Gonzalez, G. and Lohe, R. (2018). Title of report. (Bureau of Safety and Environmental Enforcement Oil Spill Response Research Project # 1092).

Bureau of Safety and Environmental Enforcement (BSEE) Report: AUTONOMOUS UNDERWATER VEHICLE DEPLOYABLE OIL SPILL IGNITER

Gino Gonzalez and Robert Lohe

BSEE
Bureau of Safety and Environmental Enforcement

AUTONOMOUS UNDERWATER VEHICLE DEPLOYABLE OIL SPILL IGNITER
FINAL REPORT

Final Report
Phoenix Document Number: DOC10024291A

For:
Karen Stone
BUREAU OF SAFETY AND ENVIRONMENTAL ENFORCEMENT (BSEE)
ACQUISITION OPERATIONS BRANCH
45600 Woodland Road, VAE-AMD
Sterling, VA 20166

September 5th, 2018

Gino Gonzalez
Mechanical Engineer
ggonzalez@phnx-international.com

Robert Lohe
Mechanical Engineering Manager
rlohe@phnx-international.com

PHOENIX INTERNATIONAL HOLDINGS, INC.
9301 Largo Drive West
Largo, MD 20774
Phone: 301.341.7800
www.phnx-international.com

TABLE OF REVISIONS

REV. No.	REV. DATE	REV. DESCRIPTION	ISSUED BY	CHECKED BY	APPROVED BY PHOENIX
-	08/03/18	Initial Release	RLL	DP	RLL
A	09/04/18	Data analysis extended	GG	RLL	DP

Executive Summary

In response to Bureau of Safety and Environmental Enforcement (BSEE) request E17PS00024 for Proposed Research on Oil Spill Response Operations on the U.S. Outer Continental Shelf, Topic 1 - Advance Development of Ad-Hoc Igniters, Unmanned Aerial Vehicle (UAV) and Autonomous Underwater Vehicle (AUV) Ignition Systems Phoenix International Holdings, Inc. (Phoenix) has designed and demonstrated an underwater deployable, in-situ igniter system. This novel igniter system has minimized the risk of unpredicted flash fires created by combustible gasses in the atmosphere surrounding the oil spill and enabled a larger margin of safety between the response crew and the potential heat source. Our proposed Small, Portable, Oxygen-driven, Remote, Torch, (SPORT) igniter, has been demonstrated to be adaptable in response to the different requirements outlined in *API Technical Report 1252, Field Operations Guide for In-Situ Burning of On-Water Oil Spills [1]* in regards to a simulated oil spill (using dodecane), the thickness of the spill, and the surrounding environmental conditions (e.g., temperature, winds, and current) among other considerations described in the operational guide.

More specifically the Scope of Work (SOW) outlined in Phoenix's contract and related Work Breakdown Structure (WBS) included:

Design and characterization of the SPORT igniter implementation in a final submersible package.

Characterization of SPORT igniter functionality in a controlled testing environment.

Demonstration test of SPORT igniter ignition of a simulated oil spill.

This SOW minimized developmental risk, by idealizing proven off the shelf components with minimum integration development; this approach enabled detailed but simple management of the effort, risk and funds. It also harvested the best experience gained in the field by previous programs while advancing the technology readiness of past proposed solutions. Our approach combines proven results in a safe, economically feasible and controllable solution to ensure results with minimum risk to human lives and the environment in the execution of an inherently dangerous activity.

This work was performed under contract E17PC00015 issued by BSEE on September 15 2017.

TABLE OF CONTENTS

introduction

Phoenix International Holdings, Inc. (Phoenix) has performed the proposed worked under contract E17PC00015 to design the SPORT igniter in a submersible package, characterize the SPORT igniter in a controlled testing environment and demonstrated the SPORT igniter ignition of a simulated oil spill. The following presents a brief background of the state of the art, introduces the SPORT igniter design, outlines the testing and characterization and presents test results.

Background Research On In-situ Burning of Oil and Existing Technologies

In-situ burning of oil spills has been studied and characterized in several papers and industry guidelines. A few key points are presented here which are applicable to the design and development of the SPORT igniter.

From *Igniters and Ignition Technology for In-situ Burning of Oil Fact Sheet, U.S. National Response Team (NRT) —Science and Technology Committee, October 1995 [3]:*

"To ignite oil on water, an igniter must deliver enough heat to volatilize the hydrocarbons in the oil fast enough to maintain the vapor concentration necessary to support burning. Additional heat energy must then be provided to actually start burning the oil."

"Thus, for successful ignition, a slick must be thick enough to minimize heat dissipation and allow the surface layer near the igniter to heat above its flash point."

"The thickness necessary for ignition depends upon the type of oil and its degree of weathering: fresh, volatile crude requires a minimum thickness of 1 millimeter (mm), whereas aged, non-emulsified crude and diesel fuels require 3 to 5 mm. Other factors affecting the ignitability of oil slicks at sea include wind speed; igniter strength, heat flux, and flame duration; ambient air, oil, and water temperatures; wave action; and degree of emulsification of the oil slick (*Buist, et al., 1994*)."

