Capacity Control Considerations for Acid Gas Injection Systems

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ABSTRACT

One of the significant challenges facing engineering and design teams is the implementation of acid gas injection systems that have wide variability, quick response times, and are trouble-free. The success and regulatory compliance of the overall production facility often depends on the robustness and performance of the acid gas injection system.

Depending on the type of injection and power system, there are a number of options for managing flows, turndowns, variable compositions, and system pressures. This paper will present a number of capacity and system control methods and how they can be implemented and managed. Advantages and disadvantages of each are reviewed with an eye towards developing a strong, responsive, and comprehensive method for controlling acid gas injection systems with consideration for effective commissioning and start-up.

1. INTRODUCTION

Acid gas is composed of a mixture of H_2S and/or CO_2 and often water vapour. Acid gas, a byproduct of gas treating systems, is usually considered to be a simplistic binary mixture of H_2S and CO_2. There are often other contaminants including methane, BTEXs, amine, and

other hydrocarbon components. Carbon capture streams are typically pure CO_2 although there are other contaminants co-captured with the carbon dioxide. For this paper, the term acid gas will be used interchangeably to describe either the acid gas from a sweetening process or the waste gas from a carbon capture scheme. Produced gas from an enhanced oil recovery (EOR) scheme will be discussed briefly as it behaves somewhat differently. A simplistic P-T plot is shown below for some typical acid gas fluids:

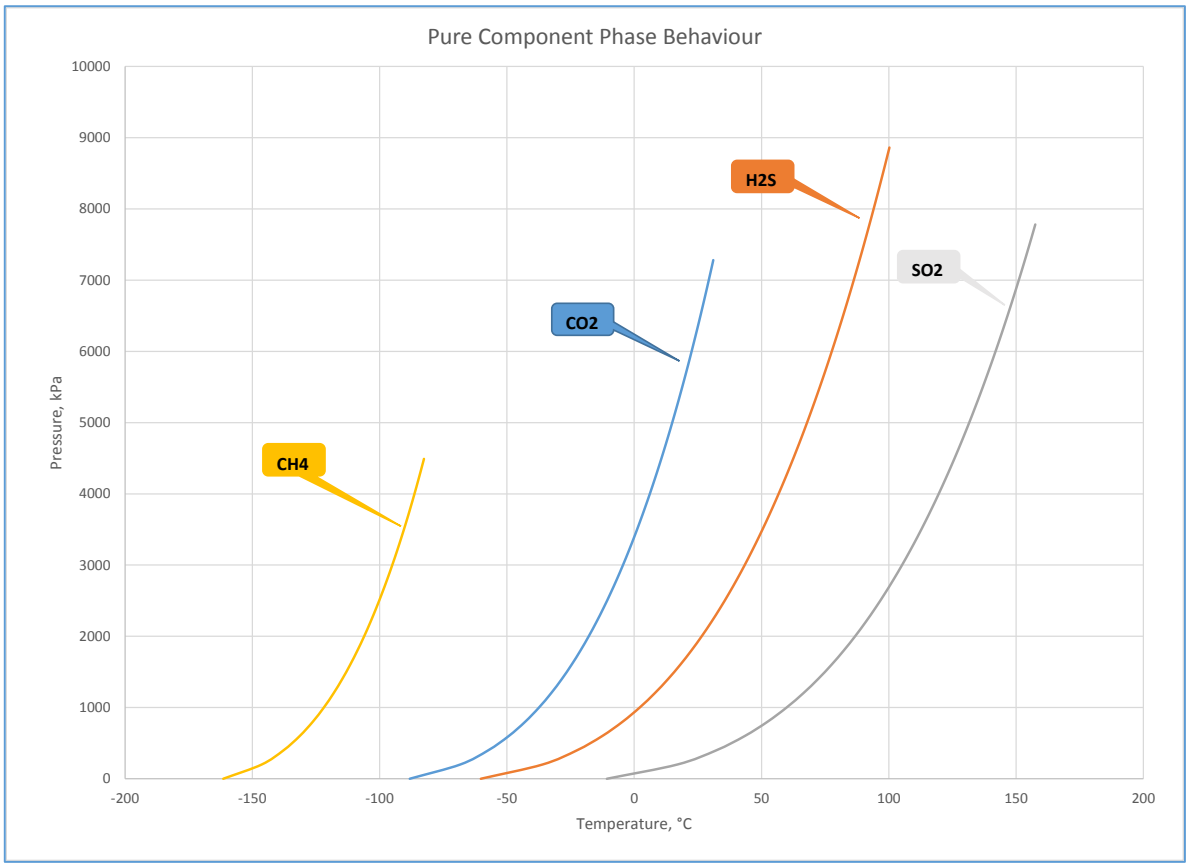

Figure 1 - Phase Behavior - Typical Acid Gas

2. REQUIREMENT FOR CAPACITY CONTROL

The acid gas streams are often captured at low pressure (40-80 kPag) from either a gas treating facility or a carbon capture system. Carbon dioxide (or CO_2) gathered from EOR systems may be captured at moderately higher pressures (1.7 bars(g)) and pure makeup CO_2 supply pressures are often higher. As the AGI equipment and injection process is often downstream of many other larger process units, the acid gas system is expected to handle everything extracted in the amine unit or recovered from the reservoir. This means that flow, composition, temperature, and often pressure are highly variable and can change

quickly without notice. In order to prevent process upsets, shutdowns, and potentially regulatory non-compliance, it's important that the acid gas injection system be able to adapt quickly (and with stability) to the changes.

Flow variances are often the most frequent, and most difficult to respond to in the design and operation of an acid gas injection system. It is not uncommon for amine plant regeneration systems to swing and allow for a significant variance in the first stage suction flow of acid gas. Maximum turndown is required as the system can go from design flow to less than 25% (4:1 turndown) in a matter of seconds if the amine system and/or control system is unstable. Adding in a co-stream suction makeup gas to assist in suction is often not a desirable choice as the addition of fuel gas, methane or other non-condensables can disrupt the injection system by suppressing the fluid head in the wellbore. For this reason, the ability to add fuel gas to the suction should be available for purging, testing, and maintenance/start-up reasons, but must be disabled during normal operation. It should also be noted that in carbon capture applications, the H_2S is substituted by SO_x/NO_x. Hydrocarbon content in EOR schemes can be 10% or higher.

Compositional variances are somewhat less disruptive as long as the variances consist of CO_2 and H_2S. The difference between CO_2 and H_2S need to be examined in two(2) different manners:

a) Basic Capacity Control

   From a compressor point of view, especially in reciprocating positive displacement compression systems, the movement of the CO_2 and H_2S fractions has very little impact on the operation of the acid gas compressor directly. The basic tenets of this statement is that the compressor has to have sufficient volumetric displacement to handle both extremes of H_2S content and that the system has sufficient power and cooling exchanger area to manage the flows. Since both components are relatively close in molecular weight, the substitution of either component has very little effect. For example, a change from 80% (mole) H_2S to 80% (mole) CO_2 results in a 2% increase in available capacity and a 4% decrease in required power. Although the acid gas compression equipment is downstream of the amine plant, poor or slow AGI system performance will have a negative effect on the amine unit. Amine units are very intolerant of process bounces; process upsets will require considerably more operator intervention, cutbacks in production and potentially a loss in revenue due to throughput limitations and chemical costs in amine and anti-foam. As well, poor or delayed system response will mean more amine plant flaring, dilution fuel consumption, and regulatory non-compliance. Even minor pressure swings in the

amine plant regeneration system (7-15 kPa) can mean the difference between stable sweetening, and erratic process swings.

b) Phase Behavior Control

From a phase behavior point of view, these two (2) components respond completely differently. It is critical that the compressor and particularly the compression cooling system and associated scrubbers be able to respond to the changes in composition. This is especially true in systems that have large swings in composition. Cooler controls that are suitable for low H_2S/CO_2 ratio applications may find themselves operating inside the phase envelope in a higher H_2S/CO_2 ratio application. The resulting condensing of acid gas and water can play havoc on a compression system. As well, the system hydrate temperatures, moisture content, and final pipeline water content will vary widely depending on the component ratio and the cooler response. Similar to the compressor capacity, a composition change from a high H_2S/CO_2 ratio acid gas stream to a low H_2S/CO_2 ratio acid gas stream will typically require supplemental dehydration to prevent the formation of hydrates and/or an aqueous acidic phase. This must be thoroughly understood, planned, and designed for in the basic design and operation of the system. Some plants are now using online analyzers and adjusting compressor performance and cooling controls based on the observed composition. Since each system responds differently, the controls must be designed for, and tuned to, the individual plant requirements.

