# THE EVOLUTION OF A HEAVY DUTY INDUSTRIAL GAS COMPRESSOR

**An insight into heavy duty industrial gas compressor technology.**

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## Background

Blackmer has been a leader and innovator in the design and manufacture of positive displacement pumps since the beginning of this century. Blackmer's prominence in the transfer of liquefied gases logically led to its introduction of reciprocating compressors for this purpose in 1980. That LB compressor line features two vertical adjacent cylinders in a common ductile iron body. Non-lubricated with crosshead construction and optional distance piece, the LB, with appropriate optional materials, is suitable for most gases. Designed as a complement to the pump line, it is an exceptional performer for liquid transfer and vapor recovery and moderate duty booster applications.

## Industry need

It became apparent both from application successes and customer requests that a demand existed for a small, non-lubricated, reciprocating compressor with process machine features and durable construction in the under 75 bhp size range. While the LB and its competition had nice features, the typical industrial liquid-transfer / vapor-recovery compressors were too short lived and light for year round continuous operation in critical services. Historical "process" compressors were too large, expensive and complex in the small power range. Something was needed to fill this gap between underbuilt and overkill.

## Objective

Blackmer focused on a gradual machinery evolution that results in the right compressor for the small-scale needs of the industrial gas industries. The technical approach assesses and retains the current design and construction features consistent with those needs. New designs and features are incorporated into a new product variant to satisfy the particular industry needs. The LB is retained in the LPG and similar applications where it successfully meets all of those demands. The heavy-duty HD variant is developed for the most demanding services in HPI and similar industries.

## Initial product assessment - LB361

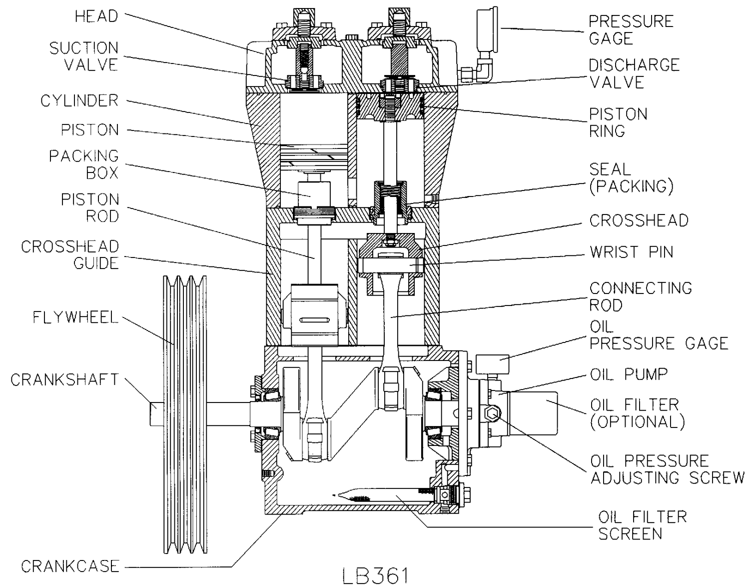
The LB compressor line included several single-stage models in single and double packed configurations in frame ratings from 7.5 bhp to 30 bhp. This article will look at the single-stage LB361 model and its evolution into the HDL342C. The table of MODEL COMPARISON lists the basic statistics of the two models.

| Model | LB361 circa 1980 | HDL342C circa 1996 |
|---|---|---|
| bore x stroke -inches (mm) | 4 x 3 (102 x 76) | 2.687 x 3 (68 x 76) |
| rated bhp (kw) | 15 (11) | 20 (15) |
| maximum speed - rpm | 825 | 825 |
| rated speed | 750 | 750 |
| rated piston speed - fpm (mpm) | 368 (112) | 368 (112) |
| piston ring width x thickness - inches (mm) | .245 x .17 (6.22x 4.3) | .307 x .348 (7.8 x 8.8) |
| rod diameter - inches (mm) | 0.75 (19) | 0.75 (19) |
| rated rod load - lbs (kg) | 4000 (1820) | 3400 (1545) |
| coolant type | air | liquid |
| wrist pin diameter - inches (mm) | .875 (22.2) | 1.0 (25.4) |
| wrist pin bearing type - material | bushing - bronze | needle bearing - steel |
| valves | generic steel plate | Hoerbiger stainless steel |
| inlet-outlet connection - inches (mm) | 1.25 npt (32) | 1.5 ANSI 600# |
| crosshead material | aluminum | cast iron |
| MAWP | 350 psig | 750 psig |

