POLLUTANT FORMATION IN MONODISPERSE FUEL SPRAY COMBUSTION

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The combustion of liquid sprays represents an extremely important class of combustion processes. In the transition region, encompassing droplet sizes in the range of 25-80 μm diameter, the mixing and evaporation processes are both incomplete at the flame front and burning occurs in a combined diffusive and premixed fashion. Under these conditions, the relative importance of heterogeneous and homogeneous effects in dominating the combustion process is switched and gives rise to a number of interesting phenomena. For example, maxima in burning velocity, extended flammability limits, minima in ignition energy, and minima in NO_x emissions have all been observed and reported. However, the actual mechanism and important physical processes controlling the anomalous NO_x behavior in such systems are not clear at this time and need to be explored.

Consequently, in November 1979, a study of NO_x formation in monodisperse spray combustion was initiated with the following specific objectives:

1) To quantitatively determine the effect of droplet size, number density, etc. on NO_x formation in monodisperse fuel spray combustion; and
2) To isolate the important physical and chemical phenomena in NO_x formation in these combustion systems.

The experimental facility developed for this study has been improved at different stages. In its current configuration the set up consists of a Berglund-Liu Vibrating Orifice Monodisperse Aerosol Generator which produces monosized droplets within 1% of the mean droplet diameter. The spray of droplets is dispersed, diluted and burned in a one dimensional flame, stabilized on a water cooled screen flame holder. The flame is surrounded by a long pyrex tube to avoid outside air entrainment. A combination gas sampling/thermocouple probe is used for NO_x concentration and temperature measurements.

Measurements have been made over the monodisperse operating range of the system encompassing droplet diameters from 36 to 70 μm and equivalence ratios from 0.8 to 1.2. Radial profiles confirm the one dimensionality of the combustion system. Prevaporized and premixed conditions were examined, as well, to give the small droplet size limit. Different hydrocarbon fuels such as isopropanol, methanol, n-heptane, n-octane, and isooctane have been used for detailed experimental measurements.

The experimental results indicate that both NO and NO_x decrease with decreasing droplet diameter in the spray, reaching a minimum around 48-58 μm for the fuels tested, and then increase again to a fairly constant value with further decrease in droplet diameter. The apparent behavior is due to increased droplet interactions as droplet size is reduced, causing a local oxygen depletion around burning droplets which results in a subsequent reduction in flame temperature and NO_x. Further reduction in droplet diameter increases NO_x, ultimately reaching the constant premixed value.

A shift in NO_x minima was observed for the fuels tested; these shifts were consistent with differences in the computed evaporation parameters. Calculations indicated that, relative to isopropanol, fuels with a higher evaporation ratio such as methanol require larger droplets initially to produce the same level of prevaporation. On the other hand, n-octane and n-heptane, with a lower evaporation ratio, achieve the same degree of prevaporization at smaller initial droplet sizes.

The extent of prevaporization and its effects on NO_x formation was further examined by preheating the air, resulting in enhanced evaporation of droplets. As expected, with more fuel in the vapor form, the minimum NO_x point was shifted towards larger initial droplet sizes.

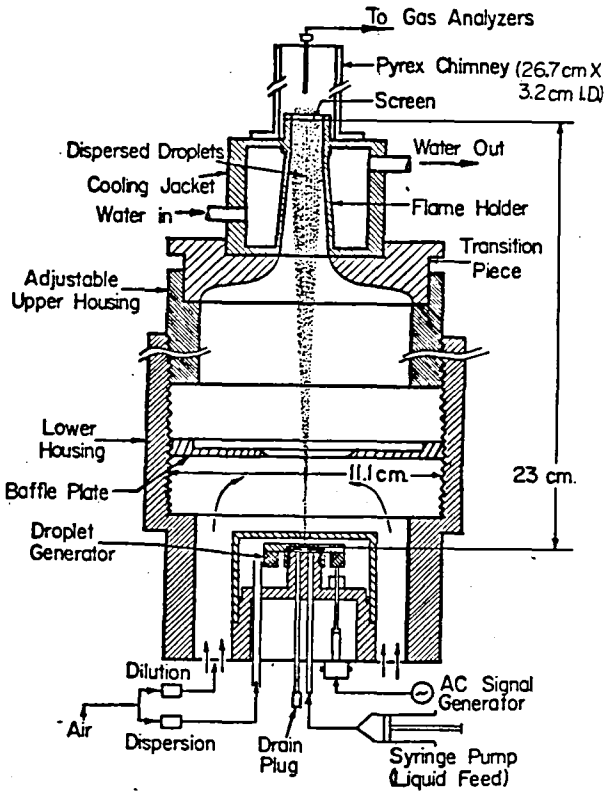
Multicomponent fuel studies and synthetic oxidizer experiments are currently underway in order to further elucidate and quantify the important processes.

