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DEVELOPMENT, FIELD TESTING AND IMPLEMENTATION OF AUTOMATED, HYDRAULICALLY CONTROLLED, VARIABLE VOLUME LOADING SYSTEMS FOR RECIPROCATING COMPRESSORS

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ABSTRACT

Automated, variable volume unloaders provide the ability to smoothly load/unload reciprocating compressors to maintain ideal operations in ever-changing environments. Potential advantages provided by this load control system include: maximizing unit capacity, optimizing power economy, maintaining low exhaust emissions, and maintaining process suction and discharge pressures. Obstacles foreseen include: reliability, stability, serviceability and automation integration. Results desired include: increased productivity for the compressor and its operators, increased uptime, and more stable process control.

This presentation covers: (1) system design features with descriptions of how different types of the devices were developed, initial test data, and how they can be effectively operated; (2) three actual-case studies detailing the reasons why automated, hydraulically controlled, variable volume, head-end unloaders were chosen over other types of unloading devices; (3) sophisticated software used in determining the device sizings and predicted performance; (4) mechanical and field considerations; (5) installation, serviceability and operating considerations; (6) device control issues, including PC and PLC considerations; (7) monitoring of actual performance and comparison of such with predicted performance; (8) analysis of mechanical reliability and stability; and (9) preliminary costs versus return on investment analysis.

INTRODUCTION

Since the 1940's, many reciprocating compressors have been equipped with manually actuated, variable volume, piston-type front head unloaders (VVPs). Adjustment of these VVPs is often difficult and potentially unsafe during operation, so any adjustments are commonly made with the unit shutdown.

Manually adjusted VVPs have always had the ability to provide the user with many levels of loading and unloading. However, most VVPs have fallen into the caveat of not being used very effectively because of the manpower it can take to adjust them. In fact, many operators only set them for nights, weekends, or long unattended periods. When they are set, they are usually set to handle the worst foreseeable condition over a certain time period. Hence, the compressor's total capability is not fully utilized.

To meet customer needs, many other concepts of unloading the compressor have been implemented: automated fixed volume pockets, timed valve closings, end deactivators, speed control, etc. Each of these methods can help to maximize a compressor's potential, albeit each has its own set of pros and cons that need to be considered prior to purchase and operation.

One of the newest methods available for loading and unloading compressors is the automated, hydraulically controlled, variable volume pocket. While concepts and prototypes have been talked about and experimented with for years, only recently have actual working devices reached the market. This technical paper and its associated presentation will cover two commercially available types of hydraulically controlled VVPs: from size selection to installation, from mechanical control to software control, and from expected results to actual achieved results.

NOMENCLATURE

- BHP: Brake Horsepower
- COPAC: Cooper Optimal Performance Automatic Controller

- DEQ: Wyoming Department of Environmental Quality
- DR-HVVP: Dresser-Rand Hydraulic VVP
- PLC: Programmable Logic Controller
- VVP: Variable Volume Pocket

The COPAC VVP can be operated manually, or via automation. When properly automated, close to 100% of the unit's horsepower can be utilized 24 hours per day, depending on operating conditions and hardware limitations.

The COPAC unit consists of three sub-assemblies as shown in Fig. 1.

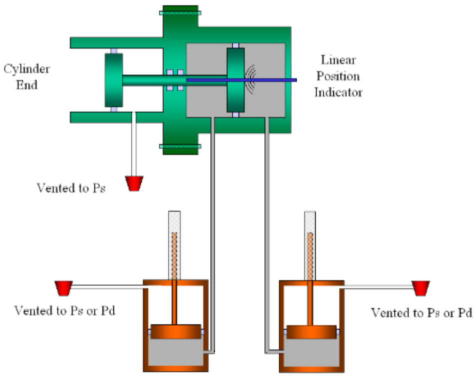

Figure - 1

(a) The variable volume piston type front head unloader and hydraulic cylinder (top),
(b) The Outboard (OB) hydraulic accumulator, and
(c) The Inboard (IB) hydraulic accumulator.

The automation control link is through a linear position indicator (LPI) which signals off the unloader/hydraulic piston, sending a signal back to the control panel. A visual reference of unloader position is furnished on the accumulators (both accumulators are identical in hardware). The link from the accumulators to the unloader is through hydraulics. The design of this unloader system does not require the use of hydraulic oil, that is, the same lubricating oil as used for the compressor or driver may be used. This prevents cross contamination of hydraulic and lubricating oils and does not require additional stocking, storage, dispensing, or disposal equipment. The COPAC also has an arrangement that only involves one accumulator instead of two, but that design was still in testing and will not be included in this paper's scope.

