FUEL GAS BEST MANAGEMENT PRACTICES

Efficient Use Of Fuel Gas in Compressors

MODULE 8 of 17

SUBMITTED BY: CETAC WEST

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sepac

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Background

The issue of fuel gas consumption is increasingly important to the oil and gas industry. The development of this Best Management Practice (BMP) Module is sponsored by the Canadian Association of Petroleum Producers (CAPP), the Gas Processing Association Canada (GPAC), the Alberta Department of Energy, Small Explorers and Producers Association of Canada (SEPAC) Natural Resources Canada (NRC) and the Energy Resources and Conservation Board (ERCB) to promote the efficient use of fuel gas in compressors used in the upstream oil and gas sector. It is part of a series of 17 modules addressing fuel gas efficiency in a range of devices.

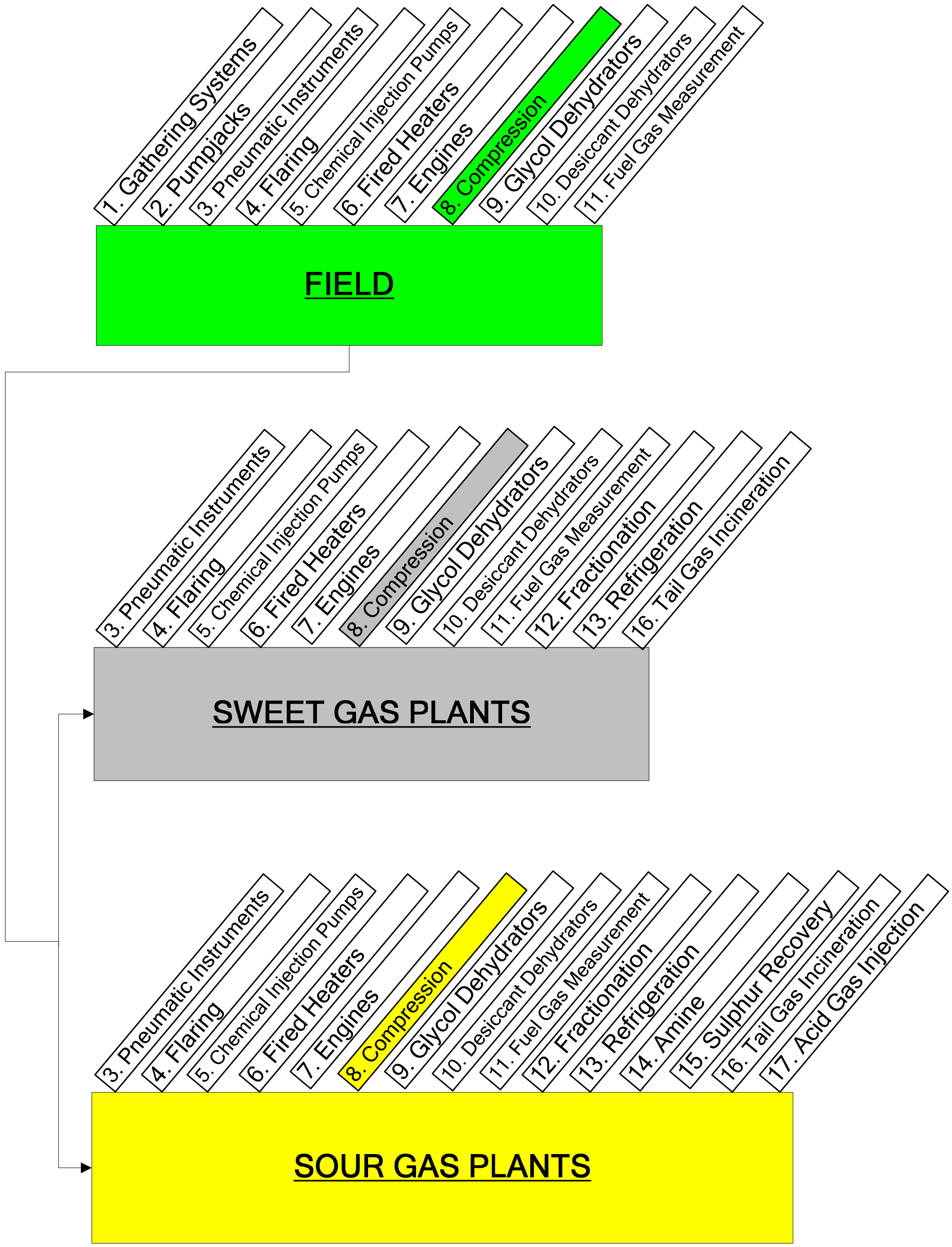
This BMP Module:

- identifies the typical impediments to achieving high levels of operating efficiency with respect to fuel gas consumption;
- presents strategies for achieving cost effective improvements through inspection, maintenance, operating practices and the replacement of underperforming components; and
- identifies technical considerations and limitations.

The aim is to provide practical guidance to operators for achieving fuel gas efficient operation while recognizing the specific requirements of individual compressors and their service requirements.

EFFICIENT USE OF FUEL GAS IN THE UPSTREAM OIL AND GAS INDUSTRY

MODULE 8 of 17: Compression



1. Applicability and Objectives

This module provides guidance for operating staff to improve compressor efficiency and recognize when fuel consumption is higher than the minimum achievable. The determination of fuel gas efficiency is made by prescribed calculations that yield the efficiency of the compressor based upon the fuel input and power required for the application. This module focuses on the application of efficiency calculations based on engine loads. The following compressor types are covered in this module:

- reciprocating compressors,
- screw compressors,
- centrifugal compressors.

This module outlines opportunities for the optimization of compressors used in the upstream oil and gas industry. Compressors are optimized when they produce the highest output at the lowest speed while using the most efficient setting for capacity adjustment. The following sections provide tools for supervisory and operations personnel to evaluate compression and not only identify, but quantify opportunities for optimization.

2. Basic Improvement Strategies

The most significant elements of long-term operating efficiency are the application of best available technology, implementation of operating and maintenance systems and management commitment. Efficient operation of rotating equipment requires:

- knowing what each equipment element was designed to do and what it is currently required to do,
- conducting periodic checks and adjustments,
- routine testing and correction of abnormalities,
- assessing opportunities to install upgrades and replace inefficient equipment, and
- retaining proper records.

2.1 Technology and Equipment

The first step in moving toward higher levels of efficient equipment operation should always be to understand what the equipment was designed to do and what modifications have been made since it was placed in service (Refer to Appendix B for a discussion on equipment). This should provide an early indication of the suitability of the installed equipment for the service and if the equipment is able to meet the prescribed performance standards. Knowledge of the equipment will also help identify what changes may be required to achieve higher levels of fuel gas efficiency. Following this, efforts should be made to bring the installation in line with manufacture's specifications for the installation, use, and maintenance of the equipment. Section 4 of this Module provides guidance for the assessment of compressors.

