Bureau of Safety and Environmental Enforcement
Oil Spill Preparedness Division
Development of a Restricted Burning Tongue Technique

Final Report

August, 2023

(Photo: Elastec, 2022)

Shon Mosier

US Department of the Interior
Bureau of Safety and Environmental Enforcement
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OSRR # 1134

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US Department of the Interior
Bureau of Safety and Environmental Enforcement
Oil Spill Preparedness Division

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Contracts:

Study concept, oversight, and funding were provided by the US Department of the Interior (DOI), Bureau of Safety and Environmental Enforcement (BSEE), Oil Spill Preparedness Division (OSPD), Sterling, VA, under Contract Number 140E0121P0018. This report has been technically reviewed by BSEE, and it has been approved for publication. The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the opinions or policies of the US Government, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

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Environmental Protection Agency	Analysis of Emissions from Methods to Improve Combustion Efficiency of In Situ Oil Burns –	https://cfpub.epa.gov/si/si_public_search_results.cfm?simpleSearch=0&showCriteria=2&sortBy=pubDate&searchAll=in+situ+oil+burns&TIMSType=&dateBeginPublishedPresented=02%2F22%2F2022

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ABOUT THE COVER

Cover image by Elastec, Inc. from testing that took part at CRREL in Hanover, NH.

GRAPHICAL ABSTRACT

EXECUTIVE SUMMARY

The Bureau of Safety and Environmental Enforcement (BSEE) entered contract with Elastec Inc. to develop a Restricted Burning Tongue Technique. BSEE had a concept for using existing Fire boom technologies but in a different configuration and in combination with a floating gate. The gate was used to restrict the flow of oil from the apex of the Fireboom into the tongue. The concept was also referred to as a wine glass configuration which the apex of the boom is the glass and the tongue is the stem. BSEE had performed lab test that showed the emissions are reduced in this configuration. Elastec was contracted due to their knowledge of burning oil on water and knowledge of Fire boom technologies. Together BSEE and Elastec developed a working prototype of the concept first presented by BSEE. The working prototype consisted of the following: Elastec's American Fire boom, a custom-built stainless steel floating gate, submerged crossmembers to hold the required tongue shape in the boom, a diesel / hydraulic power unit to operate the gate as well as, a manual operating option. Testing began in early October 2022 at Ohmsett in New Jersey where the function of the gate and Fire boom configuration were proven with oil under tow. The next test took place at CRREL in New Hampshire in late October, 2022. Burning of oil in the system was done during this test to show the systems durability and confirm that it would remain functional with several controlled burns. In addition, a Filterbelt Skimmer was used to successfully remove the burn residue from the test proving that if conditions allow and done quickly that the residue left over from a controlled burn can be recovered with the Elastec Filterbelt skimmer.

Department of the Interior (DOI)
The Department of the Interior protects and manages the Nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors the Nation's trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated island communities.

Bureau of Safety and Environmental Enforcement (BSEE) The mission of the Bureau of Safety and Environmental Enforcement works to promote safety, protect the environment, and conserve resources offshore through vigorous regulatory oversight and enforcement.

BSEE Oil Spill Preparedness Program
BSEE administers a robust Oil Spill Preparedness Program through its Oil Spill Preparedness Division (OSPD) to ensure owners and operators of offshore facilities are ready to mitigate and respond to substantial threats of actual oil spills that may result from their activities. The Program draws its mandate and purpose from the Federal Water Pollution Control Act of October 18, 1972, as amended, and the Oil Pollution Act of 1990 (October 18, 1991). It is framed by the regulations in 30 CFR Part 254 – *Oil Spill Response Requirements for Facilities Located Seaward of the Coastline*, and 40 CFR Part 300 – *National Oil and Hazardous Substances Pollution Contingency Plan*. Acknowledging these authorities and their associated responsibilities, BSEE established the program with three primary and interdependent roles:

- Preparedness Verification,
- Oil Spill Response Research, and
- Management of Ohmsett - the National Oil Spill Response Research and Renewable Energy Test Facility.

The research conducted for this Program aims to improve oil spill response and preparedness by advancing the state of the science and the technologies needed for these emergencies. The research supports the Bureau's needs while ensuring the highest level of scientific integrity by adhering to BSEE's peer review protocols. The proposal, selection, research, review, collaboration, production, and dissemination of OSPD's technical reports and studies follows the appropriate requirements and guidance such as the Federal Acquisition Regulation and the Department of Interior's policies on scientific and scholarly conduct.

1. Project Background

In-situ burning (ISB) of crude oil is a highly effective way to remove spilled oil from the environment. However, the dynamic nature of aquatic systems has negative impacts on the efficiency of the ISB event. This study assessed the linear fire boom system developed by Elastec by conducting several ISB tests in a representative environment for what the system would encounter during ocean deployment. The goal was to understand how the setup responds during a burn and identify any necessary improvements prior to an open ocean deployment.

The funding agency for this work is the Bureau of Safety and Environmental Enforcement (BSEE). BSEE was looking to assess Elastec's assembled system in a controlled open water environment at CRREL before deploying the system in an ocean environment.

For this work, the boom assembly was assessed for buoyancy and the ability to collect oil as expected in an open water environment. These test were performed at CRREL's Geophysical Research Facility (GRF) with support staff form the ERB Oil in the Environment Team.

2. Experimental Setup

a. Boom Configuration

Utilizing a combination of Elastec's American Fire Boom (yellow) and a DESMI PyroBoom (gray/orange), Elastec's hydraulic gate system was connected to create a small-scale version of the linear boom configuration tested at OHMSETT in October 2022. The system was installed in the CRREL GRF, shown in the images below.

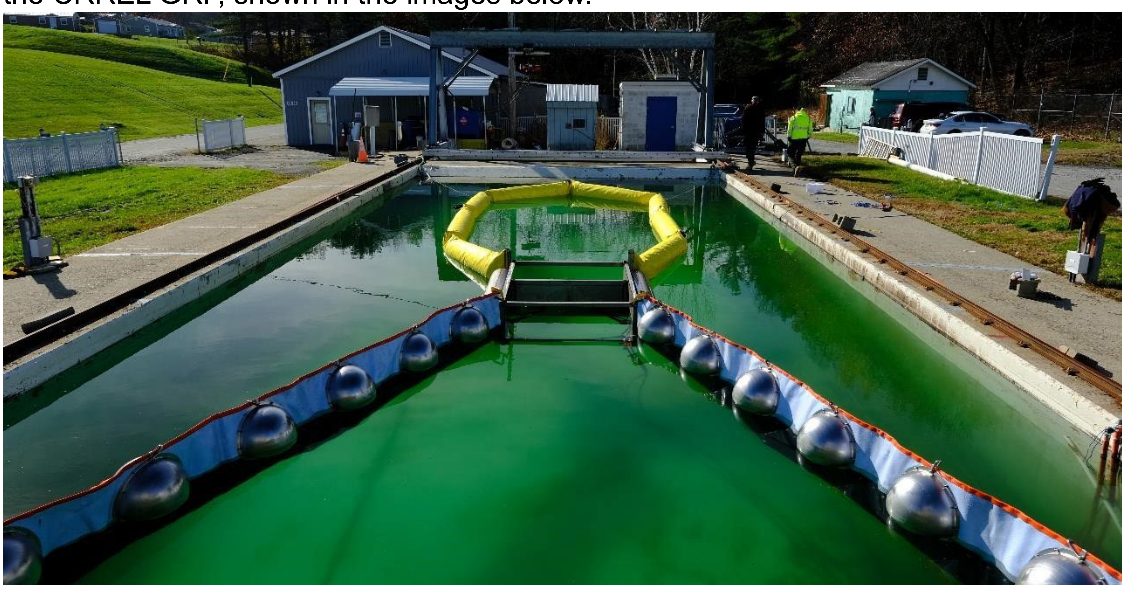

Figure 1: GRF Setup View (South)

Figure 2: GRF Setup View (North)

The containment setup was held in place with chains which were connected anchor to point in each corner of the tank. The water was approximately 7.5 ft deep, with a salinity of approximately 30 ppt. The hydraulic lines for the gate ran underwater from the gate to north edge of the tank, where they connected to the hydraulic power unit.

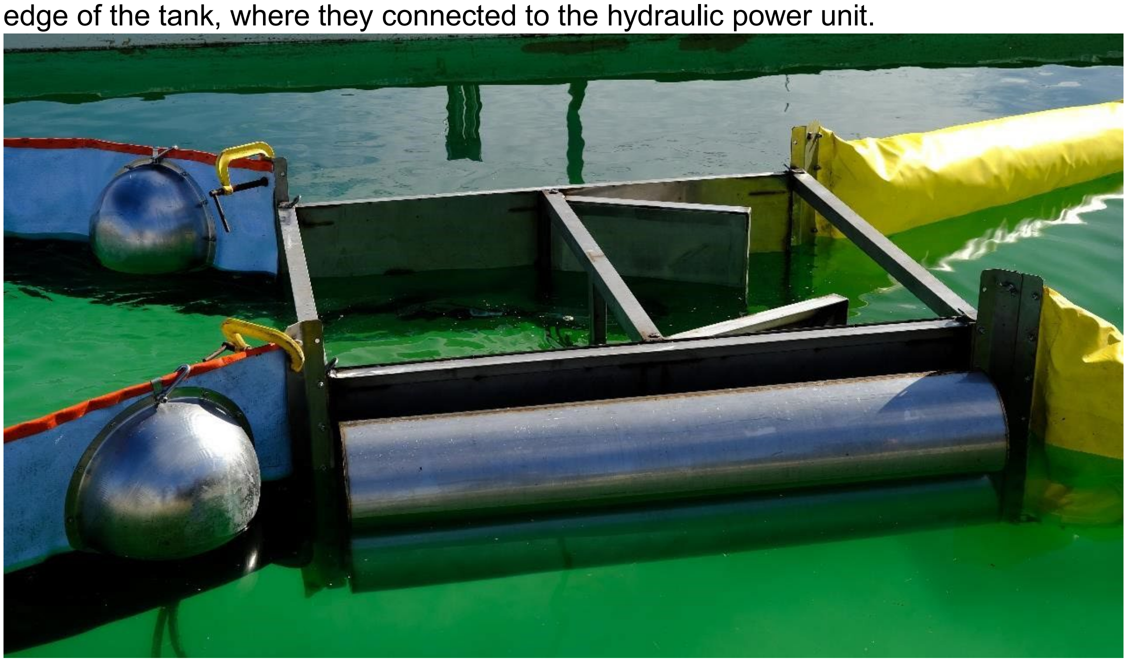

Figure 3: Elastec's Hydraulic Gate

b. Simulated Current

To create a current to simulate towing the system in the ocean, four variable speed Ice Eater propellers were mounted on the roller walkway, positioned at the north end of the tank. The ice eaters could produce current speeds from approximately 0 – 3 knots, but for these tests the simulated speed was 0.75 knots, the typical tow speed for oil collection.