**Model Comparison**

**Model Comparison**

The LB compressor was designed to handle liquefied gases and refrigerants such as Propane, Butane, Ammonia, Carbon Dioxide, Chlorine and R-22, etc. Its proven non-lubricated design and crosshead construction were directly transferable into the broadest range of gas compression. In fact, ring and packing materials and configurations, together with Nickel impregnation of cast components had already been successfully applied to over 70 organic, inorganic, hydrocarbon and reactive gases. The low rotating and piston speeds, combined with the vertical layout, resulted in long life of wearing components in those applications.



LB361
CROSS-SECTION

The primary differences in the LB and HD design considerations had to deal with broader applicability and the attendant duty cycle demands the HD would encounter outside of the liquid transfer / vapor recovery regime that the LB handled so well.

In regard to duty cycle these considerations were determined to be a) more operating hours per year: 4000 - 8500 for the HD instead of the 2000 - 4000 for the LB and b) higher average load: 40% - 85% of frame rating for the HD instead of 20% - 60% for the LB. In regard to application these were determined to be a) more effective rod sealing and packing arrangements and b) new bore sizes and working pressures to meet broad applications. The resulting design goals therefore would emphasize power consumption and efficient operation, longer and more reliable wear component life and more efficient and effective cooling.

The figure: LB361 CROSS-SECTION will assist for component reference. The table DESIGN GOALS shows the matrix of machine components and how each relates to the design goals.

| | more hours | more load % | gas sealing | efficiency | applicability | less wear |
|---|---|---|---|---|---|---|
| crankcase | | | | | | |
| rod | | | | | | |
| cross head | | | | | | |
| packing | xxxxxxxx | | xxxxxxxx | | | xxxxxxxx |
| piston | | | | | xxxxxxxx | |
| cylinder | | | xxxxxxxx | | xxxxxxxx | |
| gaskets | | | xxxxxxxx | | | |
| valves | xxxxxxxx | | | xxxxxxxx | xxxxxxxx | xxxxxxxx |
| head | | | | | xxxxxxxx | |
| piston rings | xxxxxxxx | | | | | xxxxxxxx |
| crosshead guide | | | | | | |
| distance piece | | | xxxxxxxx | | | |
| connecting rod | | | | | | |
| wrist pin bearing | xxxxxxxx | xxxxxxxx | | | | xxxxxxxx |
| oil pump | | | | | | xxxxxxxx |
| oil filter | xxxxxxxx | | | | | xxxxxxxx |
| cooling | | xxxxxxxx | | xxxxxxxx | | xxxxxxxx |

