THE DEVELOPMENT OF AN ELECTRIC
FUEL NOZZLE SYSTEM FOR COMBUSTORS

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Abstract

The investigation that Northern Research and Engineering Corporation is conducting for the U. S. Energy Research and Development Administration involves developing a fuel injection approach which utilizes electrostatic effects to improve the uniformity of the fuel/air mixture in combustion systems. The three phases of the program consist of an initial feasibility study which includes design and cold-flow testing of several nozzles, preliminary combustion testing, and final testing in an actual combustor. During the time period covered by this progress report, parametric design calculations estimating the anticipated effect of fuel charging have been completed. In addition, the experimental rig to be used in the cold-flow tests has been designed and assembled. The nozzle/electrode configurations to be tested have been designed and are currently in the process of being fabricated.

Introduction

Background

The importance of the fuel injection process in achieving acceptable performance in liquid-fuel combustion systems has increased substantially in recent years. This is due primarily to existing trends in the stringency of the design requirements which must be met, particularly with regard to pollutant emissions. One factor related directly to the

injection procedure which has considerable influence on various aspects of combustor performance is the uniformity of the fuel/air mixture in the combustion zone. For example, it has become widely recognized that burning a homogeneous mixture is a critical requirement in reducing nitrogen oxide emissions to satisfactory levels. Improving the uniformity of the fuel/air distribution is also beneficial in terms of increasing combustion efficiency, reducing smoke, smoothing the gas temperature profile in the combustor, and reducing the severity of the wall cooling problem by producing a cool nonluminous flame.

Because of the many potential advantages, considerable effort is being devoted to the development of fuel injection approaches which have the capability of producing a uniform distribution of fuel in the combustion air. Methods which have been employed with varying degrees of success include the use of multiple injection points, prevaporizing systems, high-pressure air to assist in atomization and distribution of the fuel, and premixing chambers. An approach suggested by Northern Research and Engineering Corporation which appears to offer considerable potential involves utilizing electrostatic effects to promote the rapid dispersion of fuel droplets across the combustion air stream. This is accomplished by electrically charging the fuel droplets in the spray from a conventional atomizer by means of a high-voltage electrode. The cloud of charged droplets will tend to expand due to the Coulomb forces between individual droplets resulting in a uniform distribution of the fuel throughout the surrounding air. The practical application of this concept is being investigated by NREC in a program currently being conducted for the U.S. Energy Research and Development Administration Office of Conservation under Contract No. EY-76-C-02-2955.*000.

Program Description

The over-all objective of the program is to develop a fuel-nozzle configuration utilizing electrostatic effects which produces a demonstrated improvement in the uniformity of the fuel/air distribution and consequent improvements in combustion performance. The program consists of the following three phases:

1. Phase A - Feasibility Study. The goal is to demonstrate that the basic concept is feasible in terms of providing an observable improvement in the uniformity of the fuel/air distribution. This is to be accomplished by measuring the effect of electrostatic charging on the spatial fuel distribution under cold-flow conditions (that is, in the absence of combustion) for several nozzle configurations. The technical effort required in this phase includes initial parametric calculations to estimate the anticipated effect, design of the nozzle/electrode configurations based on the results of these calculations, cold-flow testing of the selected nozzle designs, and critical analysis of the experimental results obtained.
2. Phase B - Preliminary Combustion Tests. The principal objective is to determine the effects of fuel charging under combustion conditions. This will involve testing two of the nozzle configurations examined in the previous phase. The tests will be conducted in a simple duct with a conventional V-gutter flameholder. The measurements will consist of radial profiles of gas composition, temperature, and total pressure (velocity) at three axial positions.
3. Phase C - Combustion Tests. The objective of this phase is to determine the effects of fuel charging on the performance of an actual combustor. This will be accomplished by installing one of the nozzle configurations in an existing burner and measuring the resulting effects on performance in terms of emissions, exit temperature profile, and stability.

The current status of the program is that the first phase has been partially completed. The technical effort which has been conducted consists of performing the parametric calculations, design of the nozzle/electrode configurations, and fabrication and assembly of the cold-flow test rig. The results obtained to date are described in more detail in the remainder of this report.

