

## ONE-STEP OFFSHORE OIL SKIM AND BURN SYSTEM FOR USE WITH VESSELS OF OPPORTUNITY

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### ABSTRACT 300244:

Vessels of opportunity (VoOs), such as fish and shrimp boats, can be employed to aide offshore oil spill response operations. During the 2010 *Macondo* response, VoOs were utilized to collect surface slicks in booms, however, VoOs were not equipped to skim and recover the collected oil. Because of this, dedicated skimming vessels were directed to VoOs to skim and store the oil. This process is not very efficient as VoOs can often remain idle for long periods while waiting for dedicated skimming vessels to arrive and process the collected oil.

The research presented here aims to improve the effectiveness of VoO operations through development of a one-step skim and burn system. The system under development is based on the combined use of oleophilic skimmers, which can recover oil and water mixtures capable of direct combustion. Our concept would be for a VoO to collect oil in the booms, skim the oil from the booms using an oleophilic skimmer, and then pump the recovered mixture to a floating combustion system located downwind without the need for large volumes of interim storage or decanting.

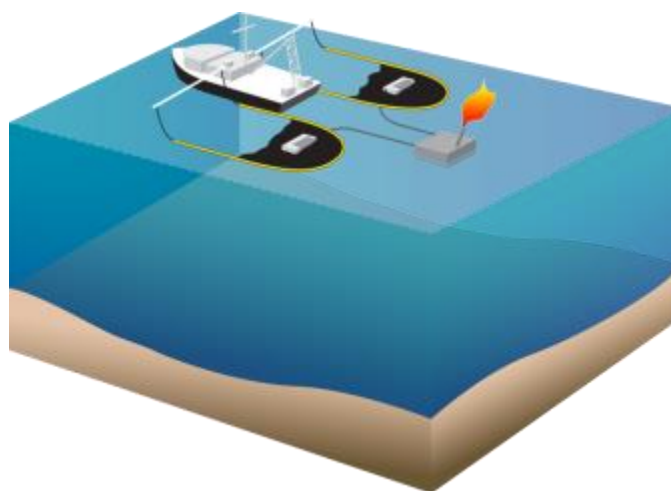
The three primary objectives for system development and design are to 1) improve combustion efficiency, thereby reducing environmental impacts; 2) achieve burn rates comparable to oil recovery rates of the oleophilic skimmers utilized, enabling more efficient oil spill response operations and less down-time; and 3) design a relatively simple and robust system that will enable safe burn operations.

Experimental results from initial testing of small and medium scale burning systems will be presented. Direct combustion of skimmed oil was successfully demonstrated. Further, burns were completed with decreased smoke generation and burn residue compared to in situ burning.

### INTRODUCTION:

Vessels of opportunity (VoOs), such as shrimp and fishing boats, can be employed in response to large-scale offshore oil spills, e.g., over 3000 VoOs were involved in the clean-up efforts during the recent *Macondo* spill in the Gulf of Mexico. VoOs during this spill were outfitted with short sections of boom deployed on outriggers to collect oil and emulsions for

recovery. VoOs are not authorized to store oil that has been recovered by skimmers. Because of this, the efficiency of VoOs can be limited because of their reliance on other vessels that can store recovered oil. An integrated one-step skim and burn system is a promising technology that can improve the efficiency of VoOs. This system also eliminates the time-consuming steps of storage, transportation, and disposal of recovered oil. The key components of a one-step skim and burn system are the oleophilic skimmer and the floating burner. A conceptual drawing of such a system is shown in Figure 1. This system is not limited to use with VoOs as larger oil spill response vessels that can skim and store recovered oil may also be able to use a skim and burn system to avoid collection and offloading of oily water.



**Figure 1.** A one-step offshore oil skim and burn system for use with VoOs.

New oleophilic skimmers enhance the one-step skimmer-burner system because they are capable of recovering oil with minimal water pick-up. The recovered product may be directly burnable. Prior skimming systems have had issues surrounding oil recovery efficiency. Under certain circumstances weir-type skimmers may have poor efficiencies – with some systems collecting as much as 90% water and only 10% oil. Oleophilic skimmers have reversed these numbers and can collect 90% oil (and only 10% water). An oil mixture that is greater than 50% water may prove difficult to ignite. An oil mixture that is 90% oil is readily burnable.