**Design Goals**

## Packing

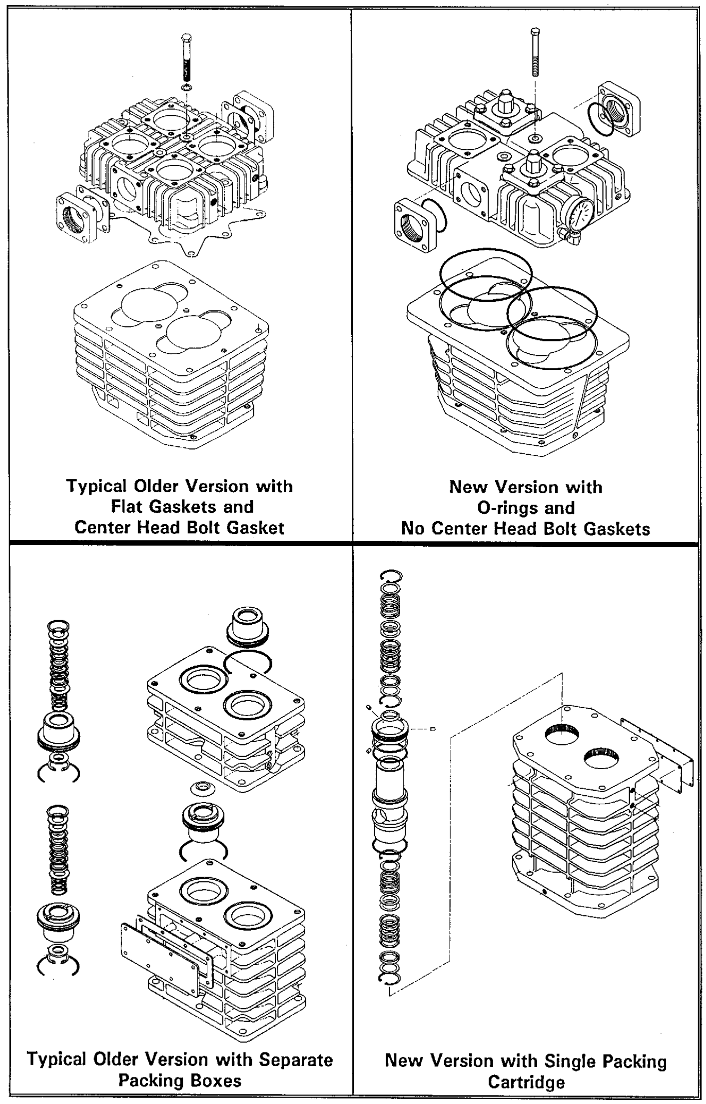
Changes to the packing design included configuration, construction and adjustment.

The LB was initially available only in single seal and two seal configurations. The single seal is adequate if some oil migration to the gas stream is acceptable. Two seals are required to keep the gas stream oil-free. A separate distance piece was used to space and support the individual packing boxes. See the illustration CYLINDER - HEAD - DISTANCE PIECE for a view of the separate packing used at that time. The LB version circa 1991 is shown on the lower left.

In contrast, the HD design, shown on the lower right of the same illustration, uses a standard distance piece for single packing applications, a long distance piece for the two seal configuration and a two-compartment, double-distance piece layout for triple packed API-618 Type D arrangements.

## Seal Area Construction

These three basic configurations are shown in the figure TYPICAL SEAL AREA CONSTRUCTION. Pressurization, purging and venting are possible in each distance piece and provide the best available leakage control for reciprocating gas compressors.

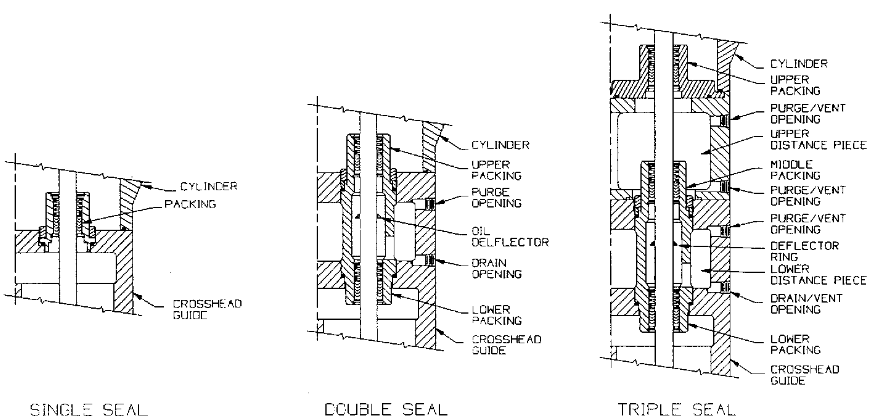

Typical Older Version with Flat Gaskets and Center Head Bolt Gasket

New Version with O-rings and No Center Head Bolt Gaskets

Typical Older Version with Separate Packing Boxes

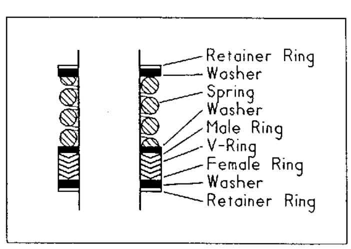
New Version with Single Packing Cartridge

