FINAL TECHNICAL REPORT

1.1 DOE Award Number	DE-FC36-01ID13997
1.2 Name of Recipient	Davidson Instruments, Inc. P.O. Box 130100 The Woodlands, TX 77393-0100
1.3 Project Title	Assuring Mechanical Integrity of Refinery Equipment Through Global On-Stream Inspection
1.4 Principal Investigator	John W. Berthold

1.5 Consortium	DOE Lawrence Berkeley Laboratory
	Shell
	Gayesco, Inc.
	Petroleum Environmental Research Forum (PERF)
	    ExxonMobil
	    ChevronTexaco
	    Saudi Aramco
	    Petrobras
	    Physical Acoustics Corp.
	    Cornell University
	    Ohio State University

2.0 Distribution Limitations	None

3.0 Executive Summary

The development of global on-stream inspection technology will have a dramatic effect on how refinery operations are managed in the U.S. in the future. Global on-stream inspection will provide assurance of the mechanical integrity of critical plant equipment and will allow refineries to operate more efficiently with less impact on our environment and with an increased margin of safety.

Because refining operations are continuous operations, down time of critical equipment results in lost production opportunities that can never be recovered. Minimizing down time, therefore, is the key to maximizing the efficiency, productivity, and profitability of operations in the refining business. If down time at a typical refinery could be reduced by six days per year through global on-stream inspection, productivity of the refining industry would increase by 2% percent resulting in hundreds of millions of dollars increase in the gross national product, enormous energy savings, and less impact on the environment.

This project was planned in January 2001 as a three-year project but was terminated due to changes in the Congressional Appropriations Bill in GFY 2003.

4.0 Comparison of Accomplishments and Goals

Goals and Objectives	**Accomplishments**
Design, fabricate, and test, and use fiber optic based acoustic emission sensors capable of detecting cracks in pressure vessels and piping and capable of operating at 1000ºF	Technical progress was made in design and fabrication, but work was not completed because project funding was terminated.
Design, fabricate, and test fiber optic sensors for continuous monitoring of furnace tubes that are operating at 1400ºF and where the ambient temperature approaches 1800ºF.	Technical progress was made in design, fabrication, and test, but work was not completed because project funding was terminated.

5.0 Summary of Project Activities

5.1 NDT of Pressure Vessels and Piping. In these tasks, Davidson's objective was to use optical methods to detect, locate, and characterize flaws (i.e. cracks and corrosion) in critical refinery equipment.

Task 1 – Fiber Optic Acoustic Emission (AE) Sensor

Subtask 1 – Proof of Concept Studies. In Phase 1 of the project, DOE Lawrence Berkeley Laboratory (LBL) conducted a study and issued a report establishing the technical feasibility of using optical methods to detect mechanical waves in steel.

In Phase 2 of the project, LBL conducted a study and performed limited experimental work to determine the technical feasibility of developing a fiber optic fluorescence sensor to detect benzene, ethylene, and other fugitive emissions caused by cracks in pressure vessels and piping. A comprehensive literature search was conducted to understand the prior work in this field. No references were found that provide a cost-effective fiber optic sensor for the detection of fugitive emissions of hydrocarbon species based on fluorescence. The experimental work involved testing of the spectral reflection from resin/dye combinations while in various hydrocarbon vapors. Most of the dye/resins exhibited some change in the amplitude of the fluorescence when in the presence of the hydrocarbon vapors. Based on these experiments, it appears that there may be great potential for development of cost-effective fiber optic sensors for the detection of fugitive emissions in refineries. Further research is warranted to ascertain the best resin/dye combination for a particular or specified gas species.

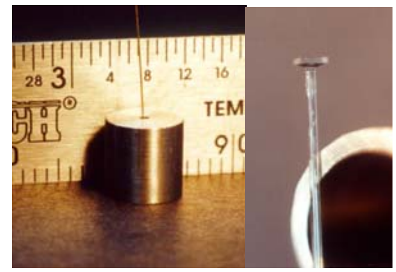

Figure 1 – Resonant and MEMS Sensors

Subtask 2 – Laboratory Prototype Testing. Davidson examined two design variations for acoustic sensors to be used in high temperature environments (up to 1000^{o} F) and a third for temperatures up to 500^{o} F. Option 1 is a narrowband resonant cavity sensor. Option 2 is based on a broadband sensor decoupled to minimize the effects of resonance. Option 3 is based on MicroElectroMechanicalSystem (MEMS) manufacturing methods. Fabrication of the MEMS sensors was started but not completed, and testing was not performed before termination of funding. Photographs of the resonant cavity and MEMS based sensors are shown in Figure 1. A prototype signal conditioner with high frequency response was fabricated and tested. A second generation prototype signal conditioner was designed.

Subtask 3 – Field Prototype Testing. During the course of the project work, Davidson met and discussed the status of the technology with the key members of the research staffs of the major U.S. refiners, (i.e. Shell, ChevronTexaco, ExxonMobil), and the major U.S. AE equipment and service providers.

Task 2 – Acoustic Emission (AE) Algorithm Development.

