Report 6: Cost-Effective Reciprocating Engine Emissions Control and Monitoring for E&P Field and Gathering Engines

Technical Progress Report

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Abstract

During the sixth reporting period, the main goal for the team was to focus on acquiring an Ajax DP-115 engine to begin the plans for Task 5 and to begin the assessment of emission control technologies as discussed in Task 4. An Ajax DP-115 two-stroke cycle engine was located and purchased in Oklahoma City. This engine is typical of those commonly found in the exploration and production industry.

The exhaustive list of emission reduction and control technologies from Task 3 were reduced to a very few that have a high potential of reducing emissions. A list of emission control technologies was created and a comparison of technologies and prospective outlook is shown in Table 1.

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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 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

Effort during this reporting period focused on: 1) Task 5, acquisition of an Ajax DP-115 two-stoke cycle engine; and 2) Task 4, identify market gaps between practical options and current permitting requirements. At this point, the first three tasks are complete.

Task 5.0: Acquire an Ajax Two-Stroke Cycle Engine for Laboratory Testing

The research team worked with Hanover and Universal Compression to determine the most appropriate engine to use for laboratory testing. The laboratory tests will measure the effectiveness of a menu of emissions reduction and control technology prior to installing and testing these technologies in a field setting. As discussed in previous quarterly reports, the exploration and production industry has essentially two types of engines: 1) rich-burn four-stroke engines and 2) two-stroke cycle engines. Regulatory requirements suggest that the emissions from rich-burn four-stroke cycle engines will be mitigated by using exhaust gas catalysts. Test data for some of these engines was reported in Quarterly Report 3. Regulatory requirements for the two-stroke cycle engines are not as clear. The target emissions level is known to be 1 g/bhp-hr, although this is a case-by-case basis. Emission reduction technologies have not been identified for these engines, as demonstrated in the literature.

The research team, in consultation with Universal Compression and Hanover, determined that the most significant gains would come from evaluating emission reduction and control technologies on an Ajax engine. Each rental fleet company owns over 1,500 Ajax engines. The Ajax engine is a non-turbocharged two-stroke cycle engine that has been in production for decades. While there are several models of Ajax engines, they are all geometrically similar. This geometric similarity suggests that if an emission reduction technology successfully works on one model, then it can be successfully transferred to the other models. Ajax estimates that about 30% of the existing compression fleet is made up by Ajax engines. As stated above, the remainder of the fleet is comprised of mostly rich-burn four-stroke cycle engines.

An Ajax DP-115 engine was located in Oklahoma City and purchased for this project. This particular engine was fitted with an older-style cylinder head and is representative of the plethora of Ajax engines that exist in the field. This engine will be overhauled in Oklahoma City, and then transported to K-State to retrofit the engine with a plethora of emission reduction and control technologies.

Task 4.0: Emission Reduction Technologies

Work on this task will continue through the next three quarterly reports. The purpose of this task is to determine which emission technologies have the most promise to meet the potential regulatory requirements.

As discussed in previous quarterly reports, low emission combustion technologies for natural gas engines utilize one or more of:

- high energy ignition systems,
- pre-combustion chambers,
- turbochargers,
- catalysts, and/or
- lean-burn technologies.

Each of these technologies is used to reduce NO_x emissions. The applicability of these varied technologies, however, depends on the particular engine (for example, catalysts seem to be the low emission system of choice for rich-burn four-stroke cycle engines).

The following sub-sections discuss the key features of how each technology applies to an engine, and the potential of each technology to meet impending regulatory requirements. Each sub-item is summarized in Table 1 that appears on page six of the report.

Uncontrolled Emission Rate

As a starting point, the product literature from Ajax Superior Division of Cooper Compression was reviewed to determine the uncontrolled emissions from an Ajax two-stroke cycle engine. When the engine operates in an uncontrolled emissions mode of 110 to 720 bhp, the NO_X emissions are close to 9.5 g/bhp-hr. This number does vary with the BMEP of the engine. This is most likely due to the fact that the higher BMEP engines exhibit a higher peak temperature that, in turn, leads to a higher NO_X emission. Current indications from regulatory agencies suggest that the NO_x emissions from exploration and production engines will have to be below 1 g/bhp-hr. The following technologies are compared to the uncontrolled emissions rate of 9.5 g/bhp-hr.