The concept of floating burner systems emerged after the *Torrey Canyon* spill in 1967. Early models of floating burners were developed based on general concepts ranging from the collection of surface oil and transfer to a combustion area, e.g., Pittsburgh Corning Floating Incinerators, BP Elijah Burner (Battelle, 1979), to the redirection of leaking underwater pipe into a combustion area e.g., Pipeline Rupture Burner, Dome Sub-Sea Blowout Burner (Battelle, 1979, Buist and Potter, 1982). Initial design considerations were focused on two aspects: i) to increase the amount of the heat of combustion that is radiated back to the slick; and ii) to improve the mixing of combustion air with fuel. To improve the burner performance, enhancement techniques were developed, such as acoustic or air jet techniques incorporated in

An Acoustic Burner and Air Jet Atomizing Burner (Koblanski 1983, Lipski 1986, Caron 1988). Additional simplified enhancement techniques that aimed at air entrainment into a combustion zone and air injection enhancement of in-situ combustion have also been evaluated (Lipski 1986, Caron 1988, Belore and Seeley 1990, Franken *et al.* 1992, Nordvik *et al.* 1995). These enhancement techniques helped accelerate the combustion of oil versus simple in-situ burning, but they also increase the capital cost and the level of complexity. For offshore deployment of a floating burner system, the ideal design should reduce ancillary equipment while improving combustion rate and efficiency (i.e., less smoke).

Three floating burner systems were chosen for evaluation. Practical considerations for evaluation include combustion rate and efficiency, safety, reliability, and cost. Results from bench and meso scale tests of a chimney style burner, design considerations for a flare burner system, and background testing results of a rotary cup burner will be discussed.

### BURNER DESIGNS:

For the integrated skimmer-burner system, oil recovered by an oleophilic skimmer placed inside a boom would be pumped to the burner. The burner and supporting components could be mounted on a floating platform or even a barge trailing the oil skimming operation. Three floating burner designs are under evaluation: i) a chimney style burner, ii) a nozzle / flare style burner, and iii) a rotary cup burner. Representative pictures of each burner are shown in Figure 2. The design principles and concepts for each of the three burners are summarized below.



**Figure 2.** a) Chimney style burner, b) nozzle / flare style burner (courtesy of Zeeco Inc.), c) rotary cup burner (courtesy of SL Ross Inc.).

### Chimney Style Burner

This design concept uses a ring or a pan to hold oil, a chimney, and compressed air injection system (Figure 3a). The compressed air system allows air to be injected into the oil in the ring or pan in a way that causes oil to be atomized up into the chimney. Atomizing the oil into droplets using compressed air nozzles placed within a small pool of oil provides additional surface area for combustion and also provides combustion air. A bench scale chimney burner is shown in Figure 3b. Compressed air, introduced via stainless steel tubes was used to aid atomization via flow through perforated tubing just below the oil surface. Three of the tubes, referred to as perimeter nozzles, were configured at an angle to the walls to induce a swirling motion within the stack, and a fourth tube was centrally installed to contribute to the atomization of oil during the burn tests, as shown in Figure 3c.



**Figure 3.** a) Flow diagram of a chimney burner; b) the bench-scale prototype, c) air injection nozzles in the bench-scale burner; d), e) the meso-scale burner.