**Cylinder - Head - Distance Piece**




**TYPICAL SEAL AREA CONSTRUCTION**

**SEAL ORIENTATION - SINGLE SEAL COMPRESSORS**



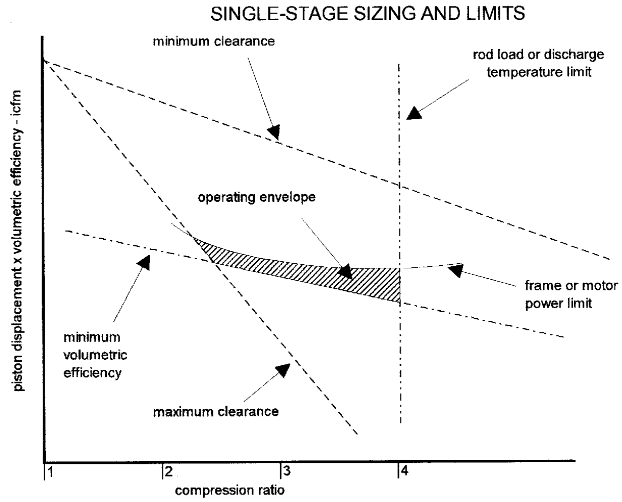

The construction of the two seal arrangements incorporates a single packing case that simplifies assembly and assures that both packing sets are aligned with each other. This extends life through uniform, even wear.

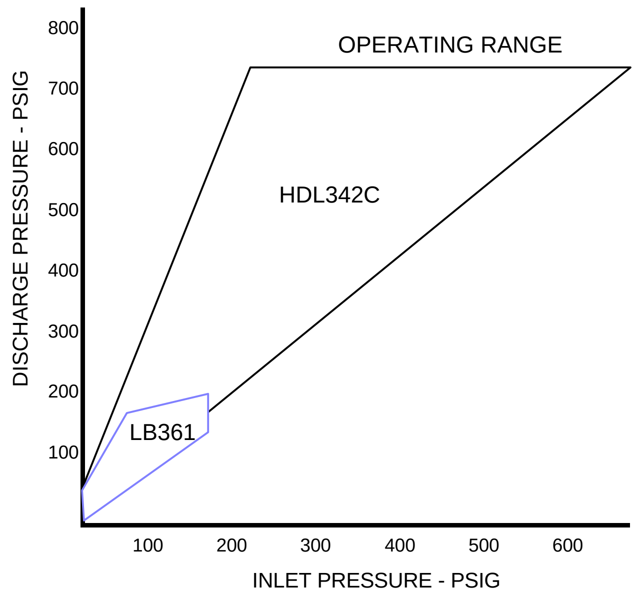
Another important design inclusion is self-adjusting packing. This reduces both wear and leakage by adjusting the rod to packing-ring friction force automatically. This feature, just as the addition of a frame mounted oil filter, addresses the needs of uninterrupted, continuous operation.

## Piston Bore

The relationship of the various parameters and their impact on the compressor operating envelope can be seen from the figure SINGLE-STAGE SIZING AND LIMITS. A significant broadening of applicability is achieved by bore reduction. Reciprocating compressors are positive displacement machines whose capacity and power are related to bore size for any given stroke and speed. The bore is reduced to permit operation at higher suction or discharge pressures in order to keep the absorbed power within the limits of the basic frame design. This limits the capacity through the compressor at elevated suction pressures. This enhances its use as a pressure booster. This also produces substantial added casting material for pressure containment, allowing the higher discharge pressures that these applications require.

The map OPERATING RANGE demonstrates the broadened range of suction and discharge pressures which results from the reduced bore and increased working pressure.



