Report 18: Cost-Effective Reciprocating Engine Emissions Control and Monitoring for E&P Field and Gathering Engines

Technical Progress Report

DOE Award DE-FC26-02NT15464

Work completed: Jan 1, 2007 – March 31, 2007

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Submitted by

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April, 2007

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Abstract

This report highlights work done on a project intended to lower the cost of environmental compliance and expedite project permitting for Exploration and Production (E&P) operators by identifying, developing, testing, and commercializing emissions control and monitoring technologies. Promising technologies have already been identified and developed. Current work focuses on testing these promising technologies. Specifically, several technologies are being tested in the laboratory for application to lean-burn engines or fully characterized on-site for use with rich-burn engines. Upon completion of these tests, the most cost-effective and robust technologies will be tested in the field and commercialization will ensue.

During this quarter, progress in laboratory testing for lean-burn engines included testing an Eco-Jet pre-combustion chamber with a 0.20" orifice and varying fuel supply pressure. Unfortunately, these tests revealed that the engine continues to suffer from operational difficulties. Trends were found in the data collected, though results are not compared to previous data due to the operational difficulties.

Work toward characterizing the effectiveness of NSCR systems occurred during this quarter, as well. Several participants have been identified for the NSCR characterization project, and the participants are poised to begin as soon as contractual details are completed. Other progress included work toward developing a data analysis program to automate analysis of the large amounts of data expected to be collected during the NSCR characterization. Additionally, approval for the changes to be made to test sites was received.

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Introduction

The objective of this project is to identify, develop, test, and commercialize emissions control and monitoring technologies that can be implemented by exploration and production (E&P) operators to significantly lower the cost of environmental compliance and expedite project permitting. The project team will take considerable advantage of the emissions control research and development efforts and practices that have been underway in the gas pipeline industry for the last 12 years. These efforts and practices are expected to closely interface with the E&P industry to develop cost-effective options that apply to widely-used field and gathering engines, and which can be readily commercialized.

The project is separated into two phases. Phase 1 work, which has already been completed, established an E&P industry liaison group, developed a frequency distribution of installed E&P field engines, and identified and assessed commercially available and emerging engine emissions control and monitoring technologies. Current and expected E&P engine emissions and monitoring requirements were reviewed, and priority technologies were identified for further development. As a part of Phase 2, the identified promising technologies will be tested on a laboratory engine to confirm their generic viability. In addition, a full-scale field test of prototype emissions controls will be conducted on at least ten representative field engine models with challenging emissions profiles. Emissions monitoring systems that are integrated with existing controls packages will be developed. Technology transfer/commercialization is expected to be implemented through compressor fleet leasing operators, engine component suppliers, the industry liaison group, and the Petroleum Technology Transfer Council.

Forecasts of future U.S. natural gas demand of 30 trillion cubic feet (Tcf) /yr by 2015 require 36% production growth from 2001 levels. Demand growth will be addressed by both conventional gas and coal-bed methane. The majority of the increase in conventional gas production is expected from three primary areas: Offshore Gulf of Mexico, Rocky Mountains, and Canadian imports. Mature basins in the Southwest and Mid-Continent areas also will contribute to the total domestic supply, and maximizing their output will be necessary to meet the aggressive 30 Tcf gas demand target.

Oil and gas production operations in the United States face a wide variety of environmental regulations that are imposed by multiple, sometimes overlapping, jurisdictions. In particular, onshore production must grapple with existing and emerging regulations that address National Ambient Air Quality Standards for ozone, fine particulates, and NO₂, regulations regarding acid deposition and regional haze, and pending air toxics regulations, all of which will limit emissions from compressor engines. NO_x and formaldehyde will be the likely focus. The scope of these regulations will include the assessment of the need for emissions controls on the wellhead and field gathering reciprocating engine-driven compressor and pumping equipment that is ubiquitous in E&P operations. Current estimates are that approximately 15 million horsepower are presently operating in upstream production applications (Hanover Compressor Company 2001 10-K Annual Report filing). At an average size of 250 hp, this implies a total E&P fleet of 60,000 engines.