Figure 4: Ice Eater Propellers

As a safety precaution, the ice eater speed could be increased to keep the burning oil in the containment area and away from the structure of the GRF at the North end. Additionally, a deluge system was constructed on the East and West sides of the tank. This was done to pump water over the side of the concrete and back into the tank, which protected the facility from the immense heat of the burns. There were two 60 ft PEX tubes on each side of the tank, with holes every 4 in and a submersible pump on each end (4 total) for the needed pressure.

c. Oil Injection System

To streamline the process for adding oil to the burn area, the CRREL team developed an underwater oil-injection system. This consisted of a tubing stand with a displacement cap at the top that sat approximately 8 in below the water surface, which allowed the oil to be displaced before it reached the surface. At the bottom of the tube a 1 in petroleum hose connected and ran under water to the north side of the tank, where it connected to a 0-56 gpm diaphragm pump. The pump was fed from one of the 330 gal oil totes, which contained fresh Alaska North Slope crude oil. The weight of oil added for each test was monitored via car scales under the oil tote. The flow rate of the pump was controlled with a regulator valve on an air compressor, which was set at approximately 10 gal/min. The injection system was positioned halfway between the propellers and the gate. This allowed for the oil to be introduced safely, so if the oil slick ignited in front of the gate, the supplied oil could only burn once it reached the surface.

Figure 5: Oil Injection Position

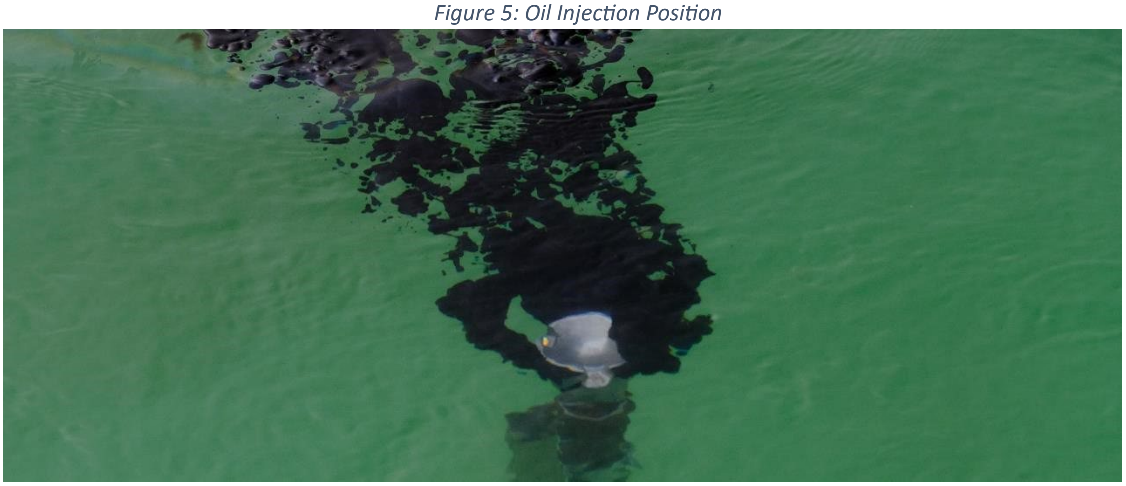

Figure 6: Oil Being Pumped into the Tank

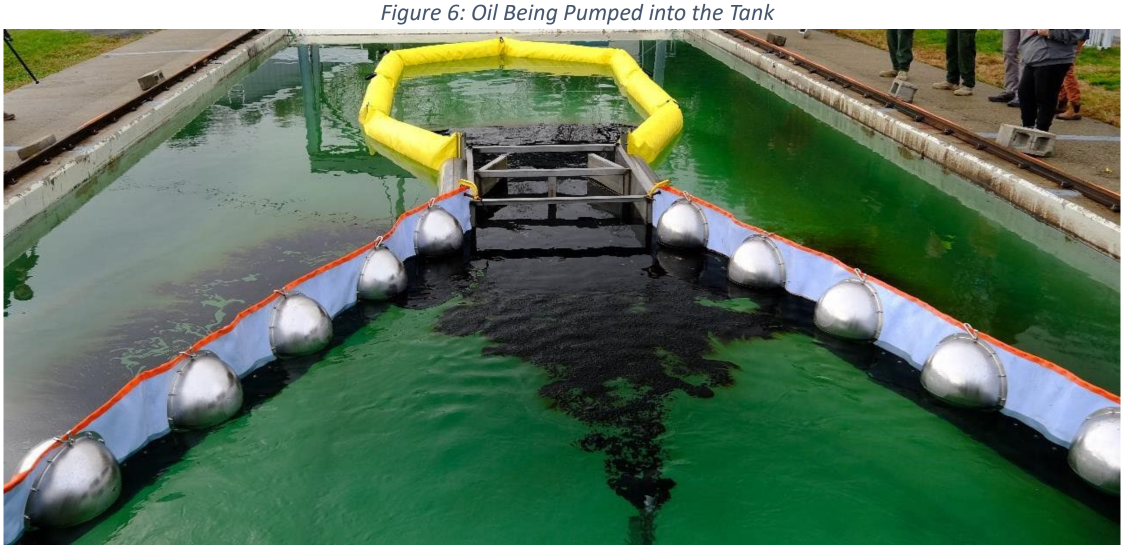

Figure 7: Oil Flowing into Containment Area

Due to some gapping between the Elastec gate and the DESMI PyroBoom, a small amount of oil escaped outside the containment area. However, due to the current circulating, the oil returned to inside of the containment area and was burned.

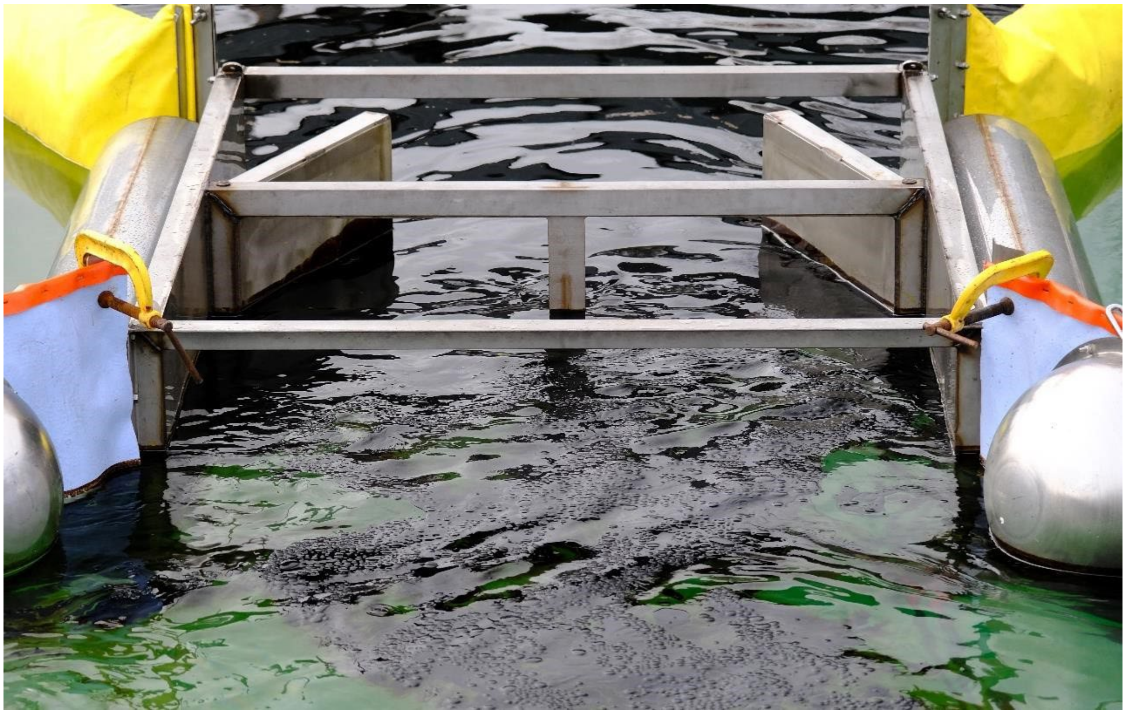

Figure 8: Oil Flowing Through Gate

3. Test Procedure

Six burns were conducted during the test week at CRREL. The step by step procedure is outlined below:

1. Notify Hanover Fire Dept
2. Take initial weight of oil tote and determine target end weight
3. Start ice eater propellers and set to 0.75 knots
4. Start the 4 deluge pumps
5. Start video recording systems (GoPros & Ricoh camera)
6. Open valves, connect air compressor, and begin pumping oil into containment area until target volume has been added (test dependent)
7. Signal for UAS system to take flight
8. Once UAS's are in position, ignite oil slick within containment area using a propane torch
9. Monitor area during burn, turning up speed of ice eaters if necessary
10. Adjust doors on the gate to open or close more, depending on conditions

11. If continuing to add oil during burn; once target volume is reached, stop pumping, disconnect air compressor, and close valves
12. Upon completion of burn, put out any small flames still burning on the fire boom and allow area to cool
13. Weigh out absorbent materials (pad, bags, etc.) for collecting residue
14. Collect burn residue and clean containment area
15. Allow collected residue and absorbent materials dry (overnight) and record final weight

Depending on the configuration of each test, some parts of the procedure were slightly different. The different parameters for each burn are described below.

Burn 1: 160 gal of oil total all at once, gate was then closed, then ignited
Burn 2: 80 gal of oil total all at once, then ignited, gate left open during burn
Burn 3: 80 gal of oil total, 40 gal to start then ignited, then 40 more gal added
Burn 4: 80 gal of oil total, 40 gal to start then ignited, then 40 more gal added
Burn 5: 100 gal of oil total, 40 gal to start then ignited, then 40 more gal added, then 20 more gal added
Burn 6: 140 gal of oil total, 40 gal to start then ignited, then 40 more gal added, then 20 more gal added, then 20 more gal added, then 20 more gal added

4. Results

The following table describes the oil recovery for each of the six burns.

	Pre-Burn Oil Weight	Total # of Trash Bags*	Total # of Absorbent Pads**	Total Mass - Dry (bag, pads, oil)	Total Mass of Oil Recovered	Burn Efficiency
Burn 1	1136 lbs	4	144	117.58 lbs	104.46 lbs	**90.8%**
Burn 2	568 lbs	1	30	36.30 lbs	33.50 lbs	**94.1%**
Burn 3	568 lbs	1	40	32.34 lbs	28.74 lbs	**94.9%**
Burn 4	568 lbs	1	45	39.02 lbs	35.02 lbs	**93.8%**
Burn 5	710 lbs	1	22	31.64 lbs	29.48 lbs	**95.9%**
Burn 6	994 lbs	1	30	31.16 lbs	28.36 lbs	**97.2%**

* Average mass of trash bag = 0.40 lbs
**Average mass of absorbent pad = 0.08 lbs

Figure 9: Burn View from East

Figure 10: Burn View from a Distance

Figure 11: UAS in Smoke Plume

5. Recovery Skimmer

In addition to the absorbent pads for recovering burn residue, one method of recovery tested during this experiment was the Elastec belt skimmer. This was a 14 ft, hydraulic powered system with a removable belt that collected into a tank that could be decanted to remove water. It could be deployed from the side of a vessel, by angling the cantilever out into the burn residue.

