Full horsepower torque effort curve
- Part load torque effort curves (highest power of each single acting step)
- +10% of max horsepower for nameplate power (Service Factor is not to be used to meet this 10% margin requirement.)
- The motor stub shaft and the section through the drive end bearing should equal or exceed the compressor drive stub diameter. JGE:K:T/6 and KBB:V frames have flanged drive end connections on the crankshaft, use the crankshaft journal diameter for the minimum motor shaft diameter. Crankshaft diameters can be found in ER-83, Frame Data Sheets and Torsional Supporting Documents.

Studies necessary

- Motor start up analysis - Does the motor have enough torque to reach full speed fast (before the high inrush current overheats the motor)
  - This is done by the motor supplier and requires the compressor inertia value from the start up curve or mass elastic data, the coupling inertia, inertia from any added flywheel or crankshaft detuner
- Current pulsation analysis
- Torsional analysis
- Lateral analysis may be necessary depending upon lengths

Data necessary for Torsional from Motor Supplier

- Mass elastic data (inertia and shaft stiffness)
- Shaft detail drawing for vibratory stress calculations
- Minimum additional inertia (flywheel) to limit current pulsations

***Generating Final Start Up Torque Curve**

- Run start up curve at highest suction pressure (or settle out pressure) and default pressure loss settings of 25 psi times the number of stages
- Load cylinders if manual capacity devices are used, and unload cylinders if pneumatic capacity devices are used (suction valve unloaders and pneumatic pockets)
- Apply the "flow at startup" value from the start up torque data to size the bypass line

- Calculate the bypass line pressure drop at the "flow at startup" (from final stage cylinder discharge flange through vessels, coolers, bypass line, bypass valve, suction scrubber, suction vessel to first stage cylinder suction flange)
- Provide the final flywheel inertia from the torsional analysis and current pulsation analysis for the final start up torque calculation
- Rerun the start up curve with the calculated bypass line losses

Start up torque is used to determine if an engine starter, or electric motor driver has enough torque to start a compressor. Refer to Starting Torque topic for more specific information on starting torque curves and data.

Process Application Definition

Process compressors are typically used in petroleum, chemical and gas industry services for handling process gas with either lubricated or non-lubricated cylinders. These are moderate speed compressors meeting the demands of API-618 for critical service. API-618 has defined these compressor applications as having and expected uninterrupted operation of at least 3 years as a design criteria.

Process Compressors are separated from Oil and Gas compressors by function and required maintenance intervals. Oil and Gas compressors are commonly driven by natural gas fueled engines with major maintenance intervals of up to 18 months with regular preventative maintenance at every three months. Process compressors are generally electric motor driven and require a target of 3 years between any maintenance.

Ariel has developed a line of compressors to meet the demands for longevity and reliability dictated within API-618. This includes moderate rotating speed application, low average piston speeds, low piston wear band loading and process gas emissions control capabilities.

For applications guidelines on the Ariel Process Compressor refer to the Process Table of Contents.

These applications generally include any gas compressor application in:

- Refineries
- Petrochemical Plants
- Chemical Plants
- Industrial Gas Facilities

Excluded from Process Definition:

- Lubricated natural gas services
- Lubricated fuel gas boosters with up to 50% hydrogen
- Lubricated refrigeration
- Lubricated air, nitrogen or carbon dioxide
- Non-lubricated fuel gas boosters

Process Equipment Selection

Process Frames: JGA: JGJ: JGK: JGT: JGD: JGF: KBU: KBB

Process Cylinders: JG: RJ: K: T: D: F: U: B

Required Equipment for Process Offerings:

- Wearbands with a 5 psi piston and rod loading
- Ion nitrided cylinder bores
- Helium leak testing of cylinders in applications less than 12 MW
- Long two compartment distance pieces (API-618 Type C)
- Purged and water cooled packing with lapped packing cups
- Purged intermediate and wiper packing
- Indicator taps on cylinders

Optional Equipment Available for Process Offerings (typical additions)

- Non-lubricated cylinder design
- Suction valve unloaders
- Tungsten carbide piston rod coating
- BICERA crankcase doors
- Stainless steel tubing with stainless steel fittings
- Material certification

Capacity and Power Guarantee Tolerances within the Reciprocating Packager's Standard Section 2.