Background

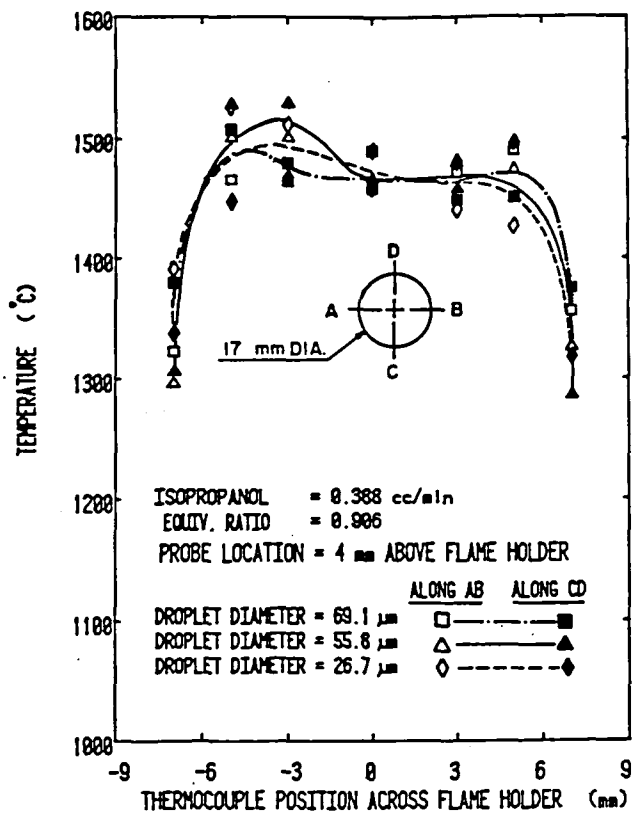
- Spray Burning Widespread
  - 30-50% of Total Energy Consumption
- Modes of Spray Combustion
  - Premixed
  - Diffusive
  - Transition
- Transition Region Effects
  - Increased Flame Speeds
  - Broadened Flammability Limits
  - Lower Ignition Requirements
  - Reduced Emissions

Previous Work Demonstrated an Anomalous NO_x Behavior

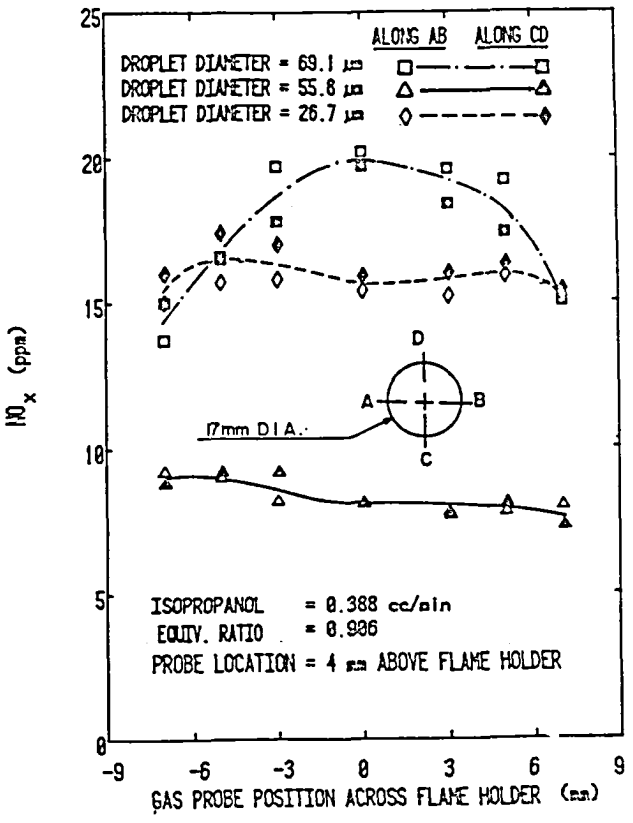
- Droplet Size Affects NO_x
- Minimum NO_x Formation at an Optimum Droplet Diameter
- The Optimum Droplet Diameter Depends on Fuel Properties and Evaporation Characteristics



