Engineering Notes

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Burning Sprays of Jet A Fuel-Water Emulsions

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Introduction

SINCE emulsification of fuels with water has been shown to be beneficial for reducing pollutant emissions in spray combustors such as furnaces[1] and diesel engines,[2] it appears to be a potential method for curtailing the emissions of smoke and NO_X from jet engines. However, the high volatility of jet fuel tends to lessen the beneficial effects of emulsification on combustion. Although one full-size gas turbine combustor study[3] using JP-5 fuel-water emulsions has indicated that exhaust smoke can be reduced, it appears necessary to perform some diagnostic studies of the effects of emulsion parameters on the flame characteristics of burning sprays before the potential benefits of emulsification are fully realized.

The surfactant and water contents can affect the microstructure[4] and physical properties of emulsions.[5] Also, they can influence the fuel/air mixing rate and flame temperature, because of the possible disruption of drops and additional diluents in the flame. Hence, this Note presents some of the results of a detailed study[4] of the characteristics of burning Jet A fuel-water emulsions and deals with the effects of 1) adding surfactant to the fuel, 2) varying the surfactant concentration in emulsions, and 3) varying the water concentration of emulsions on a) flame stand-off distance, b) flame length, c) flame spread, and d) the fraction of heat release radiated by burning sprays over an air-blast atomizer.

Experiment

These studies were performed using the fuel nozzle of a TF-41 (Detroit Diesel Allison Division) combustor modified to function as an air-blast atomizer. The emulsions of Jet A fuel, water, and surfactant were prepared using a high-speed mixer. The surfactant was a mixture of 75% SPAN 80 and 25% TWEEN 85 (ICI America, Delaware) and had a HLB (Hydrophile Lipophile Balance) of 6. The flames were photographed in color to record the changes in appearance, flame length, and flame stand-off distance. The total radiant power emitted from the flame was measured with a wide view angle (150°) radiometer, and the fraction of heat release radiated was calculated using the procedure adopted in Ref. 6. The details of the experimental set-up, procedure, and emulsion characteristics are given in Ref. 4.

Results

From the color photographs of the flames, the following points were noted: 1) the air-blast atomized pure Jet A fuel flame has a bluish core and light yellowish periphery at low fuel rates, and an increase in fuel flow rates turns the periphery intensely yellowish, 2) the addition of a surfactant to fuel reduces the bluish color of the flame core; 3) the increase in water content of emulsions decreases the luminosity and yellow color of the entire flame.

Figure 1 shows the variation of the distance from the nozzle at which the flame stabilizes with flow rate and characteristics of emulsions. The letters *F, W,* and *S* indicate the fuel, water, and surfactant content of emulsions. It is seen that: 1) the addition of surfactant to pure fuel does not change the flame stand-off distance; 2) the increase of surfactant concentration in emulsions decreases flame-stand-off distance; and 3) the increase in water content of emulsions does not show any systematic effect on flame stand-off distance. The negligible effect of surfactant when added to pure fuel suggests that the evaporation characteristics of fuel droplets, which determine the fuel vapor concentration in the near-nozzle region, are not significantly affected. The decrease of flame stand-off distance with the increase of surfactant concentration in emulsions is primarily caused by the reduction in the internal

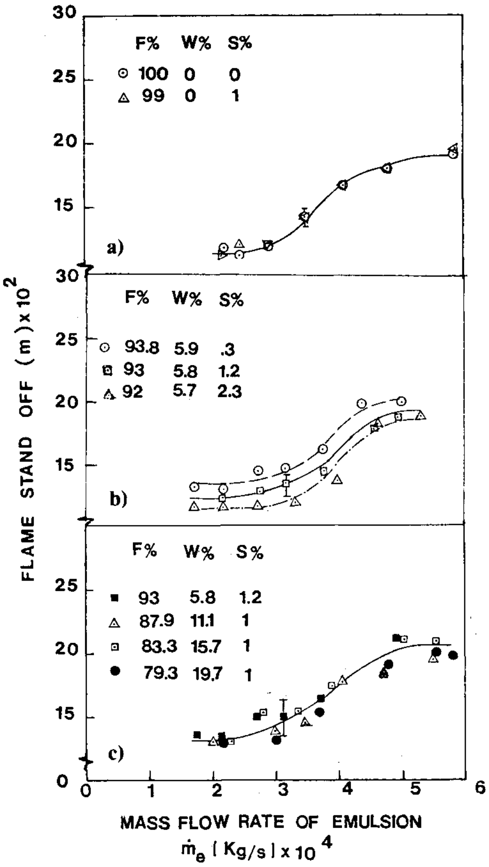

Fig. 1 Effects of a) surfactant addition to pure Jet A fuel; b) surfactant concentration in Jet A fuel-water emulsions; and c) water concentration in Jet A fuel-water emulsions on flame stand-off distance of sprays burning over an air-blast atomizer.

