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Experimental Study of Initial Fuel Temperature on the Burning Rates of Kerosene Pools in Cold Environment

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ABSTRACT
Oil spill cleanup in Arctic is usually done by in-situ burning. The fuel oil will have a very low initial temperature as well as cold boundaries. This study focuses on the variation of the mass burning rate of the fuel with varying initial temperatures of the fuel, which is kept in a metal bowl surrounded by ice. Kerosene is chosen as the fuel. The bowl diameters have been varied from 30 mm to around 50 mm. The fuel bowl is kept surrounded in an ice bath and is ignited after it attains a particular temperature. The initial temperature of the fuel is varied from 4^{o}C to 16^{o}C. Experiments are carried out for 5 minutes after which the flame is quenched. The results show that with increase in the initial temperature of the fuel the mass burning rate also increases. The mass burning rate also increases as the fuel bowl diameter increases. The surface temperature of the fuel, just after quenching, increases with an increase in the initial temperature of the fuel. The ignition time of the fuel is reduced with increase in initial temperature of the fuel and with increase in bowl diameter. The flame height variations are also recorded.
Key words: Kerosene, initial temperature of the fuel, mass burning rate, surface temperature, Ignition time.

1. INTRODUCTION

Oil spill cleanup in Arctic is usually done by in-situ burning. After burning, collection and transport of the residue matter becomes much easier. Ice and oil can interact in many configurations having different shapes and sizes, such as channels and cracks between ice sheets or basins created naturally. However, there is no statistical data reported on the size and shape of these cavities. There are several studies reported on in-situ burning of crude oil in icy as well as non-icy conditions [1-6]. Janne et al. [7] tested the ability of different oil samples to ignite in specially designed burning cells. The large-scale field experiments and the burning cell ignitability were in good agreement. Bellino et al. [8] reported mass loss rate of oil burning in ice channels. They reported that the reduction in the burning rate is due to the melting of the channel walls, which in turn resulted in the attainment of critical thickness of the oil layer. Farmahini et al. [9] used cylindrical ice cavities to investigate crude oil burning. Considerable heat sink effect was realized in the icy walls of the cavity, especially for small the cavities (5 cm - 10 cm). Heat from the flame melted the ice, which in turn changed the geometry of the cavity (diameter of the pool increases). Because of the change in the oil pool diameter, mass loss rate was affected. Therefore, a strong relationship existed between the mass loss rate and the change of the pool and cavity diameters. They further found that due to the expansion of the cavity, the average mass loss rate of crude oil in the ice cavity is greater than the mass loss rate in a constant diameter bowl.

Due to scarcity in the studies of burning of kerosene in cold environment, this study has been motivated. This study focuses on the variation of the mass burning rate of the kerosene with varying initial temperatures of the fuel, which is kept in a metal bowl surrounded by ice. The bowl diameters have been varied from 30 mm to around 50 mm. The fuel bowl is kept surrounded in an ice bath and is ignited after it attains a particular temperature. The initial temperature of the fuel is varied from 4^{o}C to 16^{o}C. Experiments are carried out for 5 minutes after which the flame is quenched.

2. EXPERIMENTAL SETUP

Figure 1 shows the experimental setup built to study the effect of initial fuel temperature on the burning rate of kerosene pool. The setup consists of a weighing balance, which is used to measure the temporal variation of mass of ice and fuel together. It has an accuracy of 0.1 g. On the top of weighing balance a wooden block and on it top, a thin metal sheet is placed. Above the wooden block, two concentric bowls are kept. The outer diameter of the larger outer bowl is 79 mm and the inner bowl, where fuel is present, the diameter (d) varies as 30 mm, 38 mm and 49 mm, as shown in Fig. 2. The annular space between two bowls is filled with ice. The wall thickness of both the bowls is around 0.5 mm and the height of fuel bowl is around 20 mm .

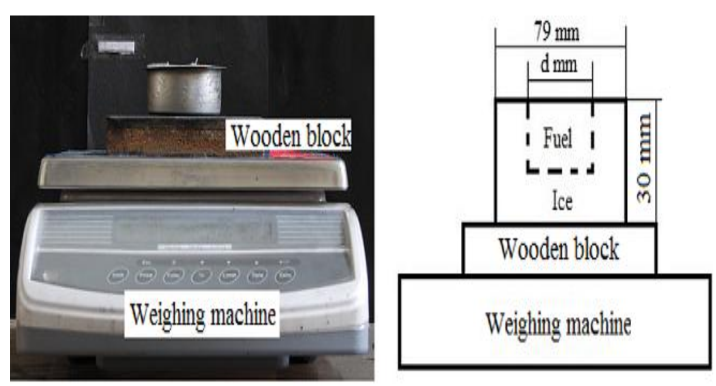

Fig. 1: Front view of Experimental setup

The initial temperature of ice is in between -4^{o}C to -2^{o}C. Ice is casted in the annular space by filling water in the space between outer bowl and the fuel bowl and keeping this in a freezer. Commercially available kerosene is poured in the fuel bowl and is stirred thoroughly such that it reaches a given initial temperature. Immediately, ignition is onset with the help of a butane flame (diffusion flame). The time taken for ignition (until a flame sustains over the pool) and the temperature of the liquid pool just after the onset of ignition are also recorded. A K-type thermocouple is used to measure the temperatures with an accuracy of ±1°C.