Temperature variances are somewhat less disruptive as long as the system has the mechanical limits to manage the temperature swings. The primary issue with feed acid gas temperature is the changing water content. Clearly, lower inlet gas temperatures will suppress water content and will lower the amount of water rejected by the AGI compressor. As well, lower temperatures will lower the 1st stage discharge temperature and will also lower the volumetric requirement. For example, decreasing suction temperature from 30°C to 10°C will increase available compressor capacity by just over 4% with only a 2% increase in required power. Water content will decrease considerably but has very little impact if the remaining stages operate as before. Even moderate ambient temperature swings can have a significant effect on cooling performance (both in discharge cooling as well as piping systems) and corresponding compression system consistent performance. This means that part of the success of any capacity management system is predictable temperature stability. This is even more important in an acid gas compressor where temperature, composition, and water content are closely connected. As well, long suction headers can introduce a

time lag or system delay into the response of the compressors; long piping runs can also provide for condensation, fluid buildup, and carryover.

Pressure has the most direct impact on system capacity. At the lower suction pressures common in most AGI systems, even a 10 kPa decrease in suction pressure will have a significant effect on available system capacity. Available compressor capacity drops by almost 8% with a similar power drop with only a 10 kPa drop – this reinforces the need for good suction pressure control as well as consistent system performance. Given the low system pressures, the system must control to a very precise pressure. While 50-100 kPag swings in a normal natural gas compressor application suction pressure are not uncommon, this system is expected to control suction pressure within a 3-7 kPa range or tighter. Large swings in control will feed backwards to the amine unit and cause process instability resulting in flaring, off-spec products, and increased operating costs. In some facilities, the acid gas compressor is used to directly manage the pressure in the regeneration system. This is quite successful and avoids any additional pressure drops on the suction of the acid gas compressor system or pressure increases in the amine regeneration system.

Finally, it must be realized that the acid gas compression system is a critical keystone in both plant on-line time and regulatory compliance. While the purpose of this paper is to focus on AGI capacity control considerations, the upstream performance of the amine regeneration system will have an effect on the entire system. For this reason, the plant acid gas system must be examined in its entirety. Regeneration system pressure bounces, rapid flow variances, flare controls and temperature swings will all propagate through the compressor and very little can be done to smooth this behavior if it's generated upstream. Poor amine regeneration unit performance will make for difficult acid gas compressor control. Retrofitting acid gas units into existing amine units will often trigger an amine unit controls upgrade for improved stability.

Few plant owners will have patience and tolerance for an under-performing acid gas disposal system when they begin to jeopardize the primary basis of the facility – online performance. Acid gas compressors warrant extra attention to ensure strong, robust, and rapid responding (yet stable) capacity control systems. This is not the place for cost cutting in an attempt to save equipment capital expenditures.

3. ACID GAS INJECTION SYSTEMS

In order to discuss capacity control methodology, it's important to define and explain the types of systems encountered, and why they may require different capacity arrangements.

a) Reciprocating Compressors

This type of compressor covers the majority of acid gas injection systems currently in operation. They are multi-stage positive displacement machines with cylinders (double acting and single acting), interstage process gas cooling, and are direct drive either by an electric motor or by an engine drive system. Capacity control in these types of systems are essentially managing the volumetric flow of gas into the suction of the compressor by monitoring pressure at various points.

b) Compressors/Pumps

This arrangement is usually required for systems that require higher discharge pressure, or systems that may be separated by a long pipeline. Capacity control can thus be divided into both sub-assemblies as the need for capacity control may differ from compressor to pump depending on the type of pump, type of suction control system, and location.

c) Screw Compressors

While the use of screw compressors is unusual in acid gas applications, they may be utilized as booster compressors to allow a smaller final compressor. Screw compressors may also be used as EOR boosters to compress VRU and treater vapours to the main compressor suction. As such, they have their own capacity control methods and limitations.

d) Centrifugal Compressors

Centrifugal compressors may be utilized in large, high volume acid gas applications where the use of reciprocating compressors is impractical or where the footprint requirements must be smaller. These compressor may be either electric drive or engine drive depending on the system, power demands, and volume needs of the injection system. Similar to the reciprocating compressor systems, these can also be combined with a pumping system to ensure higher delivery pressures.

4. COMPRESSOR DESIGN CONSIDERATIONS

There are a number of fundamental key points that must be stressed and constantly reinforced:

a) The concept that acid gas compression equipment is actually a process unit. Clearly this is a compressor in the traditional sense of gas compression, however, there are significant process changes taking place inside the system including pressures, temperatures, compositions, and water content. Understanding and treating this as a process unit aids in evaluating the different compounding effects of the various capacity control systems. This system will not always behave like a traditional natural gas compressor and this must be considered in the design of the systems.

b) The acid gas compression system must be examined in its entirety from the amine regeneration through to the sand face of the injection reservoir. The system behaves in an integrated manner and it is critically important to consider the entire AGI system as a fluid delivery system. The compressor receives the acid gas fluid, compresses it up to the required pressure, and delivers the fluid to the reservoir. This also means that upsets and process bumps that originate in the amine system will work their way through the injection system; this must be considered in the system design and operation. Conversely, wellbore issues, upsets, and changes in wellbore performance will feed back to the compressor and potentially backwards into the amine system process.

c) Interstage equipment including dehydrators, chilling systems, and process units can be affected by swinging process pressures. It is critical to provide stability for the consistent, smooth operation of interstage equipment. As well, interstage equipment must be reviewed for various process conditions that could be generated during system operation.

d) Compression system capacity control and process cooling act hand-in-hand and must be well thought out when designing, developing and operating an acid gas injection system. All these systems interact constantly and must be considered from the start of the project as they can have considerable effects on the equipment and the success of the scheme. There is little success in capacity control if temperatures and pressures are unmanageable. Given the variability with pressures, temperatures (process and ambient), compositions, and flows changing, special attention must be given to the process gas cooling. A thorough understanding of phase behavior, hydrate forming conditions, ambient temperature effect, startup, and turndown is required for successful cooling system design.

e) These systems are dynamic in nature and are constantly changing and adapting to variations in flows, pressures and temperatures. Given the rapid variances and the way the feed gas is generated, combined with scrubber dump operation, steady state performance is seldom achievable. Understanding this is essential to successful compressor design and operation. Acid gas compressor scrubber dumps are often cascaded back to allow for degassing of system water – this drop-down or cascade system can have a significant effect on compressor performance as the fluid moves down through the scrubbers. Cascading can also prevent the effects of control valve seat failure and level control failure; high pressure acid gas saturated liquid and/or acid gas may be sent directly to a drain tank.

f) Finally, safety is of paramount importance in the development, design, and operation of any acid gas injection system. While acid gas injection and handling systems are more commonplace than ever before, this does not negate the risk or the need to be extra diligent in safety requirements for these systems. Pressures are often high (exceeding 80-140 bars) and when combined with hot, vibrating, rotating equipment, and lethal process fluids can make for a significant operating risk. Awareness and understanding of all the facets of an acid gas injection system is fundamental for safe effective operation.

5. CAPACITY CONTROL IN RECIPROCATING AGI COMPRESSORS

Each of the compressor systems has different needs, different system responses and requires that capacity control be managed in its own way.

a) Reciprocating Compressors

The key to understanding and developing capacity control needs in a reciprocating compressor is to understand that the compressor is essentially a fixed volumetric displacement type of system. A number of capacity control methods can be employed (often together) in a reciprocating compressor.

