Low air pressure effects on burning characteristics of typical oil with forced irradiance

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Abstract. In this paper, a report is given on an experimental study of the combustion characteristics of typical oil with forced irradiance under two fixed ambient pressures, which may occurred in real fires. Mass loss and flame axial heat flux distribution were measured to evaluate the hazards. The burning intensity at reduced pressure is relatively lower under the circumstance without incident irradiance because the thin air for reduced pressure may attenuate the combustion. However, the burning intensity at lower pressure is higher due to the lower boiling temperature when the irradiance reaches to 10 kW/m^2.The flame could engulf sufficient air to complete the combustion process for atmospheric pressure condition compared with that under low pressure, and thus resulting in relatively higher flame temperature for a fixed flame height. While in the unified plume region, the weaker air entrainment under lower pressure leads to a poorer cooling effect, i.e. higher plume temperature.

1. Introduction

The combustion characteristics of typical oils with external irradiance have been experimentally studied in the past few decades since the combustible may be radiated by the ceiling or adjacent fire source in real fire. Apte[1] studied the effect of fuel type on combustion characteristics of pool fires using solvents, alcohol and their blends, it is concluded that the smoke extinction area (SEA) increases with the CO and CO_2 yields which in turn increase with the carbon fraction and the aromatic content of the fuel/fuel blend. By testing 14 different crude oils, it is discovered by Iwata [2] that heat release rate (HRR), mass loss rate (MLR), flame radiation, and smoke yield correlates well crude oil density linearly. The ignition and combustion characteristics of three typical oils (diesel, lubricating oil, and aviation kerosene) was studied by Chen[3] and he found that the maximum and average value of HRR, average MLR, and CO/CO_2 ratio seems to be linear with forced irradiance.

In recently year, the pressure effect on the combustion behavior of typical oils has been vastly analyzed since the low ambient pressure environment in plateau districts and cruising airplanes [4-7]. Previous studied and discussion have showed that fire characteristics such as mass loss rate, heat release rate, flame temperature and flame shape is effected by high altitude. However, as far as author’s knowledge, no study have been reported on pool fires with external radiant flux under low pressure. Considering the combustion characteristics of typical oils may provide basic knowledge needed for fire protection on Tibet plateau, bench-scale tests of liquid pool fires of typical oil under different external forced irradiance were studied in this study.

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2. Experimental Setup

The experimental setup of the chamber fire tests is illustrated in figure 1. Liquid N-Heptane with an industrial purity greater than 99% was selected as testing fuel, whose burning characteristic is similar to diesel. A circular pan with diameter of 10 cm and height of 2 cm was adopted, and the liquid N-heptane was filled to a height of 1.6 cm in each test. Five radiative heat flux, i.e., 0.03, 5, 10 kW/m^2, were selected originating from the conical heater, which is accordance with the heating source of the standard of ISO 5660. An altitude chamber with the internal size of 2×3×2 m was adopted to provide the low air pressure condition. Experiment under two fixed ambient pressure, i.e. 64, and 100 kPa will be conducted with the adjusting accuracy of chamber pressure is ±1 kPa.

An electronic scale with resolution of 0.01 g was used to record the mass loss. A radiative heat flux sensors was located with a horizontal distance of 60 cm from the burner centre. An array of 19 thermocouples spacing 5 cm was located vertically along the axis of the burner. The temperature measurements reported in this study were the direct thermocouple readings without radiation correction which may yield an uncertainty less than 10% [8] depending largely on the level of soot radiation. The sampling rates of electronic scale and thermocouple were both 1 Hz. The fuel was ignited by applying 25 V electric current on 0.3-mm-diameter Ni-Cr wire.

