AN EXPERIMENTAL INVESTIGATION OF
SYNFUEL SPRAY CHARACTERISTICS AND
COMBUSTION DYNAMICS

MASTER

QUARTERLY TECHNICAL PROGRESS REPORT
FOR THE PERIOD
JANUARY 1 to MARCH 31, 1981

APRIL 1981

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Prepared For:

THE UNITED STATES DEPARTMENT OF ENERGY
PITTSBURGH ENERGY TECHNOLOGY CENTER

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SPECTRON
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TECHNICAL STATUS

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Section 1

OBJECTIVE AND SCOPE OF WORK

The utilization of synthetic liquid fuels derived from coal and shale oil to reduce demand for petroleum-based liquid fuels has created a need for improved combustion technology. While progress has been made in understanding spray combustion processes of petroleum liquids, limited experience with the combustion of synthetic fuels indicates considerably different combustion characteristics. Potential problems associated with the use of synfuels include plugging and fouling of fuel injectors, irregular burning, greater sooting, increased NO_x emissions, and high variability between fuel samples. An improved understanding of the fundamental combustion processes associated with these synthetic fuels is necessary for the development of advanced combustion systems capable of utilizing them in an environmentally acceptable manner.

The primary objective of this project is to obtain fundamental information on the characteristics and behavior of both petroleum-based oils and synthetic fuels in spray combustion by applying advanced optical diagnostic techniques to study the processes of fuel injection and atomization, droplet ignition, and spray flame combustion. Specific objectives are identified in Table 1.

This program is being conducted in three phases. The first phase, Cold Flow Spray Experiments, explores spray formation characteristics of both a synthetic fuel spray and petroleum-based fuel sprays. Holography and the droplet sizing interferometry (DSI) will be used to examine spray formation processes and spray characteristics, respectively. Spatial distribution measurement of the droplet size, velocity, the air mean velocity, turbulence intensity, and the droplet size-velocity correlation will be made for selected nozzles. Spray characteristics and formation mechanisms will be correlated with injector parameters and fuel type.

In the second phase, Monodispersed Droplet Combustion, ignition characteristics will be studied using a monodisperse droplet stream. Droplet combustion phenomena will be observed, documented, and analyzed (including swelling, micro-explosions, and flame structure) using holographic

TABLE 1

PROGRAM OBJECTIVES

I. PRIMARY OBJECTIVE

Obtain fundamental information on the characteristics of synthetic fuels and heavy oil-based fuels in spray combustion processes.

II. SPECIFIC OBJECTIVES

PHASE 1 - Cold Spray Experiments

- a. Explore spray formation characteristics of synfuels and heavy oil-based fuels for a variety of injectors.
- b. Characterize a selected synfuel and petroleum-based fuel sprays in detail for specific injectors.
- c. Correlate spray characteristics and formation mechanisms with injector parameters and fuel type.

Phase 2 - Monodispersed Droplet Combustion

- a. Extend current droplet sizing techniques to hot flows with burning single-size droplets and flames.
- b. Explore preignition characteristics of synfuel and heavy oil-based fuels for a range of droplet sizes.

Phase 3 - Spray Combustion Experiments

- a. Verify droplet sizing techniques for laboratory spray flames.
- b. Explore spray injection characteristics in the combusting flow.
- c. Characterize a synfuel and a petroleum-based fuel sprays in a combusting flow and compare with cold flow results.

imaging and interferometry. A second objective will be to extend the current droplet sizing interferometer (DSI) to hot flows with burning droplets and evaluate it by comparison with holographic measurements.

In the third phase, Spray Combustion Experiments, optical droplet sizing techniques (DSI) will be verified for laboratory spray flames. Spray injection characteristics (including spray formation, droplet size and velocity distributions) of a synfuel and petroleum-based fuel will be explored in a combustng flow and compared with cold flow results.

The program schedule is shown in Figure 1 by subtask. Efforts during the second quarter of this program were directed at (1) the cold spray experiments (Task 1.0) with the completion of the design and construction of the spray rig being the primary task, (2) the preliminary design of the monodisperse droplet combustion experiment, and (3) the construction of a prototype oil burner experiment with the acquisition of preliminary holography data.

Figure 1.