Proven processes and technology are available to both optimize and sustain optimized equipment operation. The important issue is to recognize an opportunity for application of the technology in this regard. Opportunities can be most easily recognized by consulting with industry experts to understand what technologies exist and how they can be applied to operations.

Centrifugal compressors are commonly matched to turbine engines since the engine speed may match or be very close to the compressor speed. It is also common for engine and compressor to be packaged as a modular unit by the engine manufacturer. These units are compact and reliable for high power requirements, however upstream oil and gas applications do not normally require this type of equipment.

Reciprocating engines driving reciprocating compressors are by far the most common equipment combination. The speed of the engine is normally selected to match the maximum operating speed of the compressor. Reciprocating compressors that are built integrally with the compressor are found at older installations although smaller integral compressors are available as new machines. Integral compressors run at very slow speeds (300 to 400 RPM) compared with the separable machines.

The next most common application of engine driven equipment in upstream oil and gas applications is the reciprocating engine driven screw compressor. It is common to increase the size of the screw compressor and run it at the engine speed to avoid the gearbox. Larger units tend to be equipped with gears since the engine speed is reduced as the rated power increases.

2.2 Efficiency Assessment

The volumetric efficiency (VE) is calculated as the volume delivered from the cylinder over the swept volume of the cylinder. The ratio is expressed as a percentage with a higher number indicating better performance. VE is calculated for both suction and discharge. The suction VE is used as the guide to simplify the optimization exercise

Screw compressors use a similar concept for volumetric efficiency defined as suction volume over discharge volume at the point of gas delivery (the volume index (V_i)). Most screw compressor models offer a specific choice of V_i sizes to adapt to the conditions. V_i is most easily estimated from field parameters using the formula:

$$V_i = (CR)^{k},$$

Where:

- CR= Compression ratio, the absolute discharge pressure divided by absolute suction pressure.
- *k* = ratio of constant pressure specific heat to constant volume specific heat.

In both instances it is not possible to obtain a volumetric efficiency of 100% due to variance in gas properties, temperature and the physical characteristics of the compression volume.

The tables below show the target values operations personnel can strive to attain in their equipment configurations.

Table 1.1
Target Volumetric Efficiency in Screw Compressors

Compression Ratio	V_i
2.0	1.7
3.0	2.3
4.0	2.9
5.0	3.4
6.0	4.0
7.0	4.5
8.0	5.0

Table 1.2
Target Volumetric Efficiency in Reciprocating Compressors

Reciprocating Compressor Cylinders	Suction VE
Double Acting Cylinders	70% to 85%

Decisions to carry out adjustments or replace components should be made on an individual compressor basis with consideration for health, safety, environmental and economic considerations. Where adjustments to existing systems are practical, these should be carried out at the time of testing. At that time, minor component replacements can also be undertaken. When equipment shut down is required to undertake improvements, the repair/replacement may be delayed until the next planned shutdown provided this does not pose any safety concern. Section 5 of this MODULE provides guidance for assessing performance deficiencies and possible corrective actions for the compressor.

2.3 Training/Expertise

It is important to include training and education in any efficiency enhancing program. When an operating system is properly understood, correctly operated and adequately maintained, the operations group will be in a better position to provide feedback. An understanding of the equipment and operating scenarios that may impact the operating efficiency is critical to identifying additional opportunities for improvement.

3. Inspection, Monitoring and Record Keeping

Operators should have a record program to support the company's rotating equipment testing and improvement system. Proper record keeping should assist in ensuring that sub-optimal equipment is identified and that appropriate follow-up actions are implemented. This information will also assist in establishing the assessment frequency for each piece of equipment to achieve cost-effective fuel gas efficiency improvements.

Although each company will define its record keeping system, an effective program will include the following information:

- data sheets for each package,
- expected fuel gas consumption for each engine,
- records of changes performed for each unit,
- efficiency testing results, and
- economic analysis performed on underutilized compressors that have not been adjusted or modified.

Record keeping in support of a company's fuel gas estimates, where measurement is not provided, may be audited by the ERCB to assess compliance. In addition, records need to be maintained to demonstrate compliance with ERCB Directives related to NO_x and SO_x emissions.

4. Rapid Feasibility Assessment

Reciprocating and screw compressors are the most common machine driven by an engine in upstream oil and gas applications. Optimizing the engine alone to reduce fuel consumption addresses half of the issues. Addressing the load for optimum engine utilization is necessary to address the other half of the issues. Equipment condition in good working order is required as a starting point. Reciprocating and screw compressors will be examined in this discussion. The discussion is not intended to provide a comprehensive treatment of compressor operation, control and maintenance. The information is limited to the perspective of optimizing fuel consumption alone.

This module will lead the worker through a discussion of the variables that affect optimization. The equipment condition and performance will vary based on the following topics.

4.1 Number of Operating Hours

Maintain records showing when the equipment was installed, last overhauled or nearing a major maintenance milestone. Maintain records as to what items were checked, adjusted, repaired or replaced. Tired and worn equipment uses more energy to produce the same throughput or perhaps limits capability.

4.2 Capacity Adjustment Devices

Compressors are available in many sizes to allow a more economical design for a range of applications. The initial sizing of a machine should be based on the anticipated process conditions, usually the largest demand estimated in the life of the application. The compressor must be equipped to allow optimization by including devices that allow capacity adjustment on each cylinder and for the entire process system. Broken, faulty or improper screw compressor slide valve control or volume index (Vi) must be avoided for efficient compressor operation.

If conditions change, such as decreasing reservoir pressure or flow, then the equipment is often oversized for the new conditions. Designers rarely examine the future conditions required for the equipment. The result may be that an oversized machine is in service for a majority of its service life. Regardless of how the equipment is sized, capacity adjustment is needed to adapt to the changing conditions.

Compressor flow capacity control can be achieved by changing clearance in the compressor cylinders, screw slide valve position, adjusting process devices such as suction pressure, backpressure and recycle valves, or adjusting engine speed. Each of the capacity control devices must be considered to optimize the engine load. An optimized engine load will lead to the minimum fuel consumption. Different control options are outlined below:

Process Suction Pressure Control Valves

Process suction pressure control valves can increase the compression ratio by reducing suction pressure. Increasing the compression ratio will increase the work done for compression. The suction pressure control valve is normally considered a device to assist unit starting or manage transient suction pressure increases. The most engine efficient setting for the suction pressure control valve allows the suction pressure to be maintained at a maximum.

