Energy Audit of a Typical Compressor Station - Where Waste Heat Comes From

by

Robert J. McKee
Southwest Research Institute

Presented at the
Gas Electric Partnership Meeting
January 31, 2008
Introduction

- The efficient use of energy at natural gas compressor stations is an important issue.
- Recovery of waste heat can improve the efficient use of energy at new and existing stations.
- Technology exists to audit the energy use at compressor stations and gas facilities.
- GMRC sponsored a demonstration audit of the energy usage at a natural gas compressor station
Purpose of the Energy Audit

- To demonstrate the techniques that can be used to measure energy usage.
- To identify the typical energy usage and expected results for a compressor station.
- To identify and quantify the sources of waste heat that might be recovered.
Background

- Operating companies typically do not conduct energy audits.
- Some companies conduct performance tests but do not identify waste heat availability.
- Typical performance tests determine compressor acceptance, unit deterioration, and operational limits, not energy flows.
- GMRC project to demonstrate techniques for energy audits and to improve energy usage.
Test Procedures

- A control volume approach for components, units, and the whole station is used (examples).
- Efficiency is output over input, where output is work done and input is fuel (and other) energy.
- Compressor performance determination and energy flows require special tools, care, skills, and attention to operating conditions.
- Compressor performance determination is not a complete energy balance.
Diagram of a Compressor System for Energy Audit Analysis

Flow In at $P_s, T_s$

Heat Energy in from Fuel

Waste Heat Out

Flow Out at $P_d, T_d$
Measurement Approach

- Measure Recip Performance, Flow, Wout, $\eta$
- Measure Engine Fuel Qin, Energy Input
- Measure Centrifugal Performance, Flow, Wout, $\eta$
- Measure Turbine Fuel Qin, Energy Input
- Measure Surface Heat Losses - Thermal Images
- Measure Piping Pressure Drop
- Evaluate Cooling Water & Lube Oil Losses
- Evaluate Electrical Uses & Billing (Name Plate)
- Others
A Typical Compressor Station

In Flow

R1  R2  R3  R4

C1   C2

Out Flow
Reciprocating Compressor Efficiency as a Function of Speed
Compressor Performance Optimization

- As indicated by test results, if flow is to be increased - speed should NOT be increased - rather unloaded cylinders should be loaded.
- If necessary to control power with more loaded cylinders, the compressor should be slowed.
- More units with loaded cylinders for a given flow may allow a compressor to be shut down.
- An optimization routine to select the most efficient configuration for a given flow is needed.
Energy Use by a Compressor

- For one compressor with $Q=32.7$ MMSCFD, $P_s=564$, and $P_d=947$ psia, theoretical HP = 730.3.
- Measured compressor HP = 812.8 such that efficiency is 89.9%.
- Fuel input is approx. 199.8 MSCFD with a lower heating value of 940.5 BTU/ft$^3$ or 3077 HP.
- Efficiency of the engine (812.8 HP) is $26.4 \pm 0.9\%$.
- Overall efficiency of the compressor unit is the product of efficiencies or 23.7%.
Where Does the Rest of the Energy Go?

- Output and input are now accounted for.
- Remaining energy is lost or rejected heat in the exhaust stack, cooling water flows, and heat leaks.
- Some rejected heat (approx. 28%) is necessary due to the second law, but the rest is waste energy.
- Measurements of the stack and cooling water energy flows were made to quantify where the rejected energy goes.
Exhaust Gas Losses

- Velocity traverse with temperature measurement of exhaust gas leads to exhaust HP = 1022.
Removal of Heat by Cooling Water

- From the jacket water pump curve, measured head, flow, and temperature rise (138 to 151°F), the power rejected was determined as 564.9 HP.
- Lube oil cooling water heat flow and temperature rise were also measured, and the power removed was determined to be 630 HP.
- Heat loss from the hot surfaces was estimated from surface temperature and area to be 5 HP.
- Mechanical friction is 2% of compressor power.
## Summary of Energy Use for One Engine Driven Compressor

