Compressor Unit Efficiency Performance Metrics

Gary Choquette
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Background

Knowing that a compressor unit is running according to its expectations helps ensure it is running at maximum profitability and is minimizing its environmental impact. There are several key performance indicators that can be readily calculated to help ensure peak performance. Performance indicators are most effective when they have been normalized. Normalized parameters are calculated such that a value of 100 indicates the unit is operating exactly as expected for the current operating conditions. For example, the expected efficiency of a reciprocating gas compressor can vary significantly depending on the compression ratio of the unit. If the compression ratio varies significantly during normal operations, tracking the relative compressor efficiency provides a better indicator of the unit performance than monitoring the actual compressor efficiency. As will be discussed later, some non-normalized parameters are beneficial to monitor when they relate to the overall cost to operate a unit.

Relative Efficiency

Relative efficiency is a performance parameter used to assess the overall health of a compressor unit. It is a parameter that provides a real-time metric to monitor overall compressor unit performance. As an example, a unit that has a mechanical problem that causes the engine to consume excess fuel will have a low relative efficiency. Examples of these engine mechanical problems include misfires due to ignition system problems, leaky fuel valves, and to a lesser extent, scored cylinder liners. Likewise, mechanical problems in the gas compressor that reduce the load on the unit will also reduce the relative efficiency. An example is a severely damaged suction compressor valve.

In concept, this metric can be applied to compressor units of all types (electric motor, reciprocating engine, or gas turbine driving a reciprocating or centrifugal compressor). Relative efficiency is currently only widely used for reciprocating engine driven reciprocating compressors.

Relative efficiency is the percent of compressor geometric power divided by the engine fuel based power. Specifically:

$$\eta_{Rel} = (HP_{CompGeo}) / (HP_{Fuel}) * 100$$

The fuel power is typically calculated from two curves, one that defines the break specific fuel consumption as a function of engine speed, the second defines the break specific fuel consumption as a function of engine torque. A typical set of fuel curves is shown in Figure 1 below.

Compressor geometric power is calculated based on the compressor piston displacement, gas composition, suction and discharge pressure, and suction and discharge temperature. Ideally, the fuel based power and the compressor geometric power are the same, which would produce a relative efficiency of 100 percent. Note that a relative efficiency of 100 percent does not indicate that the unit is highly efficient, only that it is operating as it is expected.

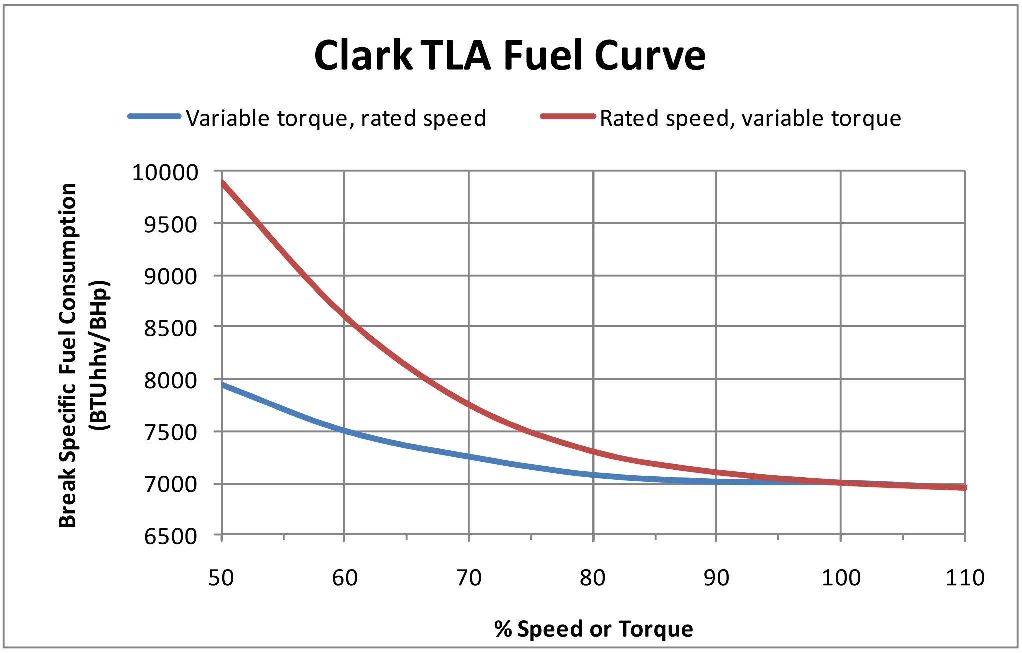

Figure 1 - Typical Engine Fuel Curve

When the relative efficiency is not close to 100 percent, either there are measurement errors, configuration errors, or there are mechanical problems with the engine and/or the compressor. As a general rule, a well maintained and modeled unit should maintain a relative efficiency of 100% with an acceptable tolerance of ±5%.

Measurement Errors

Errors in the measurement of parameters used for fuel and compressor geometric power can result in errors in the overall unit relative efficiency. As with all performance metrics, garbage in the input data leads to garbage in the output data.