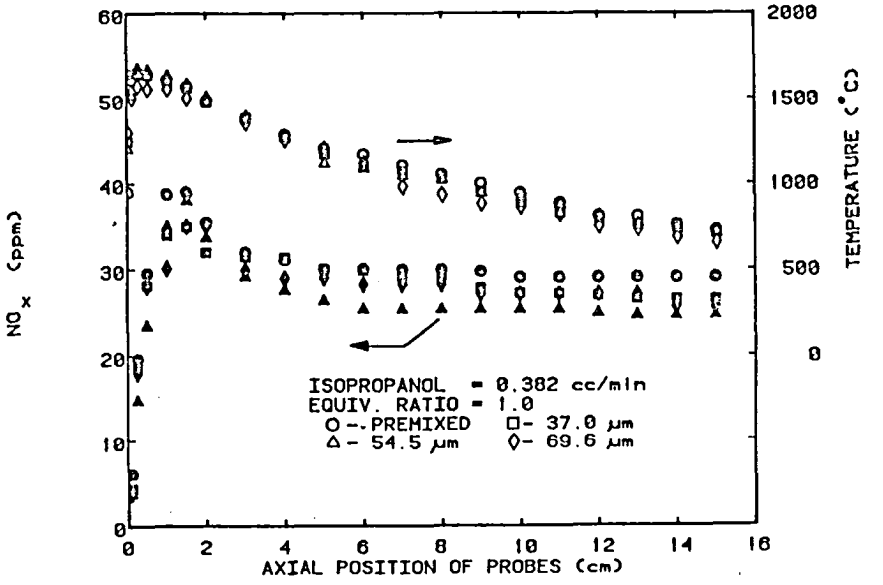
ONE DIMENSIONAL VIBRATING ORIFICE BURNER DETAIL



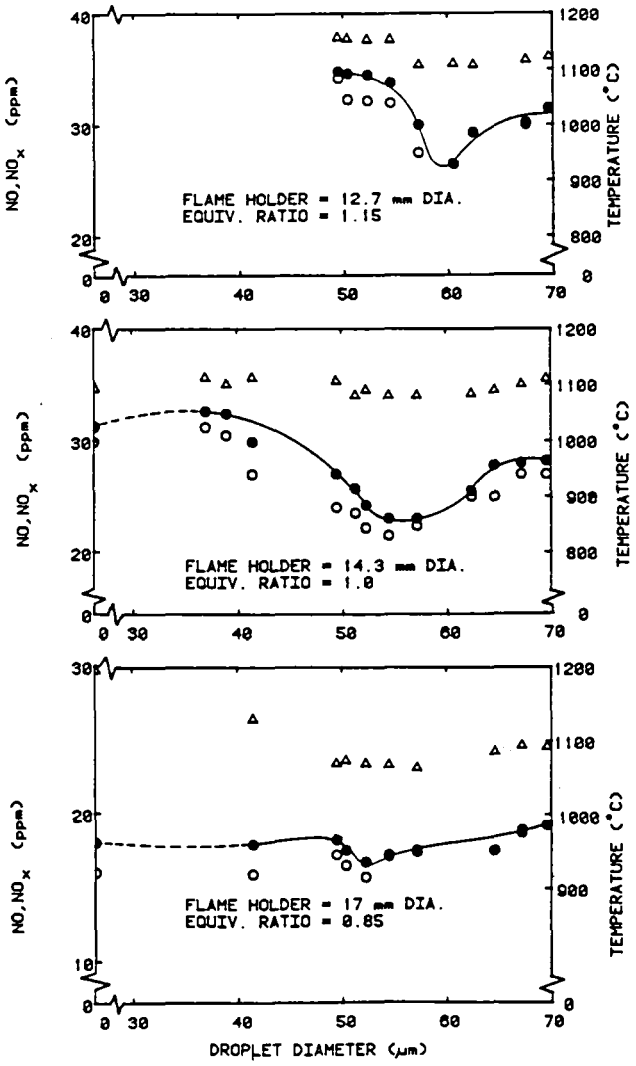
TEMPERATURE TRAVERSE ACROSS THE BURNER



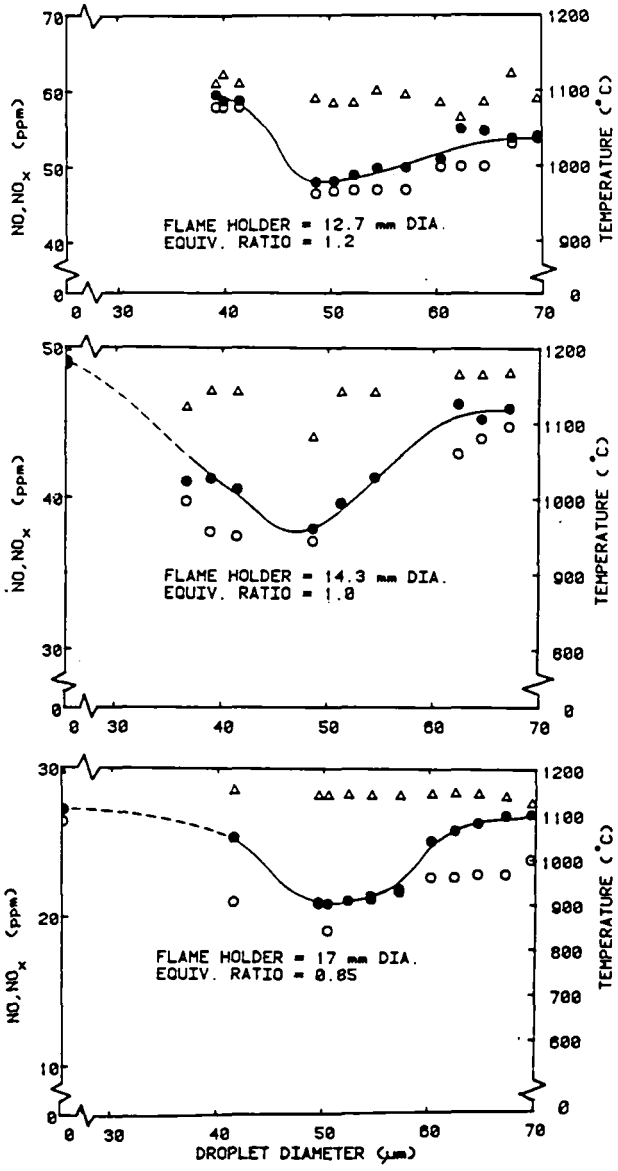
NO_x TRAVERSE ACROSS THE BURNER



AXIAL TEMPERATURE, AND NO_x PROFILES ALONG THE BURNER CENTERLINE



DROPLET SIZE EFFECT USING ISOPROPANOL AT 0.382 CC/MIN



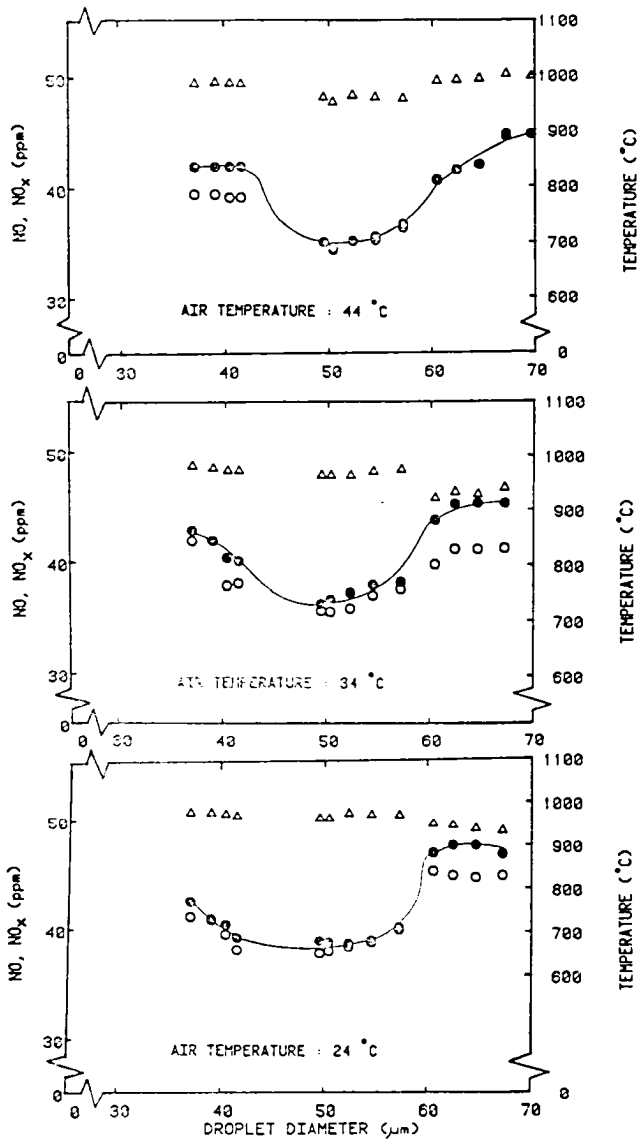
DROPLET SIZE EFFECT USING N-HEPTANE AT 0.382 CC/MIN

Computed Fuel Evaporation Parameters

