A Portable Analyzer for Complete Fuel Characterization

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A Portable Raman Instrument for Fuel Characterization

PROBLEM STATEMENT

Since 2002, the United States has been involved in two major war efforts, Afghanistan and Iraq. The most important supply required for sustained warfare is adequate fuel. The magnitude of this requirement is reflected in the fact that every day several hundred fuel trucks leave Kuwait to bring fuel to US forces in Iraq (Washington Post, May 2005)! The responsibility of providing adequate fuel is shared by the military branches. The US Marine Corps is responsible for evaluating captured fuel: "use it or burn it", the US Navy is responsible for supplying additional fuel, while the US Army is responsible for distributing fuel to all US Forces during military operations. Throughout these fuel handling operations, the type and quality of the fuel must be measured and/or verified.

The US Marine Corps has expressed the need for a portable fuel analyzer that can be used to identify fuel type (diesel, gasoline, or jet) and properties (cetane index, octane rating, etc.) in real-time to make decisions regarding captured or host nation fuel. The US Navy has expressed the need for a fuel analyzer to monitor the quality of the fuel being transferred as part of their *Expeditionary Fuel System*. The US Army has expressed the need for a fuel analyzer capable of measuring all critical operational properties to eliminate the numerous analyzers currently being used to measure one or two properties each. In all cases current fuel analyses requires several hours, which can slow military operations, make forces vulnerable to attack, and cost millions of dollars per day. Due to incorrect fuel information, the US Forces had to delay their attack on Baghdad for four days (BBC, March 2003)!

During a Phase II SBIR meeting, which included representatives from the US Air Force, Army, Marine Corps, and Navy, the following fuel parameters were given the highest priority: cetane index, cloud point, density, distillation values, flash point, sulfur content, and viscosity. In response to these requirements, Real-Time Analyzers has developed a *Portable Fuel Analyzer* (the *PFA*) based on Raman spectroscopy that can distinguish gasoline, diesel and jet fuels, and determine these priority fuel parameters, as well as additional important chemical composition and physical properties (see table page 3).

WHO CAN BENEFIT?

In addition to the US Marine Corps, Navy, and Army, the remaining military branches, especially the US Air Force, can benefit from a portable fuel analyzer that provides rapid comprehensive analysis. In the specific case of the US Air Force, accurate determination of the supplied fuel's net heat content and freeze point define the flying range and altitudes that can be used. Fuel analysis on the tarmac can greatly enhance mission performance.

BASELINE TECHNOLOGY

The military currently uses two levels of technology for measuring fuel quality during operations, the Petroleum Test Kit (PTK) and the Tactical Petroleum Laboratory, Medium (TPLM). Although the PTK is easy-to-use, small (briefcase-sized), light-weight (transportable by one soldier), and relatively inexpensive ($4565), it is extremely limited and can ONLY measure fuel density, water and particulate contamination.

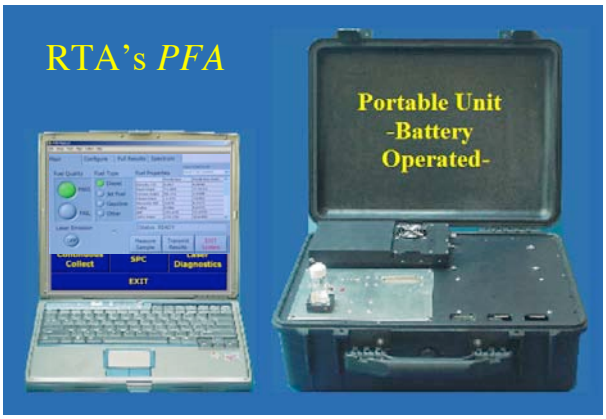
At the other logistics extreme is the TPLM. It is in essence a wet chemical laboratory on wheels, the size of a tractor trailer truck. It requires a power generator, a heating and air conditioning unit and hot and cold water. It can perform 16 standard tests, but this requires in excess of 5 hours, and if the time to transport the sample from the field to the TPLM is taken into account, turnaround is better expressed in days. Consequently, the TPLM is incapable of providing timely analysis and has limited mobility, and costs $245,000.