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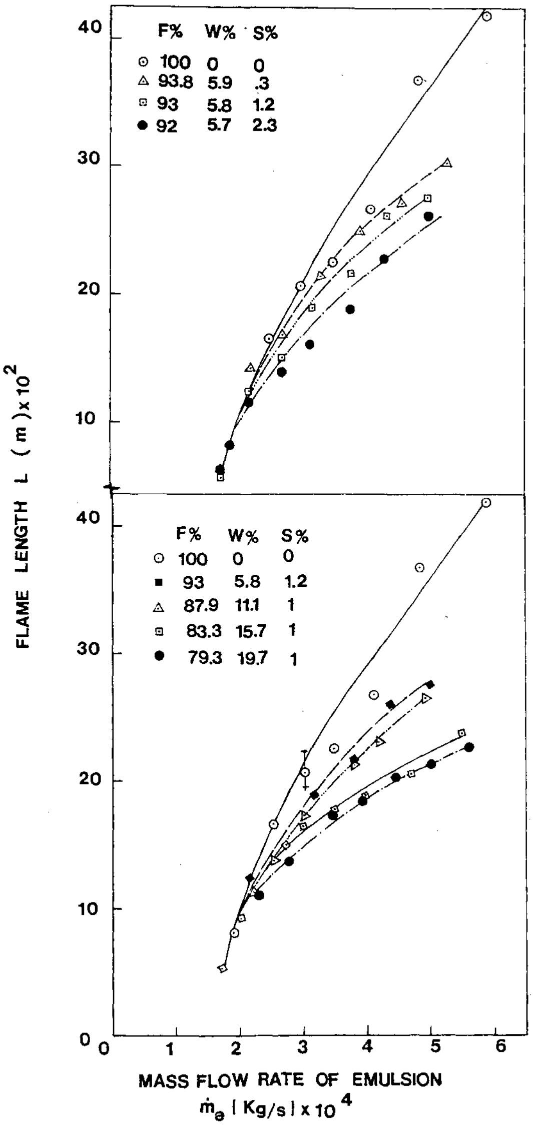

Fig. 2 Effects of surfactant and water concentrations in Jet A fuel-water emulsions on the flame length of sprays burning over an air-blast atomizer.

phase droplet size of emulsions. The decrease of internal phase drop size increases the heating and evaporation rates of drops and thus increases the flame velocity of propagation in the near-nozzle region, which moves the location of flame upstream. Also, the counteracting effects of water on the vaporization of emulsion droplets through its thermal sink effect and decrease of endothermic pyrolysis reactions (such as reactions where the heavier hydrocarbon molecules crack into lighter molecules absorbing energy from the system) are the probable reasons for the absence of any systematic variation of the flame stand-off distance with changes in water content.

The effects of surfactant and water concentrations of emulsions on the length and maximum width of the flames are shown in Figs. 2 and 3. The addition of surfactant to pure fuel (not shown in these figures) did not change either flame length or flame spread. It is seen that: 1) the flame length decreases with the increase of both water and surfactant concentrations; 2) the maximum flame width decreases with the increase in surfactant content; and 3) the maximum flame width decreases up to a water content of 5.8%, and then increases with further addition of water. The decrease of flame length of emulsion sprays with increase in surfactant and water concentrations are primarily caused by the reduction of burning soot[4] and the enhancement of gas-phase combustion.

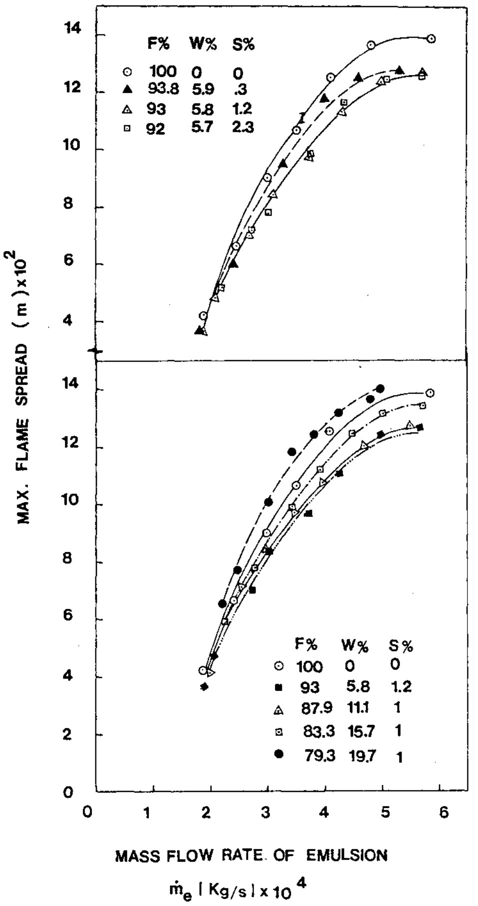

Fig. 3 Effects of surfactant and water concentrations in Jet A fuel-water emulsions on the maximum flame width of sprays burning over an air-blast atomizer.