Figure 12: Elastec Belt Skimmer

It was noticed that with the high viscosity of the burn residue, once the belt on the skimmer was saturated, it was difficult to scrape the residue from the belt. Since it was so thick, the residue caused the belt to stick to the cantilever arm and the hydraulic power unit was not capable of overcoming the resistance. The belt skimmer was successful in recovering all the burn residue, and just needed to be thoroughly cleaned prior to using again.

Figure 13: Elastec Belt Skimmer with Oil

Analysis of Emissions from Methods to Improve Combustion Efficiency of *In Situ* Oil Burns

Final Report

January 24, 2023

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ABSTRACT

A modified boom system was tested for its ability to improve the combustion efficiency of in situ oil burns at sea. The boom system served to concentrate the skimmed oil to promote combustion. Test trials of oil burns on water were conducted at the US Army Corps of Engineers (ACE) facility in Hanover, New Hampshire. Emission measurements were taken with the Kolibri, a system of gas and particle sensors developed by the US Environmental Protection Agency's Office of Research and Development, attached to an unmanned aircraft system (UAS). The UAS was flown into the plume of the burns to measure gas and particle compositions.

Six in situ oil burns were conducted within a contained boom with length:width aspect ratio of 3:1 using three different initial oil masses per area 25.6, 12.8 and 6.4 kg/m^2. In four of the six tests additional oil was added as the burn progressed to mimic real offshore oil burns where oil is continually collected during the burn. The modified combustion efficiency, MCE_T, ranged from 0.87 to 0.65 (unitless) and emissions of particles of aerodynamic diameter of 2.5 µm, $PM_{2.5}$, ranged from 159 to 629 g/kg initial oil. $PM_{2.5}$ emissions decreased with increased MCE_T. The lowest $PM_{2.5}$ emission factors were emitted when burning 160 gallons of oil all at once (25.6 kg/m^2) and when oil was continuously added to an initial 40 gallons burn (starting at 6.4 kg/m^2, 40+40+20+20+20 gallons, total of 140 gallons,). These lower $PM_{2.5}$ emission factors and corresponding MCEs were similar those found from a previous boom aspect ratio study at the ACE facility using a boom aspect ratio of 1:1. The larger scale used in this study with a burn area of 20.1 m^2 (versus 3.4 m2) and 1136 kg initial oil (versus 31 kg) may be why these two studies had similar results despite different boom aspect ratios. The larger scale used in this current study resulted in similar mass loss percentage (93.8-97.1%) as in the boom aspect ratio study (94.3-99.6%) when the initial oil area density was less than 12.8 kg/m^2.

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TABLE LIST

FIGURE LIST

ACRONYMS

BSEE	Bureau of Safety and Environmental Enforcement
CEMM	Center for Environmental Measurement and Modeling
CO	Carbon monoxide
CO_2	Carbon dioxide
CRREL	Cold Regions Research and Engineering Laboratory
EC	Elemental Carbon
EPA	Environmental Protection Agency
FR	Fast Response
GRF	Geophysical Research Facility
ISB	In-situ burning
MCE	Modified Combustion Efficiency
MOBE	Multi-Partner Research Initiative Offshore Burn Experiments
NDIR	Non-dispersive infrared
NIOSH	National Institute for Occupational Safety and Health
NIST	National Institute of Standards and Technology
NS	Not sampled
OC	Organic Carbon
ORD	Office of Research and Development
OTM	Other Test Method
PEM	Personal Environmental Monitor
PM	Particulate matter
$PM_{2.5}$	Particulate matter, with diameter equal to or less than 2.5 µm
PMI	Personal Modular Impactor
ppm	Parts per million
RH	Relative humidity
SOP	Standard operating procedure
TC	Total Carbon
TOA	Thermal-optical analysis
UAS	Unmanned aircraft system
UDRI	University of Dayton Research Institute

1 INTRODUCTION

In-situ burning (ISB) is the controlled burning of oil spilled from a vessel or pipeline. There were multiple ISB events after the Deepwater Horizon oil spill on April 20, 2010, including 410 ISBs conducted by the Coast Guard [1]. Proponents of ISB suggest that it offers a rapid and simple means of reducing the environmental impact of oil spills. During ISBs, the majority of spilled oil is converted to gaseous combustion products. ISB emits a black plume composed of 80-84% by weight carbon dioxide (CO_2) and water; the remaining components are other gases and soot particles. One of the main concerns with ISB is the trace gas constituents and particulate matter (PM) in the smoke plume. Measuring smoke/combustion emission is crucial to quantify the potential release of air toxics, PM, and other pollutants.

The Department of Interior, Bureau of Safety and Environmental Enforcement (BSEE), the project sponsor, is pursuing a line of research to conduct full-scale tests of modified boom configurations in the Canadian Multi-Partner Research Initiative Offshore Burn Experiments (MOBE) planned for the summer of 2023. This current effort reported here intends to determine if alternate boom geometries will result in a reduction of particulate matter (PM) and trace pollutants in the plume and reduced amounts of burn residue. Lessons learned from this current effort are intended to be applied to the MOBE effort.

The US Environmental Protection Agency's Office of Research and Development (ORD) deployed its lightweight emission sampling/sensor system, the "Kolibri," on an unmanned aircraft system (UAS) for particle and gas measurements in the ISB plume. Among other measurements, the Kolibri is comprised of sensors for CO_2 and carbon monoxide (CO), both critical measurements for determination of emission factors, as well as lightweight systems for batch and online sampling of $PM_{2.5.}$

This effort measured emissions from a five-day campaign of oil burns on water at the U.S. Army Corps of Engineers, Cold Regions Research Engineering Laboratory (CRREL). The objective of this study was to evaluate the relationship between emissions and burn efficiency from ISB of crude oil on water using a new boom technique called the "burning tongue" that aims to improve burn efficiencies (Figure 1-1). The name is derived from the physical configuration of the boom which is deployed to corral and concentrate the oil into a narrow ("tongue") section for ignition. The study also derived emission factors from the in-situ oil burns.

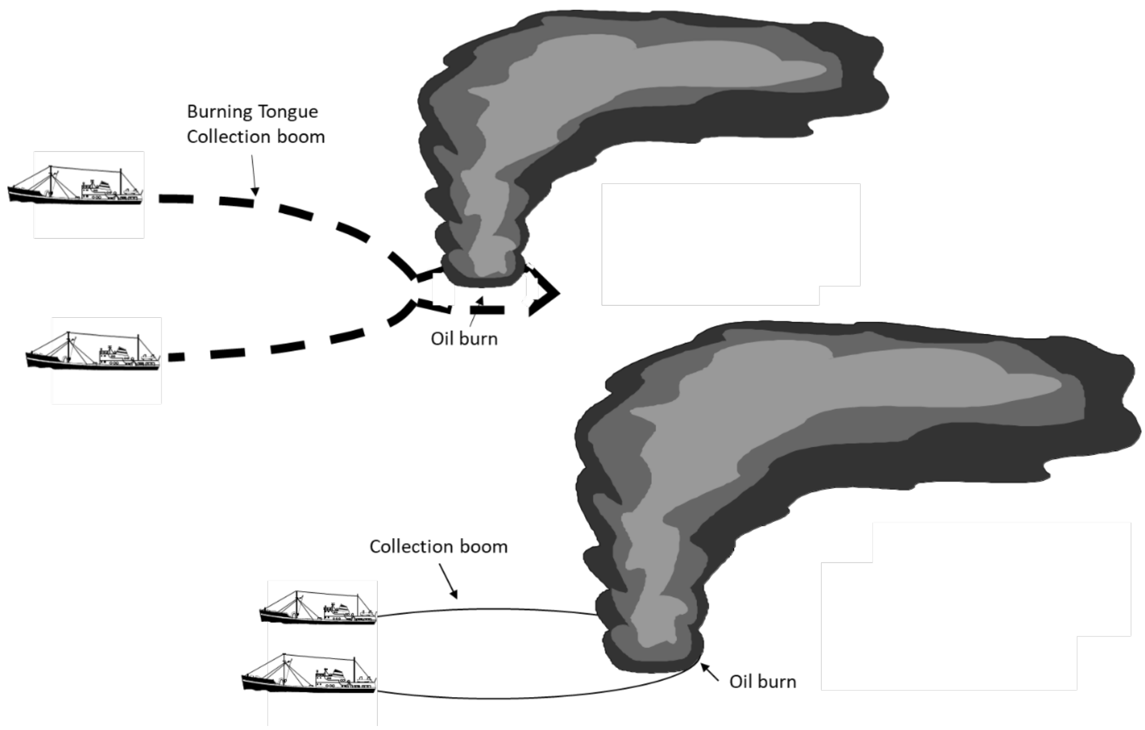

Figure 1-1. Schematic of the new burning tongue collection boom (top) and standard boom (bottom). Not to scale.

2 MATERIALS AND METHODS

2.1 Test Location

Testing took place at the CRREL facility located in Hanover, New Hampshire. The facility used for the testing was CRREL's Geophysical Research Facility (GRF) water-filled, in-ground tank shown in Figure 2-1.

Figure 2-1. Geophysical Research Facility at CRREL - 20m x 6.7m x 2.1m; water-filled tank.

2.2 Test Set-Up

The boom in the GRF tank was assembled to simulate the narrow part of the burning tongue boom configuration (Figure 2-2). The narrow tongue part of the boom was 30 feet (9.1 m) long and 10 feet (3.05 m) wide boom with a boom ratio of 3:1 and a burn area of 217 ft^2 (20.14 m^2). A hydraulic gate was configured between the wide and narrow part of the boom to control the amount of oil released into the tongue. The GRF tank was equipped with propellers to generate a 0.75 knot current simulating an actual towed boom used for oil spilled at sea. The crude oil (Alaska North Slope) was introduced into the GRF through an underwater oil-injection system developed by CRREL at a speed of approximately 10 gal/min. The boom setup, pre- and postburn is shown in Figure 2-3. For each burn test, members of CRREL handled the oil injection, ignition, and post-burn residue collection.