Recycle (or Bypass) Valve

A recycle (or bypass) valve is a standard item on a compressor. This valve is used to pressure balance the machine (suction to discharge) on starting. It is also used to avoid shutting down a compressor during upset pressure conditions. The compressor can run on standby, normally for a short duration, with all the gas shuttled from discharge to suction. Automated controls can close the bypass to begin producing gas when the pressures return to normal. A bypass valve should be closed during normal operation to avoid burning fuel to produce gas that is recycled to suction. Bypass valves can continuously bleed gas due to seat erosion or by actuation from the control systems. This is quite common and a significant source of wasted energy in natural gas production.

Backpressure Control Valves

A backpressure control valve is often used on screw compressors. Increasing the backpressure will increase the compression ratio which in turn will increase the work done for compression. This valve is normally employed to maintain a certain minimum compression ratio in order to avoid the use of a full time oil pump. The oil flow is then motivated by the pressure differential. Units with full time oil pumps normally don't require the use of a backpressure control valve. The compression ratio and specifically the discharge pressure will also determine bearing load.

Slide Valve Position

Slide valve position should be set at a minimum to have the compressor run at optimum efficiency (100% slide position normally designates full load). Application of the slide valve introduces parasitic power due to internal gas recycling. It should be noted that the power requirement will be much higher when the slide valve position is 90% than when it is at 100%. Power requirements then drop off rapidly as it approaches 0%. Inefficiency introduced through the use of the slide tends to increase discharge temperature until the flow is substantially reduced. The discharge temperature is also heavily influenced by oil flow so the net affect is expressed by the machine and not necessarily the individual contribution. Finally, the volume index (Vi) has a large influence on power requirements. The correct Vi selection can reduce power consumption by 20% to 30%. Generally speaking, a higher Vi is required for lower suction pressure and higher compression ratio.

Cylinder Clearance

Cylinder clearance should be set at a minimum to have the compressor run at optimum efficiency. Each cylinder has a minimum clearance inherent in the design. This is commonly known as the “base clearance” and it can not be adjusted. Clearance may then be added in various ways to decrease the efficiency of the cylinder. The clearance is set to the desired or available gas volume that must be produced. Clearance is also used to lower temperature or adjust the compression ratio on a particular stage of compression.

A compressor performance analysis using the manufacturer’s performance software is required to determine the optimum clearance settings. It should be noted that the clearance should be set to the minimum value for required processing conditions rather than simply the minimum clearance. Please consult with an expert before making cylinder clearance adjustments.

Cylinder clearance is changed by using devices that introduce volume into the gas compression chamber that is not used for compression. This allows additional space in the cylinder for gas expansion and compression that reduces the efficiency and throughput. Since compression is most commonly performed on both sides of the piston on alternating strokes, we refer to “crank end” and “head end” orientation for clearance adjustment. Space can be added at the head end cylinder head with fixed or variable adjustable devices, under the valve seats with special cages that position the valves away from the edge of the cylinder, and unloading devices that can completely disable the crank or head end of a cylinder. Generally speaking, it is usually more favourable to unload the head end first for mechanical and torsional reasons. The operator should be aware that damage to the compressor may result if the unloading is not performed properly. The compressor manufacturer will advise the best way to unload the cylinder for equipment health.

Engine Speed Adjustment

Engine speed adjustment will change flow by the same amount. Using engine speed for capacity control should be considered after all other capacity control devices are optimized. The engine torque is reduced at lower speeds. Engine speed may also be adjusted with gear sets between the engine and compressor (speed increaser). However, if less power is required to perform the work then reducing engine speed will reduce fuel consumption. Addressing the reciprocating compressor cylinder clearance, screw slide valve position, Vi and process control valve settings before adjusting engine speed will ensure that the minimum engine power is applied for the application.

4.3 Piston Rings, Packing and Valves

Piston rings and packing glands must seal to avoid leakage of process gas. Broken, faulty or improper springing and lift of reciprocating compressor valves must be avoided for efficient compressor operation. Purge systems must be operating properly and gaskets must be in place to avoid leakage. If any of these components are not functioning correctly then gas recirculation or escape leads to compression inefficiency.

4.4 Rotor Tolerance

Screw compressor rotors and casings have a close tolerance to avoid leakage of process gas. The tolerance can be affected by mechanical damage, wear or operating at pressures (or compression ratios) beyond the design limits. If any of these components are not within specified tolerance then gas recirculation and/or leakage leads to compression inefficiency.

4.5 Oil Condition and Specification

Keeping oil uncontaminated is the key to maintaining bearings and rotating elements in good operating condition. Oil analysis is used widely for condition monitoring. The selection of oil for screw compressors and reciprocating compressor cylinder lubrication must be matched to the application. Using an incorrect oil type for certain applications will result in viscosity change or deposition on components.

4.6 Process Aspects

High vibration in the system (torsional, acoustical or mechanical) can limit operating speed, thereby creating inefficiency. Plugged cone strainers can lower suction pressure and reduce efficiency.

Distance piece design in corrosive applications will allow safe and reliable operation of the reciprocating compressor by directing gas leaks to vent systems. Packing leakage will occur when the unit is shut down and the cylinder is under pressure. Packing leakage is also expected at a higher rate during a new component break in period. Packing leakage may also be the result of wear or component failure that results in inefficient operation and unnecessary emissions.

4.7 Measurement Accuracy

Effective optimization depends on accurate analysis and assumption. The pressure and temperature readings of the compression equipment and the process parameters are used to perform that analysis. Compressor performance programs make assumptions regarding where the readings are taken, normally at the inlet and outlet flanges. Instrumentation sensing points which are not in place at those locations will incorporate some error in the form of pressure drop or temperature variation.

Calibrated sensing equipment of the appropriate accuracy is also necessary. Pressure sensors in very low pressure applications that are mounted below the sensing points may contain oil in the sensing line that will add a static pressure head to substantially affect the pressure reading. The worker must compensate for variances or move sensors to appropriate locations.

5. Operational Checks, Testing and Adjustments

The impact of performance and service requirements on efficiency necessitates the identification of what constitutes good performance for each piece of rotating equipment. The performance envelope must consider the range of process conditions that are normally encountered. This may require a compromise to maintain the desired operation of one equipment element.

Attaining these levels of performance may not be possible in all cases especially when a unit is grossly oversized in its current application. Units that cannot meet the objective are candidates for upgrade or replacement. The variety of variables and components make efficiency testing a complex effort.

A logic diagram is presented in Figure 5.2 and 5.3 to help identify the various optimization strategies for reciprocating and screw compressors. The logic diagram leads through the controls and clearance issues to identify which conditions dictate a change in control or physical parameters such as a repair or replacement.

5.1 Operational Checks

Indicators of efficient operation can be identified through engine power utilization, throughput, operating temperatures and other aspects. However, these all require further analysis to allow the operator to understand how efficient that compressor is running. Engine efficiency can be derived by monitoring the brake specific fuel consumption (BSFC see Module 7: Engines). Any change in engine efficiency or fuel quality will trigger a change in the BSFC. Compressor efficiency is gauged by volumetric efficiency. Remember that we are optimizing the compressor so that the engine load is also optimized.

