Report 10: Cost-Effective Reciprocating Engine Emissions Control and Monitoring for E&P Field and Gathering Engines

Technical Progress Report

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Abstract

During this reporting period work focused on completion of the extensive data acquisition system, Ion Sense technology installation, and test matrix development. The Ion Sense technology, which measures gaseous species concentrations within the cylinder during combustion and post-combustion, was installed and was operable at the end of the reporting period. Finally, an issue with engine detonation was addressed.

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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 their 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 establishes an E&P industry liaison group, develops a frequency distribution of installed E&P field engines, and identifies and assesses commercially available and emerging engine emissions control and monitoring technologies. Current and expected E&P engine emissions and monitoring requirements will be reviewed, and priority technologies will be identified for further development. The identified promising technologies will be tested on a laboratory engine to confirm their generic viability. In addition, during Phase 2 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.

Research Progress

The objective during the last quarter was to complete the data acquisition system and to conduct a baseline test on the Ajax DP-115. The data acquisition system will acquire a multitude of data, and will include a start up and shut down procedure. This system will include emergency control safeties to shut down the engine. For each test on the Ajax engine, the data acquisition will record:

- Air Inlet Temperature
- Barometric Pressure
- Ambient Air Humidity
- Peak In-cylinder Gas Pressure
- Exhaust Gas Temperature
- Engine Coolant Temperature, Inlet and Outlet
- Fuel Manifold Pressure
- Engine Speed
- Torque
- In-cylinder Ion Sensor Traces
- Air and Fuel Flow Rate

An emission analyzer will directly write all emissions data to a database. During initial trials, a few difficulties were identified with the data acquisition system and these were addressed.

The Ion Sense technology was installed during this reporting period. The Ion Sense is one of the monitoring technologies that measures gaseous species concentrations within the cylinder during the combustion and post-combustion process. The use of the Ion Sense will be used to infer emissions and engine performance as well as determine the in-cylinder air-to-fuel ratio. The Ion Sense technology was initially damaged on installation, but was replaced and was working properly at the end of the reporting period.

Currently the data acquisition system consists of low and high speed channels. Figure 1 illustrates the hierarchy of the extensive data acquisition system. The Engine Mapping Software program, which takes the low speed and high speed data streams and combines them into one output file, was developed and provided by Advanced Engine Technology Corporation (AETC), one of the project partners. In addition to the Engine Mapping Program, AETC also provided a LabView™ data acquisition software package that collects all high speed data. High speed data comes from the sensors that record in-cylinder pressure and ion concentrations on a per crank angle basis.

The remaining data represents low-speed data, and is collected by the NGML's Opto 22-based data acquisition system. The engine mapping program retrieves the low- and high-speed data and stores each data point into a file. Then a statistical analysis is conducted on the data to ensure that

Figure 1: Data Acquisition System.

the data point is acceptable before collecting an additional data point. This system has been fully tested.

During the setup and initial troubleshooting of the Ajax and data acquisition system, the research team discovered that the engine experienced detonation. The detonation occurred starting at 50% load and continued to 100% load. Engine speed had no effect on detonation. Figure 2 illustrates a trace of the in-cylinder pressure during a typical engine cycle. The horizontal axis is the crank angle and the vertical axis is the in-cylinder pressure. This test is with the bottom of the oil bath air filter removed and ignition timing at 3 degrees before top dead center. This particular trace was recorded at an engine speed of 300 rpm and a torque of 1,100 ft-lbs. The blue line represents the in-cylinder pressure. Starting from the left, the pressure increases as the piston compresses the charge within the cylinder. Just before the piston reaches the top of the cylinder, the spark plugs ignite the fuel/air mixture that is trapped within the cylinder. A typical in-cylinder pressure trace shows a smooth increase in the pressure as a function of crank angle, followed by a decreasing pressure. In this figure, the pressure trace exhibits an uncharacteristic instability at the peak of the pressure trace. This instability is typically caused by detonation, or fast combustion, within the cylinder. Detonation is oftentimes referred to as “knock.”

Figure 2: Pressure versus Crank Angle Trace Showing Detonation.

Figure 3 compares normal combustion, slight knock and intense knock. When comparing the figure from Heywood and the Ajax test data, it is apparent that the Ajax test data exhibits a slightly-intense knock in the cylinder. Also, the detonation was audible during the pre-test.

Several measurements were taken when troubleshooting the detonation. First, the ignition timing was retarded. The ignition timing did not effect the detonation, but what is more interesting is that the removal of the oil bath air filter to reduce the air restriction into the engine did not impact detonation. One other parameter that could potentially cause detonation was the oil that is injected into the cylinder for lubrication. By changing the oil to one that is ashless corrected the

problem, thus the detonation was most likely caused by oil that contained ash. As the oil is burned in the cylinder the oil leaves carbon build up from the ash in the oil. The carbon buildup causes the air-fuel mixture to auto ignite and thereby creating two flame fronts in the cylinder.

Figure 3: Pressure versus Crank Angle Comparison for Normal Combustion, Slight Knock, and Intense Knock (Heywood, 1998, p. 454).

Hence, detonation occurs. To resolve the detonation ashless or low-ash oil must be used.

Finally, a matrix of tests that will be conducted on the Ajax engine was developed and is shown in Table 1. The matrix includes the variables of each test, such as ignition timing, air-fuel ratio, etc. The variables on the left side of the table represent whether or not the following parameters will be varied during the particular test. This matrix will be presented to the research team, which is will meet in early July to discuss the progress of the research project and the plans for field testing.

Table 1: Ajax Engine Test Matrix.

Variables	Builds					
	Vary Filter		With Paper			
	Oil Bath	Paper Filter	Screw in PCC	Scavenge Port	Fuel Valve 180 psi	Fuel Valve TBD
Ignition Timing	No	Yes	Yes	Yes	Yes	Yes
Ignition Energy	No	Yes	Yes	Yes	Yes	Yes
Air-to-Fuel Ratio (load)	Yes	Yes	Yes	Yes	Yes	Yes
Exhaust Gas Recirculation	No	Yes	Yes	Yes	Yes	Yes

Future Work

During the next quarter, the testing describe in matrix will be completed, which will conclude Phase 1, Task 5.0. Figure 4 shows the projected time line of the testing. The first portion of the schedule shows the calibration and testing of the data acquisition system. The second half indicates testing to begin on July 20, 2005, with the baseline test. The subsequent tests are: paper air filter, exhaust gas recirculation, screw-in pre-combustion chamber, and fuel valve. The time duration between each test will allow for analysis of the data and a check for ambiguities.

Figure 4: Timeline to Complete the Ajax Tests.

References

Heywood, J.B., 1998, *Internal Combustion Engine Fundamentals*, McGraw-Hill, Inc., New York, NY.