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INVESTIGATION OF MEANS FOR PRODUCING FUEL SPRAYS OF UNIFORM DROP SIZE

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Project M988

AIR RESEARCH AND DEVELOPMENT COMMAND, U. S. AIR FORCE
CONTRACT NO. AF 33(600)-5057
BALTIMORE, MARYLAND

March, 1952

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FOREWORD

This report was prepared by the Engineering Research Institute of the University of Michigan on U. S. Air Force Contract No. AF 33(600)-5057. The work was sponsored by the Powerplant Laboratory, with Lt. C. B. Shepherd acting as Project Coordinator. Work was initiated at the University of Michigan under Project M988. This report is the first of several to be prepared on various phases of this project. Others will be published as the research progresses.

ABSTRACT

As a result of a literature search, discussions with other research workers, and our own tests, the spinning-disc atomizer has been selected for adaptation and use on this project for producing drops of uniform size. There is agreement among research workers that the spinning-disc atomizer is unique in its ability to produce drops of uniform size, when operated under carefully controlled conditions.

The spinning disc produces drops in the desired size range; the spraying of hydrocarbon fuels with constituents of widely varying volatility appears to present no difficulty.

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INTRODUCTION

This research project has for its objective the quantitative evaluation of factors which influence the burning of liquid fuel drops, when a drop is burned alone and also when a drop is burned as one of a group in an air-fuel mixture. Data on the combustion of a drop when burned with adjacent burning drops can be gathered if it is possible to produce continuously a group of drops all of the same size. This would make possible the determination, for example by photography, of the mean drop size at known time intervals before and throughout the burning period. This in turn would permit the determination of such items as the effect of drop size, fuel volatility, and mixture ratio on the rate of burning of the drops.

Since the usual fuel atomizing devices produce a heterogeneous mixture of drops of widely varying size, an immediate objective of the project was to select some type of atomizing device, other than the usual spray nozzles, best suited to produce drops of uniform size. It is a further objective to develop and adapt the device selected to meet the requirements of this project.

OBJECT

To survey the means for continuously making a quantity of drops of uniform size, and select the most suitable type for this project.

DROP-FORMING BY CONDENSATION

Devices commonly referred to as aerosol generators were investigated first. These devices consist of a heater section for vaporizing a liquid, and provision for subsequently mixing the vapor with air containing nuclei. The mixture of air, vapor, and nuclei are then admitted to a condenser wherein condensation of the vapor occurs upon the nuclei, each nucleus acting as a condensation center. By careful control of the vapor quantity, the number of nuclei, and condensation rate, liquid drops are formed about the nuclei, and may be removed from the aerosol generator.

Professor Victor K. Le Mer, with his associates at Columbia University, has done a considerable amount of work on aerosol generators of this type. Their work and aerosol generator equipment is described in References 3 and 6.

The aerosol generators made at Columbia have been used with materials such as sulfur, with volatility considerably lower than the hydrocarbon fuels which would be of greatest interest to this project. The lower volatility has the advantage that practically no material leaves the generator in vapor phase which makes the operation insensitive to the ambient temperature.

The drops produced by the equipment at Columbia University range in size up to a maximum of 10 microns in diameter, with the usual size being about 0.2 micron in diameter. Experimental work is required to determine if it is possible or practical to make uniform drops of large sizes. Considerable care must be exercised to limit the variation in diameter to $\pm$ 10 per cent. The operation of the generator is extremely sensitive to changes in the temperatures of boiler and reheater. The adjustment of these is an individual matter with each generator and substance.

It therefore appears that this method of forming drops is not well adapted to hydrocarbon fuels such as kerosene, having constituents with a wide range of boiling points. This is unfortunate, since these fuels are of principal interest for this project. Furthermore, there is little experience with these devices, and the problems pertaining to making drops of larger size are not known.

It is believed that the spinning-disc atomizer, described later in this report, is better adapted to our task, and offers more promise for our work than the condensation method. Also, much less time and money will be required to proceed to the main objective, which is the observation of burning drops.

MECHANICAL MEANS FOR FORMING DROPS OF UNIFORM SIZE

Literature Survey

The literature relating to this subject has been surveyed, and the device that now appears most promising for our purpose is the spinning-disc atomizer. Several workers have done extensive research on the characteristics of the spray produced by a spinning disc, and all agree that the disc is unique in its ability to produce uniform-size drops under certain conditions.

The British workers, Walton and Prewett[8], have observed the nature of drop formation from a flat circular spinning disc through a wide range of speeds with several different liquids. They present the following equation for drop size from the flat spinning disc:

$$d = K \left(\frac{T}{D\rho}\right)^{1/2} \frac{1}{\omega},$$

where

d = drop diameter;

D = disc diameter;

ω = angular velocity;

T = surface tension of liquid;

ρ = density of liquid: and

K = a constant for various fluids, average value, 3.8.

These authors did not report tests with hydrocarbon fuels.