PROGRAM SCHEDULE

Section 2

SUMMARY OF PROGRESS TO DATE

During the second quarterly reporting period, efforts were focused primarily on the completion of the cold spray test facility (Task 1.1). This included the final design, procurement, and installation of the fuel and instrumentation systems as well as the further definition of the optical diagnostic instrumentation and further test planning. Holocamera modifications and test configuration definition (Task 1.2) were completed.

Design of the monodisperse droplet combustor was initiated (Task 2.1). Efforts were directed towards overall combustor design and droplet generation techniques. Work was also conducted on the spray combustion experiment (Task 3), although the startup was not originally planned until the beginning of FY82. An oil burner was assembled and operated in the laboratory. Preliminary holography measurements of fuel droplets were successfully obtained within the spray flame.

Section 3

DETAILED DESCRIPTION OF TECHNICAL PROGRESS

3.1 COLD FLOW SPRAY EXPERIMENTS (TASK 1)

The task 1 efforts during the second quarter of this study were directed toward the final detail design of test facility subsystems and components, and assembly of the test facility. This included: assembling the major components; definition, procurement, and installation of instrumentation; fuel system detail designing, procurement, and installation; and further optical instrumentation definition. Test planning was also accomplished during this quarter.

3.1.1 Major Components

The major components include the test chamber, test chamber base, and air blowers. The test chamber and base were designed and fabrication initiated during the first quarter. Details of their design are presented in Reference 1. Fabrication of these components has been completed and they can be seen in Figure 2. These blowers have been procured; one for the primary air, one for the screen air, and one for the test chamber exhaust system. Each of these blowers is capable of providing at least 1200 scfm air flows (2400 scfm for exhaust blower). Variable speed drives are present on the primary air and exhaust blowers to allow varying the flow rates. Butterfly valves are also included in the primary air and screen air ducts to provide control of the screen air flow rate and further control of the primary air flow rate.

During this reporting period, a blower-box has been designed and constructed to house the three blowers, see Figure 2. This blower-box provides for filtering the air going into the primary and screen air blowers as well as positioning the blowers in a space-efficient manner. The filtering is accomplished with common, home type, furnace filters. These filters are located in the lower front, see Figure 2, and on the top and back of the blower-box. Acoustical material was placed in the box to reduce blower noise in the test area.

FIGURE 2. COLD FLOW SPRAY CHARACTERIZATION FACILITY

The necessary ducting and a plenum have been installed between the blowers and the test chamber, see Figure 2. All ducts are 6 inch diameter except that from the exhaust blower outlet to the laboratory ceiling vent which is 12 inch diameter and a 10 inch duct between the exhaust air plenum and the exhaust blower inlet. Sealing components and tape have been used to prevent leakage from the air ducts.

3.1.2 Instrumentation-Spray Characterization Facility

The instrumentation for the SDL Spray Characterization Facility needs to provide a measurement of the injection operating parameters and data sufficient to ensure control and repeatability of test conditions. The instrumentation selected is listed in Table 2. The sensing location of the instrumentation is shown by instrumentation number, in the schematic in Figure 3.

Injector operating parameters of primary interest for the mechanical (pressure) type injectors will be the fuel temperature and pressure at the injector, instrumentation numbers 8 and 1 in Table 2. In later tests on two-fluid type injectors, the pressure of the injector air at the injector, instr. No. 2, and fuel temperature will be of primary interest. An additional low range pressure gauge and/or fuel flow meter are being considered for the testing of the two-fluid injector. A thermocouple on the exterior surface of the fuel line, instr. No. 9, has been included and provides a backup measurement of the temperature conditions of the fuel at the injector. A thermocouple, instr. No. 10, will record the primary air temperature.

The air flow velocities are indicated by stagnation to static differential pressures obtained from pitot tubes in the primary and screen air ducts, instr. No. 6 and 7. To obtain accurate readings over the full range of anticipated conditions, 3 pressure gauges (3 ranges) are used for the primary air flow and 2 pressure gauges (2 ranges) are used for the screen air flow, see Table 2. In addition, the relative static pressure present in these two air flows as they enter the test chamber is monitored by a differential pressure gauge, instr. No. 5.