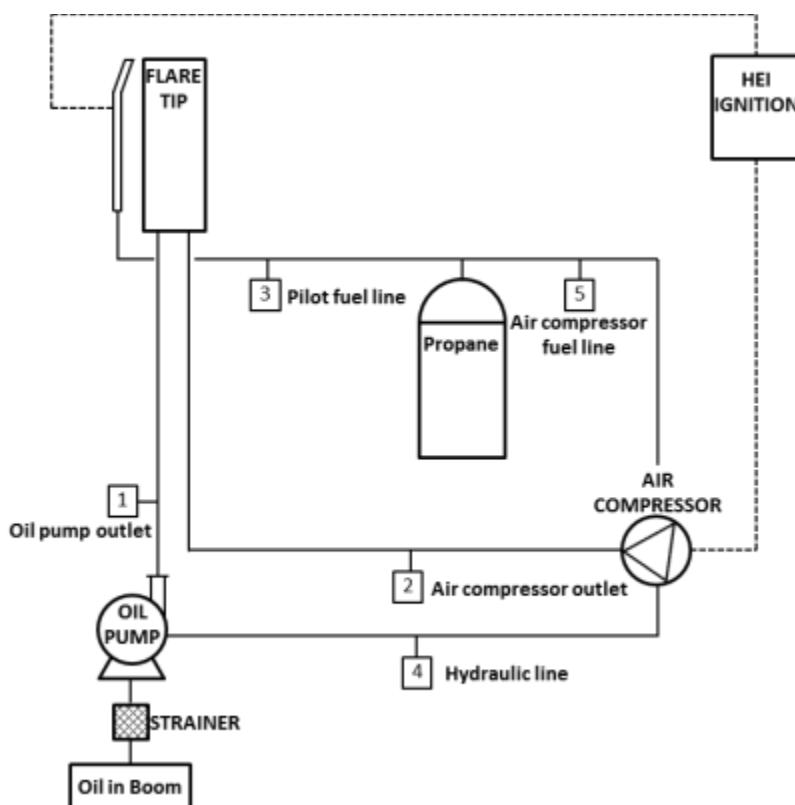
A bench-scale burner was tested to determine parameters that affect performance. Bench-scale testing results were used to guide the design of a meso-scale burner that had an inner diameter several times greater than the bench-scale prototype. The meso-scale burner was built with a support frame, containment mesh, primary burn ring, supplemental containment rings and a stack (Figure 3d, e). The burner support frame is submerged in a test tank for the test runs, holding the burner and stack at the water surface during the burns. The stack is a commercially available stainless steel, double walled chimney with a refractory lining terminating in a stainless steel gasket to protect the liner. The overall height of the stack can be adjusted by adding multiple stacks. The gap between the lip of the containment ring

encompassing the oil pool and the bottom of the stack is also adjustable to allow for varying amounts of air flow.

### Nozzle / Flare Style Burner

Another burner design under evaluation is the flare-style burner. This design concept operates similar to flare systems used during offshore well tests. The burner utilizes pressurized flow of both oil and air introduced into a flare tip. For this system, oil recovered by an oleophilic skimmer would be pumped to a flare nozzle system mounted on a barge. Main components of the flare burner system include: 1) flare nozzles, 2) pilot and pilot ignition system, and 3) an air compressor. A process flow diagram and description of streams are shown in Figure 4.

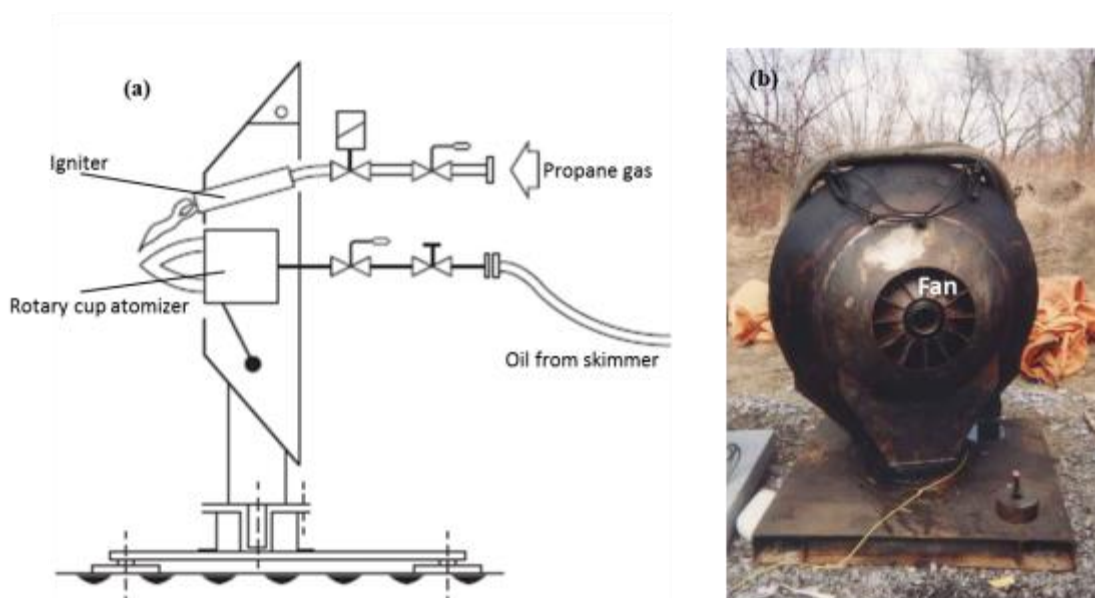
A design consideration for the flare burner concept is to develop a system of size and weight that can easily be placed on a barge and pulled by a VoO.



