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Use of immersed conductive objects to enhance the burning rate of hydrocarbon pool fires

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ABSTRACT

This study investigates the ability of thermally conductive nonflammable objects to enhance the steady state burning rate of hydrocarbon pool fires with the ultimate goal of designing a burner for faster clean-up of hazardous spills in offshore and other remote environments. In the initial set of small-scale experiments, a vertical 1 cm diameter solid aluminum cylinder with varying lengths is placed centrally in a 10 cm diameter pan fed with a continuous supply of hexane burning in quasi-steady state. The upper part of the cylinder, engulfed in the flame, heats up, and conducts heat to the lower submersed part, that transmits heat to the liquid below the pool surface. Tests reveal that the submersed lower part of the cylinder heats up sufficiently to sustain nucleate boiling, significantly increasing the burning rate, when compared to the baseline pool fire, where vaporization is achieved solely by radiative and convective heat transfer at the pool surface. The effects of cylinder length and multiple cylinders on burning rate are also characterized. To determine if the concept can also be applied to oil spill clean-up, a set of large scale tests is performed by burning crude oil/water mixtures in a 1-meter diameter pool. These tests show that burners with thermally conductive cylinders can be designed to effectively dispose of crude oil and oil/water mixtures.

1. Introduction

Outdoor burning of oil pools is an accepted disposal method for spill clean-up in offshore, wetland and other remote/cold environments when transport of the recovered oil to a fixed, land-based waste treatment facility is impractical (ASTM international, 2014a; ASTM international, 2014b; ASTM international, 2013; ASTM international, 2015; ASTM international, 2016; Michel et al., 2005; Buist et al., 2013; Lin et al., 2005). However, the average regression rate for large burns on water is only about 3.5 mm/min (Blinov and Khudyakov, 1961), which is low relative to the capacity needed to effectively burn off the quantities of oil recovered from catastrophic spills. This paper describes. an experimental investigation and “proof of concept” analysis of a new method to increase the burning rate of hydrocarbon pool fires, with a focus on potential application in oil spill cleanups.

Pool fires need only about 1–5% of the total heat released to sustain fuel vaporization and consequently combustion (Koseki and Hayasaka, 1989). The rest is lost to the environment through the buoyant convection plume and thermal radiation. Following ignition, if fuel is replenished, the fire will reach a self-limiting steady state regression rate that is determined primarily by “radiation blockage” caused by a layer of unburned fuel vapor located directly above the pool surface (Koseki and Hayasaka, 1989). Our experiments show that the burning rate of laboratory scale fires can be increased by an order of magnitude or more using thermally conductive objects that are immersed in both the flame and liquid fuel and thereby provide a second heat feedback mode between the flame and the pool, as shown conceptually Fig. 1a.

Incinerators outfitted with thermally conductive objects can be used for oil spill clean-up applications. The incinerator can be deployed in two ways depending on the spill location. If the spill occurs close to the shoreline, the modular incinerators can be placed on the shore. Then the oil, skimmed and transported to the shore, will be pumped into the incinerator and burned. For offshore oil spills, floating incinerators can be attached behind the boom and used as a skim and burn system as shown in Fig. 1b (Zhang et al., 2014). The simple but effective design of the incinerator requires no atomizing nozzles, moving parts, or compressed air, which makes it more reliable than existing burner technologies for operation in harsh, cold environments such as the Arctic.

Several studies (Nakos et al., 1990; Spinti et al., 2008; Gritzo and Nicolette, 1997; Wang et al., 2013; Russell and Canfield, 1973; Fry, 1985) have investigated the heat flow boundary conditions applicable to objects such an aircraft wing, tank, and transformer station enveloped by a pool fire. However, the focus of these studies has been to characterize the structural integrity of the immersed object as a