Process Frame Cyl Design

Ariel Process Frames include the JGA, JGJ, JGK, JGT, JGD, JGF, KBU and KBB. These frames offer:

- Shorter stroke to allow for wearbands for a 5 psi loading for lube and non-lube services
- Shorter stroke to allow for added piston rings for hydrogen compression and non-lube services
- Forged steel crankshafts
- Forged steel connecting rods
- Long two compartment distance pieces per API-618 Type C
- Piston speed limitations to meet most Process applications

Ariel Process Cylinders include the JG, RJ, K, T, D, F, U and B cylinder classes. These cylinders offer:

- Wearbands to meet 5 psi loading for both lubricated and non-lubricated services
- Wearband overtravel less than 50%
- Piston design to offer ring design and quantity sufficient for low molecular weight gases whether lubricated or non-lubricated
- Indicator connections
- Purged packing cases
- Water cooled packing cases
- Application specific valve design
- O-ring sealed valve covers
- Capacity and Load Control devices available
- 4100 series alloy carbon steel piston rods with ion nitride and optional tungsten carbide coating
- Ion-nitrided cylinder bore

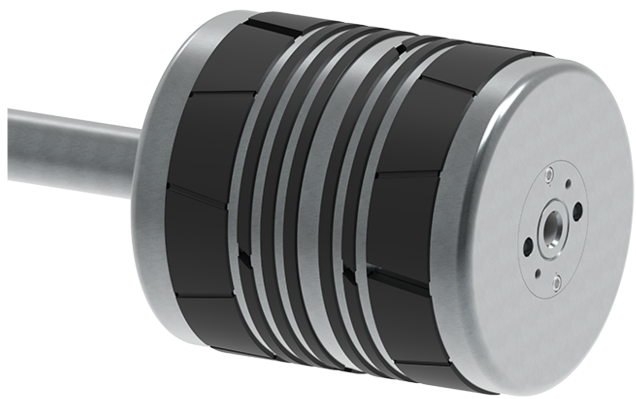
Process Piston

The Process piston includes wearbands designed for a 5 psi loading suitable for both lubricated and non-lubricated services. The piston ring and wearband materials are chosen to suit the Process gas, pressures and temperatures of each service.

Larger class cylinders utilize two wearbands located outboard of the piston rings while smaller cylinder classes have one wearband on the outboard end of the piston. The cylinder bore has been extended to allow for the travel of the wearbands.

Figure: PRC Pistons

Double Wearband



Single Wearband

Piston rod materials for Process Applications are:

Service	Material	Coating
Non Corrosive Lubricated	4100 Series Carbon Steel	Ion Nitride
Non Corrosive Non-Lubricated	4100 Series Carbon Steel	Tungsten Carbide
Corrosive Lubricated and Non-Lubricated	17-4PH Stainless Steel	Tungsten Carbide

Process Rotative Speeds

Process rotating speeds are conservatively set to meet the design philosophy within API-618 for a target of 3 years uninterrupted operation. The maximum rotating speeds, and resulting piston speeds, are listed below.

Process Frame Maximum Speed				
		Rotative Speed	Piston Speed	
Frame	Stroke	rpm	fpm	m/s
JGA	3.00	1200	600	3.05
JGJ	3.50	1200	700	3.56
JGT	4.50	1000	750	3.81
JGK	5.50	750	688	3.49
JGF	5.00	900	750	3.81
JGD	5.50	750	688	3.49
KBU	5.75	750	719	3.65
KBB	7.25	600	725	3.68

Process Motor Sizing

The main motor driver for Process compressors will typically be a direct coupled electric induction motor or direct coupled electric synchronous motor. Motor nameplate horsepower must be 10% greater than the maximum operating horsepower or greater than the discharge relief valve set point condition, whichever is greater.

Refer to Electric Motor Drive topic for information on what information is needed for quoting, purchasing and performing studies for electric drive compressors.

Motor driven reciprocating compressors typically require a torsional response analysis, current pulsation analysis and starting torque analysis. These studies will determine final coupling selection and if a flywheel is required.

Quality Assurance Programs

ISO 9001 Certification

Since 1995, Ariel Corporation has followed ISO's strategic tools and guidelines to ensure that our products and services are consistent, safe, and reliable.

Please refer to the Ariel website for further specifics on our ISO 9001 certification.

Materials Certifications and Tests

Ariel's compressor components are purchased and machined in large quantities, often in lot quantities. Raw materials suppliers are audited for their quality control and performance. These suppliers provide certain lot sample testing to verify materials chemical compositions and / or physical properties. With the large quantity of components purchased each year Ariel does not require these materials certifications, but rely on the suppliers quality control system and the auditing process. This system maintains supplier quality while limiting component costs and coordination.

