

Quarterly Research Performance Progress Report


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| Prime Recipient Name and Address | Southwest Research Institute 6220 Culebra Road, San Antonio, TX 78238-5166 |
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| Project Title | <u>NOVEL SEAL DESIGN FOR EFFECTIVE MITIGATION OF METHANE EMISSIONS FROM RECIPROCATING COMPRESSORS</u> |
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| Signature of Principal Investigator: |  <hr style="width: 300px; margin-left: 0;"/> <p style="margin-left: 0;">Klaus Brun</p> |

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1 INTRODUCTION

Methane emissions from reciprocating compressors in the U.S. natural gas industry account for over 72.4 Bcf per year according to a 2006 statement by the United States Environmental Protection Agency [1]. Methane has a global warming potential 50 times stronger than carbon dioxide, and reciprocating compressors are the machinery type with the highest contribution to methane emissions at natural gas transmission stations [1]. The largest contributing factor is leakage from the sealing components in the packing systems around the piston rods. Therefore, the team led by SwRI, NextSeal, and Williams Gas Pipeline have proposed the detailed design, fabrication, and full-scale testing of a novel seal design capable of reducing methane and natural gas leakage across the seals to virtually zero.

Current technology uses a series of specifically-cut, dry-ring seals held in place with springs and cups. However, designing seals based on today's technology inevitably leads to a trade-off between leakage reduction with minimal gaps between the seals and the rod versus allowing sufficient gaps, such that the friction between the parts is sufficiently reduced allowing for movement. Once the piston moves, the pressure differential across the packing seals creates a twisting effect on the seal, allowing substantial amounts of natural gas to leak into the casing. Ring twisting also causes increased friction and wear to the sealing rings and compressor rod. This gas is typically vented into the atmosphere, normally exceeding 11.5 standard cubic feet per hour for new, correctly-installed packing systems on well-aligned shafts [2].

This project takes the concept of liquid sealing and combines it with a novel, patented arrangement for pressure balancing across a seal arrangement (Patent No: US 7,757,599 B2 [3]) to allow for successful implementation in a dynamic environment with moving parts as shown in the figure below. The proposed seal design has been successfully implemented and tested at the bench-scale level. The seal will be designed, modeled, and fabricated for full-scale operation and tested in a reciprocating compressor system at typical operating pressures for various scenarios in a step-wise iterative method.

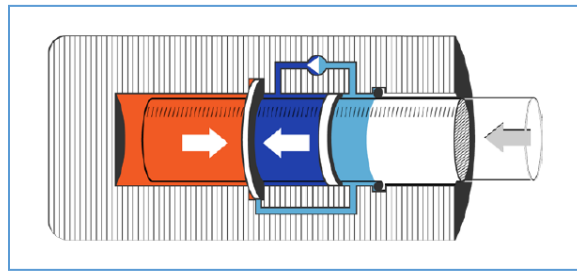


Figure 1-1. Conceptual Drawing of Proposed Seal

The project will be considered successful if the emission levels are reduced by a minimum of 95% compared to the leakage rates of industry standard rod packing seals operating in new condition with minimal wear. Emissions levels will be measured for each test to ensure project goals are being met. During design activities, the team will work in collaboration with Williams Gas Pipeline to design the seal such that it can meet a reasonable target commercial system cost to minimize business risk.

The project work will be performed in two sequential phases. The first phase will start with a thorough design review, analysis, and modeling of the liquid seal concept, as shown in Figure 1-1, as well as a hydraulic support system. The seal and support system will be customized to fit the compressor rod that will be used for the dynamic testing. The first phase will also include assembly and commissioning of the test loop and static testing of the seal. The second phase will consist of testing the liquid seal with the reciprocating compressor running (dynamic setting). Emissions will be monitored and recorded for each test to evaluate the success of the design in achieving the stated emissions reduction. This will allow the real-world benefits of the technology to be demonstrated and quantified.

This report covers the work completed in this budget quarter. The project goals and accomplishments related to those goals are discussed. Details related to any products developed in the quarter are outlined. Information on the project participants and collaborative organizations is listed and the impact of the work done during this quarter is reviewed. Any issues related to the project are outlined and, lastly, the current budget is reviewed.

2 ACCOMPLISHMENTS

2.1 Project Goals

This project will plan, design, build and assemble, and operate a liquid seal in a full-scale environment. The project scope will include the conceptual design, modeling and detail design of the liquid seal and subsystems, manufacture and testing of the seal, and specification of the success criteria for the proposed technology. This includes the design, development, and fabrication of all components of and related to the seal (i.e., control system and hydraulic support system). The liquid seal, control system, and hydraulic support system will be manufactured, fabricated, and installed along with the required instrumentation. Component-level commissioning will be performed in a staged order. Static testing of the system will also be carried out during this first phase to provide valuable information for the go/no go decision point prior to the initiation of Phase 2. The overall goal for the project will be demonstrating the potential for methane emissions reduction of at least 95% of 1% of the total compressor mass flow when operating with a liquid seal compared to state-of-the-art dry seal packing systems.