Suction and discharge process gas is utilized to drive this unloader. Gas loading is also utilized to stabilize the hydraulic components when locking the position of the COPAC. Two three-way solenoid valves are used to divert suction and discharge gas to the appropriate accumulator. With this system, it is not necessary to vent gas to a safe atmosphere. Three-eighths inch [0.953 cm] O.D. tubing suffices for the gas system.

Opening or closing the variable volume unloader is determined by the alignment of the suction and discharge gas control valves. Diverting discharge gas to the OB accumulator and suction gas to the IB accumulator results in the unloader moving inboard reducing unloader volume to the compressor cylinder, which increases the capacity of the cylinder. Diverting the discharge gas to the IB accumulator and suction gas to the OB accumulator results in the unloader moving outboard increasing unloader volume to the compressor cylinder, which decreases capacity. Actual control of opening, closing, or locking of the unloader is accomplished by the "position lock valve" (PLV). Closing the PLV prevents the flow of oil between the unloader and the accumulator. Opening the PLV allows the flow of oil to the unloader from the accumulator and from the accumulator to the unloader. It is desirable to use a normally closed solenoid valve for the PLV so the solenoid is energized only when the unloader position must be changed. The suction and discharge solenoids should also be de-energized when the PLV is de-energized; discharge gas should be diverted to the IB accumulator when the PLV is de-energized (locked or closed).

Hydraulics are the key to moving and holding items in place during the heavy forces experienced by reciprocating machinery. Another type of automated VVP uses hydraulics and controlled-balance pressures to achieve similar results, but does so through different means.

The DR-HVVP can also be operated manually or automated. The operation of this pocket relies on a combination of compressor gas cylinder pressure and solenoid valve position as detailed in Fig. 2. To add clearance to the compressor cylinder, and move the volume pocket piston outwards, solenoid "B" is energized, allowing the flow of hydraulic fluid through "B" and check valve "B" into the inner end of the hydraulic cylinder. Gas pressure in the cylinder pushes the volume pocket piston outward. To reduce clearance in the gas compressor cylinder, valve combination "A" is invoked.

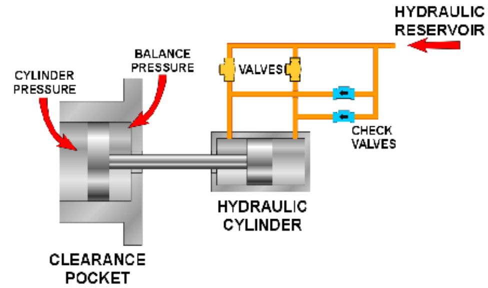

Figure - 2

The Balance Pressure used in the Clearance Pocket is a pressure that is maintained between Suction Pressure and Discharge Pressure for the cylinder on which the unit is attached. This pressure, along with the hydraulics, is used to move the HVVP's piston to allow for more or less clearance volume. During part of the piston's stroke, the pressure in the Head End chamber is close to Suction Pressure. Since the Balance Pressure is greater than Suction Pressure, the HVVP piston can move to close the pocket if the correct valves are set. Alternatively, during part of the piston's stroke, the pressure in the Head End chamber is close to Discharge Pressure. Since the Balance Pressure is less than Discharge Pressure, the HVVP piston can be moved to open the pocket if the correct valves are set.

Additional variations of variable volume pocket devices are likely to be offered in the future. These devices may utilize similar methods, including current patented features, or they may open, close and lock their volumes by other means. In any case, the market now has multiple control devices for smooth load control that utilize the most efficient way to control load on reciprocating compressors – by changing effective clearance.

LOAD CONTROL ISSUES

While there are many ways to control load on a reciprocating compressor, there are certain conditions that make automated VVPs the ideal solution. In general, clearance based solutions to control load are ideal for normal to high-pressure ratios (1.6 and higher) while suction valve control methods are often more effective for low-pressure, low-ratio applications (1.4 and lower). Thus, if changing clearance volume is the solution to your load control, then the real issue becomes whether you should use multiple and varied-sized fixed volume clearance pockets, or use VVPs, or a combination thereof. Until recently, only the fixed volume pockets could be effectively automated. Now the playing field is leveled with these new hydraulic VVPs with automation integration.

In general, automated VVPs are an ideal solution whenever you have a need to compress as much gas as possible, to maintain engine emissions levels, to maintain constant suction or discharge pressures, to maintain a process control, or any combination of these over varied operating ranges. Fig. 3. shows how much more often a unit may run at rated load (horizontal black line) when there is a HVVP effectively being used (lower chart) versus without one (upper chart) being used.