1) Variable Displacement Modifications (Variable Volume Clearance Pockets)

A traditional method, often employed on older, slow speed reciprocating natural gas compressors, is to use a method involving the manipulation of the effective volumetric displacement of the compressor. This manipulation of the clearance

pockets on the compressor will inherently shift the compression performance on all cylinders by reducing that cylinder displacement. This essentially means that the entire compressor will re-balance itself to ensure that a mass balance will always exist. Rebalancing takes place automatically so that as the volumetric displacement is reduced in a cylinder, the remaining cylinders must take up the work effort to move the gas. In most applications, the VVCP (variable volume clearance pocket) is located on the first stage. Engaging this VVCP shifts the load from stage 1 onto the remaining stages. The largest effect will be felt later in the compressor as the pressure effects are multiplied. VVCP systems inherently alter the volumetric efficiency of the machine and will shift the compression staircase around. As an example of this, the below phase envelope and compressor performance curves show the changes in the interstage conditions due to VVCP movement:

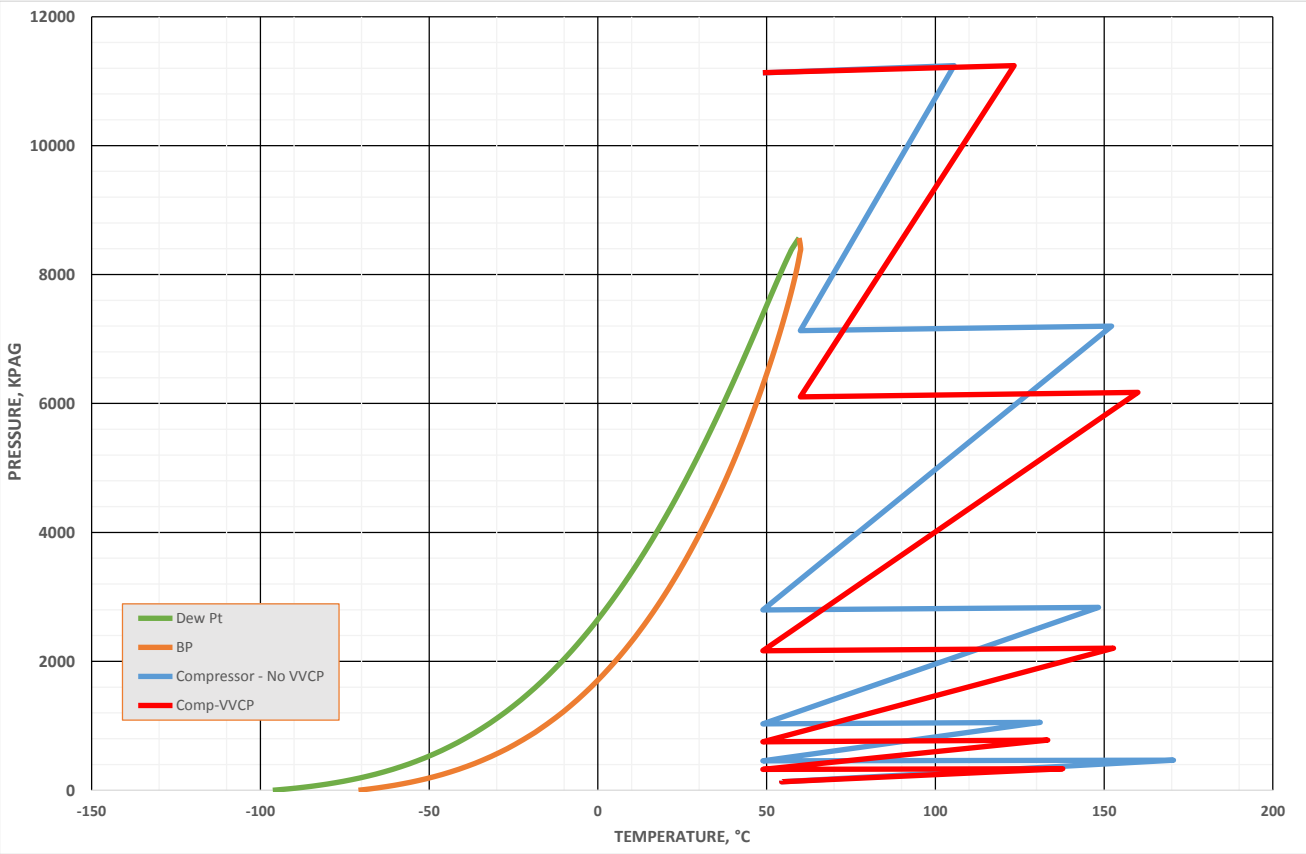

Figure 2 - Compression Performance

While the effect on the 1st stage cylinder is minimal (Pd drops about 140 kPa), the shift in work is forced up to the remaining stages resulting in a significant

1045 kPa decrease in stage 5 suction pressure and a 6°C jump in stage 5 discharge temperature. This can have a substantial effect on interstage equipment and processes that are looking for consistent, stable pressures and temperatures. Dehydration equipment is often located on the suction of the final stage; understanding the movement of pressures and temperatures is critical to the design of cooling equipment, dehydration equipment sizing, and water content of the gas stream. This decrease in interstage pressures can effect separation equipment and have unexpected results in cooling systems. This can also make multiple compressors more difficult to operate when they must all discharge to a common interstage header for dehydration or interstage processing. The addition of VVCP systems adds significantly more troublesome leak points for hazardous or potentially lethal fluids, increases machine width, and even with a zero pocket setting, adds inherent clearance. The use of VVCP capacity control is not recommended in this application.

2) Compressor Speed Modifications

Speed modifications require some additional consideration during design and implementation. The following notes apply to either electric drive or engine drive compression systems.

The entire system performance under speed control must be reviewed carefully during design. While the delivery of the acid gas fluid will be nearly linear, bypass valving and other system control valves may not be linear. As the compressor slows down, control valves may be operating near the low end of their performance curve resulting in sluggish or jerky response. For this reason, positioners on all acid gas control valves are recommended for better, faster, and more accurate response. Oversizing of control valves must be avoided.

Process cooling control of the acid gas is essential for predictable safe acid gas compression performance. This cooler control must be able to maintain the required temperatures during all process conditions, with varying conditions, with varying ambient temperatures and finally with widely varying flows. All of the cooler controls must work to achieve each required temperature for interstage cooling regardless of the compressor speed or throughput.

Depending on the size of the compressor, variable speed has some slight delays in implementation. It's important to note that a fast response is desirable for speed/capacity control, however, achieving a fast response can generate loop instability. Essentially, the system should monitor the suction pressure, adjust the speed slightly, and then reassess the pressure on a continual basis. This loop does not require derivative control and must be programmed so that the compressor speed can be manually adjusted as well or even locked at a preset speed. The compressor manufacturer needs to be aware of the variable speed requirements and to provide any additional concerns with regards to system dynamics. As well, the compressor system must be reviewed for harmonics and/or critical speeds to ensure that the system can be operated inside the entire range of desired speeds. Speed and bypass loops should be set up with slight offsets such that speed becomes the primary variable followed by bypassing.

Electric Drive Systems

This method uses simplistic speed manipulation of the compressor equipment. The effectiveness of this method is based on the nature of the system. With reciprocating compressors, this speed modification results in a nearly perfect linear change in displacement. Utilizing proper design methods and selection of equipment, it is possible to achieve up to a 5:1 (20%) turndown on compressor/driver speed resulting in excellent compression performance. While there are some minor changes in system pressures due to some dynamic effects, in general the compressor performance curve remains steady and unchanging. However, speed variances must also consider torsional and lubrication effects.

Many electric motors require a constant flow of air across the motor to ensure adequate cooling. This is normally done with the shaft mounted cooling fan. In some cases requiring large turndowns, this direct fan may not provide the proper air flow. It is common to equip the motor with a "pony blower" to ensure a constant air flow. This small blower motor is not part of the speed system and runs all the time. The pony blower should run for an extended time after a shutdown to assist in motor cooling.

None the less, this is the recommended method for capacity control.