"Oil can be burned on water without using containment booms if the slick is thick enough (2 to 3 mm) to ignite. For most crude oils, however, this thickness is only maintained for a few hours after the spill occurs. Oil on the open sea rapidly spreads to an equilibrium thickness, which is about 0.01 to 0.1 mm for light crude oils and about 0.05 to 0.5 mm for heavy crudes and residual oils. Such slicks are too thin to ignite and containment is required to concentrate the oil so it is thick enough to ignite and burn efficiently (*Fingas, Merv. [2])*"

"In the design of an ignition system, the rate of energy release must be balanced between two extremes. The igniter must provide enough heat energy for the vaporization and ignition of a slick. An abrupt, explosive release of energy, however, can blast the oil away from the igniter, decreasing the likelihood of ignition. Other considerations for design include safety in operation, storage, and transportation; simplicity of design and use; durability to survive free-falls (for aerial systems) from altitudes of at least 50 to 100 feet (15 to 30 meters); and reliability after long-term storage."

The following four common disadvantages have been determined and identified from evaluations of several previous system implementations of in-situ oil spill burning devices. These are covered *Igniters and Ignition Technology for In-situ Burning of Oil Fact Sheet, U.S. National Response Team (NRT) —Science and Technology Committee*, *October 1995*, *[3]*, and in the *Guidelines for the selection of in-situ burning equipment, Oil Spill Response Joint Industry Project, IPIECA/IOGP 2014, [5]*.

Lack of reliability after long term storage above 5 years, primarily related to solid rocket fuels and ‘thermite” based igniters.

Concerns of crew and personnel safety when manipulating open flames near the oil slick site where ignitable gases and fumes may be present, including floating gel packs with marine flares, fuel impregnated rags and propane torches.

Lack of reliability due to oil slick coating and water immersion.

Relatively high operational cost and limited operability during adverse weather conditions (e.g. Helitorch).

SPORT igniter design

Methodology

The SPORT igniter integrates two complementary ignition systems and the control electronics in a compact module configured to be reliable and effective during in-situ oil burns at sea. Once the igniter is released, activation of the SPORT igniter can be carried out remotely from a safe distance, or preprogrammed activation depending on operational requirements. Due to the low cost of the components of the system, the SPORT igniter is considered a consumable item.

The following section defines the two complementary ignition systems, exothermic rod and O2 as primary and liquid fuel as secondary. The compact SPORT igniter package is presented in Figure 1.

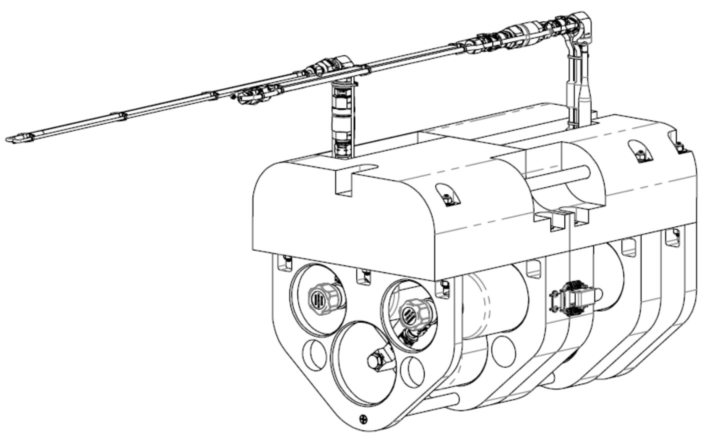

Figure 1: SPORT Igniter

Primary Ignition System

The primary ignition system of SPORT igniter is a high heat flux source to produce an un-extinguishable flux of molten metal and oxygen to ignite vapors and fuel in close vicinity of the igniter at the same time that raises the oil temperature to support burning in cold environments.

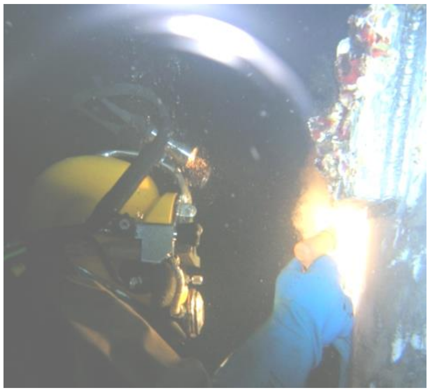

Figure 2: Phoenix Diver Performing Underwater Cutting

This high heat flux source is based on exothermic cutting rods used in underwater salvage and demolition operations. Phoenix has extensive experience using exothermic cutting devices (see Figure 2) which uses an exothermic cutting rod, and pure oxygen to produce temperatures in excess of 5000F.

While burning the exothermic cutting rod is consumed delivering extreme heat flux in the form of melted metal droplets. The burning time of the exothermic cutting rod is controlled by the pressure and flow of the oxygen from a dedicated source or canister. The flow of oxygen is set at a predetermined rate and controlled by an electronic solenoid valve and a back flash arrester to prevent ignition of the oxygen canister. The exothermic cutting rod is ignited by an electronically triggered heater and flame starter to initiate the reaction of the exothermic rod. These devices have been selected for their reliability and known capability of ignition and duration of burning while submerged. Once ignited the exothermic rod is only extinguished by cutting off the flow of oxygen or is completely consumed. All components of the proposed primary ignition system are commercial off-the-shelf components designed for reliability in the adverse environmental conditions expected for in-situ oil spill burning while providing a reliable, cost effective high heat flux source.