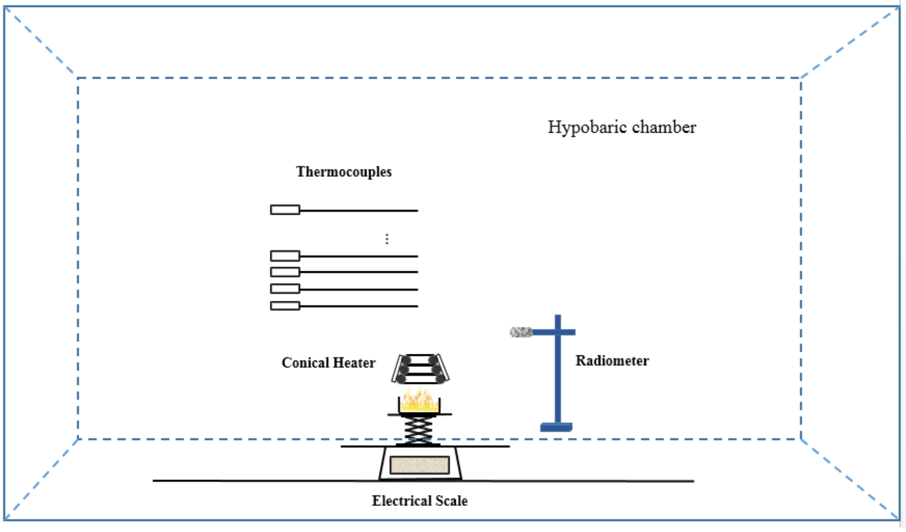

Figure 1. Experimental setup of the chamber fire tests

3. Results and discussion

For precise evaluation on the experimental results, the mass loss rates over the three repeated tests for each configuration are averaged to give the ultimate results. Based on that, the mass loss rates under three irradiances are plotted in figure 2, respectively, where the pressure effect on the results can be clearly observed.

Previous research have indicated that the mass transfer has an exponential relationship with ambient pressure, i.e. $\dot{m} \sim P^{\alpha}$, and thus, the burning intensity at reduced pressure is relatively lower under the circumstance without incident irradiance. For the case of 0.03 kW/m^2, the imposed irradiances are quite small, and play an unobservable role in affecting the heat feedback mechanism compared with that from the flame. Therefore, the combustion behaviours of these two cases seem to follow the basic trend of thin-layer pool fires, where the case under normal pressure underwent four combustion stages, i.e. pre-burning stage, quasi-steady burning stage, boiling stage and decay stage, and for the case under reduced pressure, the mass loss rate curves tend to reach to a plateau after a short pre-burning stage until the commencement of decay stage.

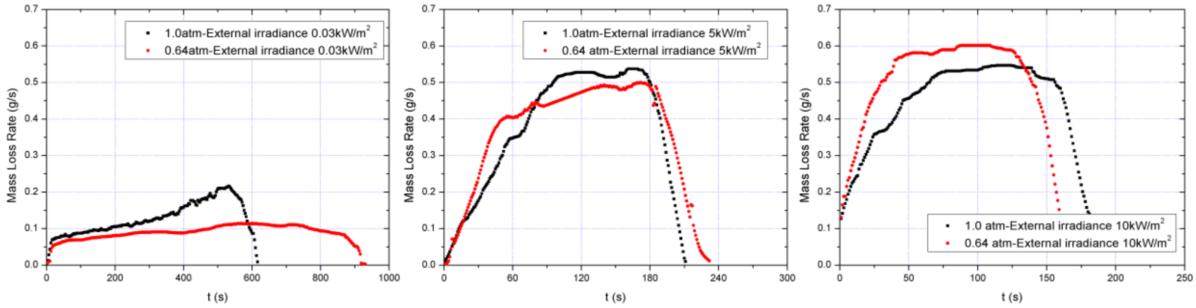

Figure 2 Comparison of mass loss rate under two different pressures

Meanwhile, it is worthwhile to note that for reduced pressure condition, the maximum burning rate at steady stage gradually approaches to the value at normal pressure, and even exceeds it at 10 kW/m^2. Correspondingly, the duration of combustion is gradually shortened with increasing irradiance, and ultimately shorter than the case of 1 atm. In effect, under these two irradiances, the burning intensities are extremely violent, showing significantly higher mass loss rates than the cases of 0.03 kW/m^2.The fact that the differences in mass loss rate between two pressures appears to be vague for irradiances larger than 5 kW/m^2 leads to an inference that a transition region between 0.03~5 kW/m^2 may exist, where the incident radiative heat flux together with the heat feedback from the flame rapidly heat up the liquid fuel to the boiling point, resulting in the drastic, but steady combustion process.

In general, the ambient pressure will influence the boiling point of the fuel. For n-heptane in current study, its boiling temperatures are 98.5 ^oC and 89 ^oC in Hefei and Lhasa [9~10], respectively, which corresponds to the tested pressures in the altitude chamber. Though the thin air for reduced pressure may attenuate the combustion, the mass loss rate may be dominated by the vaporization rate caused by the elevated incident heat flux. As shown in figure 2, as the irradiance reaches to 10 kW/m^2, the burning intensity at lower pressure is higher due to the lower boiling temperature.