Non-Selective Catalytic Reduction (NSCR)

Non-selective catalytic reduction (NSCR) can offer a large reduction in NO_x. Test data has shown that emission reductions can be between 79 and 93 percent. As explained in the previous quarterly report, the catalyst is not the ultimate solution to the emission problem. The catalyst has a break-in period during which the initial NO_x reading will be very low. Eventually, the catalyst readings will increase over time, which then requires readjustment to sensors and the air-fuel ratio controller (AFRC). However, current instrumentation is not sufficient to determine if a catalyst is actually working or not. The key disadvantage of using an NSCR system is that "out of control" operation is possible without any indication.

Selective Catalytic Reduction (SCR)

According to the industry, the operating conditions of these engines make application of selective catalytic reduction (SCR) systems infeasible. The industry also stated that low emission combustion (LEC) technology is a proven technology for natural gas-fired lean-burn engines, while SCR is not.[1] More recent information indicates that SCR technologies applied on variable load-engines experienced problems, but SCR vendors believe they have corrected that problem with a new generation of the SCR technology.[2] With the understanding that these large internal combustion engines operate over a wide range of loads, the U.S. Environmental Protection Agency (EPA) decided that there is an insufficient basis to currently conclude that SCR systems are appropriate for the large variable-load lean-burn engines. In addition, the EPA does not deem SCR as a highly cost-effective control technology for the natural gas- fired lean-burn IC engines.[3] For these reasons, this technology will not be investigated as part of this project.

Pre-Combustion Chamber (PCC)

The pre-combustion chamber was developed to produce a large amount of ignition energy to ignite a lean mixture of fuel and air. The pre-combustion chamber mounts in the cylinder head of the engine to provide an additional volume where a near-stoichiometric mixture can be created. A small amount of fuel is admitted to the pre-combustion chamber and air is forced into the pre-combustion chamber during the compression process. The spark plug is located in the pre-combustion chamber and ignites the relatively rich mixture in the pre-combustion chamber. This relatively rich mixture burns rapidly and expels a relatively large flame from the pre-combustion chamber into the engine cylinder. This large flame then ignites the remaining lean fuel-air mixture inside the cylinder.

One advantage is that the pre-combustion chamber represents a very high ignition energy source. The flame from the pre-combustion chamber allows for leaner mixtures in the main combustion chamber. These leaner mixtures in the main combustion chamber lower the peak combustion

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[1]For example, November 30, 1998 letter from Lisa Beal, INGAA, to docket A-98-12 (docket # III-D-53) and February 16, 1999 memo from Lisa Beal, INGAA, to Tom Helms, EPA.

[2]EC/R report on IC engines, section 4.2.

[3]E Stationary Reciprocating Internal Combustion Engines Technical Support Document for NOx SIP Call October 2003 Doug Grano/Bill Neuffer EPA, OAR, OAQPS, AQSSD, OPSG.

temperature, thereby lowering the NO_x formation rate. The ultimate result is reduced NO_x emissions. The pre-combustion chamber also provides a quicker ignition response to the main mixture that then leads to more complete combustion.

When the pre-combustion chamber is coupled with a lean fuel-air mixture, the entire system comprises a low emission combustion system (LEC). These systems have been found to reduce NO_X emissions anywhere from 86% to 93%. However, these systems usually include some means to increase the air that is trapped inside the cylinder while the fuel flow rate is held constant. Therefore, the power output from the engine remains relatively constant and the NO_X emissions reduce.

The research team plans to investigate several types of pre-combustion chambers and the location of the pre-combustion chamber within the cylinder head. As stated above, the purchased Ajax DP-115 has an old style cylinder head. The difference between the older and current style heads is the ability to install a pre-combustion chamber that was specifically designed by Ajax for the Ajax engines. The new style head contains an extra port to install the pre-combustion chamber. A pre-combustion chamber “kit” is available from Cooper Compression (Ajax is a division of Cooper Compression) and other aftermarket companies. Some of these technologies screw into the existing spark plug hole, while others require the installation of the new style head.

High Energy Ignition System (HEIS)

A high energy ignition system (HEIS) uses a high voltage to generate a spark in the combustion chamber. A high ignition system will create a larger spark. This larger spark will aid in the combustion process to help burn the leaner mixture. This concept works on the same principle as the pre-combustion chamber in that the goal is to ignite a lean air-fuel mixture. There are two types of ignition systems: capacitance discharge and inductive. The capacitance discharge can, in some cases, be used to spark more than once during the ignition phase. The benefit of the inductive system is that the spark duration can be controlled. The research team plans to investigate the potential of these two technologies. As with the pre-combustion chamber, these particular systems should be coupled with a lean air-fuel mixture to produce a low emissions combustion system. Since in this case the pre-combustion chamber itself is not present and therefore contributing to the NO_X emissions, the overall emissions from the high energy ignition system should be lower than the system with the pre-combustion chamber. However, data that demonstrates this reduction is not readily available.