The purpose of the checklist is primarily to collect enough data to ensure that the compressor is operating properly. These checks can be performed during a site inspection. They require instrumentation installed on the equipment or portable measurement devices. They should be undertaken on daily basis depending on the availability of operating personnel. The time to carry out the visual checks is in the range of 30 to 60 minutes. The majority of the data collected will be found on the daily log data sheets that form a part of every operator's routine.

Efficiency tests are a formal survey of equipment performance. Such testing will establish the performance of the rotating equipment and identify where action needs to be taken to improve performance. The driven equipment is required to be optimized in order to optimize the engine. An efficiency test may require several hours or days to perform. An operator must assess the results with adjustments and retesting to determine the affect of each change. An automated dynamic software tracking system is recommended to assist the operator with assessing equipment life and ranking for candidates deserving attention.

Table 5.1
Compressor Optimization Checklist

Site Location:		Date:	
Unit Number:		Time:	
Engine Model		Serial #:	
Driven Equipment Model:		Serial #:	
Unit In Service: (Y/N):		Outside Temp	

Item	**Activity**	**Records**
Hours from last major overhaul	Record hours	
Hours from last service	Record hours	
Capacity Adjustments	Record VVCP, HCA, Slide valve position (list below)	
Process gas constituents	Take sample & cf last sample	
Process pressures	Record readings in & out of each stage (list below)	
Process temperatures	Record readings in & out of each stage (list below)	
Engine speed	Record RPM	
Compressor speed	Record RPM	
Oil filter	Check condition and DP	
Oil lubricator flow	Check flow rate	
Control valve positions	Record positions (list below	
Adaptive controls effective	Yes, no?	
Adaptive controls active	Yes, no?	

General Observations and Conditions:

Operator:

Figure 5.2
Reciprocating Compressor Optimization

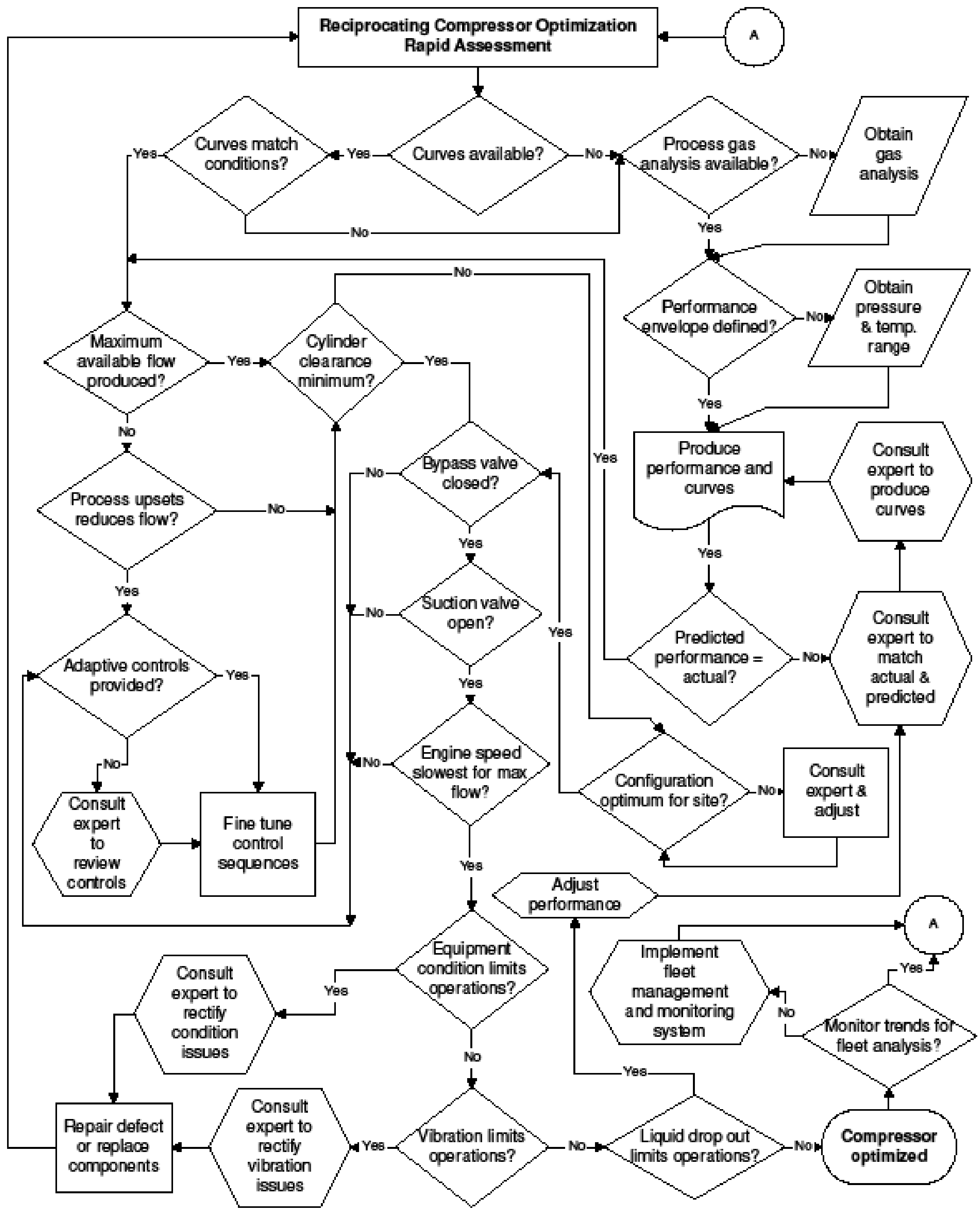
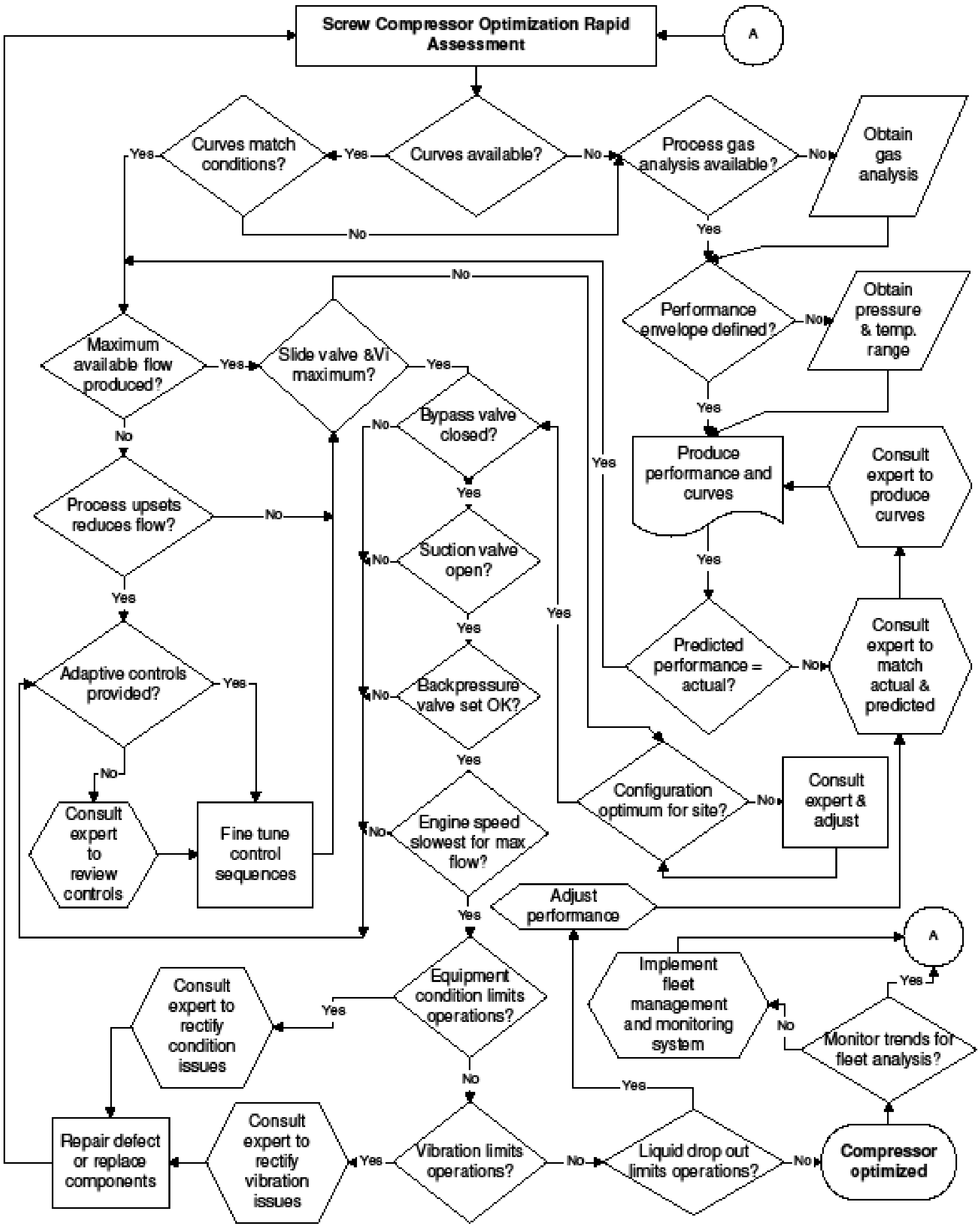