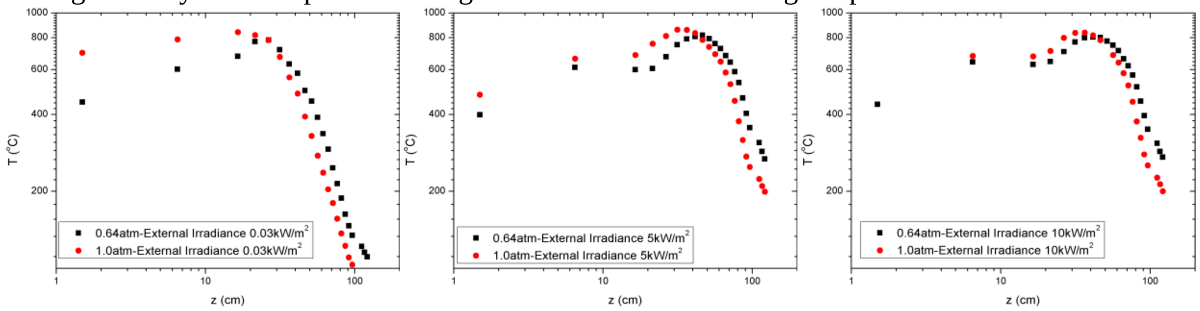

Figure 3 Comparison of centerline temperature distribution under two different pressures

Temperature is the vital parameter in fire analysis, which has been measured along the axis of the burner and plotted in figure 3. The maximum flame temperatures are about 800 ^oC. It is clear that there is a consensus among the three figures, i.e. under low pressure condition, the temperature is smaller at lower vertical height, and subsequently exceeds the temperature at normal pressure. The transition point lies between the measurement points of 30~45 cm.

Here, we simply partition the axial centreline temperature into two regions according to the correlation developed by Heskestad [11]: 1) flame region, where the temperatures are larger than 500 ^oC; 2) the oscillating flame zone and none-combusting plume regions are roughly marked as the unified plume region. As seen in figure 3, the flame temperatures at reduced pressure are lower than that for atmospheric pressure. This may be because in the flame region, the flame could engulf sufficient air to complete the combustion process for atmospheric pressure condition compared with that under low pressure, and thus resulting in relatively higher flame temperature for a fixed flame height. While in the unified plume region, the temperature will gradually decrease due to the cooling effect caused by the air entrainment. Through the experimental investigation on temperature profile of buoyant spill plume in a reduce pressure atmosphere at high altitude, Tang et al., found that the air entrainment of the buoyant spill plume is weaker in the reduced pressure atmospheric, being about 0.8 time of that in the normal pressure condition. Consequently, the weaker air entrainment under lower pressure leads to a poorer cooling effect, i.e. higher plume temperature.

4. Conclusion

In this study, an experimental study of the combustion characteristics of typical oil with forced irradiance were conducted to reveal the pressure effects on mass loss rate and flame axial temperature distribution. The burning intensity at reduced pressure is relatively lower under the circumstance without incident irradiance because the thin air for reduced pressure may attenuate the combustion. However, the burning intensity at lower pressure is higher due to the lower boiling temperature when the irradiance reaches to 10 kW/m^2.The flame could engulf sufficient air to complete the combustion process for atmospheric pressure condition compared with that under low pressure, and thus resulting in relatively higher flame temperature for a fixed flame height. While in the unified plume region, the weaker air entrainment under lower pressure leads to a poorer cooling effect, i.e. higher plume temperature.

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References

[1] Apte, V., 1998. Fire Saf. J., **31**(4) 283-298.
[2] Iwata, Y., Koseki, H., Janssens, M. L., & Takahashi, T. 2001. Fire Mater., **25**(1), 1-7.
[3] Chen, X., Lu, S., Li, C., Zhang, J., & Liew, K. M. 2014. Fire Mater., **38**(3), 409-417.
[4] Li, Z. H., He, Y., Zhang, H., & Wang, J. 2009. Proc. Comb. Inst., **32**(2), 2481-2488.
[5] Hu, X., He, Y., Li, Z., & Wang, J. 2011. Proc. Comb. Inst., **33**(2), 2607-2615.
[6] Hu, L., Tang, F., Wang, Q., & Qiu, Z. 2013. Fuel, **111**, 298-304.
[7] Tang, F., Hu, L., Zhang, X., Zhang, X., & Dong, M. 2015. Fuel, **139**, 18-25.
[8] Luo, M., He, Y., & Beck, V. 1997. Fire Saf. J., **29**(1), 1-25.
[9] Zhou, Z., Wei, Y., Li, H., Yuen, R., & Jian, W. 2014. Int. J. Heat Mass Tran., **70**, 578-585.
[10] Fang, J., Tu, R., Guan, J. F., Wang, J. J., & Zhang, Y. M. 2011. Fuel, **90**(8), 2760-2766.
[11] Heskestad, G. 1983. Fire Saf. J., **5**(2), 109-114.