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Cool flames and hot flames: Combustion experiments onboard the International Space Station

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Combustion experiments are conducted onboard the International Space Station (ISS) to study the flammability of condensed phase fuels, and to understand the fundamental aspects of diffusion flames in the absence of buoyancy. Recent droplet combustion experiments (FLEX – Flame Extinguishment Experiments) performed in the ISS have led to the discovery that certain fuel droplets, following radiative extinction of visible hot flames, can support quasi-steady burning without a visible flame, controlled by low-temperature chemistry (aka, cool flames). When the cool flame extinguished at a finite droplet diameter a condensation vapor cloud was found to form surrounding the droplet. These cool flames require relatively long residence times to burn and buoyancy-limited earthbound experiments do not provide sufficient residence time for this phenomenon to develop – limiting the ability to study the phenomena in terrestrial laboratories. Theoretical studies show that that the cool flames are formed in the negative temperature coefficient (NTC) region of the n-alkane chemistry where the chemical reactivity decreases with increasing temperature. The analysis further shows that cool-flame extinction is a chemical-kinetic/heat-transfer instability phenomenon, instead of the conventional hot-flame extinction caused competition between heat release and the rate of diffusive energy loss through heat conduction. These findings have many potential applications on earth. The next generation engine technologies, such as the homogeneous charge compression ignition (HCCI) engine, or the reactivity controlled compression ignition (RCCI) engine, can benefit from the improved understanding brought about by this discovery. Other areas of application include fuel reformulation and production of hydrogen from gasoline for use in fuel cells. Another area of importance lies in questions about fire safety in space vehicles. Since the cool mode of droplet combustion persists after hot-flame extinction, safety procedures based only on considerations of hot flames may be inadequate for assuring safety under all conditions.