Though in many oil and gas production areas the air shed emissions inventory is dominated by coal power plants, regulatory agencies continue to pursue incremental reductions in total

pollutant loading. Reciprocating engines have been identified as a meaningful source category. This is evident in Federal and State actions, as well as Environmental Impact Statements associated with new development. These engines are used to produce electricity for a leasehold, compress and re-inject natural gas for increased oil production, compress natural gas to be delivered to local gathering systems that ultimately feed into gas transmission pipelines, and drive smaller-load equipment such as pump jacks.

At present, the region with the greatest confluence of emissions concerns for small internal combustion (IC) engines is the Rocky Mountain and Intermountain West area. In these regions, significant concerns about regional haze control accelerated the implementation of NO_x and fine particulate regulations that are only pending in many other producing areas. However, the incremental adoption of regulations state-by-state, as well as the proximity of many remote production areas in the Southwest to National Parks and Class I Wilderness Area (which are protected air-sheds) may likely stimulate aggressive compressor engine controls in that and other production regions, as well. Finally, the East Texas and Louisiana regions are subject to conventional ambient ozone concerns, and have promulgated strict NO_x controls for reciprocating engines. In addition, the EPA will propose regulations in 2006 for final adoption in 2007 that will address smaller IC engines in all applications throughout the U.S. These rules include a New Source Performance Standard for IC engines, as well as air toxics standards for: (1) area sources (i.e., engines at smaller facilities), and (2) engines 500 hp and smaller at major sources.

Oil and gas production from all states will be required for the U.S. to meet the expected 30 Tcf/year gas demand and to minimize the ongoing slide in domestic oil production, and impediments to production that are created by air quality permitting must be alleviated through focused R&D efforts.

Gas compressor operations are an essential element of oil and gas production. Increased emissions constraints on compressor operations affects oil and gas production in four distinct ways:

- The length of time to obtain an emissions permit is increased as multiple jurisdictions evaluate the effects of various pollutants and attempt to define a mutually acceptable permit level for a given engine. Furthermore, permitting may become impossible when performance targets for application of emission controls to small engines are inappropriately established at levels that are technically infeasible or only achievable based on expenditures well in excess of forecasts of the implementing agencies.
- The capital and operating costs of compressor engine operation are increased as this equipment is physically modified and/or operated differently to comply with the air permits.
- The capital and operating costs of compressor engine operation are increased when expensive and maintenance-intensive continuous emissions monitors are required, as is the case in parts of California. In many settings, the cost of this monitoring exceeds the cost of NO_x control.

- Compressor operators may be forced to limit the annual hours of operation to avoid exceeding a fixed annual ceiling on allowed emissions.

Each of these situations impedes oil and gas production by:

- Deferring the start of wellhead production, and thereby increasing the general business risk in current price-volatile markets and the carrying costs of various lease and development fees,
- Directly increasing the cost of compression services used at the wellhead, and
- Artificially limiting the annual take from a well due to constrained operations.

The net effect is reduced oil and gas production for a given cost within a fixed time period. Multiplying this through thousands of production sites most certainly will have a significant negative impact on the ability of U.S. operators to meet domestic energy demands, and on the general productivity of the U.S. hydrocarbon resource base.

In addition, application of controls may result in emissions tradeoffs that can result in other deleterious environmental effects if not properly considered. These issues may be exacerbated by presumptions of technology performance that have not been proven for the engine sizes or operating applications present in oil and gas operations.

These economic and operating burdens to oil and gas operations can be reduced through a focused effort to develop cost-effective retrofit components, engine combustion controls, and engine performance monitoring options. The proposed project will significantly improve the cost-effectiveness of implementing NO_x and formaldehyde controls and monitoring on compressor engines, while characterizing emissions tradeoffs – thus ensuring that compliance with air regulations does not prevent oil and gas operations from achieving their maximum productivity at competitive production costs.