Secondary Ignition System

The secondary ignition system is a complementary fuel source to augment the primary ignition system by dispensing a liquid fuel, such as diesel fuel. An electronic spark gap ignition source ignites the liquid fuel. This increases the dispersion combustion area of the igniter in order to increase effective temperature and burning time. The secondary ignition system of the SPORT igniter is composed of canister of liquid fuel pressurized by a combustible gas as a propellant, such as MethylAcetylene-Propadiene Propane, MAPP gas, to deliver the liquid fuel in close proximity to the exothermic torch through a vented tubular dispersing nozzle. When the liquid fuel is completely dispensed the residual volume of combustible gas propellant will continue to burn to keep high temperatures in place for additional heat flux delivery. The flow of liquid fuel is set at a predetermined rate and controlled by an electronic solenoid valve in series with a back flash arrester to prevent ignition of the liquid fuel canister. All components of the secondary ignition system are commercial off-the-shelf components which are readily available and cost effective except the liquid fuel canister.

Control Electronics and Packaging

The operation of the SPORT igniter is controlled by an integral electronic control system comprising an energy source (primary battery), a timing and control circuit for the exothermic rod ignition heater and the control of the primary and secondary ignition system flow valves. The control circuit proposed for the SPORT igniter includes programmable capabilities in order to trigger the SPORT igniter activation from a selection of inputs including but not limited to: acoustic signals, ejection from the payload carrier, remote radio signal, etc. Phoenix used a remote activation module as shown in Figure 3.

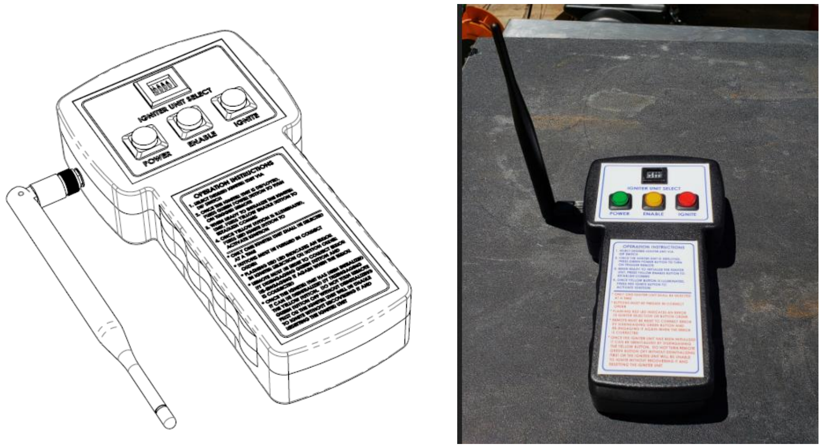

Figure 3: SPORT Igniter Controller

Conceptual Layout

A conceptual layout of the SPORT igniter is shown in Figure 4. The green cylinder is the oxygen canister and primary igniter system.

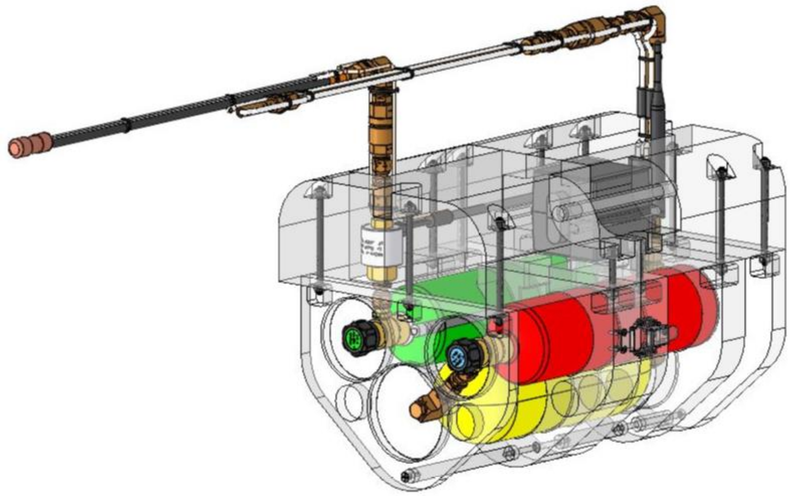

Figure 4: Conceptual Layout of SPORT

The red and yellow cylinders are the combustible gas propellant and liquid fuel associated with the secondary igniter system components. The buoyancy foam/structure members are shown as semi-translucent framing around the cylinders. In a hypothetical scenario when the SPORT igniter is deployed from an underwater payload, the system will float to the surface and remain oriented as shown in Figure 4.

Buoyancy foam provides the proper floatation for the orientation of the exothermic torch with respect to the surface of the oil spill and also provides a mounting structure for the components of the system.