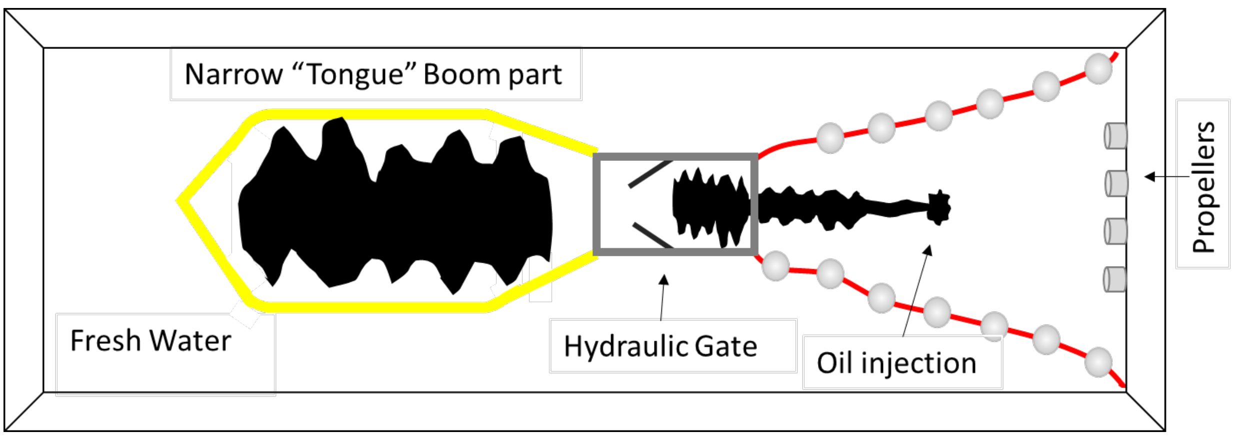

Figure 2-2. Schematic of GRF tank from above (not to scale).

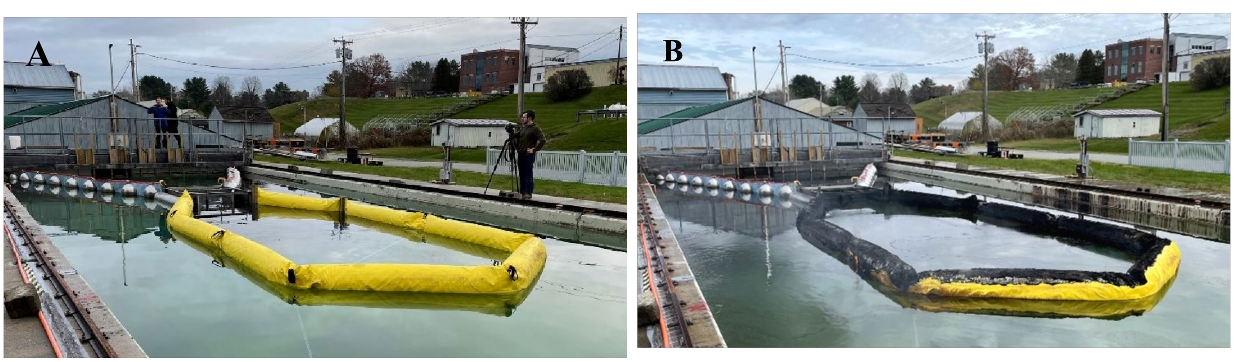

Figure 2-3. Boom configuration A) before and B) after test burn 1.

2.3 Test Matrix

Four different test scenarios were studied using the same boom configuration in each test. Two baseline tests were conducted with two different initial oil amounts (160 and 80 gallons). Three other scenarios were studied with the same start amount of initial oil (40 gallons) but varying the number of times and amount of oil was added to the ongoing burn to mimic the reality of offshore burning (Table 2-1). The initial start mass oil per area was different for two first burns (25.6 and 12.8 kg/m^2) compared to the other four burns (6.4 kg/m^2 each) (Table 2-1).

The added oil was added continuously with the hydraulic gate open when the initial oil or when first or second additional oil had burned for approximately 4 min.

Table 2-1. Test Matrix.

Burn Number	Date	Test Condition	Oil gallons	Mass Total initial oil lbs (kg)	Initial mass start oil per area kg oil/m^2
1	11/01/2022	Baseline – initial oil	160	1136 (515)	25.6
2	11/01/2022	Baseline – initial oil	80	568 (258)	12.8
3	11/02/2022	Oil added during burn once	40+40	568 (258)	6.4
4	11/02/2022	Oil added during burn once	40+40	568 (258)	6.4
5	11/02/2022	Oil added during burn twice	40+40+20	710 (322)	6.4
6	11/03/2022	Oil added during burn three times	40+40+20+20+20	994 (451)	6.4

2.4 Sampling Approach

ORD's small, light-weight emission sampling package termed the "Kolibri" was used for the aerial emission sampling, Figure 2-4. Aerial sampling was conducted by a UAS carrying the Kolibri at a height of less than 400 feet above ground level. The main sampling platform for this study was the UAS Alta X Freefly and the backup UAS was the Aurelia X8.

Figure 2-4. U.S. EPA's Kolibri emission instrument system mounted on the undercarriage of the UAS Aurelia X8.

2.5 Target Emission Compounds

Target compounds include carbon monoxide (CO), carbon dioxide (CO_2), particulate matter of 2.5 µm aerodynamic diameter ($PM_{2.5}$), elemental/organic carbon (EC/OC), and total carbon (TC). Targeted emissions and their sampling methods are listed in Table 2-2. The number of batch samples collected for each test configuration is shown in Table 2-3.

Table 2-2. Oil Burn Emission Targets

Analyte	Instrument/Method	Frequency
CO_2	K30 FR, NDIR	Continuous
CO	E2V EC4-500-CO, Electrochemical cell	Continuous
$PM_{2.5}$	PEM Impactor, Teflon filter, gravimetric	Batch
EC/OC/TC	PMI impactor, Quartz filter, thermal-optical	Batch

Table 2-3. Number of Batch Samples Collected in Each Test Configuration.

Burn #	Test Condition	$PM_{2.5}$	TC/OC/EC
1	Baseline	2	2
2	Baseline	2	2
3	Oil added during burn once	1	1
4	Oil added during burn once	1	1
5	Oil added during burn twice	1	1
6	Oil added during burn three times	2	2

2.6 Calculations

2.6.1 Emission Factors in mass analyte per mass initial oil

Measurements were used to determine emission factors based on the carbon balance method, which uses the ratio of the sampled pollutant mass to the sampled carbon mass (determined from $CO + CO_2$ measurements and, where possible, TC from $PM_{2.5}$ analyses) and the carbon percentage of the fuel (85%). The resultant emission factors are expressed as mass of pollutant per mass of oil burned (Equation 1).

$$Emission\ Factor_{initial} = Fc \times \frac{Analyte_{ij}}{C_j} \qquad \textit{Equation 1}$$

Where:

$EF_{initial}$ = The Emission Factor for target analyte i (mg $Analyte_i$/kg oil initial)
Fc = Carbon fraction in the oil (0.85)
$Analyte_{ij}$ = background-corrected concentration (mg $Analyte_i/m^3$) of the target analyte i collected from the volume element j of the plume.
C_j = background-corrected concentration of carbon (kg $Carbon/m^3$) collected from volume element j of the plume

2.6.2 Emission Factors in mass analyte per mass oil consumed

An alternative emission factor was calculated taking the oil not consumed into consideration as shown in Equation 2.

$$Emission\ Factor_{Consumed} = EF_{initial} \times \frac{mass\ oil}{mass\ oil \times oil\ mass\ loss} \qquad \textit{Equation 2}$$

Where:

$Emission\ Factor_{consumed}$ = The Emission Factor for target analyte i (mg $Analyte_i$/kg oil consumed)
$EF_{initial}$ = The Emission Factor for target analyte i (mg $Analyte_i$/kg oil initial)
mass oil = mass of oil initial
oil mass loss = fraction of oil consumed in the burn

2.6.3 Modified Combustion Efficiency

The Modified Combustion Efficiency (MCE) was used to calculate how well the oil burned.

$$MCE_T = \frac{CO_2}{CO_2 + CO + Total\ Carbon} \qquad \textit{Equation 3}$$

$$MCE_G = \frac{CO_2}{CO_2 + CO} \qquad \textit{Equation 4}$$

Where:

MCE_T = modified combustion efficiency gas + particulate phase
MCE_G = modified combustion efficiency gas phase
CO_2 = carbon dioxide in the plume in ppm
CO = carbon monoxide in the plume in ppm
Total Carbon = total carbon in the particulates (TC)

4 MEASUREMENT AND QUALITY ASSURANCE PROCEDURES

4.1 CO_2 measurements

The Kolibri system uses a CO_2 Engine® K30 Fast Response (FR) (SenseAir, Delsbo, Sweden) to measure CO_2 concentration by means of non-dispersive infrared absorption (NDIR). Sensor output voltage is linear from 0 to approximately 7900 ppmv. The response time (t_{95}) is less than 10 seconds and measurement is accurate within 5% error. The sensor can operate at temperature ranges -10-40ºC and RH 0-95%. In the field, a particulate filter will precede the sensor's optical lens and CO_2 background samples was taken daily prior to sampling. The CO_2 Engine® K30 FR was calibrated for CO_2 on a daily basis in accordance with EPA OTM-48 [2]. All gas cylinders used for calibration were certified by the suppliers that they are traceable to NIST standards. Data were recorded on a USB-based microcontroller board using an Arduino-generated data program.

The daily CO_2 system was less than 2% for each of the calibration gases which is within the ±5% acceptance criteria of the sensor (Table 3-1).

Table 3-1. CO_2 System drift.

Calibration gas concentration	11-01-2022	11-02-2022	11-03-2022
408 ppm	1.98%	0.09%	0.93%
1534 ppm	1.02%	0.15%	0.80%
1986 ppm	0.84%	0.25%	1.15%

4.2 CO measurements

The CO sensor (e2V EC4-500-CO) was an electrochemical gas sensor (SGX Sensortech, Essex, United Kingdom) which measures CO concentration by means of an electrochemical cell through CO oxidation and changing impedance. The E2v CO sensor has a CO detection range of 1-500 ppm with resolution of 1 ppm. The temperature and relative humidity (RH) operating range was -20 to +50°C and 15 to 90% RH, respectively. The response time is less than 30 seconds. Output is non-linear from 0 to 500 ppm. The sensor was calibrated for CO on a daily basis in accordance with EPA OTM-48 [2]. All gas cylinders used for calibration were certified by the suppliers that they are traceable to NIST standards. Data were recorded on a USB-based microcontroller board using an Arduinogenerated data program.

The daily CO system drift was less than 4.5% which is within the ±5% acceptance criteria of the sensor, with the exception for 11-03-2022 at 100 ppm with drift of 5.67% (Table 3-2). This drift had minimal impact on the results as the measured CO concentration in the plume was less than 22 ppm.

Table 3-2. CO System drift.

