

Fuel-dependent Effects on Droplet Burning and Sooting Behaviors in Microgravity

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Measurements of soot concentration and soot mass were performed in microgravity conditions for hexane, heptane, nonane, and decane droplets burning in air at the NASA Glenn Research Center (GRC) 2.2 s drop tower in Cleveland, OH. Experiments performed in air at 75.9 and 101.3 kPa indicate that the maximum soot volume fractions and soot mass are similar, to within experimental uncertainty, for all of the fuels tested. The flame standoff ratios (FSR) did not vary significantly for the fuels considered. The soot standoff ratio for decane was significantly smaller than for the other fuels.

Introduction

The presence of soot in combustion systems results in hardware fouling and increased operational costs. On the other hand, soot formation is a necessary component in many industrial processes. For example, it is known that the presence of soot enhances radiative heat transfer, which is of extreme importance in industrial furnace applications. Therefore, methods must be devised to effectively control soot emission from combustion processes for selective applications. One method to control soot emission from combustion systems that employ non-premixed flames involves the use of alternative fuels and the blending of fuels of varying sooting propensity.

The most extensive effort to characterize the influence of fuel structure on sooting propensity for nonpremixed flames employed the laminar gas jet flame configuration.¹ In these investigations, the fuel flow rate was increased until smoke was observed to escape from the luminous visible flame.¹ The sooting propensity of a particular fuel was assessed by comparing the flow rates for soot emission from the tip of the flame. The higher the fuel flow rate at the smoke height corresponded to a lower sooting propensity. Furthermore, these comparisons were performed at the same adiabatic flame temperature for each fuel. Controlling the flame temperature has been determined to be a necessary component to gauge relative sooting tendency of a particular fuel since the temperature defines the pyrolysis rate of the fuel.² It was reported that the sooting tendency for non-premixed flames increased for fuels with higher rates of

pyrolysis and the sooting tendency was found to obey the following order:

benzene > allene > butadiene > butanes > acetylene

Since many combustion processes involve introducing a multitude of droplets in the form of a highly atomized spray into the combustor, attempts to reduce soot emission from spray combustors can be assisted by analyzing the burning behavior of individual droplets. Although sooting tendencies have been sufficiently determined for a variety of fuels for laminar jet diffusion flames,^{1–3} extrapolation of results to droplet flames can result in erroneous conclusions.¹

Kadota et al.⁴ investigated the influence of fuel structure on soot formation for normal gravity droplet combustion. The fuels studied were pentane, heptane, decane, dodecane, hexadecane, and methylcyclopentane. It was reported that for the range of alkanes tested (pentane to hexadecane), the mass of soot formed per unit mass of fuel increased with an increase in the number of carbon atoms in the fuel.

Kadota and Hiroyasu⁵ first used optical diagnostics to determine soot concentration for normal gravity droplet flames. The fuels used in this study consisted of benzene, toluene, xylene, and pseudocumene. The measured scattered light intensity was equated to the mass concentration of soot by assuming constant soot optical and physical properties. The amount of scattered light (assumed to be proportional to soot concentration) increased as the C/H of the fuel was increased.

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(1) Glassman, I. *Proc. Combust. Inst.* **1988**, *22*, 295–311.

(2) Glassman, I.; Yaccarino, P. *Proc. Combust. Inst.* **1981**, *18*, 1175–1183.

(3) Ladommatos, N.; Rubenstein, P.; Bennett, P. *Fuel* **1996**, *75*, 114–124.

(4) Kadota, T.; Hiroyasu, H.; Farazandehmehr, A. *Combust. Flame* **1977**, *29*, 67–75.

(5) Kadota, T.; Hiroyasu, H. *Combust. Flame* **1984**, *55*, 195–201.

Randolph and Law⁶ examined the effect of fuel structure on normal gravity droplet combustion. A variety of fuels were studied, namely aromatics, phenyl-alkanes, and alkanes. The order of sooting tendency, from highest to lowest, was:

aromatics > phenyl-alkanes > alkanes

This order of sooting tendency was in qualitative agreement with laminar gas jet non-premixed flame studies.⁶

Kitano et al.⁷ determined the sooting limit of droplet flames in normal gravity. The fuels studied included heptane, decane, tetradecane, benzene, toluene, heptylbenzene, and dodecylbenzene. The degree of sooting was assumed to increase with a decrease in transmitted light measured by the phototransistor. For pure fuel droplets, it was reported that below a certain initial droplet diameter, soot was not detected (i.e. the transmittance was equal to 1). This diameter was thus defined as the sooting limit diameter. Kitano et al.⁷ concluded that for the two fuels that provided measurable limit diameters (n-heptylbenzene, n-dodecylbenzene), the order of sooting tendency, namely, that n-dodecylbenzene soots less than n-heptylbenzene, was in agreement with laminar non-premixed flame studies.