TABLE 2

INSTRUMENTATION

SDL SPRAY CHARACTERIZATION FACILITY

INSTRUMENTATION NUMBER	DATA TYPE	SENSING LOCATION	GAGE OR SENSOR
1	Pressure	In fuel line near injector	0 - 200 psi dial-type gage
2	Pressure	In injector air line near injector	0 - 10 psi dial-type gage 0 - 30 psi dial-type gage
3	Pressure	In reservoir	0 - 400 psi dial-type gage
4	Pressure	In chamber	5 - 0-5 inch H ₂ O dial-type gage
5	Static pressure differential	In primary air duct and below screen air screen	2 - 0-2 inch H ₂ O dial-type gage
6	Flow velocity	In primary air	Pitot tube with: 0-.25 inch H ₂ O dial-type gage 0-1 inch H ₂ O dial-type gage 0-3 inch H ₂ O dial-type gage
7	Flow velocity	In screen air	Pitot tube with: 0-.25 inch H ₂ O dial-type gage 0-1 inch H ₂ O dial-type gage
8	Temperature	In fuel line near injector	Type T thermocouple-probe
9	Temperature	On exterior of fuel line, near injector	Type T thermocouple-probe
10	Temperature	In primary air	Type T thermocouple-probe
11	Temperature	In fuel line near fuel line heater	Type T thermocouple-probe
12	Temperature	In reservoir	Type T thermocouple-probe
13	Weight	Under reservoir	Scale, dial on scale

FIGURE 3. FLOW AND INSTRUMENTATION SCHEMATIC

Pressure and temperature readings, instr. No. 3 & 12, in the reservoir and a thermocouple in the fuel line, instr. No. 11, provide for control of experimental parameters. The reservoir pressure is used to force the fuel through the system in the mechanical type injectors and therefore, controls the flow rate. The reservoir temperature is used in monitoring the thermostat on the reservoir heater. Thermocouple number 11 is used as the sensor for the fuel line heater controller. This controller is an RFL Industries Model 76 Proportional Temperature Controller. Its reported accuracy is $\pm 0.1^{\circ}\text{C}$ of the set point. A control dial and temperature indicator have been obtained as accessories. These are mounted on an instrumentation panel, see Figure 4.

The test chamber pressure, instr. No. 4, is monitored to prevent an excessive pressure differential between the interior and exterior of the test chamber. A scale under the reservoir, instr. No. 13, provides a measurement of the weight of liquid in the reservoir and is used to indicate the liquid level in the reservoir. It can also be used as an approximate measurement of the fuel mass flow rate if given flow conditions are maintained for a sufficient length of time.

All of the pressure gauges are mounted on the instrument panel, see Figure 4, except for the reservoir pressure gage, instr. No. 3. This gauge is a Union Carbide gauge and is attached to the nitrogen pressure regulator. The fuel pressure gauge, instr. No. 1, and the 0-30 psi nozzle-air pressure gauge, instr. No. 2, are Marshall Town gauges with reported accuracies of $\pm 0.5\%$ and $\pm 1.0\%$ of full scale respectively. All of the other pressure gauges are Dwyer Series 2000 Magnehelic gauges. The accuracy of these gauges is reported to be $\pm 2\%$ of full scale except for the 0-.25 inch of H_2O gauges which have an accuracy of $\pm 4\%$ of full scale.

Copper Constantan, type T, thermocouples are used for all of the temperature sensors. These thermocouples are connected to an electronic scanner/linearizer/digitizer (Sanlab Model 104/110). Incorporated in this system is an automatic zero and span (with a reference voltage provided by a factory burned-in, precision zero diode) calibration that compensates for any drift associated with time and tempera-

FIGURE 4. DATA SYSTEM AND TEST CONTROLS

ture effects on the electronics. The outputs from the temperature acquisition system are interfaced to a computer-based data management system. The data are displayed on a TV monitor and printer output. If desired, the data can also be stored on diskettes. An internal clock keeps track of the time of each data acquisition. The data system for the thermocouples can be seen in Figure 4.

3.1.3 Fuel System

A fuel system was designed and constructed to deliver fuel to the injector at flow rates up to 5 gph with a maximum pressure of 200 psig and maximum temperature of 210°F. The system is compatible with No. 2 and No. 6 fuel oil, and SRC II synthetic fuel. A schematic of the fuel system is included in Figure 3. The plumbing in the area of the reservoir is shown in Figure 5.

The preheater/reservoir is a modified American Appliance Co. Model ES 22 Water Heater with about 13 gallons of usable capacity.

Fuels are stored in 55 gallon drums at atmospheric pressure and are transferred by a piston type hand pump (Fill-Rite Series 5200), through the fill valve to the preheater/reservoir. Fuel transfer is conducted at atmospheric pressures.