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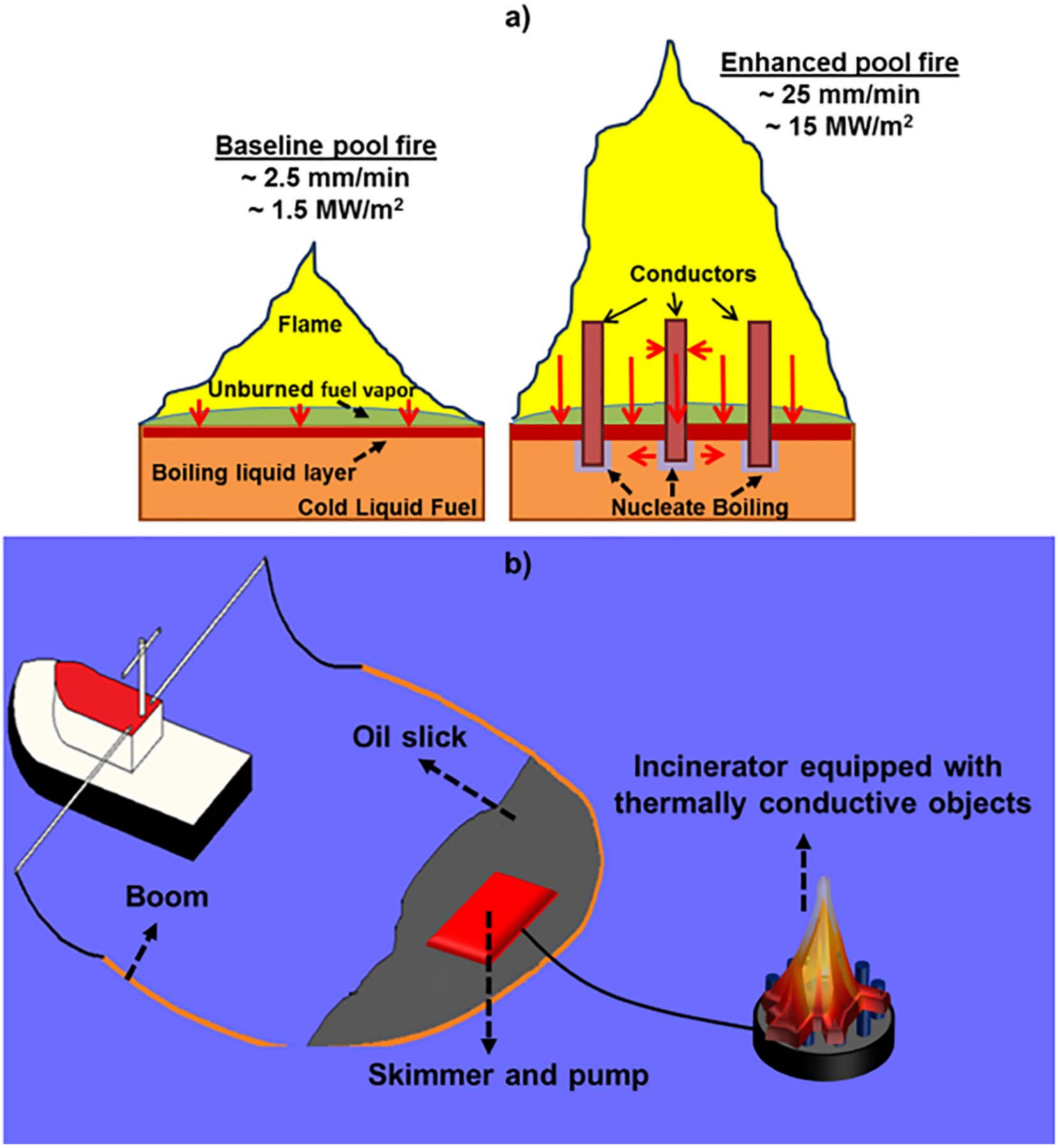

Fig. 1. a) Conceptual schematic of baseline and enhanced pool fires, b) Skim and burn system using thermally conductive objects.

function of time of exposure. This study focuses on the fire enhancement caused by increased heat feedback to the pool via conduction through the immersed object. The heat and mass transfer are further coupled by 2-phase flow effects (film boiling, nucleate boiling) that occur on the surface of the object immersed in the liquid layer.

This study first experimentally investigates the potential for enhanced burning using thermally conductive thin cylinder(s) immersed in a 10 cm diameter pan fire. Hexane was used as the fuel in order to determine if the immersion concept is valid at least for a light hydrocarbon. Then, large-scale experiments were performed burning oil–water mixtures in a 1-meter diameter pool to demonstrate the potential application of the concept in oil spill clean-up. No prior studies of this problem were found reported in literature.

2. Small-scale experimental setup

Fig. 2a shows a schematic of the small-scale experimental setup. In order to clearly observe the physical and thermo-chemical processes governing the problem, a small-scale, laminar, pool fire of a well-characterized single component fuel (hexane) is used. The experimental platform is a 10 cm diameter, 4.5 cm deep stainless steel vessel connected to a supply tank, used to maintain a constant fuel level throughout the duration of the experiment. In all experiments, the ullage or the depth of the liquid fuel surface below the rim is maintained at 1 cm. The constant level is maintained by continuously over-feeding the supply tank using a peristaltic pump. The overflow is collected in a container whose mass is measured by a load cell as shown in Fig. 2a. The mass-loss rate of the fuel is calculated by subtracting the overflow rate from the pumping rate. The fuel in the stainless steel vessel is ignited using a butane torch and the subsequent flame is recorded using a video camera. A water-cooling jacket is used to prevent heating of the stainless steel vessel. A thermocouple embedded on the surface of the vessel is used to record the wall temperature during the experiment, and the flow rate of water is adjusted to maintain a constant temperature (20 °C) on the wall.

The thermally conductive object used in the current study is a 1 cm diameter solid aluminum cylinder placed centrally in a 10 cm diameter hexane pool. A thin (0.3 cm) wood base with holes (1 cm diameter) is prepared to support the cylinder by inserting the cylinder into the base.

Experiments with different cylinder lengths and number of cylinders are conducted to systematically explore the influence of change in collector (flame-immersed section) and heater (liquid-immersed section) (Fig. 2b) surface area on the mass loss rate. Three repeat tests are performed for each case to ensure repeatability. To characterize the