Calibration gas concentration	11-01-2022	11-02-2022	11-03-2022
0 ppm	0.03*	0.07*	0.020*
20 ppm	1.28%	0.51%	4.19%
100 ppm	0.65%	1.33%	5.67%

* Absolute difference in ppm, which is within the noise level of the sensor.

4.3 $PM_{2.5}$

The Kolibri sampled $PM_{2.5}$ with SKC Personal Environmental Monitor (PEM) impactors (SKC Inc., PA USA) using 37 mm tared Teflon® filter with a pore size of 2.0 µm via a constant micro air pump (C120CNSN, Sensidyne, LP, St. Petersburg, FL, USA) of 10 L/min. Particles larger than 2.5 µm in the $PM_{2.5}$ impactor was collected on an oiled impaction disc mounted on the top of the filter cassette. The sample pump was calibrated with a Gilibrator Air Flow Calibration System (Sensidyne LP, USA). The Teflon filters were pre- and post-weigh according to 40 CFR Part 50 Appendix J and L [3, 4].

4.4 Total Carbon, Elemental Carbon, Organic Carbon

OC/EC/TC was sampled with a SKC $PM_{2.5}$ personal modular impactor (PMI) using 37 mm quartz filter via a constant micro air pump (C120CNSN, Sensidyne, LP, St. Petersburg, FL, USA) of 3 L/min. Particles larger than 2.5 µm in the $PM_{2.5}$ impactor was collected on an oiled 25 mm impaction disc mounted on the top of the filter cassette. The sample pump was calibrated with a Gilibrator Air Flow Calibration System (Sensidyne LP, USA). The OC/EC/TC was analyzed via a modified thermal-optical analysis (TOA) using NIOSH Method 5040 [5] and Khan et al. [6].

5 RESULTS

5.1 Oil Residue

The mass loss in Table 4-1 was derived by CRREL and used in this report to calculate the emission factor in mass pollutant per mass consumed oil, see Equation 2 in Chapter 2.6.2. The largest mass loss percentage (97.1%) was found when initial start mass oil per area was 6.4 kg/m^2 and oil was added four times (Burn 6, Figure 4-1). The lowest mass loss percentage (90.8%) occurred when the initial start mass oil per area was the highest, 25.6 kg/m^2, and all oil was burned at once (Burn 1, Figure 4-1). These data can be compared to the previous boom ratio study with mass losses of 94.3, 97.1 and 99.6% with boom ratios 1:1, 4:1 and 9:1, respectively with an initial oil mass per area of 9.3 kg/m^2 [7].

Table 4-1. Oil residue in each test.

Burn Number	Test Condition	Initial Oil gallons	Mass Total initial[a] oil (kg)	Residue[a] (kg)	Mass loss (%)	Burn Time (min:sec)
1	Baseline – initial oil	160	515	104.5	90.8	10:00
2	Baseline – initial oil	80	258	33.5	94.1	5:45
3	Oil added during burn	40+40	258	28.7	94.9	12:12
4	Oil added during burn	40+40	258	35.0	93.8	11:40
5	Oil added during burn	40+40+20	322	29.5	95.8	9:30
6	Oil added during burn	40+40+20+20+20	451	28.4	97.1	

[a] Measured from collected oil residue by CRREL.

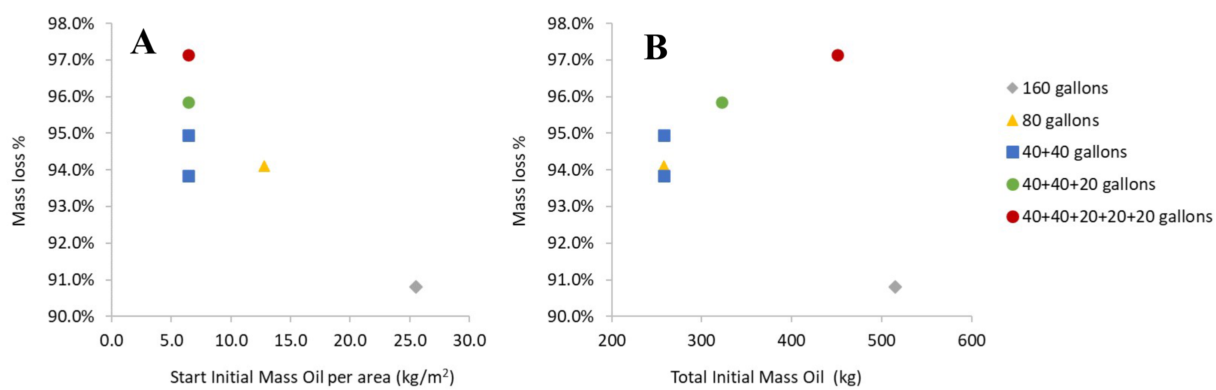

Figure 4-1. Mass loss versus A) mass start oil per area and B) total initial mass oil.

5.2 Combustion Gases

The MCE_T ranged from 0.653 to 0.870 (Table 4-2) where the higher MCE_T was similar to those found from oil burns using a boom ratio of 1:1 (0.864) [7].

Table 4-2. CO and CO_2 emission factors and MCE from each of the test configurations.

Burn No.	Test Condition	CO_2 g/kg oil initial	CO g/kg oil initial	CO_2 g/kg oil consumed	CO g/kg oil consumed	MCE_G	MCE_T
1	160 gallons	2648	40	2916	45	0.967	0.866
2	80 gallons	2678	57	2419	51	0.945	0.730
3	40+40 gallons	2351	21	2476	22	0.987	0.774
4	40+40 gallons	2398	53	2556	57	0.966	0.778
5	40+40+20 gallons	2012	56	2099	59	0.961	0.653
6	40+40+20+20+20 gallons	2598	49	2674	51	0.977	0.870

5.3 Oil Consumption and Modified Combustion Efficiency

Figure 4-2 shows the MCE_T versus mass loss. No trends or correlations were found between the oil consumption and MCE_T.

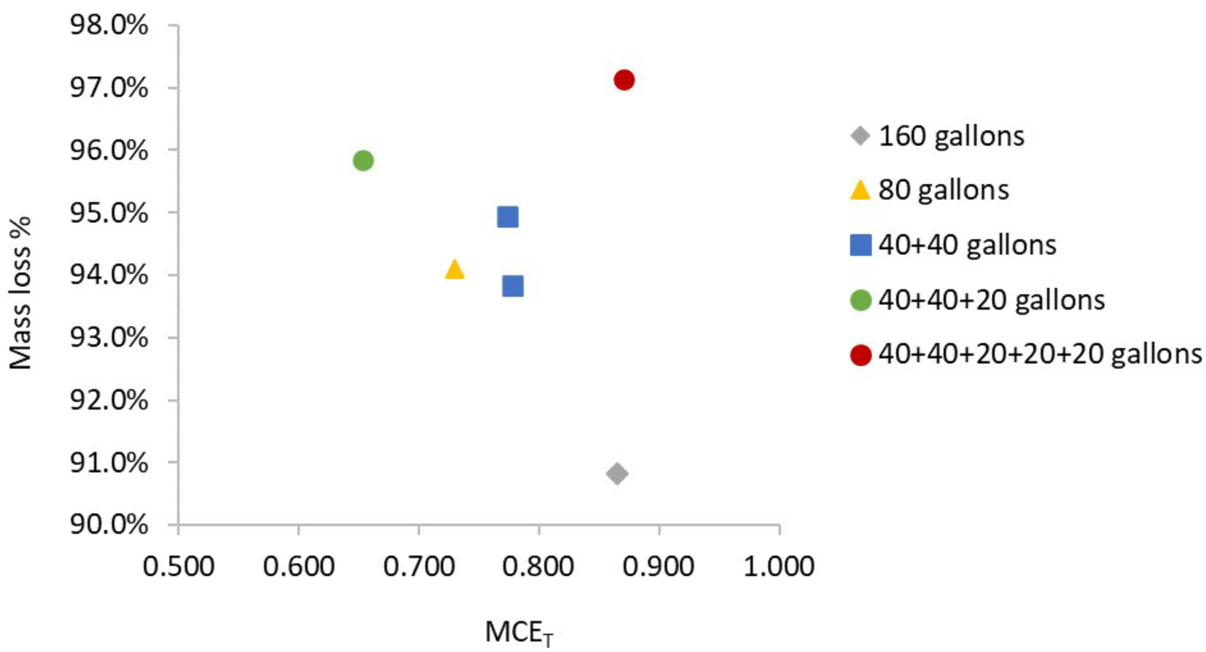

Figure 4-2. Modified combustion efficiency versus mass loss.

5.4 $PM_{2.5}$

The $PM_{2.5}$ emissions were found to decrease with increased combustion efficiency (Figure 4-3), consistent with previous results [7]. The lowest emission factors were emitted when burning 160 gallons of oil all at once and when burning 140 gallons of oil continuously added. These $PM_{2.5}$ emission factors were in similar range to those emitted from oil burns using a boom ratio of 1:1 conducted in November 2018 [7] as shown in Figure 4-4.

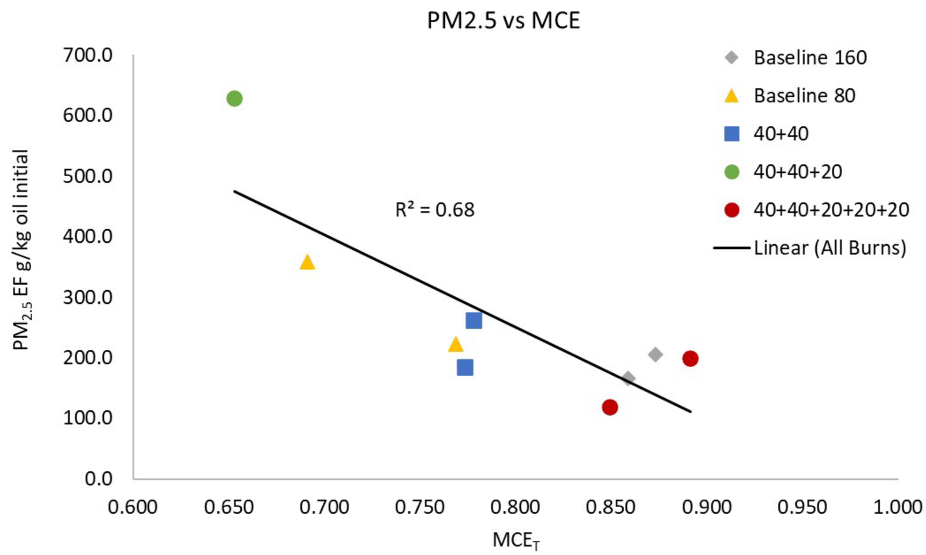

Figure 4-3. Modified combustion efficiency versus $PM_{2.5}$. Two $PM_{2.5}$ samples collected from some test configurations.