An Inspection and Test Plan has been prepared to show what Ariel and Ariel's suppliers provide for materials certifications. This list includes those tests listed as optional in the Ariel Price Book. Additional testing requests must be reviewed and approved by Ariel. Material certification with traceability are an available option for the crankshaft and cylinder body.

EN 10204:2004 specifies the different types of inspection documents supplied to the purchaser... There are several categories or Types referenced within EN 10204:2004. Below are excerpts from EN 10204:2004 and Ariel's position on these categories.

Type 2.1 non-specific inspection: inspection carried out by the manufacturer in accordance with his own procedures to assess whether products defined by the same product specification and made by the same manufacturing process, are in compliance with the requirements of the order or not.

A type 2.1 requirement would consist of a certificate of compliance written by Ariel with no inclusion of material test certificates.

Type 2.2 specific inspection: inspection carried out, before delivery, according to the product specification, on the products to be supplied or on test units of which the products supplied are part, in order to verify that these products are in compliance with the requirements of the order.

Ariel does not provide certification to Type 2.2.

Type 3.1 Document issued by the manufacturer in which he declares that the products supplied are in compliance with the requirements of the order and in which he supplies test results. ... The document is validated by the manufacturer's authorized inspection representative, independent of the manufacturing department.

Ariel provides an option for Type 3.1 material certificates for the crankshaft and cylinder body. These must be requested with the original equipment purchase order.

Type 3.2 Document prepared by both the manufacturer's authorized inspection representative, independent of the manufacturing department and either the purchaser's authorized inspection representative or the inspector designated by the official regulations and in which they declare that the proucts supplied are in compliance with the requirements of the order and in which test results are supplied.

Ariel does not provide certification to Type 3.2.

Cylinder Leak 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.

Assembly Inspections And Tests

During the assembly process, all units are subjected to a series of inspections to ensure mechanical soundness (reference ER-5.3). These include:

- Measurement and recording of critical values such as crankshaft end clearances, connecting rod side clearances, rod runout, and bearing jack clearances.
- Check operation of lubrication system components including shutdowns, pump(s), passages and fittings.
- Verify critical torque values.
- Check freedom of movement of crankshaft and connecting rod pins.

All mechanically complete units (excluding valves) are to be run tested for at least 4 hours, during which time operating parameters will be monitored and recorded on the Production Test Log (ER-5.3.1).

After the run test additional inspections are performed on the unit including:

- Measure and record temperatures of main bearing caps and connecting rods (at split lines), within 5 minutes of completion of run test.
- Visually inspect bores, piston rods, crosshead shoes and slides for any scoring or unusual wear patterns.
- Crankshaft end clearances are measured and recorded.
- Critical torques and set screws are checked and adjusted when required.
- After passing all previous inspections the unit is prepared for shipment. Final visual checks of unit and associated paperwork is performed by Quality Control.

Studies and Analyses

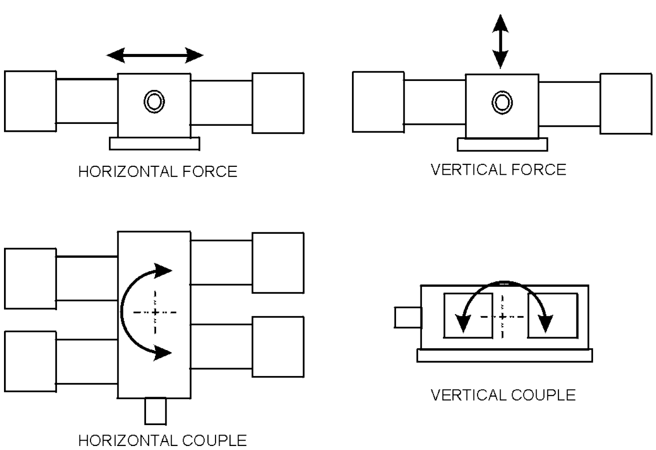
Unbalanced Forces and Couples

Reciprocating compressors develop unbalanced forces and couples due to tolerances in the reciprocating weights at the offset of the compressor throws. The unbalance comes in the form of horizontal and vertical forces and horizontal and vertical couples.

The compressor skid and foundation must be designed to dampen and transfer these forces.

All Forces and Couples act about the center of the crankshaft.

Related topic: Balanced Opposed Design



Starting Torque

Start up torque is used to determine if an engine starter, or electric motor driver has enough torque to start a compressor.