Figure 5.3
Screw Compressor Optimization



5.2 Determining Volumetric Efficiency

Volumetric efficiency simply compares the volume of gas produced to the volume of gas in the compression chamber. It is a convenient measure because it provides a uniform basis for comparison that captures physical parameters, power and the characteristics of the process gas. In order to determine volumetric efficiency the data must be collected and entered into the Original Equipment Manufacturer's (OEM) software. Proprietary aspects of equipment design and empirical performance parameters are built into the OEM software; therefore the volumetric efficiency can not be calculated without knowing these details. If the volumetric efficiency can be increased, then power is conserved and the engine BSFC will be reduced. A smaller engine BSFC number indicates lower fuel consumption.

The manufacturer's performance software is used to size a compressor. The analysis of compressor performance includes adjusting the parameters that may be changed in order to maintain throughput using the minimum engine power. Theoretically, all physical factors are a variable. In reality, it is often not practical or economical to change process gas composition, cylinders, frames and engines when clearance or other capacity adjustments will suffice. The final solution will be a balance of fuel efficiency and capital cost for equipment replacement. At some point the existing equipment will simply be operating beyond its design capacity and a physical change is required.

Most reciprocating compressor software programs allow adjusting the valve springs and lift as well as the process gas quality. These factors, in combination with the added clearance, determine the compressor efficiency. The designer will consider changing equipment size and cylinder size in combination with the valve selection to produce the best fit for the application. Indicators of repair or replacement will typically be high compression ratio, high discharge temperature, low engine utilization and sometimes liquid drop-out issues. Volumetric efficiency below 30% is generally considered to indicate very poor efficiency.

A tool for measuring the volumetric efficiency for reciprocating compressors is available. It is commonly known as a “recip trap” and it is connected to the compressor cylinders. The results of the data analysis show compressor valve dynamic behaviour, pressure-volume relationships indexed to crankshaft position and sometimes acoustical signatures.

Most screw compressor software programs allow adjusting the rotor length and diameter as well as the process gas quality. These factors, in combination with the Vi selection and slide valve determine the compressor efficiency. The designer will consider changing equipment size and compressor size in combination with the rotor selection to produce the best fit for the application. Indicators of repair or replacement will typically be high compression ratio, high discharge temperature, low engine utilization and sometimes liquid drop-out issues.

As previously mentioned, the volume index for a screw compressor depends on the suction and discharge pressure as well as the ratio of specific heat at constant pressure and volume. Since the specific heat ratio (*k*) varies with temperature and pressure it will not be constant. Estimates of *k* can be determined from the average of suction and discharge conditions as presented in Section 2. This value should be sufficiently accurate for optimization purposes as long as process conditions are reasonably stable. The selection of V_i for most screw compressors should be made in discrete steps. When fine tuning the setting to that which offers the best theoretical efficiency, the closest match to the operating conditions should be the target.

Screw compressors do not have a tool to measure volumetric efficiency like the "recip trap". If very accurate power consumption must be known screw compressor power should be measured using torsion measurement techniques. The accuracy of most OEM screw compressor programs should be sufficient for optimization purposes.

At sites where several units are operated in parallel, the optimum number of units running for service should be considered. One unit might be shut in to run the others at higher load for improved fuel efficiency. Screw compressors are often operated in series with other compressors (booster for a reciprocating compressor). In such cases the engine utilization of both the booster and boosted machine must considered. An analysis of the load on each machine for the combined throughput at a variety of pressure ratios should be undertaken to ensure both engines are operating at the minimum fuel consumption required for the duty.

5.3 Monitoring Fuel Efficient Operation

Control systems that make adjustments automatically in response to the demand are critical to maintaining efficient operations. Upsets in pressure and demand typically impose the worst operating case. Typical upsets are most often pressure swings that occur when conditions upstream or downstream suddenly change. Transient pressure swings result from plunger lift operations, wells freezing off, other equipment shut in and line pack. Declining reserves and flow also change the operating parameters but these occur over a longer time period.