**Figure 4.** Process flow diagram of a flare/nozzle style burner.

### Rotary Cup Burner

The final burner design under evaluation is a rotary cup burner, also referred to as a SAACKE burner. The SAACKE heli-portable burner was developed in the 1970s and 1980s and commercialized by SAACKE (a German company started in 1934 that manufactures industrial boiler and process firing systems and marine firing plants). This burner was tested for onshore burning of oil recovered near shore or onshore. For that application, the SAACKE burner was designed to be transported by helicopter to remote beaches that had been impacted by an oil slick. It is desired to evaluate a similar system for floating/at-sea operations. The SAACKE burner atomizes oil by centrifugal action of a rotating cup, which rotates at high speed. The rotary cup mechanism used to atomize oil is a robust approach for a wide range of oil properties requiring minimal supply of compressed air and eliminating the need for a large air compressor. The design utilizes a housing (as seen in Figure 5) capable of maximizing utilization of ambient air. An integral fan is used to direct a high-speed flow of air past the rotating cup creating and directing oil droplets into the burn zone. A conceptual design diagram of the SAACKE burner is shown in Figure 5.



**Figure 5.** a) Conceptual design of the SAACKE burner, b) front view of the original SAACKE burner (courtesy of SL Ross Inc.).

The SAACKE burner is designed to face downwind to allow maximum capture of air by the housing. In offshore skim and burn operations, it is anticipated the VoOs will be operating primarily by moving directly into the wind. This will facilitate optimal positioning of the SAACKE burner.