Engine Drive Systems

Similar to electric motor drive speed control, this methodology simply slows the gas engine drive via the governor. While this is an effective method, it can be difficult to achieve sufficient turndown. When using turbo charged engines, the system can only manage about a 25-33% turndown before the engine fails to deliver the needed power. This is clearly inadequate for most systems and additional capacity control is needed. Even using a naturally aspirated gas engine can only provide about a 33-50% reduction in delivery flow. Despite its limitations, this method is recommended for capacity control of engine drive AGI compressors.

3) Suction Pressure Control Valve

Similar to "standard" gas service compressors, capacity control is often adjusted by installing a suction pressure control valve. This flies in the face of logic due to the inherently low suction pressure that is available at the suction flange of the system. With pressures ranging from 35-80 kPag, there is very little room for additional pressure drop. In fact, selection of the first stage cylinders is often difficult in AGI applications – the designer should strive to minimize suction system pressure drop. A suction pressure control valve is virtually useless for capacity control; its primary purpose is acting as a suction limiter. This is seldom an issue for acid gas machines and it will be difficult to achieve the semblance of control for anything less than 10-15 kPag – a significant pressure drop in a system that can't tolerate much lower pressure. The use of a suction pressure control valve is not recommended unless upstream pressures can force the acid gas compressor into a higher suction pressure situation. It is recommended that the acid gas compressor be equipped with suction and discharge unit block valves that open and close automatically on a compressor start/stop permissive.

4) Suction Pressure Makeup with Fuel or other source gas.

Early versions of acid gas injection often tried to utilize a fuel gas makeup to keep the compressor suction pressure satisfied. While this worked from a suction pressure standpoint, it allowed significant amounts of non-condensable gas into the process fluid. These light ends failed to condense and accumulated in the wellbore driving down the fluid level. This, in turn, forced the compressor up to a higher discharge pressure to make up for the loss in injection fluid head. In most AGI applications, this loss of head is not reversible without a shutdown and blowing down the wellbore gas cap to flare. This manual intervention is probably regulatory non-compliant and involves a complete AGI system shutdown unless

another wellbore is available. As well, it also represents a potentially hazardous work activity. Depending on the location of the wellbore and the possibility that flaring equipment may not be located at the wellsite, relieving this pressure cap may be a major work activity. The possible requirement for a pipeline blowback, rental flare systems and temporary permits, and finally, a significant safety oversight system makes this an undesirable activity in every injection scheme. Suction makeup gas is not an acceptable capacity control solution unless the makeup fluid is similar to one of the primary components. The compressor is expected to fit the flow and volume requirements of the application and not the other way around.

However, having said that this is an undesirable event, the installation of a fuel gas makeup station into the 1st stage suction system is required. This fuel based system takes on a number of roles including:

a) Initial compressor testing and control system development. The use of fuel allows a relatively easy way to simulate an acid gas system with a non-toxic fluid. Initial AGI compressor commissioning should entail a nitrogen/helium leak test. This test is going to be ineffective until the compressor has some run time. Using fuel well in advance of the acid gas, allows the compressor to "pretend" to be in service, allows the compressor to develop some heat, differential pressure, lubrication, and allows the early tuning of start-up and control logic. This is critically important in the start-up and allows for an easier, cleaner, and safer start-up. As well, the use of fuel gas can help to mimic an AGI scheme – bypasses can be tuned, VFDs can be run and tuned, cooler controls tweaked, and finally, all shutdowns and permissives can be reviewed, tested and revised until the design engineer is satisfied with the performance of the system. Any inspection or initial servicing can be completed without the necessity of "masking-up" reducing start-up costs. In addition to this, the fuel gas run-test can build operator confidence.

b) Finally, the compressor must be purged during long term shutdowns to prevent the accumulation of sour water and acid gas during extended down times. Purging with fuel will remove acidic components, sweep out pockets of acid gas, and make the machine safer for maintenance and entry. This can be either semi-automated, or manual depending on owner preference. In any case, this loop should be disabled during acid gas injection operation to prevent the errant entry of fuel gas during injection. While this paper is not

intended to provide a complete set of acid gas design guidelines, a complete materials investigation (carbon vs stainless) is mandated on these systems to ensure proper protection of materials in a wet acidic environment. The selection of materials may mandate the type of purge system, sequencing and logic.

c) In order to ensure system stability, it can prove helpful to control the final discharge pressure of the compressor. While the injection wellhead pressure can and will vary with flow, composition and ambient temperatures, a final discharge PCV can ensure stable, consistent, and repeatable flow. This will help to make sure the recycle systems perform with a consistent upstream pressure. In addition to this, a constant and steady back pressure will ensure that the compressor performance is predictable; minor variances in pressure and temperature will show up and can be investigated.

5) Bypassing

All acid gas compression applications should have the ability to auto-bypass discharge gas back to the suction of the compression system. This comes with some caveats due to the inherently wet acid gas and the need to avoid the hydrate point. On a high pressure discharge event (like a plugged injection line or high wellbore pressure), the system allows for a semi-automated control of high discharge pressures. This hot auto-bypass will bring discharge gas back to suction and will make the compressor appear to be compressing. This will allow the amine plant acid gas to be flared and metered such that sufficient fuel can be added for dispersion requirements.

For a typical 5 stage compressor, the final stage discharge pressure of 12-14 MPag is easily well above the critical point of the mixture. Thus, the final fluid heading to the wellbore is a dense phase liquid. Using this as a bypass media to 1st stage will result in incredibly low temperatures due to the fluid behavior at these conditions. The P-H diagram below illustrates the dramatic changes in fluid temperature once the system enters the phase envelope.

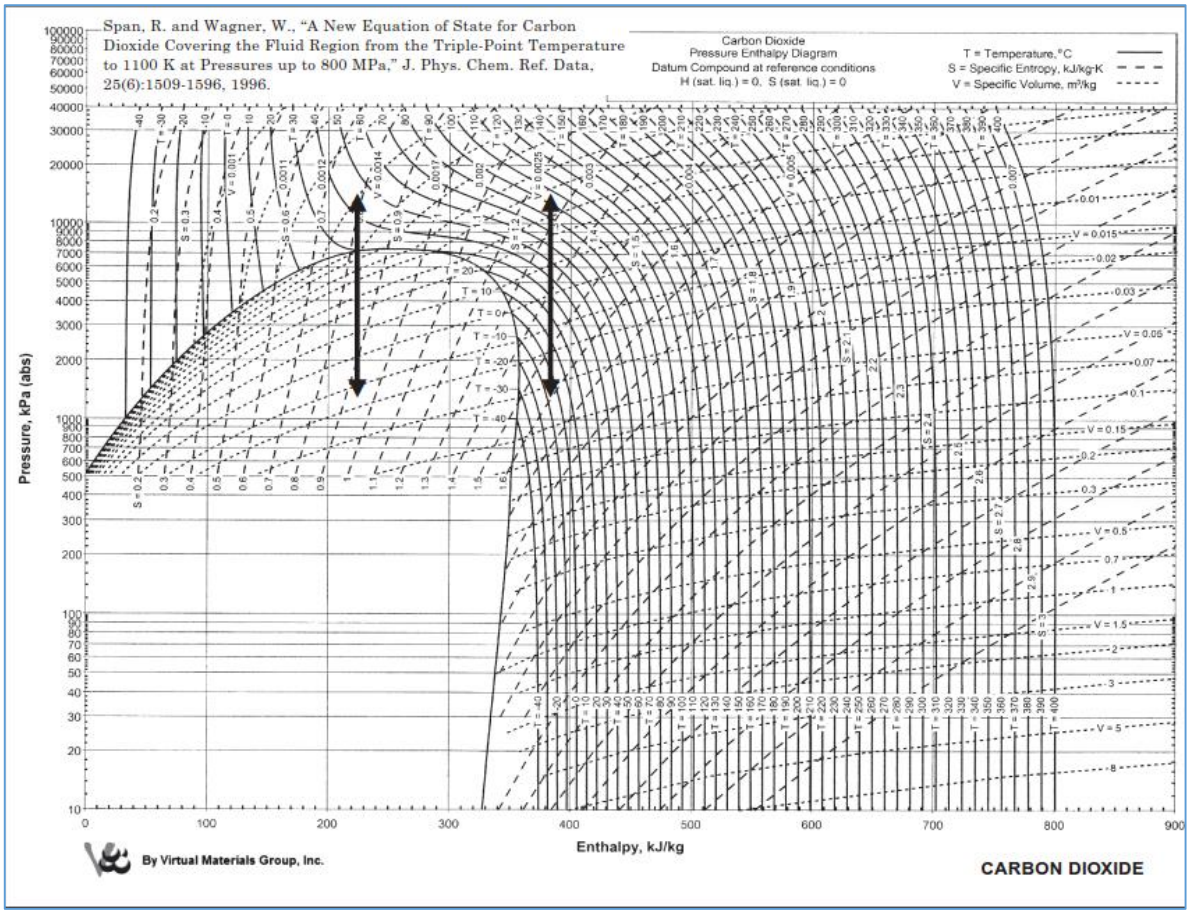

Figure 3 - CO_2 P-H Curve

As long as the fluid remains in the dense phase, the temperature changes during depressuring are quite low. A traditional cool final discharge bypass (with pure CO_2) from 14 MPag and 43°C will easily achieve -80°C when the pressure is reduced to 70 kPag. Similarly a pure H_2S stream, when depressured under identical conditions will achieve -49°C after the valve with approximately 62% liquid in the outlet.