System Interconnection and Operational Ignition Sequence

A block diagram of the SPORT igniter is shown in Figure 5 and guides the narrative of the proposed ignition system:

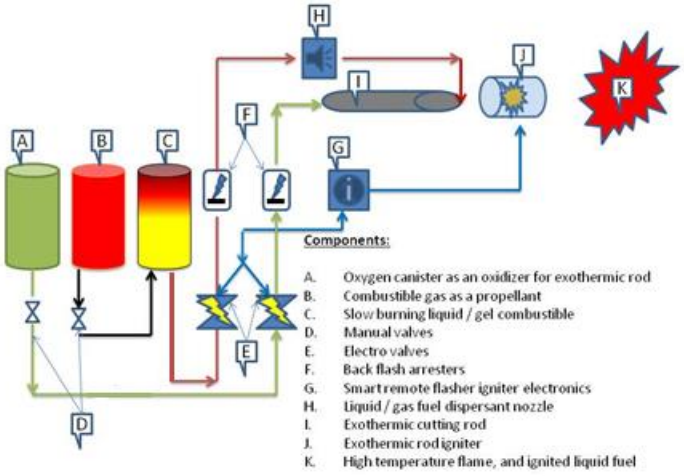

Figure 5: SPORT Functional Diagram

Once deployed into the water, the SPORT igniter rises to the water surface due to inherent buoyancy and floats at the oil slick inside the collecting boom. Once at the desired position the SPORT igniter receives a remote activation signal, triggering the electronic discharge module (G) to activate the exothermic rod starter (J) in front of the exothermic rod (I). This pre-ignites the exothermic rod tip in preparation for oxidation to start.

After a short delay, the electro valve (E) (output of cylinder A) opens, passing a pressurized flow of oxygen through the preheated exothermic rod (I) creating a torch flame with temperatures above 5000 degrees F. The torch flame disintegrates the rod igniter (J). As part of its functionality the exothermic rod (I) will also be consumed at a slower constant rate.

Subsequently the second electro valve (E) (output of cylinder B and C) will be activated enabling the combustible gas (in cylinder B) to act as a propellant for the liquid fuel (inside cylinder C), initiating the second phase of the SPORT ignition. The slow burning liquid fuel mixture dispersed from the nozzle (H) in front of the exothermic rod torch igniting the liquid fuel. The burning liquid fuel disperses on top of the oil slick in contact with water, providing sustained burning time and heat at the air / oil interface. This initiates ignition of the combustible gases and film of the oil slick to enable self sustained oil spill burning.

When the liquid fuel (from cylinder C) has been completely dispensed, the residual combustible propellant gas from cylinder (B) continues to fuel the burn, ensuring a high temperature flame out of the nozzle to keep the surrounding atmosphere at ignition temperature.

Once all liquid fuel (C), propellant gas (B) and oxygen (A) are depleted, the igniter system shuts off and continues to float inside the fire proof boom. At this time the ignition burn is completed, the oil spill is burning and the SPORT igniter can be recovered for disposal or abandoned on site.

testing and characterization

Phoenix has adopted the following guidelines for SPORT igniter field qualification testing parameters as the target requirements. These are as prescribed in the *Field Operations Guide for In-Situ Burning of On-Water Oil Spills ((API) Technical Report 1252 [1])* and the limiting factors discussed in *Oil Spill - Behavior, Response and Planning, Open-water Response Strategies: In-situ Burning*; *[6]*. Table 1 presents the target parameters.

Table 1: SPORT Igniter Test Parameters

Test Parameter	Reference Value	Description
Winds	Less than 18 knots	Testing for ignition and sustained burning in higher wind conditions.
Wave Height	Less than 3meter swells or 1m wind waves	Testing for stability of igniter position and functionality.
Current	0.75 to 1 knot	Towing velocity of the fire boom.
Oil type	Light Medium Dense	To test for ignitability with different types of oil.
Oil Thickness	Greater than 3mm	Test for ignition time and efficiency.
Emulsification	typically less than 25% water content	Will require high heat flux and sustained heating area.
Ice	10% to 20% coverage	Testing for deploy ability and temperature effects on igniter.

During the project the test parameters were reduced due to complications with obtaining the permits required to perform burns on the various oil types and emulsifications. Dodecane as an oil stimulant was substituted and utilized in the demonstration tests.

Four SPORT igniter test units were built and subjected to the following tests/demonstrations which entail increasing levels of detail and characterization.

Characterization and Demonstration Tests:

In order to verify the functionality of the system and verify full compliance to the proposed system specifications for the remote system activation, exothermic reaction delivery system (exothermic cutting rod) and accelerant fuel delivery (liquid and combustible gas) the prototype igniters were subject to an internal engineering qualification test in preparation to the customer acceptance test

The characterization test was performed from June 24, 2018 through the demonstration test on July 10, 2018 at the Phoenix, Largo, MD. Location and included the following objectives:

ENGINEERING VERIFICATION OBJECTIVES

1. Verification of the specifications and capacity assumptions for the components of the igniter.

2. Verification of the functionality of the sub systems including the O2/exothermic rod circuit, the liquid fuel dispensing circuit, and the electronic ignition system independently from each other.