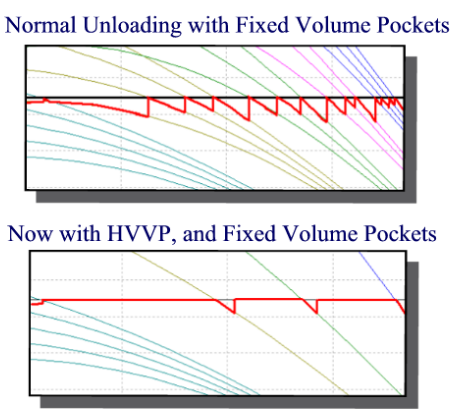

Figure – 3

Gas compression plants must deal with a variety of changing conditions that affect the operating efficiencies of the engines and compressors. These conditions include the throughput demand, compressed gas suction and discharge pressures and temperatures, ambient temperatures, and fuel composition. Since the major objective for the gas plant is to produce gas throughput as economically as possible, the station operators generally must make adjustments to the engine and/or compressor to optimize the unit performance as conditions change.

Changes in the following parameters affect the load carrying capability of the engine, capacity, fuel economy, and exhaust emissions levels:

1. Suction and discharge pressures and temperatures,
2. Ambient temperatures, and
3. Speed.

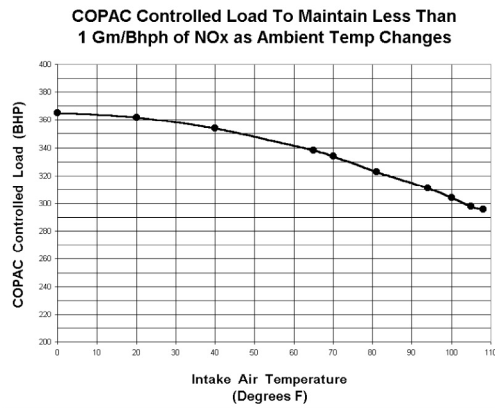

Figure - 4

An automated VVP system automatically controls unit loading to avoid engine overloading while maximizing the compressed gas flow throughout a wide variety of changes in operating conditions. Because of the stepless unloading feature provided by VVPs, the engine torque can be maintained at the highest level needed for any set of gas compression conditions. As compared to other unloading systems, which change load in sizable steps or change engine torque, VVPs provide an improvement in fuel economy by smoothly maintaining the higher engine torques.

As an example, when exhaust emissions must be at or below permitted levels, the automated VVP system can automatically adjust the load to maintain low emissions (Fig. 4.) VVPs provide continuous control of the unit load as a stepless function, rather than a finite series of steps as provided by most other unloading systems. The resulting effects are the same as if an experienced operator were continuously available to make load adjustments in response to changing station conditions.

SUPPORT SOFTWARE

Newer software is usually required to help today's compressors achieve their ideal performance. In the case for the Honeoye Gas Storage application (NY), they employed eCurves™ software with its ability to handle automated VVPs. In the case of Western Gas Resources (WY), they employed FW Murphy's Ajax Millennium Panel with its implementation of the

ACI Compressor Modeling Kernel and CES's eAjax™ software for sizing. And, in the case of Duke Energy's Kwoen Plant, they employed ePerformance™ software (Fig. 5.) All of these software packages are able to optimize the compressor by fully utilizing the flexibility and performance enhancement features of automated VVPs. While not all OEM software currently supports automated VVPs, most can compensate for them via their current methods for manual VVPs, at least in regards to performance predictions.

Today's generation of predictive software allows dynamic generation of performance curves, real-time analysis of actual data, all with full integration of HVVPs. Thus, a user is now capable of analyzing complex What-If scenarios, monitoring real-time compressor performance and being able to snapshot conditions for record keeping, for these new stepless unloading devices.

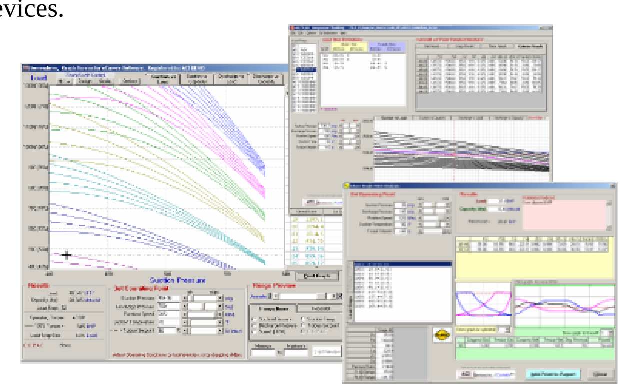

Figure - 5

Many implementations of automated VVPs will require PC and PLC based software, while some may not. For example, both the COPAC and the DR-HVVP can be operated manually. That is, an operator can direct the device (via switch, pump or dial) to open or close and then direct the device to lock when it reaches a desired position. This feature alone makes automated VVPs very useful – no more two-man crews with cheater bars trying to crank a manual handwheel VVP. Since many manual VVPs are rarely set because of the manpower required to adjust them, some of the compressor's efficiency is lost. When might meets intelligence, as with a good operator or a well-programmed PLC, the resulting efficiency gains from the compressors can be impressive.