Vander Wal and Dietrich⁸ performed relative soot concentration measurements using laser-induced incandescence for heptane and decane fuel droplets burning under normal-gravity conditions. It was reported that the average soot volume fraction for decane was more than a factor of 2 larger than that for heptane.

The normal-gravity droplet combustion investigations have provided important insights regarding the influence of fuel structure on the sooting behavior of droplet flames under practical situations.⁹ However, since these experiments were performed under normal gravity, results from these studies are not readily amenable to modeling efforts directed to understand soot formation processes.⁹ To this end, microgravity experiments investigating the influence of fuel structure on sooting characteristics can be used. Laminar gas-jet non-premixed flame studies also represent a well-controlled geometry for investigating the influence of fuel structure on sooting tendency. However, such flames are steady, limiting investigation of sooting under steady-state conditions. Microgravity droplet flames allow investigation of sooting behavior for different fuels under transient conditions since diffusive, convective, and thermophoretic transport occurs only in the radial direction, which allows flexibility in investigating transport characteristics of heat and species related to soot formation. Therefore, research has been initiated looking at the influence of fuel type on sooting in microgravity droplet combustion.

Jackson et al.¹⁰ performed microgravity droplet combustion experiments using heptane and monochlorinated alkanes. It was reported that monochloroalkane droplets produced significantly more soot than heptane droplets. Soot concentration was not measured; the different sooting tendencies were based on visual observation of the soot-containing region. Additional microgravity studies have been performed using different alkane fuels,

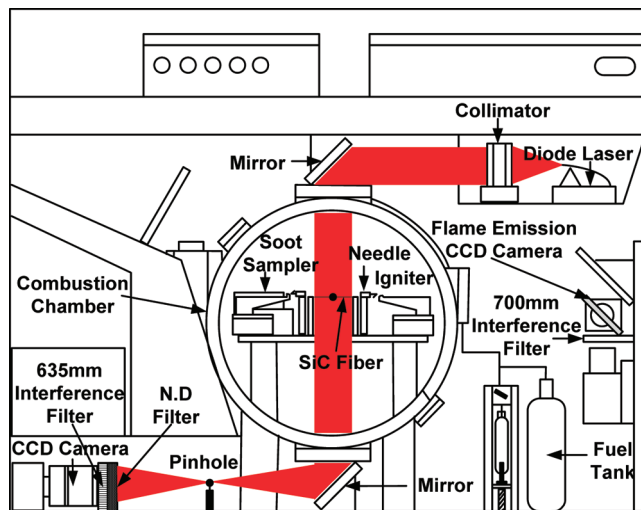


Figure 1. Schematic of experimental apparatus used for microgravity experiments.

but soot diagnostic capability in these studies was also limited to incandescent back-lighting.^{11–13}

In all of the previous microgravity droplet combustion studies,^{11–13} the degree of sooting was only visually assessed from an incandescent backlighted image of the soot containing region. Visual observation is limited due to the nonlinear nature of human vision to distinguish between light, dark, and shades in between. Although this method is adequate for identifying whether or not soot is produced in a given flame, quantitative information cannot be evaluated. Consequently, the motivation of the present study was to perform spatially and temporally resolved soot volume fraction measurements for different alkane fuels burning under microgravity conditions. To overcome this impediment toward a better understanding of sooting microgravity droplet flames, full-field light extinction and tomographic inversion techniques were used to accurately measure the soot volume fraction in the present study. The fuels considered were hexane, heptane, nonane, and decane. These fuels were selected since they are constituent components of practical fuels.