Subtask 1 – Laboratory Prototype Testing. A contract had been issued by PERF to Cornell University for a project entitled, “Automated AE source Location and Characterization”. However, Exxon, the PERF coordinator and Cornell University, were not able to come to terms regarding intellectual property rights. The contract was subsequently issued to Physical Acoustics Corporation (PAC) to integrate the results of work into its PERF-PAC software. PAC was to work with the University of Illinois to develop the automated computer algorithm. The goal of the work was to characterize the source of acoustic emissions in pressure vessels, i.e. is the AE originating from a crack or from something impinging on the side of the vessel. If the AE can be attributed to a crack growing from within the vessel wall, then further examination using high-resolution ultrasonic methods would be in order. If this algorithm had proved successful, it would have enabled widespread use of Davidson’s high temperature fiber optic acoustic emission sensors and the high temperature automated ultrasonic testing systems. However, the development work was not completed due to termination of funding.

Subtask 2 – Field Prototype Testing. Upon completion of the development of the algorithm, testing of the system was to be scheduled with the major refiners. However, the development work was not completed due to termination of funding.

Task 3 – High Temperature Flaw Characterization

Subtask 1 – Design Optimization. This work was aimed at determining the limits and capabilities for high temperature flaw detection. PERF funded two contractors to develop high temperature scanners, transducers, and couplants to determine the limits for characterizing flaws at elevated temperatures. The goal was to conduct an ultrasonic test (UT) examination of a vessel at 650^{o}F using conventional piezoelectric ultrasonic technology. A second PERF project was aimed at optimizing the design of systems for inspection of complex geometries in reactor vessels, i.e. vessel head welds and nozzles. This second PERF project was intended to consider electromagnetic acoustic transducers (EMATs), phased array ultrasonics, time-of-flight delay (TOFD) ultrasonics, and conventional pulse-echo/pitch catch ultrasonic methods. Neither of the two PERF projects was completed prior to termination of funding.

Subtask 2 – Laboratory Prototype Testing. Laboratory testing of the high temperature scanners was completed in the second quarter 2002. Development of the optimal methods for complex geometries was to have continued into 2003.

Subtask 3 – Field Prototype Testing. Field testing of the high temperature UT scanners was completed in second quarter 2002. These systems are now ready for commercial use in the field.

5. 2 Furnace Tube Temperature Monitoring. In these tasks, Davidson's objective was to use optical methods to measure the skin temperature of furnace tubes to allow furnaces to operate safely at higher temperatures than existing sensors can allow.

Task 1 – Fiber Optic High Temperature Sensor.

Subtask 1 – Proof of Concept Study. Davidson designed three variations of the temperature sensor for use at temperatures up to 1400° F. The results of the design paper studies indicate it is possible to achieve the design goals of 1400°F with resolution 2° F and accuracy of 10° F. The first design employed two quartz fibers in a borosilicate tube. The second design employed a quartz tube and sapphire fiber with a reflective coating on one end in lieu of the quartz fiber used in the first design. The third variation of the design consisted of a sapphire (Al_2O_3) window with reflective coatings, (i.e. a six-layer dielectric stack), on both surfaces.

Subtask 2 – Laboratory Prototype Testing. The first design worked well at temperatures up to 1100°F. All of the sensors failed rapidly once the temperature exceeded 1200°F. Testing of the second design showed better results up to the goal of 1400°F. Davidson placed a hold on the fabrication of the third design pending further testing of the first and second design variations in the field. No further tests were performed due to termination of funding.


Figure 2 – 46-foot Probe ready for Beta Testing.

Subtask 3 – Field Prototype Testing. Beta testing of the fiber optic instrumentation was accomplished in September 2002 at Shell Westhollow Technology Center. The interface between the thirty-two (32) channel signal conditioning instrumentation and the Honeywell control system was seamless. Further testing of the system with Davidson's thirty-two channel probe was conducted in November to determine the suitability of the system for measuring the profile of temperatures in a catalyst tube reactor. The thirty-two channel probe contained fiber optic temperature sensors based on the first design described in Subtask 2 above. The sensors tracked the thermocouple reference sensors exceeding well. Although the test did not push the temperature limits defined as the goal of this project, the test did demonstrate the design and all other aspects expected from an industrial instrumentation system. The total system performance was exceptional.

In addition to working directly with instrumentation engineers at Shell Westhollow Technology Center on this and other beta testing projects, Davidson had discussions with ChevronTexaco for a similar cooperative business relationship. In addition, Davidson worked with Gayesco, a specialty temperature measurement instrumentation contractor. Gayesco, Shell, and ChevronTexaco had all agreed to provide cost share funding and technical support throughout the laboratory test and field testing stages of the project, however with the termination of project funding, further laboratory and field testing was not performed.

5.3 Summary

Through September 30, 2002, the program was on schedule and within budget; excellent technical progress had been made across all tasks, and field trials were underway. No significant deviations from the original plan were expected. The project was terminated due to changes in the Congressional Appropriations Bill in GFY 2003.

6.0 Products Developed

None