At the basic core of enhanced compressor utilization is the PLC. Unfortunately, many older PLCs do not have the speed, memory and raw computing power of a typical desktop PC. Thus, the goal of how to make the PLC match the PC's complex predictions and controls can become a real concern in optimizing compressors with these newer, more advanced unloading devices.

Typically, one solution is to analyze the range of operating conditions for which the unit is sanctioned, and then decide how to simplify the prediction calculations. Questions typically asked might be: Is it a fixed-speed unit? Is only natural gas being compressed, or a process gas being compressed? Are all per-stage cylinders nearly identical? How many different setpoints are being employed to control the unit? Will rod load calculations be based on gas pressures at flange suffice, or will more complex net rod load calculations be required? Is the unit bounded by just one throw's rod loads, or does each throw need to be calculated? What are the potential cutoffs due to: low suction volumetric efficiencies, low discharge volumetric efficiencies, high discharge temperatures, overload conditions, crosshead pin failing to reverse, etc.?

In the case of the Duke Energy's Kwoen Plant, even after streamlining the calculations, an additional CPU module had to be added to handle the complex calculations. In this case, gas compressibilities well into the 0.740 range are being experienced, possible formation of liquids at the fourth stage's suction, and side streams of different compositions of high-acid gas (80%+ H_2S) were all contributors to making this a complex job – not to mention the effective control of 20 automated DR-HVVPs.

Many operators have experienced the implementation of technological advances. Some implementations achieved their goals, some achieved very little, and some made situations worse. With more and more automated VVPs being installed, the results are beginning to tell their story.

DEVICE LAB TESTING RESULTS

Every new device needs to be considered in great detail to determine if it truly meets the needs of the scrutinizing consumer. Automated VVPs are no exception. Some items that the potential buyer needs to be aware of are: durability of devices, reliability, integration with new or existing control panels, speed of device to open and close, limitations of use, costs versus results returned, and others. These interests can be categorized into two areas: results from the OEM and their internal tests, and results from actual field usage.

In the case of the COPAC device, it was initially tested for 24 hours straight in continuous cycling mode – full open to full close. Then it continued its tests for about a week with periodic monitoring. Some results determined:

- It opens faster than it closes,
- Time to open/close is a function of pressure differential, typically ranging from about ten seconds to two minutes (Fig. 6.),
- Use of higher stage discharge pressure can decrease reaction times by effectively increasing the differential pressure,
- Seals and rings were found to be in good shape,
- Scratches in piston and bore were determined to be from dirty oil, and
- Better connection types and solenoid valves where chosen after original threading and valves failed to meet active demand of the device.
- Effects of filters on gas and oil lines were considered.

Pressure Differential	Time Required to Open	Time Required to Close
50 psi	60 seconds	110 seconds
150 psi	26 seconds	40 seconds
250 psi	18 seconds	31 seconds
350 psi	15 seconds	25 seconds

Figure - 6

With more than a year of actual use, the COPACs installed at Honeoye Storage Corporation, NY controlling overload conditions, experienced only one real problem – an o-ring on the accumulator became pinched. It was later determined that this was most likely done during assembly.

At present, information related to the DR-HVVP is somewhat sketchy by the nature of its recent addition to the marketplace. Indications are that it can fully open or close the VVP in less than five minutes, depending on pressures and VVP size. Also, based on the user's needs, a reduced system is configurable that only uses the hydraulics to close the pocket instead of both opening and closing. In this reduced case, the cylinder's internal pressures are used to open the pocket although this method may not be as fast or as smooth as the dual hydraulic model.

From start to finish, these new devices will present the experienced compressor person with some areas of thought. Installation of the actual devices is about as challenging as typically unloading devices; however, the user must plan on installation of hydraulic controls and also anticipate changing, or adding, automation controls. Both of these items will add installation time and costs to the project.

A major concern with automated VVPs in the past has been that of excessive wear on the seals. This wear may come from either normal stroking of the device, or potentially from chucking of the VVP's piston as the main cylinder's piston compresses and expands gases. Another important concern is that of accurately sensing the VVP's piston position. That is, if you set your desired position to 57.5% open, then how close to this desired position will the device actually open? Moreover, there are additional concerns of life expectancies of the device's components.