The shape of the disc used in these experiments was similar to that shown in the photograph of Fig. 1. Others have used spinning cups[2] and still others[1] have employed vaned rotors. These devices serve to decrease the slippage of the fluid on the turning member. There is evidence that a smooth surface without projections produces the most uniform sizes of drops.

Tanasawa[7] states that the use of a spinning cup or spinning flat disc makes little difference in the resulting uniformity of drop size. He obtained remarkably good high-speed photographs showing types of drop formation which in general are similar to those of Hinze[2].

Tanasawa concluded that a very sharp-edged disc gives a slightly smaller drop diameter than a plane disc with a thicker edge. In all cases, however, the edge must be very smooth to obtain greatest drop uniformity. Tanasawa also performed tests with discs having a saw-toothed edge. The saw-toothed edge resulted in a smaller drop size.

Concerning the nature of formation of drops from a spinning disc, Hinze[2] lists three different types of disintegration that take place near the edge of the disc, which he designates as follows: (a) the state of direct drop formation; (b) the state of ligament formation; and (c) the state of film formation. Which type of fluid phenomenon will be present depends upon the operating circumstances. The author[2] further states that transition from state (a) to state (b) or from state (b) into state (c) is promoted by an increased liquid flow rate, an increased angular speed, a decreased cup diameter, an increased fluid density, and increased viscosity, and a decreased liquid surface tension.

Hinze[2] reasons that drops of greatest uniformity of size result under the circumstance of drop formation from the ligament state listed as (b) above.

Walton and Prewett[8] state their opinion that drops of greatest uniformity are produced by the spinning disc when drops are formed and released individually from the disc edge, with the rate of flow of liquid to the disc edge being so small that centrifugal and surface tension forces acting on the growing drops are substantially in equilibrium up to the time of break-away. At higher rates of flow, inertia forces become important and the fluid leaves the disc edge as a thin sheet which breaks up into spray with the usual broad drop-size distribution.

To obtain drops of the greatest uniformity, Hinze[2] lists the following requirements, among others:

1. Gravitational effects must be negligible; this means that centrifugal acceleration must be very great with respect to gravitional acceleration (ω^2 r $>$10 g).

2. Rotation must be completely free from vibration.

3. There must be a uniform supply of liquid.

4. The surface of the spinner must be smooth, particularly if the liquid layer is very thin.

Walton and Prewett[8] produced drops through a size range from 15 microns up to several millimeters in diameter. These authors and May[7] noted that the spray thrown from the disc contained a number of fine drops in addition to the main group of uniform size. These are referred to as satellite drops. The larger drops are thrown a greater distance radially from the disc before they reach their terminal velocity, and it is practical to separate the larger drops from the satellite drops by means of a controlled airstream.

May[5] found that when the smaller satellite drops were removed and fluids were used that wet the rotor readily, 90 per cent of all drops fell within a band of 5 per cent of the mean in width, and the minimum size drop was 6 per cent smaller than the mean. He is of the opinion that these figures can be improved by very accurate machining of the disc surface and edge.

Experimental Testing

The work done in our laboratory has centered around the building and preliminary operation of several spinning-disc sprayers. We have attempted to pattern our apparatus along the lines suggested by the several authors cited. In addition, we have attempted to make our apparatus of such form that (a) the photographic method of York and Stubbs[9] can be used to examine the spray produced, and (b) the method can ultimately be incorporated into a drop source capable of delivering significant quantities of uniform drops to a tubular type of burner.

In our efforts to meet requirement (a) above, we have worked principally with a disc mounted on an electric motor shaft. For purposes of photographic convenience we have dealt with spray from the disc running with the shaft horizontal (see Fig. 1). For burning convenience we have operated the sprayer with the shaft vertical. In order to use the photographic method for the observation of drops in a flame, a further modification in camera equipment is needed, as stated later.

Small air tops, which consist essentially of a flat-topped cone driven by compressed air and riding on an air bearing, have commonly been used as spinning-disc sprayers. These have been described by Walton and Prewett[8] and May[5]. These tops are apparently able to operate through a wide range of speeds with a minimum of vibration.

The electric-motor mounted-disc sprayer has many advantages for our work, such as simplicity of construction and control, and the absence of air currents as produced by the air tops. However, it has the disadvantage that some mechanical vibration is introduced. This vibration will tend to reduce the high degree of size uniformity reported for the air-supported spinning top. In the design and construction of our units, every effort must be made to reduce vibration to a minimum.

Fig. 1 shows the type and arrangement of our most recent apparatus. This view shows the relative location of camera, fuel supply, disc and motor, lens, water cell, and high-intensity light source. In this position the sprayer produces a vertical sheet of drops. In taking photographs for spray analysis, the axis of the camera and the light source has been directed perpendicular to the sheet of drops. Inasmuch as the sheet of drops is quite thin, and since the depth of focus of the camera is small, we have experienced difficulty in getting the plane of the drops into exact focus. In an effort to overcome this difficulty the camera is focused on the tip of the small wire in front of the lens; the whole camera is then moved by a lead screw such that the tip of the small wire is "in" the sheet of the drops.