A vent valve is provided to allow the venting of displaced vapors during the filling process. Once filled, the fill and vent valves, see Figures 3 and 5, are closed. Upon completion of filling the preheater/reservoir, the fuel is pressurized and heated to approximately 10°F below desired operating temperatures. Heat is transferred to the fuel by a 1500 W immersion heating element which is part of the reservoir. A bimetallic thermostat regulates the fuel temperature to within $\pm 7^\circ\text{F}$ of the thermostat set point. Maximum obtainable temperature in the preheater/reservoir is 200°F due to thermostat limitations. The reservoir is also fitted with a drain valve, and a pressure relief valve (set to 250 psig), see Figure 3, to prevent over pressurization of the reservoir.

Nitrogen gas is used to completely purge the system of air before filtering and operation, and to pressurize the system during operation.

FIGURE 5. PLUMBING AT RESERVOIR

A pressure regulator is provided to adjust the system pressure, see Figure 2. Capability to purge the fuel lines of fuel after system operation is also provided by closing the fuel flow valve and opening the line purge valve, see Figure 3.

When the fuel in the reservoir has reached the desired temperature, the fuel flow valve is opened to initiate the flow of pressurized fuel to the injector. The fuel passes through the line filter which has a sintered bronze element. The fuel then flows into a 5' heated section of the copper tubing. The purpose of this section is to provide a well controlled fuel temperature to the injector. Heat is provided by a 760 W heavy duty heating tape, 96" x 1" (Fisher #11-463-51D), which is tightly wound in a spiral around the copper tubing. Heat flux to this section is controlled by a proportional temperature controller via a feedback thermocouple (Figure 3, instr. No. 11, refer to section 3.1.2). Low thermal conductivity sections in the line have been used to significantly reduce axial heat conduction to the rest of the copper fuel line, as this effect would reduce the controllability of the fuel temperature.

From the fuel line heater, the fuel passes through the regulator valve. This is used for a fine adjustment of fuel pressure or flowrate, as desired. The fuel then proceeds through a section of flexible hose to allow for the vertical traverse of the injector assembly in the test chamber, and on to the injector. A line pressure relief valve is also provided (set at 206 psig) to prevent overpressurization of the fuel line. The line from the outlet of this relief valve connects with the vent/relief/drain line from the reservoir, and travels to an outlet in the sump. Any fuel which accumulates in the sump is hand pumped back to a fuel barrel.

An air line ($\frac{1}{2}$ " nylon) is provided for the two-fluid injectors. Compressed air is regulated and passed to the injector assembly to be mixed with the fuel.

The fuel lines are composed of copper refrigeration tubing ($\frac{3}{8}$ " O D) except where low thermal conductivity tubing is desired. Nylon ($\frac{1}{2}$ " O D) was used in the low conductivity section, and also for the fuel transfer, relief, and gas lines to reduce cost. All fittings

are brass of either NPT or compression type. Thermocouple access to obtain fuel temperature (Figure 3, instr. No.s 8, 11, and 12) is through thermocouple wells sealed by compression fittings. Unless specified as a relief or regulating valve, all valves are ball valves. The high pressure, high temperature fuel lines are insulated with $\frac{1}{2}$ " thick wrapped fiberglass insulation.

3.1.4 Optical Instrumentation Configuration

Two optical diagnostic techniques will be used to examine spray formation processes and spray characteristics in the cold flow spray experiment. Pulsed laser holography will be employed initially to study spray formation processes followed by droplet sizing interferometry (DSI) which will be used for quantitative spray characterization. Optical access to the spray chamber is through 1/8-inch thick float glass windows. Rectangular windows, frames and mounting flanges are used. Windows are positioned at 0°, 30°, and 90° relative to the transmitter beam (and transmission window). A detailed drawing of the spray chamber and window arrangement was presented in the previous quarterly report (Reference 1). The configurations to be used for the holography and DSI measurements have been defined and are discussed below.

Holography Apparatus

Figure 6 shows a schematic of the transmitter and Figure 7 one of the receiver for the two-component SDL holocamera. The information of object beam goes through two glass windows and the test volume.

The system consists of a HeNe laser for alignment and a ruby laser to take the hologram. The laser beam is split into an information beam and a reference beam. Either beam is expanded, spatially filtered and collimated. The information beam goes through the fuel spray while the reference beam bypasses the test section. The two beams are mixed on a holoplate in the plate holder.

