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**SOOT FORMATION IN
SYNTHETIC-FUEL DROPLETS****FIRST QUARTERLY
TECHNICAL PROGRESS REPORT**

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SOOT FORMATION IN SYNTHETIC FUEL DROPLETS FIRST QUARTERLY TECHNICAL PROGRESS REPORT

1.0 INTRODUCTION AND SCOPE

The objective of this project is to provide detailed information on methods of minimizing soot formation during synthetic liquid fuel combustion under conditions which minimize fuel nitrogen conversion to nitric oxide. The program consists of two tasks. The purpose of the first task, Fuel Screening Studies, is to investigate the impact of fuel properties on particulate production, to establish the importance of droplet size and examine atomizer effects, and to develop techniques for surrogate fuels productions. In the second task, Flame Studies, the fundamental details of soot formation from synfuel droplet combustion will be investigated in variable slip velocity configurations.

This present report describes technical progress during the first three months of the program effort (Oct. - Dec. 1980). During this initial period, attention has focused on the definition of the different experimental efforts and on the design and construction of the required hardware. Aspects of this work are discussed in the following sections.

2.0 FUEL SCREENING STUDIES (TASK 1)

The investigations of fuel and droplet effects within this task are to be carried out in a small (70,000 Btu/hr) vertically fired refractory tunnel furnace, under conditions of both normal excess air and staged heat release. The main criterion for this furnace is that it should approximate the temperature history of practical boiler furnaces. To this end, work initiated under Task 1 has required the redesign and modification of the tunnel furnace with particular emphasis on the cooling system. This is a variable system which allows control of both the location and rate of heat extraction.

The modification (Figure 1) encompasses three new cooling coil elements and a modification to the burner quarl to allow the coils to be moved axially within the furnace without shutdown. The designs of the modification have been completed and fabrication initiated.

Total particulate mass concentration in the furnace exhaust will be measured using the sampling technique outlined in Figure 2. The sample system incorporates an isokinetic sampling probe, 47 mm glass-fiber filter for sample collection, a scrubbing and drying section, sample pump, dry gas meter, and rotameter. The sampling probe is not cooled since soot oxidation rates are not significant at temperatures below 1500°K. The temperature of the probe and filter will be maintained above the dew point of the sampled gas to prevent condensation. Total particulate will be gathered on the filter, then the filter will be weighed. Concentration is determined based upon the volume of gas and water vapor sampled.

During the next reporting period, the Fuel Screening studies will be initiated in the tunnel furnace. A detailed test plan is currently being reviewed and will be finalized when the fuels to be tested are known.

Figure 1. Modification to Tunnel Furnace Cooling System.

Figure 2. Total Particulate Mass Sampling System.

3.0 FLAME STUDIES (TASK 2)

The principal accomplishments during the reporting period were: 1) development of a detailed work plan describing and scheduling the various aspects of this task, 2) completion of the burner design for the droplet experiments, 3) design and construction of the synfuel heating and delivery system for the droplet experiments, and 4) completion of a series of exploratory experiments involving the use of currently available diagnostics on droplet streams.

The work plan consisted primarily of an outline and schedule of the various subtasks within Task 2 (e.g., burner design, burner construction, data acquisition, etc.). More importantly, development of the work plan focused attention onto the development of diagnostic techniques which will be required when the experimental systems become available later in the program.