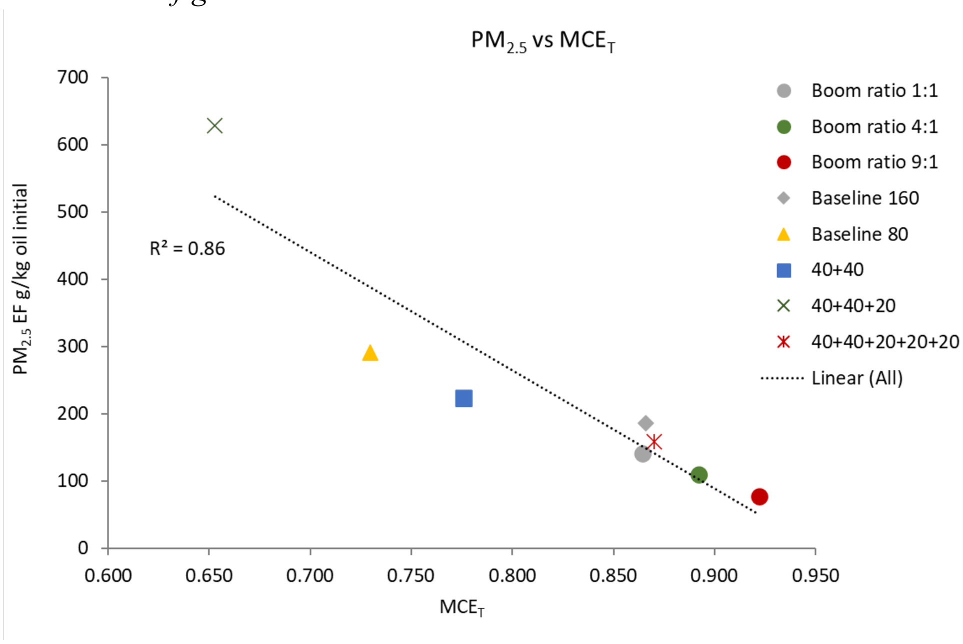

Figure 4-4. $PM_{2.5}$ emission factors versus modified combustion efficiency from this study and a previous study using different boom ratios Aurell et al., 2021 [7].

No apparent trend was found between $PM_{2.5}$ emissions and Oil Mass Loss (Figure 4-5), which is in agreement with the previous boom aspect ratio study conducted in November 2018 that did not see any trends between PM emissions and Oil Mass Loss [7]. Emission factors from each test configuration are shown in Table 4-3.

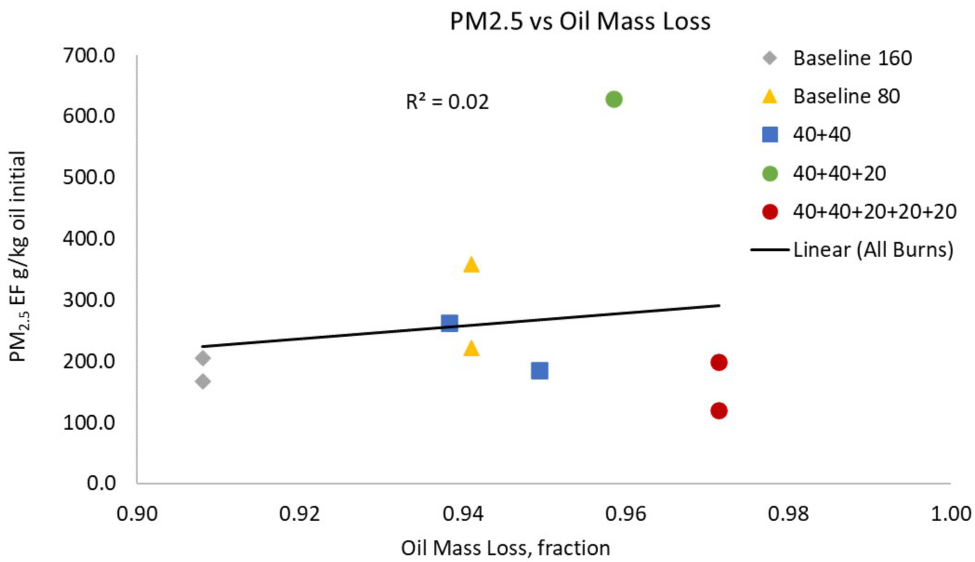

Figure 4-5. Oil mass loss versus $PM_{2.5}$.

Table 4-3. $PM_{2.5}$ emission factors from each test configuration.

Burn No.	Test Condition	$PM_{2.5}$ g/kg oil initial	$PM_{2.5}$ g/kg oil consumed	MCE_T	MCE_G
1	160 gallons	186.1	204.9	0.866	0.967
2	80 gallons	290.7	308.9	0.730	0.945
3	40+40 gallons	185.5	195.4	0.774	0.989
4	40+40 gallons	262.3	279.5	0.778	0.958
5	40+40+20 gallons	628.9	656.2	0.653	0.851
6	40+40+20+20+20 gallons	159.1	163.8	0.870	0.977

5.5 Total Carbon, Elemental Carbon and Organic Carbon

The TC/EC/OC emission factors are shown in Table 4-4. On average, 81% of the PM mass was carbon, of which 74% was elemental carbon.

Table 4-4. Total carbon, elemental carbon, and organic carbon emission factors.

Burn No.	Test Condition	OC	EC	TC	OC	EC	TC
		g/kg oil initial			g/kg oil consumed		
1	160 gallons	10.2	96.6	106.8	11.2	106.4	117.6
2	80 gallons	130.7	154.8	285.5	138.9	164.5	303.4
3	40+40 gallons	139.4	97.4	236.8	146.8	102.6	249.4
4	40+40 gallons	40.9	164.1	205.0	43.6	174.8	218.5
5	40+40+20 gallons	138.6	299.1	436.9	144.6	312.0	455.9
6	40+40+20+20+20 gallons	12.6	85.4	98.1	13.0	88.0	101.0

6 CONCLUSIONS

Six in situ oil burns were conducted using a boom ratio of 3:1 using three different initial oil masses per area 25.6, 12.8 and 6.4 kg/m^2. In four of the six tests additional oil was added as the burn progressed in order to mimic real offshore oil burns with continual oil collection. The MCE_T and $PM_{2.5}$ emissions ranged from 0.87 to 0.65 and 159 to 629 g/kg initial oil, respectively, where the $PM_{2.5}$ emissions decreased with increased MCE_T. This near four-fold range in the $PM_{2.5}$ emission factor for similar conditions of oil addition (40+40+20 gallons and 40+40+20+20+20 gallons) is both promising and challenging, indicating that further study would be necessary to understand the combustion phenomena that lead to these differences. The lowest $PM_{2.5}$ emission factors were emitted when burning 160 gallons of oil all at once (25.6 kg/m^2) and when oil was continuously added to an initial 40 gallons burn (starting at 6.4 kg/m^2, 40+40+20+20+20 gallons, total of 140 gallons). These lower $PM_{2.5}$ emission factors and corresponding MCEs were similar to those found from a previous in-ground tank study at CRREL using a boom aspect ratio of 1:1. The larger scale used in this study with a burn area of 20.1 m^2 and 1136 kg initial oil compared to the 3.4 m^2 and 31 kg initial oil used in the boom aspect ratio study may be why the results in this study using a boom ratio of 3:1 were similar to those with a boom ratio of 1:1. The larger scale did not affect the mass loss as the mass loss percentage was in the same range in this study (93.8-97.1%) as in the boom ratio study (94.399.6%) when the initial oil mass per area was less than 12.8 kg/m^2. While conclusions are tempered by lack of repeats, it appears that incremental addition of oil results in greater oil consumption (Figure 4-1) and lower $PM_{2.5}$ emission factors.

7 REFERENCES

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December 5, 2022

Executive Summary and Operational Notes

BSEE Order 140E0122F0110, Project #1134 Ohmsett Tank System Test: Elastec Restricted Burning Tongue

Ohmsett Task Order #T172-070

1. Background

This submittal is in response to testing conducted at the Ohmsett Facility during the week of October 10, 2022, for BSEE under BSEE Order# 140E0122F0110.

In situ burning (ISB) is a major tool employed in open water oil spill response. However, along with the targeted thermal destruction of most of the oil slick, ISB produces burn residue that chiefly consists of unburned oil, thermally damaged oil, and products of incomplete combustion. This residue is problematic in that it is often viscous and tar-like, and tends to sink upon cooling. Sinking residue has the potential to smother benthic life and foul fishing nets.

Under the current BSEE project (Contract #140E0121P0018) Elastec American Marine (Elastec) of Carmi, Illinois is reconfiguring their fire boom to improve burn efficiency thereby reducing burn residue. However, even with improved efficiency, burn residue will still be produced. Consequently, Elastec has also modified its candidate belt skimmer to effectively remove burn residue from the modified boom system.

2. Objectives

The stated objectives for this phase of the Restricted Burning Tongue evaluation included:

1. Develop deployment and retrieval procedures.
2. Observe oil behavior and measure oil slick thicknesses at the gate and into the boom at operational tow speeds and chosen wave conditions. This should include entrainment above and below the boom.
3. Determine optimal tow speeds.
4. Develop oil flow profile and velocities.
5. Determine timing and location of future ignitions.
6. Determine operational functionality of the Elastic Filter-belt skimmer to recover oil from the apex of the linear boom.

Objectives 1 and 6 could not be performed during the Ohmsett portion of the boom's evaluation. Regarding Objective 1, Ohmsett is not physically configured to accommodate the normal at sea mode of launching this system. Additionally, the Elastic Filter-belt skimmer was not included as part of the Ohmsett test program. Therefore, Objective 6 could not be met. However, several observations were documented that could be relevant in further evaluation of these features. These observations are presented later.

Objective 2 was addressed through use of digital cameras affixed to the top of the boom directly across from visual water level gauges placed at water surface within the boomed area. Entrainment was observed visually above the water surface, and a subsurface camera was employed at the boom apex.

Operational observations and digital photo/video documentation were used to provide information to assist with the evaluation for Objective 4. However, actual flow profiles and velocities are left to others to evaluate as Ohmsett was not equipped for this evaluation at this time.

3. Test Setup

Figure 1 (below) is a sketch of the Elastec Restricted Burning Tongue system as tested in the Ohmsett test basin.