Experimental Description

Experiments were performed at the NASA-GRC 2.2 s drop tower. A detailed description of the NASA-GRC 2.2 s drop tower can be found elsewhere.¹⁴ The experimental apparatus is displayed in Figure 1. The central component of the experimental apparatus is the 12 L stainless steel combustion chamber that contains the fuel delivery system, droplet generator, and the ignition assembly. During the microgravity experiments, the fuel droplets were generated using two opposed hypodermic needles of 0.25 mm diameter that are separated by 0.5 mm. Fuel was pumped through the needles by a 1.0 mL solenoid-activated syringe attached to each needle. Each hypodermic needle was attached to a separate rotating galvanometric device. The dispensed fuel formed a liquid bridge and the rapid rotation of the needles in opposite direction deposited the droplet onto a long 15 μm diameter SiC fiber. The fiber was used to fix the location of the droplet and prevent the droplet from moving out of the field of view. The liquid fuel droplet was ignited using two horizontally opposed hot-wire igniters.

(11) Shaw, B. D.; Dryer, F. L.; Williams, F. A.; Haggard, J. B., Jr. *Acta Astronaut.* **1988**, *17*, 1195–1202.

(12) Jackson, G. S.; Avedisian, C. T. *Proc. R. Soc. London A.* **1994**, *446*, 255–276.

(13) Callahan, B. J.; Avedisian, C. T. Combustion of Nonane Fuel Droplets in Microgravity, AIAA Paper: 99 1077; AIAA: 1999.

(14) Manzello, S. L.; Choi, M. Y. *Int. J. Heat Mass Transfer* **2002**, *45*, 1109–1116.

(6) Randolph, A. L.; Law, C. K. *Combust. Flame* **1986**, *64*, 267–284.

(7) Kitano, M.; Kobayashi, H.; Sugimoto, T. *Combust. Sci. Technol.* **1991**, *78*, 19–31.

(8) Vander Wal, R. L.; Dietrich, D. L. *Appl. Opt.* **1995**, *34*, 1103–1107.

(9) Avedisian, C. T., Soot Formation in Spherically Symmetric Droplet Combustion. In *Physical and Chemical Aspects of Combustion*; Dryer, F. L., Sawyer, R. F., Eds.; New York: Gordon and Breach, 1996; pp. 135–160.

(10) Jackson, G. S.; Avedisian, C. T.; Yang, J. C. *Int. J. Heat Mass Transfer* **1992**, *35*, 2017–2033.

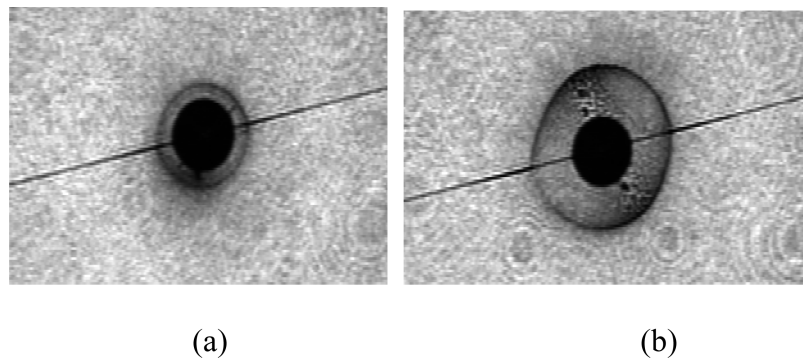


Figure 2. Laser-backlit images of decane and hexane droplets burning in air at 75.9 kPa. (a) Decane and (b) hexane.

For soot light extinction measurements, light from a 635 nm diode laser attached to a single-mode fiber optic cable was expanded to 50 mm diameter. The variation of the laser intensity over the field of view was less than 3% in order to maintain the highest signal-to-noise ratio. The expanded and collimated beam was directed through the top optical port of the combustion chamber using a front-reflecting 75 mm diameter mirror positioned at 45°. The optical port was fitted with a 50 mm diameter quartz window treated with a broadband antireflection coating. The beam was transmitted through the combustion chamber and then focused using a second 75 mm mirror positioned at 45°. The reflected beam was then imaged through a spatial filter to an 8 bit high-resolution CCD camera (with a frame rate of 30 fps) located on the bottom optical plate. A 105 mm f/1.8 camera lens was used to obtain the magnification required to spatially resolve the droplet and the soot-containing region. An image quality interference filter of wavelength 635 nm with a full-width, half-max bandwidth of 10 nm and an absorption neutral density filter of optical density of 3.0 were placed directly in front of the camera lens to eliminate flame emission.