Production requirements typically dictate compressor settings; therefore, sporadic shut downs and unreliable operations are a reality. It is important to recognize that the adaptive capability of the control system must respond quickly enough to avoid shut down. Optimized operation is not possible in such cases without the appropriate automated adaptive controls. Equipment life may also be extended with adaptive controls.

Analysis that incorporates operating conditions, such as volumetric flow rate, and compressor efficiency is essential in order to provide signals of the health of the compressor and the influence of operational factors on performance. In order to determine flow trends, the compressor must be equipped with an individual process gas meter and a means to perform the calculation. If we match these compressor parameters to engine BSFC then we can gauge if fuel consumption is minimized at maximum process gas production. Optimum operating conditions should then be documented.

Operators should review the efficiency of their equipment each month. If time and resources do no permit a monthly review then a quarterly review should be undertaken as a minimum. If conditions for the driven equipment or the engine have changed then the BSFC and volumetric efficiency should be reviewed again to determine a new baseline. Operations personnel should consider that this measure is as much an indicator of equipment condition as it is fuel consumption.

It takes a concerted effort to monitor unit performance and the influences that are inducing changes in its operating environment. Continuous vigilance is needed to maintain optimized operations. Operators of large fleets will recognize that this is daunting task. An automated software system approach to monitoring engine performance with an integrated operator interface is recommended. Fleet management software is available that present ranked operating and efficiency data for review. This is by far the most practical approach to trending unit performance.

Appendix A
Glossary of Terms

A

AIR-FUEL RATIO - The ratio of the weight, or volume, of air to fuel.

AMBIENT AIR - The air that surrounds the equipment. The standard ambient air for performance calculations is air at 80 °F, 60% relative humidity, and a barometric pressure of 29.921 in. Hg, giving a specific humidity of 0.013 lb of water vapour per lb of dry air.

AMBIENT TEMPERATURE - The temperature of the air surrounding the equipment.

ATMOSPHERIC AIR - Air under the prevailing atmospheric conditions.

ATMOSPHERIC PRESSURE - The barometric reading of pressure exerted by the atmosphere. At sea level 14.7 lb per sq in. or 29.92 in. of mercury.

B

BAROMETRIC PRESSURE - Atmospheric pressure as determined by a barometer usually expressed in inches of mercury.

BRAKE SPECIFIC FUEL CONSUMPTION (BSFC) – A measure of fuel efficiency for gas engines. It is normalized with load and power to establish a uniform means of comparison. Imperial units are most common: Btu/(BHP-h).

BRITISH THERMAL UNIT (Btu) - The mean British Thermal Unit is 1/180 of the heat required to raise the temperature of 1 lb of water from 32 °F to 212 °F at a constant atmospheric pressure. A Btu is essentially 252 calories.

C

C - Carbon element

CO - Carbon monoxide.

CO_2 - Carbon dioxide.

CLEARANCE – The amount of volume not used in compression for a reciprocating compressor cylinder. Clearance adjustment devices can variable head end volume pockets, fixed volume bottles, valve chairs or cylinder end unloading devices.

COMBUSTIBLE LOSS - The loss representing the unliberated thermal energy occasioned by failure to oxidize completely some of the combustible matter in the fuel.

COMBUSTION - The rapid chemical combination of oxygen with the combustible elements of a fuel resulting in the release of heat.

COMBUSTION AIR - Air used in the combustion process. Air contains oxygen which is required to combust fuel.

COMBUSTION EFFICIENCY - The effectiveness of the engine to completely burn the fuel. The air content will vary depending on the combustion process used for the engine while converting all combustibles in the fuel to useful energy.

COMPLETE COMBUSTION - The complete oxidation of all the combustible constituents of a fuel.

COMPPRESSION RATIO - The ratio of discharge pressure to suction pressure. The use of absolute pressure units is recommended when calculating compression ratio.

COMPRESSOR FRAME – The compressor frame for a screw compressor is the main pressure retaining housing that contains the lubrication, rotors and running gear. In the case of a reciprocating compressor, the frame does not retain pressure but houses the lubrication and running gear of the rotating elements.

COMPRESSOR CYLINDER - The pressure retaining components where the pistons travel to compress the gas in a reciprocating compressor. Cylinders may be referred to as single acting or double acting depending if the gas is compressed on one or both sides of the piston. Cylinders are available in many sizes and pressure rating to allow flexible compression strategies and multiple stages of compression. Normally one cylinder is attached one throw of the compressor frame but tandem cylinders are also available where two bore sizes are installed on one throw.

CONDUCTION - The transmission of heat through and by means of matter unaccompanied by any obvious motion of the matter.

D

DESIGN LOAD - The load for which equipment is designed, considered the maximum load to be carried.

DEW POINT - The temperature at which condensation starts.

DISTANCE PIECE – The housing assembly containing the piston rod and crosshead guide between the frame and cylinders for a reciprocating compressor is known as the distance piece. It can contain none, one or two compartments separated by oil wipers with optional purge and vent assemblies. Distance piece compartment lengths should be long enough that one point on the compressor rod can not pass through more than one packing or oil wiper assembly. The purpose of the compartments is to isolate the frame from corrosive gases leaking from the cylinder.

DRY GAS - Gas containing no water vapour.

E

EFFICIENCY - The ratio of output to input. See also Combustion and Thermal Efficiency.

ENGINE SPEED – The number of revolutions an engine turns in a unit of time. Normally expressed in RPM or sometimes Hz.

EXCESS AIR - Air supplied for combustion in excess of that theoretically required for complete oxidation.

F

FLUE GAS - The gaseous product of combustion in the flue to the stack.

FUEL-AIR MIXTURE - Mixture of fuel and air.

FUEL-AIR RATIO - The ratio of the weight, or volume, of fuel to air.

G

GAS ANALYSIS - The determination of the constituents of a gaseous mixture.

GAS PRESSURE REGULATOR - A spring loaded, dead weighted or pressure balanced device which will maintain the gas pressure to the burner supply line.

GAUGE PRESSURE - The pressure above atmospheric pressure.

H

HEAT BALANCE - An accounting of the distribution of the heat input, output and losses.

HEATING SURFACE - Those surfaces which are exposed to products of combustion on one side and water on the other. This surface is measured on the side receiving the heat.

HEATING VALUE - The quantity of heat released by a fuel through complete combustion. It is commonly expressed in Btu per lb, per gallon, or cu-ft.

HERTZ (Hz) – A unit of frequency that is defined as one cycle per second. Hertz are sometimes used as an alternate means to express engine speed.

I

INCOMPLETE COMBUSTION - The partial oxidation of the combustible constituents of a fuel.