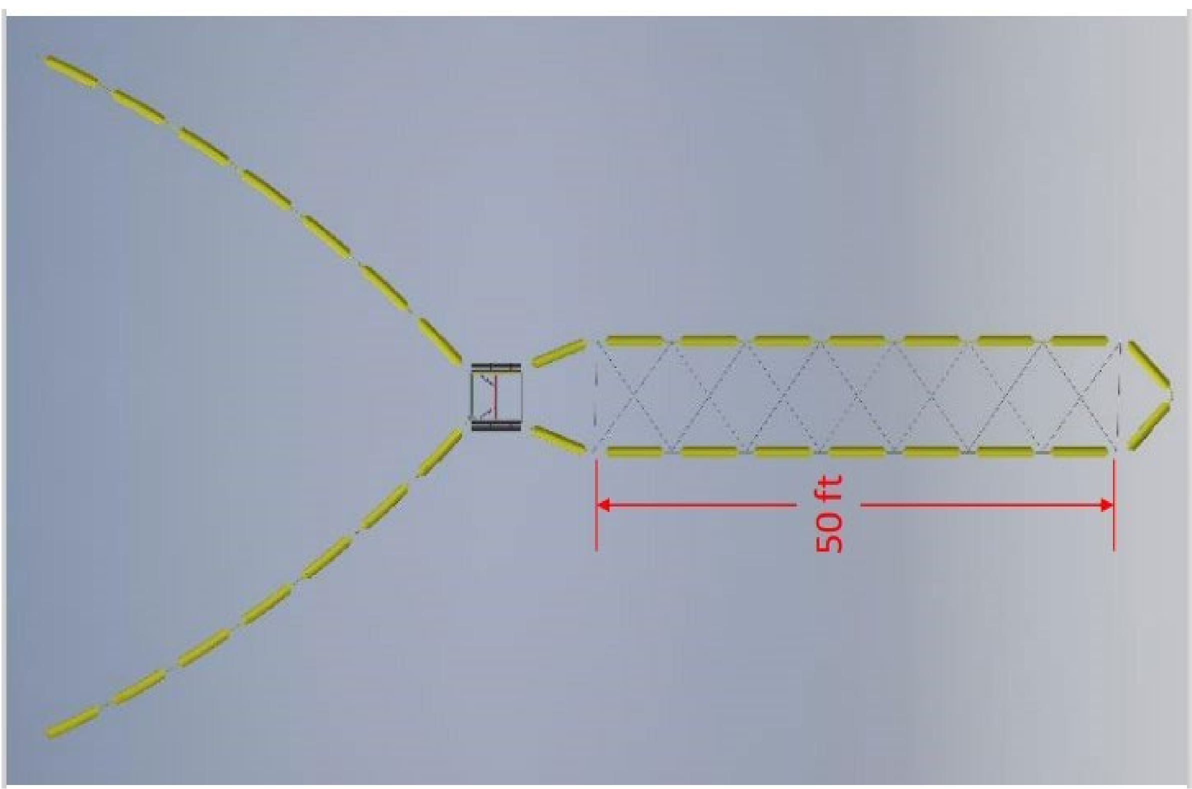

Figure 1. Elastec Restricted Burning Tongue System Setup

As indicated, the linear and parallel sections of fire boom are 50-feet (15.2 m) long, and the inner width is approximately 4-feet (13.1 m). The total enclosed area, including apex and gate attachment, is approximately 217 ft^2 (20.16 m^2). The stem (fire boom) shape is compliantly maintained by several cross-support members (struts) along the length of the stem.

Figure 2 (below) is an isometric and projection drawing of the floating gate system that is connected at the head of the stem boom. The gate was opened and closed hydraulically either through manual pumping or by using the supplied power pack.

The boom stem and gate system were rigged to the Ohmsett main bridge using two 50-foot sections of fire boom attached to the bridge tow points set at 50-feet apart.

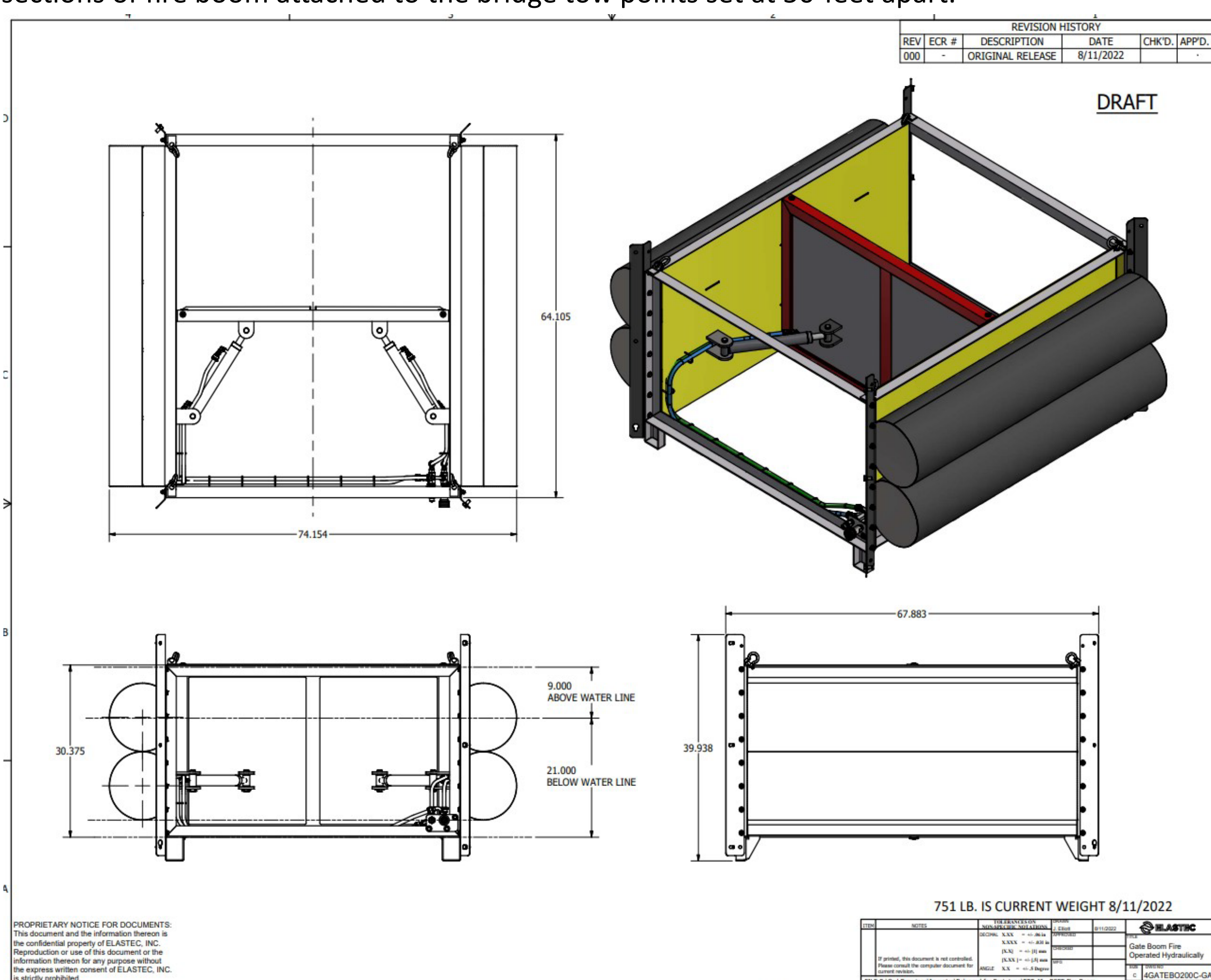

Figure 2. Floating System Isometric and Projection Drawings

The oil used was Ohmsett Specification Hydrocal 300 which was metered onto the water surface in front of the system.

GoPro cameras were used in four locations. 0ne was mounted on the north bridge at a height of approximately 13 feet off the water surface and faced south over the boom stem. Two were mounted to the east boom stem section directly across from the wave gauges (measuring sticks) on the west boom section, one at the north extremity, the other at the south extremity; and one camera was deployed subsurface at the boom apex.

4. Test Execution

Ten test runs were performed, including four duplicate runs. After observing initial sea keeping demonstration runs with and without oil, two speeds were chosen: 0.75 knots and 1.00 knots. Further, after observing various wave forms, a single wave was chosen with a wave generator setting of 15 cpm @ 12-inch (30.5 cm) stroke. This setting yields a 1/3 significant wave height of 12.5-inches (31.75 cm), and average wavelength of 51-feet (15.5 m). This wave form produced enough specific wavelength to reasonably challenge the apparent waterline of the Burning Tongue system. The predominant wave height of this form provided enough attack to challenge the system for tossing and entrainment. Overall, this wave form provided enough of the characteristics needed to evaluate the system in the time provided.

The Specification Hydrocal 300 was distributed onto the water surface in the lead boomed at approximately 8 feet in front of the north face of the Main Bridge. Distribution rate was 50 gpm.

Test 1 was a preliminary test in calm water conducted to provide observation of basic handling and performance of the Burning Tongue system. It began with an oil preload of 150 gallons in the lead boom area in front of the system gate. During the 5:40 minute run, oil was distributed from the bridge at 50 gpm starting 30 to 40 seconds into the run. Approximately 150 gallons was distributed in addition to the 150-gallon preload. Consequently, approximately 300 gallons of oil was encountered and captured during the 0.75 knot run.

Observation of **Test 1** led to the determination that **Test 2** start with 200 gallons of preload in front of the gate in addition to the 300 gallons already in the boom stem. This resulted in a 500gallon total boom loading by test's end. The test was run at 0.75 knots in calm water.

Test #3A was run with the previous 500-gallon total load in the boom stem for observation at

1-knot in calm water. No further oil was distributed. However, Elastec failed to close the gate doors at the end of the run. This resulted in 150 to 200 gallons of oil washing back into the lead boom area. Almost all this oil was captured using the fire monitor. Consequently, this oil was used as an oil preload (150 to 200-gallons) in front of the gate for a second run labeled as

Test 3B, which was conducted at 1 knot. No further oil was distributed from the Main Bridge during any part of **Test 3**.

As a result of our observations during the previous runs it was decided that the same 500-gallon total stem oil load would be used for all subsequent tests as follows: Approximately 150 to 200 gallons of captured oil from the previous test run would be back-washed into the lead boom area during the return trip north to the starting point. This oil would be held in the lead boom for use as a preload for the next run. From this point forward, the variables would be waves, and speed. This mode allowed for good observation of system performance while providing operating efficiently regarding oil changes. **Test 4** through **Test 6** on October 11th, and **Test 7** through **Test 10** on October 12th all used this oil recovery method. Variables were reduced to advancing speed (0.75 knots or 1.00 knots), waves, and run duplication.

Test 4 was conducted with 150-200 gallons of oil as a preload, the balance of 500 gallons of oil in the stem, a wave setting of 15 cpm @ 7.5 inches, and at 0.75 knots. The 1/3 significant wave height of 9 inches, and wavelength of 51 feet allowed observation of a long wavelength at low height.

Test 5 was conducted as a repeat of **Test 4** using a longer wavelength, higher wave height setting of 15 cpm @ 12.5 inches. This produced waves of 12.5-inch significant height and 51-foot average wavelength. After observing the system's reactions this wave setting, and the **Test 4** wave setting, it was decided that the test program would be conducted at a wave variable of either 15 cpm @ 12.5 inches, or "no waves" (calm water). The remainder of the tests (**Test 6** through **Test 10**) were conducted using this combination of wave environments, speeds of 0.75 knots or 1.00 knots, and the 150–200-gallon preload. The balance of the 500-gallon total remained in the stem.