In the present study, the soot volume fraction measurement was measured using the full-field light extinction/tomographic inversion technique. In this technique, the line-of-sight projection data can be related to the transmittance of the light (expressed by Bouguer's law) through the soot-containing region:

$$\frac{I}{I_0} = \exp\left(-\frac{K_e f_v L}{\lambda}\right) \quad (1)$$

where I is the transmitted intensity, I_0 is the incident laser intensity, K_e is the extinction constant of soot (which was determined using the light-extinction/gravimetric calibration technique¹⁵), f_v is the soot volume fraction, L is the path length of the laser light, and λ is the wavelength of the laser light. The equation for projection values (associated with soot volume fraction) can be then rearranged as:

$$P_{fv}(x) = \int_{-\infty}^{+\infty} f_v(r) dy = -\frac{\lambda \ln\left(\frac{I}{I_0}\right)}{K_e} \quad (2)$$

To obtain the projection values, P_{fv} , the intensity ratio distributions (I/I_0) were calculated by dividing the gray-level values (I) for the soot-attenuated images along the line analysis by the corresponding intensities (I_0) measured for the background images (which was captured prior to droplet ignition). The measured intensity ratio distribution was then averaged using a moving 5-point operator. Finally, soot volume fraction distributions were obtained by applying a three-point Abel inversion to the projected light extinction measurements.¹⁶

The droplet diameter was determined by digitizing the laser backlit images of a droplet as a function of time. Once the droplet combustion apparatus was released into free-fall, the laser-backlit images of the droplet were captured at 30 fps by an 8 bit high-resolution CCD camera (the same camera used to measure the soot volume fraction). The laser backlit images obtained were then digitized frame-by-frame with a high-resolution frame acquisition software and an image processing board. To accurately measure the droplet diameter with time, each digitized image of the laser backlit droplets was analyzed to distinguish the droplet from the background by applying appropriate graylevel thresholds. The threshold droplet diameter at each frame was then calculated using the Feret mean diameter method where the average value of 6 diameter measurements at various angles are used to calculate the mean droplet diameter. This technique was preferred over the area mean diameter method, which was found to be sensitive to the threshold value that was used to differentiate the droplet from its background.

The luminous droplet flames were imaged using an 8 bit high-resolution CCD camera through the eastern optical port of the combustion chamber (see Figure 1). A 300 mm plano-convex lens was placed in front of the optical port to improve spatial resolution by magnifying the flame image. Additionally, the neutral density filter was used to obtain unsaturated flame images. The flame diameter was then determined by measuring the spatial extent of the luminous region of the SiC fiber (the same fiber used to tether the droplet) using a digital image processing technique.

Results and Discussion

Soot volume fraction was measured for hexane, heptane, nonane, and decane droplets burning in air at 75.9 kPa. The initial droplet size ranged from 1.46 to 1.53 mm for all droplets. Analysis of similar-sized droplets was essential since the initial droplet size is known to affect the residence time within the fuel-rich region and thus cause variations in the degree of sooting.¹⁷ Reduction in pressure was necessary to circumvent the large signal attenuation that was observed in some of the experiments. Pressure reduction is a proven method for reducing sooting in microgravity droplet combustion.¹⁸

Figure 2 displays the laser-backlit images of decane and hexane droplets burning in air at 75.9 kPa. As shown in the figure, the magnitude of sooting for both fuels is quite similar, but the sootshell for decane exists closer to the droplet surface compared to hexane. A sootshell in microgravity droplet flames is formed due to the counteracting influences of thermophoretic flux, which transport the soot particles formed near the flame front toward the droplet, and Stefan flux, which transports the particles away from the droplet.^{12,13} Since Stefan and thermo-

(15) Choi, M. Y.; Mulholland, G. W.; Hamins, A.; Kashiwagi, T. *Combust. Flame* **1995**, *102*, 161–169.

(16) Manzello, S. L.; Choi, M. Y.; Kazakov, A.; Dryer, F. L.; Dobashi, R.; Hirano, T. *Proc. Combust. Inst.* **2000**, *28*, 1079–1086.

(17) Lee, K. O.; Manzello, S. L.; Choi, M. Y. *Combust. Sci. Technol.* **1998**, *132*, 139–156.

(18) Lee, K. O.; Choi, M. Y. *Int. J. of Microgravity Sci. Tech.* **1997**, *X2*, 86–94.