## EVALUATION DISCUSSION:

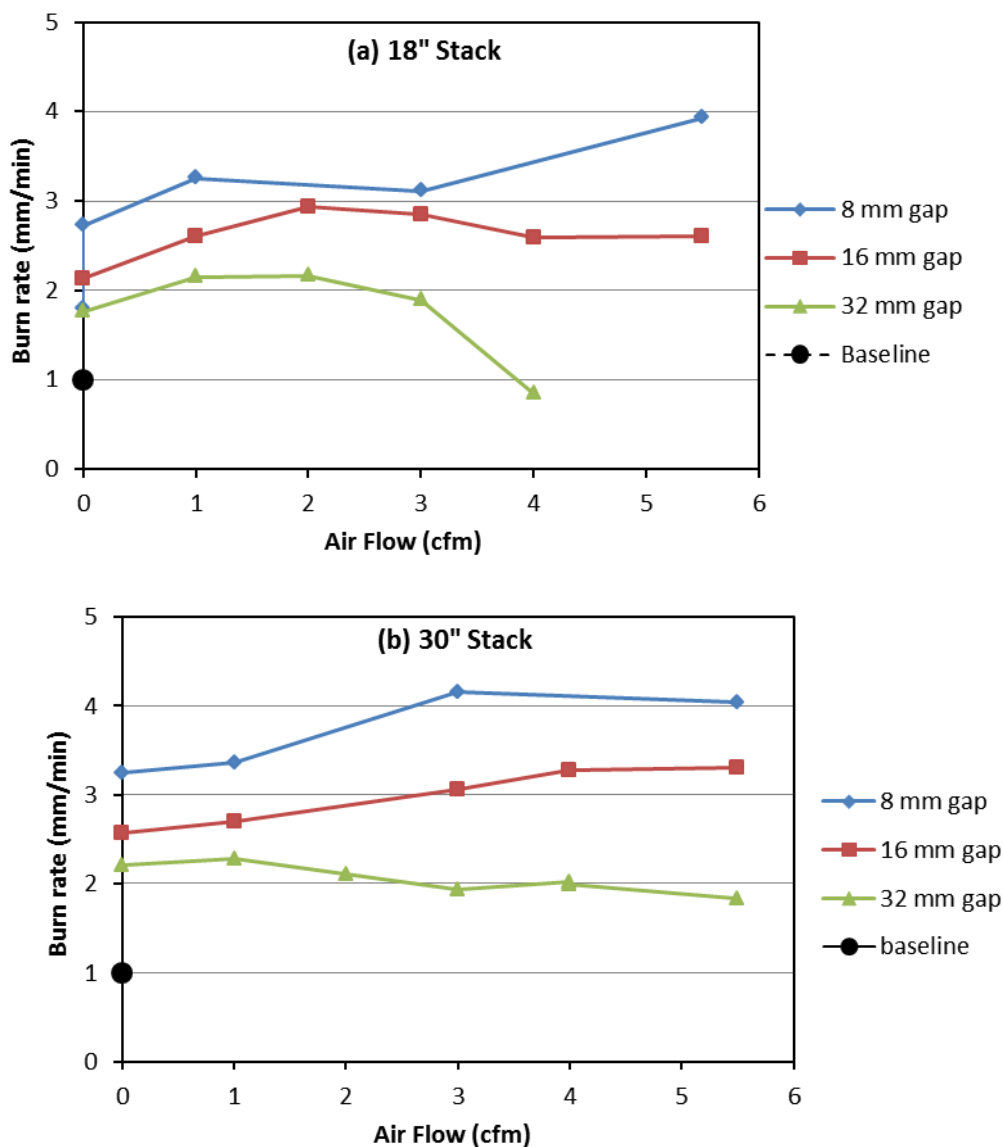
In this section, a summary of the current status of evaluations and suggested future evaluation are provided. Preliminary testing results of the chimney style burner, results of a desk-top study of the flare burner, as well as background testing results of the rotary cup burner are discussed.

### Chimney Style Burner

A preliminary feasibility study of the chimney system was completed. The proof of concept stage included testing of bench- and meso-scale prototypes using various configurations of air injection, chimney size and placement. A total of forty-five bench-scale tests and twelve meso-scale tests were completed; detailed results have been presented elsewhere (Cooper *et al.*, 2012). Here a summary is provided of bench and meso-scale testing results. The bench-scale test runs were designed to evaluate several parameters including stack height, air jet angle, air volume, air velocity, air jet height above surface, and air gap height. The oil used during the bench-scale testing was Endicott crude produced in Prudhoe Bay, Alaska.

The air gap between the stack and pan and compressed air injection rate are two parameters that impact combustion rate and efficiency. The test results of two chimney stack heights (18 and 30 inch) and three air gap values (8, 16 and 32 mm) are shown in Figure 6. The highest burn rates were achieved with the smallest air gap tested (8 mm air gap) for both chimney heights and all air injection rates tested. This may be due to the smaller air gap having a “throttle” effect. This throttle effect may have increased the speed of the ambient air entering the chimney stack allowing the air to penetrate deeper into the center of the chimney to facilitate an improvement in the distribution of air. Compressed air injection through three perimeter nozzles also had a significant impact on both the smoke generation and burn rates. Burn rate increased up to 4 mm/min as the air injection rate increased for both chimney heights with an 8 mm air gap. In contrast, the burn rate in the baseline control test, i.e., no air injection and no stack, was approximately four times less. Bench-scale testing results also indicated that stack height had an effect on burn rate, however, this effect was diminished as air injection rate increased.

Although a higher air injection rate and smaller air gap resulted in a higher burn rate, some disadvantages were also observed during the testing. First, flames were extremely intense at the highest burn rates, and appropriate materials of construction will be required to handle the excessive heat. Second, combustion efficiency was also adversely affected as incompletely combusted oil particles splattered from both the stack and the oil pool during the intense burn. Third, flare-outs were observed during several of the test runs which could be a potential drawback during operation.