Design of Test Nozzles

Basic Configurations

The initial approach which has been adopted for demonstrating the feasibility of the concept involves modifying conventional atomizers by the addition of an electrode rather than attempting at the outset of the investigation to design an optimum electric-nozzle configuration. The atomizers selected for this purpose are all commercially-available designs typically used in a variety of industrial applications. The designs which have been procured for use in the testing program are listed in Table I. As can be seen, two types of nozzle, operating on different principles of atomization, and several sizes of each type have been chosen to provide a range of spray characteristics.

Basically, there are two general methods that have been identified by which the electrical charging of the fuel can be accomplished. These are shown schematically in Figure 1. In the first approach, electrical charges are induced in the bulk of the fluid upstream of the nozzle. A typical electrode configuration would be as shown in Figure 1a. This consists of a cylindrical charging section mounted in the fuel line upstream of the nozzle. The central electrode is maintained at a high voltage relative to the grounded wall of the cylinder. The fuel is charged by passing through the resulting high-intensity field. When the fuel has flowed through the nozzle and atomization occurs, each of the droplets formed retains the charge contained in the mass of liquid comprising the drop.

The second method which will be investigated consists of charging the fuel droplets directly in the spray region. Various electrode arrangements are possible depending on the geometry of the nozzle and combustion system. The selected configuration for the testing program is shown schematically in Figure 1b. The ring electrode at high voltage is centered downstream of the grounded nozzle and electrically insulated from it. As the voltage is increased, a corona discharge occurs causing an ionization region of high charge density around the electrode. The location of the electrode is arranged such that the fuel spray passes through the corona region and the droplets become charged.

Parametric Calculations

In order to define more specifically the performance requirements of the nozzle/electrode configurations, it was necessary to estimate the anticipated variation of the rate of spray dispersion with degree of fuel charging. An approximate analytical model was derived for this purpose. The model assumes that the spray leaves the nozzle as a cylindrical cloud of charged droplets and that subsequent dispersion is accomplished only by mutual Coulomb repulsion of the drops. Calculations were performed using the model to investigate the approximate effects of droplet charge, size, and velocity on the dispersion rate as represented by the variation of spray diameter with axial distance from the point of injection. Typical results are shown in Figure 2 for a droplet diameter of 50μ and a velocity of 50 ft per sec. As can be seen, the calculations indicate that the degree of charging required to achieve a rapid dispersion rate is a value of N_e on the order of 2×10^6 elemental charges per droplet corresponding to a charge density (S) in the fuel of about 5×10^{-6} coul per cu cm. Equivalent values computed for other drop sizes were found to be on the order of $N_e \approx 10^5$ for 10μ and $N_e \approx 10^7$ for 100μ drops. It should be noted that the required values of N_e quoted here are most likely somewhat conservatively high because of the assumptions contained in the simplified model used for the calculations (for example, ignoring the fact that the spray is initially a hollow cone rather than a jet). In any event, the results obtained provide a reasonable estimate at least of the level of charging which should be the goal in the design of the test nozzles.

A design study of the bulk-charging configuration was conducted using an approximate model developed to represent the charging process. The parametric calculations performed consisted of estimating the variation of the outlet charge density with fuel properties, flow rate, applied voltage, and the dimensions of the configuration. The results obtained are illustrated by the data plotted in Figure 3 which show the level of charging as a function of the length and diameter of the charging section. The data indicate that the degree of charging which can be achieved with a practical configuration is approximately two orders of magnitude lower than the design goal. However, it is probably somewhat premature to conclude that this approach is not worth pursuing because of the uncertainties

inherent in the preliminary analysis with respect to the accuracy of the analytical models used. Therefore, it has been decided to continue investigation of the bulk-charging approach at least through the initial stages of testing.

Design calculations have also been performed for the droplet-charging configuration. The analytical model utilized was developed on the basis of relationships available in the literature for analysis of electrostatic precipitators. The parametric investigation consisted of determining the variation of the degree of droplet charging with droplet size, electrode voltage, and configuration dimensions. Typical results are given in Figure 4 which shows the variation of charging level with the axial location of the electrode with respect to the nozzle for a selected set of conditions. Also plotted is the corresponding diameter of the ring electrode which was calculated with the constraint that the diameter be equal to that of the spray assuming a nominal cone angle of 70 degrees. As can be seen from the results, the estimated level of performance of the droplet-charging approach is superior to that of the bulk-charging configuration and is approximately equal to the design goal. Consequently, it appears that this approach offers considerable promise of achieving the desired objectives.