TECHNOLOGY DESCRIPTION

RTA is developing a *Portable Fuel Analyzer* (the *PFA*) based on Raman spectroscopy that has the portability of the PTK and that performs the comprehensive analysis of the TPLM. It will allow the US Marine Corps to rapidly determine if captured or host nation fuel is usable, it will allow the US Navy to ensure quantity (by type) and quality of delivered fuel, and it will allow the US Army to plan, resource and execute the distribution of imported or host nation fuel.

Real Time Analyzers' "stand-alone" *Portable Fuel Analyzer* is briefcase-sized (30 lb), one-person-portable, battery-operated, and exceptionally easy to use (see figure below). The prototype *PFA* employs a laptop computer for analysis and has the capability of wireless data transmission to forward or rear command, as may be required. The operator places the fuel sample contained in a glass vial onto the sample holder of the PFA, and presses the "Measure Sample" button. In 1 minute, the Raman spectrum is measured and spectral analysis software determines fuel type (gas, diesel, jet), chemical composition and physical properties, including all of the priority fuel parameters and more as shown in the table below.

RTA's Portable Fuel Analyzer.



Properties Determined by the PFA.

Chemical	Physical
acidity	**cetane index**
alcohols	**cloud point**
aromatics	**density**
benzene	**distillation values**
carbon residue	**flash point**
ether	freeze point
olefinics	lubricity
saturates	net heat of combustion
sulfur content	octane rating
	pour point
	viscosity

Critical Properties are **Bold**.

The following table summarizes the features, advantages and benefits provided by the *PFA*, which will cost under $50,000 when it has reached production.

Features, advantages and benefits provided by RTA's *Portable Fuel Analyzer*.

Features	Advantages	Benefits
Raman spectroscopy	Molecular structure	Provides comprehensive chemical analysis
Interferometer	Wavelength stability	Allows calculating physical properties
Point-and-shoot optics	NO sample preparation	1-minute determination of all fuel properties
Small, light-weight, rugged, waterproof	One-person portable, field usable	Allows fuel reconnaissance and distribution. Keeps US Forces moving

CURRENT STATE OF DEVELOPMENT

During the Phase I portion of this program, RTA demonstrated that Raman spectroscopy could be used to identify fuels as diesel, gasoline, or jet, as well as determine some properties, such as octane number and cetane index. During the first year of the Phase II program an industrial-grade Raman analyzer was completely redesigned to reduce its weight and size from 184 pounds and 22 cubic feet to 28 pounds and 1.25 cubic feet, making it extremely portable. During this redesign, a fair amount of ruggedness was built into the *PFA*, and it has successfully been transported and used to make measurements at military facilities three times during this program without any start-up or operational failures or shortcomings, indicating that it has matured to a Technology Readiness Level of 5.

The focus of the second year of the Phase II program has been to develop the spectra-to-fuel property correlations. At the start of the second year, representatives from the US Marine Corps, Navy, Army, and Air Force, selected the following fuel properties as having the highest priority: cetane index, cloud point, density, distillation values, flash point, and viscosity. Correlations have been successfully developed by obtaining 450 fuel samples from around the world, measuring their Raman spectra and developing the necessary software algorithms. (RTA's fuel data base represents a substantial barrier to competitors.)

We demonstrated the capability of the *PFA* by correctly identifying and quantifying the priority fuel properties for a series of unknown samples during Phase II reviews at military facilities (Patuxent River, MD and SAIC, Stafford, VA).

RTA is currently performing the Phase II Option Task (Jan-Jun 2006). During this period, the *PFA* will be independently tested by US Navy, Marine Corps, and Army personnel in their labs. Side-by-side measurements of fuels will be performed using the *PFA* and standard lab instruments. These tests and measurements will validate the performance of the *PFA*, as well as provide important feedback regarding the user interface (e.g. what is the appropriate screen presentations for operating the software and providing the data). Completion of the Phase II Option Task will bring the *PFA* to a TRL of 6, as a working prototype that integrates all of the necessary components will have been proven and validated outside the laboratory.