Start up torque is characterized by two main components, break away torque and speed up torque. The break away torque is the static friction and gas load on the piston rod area at zero rpm. The speed up torque is the dynamic friction and the pressure load on the cylinders as the unit speeds up toward full speed.

Ariel provides start up torque data within the Ariel Performance Program. All start up torque calculations provided assume that a bypass or gas recirculation line is installed and open, sized to bypass 100% of the compressor flow.

The break away torque is dependent on the pressure on the unit when the start button is pushed. Higher start up pressures will result in higher break away torque. If the break away torque must be reduced for starting, the pressure on the unit must be reduced. Six throw units are mostly exempt from this as the phasing of the six throws offers a cancellation of the individual throw torques from the pressure on the piston rod.

The speed up torque can be impacted by both the starting pressure, as well as the bypass line pressure loss. Smaller bypass lines will have higher pressure losses, resulting in higher torques as the unit approaches full speed.

Start Up Torque Calculations:

- Use the highest suction pressure that the unit will see when the start button is pushed. This may be a normal (max) suction pressure, or a settle out pressure.
- Load all manual capacity devices (close VVCP's, remove spacers, double act cylinders if valves are removed manually for single acting cases).

- Unload all panel controlled capacity devices (open FVCP's, single act if SVU's are provided)
- Consider and calculate the bypass line pressure losses for a more accurate torque curve.
- Apply the final flywheel inertia from the torsional analysis and current pulsation analysis for the final start up torque calculation

Bypass Line Pressure Losses:

- Ariel provides an entry for the bypass line pressure loss. This is a value multiplied by the number of stages, for a total pressure loss.
- The default value is 25 psi times the number of stages. This is only a rough value for a beginning assumption.
- The start up torque calculation will include a "flow at Start up". Apply this value when calculating the bypass line pressure loss. At the lower ratios of start up (bypass line open) the flow can be much higher than the compressor design flow.

For electric motor drives, please also refer to Electric Motor Drives topic.

Typical Starting Torque Data and Curves provided within the Ariel Performance Software:

Speed RPM	Srv 1 Disch psig	Power BHP	Mean Torque ft-lbs
0	350.00	0.00	3207.5
90	350.250	5	299.4
180	351.000	16	472.6
270	352.250	39	760.8
360	354.000	80	1163.5
450	356.250	144	1679.7
540	359.000	237	2308.4
630	362.250	366	3048.6
720	366.000	534	3898.7
810	370.250	749	4857.6
900	375.000	1015	5923.7

Friction Breakaway Torque: 1400.00 ft-lbs

Total Running Gear Inertia: 82838.289 lb·in2
Expected Startup Flow at full speed: 115.644 MMSCFD

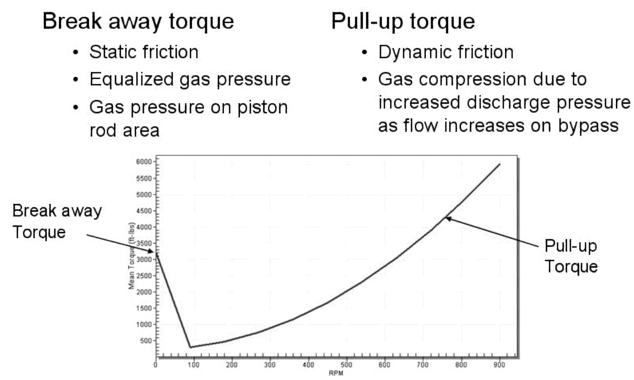
Disch Press equals Suction Press

Breakaway Torque

Starting Torque (Pull-up Torque)

Disch Press increases as speed increases flow

Compressor Inertia



Torsional Vibration Analysis

Torsional Vibration Analysis is the analysis of the torsional dynamic behavior of a rotating shaft system as a result of forced vibration. Torsional vibration, or twisting, is different from lateral vibration, or shaking. A torsional system, compressor, driver, and coupling, are modeled as a mass-elastic system (inertia and stiffness) to predict stresses in each component. Mass-elastic properties of the system can be changed by adding a flywheel (additional inertia), using a soft coupling (change in stiffness), or by viscous damping (absorb natural frequency stimulation). Not all systems require any modification to the mass-elastic properties to achieve a torsionally sound system.

Ariel Corporation can provide the data for the compressor necessary to perform a torsional vibration analysis. This includes the torque effort curves (torque versus crank angle), mass elastic data and fourier coefficients representing the torsional driving forces. The torsional analysis is the responsibility of the Packager.

Care must be taken to represent the operating conditionsthe unit will see, including any partial load conditions. Any single acting cylinder operation is important to include as these cases can represent the more dynamic torque effort curves.