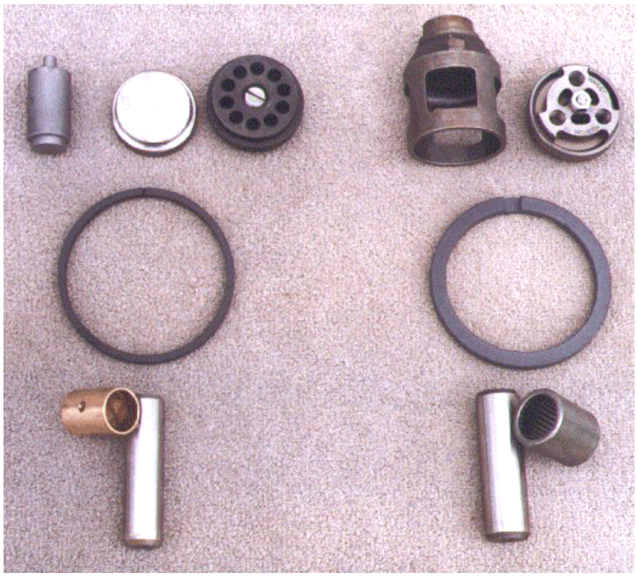

## Piston Rings

The piston rings were greatly increased in depth and width to increase the cross-section approximately 2.5 times that of the LB model. Each of these aspects results in lower rates of radial wear. Together they provide the long life demanded of continuous duty applications. Also, the ring design is now step-cut instead of tangential-cut to provide better sealing at the potential higher differential pressures. The standard material for rings and packing remains PTFE for most non-lubricated applications or other materials selected as required. See the photo of COMPONENT COMPARISON. The HD parts are on the right. The piston rings are in the center row.

## Compressor Valves

The LB compressor uses a generic design of a metal plate valve. It is held to its seat by means of a post and cap. The cap and post arrangement is an outgrowth of the liquefied gas applications. In those, a liquid relief valve is substituted for the suction valve post. The liquid relief valve can be noted on the LB361 CROSS-SECTION. This provides an internal liquid relief should liquid enter the cylinder. This type of suction and discharge valve meets the life and cost parameters of the service and is generally replaced rather than repaired when it is worn.

By comparison, Hoerbiger stainless steel valves are used in the HDL342C to provide the high industry standard for long life and efficient operation. Cook-Manley valves with PEEK plate material are also available on this model and are standard on most HD compressors. Since the HD compressor and its application are an engineered product, these two excellent choices of valve type and material permit optimization of equipment design to the application. The HD valves are retained by a ductile iron cast cage that results in a simple and robust design. The HD valve components, valve and cage, are shown in the upper right of the COMPONENT COMPARISON photo.