3. Evaluation of the functionality of the remote triggering system and radios.

4. Verification of the full functionality of sub-systems as an integrated system, including the dimensional verification of the assembly and weight and buoyancy estimates.

Customer Acceptance Tests

The Customer acceptance test parameters included the following test scenarios:

Quiescent Test - This is the basic characterization test to determine the baseline performance of the system including duration of the burn. Figure 6 indicates the Dodecane ignition subsequent to exothermic rod and liquid fuel ignition.

Figure 6 Quiescent Test Burn

Ice Test – The ice test provides a 20-30% coverage of ice and lowers the water and simulated crude oil temperature during the test. Three water/dodecane interface temperatures were monitored during this test. Figure 7 shows Dodecane ignition with wind speed of 18 kts.

Figure 7 Ice Coverage Test

Wind Test - The wind test is to determine the igniter operation in wind conditions up to the test parameter speeds, 18 knots. These wind speeds were attained by high velocity blowers. Burn duration and temperatures were recorded. Figure 8 shows Dodecane ignition with wind speed of 18 kts.

Figure 8 Wind Test Ignition at 18 kts

Submersion Test - Ignition tests were performed during and after submergence in the Phoenix outdoor test tank. This test demonstrated the capability of the igniter to perform in a completely submerged environment. Figure 9 shows continued burn with the igniter system submerged. Note the exothermic rod burn continues while underwater and the surface flame is MAPP gas ignited from the igniter, no Dodecane is on the surface of the water during this test.

Figure 9 Submersion Test

Current Test: This test demonstrated the capability of the igniter to perform in a moving water field. Burn duration and temperatures were recorded.

Figure 10 Current Test at 0.5 kts

Wave Test: This test characterizes the ability of the system to ignite and burn in various orientations and motions of simulated wave action. Burn duration and temperatures were recorded.

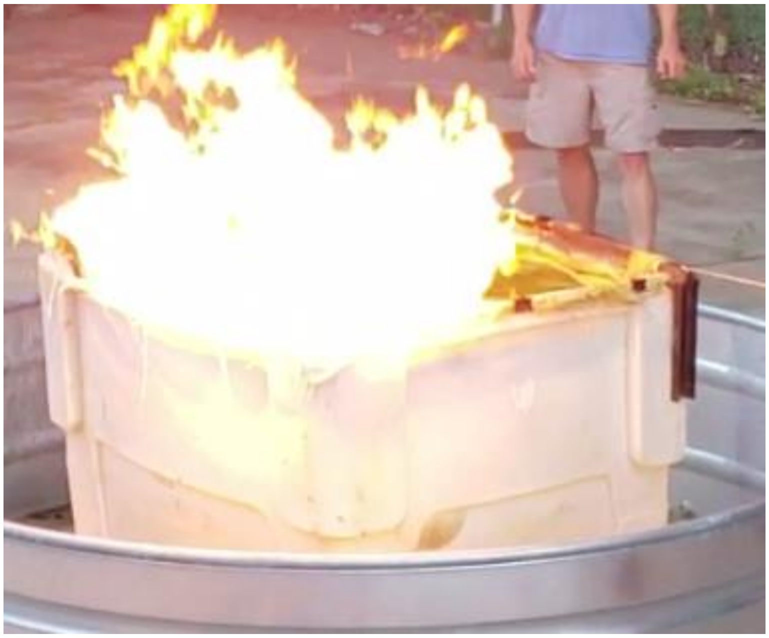

Figure 11 Wave Test with 6 inch waves

Test Results

Engineering Qualification Tests

Completed data collections for the engineering qualification tests are included in the following tables:

Table 2: Dimensional and Fit Compliance

Step	**Description**	**Part Fit and Compatibility Verification (OK)**	**Leak Test , Proper Fit Completion Check**	**Observations**
1	Complete assembly of oxygen system as per drawing 10024664	OK*	OK	* Modification to lower Broco rod assembly, component rearranged , no BOM modification needed
2	Complete assembly of gas/ fuel system as per drawing 10024664	OK*	OK	*New riser nipple shorter installed to lower fuel delivery system, flex copper was also used for directionality.
3	Complete assembly of electrical system as per drawing 10024664	OK	OK	Verification completed with inert test on bench
4	Complete assembly of buoyancy assembly as per drawing 10024796	OK*	OK	*Completed as per documentation, hardware needed to be loose to fit irregular batteries.

Table 3: Oxygen Flow Requirements Ideal Conditions

Step	Description	Oxygen Regulator Open @	Exothermic Rod Ignition Pass / Fail	Burning Time (Second)	Observations, Including Calculated Burning Rate (inches/sec)
1	Test oxygen circuit minimum flow	1/4 Flow	Fail	N/A	No flow at given reg. position
2	Test oxygen circuit medium flow	1/2 Flow	Pass	1':20"	Completed burn and igniter separation
3	Test oxygen circuit above medium flow	3/4 Flow	Pass	1':20"	Same as before
4	Test oxygen circuit maximum flow	Full Flow	Pass	0':59"	Residual O2 continue after rod completion