**Figure 6.** Combustion rate vs. air injection rate: a) 18 in, and b) 30 in chimney stack height.

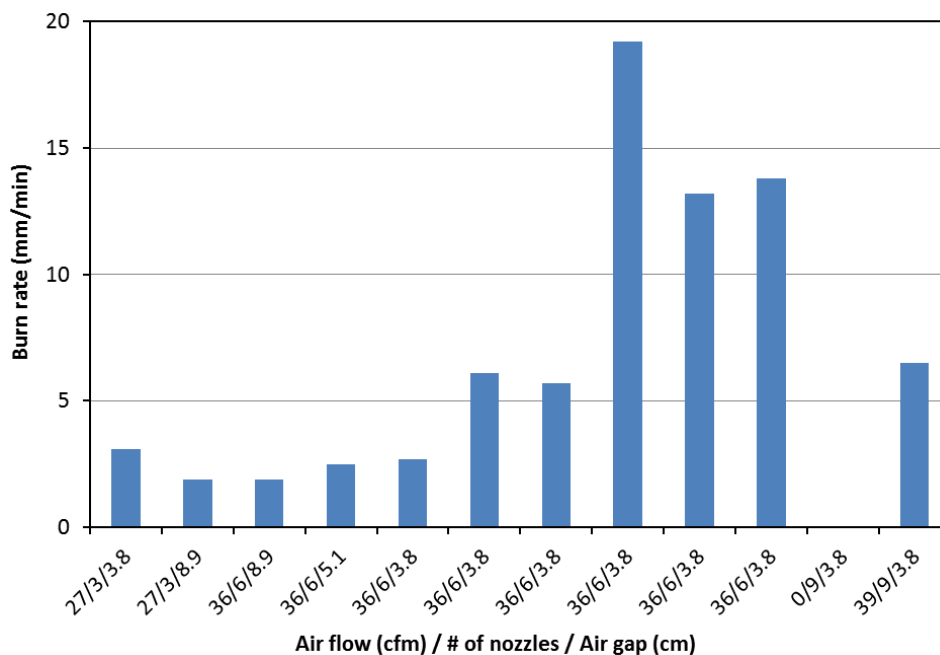
A series of test runs were conducted at an outdoor test tank to determine the performance of the meso-scale burner. A number of parameters including stack height, air volume, number of atomizing nozzles, and gap height were identified for evaluation. Results of meso-scale burning tests are shown in Figure 7. Similar to bench scale tests, air gap was found to have a significant impact on combustion rate. Again, this is attributed to the “throttle” effect created when the air gap is narrow, i.e., a narrower air gap restricts air flow, allowing higher-velocity ambient air to be drawn deeper and mix more thoroughly into the chimney stack to enhance burning.

A prominent feature observed during the meso-scale testing was three distinctive burn stages: i) the initial start-up phase (preliminary burn), ii) an intense combustion phase (intense



burn), and iii) a final, slower phase that occurred after oil flow was shut off as the flames extinguished (flameout/extinguishing flame). The preliminary burn, lasting approximately 1 minute, represents the time for the initiation of the fire until flames completely covered the oil pool area and just prior to engaging the air injection. The intense burn started with the air injection, which triggered noticeable increases in the flames until the termination of the oil flow to the burner assembly. The flameout stage lasted approximately 10 - 20 seconds, corresponding to a noticeable reduction in flame intensity until the flames in the oil pool reduced below 25% coverage.

The meso-scale test successfully demonstrated the basic concept of combining an oleophilic skimmer and a floating burner. The highest achieved combustion rate was close to 20 mm/min. When the 20 mm/min rate is scaled to a 1.83 m (6 ft) diameter chimney burner, oil is expected to be consumed at a volumetric rate of 3.16 m<sup>3</sup>/hr, (approximately 20 bbl/hr).



**Figure 7.** Meso-scale testing results of chimney burner.

Additional work with respect to the chimney burner may include: 1) additional feasibility testing (bench- and meso-scale) to further understand scaling and operational parameters and 2) establishing full scale design specifications.

### Nozzle/Flare Style Floating Burner

Preliminary desktop design studies on the flare floating burner concept were completed. The goal of the desktop study was to design a flare burner system that minimized the system footprint and weight to be compatible with use by vessels of opportunity (VoO).