The testing will demonstrate operability of a liquid seal in static and dynamic environments. The demonstrated seal performance must achieve an overall methane emission reduction of 95% or greater of 1% of the total compressor mass flow. The performance of the primary test concept and associated subsystems (i.e., control system and hydraulic auxiliary system) will be monitored and characterized. Testing will include steady-state, dynamic, and limited endurance/wear operation. The data will be analyzed in a staged order during all testing operations, conclusions will be made about the readiness of the liquid seal for commercial application and emissions reduction, and a report will be prepared. The amount of emission reduction will be quantified.

The project work is split into two budget periods. Each budget period consists of 18 months. The milestones for each budget period are outlined in Table 2-3. This table includes an update on the status of that milestone in relation to the initial project plan. Explanations for deviations from the initial project plan are included.

2.2 Accomplishments

The work completed in the 1st quarter of the first budget period of the project is discussed in detail in the confidential appendix of this report. In addition, the project management plan was completed and submitted for DOE approval. SwRI and NextSeal had a kickoff meeting and ongoing biweekly project meetings since to collaborate on the seal design.

2.3 Opportunities for Training and Professional Development

There were no opportunities for training or professional development during this quarter.

2.4 Dissemination of Results to Communities of Interest

No results have been disseminated to communities of interest during this quarter.

2.5 Plan for Next Quarter

During the next quarter, the technical work on the project will continue. This work will include 1) finalizing a solid model of the seal design, 2) fabricating the seal concept, and 3) designing the support

system. The proposed dimensions for the dynamic pressure equalization active valve will be incorporated into the casing design.

2.6 Summary Of Tasks For Next Quarter

- Finalize model design for the reciprocating packing seal
 - Develop a solid model of the new seal design seal
 - Determine if existing packing cups can be used for new design
 - Design inlet and outlet for liquid
 - Determine the seal types and materials used between each section of the packing

- Support System Design
 - Select the liquid supply pump, additional valves, piping, and storage tank for the hydraulic system
 - Create a P&ID of the support system

Table 2-1. Summary of Milestone Status

| Budget Period | Milestone Letter | Milestone Title/Description | Planned Completion Date | Actual Completion Date | Verification Method | Comments (Progress towards achieving milestone, explanation of deviations from plan, etc.) |
|---------------|------------------|---|-------------------------|-----------------------------|---|--|
| BP1 | A | Project Management Plan | 10/30/2016 | 10/30/2016 | Deliver a project management plan for review and approval by the DOE project officer. | none |
| | B | Detail Drawings of Seal Design, Modeling Results and Benchmark Testing | 4/28/2017 | 75% completed – in progress | The compressor and test loop will be modified for this test. Benchmark testing of leakage with typical packing over a range of conditions will be performed. Modeling results of the seal will be reported and detail drawings of the seal specific to the compressor used for testing will be delivered. | none |
| | C | Detail Design of Support Systems | 4/28/2017 | Not Started | Piping and Instrumentation Diagrams (P&ID) of subsystems will be developed as well as a plan for integration with the seal. | none |
| | D | Procurement, Fabrication and Installation | 7/31/2017 | Not Started | Materials list will be developed and quotes from vendors will be obtained. The parts required for fabrication will be purchased and installed, and the set-up commissioned for testing. | none |
| | E | Test Plan | 9/29/2017 | Not Started | A test plan will be developed for the project based on the initial benchmark testing to include metrics for evaluating the performance of the | none |
| | F | Critical Path Milestone FY1 – Static Testing with Emissions Measurement | 9/29/2017 | Not Started | Report on completion of static testing to include wear, leakage, emission levels. | none |
| BP2 | G | Critical Path Milestone FY2 –Dynamic Test | 3/21/2018 | Not Started | Report on the completion of the dynamic testing and its associated metrics of success. | none |
| | H | Emissions Measurement | 3/21/2018 | Not Started | Report on the measured emissions level as compared current industry standard levels to evaluate the success in meeting the 95% reduction in emissions. | none |
| | I | Lifetime Testing | 4/20/2018 | Not Started | Report on the results of the lifetime testing as well as draw conclusions about possible failure modes. | none |
| | J | Final Report | 4/30/2018 | Not Started | Deliver the final report documenting the seal performance, wear, emissions, suitability for commercial application, and all relevant measurements | none |

3 PRODUCTS

With any technical work, results will be documented and reported to the appropriate entities. Also, the work may produce new technology or intellectual property. This section provides a summary of how the technical results of this project have been disseminated and lists any new technology or intellectual property that has been produced.

3.1 Publications

No written works have been published during this last quarter. Also, no abstracts for future papers or conferences have been submitted for this project.

3.2 Websites or Other Internet Sites

The results of this project have not been published on any websites or other internet sites during the last quarter.

3.3 Technologies or Techniques

No new techniques or technologies have been developed in the last quarter.