Table 4: Flow Requirements Ideal Conditions

Step	Description	Gas Regulator Open @	Fuel Dispensing Pass / Fail	Dispensing Time for Full Fuel Delivery (Seconds)	Observations
1	Test fuel circuit minimum flow	1/4 Flow	Fail	n/a	No gas flow
2	Test fuel circuit medium flow	1/2 Flow	Pass	15':07"	Very slow flow of diesel, dripping
3	Test fuel circuit above medium flow	3/4 Flow	Pass	10':30" – 11':20"	Flow is Ok but slow for spray nozzle
4	Test fuel circuit maximum flow	Full Flow	Pass	9':51"	Still slow on full 1lt diesel

Table 5: Electronic Trigger Objectives Verification

<table>
<tr><th>Objective</th><th>Pass</th><th>Fail</th><th>Test Observations</th></tr>
<tr><td rowspan="4">Test functionality of the trigger station</td><td>x</td><td></td><td>- Dip switch functional</td></tr>
<tr><td>x</td><td></td><td>- Green switch enables power</td></tr>
<tr><td>x</td><td></td><td>- Yellow switch enables electrical igniter</td></tr>
<tr><td>x</td><td></td><td>- Red switch activates ignition sequence</td></tr>
<tr><td rowspan="4">Test functionality of the electrical igniter module and verify ignition sequence</td><td colspan="3">The Red switch in the trigger station activates the following sequence in the electrical igniter module:</td></tr>
<tr><td>x</td><td></td><td>- Oxygen valve control enables</td></tr>
<tr><td>x</td><td></td><td>- Spark control enables</td></tr>
<tr><td>x</td><td></td><td>- Timer waits 5 sec</td></tr>
</table>

	x		- Gas valve control enables, Spark Gap activates
Test safe operational distance	x		- Minimum distance 150yrds

Notes:

Trigger Station

The system only works if only one dip switch is selected. If 2 or more dip switches are selected the system won't respond and it will flash the RED led.

The Green switch powers the trigger unit.

The Yellow switch enables the igniter module. Yellow switch will only enable - if the green switch is latched.

The Red switch enables the ignition process. Red switch will only enable - if the green and yellow switches are latched.

If an error in the sequence occurs, the red LED flashes.

To reset the unit and correct the error unlatch the Red, Yellow, and Green switches in that order. Be sure only one igniter unit is selected and press the Green switch to turn the trigger station back on.

To disable the igniter module once it has been enabled (Yellow switch latched), just un-latch the Yellow switch.

When the Green switch and Yellow switch are latched, and the RED switch is pressed on, the system will start the ignition process

Electrical Igniter Module

Once the ignition process starts, wait for the spark gap igniter and then depress the red switch.

The oxygen valve receives 12VDC (1A) and the valve opens.

The oxygen spark and liquid fuel spark are both enabled via 3.7VDC battery.

The electronics is programmed to wait 5 seconds before enabling the gas valve. This time can be modified via software upgrade if required.

The gas valve receives 12VDC (1A) and the valve opens.

The electrical igniter module can only be reset by cutting power off, or by unlatching the red bottom after spark gap activation.

Operational Distance

System tested at 150 yards with direct view as per requirements.

RF link might reach 1000 m according to specs.

Customer Acceptance Test Rehearsal

With one system fully integrated evaluate performance under simulated operational conditions, for functionality assurance; all possible environmental parameters should be simulated in sequential order to identify system limitations. Repeat the process as necessary until all simulated “Pass” conditions are achieved, while documenting the changes to system parameters in the observations column as required.

Table 6: Acceptance Test Pass/Fail Verification

Test #	1	2	3	4
Winds	-	Yes 15 Knots	-	-
Wave Height	-	-	Yes 8” max	-
Current	-	-	-	Yes
Ice	-	-	-	-
Result Pass/Fail	Pass	Pass	Pass	Pass
Measured Burning Time (sec)	2’:36” before voluntary stop	1’:06” before voluntary stop	0’:49” voluntary test stop	1’:05” before voluntary test stop
Observations	Recorded Video: Unit #1 20180705_152801	Recorded Video: Unit #1 20180707_192851	Recorded Video: Unit #1 20180707_200154	Recorded Video: Unit #2 20180708_141352

Engineering Acceptance Test ResulTs and Observations

Oxygen and exothermic rod delivery system:

Primer (igniter test) demo on video IMG0710

Base line result documented on complete circuit assembly and fresh oxygen bottle. Reference video: IMG0712 start 2’:17” ends 3”:15’ reported time: 0’:59” this is with regulator on maximum flow.

Other 3 test with restricted flow were executed

Liquid Fuel delivery system:

Total of 8 tests carried out, 5 of them to verify and set desired theoretical fluid delivery times, and 3 to verify consistency in regulators and electro valve to establish minimum delivery time.

The following results and observations are documented as follows:

Full Flow IMG0699 no nozzle

Full valve on: IMG06

IMG0686: minimum regulator setting on free flow single cylinder system, but not on assembly!