The shutter in front of the plate holder only allows light to enter while the recording is taking place. This minimizes the influence of extraneous light sources.

① Ruby Laser	⑤ Mirror
② Pockel's Cell	⑥ Lens
③ Brewster Stack	⑦ Beam Expander/Spatial Filter
④ Beam Splitter	⑧ Alignment Laser (H_2-N_2)

Figure 6.
Holocamera System
Transmitter Module

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- ① Lens
- ② Mirror
- ③ Shutter

- ④ Plate Holder
- ⑤ Optional Automatic Plate Changer

Figure 7. Hologram System
Receiver Module

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Figure 8 depicts the position of the transmitter and receiver around the rig. A premagnified image of the spray can be obtained by choosing f_2 larger than f_1 . The premagnification is given by $M = f_2/f_1$. In our present configuration $M = 3$, however this value can be changed to satisfy the needs.

DSI System

An SDL droplet sizing interferometer will be used to measure the droplets size and velocity distribution. The transmitter and the receiver will be mounted on independent traverse mechanisms, and can be positioned to collect light at 0° , 30° , and 90° from the transmitted beam. Figure 9 shows the configuration for collection at 90° .

The traverse mechanisms will be fabricated to allow variation in the radial direction of up to 12 inches. The axial position will be changed by moving the nozzle up and down.

3.1.5 Test Planning

The cold flow spray experiments will consist of a spray formation study utilizing pulsed laser holography/photography and a spray characterization study using droplet sizing interferometry (DSI). These studies will utilize the same three fuels in the following order: a No. 2 fuel oil (standard reference), a No. 6 fuel oil to provide viscosity variations (with heating), and SRC II middle distillate to provide synfuel data. A separate injector screening study as originally planned will not be necessary; rather, all candidate injectors will be utilized in the spray formation study which will provide a basis for selecting two injectors for the spray characterization work.

The candidate injectors for the cold flow spray studies, listed in Table 3, are of two basic types, simplex (pressure) injectors and two fluid (air) atomizers. The simplex injectors include both hollow cone and solid cone spray patterns in three different flow rates and three different spray angles. The two fluid injectors are a Sonicore 052H and a Delavan Type SNA. The location of a simplex injector in the spray facility is illustrated in the photograph shown in Figure 10. The injector is centered in the primary air tube and extends just

FIGURE 8. SCHEMATICS OF TWO-COMPONENT HOLOGRAPHIC SYSTEM FOR FUEL SPRAY STUDIES

FIGURE 9. SCHEMATICS OF DROPLET SIZING INTERFEROMETER WITH FUEL SPRAY RIG

TABLE 3
CANDIDATE INJECTORS

● SIMPLEX (PRESSURE) INJECTORS

TYPE A - HOLLOW CONE

θ $\dot{w}$	45°	60°	90°
1 gph	✓	✓	✓
2 gph	---	✓	✓
5 gph	---	✓	✓

TYPE B - SOLID CONE

θ $\dot{w}$	45°	60°	90°
1 gph	✓	✓	✓
2 gph	---	---	---
5 gph	---	✓	✓

● TWO FLUID (AIR) ATOMIZING INJECTORS

● DELAVAN TYPE SNA

— AIR PRESSURE (3 TO 20 psi)

— FLOW RATE (1 gph)

● SONICORE 052H

— AIR PRESSURE (2 TO 25 psi)

— FLOW RATE (0 TO 5 gph)

FIGURE 10. INJECTOR POSITION IN THE COLD FLOW SPRAY FACILITY

the screen air plate. Instrumentation windows are visible in the background.

The injector variables to be investigated are fuel pressure, fuel temperature, fuel flow rate, and atomizing air pressure (for two fluid injectors). The main flow variable is the velocity of the primary air stream surrounding the injector. Nominally three values of each variable will be considered and all fuel temperature variations will be performed with the No. 6 fuel. The basic parametric variations planned for the spray formation study will involve approximately 250 different injector/test combinations. Approximately 40 different sprays will be examined as a part of the spray characterization test phase.

The objectives of the spray formation study are to define atomization mechanisms, resolve differences in fuel type, and establish the influence of the key variables. For the spray characterization study the goals are to characterize sprays (size and velocity distributions) for selected injector/fuel combinations and to establish the influence of key variables on the spray field.