**Component Comparison**

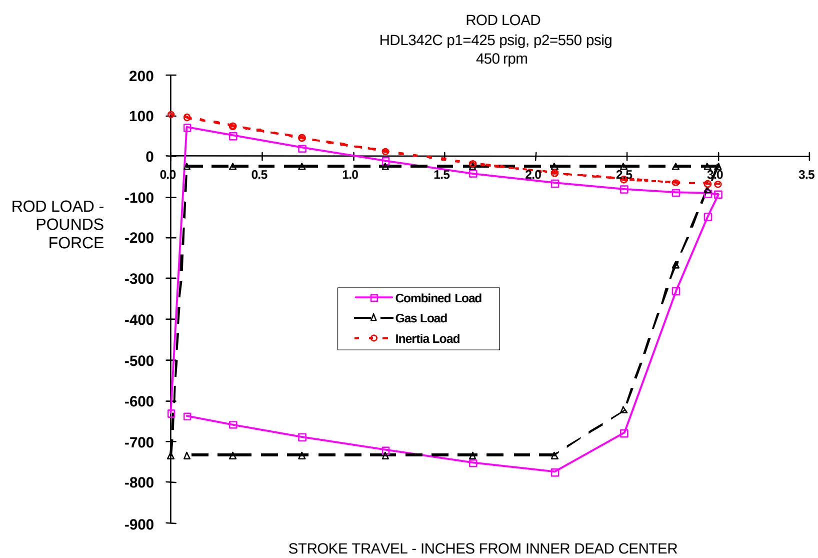
## Wrist Pin and Bearing

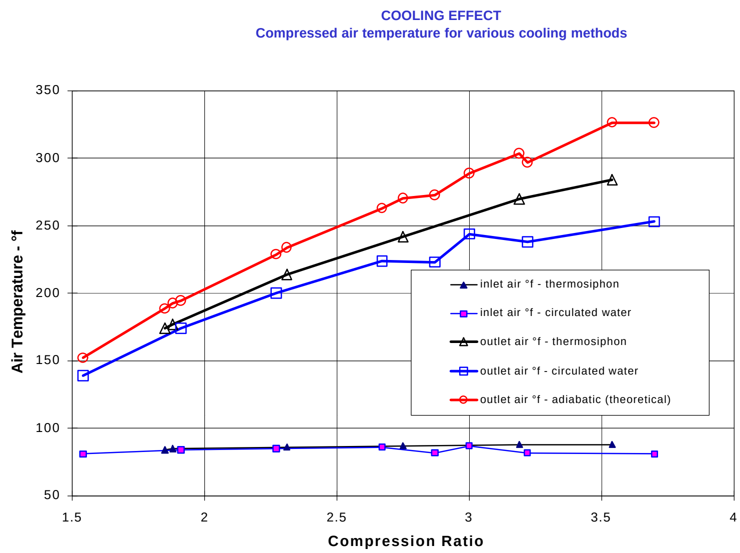
One of the factors which limits the applicability of reciprocating compressors is the rod loading at the operating condition. The significant aspects are the amount of load and the direction of load.

The HDL342C is a single-acting compressor. It compresses only on the outward stroke of each of its two pistons. The gas force is always downward on the piston face because the under-piston pressure is nominally at suction pressure but the piston face pressure varies throughout the stroke from suction pressure to discharge pressure. See the diagram of ROD LOAD.

The only force that can act to oppose the gas force is inertia. The direction of the inertial force of the piston, rod and crosshead masses alternates with the compressor rotation and is proportional to the square of the speed. Sometimes it is in the direction of the gas load; sometimes it is in opposition. If these inertial forces are low in relation to the gas forces they can fail to negate them. This can occur even on double-acting compressors for a variety of reasons including low speed, small or lightweight pistons or unloading of an end. When the combination of forces maintains the direction of rod loading in one direction throughout a full crankshaft revolution the rodload is termed non-reversing. Regardless of the magnitude of the rodload, this will be a life-limiting regime unless the compressor is specifically designed for this condition. The rodload is transmitted from the piston rod to the connecting rod through the connecting rod wrist pin and bearing in the crosshead. Like the LB, most compressors use a bushing at that location. The pin presses continually in line contact against the bushing. Continually loaded at this point of contact, lubrication is denied and eventually the bushing will wear.

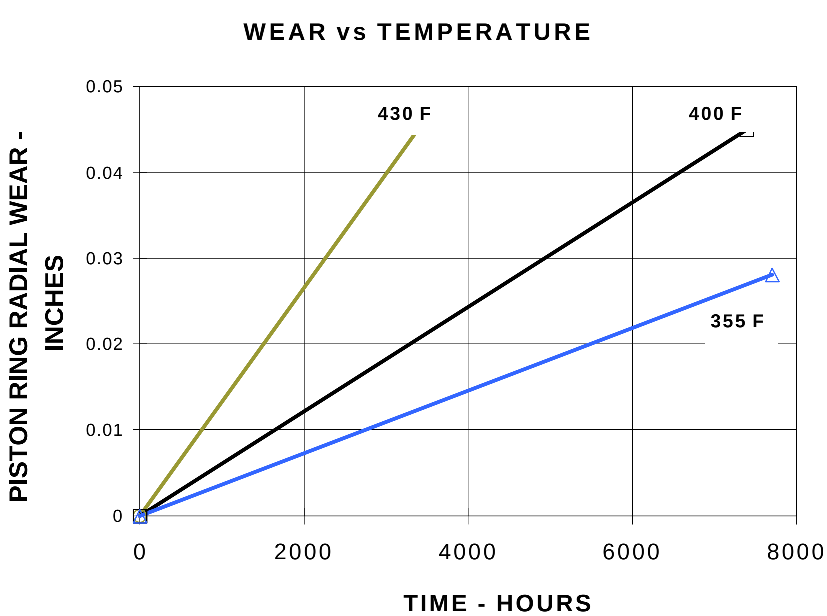
Since the HDL342C is designed for longer operation at higher average loads and higher differential pressures than the LB it incorporates an enlarged wrist pin and needle bearings. The needle bearing is designed for ample rotation and lubrication of its elements regardless of the rod reversal. The smaller wrist pin and bronze bushing are shown in the lower left of the photo COMPONENT COMPARISON. The larger wrist pin with the steel needle bearing is shown in the lower right.