When applying variations in speed and single acting cylinder configurations the torsional and acoustical response analysis will be much simplified by applying single acting configuration only at one given speed. In order to eliminate over complicating the torsional and acoustical systems, specific capacity control methods may be more attractive than others. For a discussion on these methods, and recommendations on capacity control methods, refer to the Capacity and Load Control topic.

Capacity control sequencing can be very important when considering single acting operating cases. Sequencing of cylinders for unloading can be very important to both the torsional analysis as well as the acoustical analysis. Single acting provides a much more aggressive forcing function for the torsional analysis. There is no absolute rule on which cylinders to single act at a time, but a recommendation is to **unload adjacent cylinders before unloading opposing cylinders** (unloading opposing cylinders is much more aggressive on the torsional forcing function than unloading adjacent cylinders). The opposite is true for acoustical analyses when considering single stage compressors with symmetrical pulsation vessels. These are recommendations for a more polite torsional solution, but not the only sequence that will work. A more aggressive load sequence, may just end up with a more aggressive solution to the torsional (black out speeds, torsionally soft coupling, larger flywheel...).

Once a load sequence is chosen, this needs to be applied to the torsional analysis, acoustical analysis, and the control panel logic sequence. If the unloading is to be by manual methods, such as removing valves, it is recommended to review load sequences for any possible variation single acting location.

When applying an electric motor driver, whether fixed speed or variable speed, specific attention must be made to the motor shaft design. The motor stub shaft and the section through the drive end bearing should equal or exceed the compressor drive stub diameter. JGE:K:T/6 and KBB:V frames have flanged drive end connections on the crankshaft, use the crankshaft journal diameter for the minimum motor shaft diameter.

ER-83 provides torsional analysis limitations and guidelines. Ariel provides Vibratory Torque Limits rather than allowable stress limits. Appropriate safety factor and fatigue method has been applied within these vibratory torque limits. Auxiliary end limits and guidelines are defined. Flywheel overhung weight limits are defined along with the proper calculation method.

The torsional analysis should be scheduled as early in the process as practical. Changes to the system design may be required to satisfy the torsional analysis. This may include a different coupling type or model, the addition of a flywheel, or on rare occasion a change to the compressor or driver design.

Below is a list of data necessary for the different phases of a project:

Quotation:

- System definition (compressor type / size, driver type / size)
- If electric motor, define if fixed speed or variable speed
- Include 4 to 7 operating points for review to characterize the full operational map (conditions and load steps) of the compressor

Purchase:

- Full system layout defining compressor, driver, coupling, speed control

Compressor Load Data:

- Define the full range of operating conditions
- Suction pressure range
- Discharge pressure range
- Load step sequence, including pockets and single acting
- Speed range
- Be sure to define load steps consistently throughout the case manager
- Be sure to provide the same load step sequence for the acoustical analysis and (if pneumatic capacity control devices) control panel logic

Compressor Data necessary for Torsional:

- Performance run file for the compressor defining the full operating map
- Mass elastic data
- Torsional supporting documents
- Performance report for each peak condition
- Gas analysis for each peak condition
- Crank effort curve for each peak condition
- Fourier coefficients for each peak condition

To Generate Data:

- Define the full operational map for the compressor in the Case Manager
- Define the Summary Field Configuration to include Peak-to-Peak/2 and Vector Sum 1 through 9 from the torsional section
- Run the Performance Summary and select the cases with the highest Peak-to-Peak/2 and Vector Sum 1 through 9

Run the Report Manager selecting the following reports:

- Configuration
- Mass Elastic Data
- Torsional Supporting Docs
- Performance
- Gas analysis
- Torque Demand Graph
- Fourier Coefficients

Confirmation:

Confirm Torsional recommendations against equipment on order or shipped. This includes confirmation of:

- Flywheel size
- Coupling model
- Internal flywheel size
- Detuner quantity and location
- Driver dampener