Selected Design Configurations

The design of the nozzle/electrode configurations has been completed on the basis of the results obtained in the parametric calculations. The configurations are shown in Figures 5 and 6. Both electrode assemblies are currently in the process of being fabricated and should soon be ready for testing with the various nozzles.

Design of Cold-Flow Test Rig

In order to measure the fuel charging performance of the design configurations, a preliminary series of tests in static air will be performed using the apparatus shown schematically in Figure 7. In each test, the charged spray from the nozzle is collected in a metal bucket which is electrically insulated from ground and whose capacitance has

been precalibrated. When a predetermined volume of fuel has been collected, the voltage of the bucket is measured. By a simple relationship, the density of charge induced in the fuel (C coul per cu cm) can be calculated directly from the sample volume and the measured voltage. The charge density will be determined in this fashion for each nozzle/electrode configuration over a range of flow rates and electrode voltages.

Following the completion of this initial series, the most promising configurations will be tested in the rig shown schematically in Figure 8 which has been fabricated and assembled. The nozzle being tested is mounted in a 6 inch sheet metal cylinder centered on the square duct which comprises the main test section. Four removable Plexiglas windows located just downstream of the nozzle are provided for viewing of the spray. The wire screen positioned at the inlet of the cylinder forces a portion of the air stream to flow at comparatively high velocity across the viewing windows to prevent spray impingement.

Each of the nozzle configurations will be tested over a range of fuel flow rates, air flow rates, and electrode voltages. The tests will involve visual observation and photographing of the spray. In addition, the spatial distribution of fuel will be determined by radially traversing the air stream to sample the flow and measure the fuel concentration. The traversing will be conducted through an instrument mounting plate that replaces one of the windows. The plate contains openings for insertion of probes into the test section at three axial positions downstream of the nozzle. It is anticipated that testing will commence in the near future. The initial results obtained will be the subject of the next progress report.

TABLE I
BASIC NOZZLES TO BE TESTED*

(a.) Hydraulic Pressure Nozzles

<u>Nozzle Designation</u>	<u>Nominal Capacity,** GPH</u>	<u>Spray Angle, deg</u>
WDA-5.0	5.0	70
WDA-6.0	6.0	45
WDA-6.0	6.0	70
WDA-6.0	6.0	90
WDA-8.0	8.0	70

(b.) Air Assist Nozzles

<u>Nozzle Designation</u>	<u>Nominal Capacity,*** GPH</u>
30609-5	0.89
30609-8	1.38
30609-9	1.79
30609-11	2.56

* All nozzles obtained from Delavan Manufacturing Company, West Des Moines, Iowa 50265

** Water flow rate at 125 psig

*** Water flow rate at a head of 24 in and an air pressure of 10 psig.
The spray cone angle for these nozzles varies widely with pressure.

(a.) Bulk-Charging Approach

(b.) Droplet-Charging Approach

FIGURE 1 - BASIC ELECTRODE CONFIGURATIONS

FIGURE 2 - ANALYTICAL ESTIMATE OF SPRAY SPREADING RATE WITH DISTANCE FROM NOZZLE

FIGURE 3 - ESTIMATED PERFORMANCE OF BULK CHARGING CONFIGURATION AS FUNCTION OF DIMENSIONS

FIGURE 4 - ESTIMATED PERFORMANCE OF DROPLET CHARGING
 CONFIGURATION AS FUNCTION OF DIMENSIONS

FIGURE 5 - DESIGN DRAWING OF BULK CHARGING CONFIGURATION

FIGURE 6 - DESIGN DRAWING OF DROPLET CHARGING CONFIGURATION

FIGURE 7 - APPARATUS FOR MEASUREMENT OF CHARGING PERFORMANCE

FIGURE 8 - SCHEMATIC OF COLD-FLOW TEST RIG