Regardless of the composition, these temperatures will certainly freeze any remaining water in the system (including any 1st stage scrubber liquids) as well as causing significant upset to the compressor as flashing liquids are introduced back into the system. One way to avoid this scenario is to configure the system with a single hot bypass taken from downstream of the final cylinder but upstream of the aftercooler. This is shown below in simplistic format:

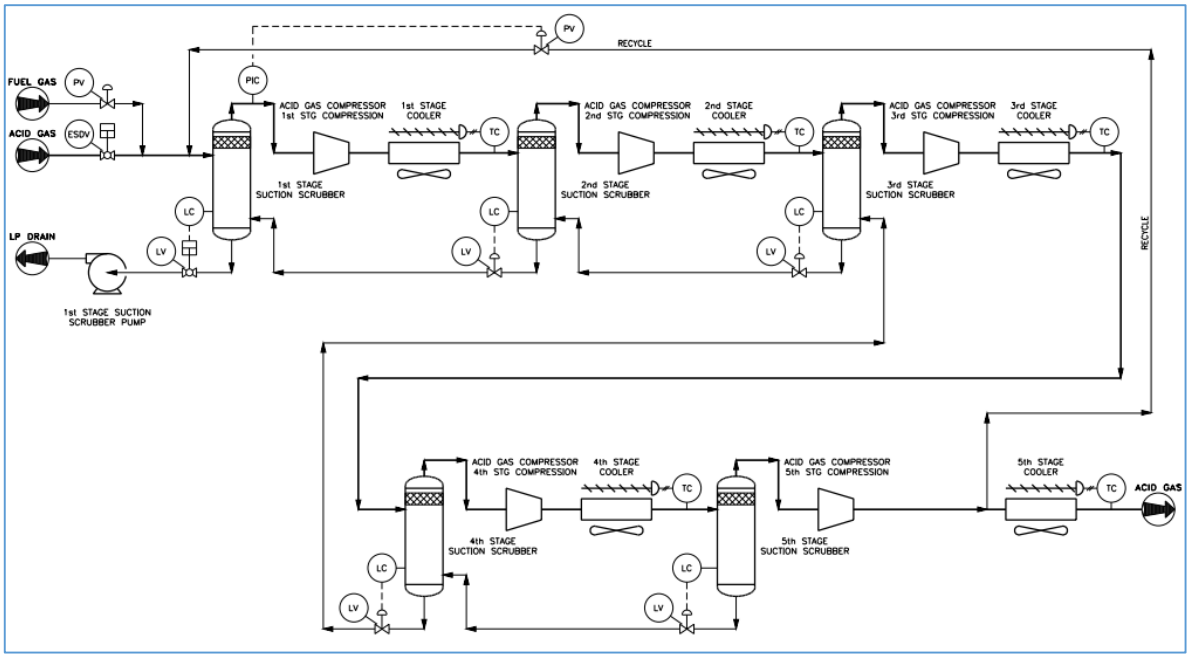

Figure 4 - Single Stage Bypass

While this works for many of the basic AGI applications, a dual bypass assembly has more flexibility with potentially less compression capacity effect. This is often configured as follows:

Primary Hot Bypass

Hot final discharge back to the 3rd stage suction scrubber – referred to as a 5-3 bypass.

Secondary Cool Bypass

Cool 3rd stage suction gas back to 1st stage suction – referred to as a 3-1 bypass.

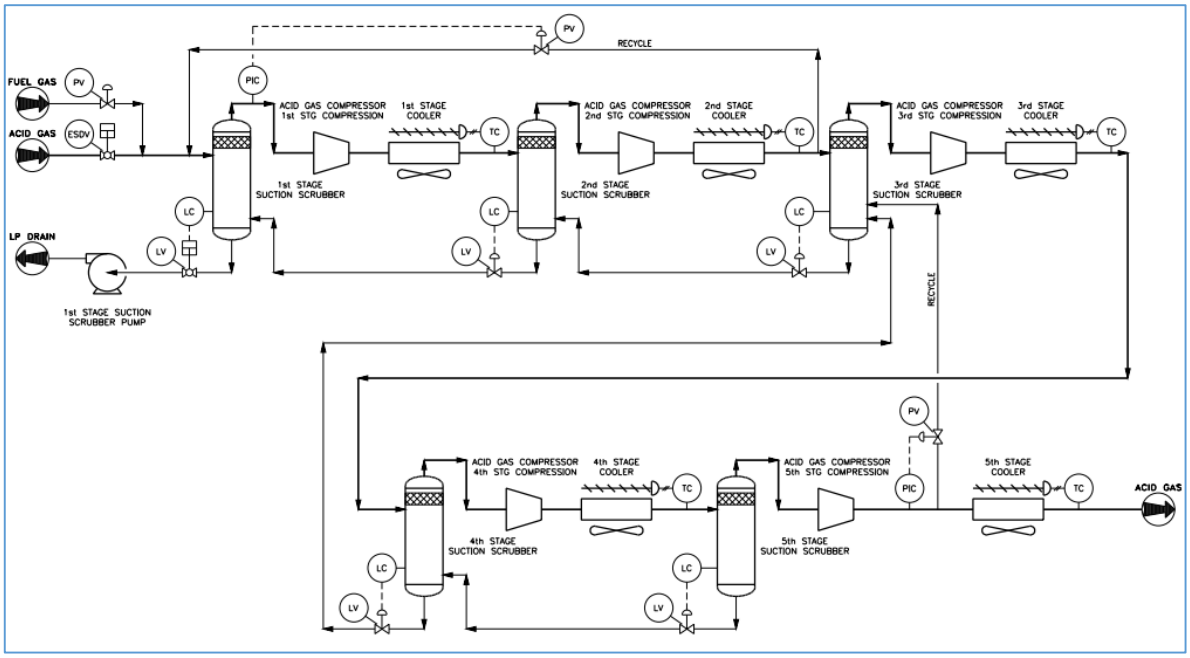

Figure 5 - Dual Recycle

A number of other versions are available including customized bypassing to allow for various process conditions and compressor requirements. Depending on the system pressures, the location of the interstage bypass can be shifted. However, it's important to ensure that no stages are left orphaned or stranded. Typically the bypasses are configured such that the interstage bypass is controlled by stage 1 suction pressure. The final bypass is controlled by a dual mechanism including high discharge pressure on the final stage injection as well as 3rd stage suction pressure. These two (2) bypasses must be configured such that when the cool bypass (3-1) opens to maintain compressor 1st stage suction pressure, the hot (5-3) bypass will also open to ensure a consistent 3rd stage suction pressure so that no stages are left orphaned and the compressor remains fully balanced with no unusual rod loads. One of the drawbacks of the dual bypass system is that differing final discharge pressures (and corresponding discharge temperatures) can have an effect on internal compressor pressures, temperatures, and system response. Since a control valve is essentially a volumetric device, it is prone to performance shifts depending on upstream pressures, temperatures, and fluid specific gravity. However, a dual bypass assembly can provide for a more stable, more predictable operation. The bypass effect (pressure, temperature, and composition) may also affect interstage equipment or processes that may be present.