INTEGRAL ROTATING EUQIPMENT – Two or more rotating equipment elements that share the same crank case and crankshaft. A compressor and engine combined into one frame forms and integral compressor. Screw or other compressors may combine a gear set in one common housing with the compressor.

M

MMBtu - Millions of Btus (British Thermal Units).

MOISTURE - Water in the liquid or vapour phase.

N

NATURALLY ASPIRATED – Atmospheric pressure engine combustion air that is drawn into the engine using the piston downward stroke as the motivation for the air flow (think of the engine as an air pump).

NO_x - Abbreviation for the sum of nitrogen mon-oxide, NO, and nitrogen dioxide, NO2.

O

ORIFICE - A calibrated opening or nozzle used to deliver fuel gas.

P

ppm - Abbreviation for parts per million. Used in chemical determinations as one part per million parts by weight.

PACKING – The packing assemblies or packing cases seal around the piston rod to retain gas in the reciprocating compressor cylinder. The assemblies are lubricated, sometime cooled and may be purged depending on the application.

PARASITIC POWER – Power lost due to the operation of components other than the directly driven equipment.

PRODUCTS OF COMBUSTION - The gases, vapours, and solids resulting form the combustion of fuel.

R

RATED CAPACITY - The manufacturers stated capacity rating for mechanical equipment; for instance, the maximum continuous power for which and engine is designed.

ROTATIONS PER MINUTE (RPM) – The number of rotations of the crankshaft per minute. It is common units of operating speed for rotating equipment.

S

SEPARABLE ROTATING EQUIPMENT – Rotating equipment elements that do not share a common crank shaft or crankcase. Rotating element shafts are connected by coupling(s).

SHELL - The cylindrical portion of a pressure vessel.

SLIDE VALVE – A movable device on a screw compressor that exposes a variable length of the rotors to afford compression. A slide valve allows some inefficiency due to internal gas recirculation.

SPECIFIC HEAT - The quantity of heat, expressed in Btu, required to raise the temperature of 1 lb of a substance 1 deg F.

STACK - A vertical conduit, which due to the difference in density between internal and external gases, creates a draft at its base.

SUPERCHARGER – An engine combustion air compressor driven from the crankshaft using a mechanical drive.

T

THEORETICAL AIR - The quantity of air required for perfect combustion.

THERMAL EFFICIENCY - The efficiency of a heater, based on the ratio of heat absorbed to total heat input. This does not include heat loss from the boiler shell.

TOTAL AIR - The total quantity of air supplied to the fuel and products of combustion. Percent total air is the ratio of total air to theoretical air, expressed as percent.

TURBOCHARGER – An engine combustion air compressor driven from the exhaust gases using a turbine wheel and gas expansion.

TURNDOWN RATIO - Ratio of maximum to minimum operating speed or throughput.

U

UNBURNED COMBUSTIBLE - The combustible portion of the fuel that is not completely oxidized.

V

VE – The internal volumetric ratio of a reciprocating compressor cylinder. It is normally adjustable and affects drive train loading, power consumption and efficiency.

V_i – Volume index; the internal volumetric ratio of suction volume to discharge volume for a screw compressor. It is normally adjustable and affects bearing life, power consumption and efficiency.

Appendix B
Equipment Considerations

Compression Aspects

The style of compressor (screw or reciprocating) must be suited to the application.

- Screw compressors are not equipped to operate at high discharge pressures (over 350 PSIG) while reciprocating compressors may be equipped to operate at very high pressure (over 6,000 PSIG).
- Screw compressors operate well at low suction pressures (even below atmospheric pressure) while reciprocating compressors do not operate with predictable flow rates at very low pressures (less than 10 PSIG).
- Screw compressors also more are suited to high compression ratios (18:1) than reciprocating compressors (4:1 per stage).
- Screw compressors are normally configured as single stage machines while reciprocating compressors can be configured in many stages.

Screw and other single stage compressors are commonly referred to as boosters. This application is specific to a moderate pressure increase usually prior to a multistage reciprocating compressor. It provides a solution to declining well pressures where one more stage of compression is required for the existing equipment. It also allows for the suction pressure to be lowered while increasing the flow capability of the equipment.

The most common gas that is compressed is natural gas. Compressor applications are typically classified into four categories. These categories are used to communicate the service that a compressor provides. The compressor will not change much from one application to the next but the control requirements will differ. The application categories are listed below.

<u>Gathering Compressors:</u>
These compressors are located closest to the wellhead. They may be screw or reciprocating compressors depending on the pressures at the well and downstream in the pipe network. They allow the gas from one or a group of wells to be gathered and brought to a common pressure for transportation to the next transition in the piping network.

<u>Nodal Compressors:</u>
These compressors are centralized in the network. They take gas from the piping systems fed by the gathering compressors and increase the pressure to allow transportation in the next series of pipelines to the processing plants. Nodal compressors may be reciprocating or screw but they are most commonly reciprocating at this point in the network.

Process Compressors:
Processing facilities such as gas plants will use natural gas and other gases such as propane. Compression of these other gases is often required. However, the population of process compressors compressing gases other than natural gas is low and the application is often specialized to the process. Consequently, we will focus on only natural gas compression for the balance of this discussion.

Sales Compressors:
These compressors are located at the end of the chain for most producers. They deliver gas into the main gas transmission lines. Their distinction is that they are located upstream of the custody transfer point for gas sales (a regulated meter). Sales compressors are often located at sites with processing equipment.

The gas being processed by the compressors is important to compressor efficiency. Compressor efficiency is a critical element to fuel efficiency because it affects the engine load. If the compressor is using too much energy to process the gas then the engine is burning more fuel than required for the task. The engine fuel consumption is not optimized unless the compressor is operating at optimum efficiency. Our consideration for the compressor in this discussion is limited to efficiency rather an exhaustive treatment of system maintenance, durability, material selection and operating aspects.

Compressor configuration will determine the efficiency at which it can operate.

- Clearance is adjusted and cooling is controlled to maintain the required operating envelope.
- Heavier gases require more power to produce the same flow rate in identical conditions and machines.
- The gas composition also has an affect on reciprocating compressor valve performance.
- The temperature of the gas dictates how much water the gas can hold at a given pressure. We normally assume that natural gas is saturated. That implies that the right combination of cooling and pressure will cause water to drop out in liquid form.
- Hydrocarbon liquids may also form under the correct conditions.
- Attention to the temperatures and pressures with the gas composition is required to manage liquid formation that will affect how the compressor is configured.

Most reciprocating compressors are designed primarily to handle sweet natural gas. These machines are then adapted to other services by changing valves for performance and construction for corrosive gases. Screw compressors are normally derived from commercial refrigeration service (ice arenas, grocery store coolers, et al). The thermodynamic model is changed to adapt to other gases. Refrigeration service is, however, a constant load. Upstream oil and gas applications call for variable flow rates and a wide range of pressures. Some of the screw compressors have been modified to suit these service requirements (for example, including a balance piston) and they are often a better choice for durability and efficiency.