Turbocharger

A turbocharger increases the air-fuel ratio, which then creates a lean air-fuel mixture inside the combustion cylinder. As discussed above, leaning the mixture reduces the peak cylinder temperature and lowers NO_x emissions. Turbocharged engines can reduce emissions of NO_x up to 40 percent by air-fuel ratio increases[4] without creating a mixture that is lean enough to require an upgraded ignition system. In the event that turbocharging is used to create a lean air and fuel mixture, a pre-combustion chamber can be added to achieve emission reductions up to 93%. In

[4]Response to Comments Phase II NOx SIP Call Rulemaking, Contract No. 68-D-00-2 83, Work Assignment No. 3-50 Jo Ann Allman EPA.

addition, turbocharging may enhance in-cylinder mixing due to higher velocities of entering air. Unfortunately, the Ajax can not be turbocharged. Nevertheless, some engines can be turbocharged, and Table 1 shows the potential decrease.

Pre-Stratified Charge

The NO_x reduction efficiency for natural gas ranges from approximately 80 to 90 percent[5]. Pre-stratified charge systems are used only on naturally aspirated engines. Unfortunately, this technology can only be applied to carbureted engines. Consequently, this technology will not be considered further in this project.

Exhaust Gas Recirculation (EGR)

Another control is an exhaust gas recirculation (ERG) valve, which controls NO_x by reintroducing cooled exhaust gases back in to the combustion chamber. This concept is frequently used by the automotive industry to control NO_x emissions. However, in two-stroke cycle engines, the problem often lies with removing a sufficient quantity of exhaust gases from the cylinder during the scavenging process. Consequently, this is not a viable alternative for two-stroke cycle engines. This particular technology is not included in Table 1 since it does not apply to this industry, especially two-stroke cycle engines.

Summary of Technologies

Table 1 compares the emission control technologies by showing the potential decrease in NO_x. The pre-combustion chamber offers an 86-93% reduction and can oftentimes be easily retrofitted when compared to the NSCR which has a potential of 79-93%. However, in order for the pre-combustion chamber to be effective, the air-fuel mixture in the combustion cylinder must be lean. Experience shows that a corrected trapped equivalence ratio in the range of 0.55 to 0.65 will accomplish the goal of 1 g/bhp-hr. This leaves the pre-combustion chamber, coupled with a lean air-fuel mixture, as potentially the most cost effect emission reduction strategy. The impact of other methods, such as high energy ignition systems, varies from engine to engine. Currently there is no method to turbocharge the Ajax; however there may be a potential way to increase the airflow rate into the engine.

Conclusions

The best plan of attack for emission control technology is is to apply several technologies to the Ajax engine beginning with a pre-combustion chamber. The research team will then assess additional technologies listed in Table 1 that could be viable for the Ajax engine Although others champion the NSCR as the best first choice, the research team determined that reducing emissions at the source can not only impact emissions, but can also lead to improved engine efficiency.

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[5]Response to Comments Phase II NO_x SIP Call Rulemaking, Contract No. 68-D-00-2 83, Work Assignment No. 3-50 Jo Ann Allman EPA.

Table 1. Comparison of NO_X control technologies and prospective outlook for use on an Ajax DP-115.

NO_X Control Technology	NO_X Emissions without Control Technology	NO_X Emission with Control Technology	Percent NO_X Emission Decrease
Non-Selective Catalytic Reduction (NSCR)	9.5 g/hp-hr	0.65 – 2.0 g/hp-hr	79 - 93%
Selective Catalytic Reduction (SCR)	9.5 g/hp-hr	-	Not Effective
Pre Combustion Chamber (PCC)	9.5 g/hp-hr	0.65 - 1.3 g/hp-hr	86 – 93%
High Energy Ignition System (HEIS)	9.5 g/hp-hr		-
Turbocharger	9.5 g/hp-hr	0.65 - 5.7g/hp-hr	40 – 93%
Pre-Stratified Charge	9.5 g/hp-hr	0.65 - 1.3 g/hp-hr	86 – 93%
Low Emission Combustion	9.5 g/hp-hr	1.5 – 3.0 g/hp-hr	68 – 84%

Further Work Planned

During the next quarter, the research team will direct most of its effort on ensuring that the purchased Ajax engine is ready for testing and establishing a set of cost-effective upgrade paths for the Ajax engine.