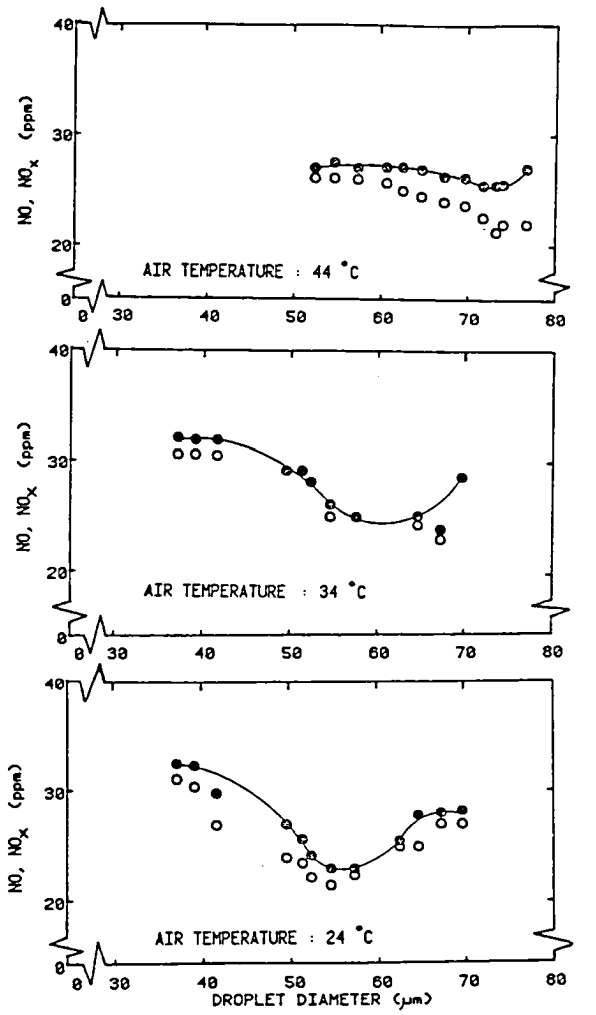
Fuel	Mass Transfer Number, B	Evaporation Constant $Kx10^{-3}$ (cm^2/sec)	Evaporation Mass Ratio $W_{Fuel}/W_{Isopropanol}$
Isopropanol	0.197	0.445	1.000
N-Octane	0.017	0.048	0.079
N-Heptane	0.089	0.243	0.787
Methanol	0.482	0.963	3.608

Relative Droplet Evaporation Effects

Fuel	Initial Diameter, μm	Final Relative Diameter, μm
Isopropanol	50	49.0
N-Octane	50	49.9
N-Heptane	50	49.6
Methanol	50	46.3



AIR PREHEATING AND DROPLET SIZE EFFECT USING N-HEPTANE AT 0.382 CC/MIN AND AN EQUIVALENCE RATIO OF 1.0



AIR PREHEATING AND DROPLET SIZE EFFECT USING ISOPROPANOL AT 0.382 CC/MIN AND AN EQUIVALENCE RATIO OF 1.0

Summary of Results and Conclusions

- Significant Effects of Droplet Diameter on NO_x Formation, With a Minimum NO_x Operating Condition Independent of Aerodynamic and Mixing Effects
- This Anomalous NO_x Behavior is Due to The Transition From Diffusive to Premixed type of Burning
- Shifts in NO_x Minimum Point are Consistent With The Physical Properties and Evaporation Characteristics of The Fuels