Basis of the Project

This project draws heavily on the experience gained from the interstate gas pipeline industry's experience with NO_x emissions reductions, and their efforts to develop cost-effective options for extensive deployment throughout their systems. A number of gas pipelines faced EPA statutory deadlines in 1994/1995 to achieve and certify dramatic reductions in compressor engine NO_x emissions across a very wide range of ageing and diverse, but critical, equipment. Even though typical pipeline reciprocating compressor engines range in size from 600 hp to 8,000 hp and are largely two- and four-stroke cycle integral compressors, there is some commonality in equipment types and operational concerns with the wellhead and gathering facilities under study in this project. Beginning in 1990, the pipeline industry embarked on a comprehensive R&D program that targeted significant (50%+) reductions in the cost of NO_x controls without any significant engine performance compromises. All of the technologies developed had to be field-retrofitable and commercially-supported. That program was a significant success and created a number of technical options that allowed up to 80% NO_x reductions in a cost-effective and operationally-acceptable manner. The individuals involved with this current project were key participants in that prior pipeline NO_x and formaldehyde reduction program.

The gas pipeline emissions control technology development effort was instructive in that it employed the following six distinct phases of activity, each of which was necessary for success:

- Obtain an industry consensus for:
 - specific engine types and models on which to focus development efforts,
 - installed cost targets, and
 - realistic emissions levels to be achieved under all operating conditions;
- Develop an inventory of installed horsepower to confirm initial industry guidance and to create a useful tool for impact analysis;
- Create a coordinated, core team of engine technologists, regulatory experts, and industry representatives to ensure that engine design issues, regulatory drivers, and practical operating considerations always were addressed simultaneously;
- Aggressively field test component and controls developments;
- Characterize the fundamental relationships between engine operating parameters and exhaust emissions so that accurate, non-instrumented emissions monitoring systems could be deployed; and
- Transfer technology results to organizations with an existing presence in the industry so that equipment could be provided on commercial terms, with emissions guarantees, and supported on an ongoing basis.

This project followed a similar broad outline with the expectation that the end product is a set of cost-effective emissions control and monitoring options that can be applied to a wide range of compressor engines in common use in oil and gas production. Operators will enjoy reduced costs of compliance, greater permitting certainty, reduced costs of emissions monitoring, and possible improved compressor performance due to improved combustion stability. All of this will sum to increased production as wells are brought online more rapidly, compression equipment is run harder and longer to facilitate increased production, and cost savings are reallocated toward additional resource base development.

Controlled Testing on KSU Ajax DP-115

Controlled tests are conducted on the Ajax DP-115 at Kansas State University to address a series of upgrades intended to improve emissions. The DP-115 is a mature two-stroke cycle lean burn (2SCLB) engine, typical of those found at gathering sites. While many technologies have already been tested, more remain. Controlled testing resumed this quarter, but data analysis indicates that additional maintenance must occur before the new results can be compared to previous results. Comparisons of various data collected during this quarter continue to indicate that a pre-combustion chamber can improve engine emissions when coupled with a judicious choice of spark timing.

An Eco-Jet pre-combustion chamber from Cameron was tested on the Ajax DP-115 this quarter. The chamber can be disassembled to change out orifices, and an orifice with a diameter of 0.02” was installed for these tests. During the tests, engine load and speed were held approximately constant, while the fuel supply to the pre-combustion chamber was adjusted to 0, 7, 10, 13, and 16 psig. The highest value was obtained by completely opening a needle valve between the main

fuel supply and the pre-combustion chamber. The needle valve was closed incrementally to reduce the pre-combustion chamber fuel supply pressure. To obtain no fuel pressure supplying the pre-chamber, a ball valve was closed completely in addition to the needle valve. Thus, the zero supply pressure can be considered to be operation with no pre-combustion chamber.

The qualitative graph in Figure 1 shows the trends in CO and NO_x exhaust gas concentration as pre-combustion fuel supply pressure increases. The actual values for emissions production are not shown in order to emphasize the qualitative nature of the observation and because, given the comparatively high amount of combustion instability, it is inadvisable to directly compare current values for emissions flow with previous values.

In Quarterly Report 17, a problem with inconsistent engine combustion was addressed by replacing the piston rings to increase the compression pressure in the cylinder. While the compression pressure increased to normal ranges, the standard deviation of peak pressure, which is an indication of combustion quality, remained much higher than it had been before June 2006. The standard deviation of peak pressure as a percentage of peak pressure actually appears to have increased since August 2006, as shown in Figure 2. This does not contradict the fact that the engine operation improved since changing the piston rings. Before the maintenance, the engine fired so infrequently that the peak pressure average was very close to that when no combustion occurred, and the deviations from the non-firing average were generally small. However, the higher standard deviation of peak pressure does indicate that the engine is operating more poorly than when the original baseline and pre-combustion chamber tests were undertaken because the comparable tests had peak cylinder pressures in the expected ranges. Furthermore, runs under conditions nearly identical to those in August 2005, with the exception of ambient temperature, showed NO_x emissions more than tripled in some cases, which is also

Figure 1. Combining adjusted PCC fuel supply pressure with retarded spark timing can produce lower NO_x flow than operation without PCC.