3.2 MONODISPERSE DROPLET COMBUSTION (TASK 2)

Design of the monodisperse droplet combustion experiment was initiated during the present reporting period. These initial efforts were directed at two primary areas -- combustor design and droplet generation.

3.2.1 Combustor Design

Two main criteria are utilized to design the combustor for the monodispersed droplet combustion experiment. First, burning droplets (light and heavy oils) will be sized with the DSI at various axial positions and holograms or flash photographs will be obtained to validate these measurements. Second, holograms of heavy oil and syn-fuel burning droplets will be obtained for various ambient conditions and various droplet size and separation. Physical changes on the droplets will thus be studied.

The combustor starts with a sintered flat flame burner manufactured by McKenna Products, which will be modified by adding a copper drop tube in the center. Figure 11 shows a schematic of this burner. The added tube will be used to inject the droplets which will be generated upstream with a monodisperse droplet generator having controlled droplet spacing. The droplets are then ignited by the flat flame which can be a mixture of methane, hydrogen, air and nitrogen. The flat flame is formed on the sintered burner which has an OD of 2 1/2". A 1/4" thick ring of nitrogen forms a shroud that surrounds the flame.

The flat flame will be mounted on a quartz tube of 3" ID and 2 ft. long. Droplets as large as 300 μm can be studied to complete burnout in this length of tube. For larger droplets we will concentrate in the first two criteria as described above.

Optosil quartz windows of 3/4" OD will be mounted on ports 2 1/2" from the centerline of the burner. The F# of collection will thus be 3.5. These flat windows are necessary to avoid the aberrations that would be introduced by the quartz tube.

A metal container will be placed on top of the burner to house the droplet generator. It will be filled with nitrogen to reduce the chances of flashback. Droplets will be injected downwards in this configuration.

3.2.2 Droplet Generation Techniques

Two different droplet generation techniques are being explored for use in the monodisperse droplet combustor. These were reviewed in the previous quarterly report (Reference 1) and consist of a pulsed droplet ejection (ink jet printing) technique and a simple constant flow orifice (needle) technique.

With pulsed droplet ejection, an electric signal is converted to pressure pulse in a chamber (via a piezoelectric crystal) resulting in the ejection of a single droplet of fluid. Droplet size is proportional to the nozzle diameter and both droplet velocity and generation frequency are inversely proportional to nozzle size. Droplet diameter ranging from approxi-

COMPONENT DESCRIPTION

- A. BURNER HOUSING
- B. SINTERED BURNER
- C. SINTERED HIGH PRESSURE SHROUD RING
- D. PARTICLE INJECTION TUBE
- E. SHROUD HOUSING
- F. SHROUD MOUNTING PLATE
- G. COOLING WATER COIL

FIGURE 11. FLAT FLAME BURNER DESIGN FOR MONODISPERSE DROPLET COMBUSTOR

mately 50 to 250 microns are anticipated with this technique. Larger diameter droplets (approximately 1 mm and greater) will be generated with the constant flow orifice technique.

During the present reporting period, specific droplet injector designs were examined, sources for piezoelectric crystals and glass nozzles were identified, and two assembled injector units were obtained. These droplet injection units will be tested with water, alcohol, and No. 2 fuel oil during the next reporting period.

3.3 SPRAY COMBUSTION EXPERIMENT (TASK 3)

Although no formal effort was originally planned on Task 3 until early FY82, the benefit of obtaining an early assessment of the application of current optical diagnostic techniques to a spray flame environment became evident. Thus, initial Task 3 efforts were conducted during the present reporting period. These efforts were directed at procuring an oil burner, making it operational in the laboratory, and obtaining preliminary holography data.

3.3.1 Laboratory Configuration

A high efficiency residential size oil burner (INTERburner marketed by Sloan Valve Company) was obtained and setup in the laboratory. The burner is currently operating on No. 2 fuel oil and has a flow capacity of 0.4 to 2.0 gal. per hour (gph) or approximately 56,000 to 280,000 BTU/hr. A simplex injector having a 60° hollow cone pattern is used to provide the fuel spray. The self contained burner unit includes a fuel pump which provides a nominal 100 psi fuel pressure, an air blower, electrical ignitor, and a control unit.