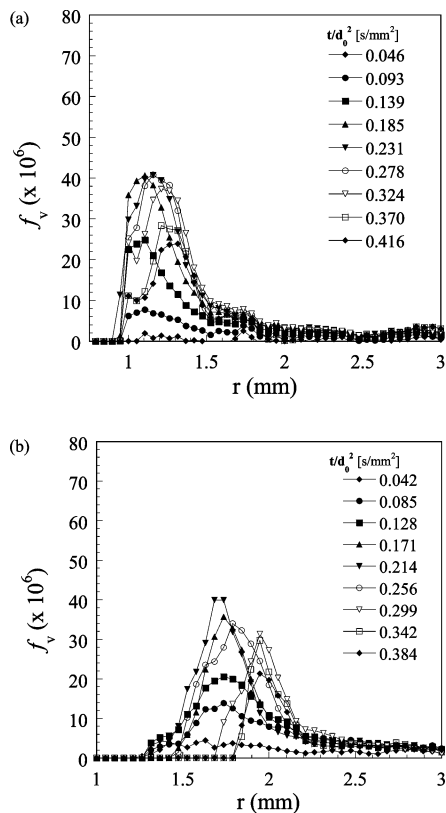


Figure 3. Soot volume fraction distributions as a function of time. (a) Decane and (b) hexane.

phoretic fluxes are strongly affected by the droplet burning rate and flame temperature, respectively, the sootshell location mainly varies due to the differences in these parameters among fuels. It is well-known that the radiative emission from the soot particles formed within microgravity droplet flames can reduce the flame temperature, leading to a reduction in the burning rate.^{16,17} Therefore, the formation of soot particles also has an indirect influence on the sootshell location through radiative heat losses, making it difficult to accurately determine the sootshell location. Nevertheless, the investigations of droplet burning rate and flame temperature of each fuel can give an idea of estimating of the sootshell location. For example, the closer proximity of sootshell for decane relative to hexane may be explained by differences in these parameters. Decane has a similar adiabatic flame temperature (2277 K) to hexane (2273 K). The actual flame temperatures for each fuel are expected to be lower due to radiative heat losses caused by the presence of soot particles within the flames. However, due to similar magnitude of soot yield for each fuel (see Figure 3), flame temperatures are expected to be close to each other, which results in a similar magnitude of thermophoretic force acting upon the soot particles. Hexane produces a higher droplet burning rate (0.72 mm/s²) compared to decane (0.62 mm/s²) resulting in the increased Stefan flow for hexane. Therefore, the increased Stefan flow for hexane may transport the soot particle further away from the droplet, producing the larger sootshell compared to decane.

Figure 4 displays the measured maximum soot volume fraction, $f_{v,max}$ at 75.9 kPa for each fuel as a function of the number of carbon atoms. For each fuel investigated in the present study, the $f_{v,max}$ was determined from temporal measurement of soot volume fraction (see Figure 3). The uncertainty in the measurement of soot volume fraction using the full field light extinction technique is mainly associated with fluctuations in the laser/detector combination. The influence of measured

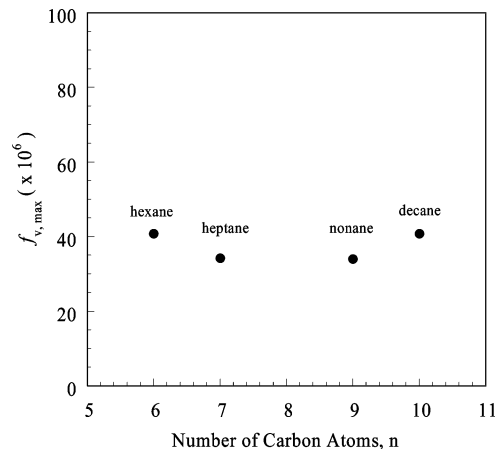


Figure 4. Maximum soot volume fraction as a function of the number of carbon atoms in the fuel.

laser/detector fluctuation on the soot concentration varies with the level of attenuation through the soot-containing region. A typical fluctuation (3%) in the measured laser intensity ratio (I/I_0) causes a 7.5 ppm change ($\pm 15\%$) in soot volume fraction calculation using 3-point Abel inversion for a case when the soot volume fraction is 50 ppm. In microgravity droplet flames, the sooting propensity is defined by the rate of soot production and the subsequent “trapping” of the soot particles as they are transported and collected within the sootshell. If the efficiency of the transport of the soot particles from the location of soot formation to the sootshell is similar for all cases, then the sooting tendency is controlled by the rate of soot formation. In a prior experiment by Kadota et al.,⁴ the soot mass emitted from open-tipped flames of various fuel droplets burning in normal-gravity was measured. The mass of soot formed per unit mass of fuel can be obtained from the trends observed by Kadota et al.⁴ On the basis of their data, the percentage of soot formed increased from 6% for hexane and 8% for decane, with heptane and nonane bounded by these two limits. Therefore, the soot produced in the normal-gravity environment (in the absence of the trapping mechanism of thermophoresis) was similar for all of the fuels.