With new cylinders and/or compressors, the OEM can often install the device onto the cylinders prior to shipping. With retrofits, the installation may be done at the compressor site. Because of the sizes and weights involved, a crane will be required for most jobs and will require two to four days. Welding services may be required to mount power systems and/or hydraulic oil reservoirs or accumulators. Since both common designs mount on cylinder head ends, they can usually be installed without removing the cylinder head – some heads may require modifications while some cylinders may altogether require new heads.

Most HVVP devices are about the same length as a manual VVP of the same volume with its handwheel fully cranked out. Some additional room may be required for installation or servicing. Also, safe locations for the hydraulic systems need to be considered.

DEVICE FIELD TESTING RESULTS

Field Application #1. Honeoye Storage Corporation (Fig. 7.) in New York had an ongoing problem with their Superior WH-64 (4-throws, 6¼-inch [15.875 cm] cylinders, 1500 MAWP [103.4 bar]) compressors with four manual VVPs experiencing overload situations during the 128 hours per week of unmanned operations. The station's real-time monitoring systems would detect overload on an engine and shutdown the unit. To reduce potential shutdowns, Honeoye often would set the manual VVPs to allow the unit to handle the worst cases that it might experience during the unmanned hours. However, this usually resulted in less than ideal gas flows, and there were still times of undesired shutdowns. The proposed solution was to remove one of the manual VVPs and replace it with an automated VVP. Then, tie the opening and closing of the automated VVP to the monitoring system. Thus, whenever the system was approaching shutdown conditions, the VVP would begin to open to unload the unit. As conditions changed to desire more horsepower, the VVP would close and thus load the unit.

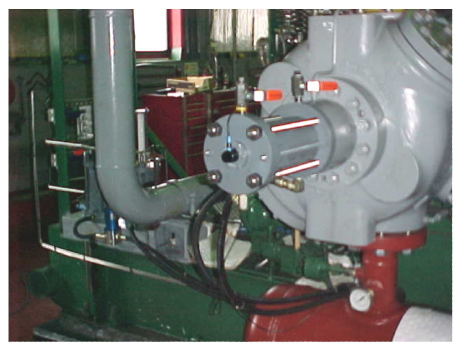

Figure - 7

A single COPAC was sized to match the existing manual VVP and installed. Problems with injecting oil into the accumulators were realized and later solved. Questions about whether one or more COPACs would be required to handle the varied operating conditions arose.

After a few months the COPAC's position was improper according to the accumulators' visual indicators. An inspection indicated that one of the accumulator's o-rings had been pinched, probably during installation. As a result, some oil was lost and this lead to inaccurate visual indication. This did not affect the magnetic sensor located in the COPAC. The o-ring was replaced and the unit re-enabled. A later inspection about a year later, of the entire COPAC device, revealed no wear and no degradation of the product. It should be noted that the primary purpose of the visual indication on the accumulators is troubleshooting and proper loading of the hydraulic oil media, not for automation control.

Honeoye uses dynamic performance curves to best determine optimal settings on the three manual VVPs and best initial setting of the hydraulic VVP to handle expected changes in operating conditions while maintaining better flows during unmanned hours. Shutdowns are no longer commonplace and only one COPAC per unit was necessary. However, to avoid areas of low suction volumetric efficiencies, additional COPACs are being considered.

Field Application #2. The Powder River Basin in Wyoming has an abundance of coal bed methane gas available. Historically, integral engines/compressors have been used throughout this area to gather this gas. However, stricter environmental laws from the Wyoming Department of Environmental Quality (DEQ) specify that the NO_X exhaust emissions shall not exceed 1.0 g/BHPh for newer engines.

For most types of engines, the NO_X exhaust emission levels increase as the ambient temperature increases and as the amount of load applied to the engine increases. This means that, at a given load, the NO_X level would be the highest when the ambient temperature is at the highest level for the year. The highest annual ambient temperature in Wyoming is approximately 100 °F [40 °C]. As a result, to prevent NO_X exhaust emissions from going above the permitted level, the engine must be limited to the amount of load that would produce 1.0 g/BHPh on a 100 °F [40 °C] day. If the unit cannot accommodate changes in ambient temperature by dynamically altering its maximum load, then the unit would be limited for the whole year by the maximum load for the highest ambient temperature.

To better illustrate this, the average ambient temperature at the test site was 44 °F [6.7 °C] and at this temperature the engine being tested could produce 350 horsepower [261.0 KW] and still comply with the emissions permit. However, since there was no current emissions control, the horsepower would be limited to 304 BHP [226.7 KW] so that when the ambient temperatures do rise later in the year, the engine will always be in emissions compliance. This is neither ideal for the OEM selling the equipment or for the user of the equipment. Especially in Wyoming where there are many more cold days than there are hot days.