TECHNOLOGY AVAILABILITY

The next phase of product development after the Phase II Option Task will involve Prototype Shakedown and further Product Engineering. Prototype Shakedown will be accomplished by building two prototypes for military testing. These tests will include further evaluation and validation of the *PFA* in terms of analysis accuracy and precision (quantified measurement error), as well as hardware and software performance. Further product engineering is required to ensure successful operation in the field. Specifically, analyzer ruggedness will be addressed. Many analyzers fail in the field because they lack the ability to handle shock and vibrations, changes in temperature, and mistreatment. RTA's engineers are experts in "ruggedizing" analyzers to withstand such conditions. All

components in the *PFA* are already shock mounted, but two additional levels of shock resistant can be incorporated in the base plate and the case. Implementing these improvements will also eliminate any problems associated with vibration. The source laser and detector, the most temperature sensitive components, are already stabilized such that ambient temperatures have no effect on performance. In the present application, spilling of fuel on the analyzer must be considered. To eliminate this and other potential problems, the lower case of the analyzer, which contains all of the instrument components, will be hermetically sealed. The source laser currently passes through a small window into the sample holder, which holds a glass vial containing the fuel sample (see photograph on page 3). This window and all other openings (e.g. screw holes) can be sealed or in some cases removed. Other planned improvements include integrating a hermetically sealed touch-screen computer or palm pilot into the analyzer, and implementing wireless communication capabilities. RTA plans to transition the *PFA* to TRL 9 in 2.5 years beginning in July 2006, after the Phase II Option Task with financial investment and partnering as summarized in the following table.

Requirements, funding and participants needed to transition the PFA to TRL 9.

TRL	Tests/Engineering	Performance Dates	Funding Required	Performing & Funding Organization
7	Prototype Shakedown	7/2006-6/2007	$0.5 million	MARCOR,NRL,TARDEC
	Analysis			
	Hardware			
	User Software			
7	Product Engineering	7/2006-6/2007	$1 million	
	Ruggedization (shock, temperature, spill resistance)	7/2006-6/2007		RTA & all users*
	Embedded Computer	2007		RTA
	Wireless Communication	2007		RTA & all users
	User Software	2007		RTA & all users
7	Manufacture			RTA
	Military Grade	2008	$1 million	RTA & Prime
8-9	Production – 50 Units	2009	$2.5 million	RTA & Prime
8-9	Production – 50 Units	2010	$2.5 million	RTA & Prime
	Total		$7.5 million	

* all users include MARCOR, NRL, TARDEC (and any others deemed necessary)

The most straightforward form of funding Prototype Shakedown is for MARCOR, NRL, and/or TARDEC to purchase next-version prototypes for testing. These would be built by

RTA and given to the respective fuel laboratories. Dr. Robert Morris of NRL has submitted an internal proposal to buy two instruments for exactly this purpose.

Another important opportunity exists to field test the *PFA* in the near term. The US Army, through the Tank Automotive Research Development and Engineering Center (TARDEC), is currently developing the Petroleum Quality Analysis System (PQAS). The PQAS represents a significantly more mobile TPLM. It consists of a heavy-variant HUM-VEE equipped with a trailer to transport test equipment, supplies and a tent. The equipment includes some, but not all of the TPLM instruments for testing jet and diesel fuels. **The PQAS is a logical initial deployment of RTA's *PFA*.**

REFERENCES

The following personnel have been involved in this program as follows: Mr. Estes has participated in the coordination and review of this program for the US Marine Corps for most of the Phase II program. Dr. Morris has been evaluating the Raman-to-fuel property capabilities of the *PFA* during the past year. CWO Ezell is in charge of fuel analysis training for both the Marines and Army, and has participated in defining the needs that the *PFA* must satisfy. Mr. Hutzler and Mr. Schmitigal have been involved in developing fuel analysis methods and analyzers for the Army. Dr. Morris and Mr. Schmitigal have also supplied numerous samples to aid in the development of the *PFA*.

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ABOUT THE COMPANY

Real-Time Analyzers designs, manufactures and markets patented, low cost, portable, rugged, Raman chemical analyzers for the Department of Defense, Homeland Security and Pharmaceutical Industries. RTA's scientists are world-class experts in the field of Raman spectroscopy and its applications. This includes over 65 years of experience and over 100 published scientific papers. RTA's engineers are experts in the design of chemical analyzers, and have 55 years of experience designing instruments for various manufacturing companies. In its short 5-year history, the US Army, Air Force, Marine Corps, Navy, Missile Defense Agency, DOE, NIH, NSF, USDA, EPA, and NASA have funded the development of chemical analyzers through RTA. RTA is using this funding and its core competencies to develop products for its target markets. Close-to-market products include an anthrax and anthrax hoax material detector and an in-line drug production monitor.