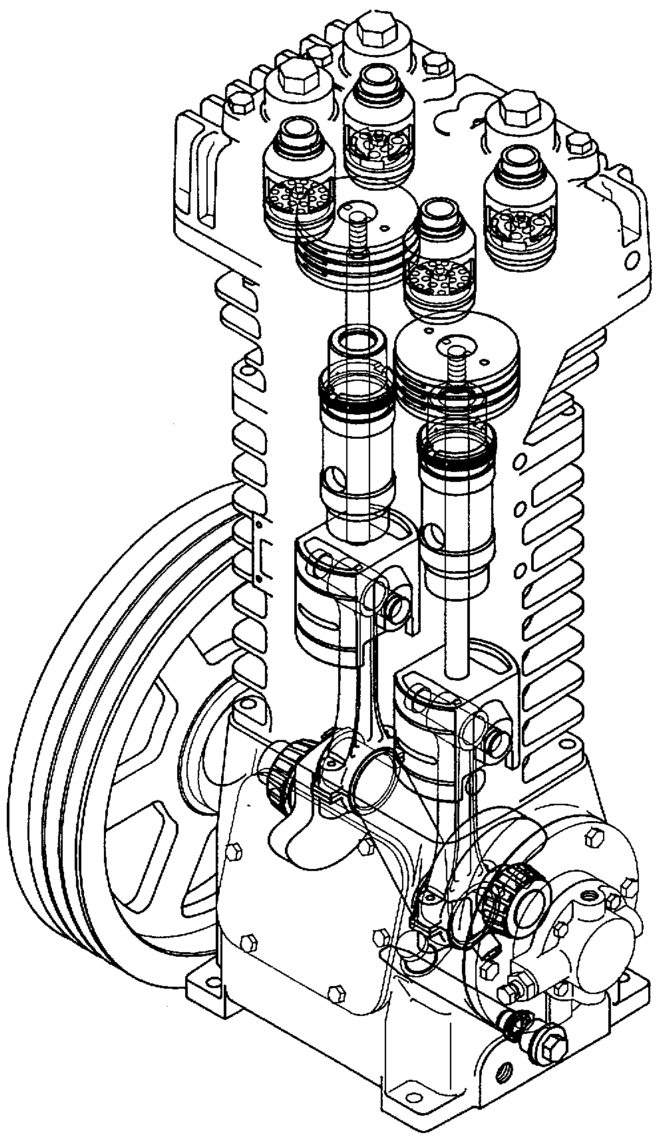



**Cylinder Cooling**

Effective cooling is an important design implementation to prolong component life and extend the range of compression ratio and gases that the reciprocating compressor can handle. Water-cooling is particularly effective in small compressors because the mass flow of the gas is small in relation to the mass of the compressor cylinder. The large water passages of the HD compressor provide significant temperature reductions. See the chart of COOLING EFFECT. The HD low - flow ( 1 gpm ) coolant system circulates through the cylinder body and cylinder head. Gas sealing is by "O" ring; coolant connections and inter-connections are with external tubing jumpers. Compressed gas and coolant are separated by parent metal. See the illustration CYLINDER - HEAD - DISTANCE PIECE for a view of the LB gasket version, upper left, and the HD "O" ring version, upper right. The low-flow system is effective in forced or natural convection cooling systems. This permits simple closed-loop water-cooled systems that do not require coolant pumps or central systems.



The ring, packing and valve materials used in modern non-lubricated compressors have reduced life at elevated temperatures. See the chart of WEAR vs. TEMPERATURE from data that was obtained in a long-term laboratory test program. In general, manufacturers prefer to limit gas temperatures to 300 f for satisfactory life. Liquid coolant not only minimizes the gas temperatures for any given compression ratio or gas but, more importantly, it eliminates hot spots which cause locally high wear, degradation and aging. Liquid filled cooling passages increase the heat flux to reduce the temperature at rings and valves. The liquid coolant reduces the metal temperatures at the sliding surfaces and is an important factor contributing to the low wear rates needed for long life in continuous duty applications.



ISOMETRIC SECTION HDL342C

The HDL342C pictured in ISOMETRIC SECTION HDL342C is a current production model well suited for pressure boosting applications. It is the planned outcome of a nearly two decade evolution of the small, heavy duty, process and industrial gas compressor.