3.4 Intellectual Property

No intellectual property such as patents or inventions have been submitted or developed in the last quarter.

3.5 Participants & Other Collaborating Organizations

The work required to develop the novel seal design for methane emissions reduction in reciprocating compressors requires the technical knowledge and effort of many individuals. Three companies, SwRI, NextSeal, and Williams Gas Pipeline are partnering to complete the work. This section provides a summary of the specific individuals and organizations who have contributed in the first quarter.

3.6 Southwest Research Institute (SwRI) – Prime Contractor

The following list provides the PI and each person who has worked at least one person month per year (160 hrs. of effort) in the last quarter.

- Sarah Simons
 - Project Role: Co-Principal Investigator
 - Nearest person month worked: 1
 - Contribution to Project: Project management, Testing and Design Review
 - Funding Support: DOE
 - Collaborated with individual in foreign country: Yes
 - Country(ies) of foreign collaborator: Sweden
 - Traveled to foreign country: No
 - If traveled to foreign country(ies), duration of stay: N/A

- Ryan Cater
 - Project Role: Co-Investigator
 - Nearest person month worked: 1
 - Contribution to Project: Testing, Design Work
 - Funding Support: DOE
 - Collaborated with individual in foreign country: Yes
 - Country(ies) of foreign collaborator: Sweden

- Traveled to foreign country: No
- If traveled to foreign country(ies), duration of stay: N/A

3.7 Other Organizations

In this project, SwRI is collaborating with NextSeal. NextSeal is a subcontractor and cost-share supporter for this project. More information about their participation is listed below.

- NextSeal AB
 - Location of Organization: Sweden
 - Partner's Contribution to the Project: Testing and Design Support
 - Financial Support: N/A
 - In-kind Support: Labor hours and cash contribution
 - Facilities: N/A
 - Collaborative Research: NextSeal supports the testing and design tasks for the first budget period
 - Personnel Exchanges: N/A

- Williams Gas Pipeline
 - Location of Organization: Houston, Texas
 - Partner's Contribution to the Project: Design and Implementation Support
 - Financial Support: N/A
 - In-kind Support: Labor hours
 - Facilities: N/A
 - Collaborative Research: Williams Gas Pipeline will support the implementation and design of the seal
 - Personnel Exchanges: N/A

4 IMPACT

Preliminary baseline data analysis from testing indicated that the amount of leakage flow through typical reciprocating compressor packing is not dependent on the mass flow (or speed) of the compressor, but rather the mean cylinder pressure.

5 CHANGES/PROBLEMS

The project was funded over a three-year period in two budget periods of 18 months each. DOE stated in the kickoff meeting that they would like SwRI to proceed as if the project will be performed in 18 months per the schedule in the proposal and outlined in the milestone dates as described in Table 2-3.

6 BUDGETARY INFORMATION

A summary of the budgetary data for the project is provided in Table 6-1. This table shows the initial planned cost, the actual incurred costs, and the variance. The costs are split between the Federal and Non-Federal share.

For the first quarter in budget period 1, \$88,830 was spent. This exceeds the planned amount shown in the PMP since the planned budget table was spread across three years per the funding agreement. However, the project is being performed at the planned schedule of 18 months. Therefore, the budget will be spent at an accelerated pace to allow the project to be finished in 18 months.

Table 6-1. Budgetary Information for Period 1

| Baseline Reporting Quarter | Budget Period 1 | |
|----------------------------|------------------------|------------------|
| | Q1 | |
| | 10/1/2016 - 12/31/2016 | |
| | Q1 | Cumulative Total |
| Baseline Cost Plan | | |
| Federal Share | \$66,374 | \$66,374 |
| Non-Federal Share | \$45,424 | \$45,424 |
| Total Planned | \$111,798 | \$111,798 |
| Actual Incurred Cost | | |
| Federal Share | \$85,093 | \$85,093 |
| Non-Federal Share | \$3,737 | \$3,737 |
| Total Incurred Costs | \$88,830 | \$88,830 |
| Variance | | |
| Federal Share | -\$18,719 | -\$18,719 |
| Non-Federal Share | \$41,687 | \$41,687 |
| Total Variance | -\$22,968 | -\$22,968 |

7 REFERENCES

- [1] Machu, Gunther and Jackson, Matt, "A New Packing Ring Design-Improved Sealing Efficiency and High Durability," Sealing Technology, September 2011.
- [2] R. Subramanian, L. L. Williams, T. L. Vaughn, D. Zimmerle, J. R. Roscioli, S. C. Herndon, *et al.*, "Methane emissions from natural gas compressor stations in the transmission and storage sector: Measurements and comparisons with the epa greenhouse gas reporting program protocol," *Environmental science & technology*, vol. 49, pp. 3252-3261, 2015.
- [3] Adolfsson, Bengt, "Sealing Arrangement for Relatively Movable Parts and Device Including Such a Sealing Arrangement," U.S. Patent 7,757,599 B2, July 20, 2010.