There are several alternative temperature based bypass arrangements that are currently in use.

Type 1 – in some cases, using hot discharge gas results in 1st stage suction gas temperature that is still too warm. In this application, final discharge gas from the outlet of the final aftercooler is used in a blending/mixing arrangement to make for an integrated bypass system. This is better illustrated below:

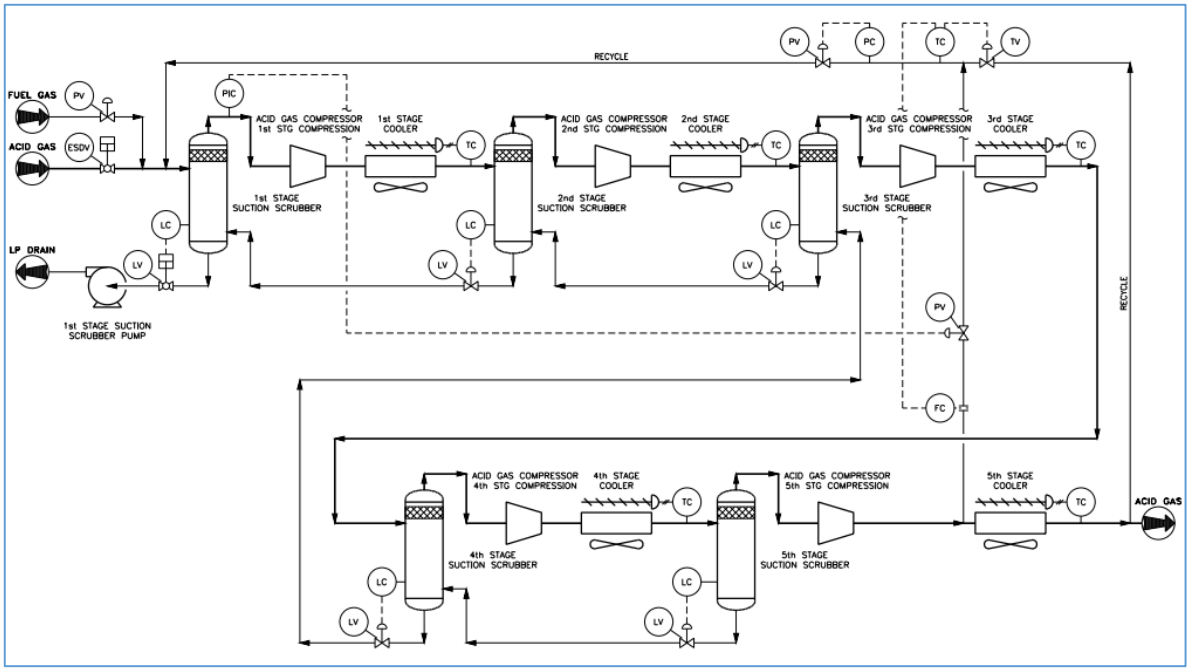

Figure 6 - Cascade Temperature Bypass System

This system has been used with success, however, the control system is elaborate and somewhat complex. Tuning is difficult and compositional changes may require some additional tweaking as temperature changes are compositionally sensitive. It will be costlier with additional control elements and piping.

Type 2 – An alternate methodology is to withdraw the bypass source gas from an intermediate point on the cooler. With a low ratio compressor and relatively low discharge pressures, the hot discharge gas does not cool adequately downstream of the hot recycle valve. This method results in a basically a custom temperature for the hot bypass but it introduces several new variables including cooler control, ambient temperature effects, and cooler first pass performance. Depending on the location of the bypass tie-ins, 3rd stage scrubber capacity must be reviewed.

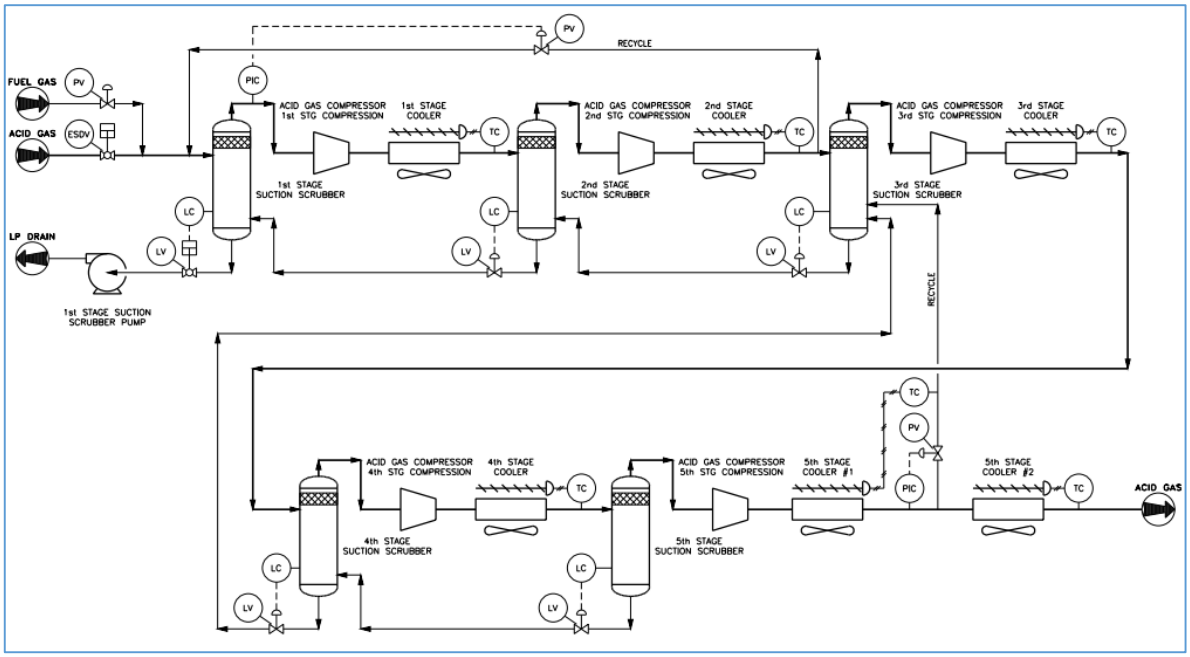

Figure 7 - Intermediate Cooling Dual Bypass

Regardless of the type of bypass assembly, it is critical that the compression and process design team examine the system performance during bypassing operation. Temperatures can shift rapidly resulting in pressure shifts. Even minor pressure shifts can alter the compressor performance curve (See Figure 2) during the auto-balancing step and can potentially shift the curve into the phase envelope. This could result in inter-stage condensing and liquid acid gas formation. While machine damage can be avoided with proper instrumentation, this event will cause additional process issues with cascade dumps, rapid temperature drops, and an apparent loss of compressor capacity and the appearance of random shutdowns.

6. CAPACITY CONTROL IN RECIPROCATING COMPRESSOR/PD PUMP COMBINATIONS

This system is configured with a typical reciprocating PD compressor followed by a higher pressure plunger/diaphragm or other fixed displacement type injection pump. These types of systems are often used when injection pressures are extremely high, the compressor is unable to achieve the necessary pressure, or the pump is better configured to deal with the fluid. Each of these systems will require a custom engineering solution – pressures, temperatures, and compositional changes make this a complex process engineering system.

a) Compressor Capacity Control

In this integrated compressor/pump configuration, all the compressor control methods listed above remain viable alternatives and can be used to "tune" the compressor to the required process needs. A standard dual bypass should provide adequate control. In most acid gas compressor applications, the precise control of the final aftercooler temperature is relatively unimportant. However, in pumping applications, the final aftercooler is critical to increase fluid density, lower compressibility and increase the volumetric efficiency. In this application, the pump fluid must be relatively consistent, and of course, must remain in liquid phase. In theory, it is possible to go directly from the final stage of aftercooling directly into the pump, however, the potential for vapour bubbles requires the installation of a suction separator. This will allow any non-condensable vapours to break out and be removed from the vessel prior to entering pump suction.