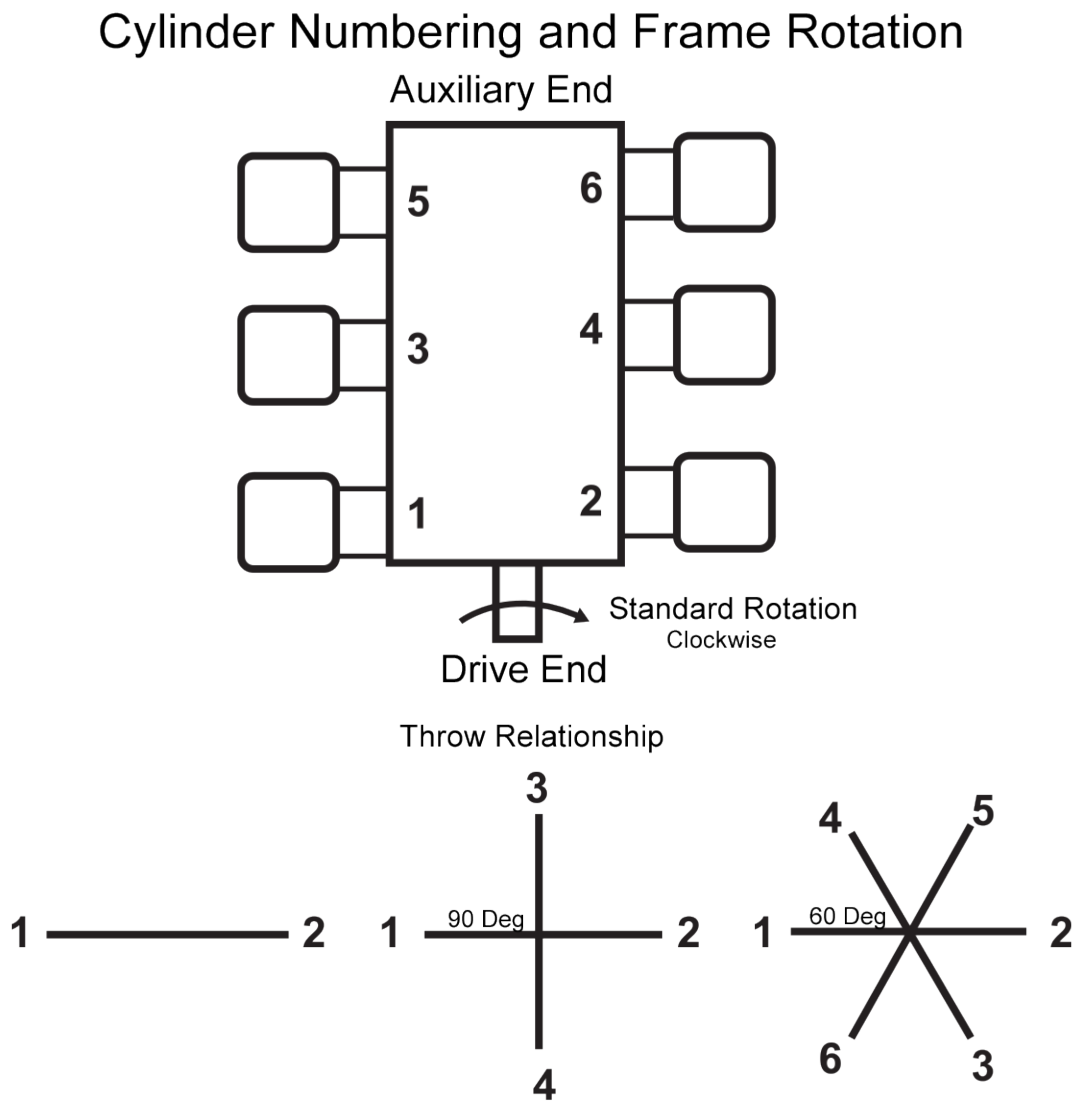
Confirm Torsional solution through field verification at start up for larger, more complicated and new driver compressor combinations, including

- Large Electric Motor Drives
- Variable Frequency Drives
- New Combinations of Driver / Compressor
- Complex Torsional Designs (black out speeds, torsionally soft couplings, black out load steps)

Documentation:

- Recommend including the Torsional Study report in the unit records book for the end user and jobsite

Cylinder Numbering and Phasing



Throw Phase Angles
(viewed from drive end toward aux end)

2 Throw	4 Throw	6 Throw
Lagging	Lagging	Lagging
Throw 1&2 0 Degrees	Throw 1&2 0 Degrees	Throw 1&2 0 Degrees
	Throw 3&4 270 Degrees	Throw 3&4 120 Degrees
		Throw 5&6t 240 Degrees
Leading	Leading	Leading
Throw 1&2 0 Degrees	Throw 1&2 0 Degrees	Throw 1&2 0 Degrees
	Throw 3&4 90 Degrees	Throw 3&4 240 Degrees
		Throw 5&6 120 Degrees

* Standard Rotation for the JGI frame is counter-clockwise