Hydraulic VVP

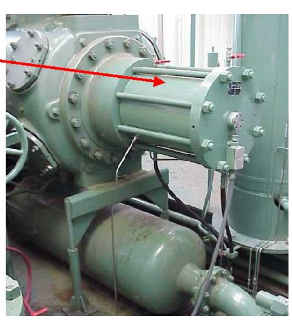

Figure – 8

It was decided to add an automated VVP (Fig. 8.) to one integral engine/compressor to keep the NO_X exhaust emissions in compliance by automatically adjusting the load on the engine as the ambient temperature changes. The COPAC would be added to the 23-inch [58.42 cm] first stage cylinder's head end. If this worked in practice as in theory, then the engine could be used much more effectively throughout the year, while staying within the emissions guidelines.

Previous field and lab tests were used to determine the amount of load that can be applied to the engine at various ambient temperatures and still remain at or below the 1.0 g/BHPh exhaust emissions level. The PLC controller used this information, along with predictive load algorithms, to calculate the maximum allowable load at a given ambient temperature. The actual load on the engine was calculated and compared to the allowable load. The controller then adjusted the HVVP so that the actual load matches the allowable load.

This system was installed in July of 2001 on an Ajax® DPC-2802LE at Spotted Horse, Wyoming. Emissions and performance testing was done at the request of the DEQ. To get the largest ambient temperature change in the shortest period of time, the test was started at sunrise and went until the hottest part of the day. Using this procedure, testing was done with the ambient temperatures changing from 70 °F [21.1 °C] to 108 °F [42.2 °C]. As the ambient temperatures increased, the COPAC system unloaded the engine and kept the engine in emissions compliance. The system is continuously monitored via satellite modem. As of June-2002, there have been no problems with this system.

Data from the unit was continually taken by the Ajax Millennium Panel and sent via satellite to FW Murphy's website where it was analyzed. The data includes: Date, Time, Speed, Predicted BHP, Maximum Allowed BHP, Current COPAC Position, Suction Temperature, Suction Pressure, First Stage Discharge Pressure, Second Stage Discharge Pressure, and Manifold Temperature (used as Ambient Temperature). The purpose of collecting the data was two-fold: first, to verify that the unit was performing as programmed, and second, to determine how much more additional load the unit could produce and still stay within the emissions requirement.

The data was reviewed in January 2002. The data confirmed that the unit was adapting to the changes in operating conditions and to changes in ambient temperatures as desired. Moreover, the additional HP as a result of using the HVVP ranged from 0.8% to 27.7%, with 6.5% being the average. Over 80% of the data fell within one standard deviation. Thus, the base conclusion of using 6.5% for the general increase in HP was made. However, when one takes into account the original derating of the engine to meet emissions based on the hottest day of the year, the increase in flow jumps into the 15%-20% range.

While the COPAC HVVP met its tasks to control load, and thus emissions, there were some items that came to light during the field test. Some areas undergoing further review are: (1) The current design of the COPAC Hydraulic VVP has gas on top with oil on the bottom of the accumulators. Does this lead to moisture buildup in the accumulators? If so, would transposing the two mediums help the situation? (2) Are predictive algorithms effective in high gas pulsation environments? And (3) Pneumatic solenoid valves seem to work fine for the applications. Are they good for all scenarios?

Field Application #3. Duke Energy's Kwoen Gas Plant (formerly Westcoast Energy, Inc.'s) has been designed as a bulk Acid Gas removal facility (Fig. 9.) The plant straddles a main sour gas transmission pipeline, and its main purpose is to reduce the load on the downstream sulfur plant by reducing the hydrogen sulfide content in the pipeline gas stream. The process incorporates an absorption method to remove the H_2S, using a physical solvent. The solvent is re-generated in a four step flash process, where the Acid Gas is liberated in the final two flash steps. The first two flash steps yield considerable amounts of methane, so the gas at these flash pressures is recycled back to the inlet of the process. The facility incorporates three main compression trains: Inlet, Recycle and Acid Gas. The Inlet Train consists of 11,000 HP [8,202.7 KW] to supply feed gas to the plant. The Recycle Train consists of 5,000 HP [3,728.5 KW] to recycle gas back to the inlet of the process. The Acid Gas Train consists of 13,800 HP [10,290.7 KW] to compress the Acid gas to injection disposal pressures.