Fig. 2: Bowls filled with ice and fuel; fuel bowls having diameters of 30 mm, 38 mm and 49 mm

High-definition digital camera is used to capture the images and videos. The ignition time, duration of burning and flame height are also recorded. The experimental procedure is as follows: (1) The fuel is weighed in a separate pan. (2) After removing the extra ice (from outer bowl) and cleaning the fuel bowl, the mass of the empty fuel bowl along with surrounding ice bowl is noted down. (3) The fuel is poured into the fuel bowl and the weight of ice, bowls and fuel is noted down. (4) The fuel is stirred and using the K-type thermocouple, the initial temperature of the fuel is measured. (5) The fuel is ignited when the required initial temperature is attained, using a butane flamer. (6) Stop watch is switched on, and after every 30 s interval, the combined mass of ice, bowls and the fuel is measured. (7) The experiment is carried out approximately for 5 minutes after the onset of ignition. (8) The flame is put-off and the combined mass of the remaining fuel, ice and the bowls is measured. Each experiment is carried out for at least three times to check for the consistency.

3. RESULTS AND DISCUSSION

Figure 3 shows the flame photographs for different initial temperature of the fuel burning in bowls of different diameters. The flame is basically a diffusion flame (non-premixed) and is highly luminous. The flame luminosity is due to soot particle radiation. Kerosene is a sooty fuel and formation of soot starts near to the burner exit. Soot particles leave the flame indicating that in this mode of combustion soot oxidation is not complete. The flame is also oscillatory as in the case of any diffusion flame. This is due to interaction of the flame with the entraining flow field. Based on the pool diameter and initial temperature flame height seems to vary.

Figure 4 shows the variation of ignition time with initial temperature of the fuel for different fuel bowl diameters. With increase in initial temperature of the fuel, the time of ignition of the fuel decreased, as the amount of heat required to heat-up the fuel decreases. The time for ignition decreases as the diameter of the fuel bowl increases. However, this effect is significant at low initial temperatures only. This is due to the lesser surface area available for heat transfer when the bowl diameter is small. As the initial temperature of the fuel increases, the difference between the ignition times for different fuel bowl diameter cases becomes insignificant. This can be attributed to overall decrease in the heat required for liquid-phase heating up.

Variation of the combined mass of fuel and ice with time is shown in Fig. 5 for different initial temperature of the fuel and for different fuel bowl diameters. Since there is no significant melting of ice and vaporization of water during the experimental time of 5 minutes, the combined mass presented will directly represent the variation of mass of fuel alone.

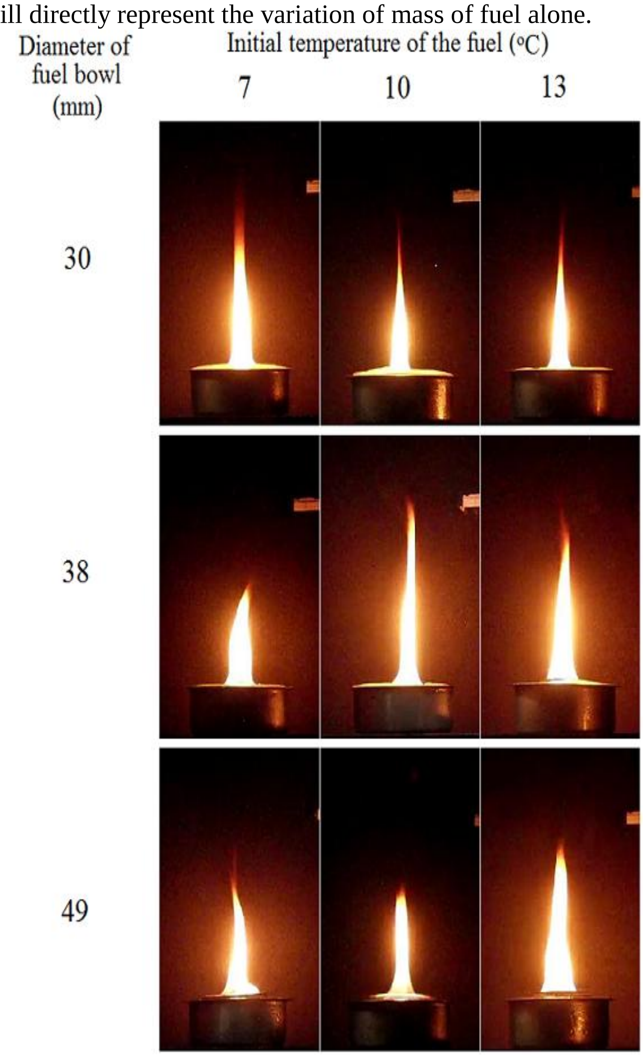

Fig. 3: Instantaneous flame photographs for different fuel bowl diameters and for different initial temperatures of the fuel