To determine whether similarities in sooting propensity exist for the microgravity flames, the soot mass contained within the flame was calculated. It is possible for droplets to have similar magnitude of soot volume fraction but different magnitudes in sooting due to the extent of soot-containing region and the location of the sootshell. In this study, the mass of soot was calculated by integrating the soot volume fraction distribution with respect to the volume of the soot-containing region and multiplying by the density of soot. The soot density used was 1.8 g/cm³.¹⁵ The maximum mass of the soot for hexane, heptane, nonane, and decane experiments are 1.37, 1.27, 1.29, and 1.39 μg , respectively. The maximum mass of soot was selected from the integration of temporal soot volume fraction distribution for each of the fuels (see Figure 3). This analysis suggests that, to the extent of the uncertainty inherent in our experimental measurements, the sooting propensity for the alkane fuels tested is similar under microgravity conditions.

The soot standoff ratio (SSR) and flame standoff ratio (FSR) were measured for hexane, heptane, nonane, and decane droplets burning in air at both 101.3 and 75.9 kPa. The uncertainty in these measurements was less than $\pm 5\%$. The FSR is defined as the ratio of the instantaneous flame diameter to the instantaneous droplet diameter. The SSR is defined as the ratio of the instantaneous sootshell diameter to the instantaneous droplet diameter. Figures 5 and 6 display the measured FSR and SSR

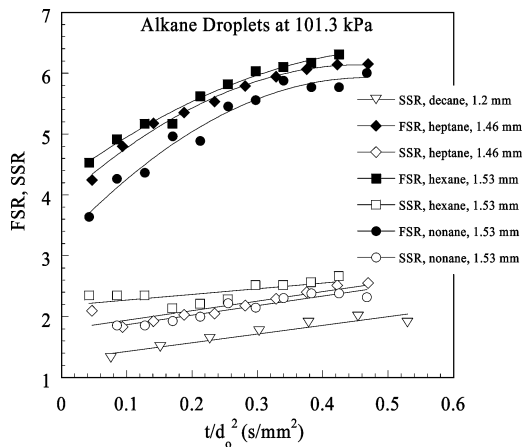


Figure 5. Flame standoff ratio (FSR) and soot standoff ratio (SSR) as a function of fractional burning time for various droplets burning in air at 101.3 kPa.

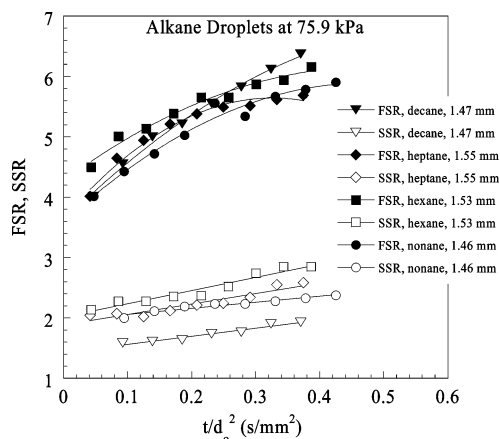


Figure 6. Flame standoff ratio (FSR) and soot standoff ratio (SSR) as a function of fractional burning time for various droplets burning in air at 75.9 kPa.

as a function of fractional burning time for 101.3 and 75.9 kPa, respectively. When comparing the FSR for all fuels at 101.3 kPa, the FSR was observed to increase as a function of time in accordance with the fuel vapor accumulation effects.¹⁹ Dramatic differences in the magnitudes of the FSR were not observed when comparing the burning of different fuels. In addition, the FSR increased for each fuel and did not reach a maximum value during the observation period. This was due to the fact that the limited microgravity times did not allow a significant fractional burning of the fuel droplet.¹⁷ What is striking is that the SSR for decane is significantly smaller than for the other fuels. The trend of increasing SSR was observed to occur in the following order:

$$\text{decane} < \text{nonane} < \text{heptane} < \text{hexane}$$

Similar behaviors were observed for the measured FSR and SSR for experiments performed at 75.9 kPa. In addition, the magnitude of the FSR measured at 75.9 kPa was similar for all fuels and was in good agreement with experiments performed at 101.3 kPa. For example, at a fractional burning time of 0.37, the FSR was 6.0 at 101.3 kPa and 5.7 at 75.9 kPa for heptane. Similarly, at a fractional burning time of 0.38, the FSR was 6.1 at 101.3 kPa and 6.1 at 75.9 kPa for hexane. Therefore, the FSR was relatively insensitive to ambient pressure.

