WHY ARE POOL FIRES ANCHORED?

S. Venkatesh, A. Ito, and K. Saito

Combustion and Fire Research Laboratory
Department of Mechanical Engineering
University of Kentucky
Lexington, KY 40506–0108

ABSTRACT

This paper attempts to answer the question, "Why are small scale pool fires anchored?" by providing and interpreting a new set of experimental data. For momentum–controlled, high Reynolds (Re) number turbulent–jet diffusion flames, the formation of a premixing zone is suggested as the primary reason for the flame anchoring. For buoyancy–controlled pool fires, however, the existence of the premixing zone at the flame base is not clear because both Re and Fr (Froude number) are low. To improve our understanding of the flame anchoring mechanism and structure of buoyancy–controlled liquid pool fires, we employed small scale pool fires whose diameters range between 1.5 – 20 cm. Our measurements include flow visualization by a particle–track laser–sheet technique (PTLS) combined with a high speed video camera and temperature profiles by a fine thermocouple. We found from those measurements that major air entrainment occurred through the primary anchoring zone, PAZ, which consists of a small area covering approximately 1 cm high and around the circumference just above the dark zone; while air entrainment through the quenching zone (a dark zone formed between the visible flame edge and the burner port) was negligible. The structure of the PAZ was found to be premixed flame (another interpretation may be it is similar to counter–diffusion flame). This enables the pool fires to anchor at the burner port. In addition, we visualized the existence of a vortex ring at a stagnation zone in the fuel vapor phase for both propanol and hexane pool fires, in agreement with qualitative observation by other workers.

OBJECTIVES

(1) Understanding the mechanism of flame anchoring in pool fires. We investigate if and how the PAZ controls the flame anchoring. The cross–sectional area of PAZ is at most 1 cm high x 1 cm wide in radial direction consisting of the pan's brim surface, a sub–millimeter size dark (quenching) zone, a millimeter–size visible leading flame edge, and an extended (believed to be diffusion controlled) flame zone. We divided McCaffray's continuous flame zone into three subzones: the quenching zone, PAZ, and post PAZ, and studied each zone thoroughly. Figure 1 shows a schematic of the five–zone structure.

Much work has been conducted on the stability and liftoff of laminar and turbulent jet diffusion flames. The common understanding is that premixing occurs near the base and is responsible for anchoring and stabilization. The results by Takahashi et al. on turbulent jet diffusion flames show mixing of the fuel and air through a circulation zone established at the burner rim due to strong shear stresses, leading to flame anchoring. For liquid pool fires, Bouhafid et al suggested the formation of a premixed reaction zone as the mechanism of flame anchoring due to the observed strong radial component of the air velocity induced by the plume. We think that in a pool fire, the fuel and oxidizer velocities at PAZ are much smaller, perhaps insufficient to produce shear stress induced circulation zones observed for the turbulent jet diffusion flames.

(2) Understanding of the mechanism of air entrainment at PAZ and other heights. According to Bouhafid et al and this study, convective air entrainment likely occurs at PAZ in order to satisfy mass conservation because of the rapid acceleration of the

buoyant gases in the flame interior. In the intermittent region, however, air entrainment occurs mainly by relatively large–scale buoyancy–induced mixing as explained by Weckman et al, Zhou and Gore and Cetegen. In the post–PAZ region where the flame is a pseudo laminar continuous flame, air streamlines are parallel to the visible flame surface (to be shown in Fig. 3), and air transport to the flame surface is by diffusion.

(3) Experimental confirmation of the stagnation and re–circulation zone. Based on thermocouple temperature and CO, CO_2 concentration measurement data, Bouhafid et al predicted the existence of a stagnation and re–circulation zone in the fuel–vapor phase just above the liquid fuel surface. Yet there is no experimental data to directly verify their prediction; therefore, flow–visualization experiments were conducted in order to examine the proposed stagnation and re–circulation zones.

SUMMARY AND CONCLUSIONS

(1) Based on our experimental measurements on pool fires in diameter of 1.5 – 20 cm of propanol and hexane, and finite–rate chemistry concepts, the entire flame sheet of a pool fire is established to have a triple flame structure. The structure of the flame at the base was established from PTLS data and through a comparison of the location of the flame sheet in the convective–air entrainment zone for fuels with different stoichiometric fuel–air requirements.

(2a) Air entrainment through the quenching zone was found to be a small fraction of the net air entrainment near the base for the pool fires. Our data show that the ratio of the total mass of air entrained into the flame interior through PAZ to the total mass of air entrained through the quenching zone was 0.05.

(2b) The fluid–dynamic structure of the anchoring mechanism of a buoyancy–dominated small scale pool fire and a momentum–dominated jet diffusion flame is different. In a jet diffusion flame, the Reynolds shear stress near the rim of the burner induces a stagnant re–circulation zone where the fuel and the oxidizer are mixed and the flame anchors. To the contrary, in a pool fire the shear stresses at the rim are two orders of magnitude lower and turbulent mixing does not occur. Finite–rate chemistry establishes the presence of a molecular–diffusion mixing zone. Therefore, the flame anchors at the base.

(3) For both propanol and hexane pool fires with their diameter range between 1.6 cm and 10 cm, the formation of the stagnation re–circulation zone predicted by Bouhafid et al was experimentally confirmed.

ACKNOWLEDGEMENTS

We would like to thank F.A. Williams, A.S. Gordon and T. Hirano for their valuable comments. This study was supported in part by the National Institute of Standards and Technology under grant #60NANB1D1123, in part by NASA–Kentucky EPSCoR program and in part by the Center for Manufacturing Systems at the University of Kentucky.

REFERENCES

Venkatesh, S., Ito, A., Saito, K., and Wichman, I.S., Twenty–sixth International Symposium on Combustion, The Combustion Institute, 1996. to appear.

Qian, C., Tashtoush, G., Ito, A., and Saito, K., Proc. International Conference on Fire Research and Engineering, Edited by D.P. Lund., Society of Fire Protection Engineering, 1995.

Tashtoush, G., Narumi, A., Ito, A., Saito, K., and Cremers, C.J., Proc. Eight International Symposium on Application of laser Techniques to Fluid Mechanics, Lisbon, Portugal, 1996.