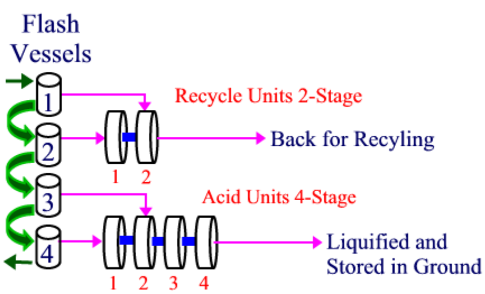

Figure – 9

The process is heavily dependant upon reliable control of the flash pressures to ensure the stream compositions remain relatively void of any hydrocarbon gases in the final two flash steps. The control of the flash stream pressures is achieved by using compressors that have the ability to adjust precisely to changing conditions, be those changes small or large.

The compression trains that use cylinder head-end clearance adjustment are the Recycle and Acid Gas trains. The Recycle compressors are two-stage, four-throw Dresser Rand HOS frames. Hydrocarbon rich gas from the second flash step is compressed through two 9.5-inch [24.13 cm] cylinders, cooled, and then combined with gas from the first flash step. The combined gas stream then enters the second stage of compression, comprised of two more 9.5-inch [24.13 cm] cylinders. Each of the cylinders is equipped with a DR-HVVP.

The Acid Gas compressors are four-stage, six-throw Dresser Rand HOS frames. Hydrogen Sulfide rich gas from the final flash step is compressed through two 22-inch [55.88 cm] cylinders, cooled, and then combined with gas from the third flash step. The combined gas stream then enters the second stage of compression, comprised of two 19.5-inch [49.53 cm] cylinders. Further compression through a single 14-inch [35.56 cm] and a final 9-inch [22.86 cm] cylinder brings the gas up to injection disposal pressures. All of the first and second stage cylinders are equipped with DR-VVPs while the third and fourth stage cylinders are equipped with standard manual VVPs.

A large degree of compressor turndown was required for this project since the compressors are tied into a process where gas volumes can fluctuate from essentially zero to full capacity. Energy conservation is of significant importance in the project, not only from an environmental perspective, but also from a cost savings. Design consideration of the compressors operating on recycle control was intended as a last result. Operation of the compressors using more traditional means of cylinder capacity control, such as head end unloading was far too abrupt for this process. Manual VVPs appeared to provide a suitable means of capacity control, but often this has meant that the compressor might need to be shutdown and depressurized before attempting to make a volume pocket adjustment. A need for a method of head end clearance adjustment while the compressor was operating resulted in the decision to equip the compressors with the hydraulically actuated, variable volume pockets.

Control of the compressor is of paramount importance. Not only is a precise method of control required for the process, but also for ensuring that the compressor is not compromised mechanically due to operation outside the compressor OEM's constraints, or the liquefaction of the gas due to the properties of the gas at certain pressures and temperatures.

To reduce the potential wear on the pocket components, the pocket will be actuated in defined steps through feedback from a position sensor on the piston rod. The facility PLC controls the setting of the pocket with respect to the process variable. The PLC uses built-in logic to ensure that the volume pocket will not be moved to a position that would cause the compressor to shutdown due to a mechanical limitation.

Field Tests are scheduled for July 2002, and thus are not available for inclusion into this paper. However, details of the tests will be available during the presentation of this paper.

COSTS VERSUS REVENUES

Sometimes you really need new technologies: sometimes you just want new technologies. One factor in deciding between needs and wants is initial cost and corresponding return on investment.

If you require stepless unloading, then you will likely need either automated variable volume unloaders, or one of the timed suction valve closing methods. In general, clearance-based solutions are always more efficient, often more effective and usually less costly. However, costs depend on a lot of factors and you should consult with you vendor, packager, OEM, etc. to determine which method is best for your immediate and long term needs.

Fig. 10. details how a typical automated variable volume unloader can keep your compressor running at full load for much of the operating map. In this particular case, an HVVP is added to a free head end with fixed volume pockets on the other three head ends of a four-throw single-stage unit. In the top chart, the red line details at which unloading steps the compressor would operate for various suction pressures (x-axis). The bottom chart details the same with the HVVP installed. For the top chart, the average achieved BHP for the area where the unit could achieve 100% full load is 91%: for the bottom chart, the average is 100%. Thus, over this range, the HVVP would be able to flow more gas and thus generate more revenue for the operator. In this example, the unit would be expected to flow about 2% more per year, on average. Increased flows would vary by system and expected operating conditions, but many would realize anywhere from 1% to 5% increases in flows. This amounts to thousands, and hundreds of thousands of dollars of revenue from addition flows.