<table>
<thead>
<tr>
<th>Description</th>
<th>Percentage</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Work done by Compression</td>
<td>26.6%</td>
<td>812.8 HP</td>
</tr>
<tr>
<td>Exhaust Gas Losses</td>
<td>33.5%</td>
<td>1022 HP</td>
</tr>
<tr>
<td>Jacket Cooling Water Losses</td>
<td>18.5%</td>
<td>564.9 HP</td>
</tr>
<tr>
<td>Lube Oil Cooling Losses</td>
<td>20.7%</td>
<td>630.0 HP</td>
</tr>
<tr>
<td>Heat Leak Losses</td>
<td>0.2%</td>
<td>5.0 HP</td>
</tr>
<tr>
<td>Mechanical Friction Losses</td>
<td>0.5%</td>
<td>16.3 HP</td>
</tr>
<tr>
<td><strong>Total Compressor Engine Power</strong></td>
<td></td>
<td><strong>3051.0 HP</strong></td>
</tr>
</tbody>
</table>
Reciprocating Compressor Station Energy Balance

- Four units operating the same, with flow of 131.7 MMSCFD, from suction to discharge pipeline for a total output power total of 3194 HP.
- Total input fuel energy of 12,115 HP ± 1 to 2%.
- Auxiliary pump and air power input is 35 HP.
- Piping pressure drop in this case amounts to 116.3 HP, which is variable and difficult to measure.
- Station lighting and facility use is 168 HP.
### Summary of Energy Uses and Loss for a Compressor Station

<table>
<thead>
<tr>
<th>Description</th>
<th>Percentage</th>
<th>Energy Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Work to the Compressor</td>
<td>25.6%</td>
<td>3194 HP</td>
</tr>
<tr>
<td>Exhaust Gas Losses</td>
<td>32.7%</td>
<td>4088 HP</td>
</tr>
<tr>
<td>Jacket Cooling Water Losses</td>
<td>18.1%</td>
<td>2260 HP</td>
</tr>
<tr>
<td>Lube Oil Cooling Losses</td>
<td>20.2%</td>
<td>2520 HP</td>
</tr>
<tr>
<td>Heat Leak Losses</td>
<td>0.2%</td>
<td>20 HP</td>
</tr>
<tr>
<td>Auxiliary Pump Uses</td>
<td>0.3%</td>
<td>35 HP</td>
</tr>
<tr>
<td>Station Yard Piping Pressure Drop</td>
<td>0.9%</td>
<td>116 HP</td>
</tr>
<tr>
<td>Mechanical Friction</td>
<td>0.5%</td>
<td>64 HP</td>
</tr>
<tr>
<td>Station Lighting and Facility Uses</td>
<td>1.3%</td>
<td>168 HP</td>
</tr>
<tr>
<td>Purging, Venting, and Sample Losses</td>
<td>0.2%</td>
<td>32 HP</td>
</tr>
<tr>
<td><strong>Total Energy Usage</strong></td>
<td></td>
<td><strong>12,497 HP</strong></td>
</tr>
</tbody>
</table>
Uses of Rejected Heat

- Preheating of inlet air — if operating temperature and back-pressure do not become too high.
- Preheating fuel gas before pressure regulation to prevent freeze-up problems, which also adds BTU (83.7 HP/unit) to the engine.
- Preheating fuel gas after pressure regulation to add energy to the fuel which requires less fuel (90 HP/unit) for the same output.
- Increasing fuel gas temperature from 72 to 125°F, using cooling water waste heat, reduces the fuel requirement by 2.9%.
Centrifugal Compressor Performance Results

- This performance test was limited to off-design, high suction pressure, low speed, part load, re-circulating flow conditions.
- Measurements made with both special and installed instrumentation.
- Both sets of data were analyzed per ASME PTCs, and compared to manufacturer’s curves.
- Accurate test instruments or more care with installed devices are needed for energy audits.
Centrifugal Compressor Head Curve with Test and Station Data

Volumetric Flow Rate

Head ft

Design
SwRI Data
Station

GMRC
Gas Machinery Research Council est 1952
Summary of Centrifugal Compressor Performance

- Compressor efficiency is low due to off-design operation.
- Results are scattered because of low ratio short duration tests, and poor fuel flow measurement.