Figure 12 shows a photograph of the laboratory arrangement used to obtain preliminary holography data. The burner is mounted on a stand and the exhaust is drawn off via an exhaust duct. The holocamera and laser power supply are shown in position. The holocamera schematic and specifications are shown in Figure 13. The holocamera is the same model used to obtain preliminary spray formation data presented in the previous quarterly report (Reference 1). A 1 to 1 magnification was employed which provides a useable

FIGURE 12. SPRAY FLAME HOLOGRAPHY CONFIGURATION

SPECIFICATIONS

SAMPLE VOLUME

SAMPLE VOLUME DIMENSIONS WIDTH X DEPTH (mm)	25x5	50x50	100x200
*RESOLUTION (μm)	2	4	6

CHARGE TIME	— 10 s
PULSE WIDTH	— 20 ns
PULSE SEPARATION	— 1 to 500 μs
RESOLUTION	— to 2 μm
ALIGNMENT LASER	— 2mW HeNe
COHERENCE LENGTH	— 1 m
WAVE LENGTH	— 694 nm
LASER OUTPUT ENERGY	— 50 mJ/pulse

ELECTRICAL	— 110 Vac 60 Hz 20 Amps
COOLING	— Closed System, Refrigerated and Heated
WEIGHT-POWER SUPPLY	— 170 lb.
HTRC	— 150 lb.
HTC	— 120 lb.
SIZE-TRANSMITTER	— 27" x 40" x 7"
RECEIVER	— 27" x 16" x 7"

*Defined as the width of distinguishable bars on the USAF 1951 resolution chart.

FIGURE 13. HOLOCAMERA SYSTEM

volume of approximately 100 mm diameter by 200 mm in depth. The flame diameter was approximately 3 inches (76 mm) so that the entire diameter was included in the holograms

3.3.2 Preliminary Holography Results

Holograms of the spray flame were made for two different conditions. First, the burner was operated in the standard configuration with the spray injector submerged in the air cone and with a swirl plate to provide a flame stabilizing swirl flow around the injector. The highly turbulent flame shown in Figure 12 represents this mode of operation. A second mode of operation involved removing the air cone and swirl plate so that the injector was visible in a parallel air stream. In this configuration, the initial flame sheet above the injector was laminar with turbulent structure appearing further up in the flame.

A sample of results corresponding to the swirl flow configuration is shown in Figures 14 and 15. Figure 14 identifies the location of photographs shown in Figure 15. All frames are the same size and cover approximately a 1/4 inch by 3/8 inch area. Frame 1 is located just above the air cone while the remaining frames are each approximately 7/8 of an inch above the succeeding one. A 100 micron wire was included in the photograph of the reconstructed image to provide a size reference. The appearance of fringe patterns in the photographs was due to high frequency noise in the holocamera and reduced the resolution and quality of the holograms. This can and will be improved for the later spray holography work.

Some key observations associated with these results include the following:

- (1) Fuel droplets can be imaged within the turbulent spray flame. Thus, application of other laser diagnostic techniques (DSI) to spray flames appears promising.
- (2) Moving away from the injector (frames 1 through 4 in Figure 15), droplet number density appears to decrease while mean droplet size increases. This is consistent with the burn out of smaller droplets.

SPRAY FLAME HOLOGRAPHY DATA

- SWIRL AIR FLOW
- SIMPLEX INJECTOR:
60° SPRAY ANGLE
1 GPH FLOW RATE
- HOLOGRAM MAGNIFICATION:
1 TO 1

FIGURE 14. SPRAY FLAME HOLOGRAPHY DATA - SWIRL FLOW

Frame 2

Frame 4

Frame 1

Frame 3

FIGURE 15. SPRAY FLAME HOLOGRAPHY DATA - SWIRL FLOW

- (3) The turbulent flame structure is visible (particularly in frame 3 of Figure 15) with the scale of turbulence increasing with distance from the injector.
- (4) For the non-swirl case, the turbulent structure does not appear until approximately two inches above the injector and is less apparent than in the swirl case.
- (5) For the non-swirl case, the liquid breakup and near spray field appears identical to that of the corresponding cold flow spray.
- (6) Details of the flame structure surrounding individual droplets or droplet arrays did not appear in these results.

REFERENCES

1. "An Experimental Investigation of Synfuel Spray Characteristics and Combustion Dynamics; Quarterly Technical Progress Report for the Period October 1 to December 31, 1980", SDL Report No. 81-2176-04Q, January 1981.