Engine

Fuel based power requires the measurement of fuel flow, engine speed, and chemical energy of the fuel (Btu/Scf). Orifice measurement is often used for engine fuel flow measurement which requires the measurement of static pressure, a differential pressure, and a fuel gas temperature. In addition, configuration information is required such as the use of flange taps or pipe taps, and if the static pressure transmitter is located upstream or downstream of the orifice plate. If a beveled orifice plate is used, the bevel must be placed on the downstream side.

Fuel curves are typically based on the lower heating value of the fuel but the chemical energy of the fuel is usually calculated on a higher heating value. For natural gas, the lower heating value is typically 90.3 percent of the higher heating value. Changes in the percent nitrogen and carbon dioxide in the fuel gas stream will have a minor effect on relative efficiency calculations as they typically only affect compressibility to a small effect.

Compressor

Compressor based power requires the measurement of suction pressure and temperature, discharge pressure and temperature, compressor speed, and load step. In addition, configuration information is required on the compressor configuration for each load step (displacement and clearance) and performance factors that will be discussed below under configuration. Changes in the percent nitrogen, carbon dioxide, and the specific gravity of the compressed gas stream will have a minor effect on relative efficiency calculations as they typically only affect compressibility to a small effect. Likewise, suction and discharge temperature are used in compressibility calculations and only have a minor effect on relative efficiency calculations.

The table below describes the measurement errors required to produce a positive five percent error in the relative efficiency (relative efficiency equals 105%) of a C-B GMWH-8 unit configured correctly and in good mechanical condition.

Parameter	Correct parameter	Value with 5% error	% change in parameter[1]
Fuel static pressure (Psig)	65.0	59.7	-6.69
Fuel temperature (°F)	70.0	110.8	7.70
Fuel differential pressure ("H2O)	9.78	9.07	-7.26
Engine/compressor speed (RPM)[2]	250	258	3.20
Fuel BTU/Scf hhv	1028	990	-3.70
Fuel specific gravity	0.600	0.647	7.83
Suction pressure (Psig)[3]	390	N/A	N/A
Discharge pressure (Psig)	588	611	3.90

The parameters that have the smallest percent change in parameter (on an absolute value basis) are the parameters that require the highest accuracy and repeatability for reliable relative efficiency calculations. In the example above, engine speed is the component requiring the highest level of accuracy followed by fuel heating value. Note that these sensitivities are unit specific based on the actual equipment installed and operating

[1] Percent errors are calculated on an absolute basis for temperatures and static pressures
[2] The impact of speed measurement errors are dependant on the shape of the fuel curve and compressor performance curves.
[3] For the unit modeled, a +5% error was not achievable due to the interaction of reduced flow through the compressor with decreasing suction pressure. A suction pressure of 370 psig produced a relative efficiency error of 1.3%. The error induced by inaccurate suction pressure is dependant on the compressor configuration and operation.

conditions. If the data used for the relative efficiency calculations are accurate, there is usually a mechanical problem that needs to be addressed to restore the performance. It should be noted that units with high relative efficiency are also of concern. The most common situation that causes this condition is when there are mechanical issues with the gas compressor that cause it to use more power than expected such as failed compressor rings or scored liners.

Relative Overall Efficiency

Relative overall efficiency is also a key performance parameter used to assess the overall health of a compressor unit. It differs from relative efficiency in the way the compressor horsepower is measured. Like relative efficiency, this metric can be applied to compressor units of all types and should be within ±5% of 100%. Relative overall efficiency is the percent of compressor gas power divided by the engine fuel based power. Specifically:

$$\eta_{OvRel} = (HP_{CompGas}) / (HP_{Fuel}) * 100$$

The compressor gas power is calculated based on the flow rate through the compressor, the pressure rise across the compressor, and the expected efficiency of the compressor. While this metric is very similar to the relative efficiency calculation, it differs in that it will identify some problems that the relative efficiency calculation will not. Examples include situations where the actual fuel power and actual compressor power are both less than expected at the same time. The calculation of gas power requires the measurement of gas flow through the compressor. Compressor gas flow is a common measurement for centrifugal compressors (as it is required to perform surge control) but is not common for reciprocating compressors.

Overall Efficiency

Overall efficiency is not a normalized parameter but it does provide an overall metric that closely ties to operating cost. It's also a key performance parameter used to assess the overall health of a compressor unit. It differs from relative efficiency in the way the compressor horsepower is measured. Like relative efficiency, this metric can be applied to compressor units of all types and should be within ±5% of 100%. Relative overall efficiency is the percent of compressor gas power divided by the engine fuel based power. Specifically:

$$\eta_{Ov} = (HP_{Gas}) / (HP_{Fuel}) * 100$$

The gas power is calculated based on the flow rate through the compressor and the pressure rise across the compressor. This calculation also requires the measurement of gas flow through the compressor. If individual unit flow measurement is not available but station flow rate is, this parameter can be calculated at the station level. If a unit or station is operating regularly at low overall efficiency (<50%), modifications to improve the efficiency are usually economical.

Summary

To ensure peak operating performance from gas compression equipment, an operator must be able to monitor and track the health of the equipment. The different forms of efficiency presented here are useful tools for operators to track and monitor the operation of their equipment. Ensuring peak operating efficiency reduces operating costs and environmental impacts.