¾ valve on IMG0697 10’:30’

¾ regulators open IMG0691 11’:20”

IMG0696 ¼ valve no flow resulted

IMG0692 restricted flow 15’:00”

Free flowing liquid delivery system as minimum delivery time without flame arrestor or nozzle, no flow restrictions,

Test 1, regulator at maximum flow dispensing time: 0’:35”   reference video IMG072

Test 2 regulator at max flow – ½ turn, dispensing time: 0’:45”   reference video IMG075

Test 3 Regulator at max flow -3/4 turn, dispensing time: 1’:20” reference video IMG074

Test 4 Regulator at max flow -1.25 turn result in no flow, regulators are set from factory to operate from fully open minus ¾ turn. Reference video IMG0703

Observations and results for free flow liquid fuel:

regulator flow regime between min and max is 1 Lt /0’:35” and 1lt/ 1’:20” or about 1lt/ min

Pressure drop on real assembly created by flashback arrestor and dispensing nozzle.

Electronic Integration test:

Current electronics circuit tested on integrated system producing the following observations:

Settings:

Stand by time from activation: 1 second

Oxygen Flow initialized

Igniter for Broco Rod Initiates 0.5 seconds after, duration is 0.5 seconds.

Gas dispensing Circuit Stand By 15 seconds.

Both Spark gap and Valve Open at the same time and remain open.

Upon activation of the second valve (Liquid Circuit) Oxygen valve isolates at once every 3 seconds rate, source for this is unknown but may be related to battery levels.

On a side Note the fluctuation on the oxygen valve increases the dispersion of the molten metal and heat at the tip of the Broco rod.

In summary the capabilities of the SPORT Igniter include:

The times for exothermic rod burn consumption and total igniter duration for the characterization tests and additional engineering tests are tabulated and averaged in Table 7, below reporting the average time for exothermic rod consumption of 1’:16” is total time of the exothermic rod burn. The times recorded for total igniter duration are up to the time the fire is extinguished by application of a fire extinguisher. The last tabulated value of 14’:54” (reference to video

20180710_112944) is for a full duration burn of both the exothermic rod and the MAPP gas/fluid delivery system.

Note that the Dodecane did not ignite in all tests due to residual fire extinguisher material remaining in the test tank. These are recorded in the observations in the results table.

During the customer acceptance test there were a total of eight tests from a combination of the four available units. The total duration of the customer acceptance test was 2.5 hours. During this time period each unit was tested and subsequently refurbished and retested.

Refurbishment included replacement of the exothermic cutting rod and igniter, installation of new oxygen (O2) and MAPP gas cylinders and a limited deck check for functionality of the system.

Table 7: SPORT Burn Duration Test Results

TEST	EXOTHERMIC CONSUMPTION (mm:ss)	TOTAL IGNITER DURATION (mm:ss)	OBSERVATIONS	VIDEO FILE NAME
Customer Acceptance Ice Test (Unit 1)	01:27	03:38	Spark gap intermittent after flames, O2 dispensing evident	20180710_090815
Customer Acceptance Wind Test (Unit 3)	No Data	01:22	18 kts	20180710_093740
Customer Acceptance Wave test #2, (Unit 2) refurbished	01:12	02:12	no dodecane ignition, Significant fire extinguisher residue in tank	20180710_095830
Customer Acceptance Current Test (Unit 3) refurbished	01:31	No Data	Full igniter immersion, reactivates after surfacing	20180710_104000
Customer Acceptance Wave test #3, (Unit 1) refurbished	01:17	01:54	Full igniter cycle, Exothermic rod complete cycle with water immersion, no significant Dodecane ignition, Significant fire extinguisher residue in tank	20180710_105611
Customer Acceptance Wave test #4, (Unit 4)	01:09	01:45	Exothermic rod underwater, fix igniter to tank wall, significant fire extinguisher residue in tank.	20180710_112944
Engineering Quiescent Test (Unit 1)	01:19	02:30	First successful test, dodecane included, Old Exothermic Rod igniter	20180705_152801
Engineering Quiescent Demo (Unit 2)	00:58	14:54	Unit deployed underwater, activated on the surface, double inmersion, No dodecane in the tank for visualization purposes.	20180723_165300
AVERAGE TIME	**01:16**	**04:02**		

Temperature measurements:

At the request of the program POC, Temperature measurements were recorded at the water/dodecane surface at three locations (under the exothermic rod igniter, under the fluid dispenser nozzle and at the igniter foam body) during the ice test performed during the customer acceptance test. The recorded temperatures are presented in Figure 12 with notations for flash point temperatures and times for ignitions.