Design of the droplet studies burner has been completed and construction is anticipated in the next reporting quarter. The burner was designed to provide a droplet environment which corresponds to the conditions found in spray combustion. Of particular importance was design for the ability to vary combustion parameters (e.g., gas temperature, gas composition, synfuel types, gas-droplet slip) in a relatively independent manner. The main features of the burner, illustrated in Figure 3, include a downfired flat flame supported on a sintered surface, two modes for droplet injection, optical access, and availability of sampling ports for gas, liquid, and soot. The two modes of droplet injection provide the configurations for studying the extremes of gas-droplet slip. In the co-flowing mode, the droplets enter the burner through a port in the sintered flame holder. In this configuration, low slip behavior can be observed. For cross-stream injection, the droplets are injected at 90° to the flow direction. In this configuration, both droplet and gas velocities may be varied to provide different degrees of slip. More importantly, soot formed from the droplet stream is swept away from the droplets such that soot and liquid collection and analysis may be performed independently. The use of O_2 -enrichment/ N_2 dilution allows stoichiometry, temperature, and gas velocity to be controlled, within limits, independently. Both the droplet and soot fields are available for high speed cinematography and spark shadowgraphs through the optical access windows.

Figure 3. Burner Design Showing Droplet Injection in the Crossflow Mode.

From the outset, the formation of well defined and controlled droplets for burner injection was recognized as the most technically demanding aspect of the construction phase of the present task. The principal problem foreseen was the uneven heating of the fuel stream prior to droplet formation; too little heat results in a prohibitively high viscosity, while excessive heat can cause cracking or coking of the fuel. Thus, great care was used in the design and construction of the oil feed and storage system. The entire apparatus is surrounded by a heated, circulating fluid to provide the necessary even, controlled heating. The apparatus, shown schematically in Figure 4 delivers the hot fuel, under pressure, to the droplet generator.

For this task, droplets will be generated by the vibrating orifice technique (Berglund and Liu, 1973). This conceptually simple system, shown in Figure 5, uses a piezoelectric ceramic to vibrate a small orifice through which the heated fuel is forced under pressure. In the absence of vibration, the liquid jet emerging from the orifice will break into droplets of an approximately known size due to the natural instability of the jet. The vibrating orifice induces the breakup of the jet at other frequencies, and thus may be used to form droplets of predetermined, well characterized sizes. The action of the crystal has only a limited range of usefulness, centered about the natural jet breakup frequency. While this effectively limits particle diameter control by frequency to approximately 25% about the natural breakup size, changes in fuel flow rate produce a broader controllable size range.

Recognizing that the generation of controlled size, heavy fuel oil droplets is a key task to the success of the proposed experiments, a considerable effort was expended during the reporting period in gaining experience with the operation, capabilities, and limitations of the droplet generator. Since the heating system for the real fuels has only recently become available, these exploratory experiments were performed with water, methanol, and heptane. Although these experiments were used primarily to gain experience with the droplet generator, two of the diagnostic techniques available were also tested.

Particle sizing measurements were carried out using a Malvern droplet/particle analyzer (Model 1800). This instrument develops a size distribution based on a measured angular distribution of laser light diffracted by the droplet stream. The results were not entirely satisfactory because the instrument has

Figure 4. Schematic of Synfuel Heating, Pressurization, and Delivery System.

Figure 5. Schematic Diagram of the Liquid Orifice Assembly.

difficulties fitting a size distribution to nearly monodisperse aerosols. However, the results indicated the presence of a very monodisperse spray whose mean size was correctly predicted by the orifice and frequency calibration.

A number of spark shadowgraphs of the droplet stream were obtained as part of a series of exploratory experiments. Conditions examined included use of 50 and 100 μm orifice plates, and jet breakup under vibrating and non-vibrating (natural break-up) modes. The natural break-up mode showed relatively unsteady operation, with droplets of various sizes formed in an unrepeatable manner. The vibrating mode produced droplets of markedly repeatable size. When the vibrational frequency was tuned to near the limits of normal operation, the orifice produced paired droplets (doublets) which coalesced into single, evenly spaced droplets shortly after formation.

Planned work for the next reporting period includes:

- Construction of the droplet burner.
- Generation of droplets from real fuels.
- Exploratory experiments on real fuel droplets in the burner using high speed cinematography and spark shadowgraphs.

Reference: Berglund, R.N. and Liu, B.Y.H., "Generation of Monodisperse Aerosol Standards," Env. Sci. and Tech. 7, 147 (1973).