The differences in the masses in the various initial temperature cases are due to differences in the initial mass of ice used in the experiments. Therefore, it would be meaningful if only the mass loss rate is compared between the cases (slopes of the curves) and not the instantaneous mass itself. The combined mass of the fuel, bowl and ice varies much gradually with time for fuel bowl diameter of 30 mm. In the experimental duration of 300 s, only a mass of approximately 0.5 g is lost. The heat from the flame and the heat lost to surrounding ice are comparable for this case. The slope of the mass loss curve increases as the bowl diameter is increased to 38 mm. The increase in the surface area for the heat transfer from the flame causes more fuel to vaporize from the surface.

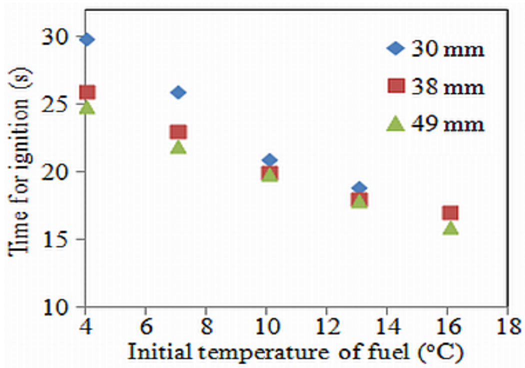

Fig. 4: Variation of iginition time of the fuel with its initial temperature for different bowl diameters

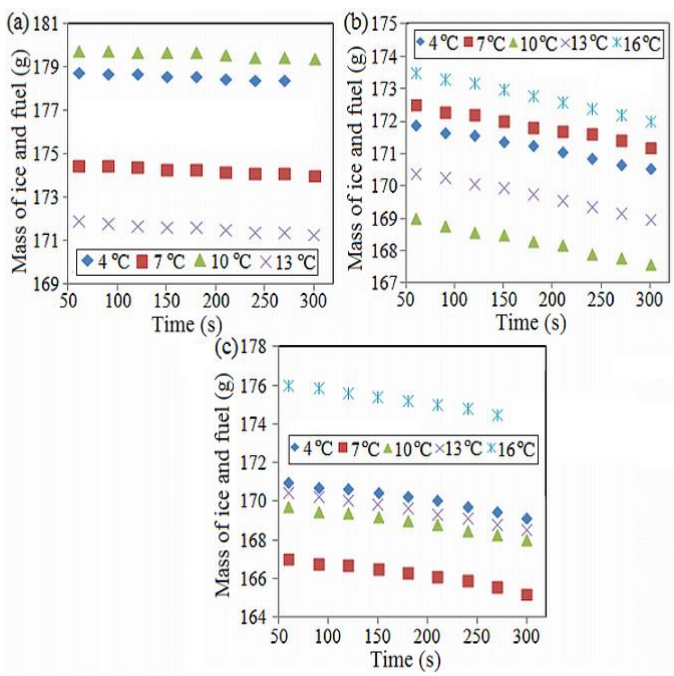

Fig. 5: Variation of mass of fuel, bowl and ice with time for different initial temperatures of the fuel and for bowl diameters of (a) 30 mm, (b) 38 mm, and (c) 49 mm

When compared to 30 mm diameter case, the heat lost to surrounding ice is increasingly compensated by the heat transferred by the flame to the fuel surface for this case. The slope is in general constant; linear variation is observed for this case. For the case of higher bowl diameter of 49 mm, the slope of the mass loss curve is slightly non-linear.

Figure 6 presents the temporal variation of combined mass of fuel, bowl and ice for different bowl diameters and initial temperatures. It is apparent that the slope of mass loss curves for 30 mm case are very small indicating a smaller mass burning rates for that case. As the initial temperature is increases, there is a slight increase in the mass loss rate. It is also clear that the mass loss rates increases with bowl diameter and becomes non-linear for the largest bowl diameter case of 49 mm.. Since the bowl height is almost the same, as the bowl diameter is increased the rate of increase of fuel surface area is higher than the rate of increase of bowl wall surface area. As a result, the increase in the heat transfer rate from the flame to the fuel surface due to increased surface area associated with increasing bowl diameter forms the basic reasons for these trends.