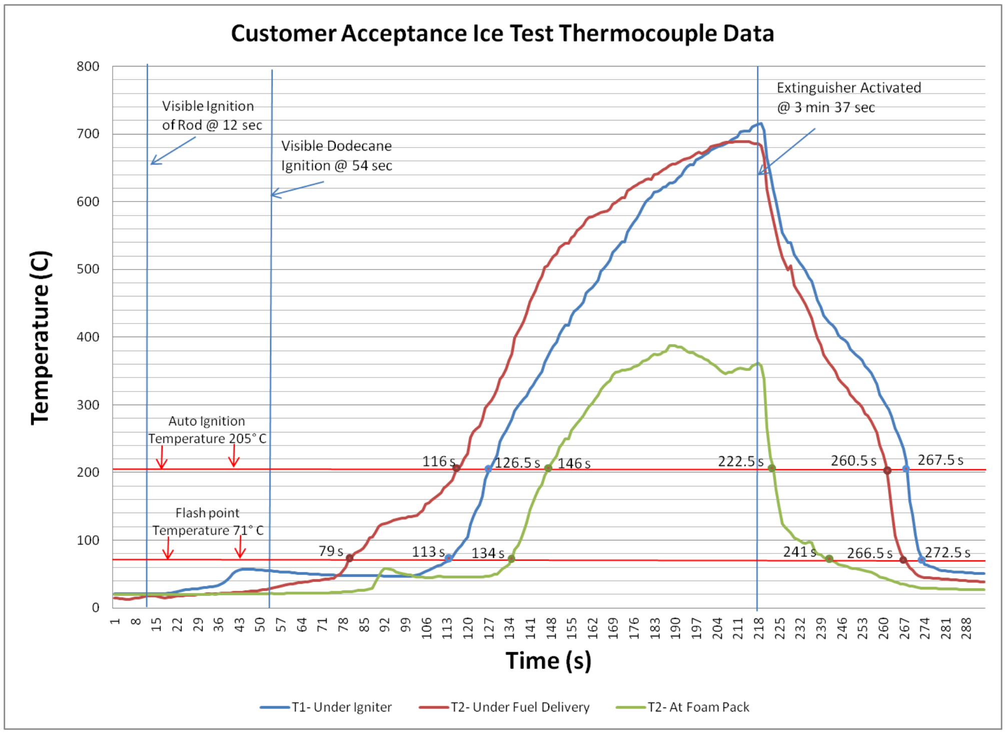

Figure 12: Thermocouple Data from Ice Test Ignition

FUTURE WORK

Based on the test results to date with the prototype systems Phoenix has identified several areas for future work. These include:

Study the feasibility for the implementation of more robust gas and fuel rated valves with the added requirement of being able to function throughout a range of liquid fuels including gelled diesel fuels.

Evaluate additional testing required to characterize and optimize the liquid fuel quantity and composition.

Study and implement the optimization of the exothermic cutting rod ignition timing with respect to the liquid fuel dispensing and ignition.

Perform additional testing in more representative environmental conditions, i.e. wave, wind and temperatures, including ice coverage on a larger scale tank including testing with actual crude oil of various types, emulsifications and weathering.

Evaluate the integration of interchangeable system configurations to combine the exothermic rod channel and the liquid dispersion channel in to a unique "Coaxial high heat" dispensing system, and required changes to include the ability for dispensing gelled fuels.

Evaluate the feasibility and integration to an autonomous underwater vehicle (AUV) payload system and demonstrate the deployment concept in a simulated control scenario

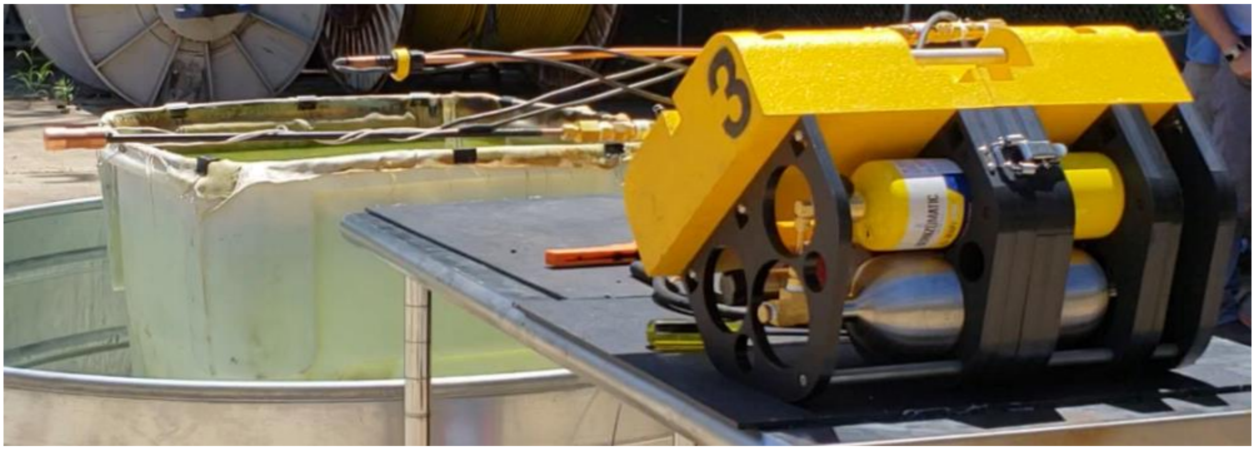

Figure 13: SPORT Unit 3 preparing for burn test

Conclusion

Overall, the test results obtained from prototype development of the SPORT igniter system are encouraging as a reliable and effective method for in-situ oil burns at sea. The SPORT system was able to ignite an oil spill stimulant (dodecane) in various environmental conditions including wind, current, wave and ice. Timely refurbishment (less than 20 minutes) of the systems was also demonstrated during the acceptance test by replacing expended components.

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Figure 14: Phoenix Oil Spill Igniter Development Team