Initial design parameters were established for a flare design, in particular a smokeless oil burner. Several parameters were evaluated for effective combustion. First, the pressurization of the oil in the flare tip was evaluated. A pressure of 200 psig ensured proper atomization for the design evaluated. This pressure can be achieved by using a hydraulic pump powered by an air compressor. Second, the compressed air flow was evaluated. A compressed air flow of 185 SCFM should provide secondary atomization of the oil and additional air for combustion. Third, the design included a continuous pilot on the flare tip with high heat release (up to 325,000 BTU/hr). Propane may be used as the pilot fuel gas as it is commonly used as a pilot fuel gas.

This flare burner may be able to flare oil-in-water emulsions with up to 50% water; however, but testing is needed to determine feasible maximum water contents that are burnable for this particular design. Additional work with respect to the flare burner design may include: 1) building a prototype system and 2) testing the prototype to determine operational boundaries (e.g., oil properties), optimal operating conditions, and refined design parameters.

### **Rotary Cup Floating Burner**

The rotary cup SAACKE burner was first tested in the 1970 - 1980s burning light oil containing 0, 40 and 60% water with a respective burning rate of 1710, 2496, and 3300 liters/hr (Vanderkooy, 1981; Buist and Vanderkooy, 1982), equivalent to 10 - 20 bbl/hr. Subsequent land-based tests are summarized below. Several field trials were successfully conducted by Dome Petroleum Ltd. and S.L. Ross Environmental Research Ltd. in the Arctic near the Beaufort Sea (McCourt *et al.*, 1996). In 1981, the SAACKE burner was tested in a spill site in the MacKenzie Delta N.W.T. (Buist and Vanderkooy, 1982). A total of 800 m<sup>3</sup> of diesel fuel and water mixture was disposed of using the SAACKE burner in a period of 30 days. The maximum water content of the mixture successfully burned was 80% by volume. The SAACKE burner was also used to dispose of a wide range of oil mixtures with a wide range of viscosities. In 1996, the SAACKE burner was tested on the eastern shore of Ellesmere Island, N.W.T. (McCourt *et al.*, 1996). In five days, it disposed of 39,000 L of waste containing aviation fuels, diesel, kerosene, stove oil and lubricating oil, at an average disposal rate of 800 L/hr. A clean flame with no visible smoke was observed during the operation. The SAACKE burner was also used to dispose of 2200 L of oily water containing suspended solids that was produced from oil drum cleaning operations (McCourt *et al.*, 1996).

One idea for the skimmer-burner concept is to use a SAACKE burner design with an oleophilic skimmer at-sea (i.e. to be towed behind a vessel and skimmer). The system may use a single burner unit or multiple units operated from a barge in parallel to accommodate a range of oil recovery rates.

Additional work with respect to the SAACKE burner may include conducting a desktop study or any other suitable testing of the SAACKE burner for the skimmer-burner concept.

### **SUMMARY AND CONCLUSIONS:**

A one-step skimmer-burner system is under evaluation to improve the efficiency of vessels of opportunity to respond to large offshore spills. Three floating burner designs were discussed and the potential feasibility of an integrated skimmer-burner system was discussed.

Evaluation is in the very early stages; therefore evaluation of all three burner designs continues. One design may prove much more robust and/or efficient (economical and operationally) than the others, or there may be more than one that is suitable for commercialization given the range of environments and oil properties in which these technologies could be deployed.

Practical considerations for operating a floating burner system include many factors, such as safety and reliability, combustion rate and efficiency, oil viscosity and water content, total system weight, total cost, operating window (weather conditions, offshore locations), etc. As of the time of writing, the chimney burner has undergone the most evaluation under this project as two prototypes have been tested. Testing of the prototypes was successful and indicated that a full-scale system could achieve burn rates comparable to the capacity of oil encounter rates using booms on VoOs. Additional evaluation is warranted to further understand design parameters in order to minimize the size and weight of a full-scale system. The flare burner concept has undergone a desk-top study to design an operational system that is capable of sitting on top of a barge and capable of being transported by a truck. The SAACKE burner has not been evaluated in this application although it has undergone previous study as a tool to burn oil recovered on shorelines in remote locations. Additional evaluation of all three burner designs is warranted.

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