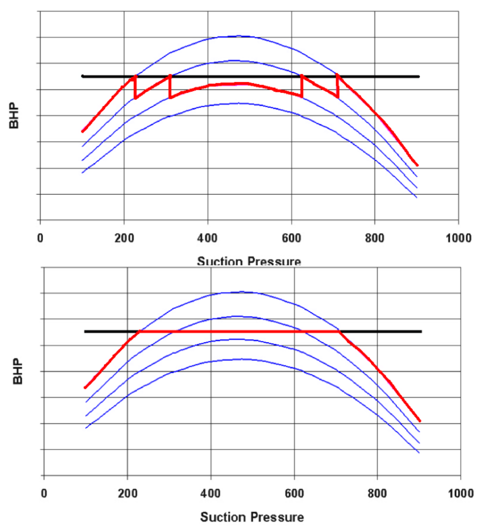

Figure - 10

You can estimate an expected increase in flow by taking the average percent difference of load step sizes in your current unloading sequence and taking half of that. Thus, if on average your load step sizes are about 5%, then your expected additional flow would be about 0.5 * 5% = 2.5%. Please note that if you have large load step sizes, or if operating conditions do not change much, then real measured results of similar applications would be more ideal in predicting what gains you might experience by adding an HVVP to your existing unit.

Depending on a variety of factors, an HVVP device can pay for itself within a few months to upwards of a couple of years. Some key factors include: volume of gas compressed, size and price of HVVP system, and the revenue of additional gas compressed.

In the case of the unit in Wyoming (see Field Test #2) using an HVVP to control emissions, the additional revenue can be substantially more. Without the device, the unit could only load to 304 HP [226.7 KW] all year long to meet regulations on emissions: with the HVVP it can load up to 350 HP [261 KW] during the colder months – over 15% more HP. Fig. 11. details how the unit performed with the HVVP being utilized. In this case, the table's data is calculated by taking the average BHP with the HVVP installed for each day and divide it by the lowest BHP allowed during any 1-hour period of that day (the case where the manual VVP would have to have been set to prevent the unit from either overloading or exceeding allowed emissions.) Next, the minimum, maximum and average for the days in that month were determined.

Additional BHP Availability via COPAC

Month	Minimum	Maximum	Average
August	0.9%	12.6%	6.6%
September	1.0%	19.3%	8.1%
October	0.8%	27.7%	5.3%
November	1.8%	13.0%	5.7%

Four Month Average = 6.4%

Figure - 11

The data clearly indicates that adding an HVVP can significantly increase allowable HP for some particular applications. And in most cases, more HP means more flow, which in turn, usually means more revenue. In the case for this Ajax unit, an average of 6.4% increase in HP corresponded with an average of 6.7% increase in theoretical flow for the operating map covered.

For applications of HVVPs such as those used at Honeoye Storage Corporation, where the devices are used to prevent overloading of the engine and the corresponding shutdown, determination of return on investment can be difficult to quantify. However, a quote from the station's superintendent, Scott Warnshouse can provide insight to their experiences: "The COPAC has allowed us to run at a higher load percentage when unmanned, in turn giving us a higher operating efficiency. To date, we have been very satisfied with the COPAC operations."

CONCLUSIONS

The main goal of automated, hydraulically controlled, variable volume pockets is to provide additional compressor performance. Both the COPAC and the DR-HVVP have shown great promise in delivering on their potentials. With clearance-based unloading being almost always the most effective way to unload a reciprocating compressor, these devices have changed the basic operation -- one from you adapting to the unit's performance to one where the unit adapting to your needs.

Operators of reciprocating compressors have many choices for unloading: manual VVPs, fixed volume pockets, end deactivators (holding valves open, removing valves, or going to zero volumetric efficiency), timed-valve closing devices, timed-plugs in fixed volume pockets, speed, suction-throttling, variable stroke pistons, and now HVVPs.

Clearance based solutions are best, provided the amount of clearance is achievable on that unit. Most end deactivation methods lead to parasitic losses and often to higher pulsation effects. Timed-valve methods lead to back flows, and thus to additional valve losses and pulsations. Timed-plugs in pockets may lead to excessive maintenance situations. Changes to speed reduce allowed BHP to keep the driver at a constant torque, and often increase emissions. Suction-throttling control methods just plainly waste energy. And lastly, variable piston stroke solutions are not viable at the present time.

In general, many applications will only need one HVVP in conjunction with fixed volume unloaders to smoothly load and unload the unit. For maximum control such as required in process environments, or for applications experiencing low volumetric efficiencies, multiple HVVPs may be required.

Once an HVVP is automated via your unit's PLC, then you will start to realize some level of compressor optimization such as more capacity, optimizing power economy, maintaining lower exhaust emissions, or maintaining process suction and discharge pressures. For more information on what may be best for your unit's need, contact your packager, your OEM, a compressor rental company or an engineering service company specializing in reciprocating compressor performance.

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http://www.aciservicesinc.com

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FWMurphy
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Honeoye Storage Corporation, Honeoye, New York
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