5. Results

Table 1 represent the program test matrix as performed. The following link may be used to access the Excel spreadsheet of this matrix: FD110 Test Matrix.xlsx. The spreadsheet includes video links to the tests as performed. Duplicate runs are represented by same color columns.

Included with this Summary are files for Visual Documentation organized by test, Laboratory Data for tank water for 10-12 and 10-13-22 (FD110 Lab Data\Tank Water Characteristics T127070.xlsx), and Spec Hydrocal 300 data (FD110 Lab Data\Oil Characteristics T127-070.xlsx). Note that only oil from a single batch was used.

Wave data for each of the two wave forms is included (FD110 Wave Data). Wave data was taken during testing on 10-11-22.

Visual Documentation may be viewed at FD110 Visual Documentation.

Also included are PDF files for Figure 1, the Boom Stem, and Figure 2, the system Gate. **Table**

1. Test Matrix as Performed

Test	Date	Time	Waves	Tow Speed, kts	Description	Video Link to North Bridge	Subsurface Video Link
# 1	10/11/2022	1118 hrs	N/A	0.75	150 gal. preload; dipsensed 150 gal. oil @ approx. 53 gpm for 2.83 min.; total to boom = 300 gal.	FD110 Visual Documentation\Test 1\North Br	N/A
# 2	10/11/2022	1152 hrs	N/A	0.75	200 gal. preload added to 300 gal. of oil already in stem.	FD110 Visual Documentation\Test 2\North Br\GH018533.MP4	N/A
# 3A	10/11/2022	1348 hrs	N/A	1.0 kt	First higher speed test. Used 500 gal. of oil left from Test 2. Experienced 150 - 200 gal.wash-back upon stopping.	FD110 Visual Documentation\Test 3\North Br\GH014431.MP4	N/A
# 3B	10/11/2022	1351 hrs	N/A	1.0 kt	Ran test over using 150-200 gal. left from 3A as a preload.	FD110 Visual Documentation\Test 3\North Br\GH014432.MP4	N/A
# 4	10/11/2012	1427 hrs	Low, long wavelength, rolling wave. Setting: 15 cpm @ 7.5-inch; Avg H=9-inch, λ=51-ft	0.75	Approx. 150 to 200 gal. of 500 stem gal. washback into cup to start test	FD110 Visual Documentation\Test 4\North Br\GH014433.MP4	N/A
# 5	10/11/2012	1448 hrs	High, long wavelength, rolling wave. Setting: 15 cpm @ 12-inch; Avg H=12.5-inch, λ=51-ft	0.75	Approx. 150 to 200 gal. of 500 stem gal. washback into cup to start test	N/A	N/A
# 6	10/11/2012	1508 hrs	High, long wavelength, rolling wave. Setting: 15 cpm @ 12-inch; Avg H=12.5-inch, λ=51-ft	1	Approx. 150 to 200 gal. of 500 stem gal. washback into cup to start test	FD110 Visual Documentation\Test 6\North Br\GH014436.MP4	N/A
# 7	10/12/2022	0948 hrs	N/A	0.75	Approx. 150 to 200 gal. of 500 stem gal. washback into cup to start test	FD110 Visual Documentation\Test 7\North Br\GX010002.MP4	FD110 Visual Documentation\Underwater 10.12.22\Test 7\GH018499.MP4
# 8	10/12/2022	1008 hrs	N/A	1	Approx. 150 to 200 gal. of 500 stem gal. washback into cup to start test	N/A	FD110 Visual Documentation\Underwater 10.12.22\Test 8\GH018500.MP4
# 9	10/12/2022	1025 hrs	High, long wavelength, rolling wave. Setting: 15 cpm @ 12-inch; Avg H=12.5-inch, λ=51-ft	0.75	Approx. 150 to 200 gal. of 500 stem gal. washback into cup to start test	FD110 Visual Documentation\Test 9\North Br\GX010004.MP4	FD110 Visual Documentation\Underwater 10.12.22\Test 9\GH018501.MP4
# 10	10/12/2022	1040 hrs	High, long wavelength, rolling wave. Setting: 15 cpm @ 12-inch; Avg H=12.5-inch, λ=51-ft	1	Approx. 150 to 200 gal. of 500 stem gal. washback into cup to start test	FD110 Visual Documentation\Test 10\North Br\GX010006.MP4	FD110 Visual Documentation\Underwater 10.12.22\Test 10\GH018502.MP4

NOTE: Matched color rows indicate duplicate test runs. Clear rows are individual tests.

6. Observations

Several operational notes and observations were made during this test program. We feel these are of importance, especially since this program relied heavily on observed behavior of the subject system.

- Although a stated objective in the RFQ was to develop deployment and retrieval procedures, this was not possible during this test program. Without engaging in a major reconfiguration, the Ohmsett Facility is not configured to provide an at sea style deployment. However, it was noted that the fire boom used was very heavy and cumbersome, which may be unavoidable. Further, the strut system installation on the boom stem appeared to be difficult and required a lot of time to install. This was so despite being deployed in a quiescent tank of water with good weather.
- The configuration of boom mounted cameras opposite at surface rulers was wholly inadequate for determining oil thickness in the boom.
- Although only two wave forms were employed, it became immediately clear that wavelength and significant wave height had a dramatic effect upon fluid movement through and in front of the gate, and within the boom stem. Entrainment was also affected.
- Two speeds were tested, 0.75 knots and 1.00 knot. At any speed over 1.00 knot, the system experienced instability including a tendency to submergence or planning. A speed of 0.50 knots was determined to be too slow.
- Entrainment due to the inertial forces of startup notwithstanding, entrainment took place to a greater or lesser extent during many of the runs. Given the approximately equal oil loading in the stem boom, the major factors in entrainment were presumed to be speed and surface conditions. A handheld subsurface camera at the boom apex showed that at 0.75 knots and calm surface, entrainment took place minimally (Test 7). Surprisingly, entrainment seemed only slightly greater at 1.00-knot and calm surface (Test 8). In waves, entrainment increased at 0.75 knots (Test 9), and further increased at 1.00-knot (Test 10). This was visually confirmed on the surface on a real-time basis by the Ohmsett technician deploying the subsurface camera. It would be logical to assume that various combinations of speed, oil loading, and surface condition would affect entrainment in varying ways. However, none of the entrainment was fully developed or extreme. It is unclear how burning would affect entrainment.
- Gate operation was hydraulically actuated by a small diesel driven power pack. The system was supplied with an optional manual pump override. However, manual operation required several pumping strokes and was rather slow to react.

FD110 BSEE/Elastec Burning Tongue Boom Tests

Test	Date	Time	Waves	Tow Speed, kts	Description	Video Link to North Bridge	Subsurface Video Link
# 1	10/11/2022	1118 hrs	N/A	0.75	150 gal. preload; dipsensed 150 gal. oil @ approx. 53 gpm for 2.83 min.; total to boom = 300 gal.	FD110 Visual Documentation\Test 1\North Br	N/A
# 2	10/11/2022	1152 hrs	N/A	0.75	200 gal. preload added to 300 gal. of oil already in stem.	FD110 Visual Documentation\Test 2\North Br\GH018533.MP4	N/A
# 3A	10/11/2022	1348 hrs	N/A	1.0 kt	First higher speed test. Used 500 gal. of oil left from Test 2. Experienced 150 - 200 gal.wash-back upon stopping.	FD110 Visual Documentation\Test 3\North Br\GH014431.MP4	N/A
# 3B	10/11/2022	1351 hrs	N/A	1.0 kt	Ran test over using 150-200 gal. left from 3A as a preload.	FD110 Visual Documentation\Test 3\North Br\GH014432.MP4	N/A
# 4	10/11/2012	1427 hrs	Low, long wavelength, rolling wave. Setting: 15 cpm @ 7.5-inch; Avg H=9-inch, λ=51-ft	0.75	Approx. 150 to 200 gal. of 500 stem gal. washback into cup to start test	FD110 Visual Documentation\Test 4\North Br\GH014433.MP4	N/A
# 5	10/11/2012	1448 hrs	High, long wavelength, rolling wave. Setting: 15 cpm @ 12-inch; Avg H=12.5-inch, λ=51-ft	0.75	Approx. 150 to 200 gal. of 500 stem gal. washback into cup to start test	N/A	N/A
# 6	10/11/2012	1508 hrs	High, long wavelength, rolling wave. Setting: 15 cpm @ 12-inch; Avg H=12.5-inch, λ=51-ft	1	Approx. 150 to 200 gal. of 500 stem gal. washback into cup to start test	FD110 Visual Documentation\Test 6\North Br\GH014436.MP4	N/A
# 7	10/12/2022	0948 hrs	N/A	0.75	Approx. 150 to 200 gal. of 500 stem gal. washback into cup to start test	FD110 Visual Documentation\Test 7\North Br\GX010002.MP4	FD110 Visual Documentation\Underwater 10.12.22\Test 7\GH018499.MP4
# 8	10/12/2022	1008 hrs	N/A	1	Approx. 150 to 200 gal. of 500 stem gal. washback into cup to start test	N/A	FD110 Visual Documentation\Underwater 10.12.22\Test 8\GH018500.MP4
# 9	10/12/2022	1025 hrs	High, long wavelength, rolling wave. Setting: 15 cpm @ 12-inch; Avg H=12.5-inch, λ=51-ft	0.75	Approx. 150 to 200 gal. of 500 stem gal. washback into cup to start test	FD110 Visual Documentation\Test 9\North Br\GX010004.MP4	FD110 Visual Documentation\Underwater 10.12.22\Test 9\GH018501.MP4
# 10	10/12/2022	1040 hrs	High, long wavelength, rolling wave. Setting: 15 cpm @ 12-inch; Avg H=12.5-inch, λ=51-ft	1	Approx. 150 to 200 gal. of 500 stem gal. washback into cup to start test	FD110 Visual Documentation\Test 10\North Br\GX010006.MP4	FD110 Visual Documentation\Underwater 10.12.22\Test 10\GH018502.MP4

NOTE: Matched color rows indicate duplicate test runs. Clear rows are individual tests.

FD110	Burning Tongue/Elastec
Spec. Hydrocal Tank 6	
Sample ID	FC110-01
Viscosity (η in cP)	327.0
Density (g/cm^3)	0.9197
IFT (dynes/cm)	12.7
Water Content (%)	22.0

FD-110		
Water Quality		
	10/12/2022	10/13/2022
pH	7.54	7.76
Conductivity (mS)	42.4	41.5
TDS (ppt)	27	29.2
ORP (mV)	272	210
Temp C°	16.6	16.8
Turbidity (NTU)	0.47	12.23
Density (g/cm^3)	1.021	1.021
Salinity (ppt)	27.23	26.8