The d^2 -law analysis of the FSR suggests the following relationship:

$$\frac{r_f}{r_s} = \frac{\ln[1 + B]}{\ln[1 + im_{\infty}]} \quad (3)$$

where r_f is the flame radius, r_s is the droplet radius, B is the transfer number, i is the stoichiometric index, and m_{∞} is the mass fraction of oxidizer far removed from the flame (infinity). The only term that is sensitive to the pressure is the transfer number, B , which is dependent on the latent heat of vaporization. However, the latent heat of vaporization is expected to decrease only slightly with a decrease in pressure from 101.3 to 75.9 kPa. In addition, the latent heat of vaporization appears within the natural logarithm, further suppressing the influence of pressure on the d^2 -law prediction of the FSR. Therefore, to the extent for which the assumptions used in the d^2 -law are correct, the pressure has very little influence on the variation in the flame standoff ratio, and this is confirmed by our experimental measurements. The SSR, however, is again lower for decane compared to the other alkane fuels tested at 75.9 kPa. For example, at a fractional burning time of 0.37, the SSR was 1.9 for decane at 101.3 and 75.9 kPa. This result is noteworthy since the sootshell location for decane did not vary between the 1.2 mm droplet at 101.3 kPa and the 1.47 mm droplet at 75.9 kPa. Consequently, the difference in the SSR for decane is not due to differences in ambient pressure.

Comparisons were made of FSR and SSR for hexane, heptane, nonane, and decane measurements available in the literature. Jackson and Avedisian¹² investigated droplet burning in microgravity using heptane droplets burning in air at 101.3 kPa. Similar to the measurement of SSR displayed in Figures 5 and 6, the SSR was reported to increase as function of time after ignition in the experiments of Jackson and Avedisian.¹² The magnitudes of SSR were similar for the all of the droplet sizes studied and were consistent with the values measured in Figures 5 and 6. For example, at a fractional burning time of 0.37, Jackson and Avedisian¹² reported the SSR for heptane was equal to 2.5. Callahan and Avedisian¹³ investigated nonane droplet combustion in microgravity. The initial droplet diameter was varied from 0.55 to 0.57 mm, and droplets were burned in air at 101.3 kPa. Although the SSR was not reported in their study, the images obtained from the high-speed photography of the soot-containing region were used to calculate the SSR. For an initial droplet diameter of 0.55 mm, the SSR was calculated to be equal to 2.5 at a fractional burning time of 0.77. Although the initial droplet size was considerably smaller for the nonane experiments of Callahan and Avedisian¹³ than the nonane experiments reported here, the magnitude of the SSR are remarkably similar. Shaw et al.¹¹ investigated decane droplet combustion in microgravity. The initial droplet diameter was varied from 1.1 to 1.2 mm, and the droplets were burned in air at 101.3 kPa. At a fractional burning time of 0.50, the value of the FSR obtained from the measurement of Shaw et al.¹¹ was 5.55. This value compared favorably with the value of 5.8 measured for the 1.2 mm decane seen in Figure 3. The SSR was measured to be 1.8. These comparisons with measurements in the literature provided the following observations: (1) the measured FSR and SSR agreed favorably with measurements performed by other investigators,^{11–13} and (2) the SSR for decane is significantly lower than for the other fuels.

Conclusions

Measurements of soot concentration and soot mass were performed for the first time in microgravity conditions for a

wide range of fuels. Experiments performed in air at 75.9 and 101.3 kPa indicate that the maximum soot volume fractions and soot mass are similar, to within experimental uncertainty, for all of the fuels. A possible explanation is that the rate of soot formation and thermophoretic transport may be of similar magnitudes for the fuels studied.

Burning behaviors of various alkane fuel droplets (hexane, heptane, nonane, and decane) were measured. The FSR did not vary significantly for the fuels considered. The FSR was also found to be relatively insensitive to the ambient pressure. Although, a trend of larger soot standoff ratio was observed in the order of

hexane > heptane > nonane > decane

the SSR for decane was significantly smaller than for the other fuels.

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