Near the periphery of the disc the spray consists of drops in two size groups; this is in agreement with the performance reported by others. At somewhat greater distance from the periphery, most of the smaller satellite drops drift out of the spray sheet and the spray is observed to be quite uniform. Further modification of apparatus is needed to remove these satellite drops.

Fig. 2 indicates the nature of the spray at a point several inches away from the disc edge. Although a considerable degree of definition is lost in copying and printing, it can be seen that the bulk of the spray consists of drops in a rather narrow size range. A comparator examination of the negtive yields the following count of drops in focus in this photograph:

Total in focus: 80 drops

Size 85 - 90 : 70 drops

Size 40 - 45 : 10 drops

The print size is approximately three times the size of the region photographed. The several very small spots observable in the print result from minute flaws in the film.

As a result of our work it is believed that, with further improvements expected in technique, drops may be produced of such uniformity that more than 90 per cent of the drops will be within ± 5 per cent of the mean diameter.

FUTURE PLANS

Having selected what is believed to be the most suitable means for producing uniform size fuel drops, we will concentrate efforts on learning more concerning the characteristics of the device so that improvements can be made.

Equipment is being prepared for photographing the drops thrown from the disc as they burn in a plane ring concentric to the disc. This requires a rapid camera-shutter action to prevent the light from the flame from fogging the film. In addition, to obtain definition of the drops in the burning zone, the shutter must be automatically synchronized with a high-intensity light source to minimize further the effect of the flame on the film.

It is planned to photograph a field of drops of uniform size with this equipment at known points ahead of and throughout the flame zone. Effort will be made to establish the velocity of the drops at the various points by means of the double-exposure photographic technique of Professor J. L. York[9]. The photographs and test data will provide the following information: total distance traveled by a drop, the velocity of the uniform drops at any point, and the mean diameter of the uniform drops at progressive points along their path. This information will make possible a determination of the rate of change in mean diameter of the drops before and through their burning process. When this technique is established, a program will be started to determine the time required to burn drops as a function of drop size. The influence of other important variables can also be considered then.

It is expected that observing the combustion of drops directly after they are thrown from a spinning disc will be a worthwhile activity for some time.

In addition, some thought has been given to means for gathering the drops thrown from a sector of each of several spinning discs and delivering this spray of uniform drop size to a small combustor. It is believed that such a device will prove to be possible.

It is believed that quantitative information on the time required to burn drops of the liquid fuel, and the factors which influence it, will ultimately prove to be of significant value in the design and development of gas turbine combustors.

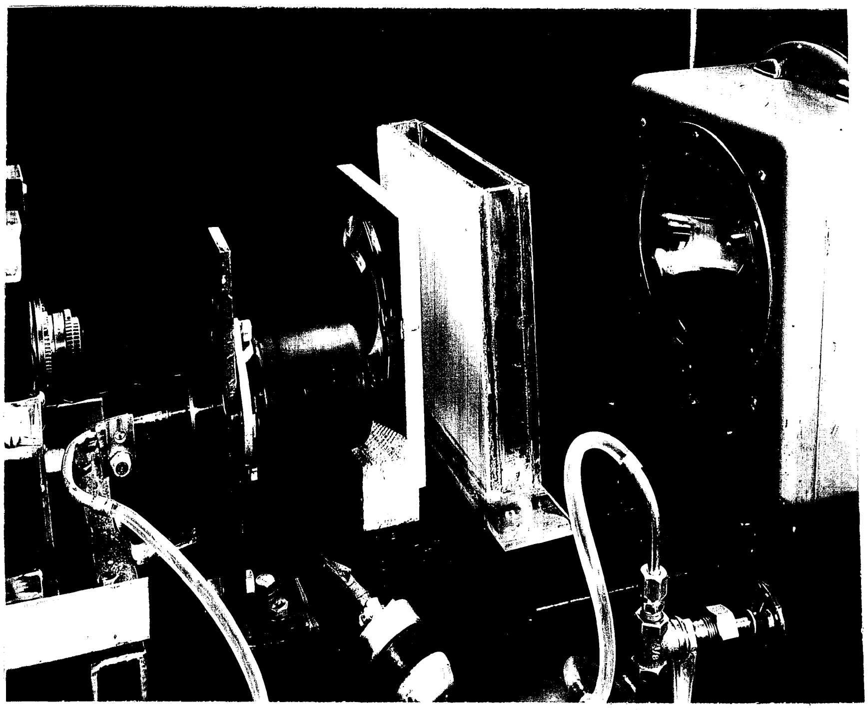

Fig. 1. Equipment for Photographing Drops from a Spinning Disc.

Fig. 2 Photograph of Drops Thrown from a Spinning Disc.
The liquid used in this experiment was kerosene.

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