Gases that require special attention for performance and configuration contain elements other than methane in variable amounts. Common components found in natural gas to supplement methane are water, ethane, propane, butanes, pentanes, hexanes, heptanes, nitrogen, hydrogen sulphide, carbon dioxide, hydrogen and helium. Gases found in specific process applications include natural gas and others that may not have any methane. Examples of such gases are acid gas (CO_2 + H_2S), carbon dioxide, hydrogen, ammonia, propane and nitrogen.

Vendor supplied software programs for their specific compressors need to be employed to evaluate the compressor performance as well as the component selections. The various software programs also have a wide range of sophistication in dealing with the gases. The thermodynamic models may not be adequate to predict liquid formation. Process simulation analysis programs should be employed to verify the results. The compressor manufacturer must also be consulted to review and select components as well as approve the performance. It is recommended that a worker with appropriate expertise be responsible to manage the performance analysis. This is especially important when considering compressor performance in a changing operating environment.

Compressors in upstream oil and gas applications are commonly required to operate with widely fluctuating performance requirements. Wells in the gathering system or other nodal compressors may cease operating. Downstream processes may shut in or other compressors may introduce more flow and line pack. Well operations such as plunger lift systems can swing the suction pressure over a wide range. Declining reservoirs or new production also change the operating conditions.

The compressors are rarely equipped to adapt quickly enough to these changes using the automatic controls typically furnished by vendors. Manual intervention is often required to change the compressor configuration. Our experience is that the configuration is not changed either because lack of equipment knowledge and training (improper adjustments can damage the compressor) or practicality (wide fluctuations over short time intervals). Adaptive controls are often installed to manage transient loads but these compressor control systems are rarely sufficient. The result is that the compressor is configured for the least production so that it can absorb the upset operating conditions without shutting down. Furthermore, adjustments for declining reservoir conditions are rarely implemented.

The propensity of the industry is to reduce the cost of operations. Automation to optimize machines is always an easy target for cost cutting. Although operators do the best they can to keep the equipment operating, suboptimal efficiency can be the result.

This load inefficiency is carried through to the engines and leads to operating the engine at speeds or loads that are not in the most efficient range for fuel consumption. Turbocharged engines operating at very low loads may also be damaged and require higher maintenance. Monitoring is appropriate in the identification of underutilized equipment is can demonstrate opportunities available for equipment optimization. The benefits are incremental production, higher reliability and fuel gas saving.

Producers should recognize that virtually every molecule of gas they produce flows through compression. Compression often becomes the bottleneck to their operations and management may not have any indication that their production is therefore being limited. A fleet compressor analysis that lends visibility to the issues should be considered.

The effort required to manage the data for such an analysis is a daunting task, especially for large fleets containing hundreds of machines. It is unlikely that manual review and analysis will be effective. Operating conditions often change faster than the team can react; therefore, the analysis should be automated to achieve the best results. Fortunately, software programs are available to provide an efficient analysis tool for fleet and asset management. Direct access to this analysis at the Plant Site will enable operators to help respond to changing conditions. Operations and management may then be informed of the issues, identify the highest priorities, evaluate the expected life of the machines, and formulate plans to enhance efficiency.

Plant Process Aspects

Facilities such as gas plants and other specific processes will use natural gas and other gases. Examples of such gases are acid gas (CO_2 + H_2S), carbon dioxide, hydrogen, ammonia, propane and nitrogen. Gases that require special attention for performance and configuration contain constituents other than methane in variable amounts. Common components found in natural gas in addition to methane are water, ethane, propane, butanes, pentanes, hexanes, heptanes, nitrogen, hydrogen sulphide, carbon dioxide, hydrogen and helium. Gases found in specific process applications include natural gas and others that may not have any methane.

Gas processing plants contain specialized systems that use or produce these special gases and other liquids. The systems will provide treatments for sweetening, drying and fractionation. Examples of such systems are dehydration and refrigeration. Compression of these gases is often required.

These compressors typically operate in relatively narrow band. Furthermore, optimization of the compressor may require adjustments of processes elsewhere in the plant. The number of process compressors is low and the application is often specialized to the process. Electric motors are the most common driver for process applications precluding any direct savings of fuel gas by compressor optimization (unless power is generated with fuel gas). Opportunity for process compressor optimization is limited. We will not focus on process optimization since it is beyond the scope of this discussion.

Generator Aspects

Power from the grid is normally preferred in upstream oil and gas facilities but it is often not available at remote sites. Generators are most commonly employed to provide power for remote facilities. Turbines or reciprocating engines may be employed to drive the generators depending on fuel quality and site power requirements. Reciprocating engines are most commonly used for of the driver. Stand-by generators are also provided for sites using the grid or other generators for the primary power requirements. Stand-by generators are normally fuelled with diesel and the primary generators are normally fuelled with natural gas. The generators provide power for site utilities, lights, heating and controls. They are not normally used for high voltage applications like high power electric motors.

Generators prefer a constant load and speed. The constant speed is required to maintain the generated power frequency. The load is imposed from the site power requirements and this may swing as much as 60%. Site power demand influences the engine power requirements which in turn dictate engine fuel consumption. The demand swings need to be accommodated by the generators in some fashion and the most common is the use of a load bank. A load bank is an external load source (heaters, etc) that is employed to use the excess power when demand is low. Using the load bank and the primary site power demand together furnishes a constant load for the generator.

The load bank represents a waste of power and thus an opportunity for fuel savings. An adaptive control system that accommodates engine fuel efficiency would produce fuel savings. A method to change engine speed with load while maintaining the generated power frequency would be worth investigating. Rapid power change requirements would also need to be considered.

One aspect of power generation that is more energy efficient is based on cogeneration. In this system, waste heat from some other process is employed as the motive source for a generator driver. Cogeneration is known to recover up to 80% of the energy in the waste heat. This application will save the power required to operate independent engine driven generators so it is worthy of mention as a fuel saving technique.

Some of the waste heat can be used as follows:

- hot water heating,
- building heating,
- generation of steam for electrical generation,
- organic Rankin cycle electrical generation.

If the plant produces only electricity, efficiencies of up to 59% can be achieved. In the case of combined heat and power generation, the efficiency can increase to 85%. Cogeneration or combined heat and power, CHP, reduce the total cost of energy and the greenhouse gas production.

The conventional design using a load bank limits an opportunity for engine fuel consumption reduction since the engines are always run at a constant speed and load. We will limit our consideration of generators for fuel savings to this discussion alone. The engines used for power generation are the same as any other application so the remaining optimization aspects (i.e. engine condition, etc.) can be determined by using the same diagnostics.

Appendix C
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