While a number of complex arrangements are potentially workable, the following arrangements will provide for strong, consistent performance.

Type 1 – This system is based on maintaining a relatively constant pressure in the suction drum as well as manipulating the system capacity to achieve stability. The suction drum can be pressure controlled to flare with a high pressure loop to ensure vessel pressure stability. Excessive flash gas or non-condensables can be sent to flare or to a plant recycle system. Once the temperature and pressure are controlled (within compositional and phase envelope limits), then the fluid level can be controlled by a variable speed positive displacement pump. This system is quite stable, and allows for the removal of non-condensables and/or components that would otherwise flash in the pump. Since the pump is a PD type (plunger, diaphragm, or fixed displacement), the pump speed is a linear method of capacity control.

Type 2 – This system is based on injecting a pure component fluid into the wellbore. This is a somewhat theoretical application in that bubbles or non- condensables will always be in the system. None the less, in a pure dense phase CO_2 pumping application, the fluid will display no interface. In this application (assuming constant temperature), the measurement of pressure in the suction system will provide capacity control. A drop in suction pressure (while remaining) in the liquid phase indicates that the pump is withdrawing too quickly and could begin to cavitate. Conversely, an increase in pressure indicates that the pump needs to speed up to provide more withdrawal capacity. In the event of employing a suction bottle or

suction separator, a pressure makeup system with sales gas or high pressure nitrogen will provide sufficient pressure stability; level can be managed via the VFD. Use of the VFD will also result in a softer, easier startup, and will be gentler on the equipment, always a desirable choice in AGI applications.

7. CAPACITY CONTROL IN RECIPROCATING COMPRESSOR/CENTRIFUGAL PUMP COMBINATIONS

This system is configured with a typical reciprocating PD compressor followed by a centrifugal pump. These types of systems are largely used in CO_2 EOR applications but also in high volume AGI systems. Several methods can be used to control the pump delivery capacity in this type of application:

Type 1 – This system is based on manipulating pump impeller speed to essentially reconfigure or customize the pump curve. While this does have an immediate effect on pump delivery capacity, the shape, performance, and starting design point on the pump curve is critically important to the turndown effect. Ideally, the pump will scale back in speed until the pump is delivering the required fluid at the required discharge pressure. At some point, depending on the curve, the system will reach a minimum flow – additional flow turndown needs will require bypassing. The pump must still be protected with a minimum flow recirculation system and this must be metered and controlled reliably. Given the energy imparted to the fluid, recycling back to the suction vessel may be adding heat to a system that can be operating at its bubble point. Ideally, this recycle fluid should be cooled back to or below original suction chamber conditions to prevent the buildup of heat from continuous recycling. This system is recommended for capacity control. See below:

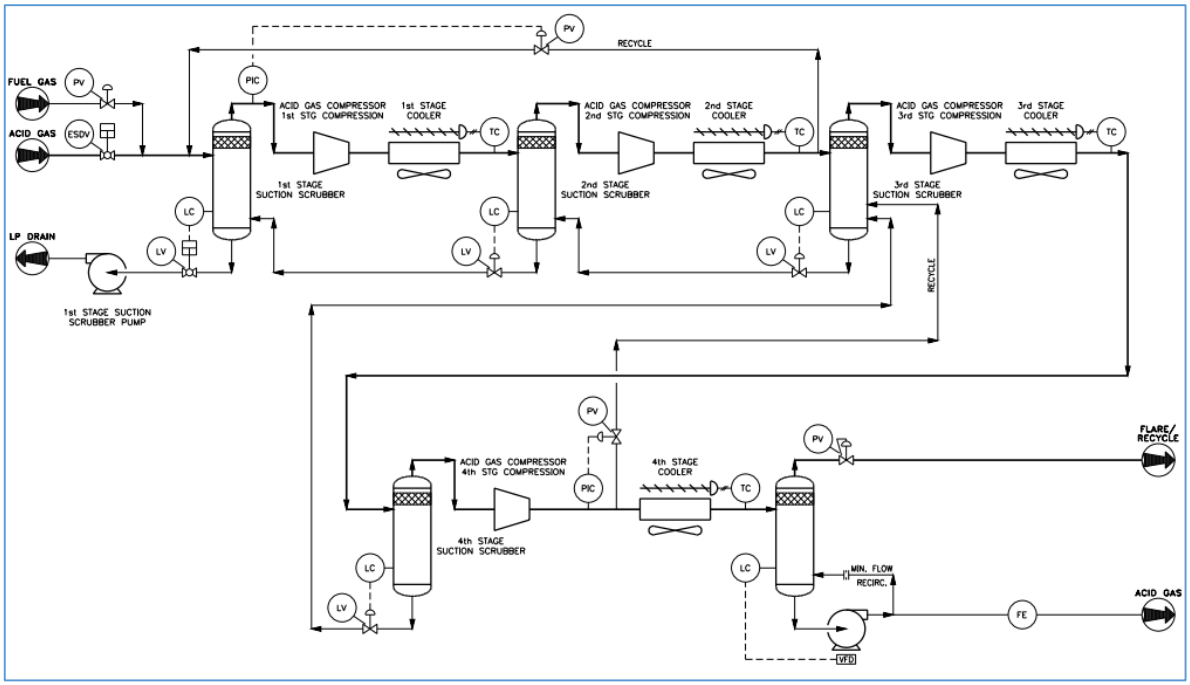

Figure 8 - Pump VFD Control

Type 2 – This alternate technology is based on discharge throttling of the fluid to essentially push the system back up the delivery curve. While this is not the most efficient approach, it can be an effective means of managing delivery flow. This is not power efficient, and throttling of dense phase acid gas requires some careful attention to materials and control methods. As well, large pressure drops will be inducing temperature drops; as long as the fluid stays in dense phase, these are likely going to be negligible. Clearly discharge throttling is not effective and not recommended for a PD pump application.