Figure 2. The standard deviation of peak pressure has increased significantly since August, 2005, indicating poor combustion quality.

an indication of operational problems.

NSCR Characterization

Among operators and regulators, non-selective catalytic reduction (NSCR) systems have been the most employed method for NO_x emissions reduction on rich-burn engines. This led the research team to consider them to be the obvious technology to use for emissions reduction in field testing of rich-burn engines. However, the results of studies conducted by McGivney (2006) and Arney (2006) indicate that current NSCR systems are not sufficient at very low emissions levels or for continuous control as ambient conditions change. Emissions levels and conditions where an NSCR system can remain a robust, continuous solution for a rich-burn engine will be determined during an industry-funded project to determine the capability of NSCR systems in the Four Corners region of New Mexico and Colorado on actual field engines. Although this work will delay official field testing until 2008, it will provide the groundwork necessary in order to ensure high quality data from the field tests on rich-burn engines. Continued progress toward starting this project was made during this quarter.

Progress toward starting the NSCR characterization project was focused on recruiting additional industry participants because the project must have wide-spread industry support in order to be truly successful. Committed participants include BP America, the Pipeline Research Council International, and the American Petroleum Institute. Including the \$50,000 of the DOE award NT15464 which will be used for this project, this comes to a total of \$475,000 for the NSCR characterization. Work on data acquisition equipment will begin as soon as Kansas State University (KSU) receives the portion of the funding from API or when the contractual

agreements are signed by all parties, whichever occurs first. Otherwise, the scope of investigation may be adjusted to allow the work to nonetheless begin in a timely manner.

Additional progress toward the NSCR characterization project included approval for the desired changes to the test sites and development of data reduction software that will allow data to be analyzed quickly, efficiently, and identically for all testing. The portions of the program that calculate important values, such as engine fuel flow, engine air flow, and emission production in g/hp-hr have been completed. They will be thoroughly checked for bugs or errors in the coming quarter through comparison with trusted results. Additionally, programs to check data for inconsistencies that must be reviewed by a researcher will be created, as will programs to display the information for easy incorporation into reports.

Conclusions and Future Work

During this quarter resumed testing indicated further operational difficulties on the laboratory Ajax DP-115 at KSU. Although these continued difficulties make comparison of recent data to previous data inadvisable, trends in the data indicated that the pre-combustion chamber could reduce emissions when coupled with adjusted fuel supply pressure and retarded spark timing. In the next quarter, additional engine maintenance will be carried out to fix the difficulties, and further pre-combustion chamber testing will resume.

Progress toward beginning work on characterizing NSCR systems for rich-burn engines continued, as well. Additional funding from industry participants has materialized, and the participants are prepared to begin building and installing data acquisition systems in the next quarter, as soon as legal documents have been signed by all participants. Additionally, changes to test sites have been approved, and work has begun to facilitate correct and timely data analysis and reporting once the NSCR characterization project begins data collection.

Acknowledgements

The authors sincerely appreciate the technical assistance from: Mr. Gene McClendon, Mr. Bruce Chrisman, Mr. Russ Holzhausen, Mr. Tom Hurley, and Mr. Drake Pate of Cameron Ajax; Mr. Pat Maloney and Mr. Kriss McDonald of Ariel; Mr. Reid Smith, Mr. Dave Brown, Mr. Gary Whittaker, Mr. Kelly Lane, and Ms. Susan Bair of BP America; Advanced Engine Technologies Corporation; Altronic, Inc.; BP America; Cameron Energy Services; Diesel Supply Company; Dynalco; Exline Inc.; Progressive Equipment Company; TSI; Emerson Process Management; Hoerbiger, and Miratech. Each of these people and companies contributed expertise, equipment, sensors, and transportation services to this project. Without these individuals and companies, this phase of the project would not have been possible.

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