<table>
<thead>
<tr>
<th>Speed, RPM</th>
<th>Flow Rate, MMSCFD</th>
<th>Efficiency, %</th>
<th>Gas, HP</th>
<th>Fuel Energy, HP</th>
<th>Efficiency, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>4500</td>
<td>932.0</td>
<td>61.5</td>
<td>3052</td>
<td>12220</td>
<td>25.0</td>
</tr>
<tr>
<td>5000</td>
<td>904.9</td>
<td>59.4</td>
<td>3931</td>
<td>14715</td>
<td>26.7</td>
</tr>
<tr>
<td>5500</td>
<td>974.5</td>
<td>59.8</td>
<td>5073</td>
<td>17391</td>
<td>29.2</td>
</tr>
<tr>
<td>5500</td>
<td>1074</td>
<td>55.0</td>
<td>5353</td>
<td>17475</td>
<td>30.6</td>
</tr>
<tr>
<td>5000</td>
<td>1075</td>
<td>52.6</td>
<td>4170</td>
<td>16989</td>
<td>24.5</td>
</tr>
<tr>
<td>4500</td>
<td>1037</td>
<td>56.5</td>
<td>3163</td>
<td>12220</td>
<td>25.9</td>
</tr>
</tbody>
</table>
Exhaust Stake Heat

Exhaust Gas at High Temperature Compared to Surrounds
Seal Oil Tank as Source of Heat

Seal oil carries a lot of heat and has to be cooled
Any Lube Oil Tank Will Due

The reserve oil tank is a source of hot oil
Heat Balance for Gas Turbine Driving a Compressor

<table>
<thead>
<tr>
<th></th>
<th>%</th>
<th>HP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Work to the Compressor</td>
<td>27.1</td>
<td>4124</td>
</tr>
<tr>
<td>Heat Losses to Exhaust, Lube</td>
<td>71.9</td>
<td>10962</td>
</tr>
<tr>
<td>and Seal Oil, etc.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Auxiliary Pump and Fan Losses</td>
<td>0.4</td>
<td>56</td>
</tr>
<tr>
<td>Mechanical Friction</td>
<td>0.6</td>
<td>82</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>15,224</td>
</tr>
</tbody>
</table>

- Turbine efficiency of 27.1% with an uncertainty of 5%.
- Implied heat rate of 9.5 KBTU/HP-hr. compared to design value at better conditions of 8.6.
Conclusions

• A method for energy auditing of compressors and stations has been demonstrated.
• The energy balance for one compressor indicates that approximately 27% of the fuel energy goes into compression and nearly 73% of the input energy is rejected to the stack, oil, cooling water, etc.
• An energy balance for an complete station shows that typically 23 to 26% of the input energy goes to compression and approximately 71% is rejected heat most of which can be drawn on as waste heat.
Conclusions - Continued

• Approximately 28% of the total energy input to a station must be rejected to satisfy thermodynamics.
• Approximately 4 to 10% of the input energy is lost as piping and related pressure drops.
• Approximately 5 to 9% is used for pumps, fans, etc.
• Potential uses for the waste heat included;
  • Pre-heating fuel gas
  • Pre-heating inlet air within temperature limits
  • Development of auxiliary power for internal use
  • Production of power for sale
An Approximate Compressor Station Energy Budget

Energy Input to Station from Fuel Gas & Electrical 100 %

Compressor Exhaust Gas Waste 24 - 30 %
Engine Cooling & Heat Losses 22 - 28 %
Auxiliary Pump Use, Oil, Water, & Air 5 - 9 %
Unit Mechanical Friction 2 %
Compressor Valve, Nozzle, & Bottle Losses 6-10 %
Station Lighting, Controls, & Facility Use 1 %
Station Yard Piping Pressure Drop 2 - 4 %
Purge, Vent, & Sample Losses 1 %

Work Delivered to Throughput Gas 26 % ± 11 %