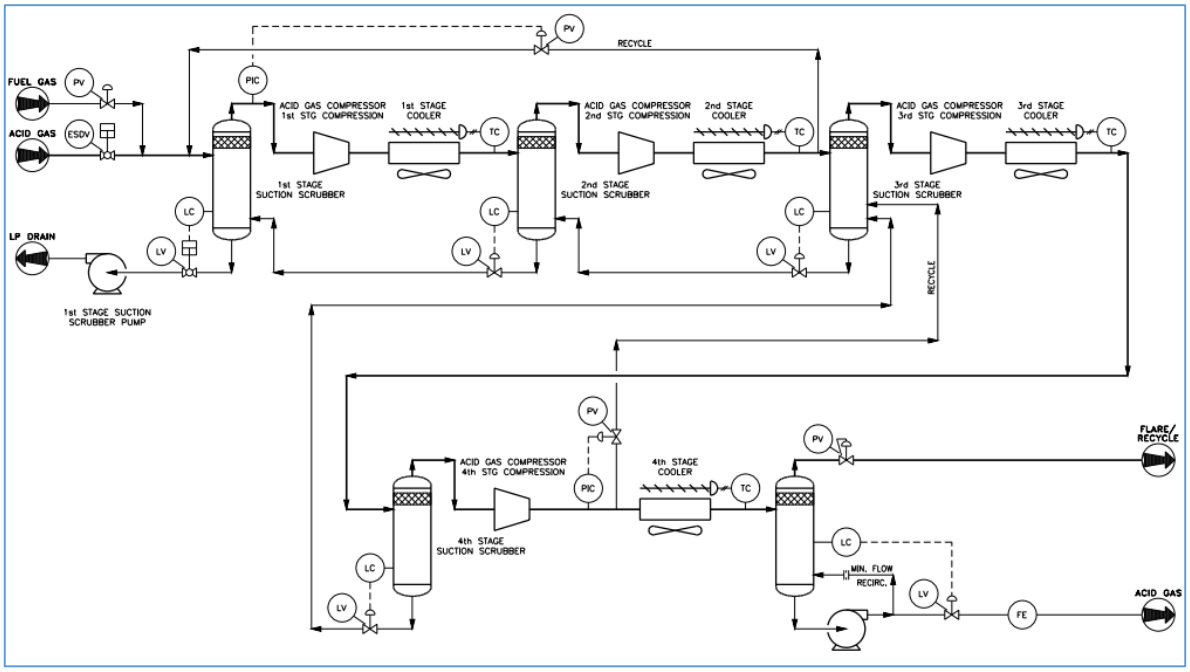

Figure 9 - Pump Discharge Throttling

8. CAPACITY CONTROL WHEN USING SCREW COMPRESSORS

The use of screw compressors in acid gas is likely limited to either booster applications or transfer applications where the need is for a low pressure acid gas delivery system. Capacity control for screw compressors is well understood and can utilize a number (or potentially all) methods. Utilizing the compressor slide valve based on suction pressure is the simplest way to control screw compressor capacity. The efficiency drops quickly with a slide valve and the HP/flow ratio is not ideal in a screw compressor system. In most applications, the slide valve can provide excellent capacity control. As well, this can be combined with bypassing (single stage obviously). Using a VFD for this application may not work well as the oil rate usually remains unchanged – thus the circulating oil can cool the compressed acid gas and potentially cross into the phase envelope resulting into condensing and oil washing with liquefied acid gas and the possible damage to the bearings. This does not happen with the slide valve. Owners often ask about using a screw compressor to boost the acid gas suction to the main compressor – this will work but the combination of equipment reliability makes this less than an ideal solution and the additional equipment adds operating complexity, sour oil handling, more footprint, and additional controls.

9. CAPACITY CONTROL WHEN USING CENTRIFUGAL COMPRESSION

Centrifugal compressors offer some significant advantages in this application. Notably, the footprint, capacity, and long term reliability of turbo equipment makes this a good choice for high volume injection applications. Similar to the use of smaller PD machines, centrifugal compressors can utilize identical technology including speed control and bypassing. There is no provision for clearance pockets (or the equivalent) in the centrifugal compressor although guide vanes can be used to provide some capacity control in certain applications. When using turbo machinery, the change in speed can be an effective way of reducing compressor system throughput. However, much like a centrifugal pump, the use of speed control is limited; the flow of gas is proportional to the speed while the delivery head is proportional to the speed of the machine squared. Finally, the horsepower is proportional to the speed of the compressor cubed while the system efficiency remains virtually unchanged. The use of integrated inlet guide vanes can also help reduce available throughput. Discharge throttling can also be an effective method to push the compressor back up on its characteristic curve but may result in high power consumption, final fluid JT concerns, and a difficult service with high pressure acid gas. Ultimately, the compressor must be protected against a surge condition – this takes place via recycling. This may be needed at or near design rates; opportunities for capacity control via speed may be limited depending on the machine configuration.

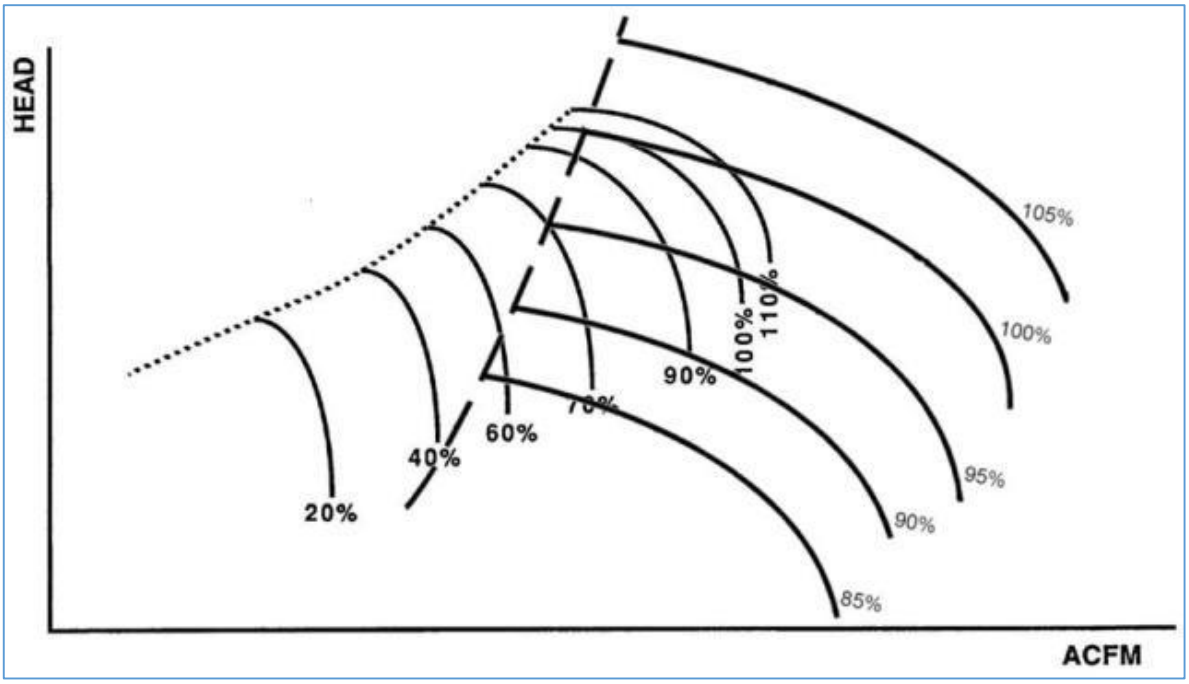

Figure 10 - Centrifugal Compressor Capacity Control

Similar to a centrifugal pump, the ability to modify the compressor speed and still deliver acid gas is a function of machine and impeller characteristics combined with static pressure/wellbore requirements and frictional pressure drops. While the use of centrifugal machines is promising from a footprint and high volume delivery point of view, these machines function best with near full loads and unchanging composition. Changing molecular weight can have a significant effect on centrifugal compressor performance – every case (including fuel gas) must be checked for capacity, power demand, cooling, and recycle capacity. This type of compressor configuration could be used for base loading with additional reciprocating machines for capacity trimming.

10. SYSTEM STABILITY

The single most important considerations for any type of capacity control are system stability followed by speed of response. Acid gas flowrates can change quickly from an amine facility and the last thing the operations team wants is a troublesome or unstable acid gas compression system when the main part of the plant is struggling to stabilize. Considerable engineering efforts should be focused on the capacity control methodology, system response, and compressor performance under off-design conditions. The entire system must be reviewed as a whole from the acid gas source to the injection well including operations, regulatory compliance, flare controls, utilities, and ambient variances. Finally, once a system and plan is selected, this control system

philosophy must be confirmed with the operations team for complete buy-in. No control system will survive if the operations team is not an essential part of the development effort – particularly in a demanding acid gas application. Acid gas capacity control is key facet of AGI applications and requires a lot of detailed attention. The following table provides an overall summary of methodologies discussed:

AGI CAPACITY CONTROL METHODOLOGY	Electric Drive Recip Compressor	Engine Drive Recip Compressor	Compression followed by PD Pump	Compression followed by Cent Pump	Screw Compression	Centrifugal Compressor
Suction Pressure Makeup	No	No	No	No	No	No
Suction Pressure Control Valve	No	No	No	No	No	No
Discharge Pressure Throttling	No	No	No	Yes - on pump	No	Partial
Speed Control	✓	Minimal	✓	✓	No	✓
Bypassing/Recycle	✓	✓	✓	✓	✓	✓
Inlet Guide Vanes	N/A	N/A	N/A	N/A	N/A	NR
Slide Valve	N/A	N/A	N/A	N/A	✓	N/A

Figure 11 - Summary of AGI Capacity Control Methods

11. SUMMARY

As described in this paper, acid gas capacity control is a critical component of acid gas injection system design and must be integrated into the overall system and plant design considerations. Each system will have unique characteristics and will require a custom solution designed to fit that application based on flows, pressures, temperatures, and compositions. While compressor capacity control is not a new topic, it must be managed carefully in these types of situations to ensure overall plant stability, minimal amine system upset, and maximum plant flexibility. The engineering contractor and plant operations must be closely aligned and work as a project team from the beginning through to start-up It's important to select an engineering contractor that has real world operating experience, real amine plant design and operating experience, and can fully support the needs of the operational teams.

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