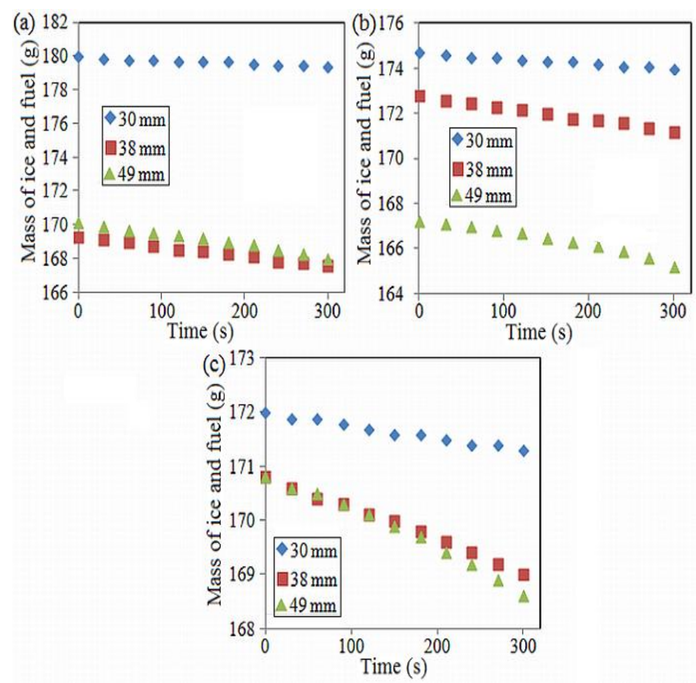

Fig. 6: Variation of combined mass of ice, bowl and fuel with time for different bowl diameters and for different initial temperatures (a) 7^{o}C, (b) 10^{o}C, and (c) 13^{o}C

Figure 7 shows the variation of average mass burning rate as a function of initial fuel temperature for different fuel bowl diameters. For a given initial temperature of the fuel, the mass burning rate increases with an increase in the fuel bowl diameter. This is due to the increase in surface area of the fuel exposed to the flame and more fuel evaporates. Further, as discussed above, the compensation of the heat loss to the surroundings by the abundant flame heat transfer also form the reason for this trend. The average mass burning rate of the fuel also increases with an increase in the initial temperature of the fuel. This increase is due to the reduction in the heat required for heating up the fuel.

Figure 8 shows the variation of the temperature of fuel just after the flame is put off as a function of initial temperature of the fuel for different fuel bowl diameters. There is a clear increasing trend for the final fuel temperature with initial fuel temperature. Also, there is not much difference in the final temperature for the cases of 38 mm and 49 mm. This confirms the earlier discussion that when the bowl diameter is increased, heat loss to the surroundings is compensated well by the flame heat transfer.

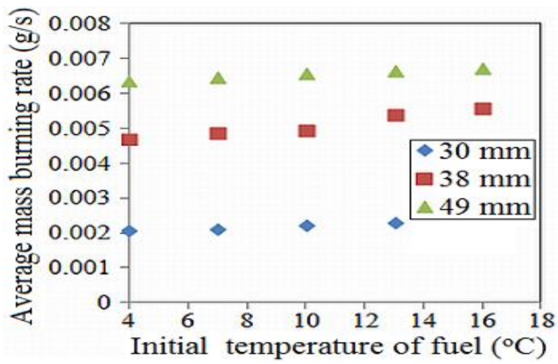

Fig. 7: Variation of average mass burning rate with initial fuel temperature for different fuel bowl diameters

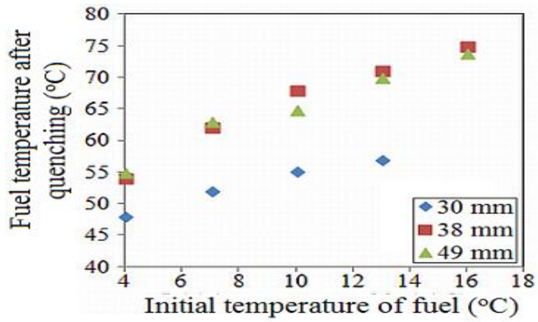

Fig. 8: Variation of fuel temperature after quenching as a function of initial fuel temperature for different fuel bowl diameters

4. CONCLUSIONS

This study focuses on the variation of the mass burning rate of kerosene with varying initial temperatures kept in a metal bowl surrounded by ice. The results show that with an increase in the initial temperature of the fuel the mass burning rate increases. The mass burning rate also increases as the fuel bowl diameter increases. The temperature of the fuel, just after quenching, increases with an increase in the initial temperature of the fuel. The ignition time of the fuel is reduced with increase in initial temperature of the fuel and with increase in bowl diameter.

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