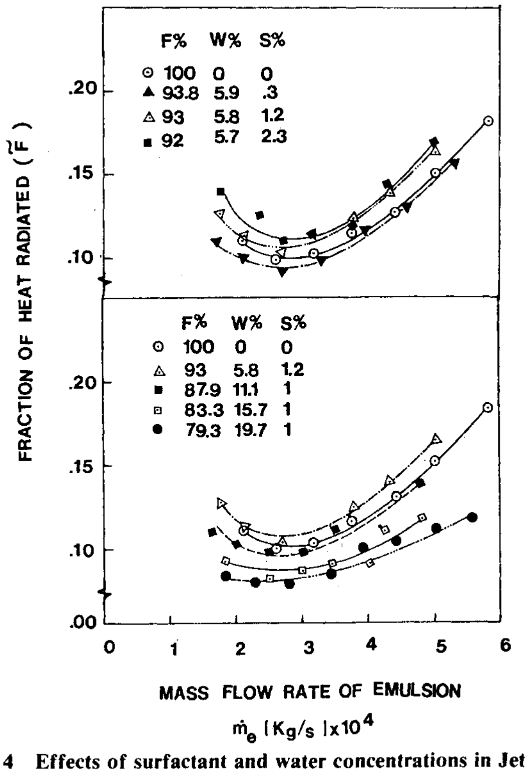

Fig. 4 Effects of surfactant and water concentrations in Jet A fuel-water emulsions on the fraction of heat release radiated from sprays burning over an air-blast atomizer.

Figure 4 shows the effects of emulsion characteristics on the fraction (F) of heat release radiated by the emulsion spray flames. It is noticed that 1) the fraction of heat release radiated decreases with small additions of surfactant, but with larger concentrations of surfactant it increases again, and 2) the fraction of heat release radiated increases with small water content and decreases with large water concentrations. When large quantities of surfactant and small quantities of water are present, the internal phase drop size becomes small as shown by the micrographs.[4] At those conditions, it is possible that fuel-air mixing is enhanced by the so-called micro-explosions caused by the evaporation of internal phase droplets. That would result in higher temperature levels, as found in Ref. 4, and increase the amount of flame radiation. However, with large concentrations of water and small amounts of surfactant, both flame temperatures and burning soot concentrations decrease, and hence, the fraction of heat release radiated from the flames is lowered. Thus, it seems that the effects of emulsion variables on flame characteristics are not monotonic. Hence, a properly matched set of emulsion characteristics would be necessary to exploit the benefits of emulsification.

References

[1] Hall, R.E., "The Effect of Water-Distillate Oil Emulsions on Pollutants and Efficiency of Residential and Commercial Heating Systems," Paper 75-09-4, presented at the Air Pollution Control Association Meeting, Boston, Mass, June 1975.

[2] Greeves, G., Khan, I.M., and Onion, G., "Effects of Water Introduction on Diesel Engine Combustion and Emissions," *Sixteenth Symposium (International) on Combustion*, The Combustion Institute, Pittsburgh, Pa. 1977, pp. 321-335.

[3] Moses, C.A., "Reduction of Exhaust Smoke from Gas Turbine Engines by Using Emulsions," Paper 75-18, presented at the Western States Section (Combustion Institute) Meeting, Palo Alto, Calif., Oct. 1975.

[4] Jahani, H., "Flame Structure of Burning Jet Fuel and Jet Fuel-Water Emulsion Sprays," M.S. Thesis, Mechanical Engineering, The University of Oklahoma, Norman, Okla., March 1979.

[5] Fogler, H.S., Reddy, S.R., Storbeck, M.L., Cross, J.B., and Siegmund, S.C., "Physical Properties and Stability of Water in Fuel Oil Emulsions," Rept. DOT/RSPA/DPB-50/78/17, U.S. Department of Transportation, Washington, D.C., March 1979.

[6] Brzustowski, T.A., "Gollahalli, S.R., Gupta, M.P., Kaptein, M., and Sullivan, H.F., "Radiant Heating from Flares," ASME Paper 75-HT-4, 1975.