July 1955

BURNING OF INDIVIDUAL FUEL DROPS IN A FURNACE

Jay A. Bolt
Michel A. Saad

The University of Michigan

Engineering Research Project No. 2253:3-19-F
Power Plant Laboratory
Contract No. AF 33(616)-2436
Task No. 30236

Wright Air Development Center
Air Research and Development Command
United States Air Force
Wright-Patterson Air Force Base, Ohio

engn
UMRØ35Ø

FOREWORD

This report was prepared by the Engineering Research Institute of The University of Michigan on Air Force Contract No. 33(616)-2436, Change Order No. Ca(55-792). The work was sponsored by the Wright Air Development Center, with Jack W. Fulton acting as project coordinator. The work was conducted at The University of Michigan under Projects 1988 and 2253-3.

ABSTRACT

A furnace has been built to study the combustion rate of falling liquid fuel drops in a hot atmosphere. The drops are detected by multiplier phototubes which trigger high intensity lights; the drop image is recorded on film in a camera opposite the light.

TABLE OF CONTENTS

LIST OF FIGURES

INTRODUCTION

Photographic observation of a burning fuel spray revealed so many variables and complexities that a theoretical analysis of the phenomena is impractical at the present time. Accordingly, it was decided that observation of individual burning drops in a hot atmosphere would provide a better starting point for the ultimate understanding of the phenomena of combustion of a liquid fuel spray.

EXPERIMENTAL EQUIPMENT

The experimental equipment consists of four units: the furnace, the photographing equipment, the detection equipment, and the timing equipment. These are described below:

A. THE FURNACE AND FUEL DROPPER

The Furnace.—The main objective in the design of the furnace was to attain the required temperatures, avoid convection currents, have uniform temperature within the furnace, and make possible the photographic observation of the drops.

The furnace, as shown in Figs. 1 and 2, consists of two heating elements embedded in two alundum pieces, 4 x 1-1/4 x 45 inches, placed opposite each other with a 1-inch space between them. The alundum pieces are cast in two stainless steel channels, thus forming the two side-wall heating surfaces of the furnace. The channels are made of 1/16-inch stainless steel sheet. The space between the alundum pieces (1 x 4 x 45 inches) is the test section or hot atmosphere through which the drops fall. Every heating element has two taps, which gives flexibility in furnace temperature control.

The resistance of each heating element is 28.5 ohms, divided into three sections of 9.5 ohms each. The resistance wire used is 16-gage chromel A (0.252 ohm per foot); it was made into a helix before being cast in the alundum. Two hundred and twenty volts are applied to every two sections of the resistance wire (19 ohms), giving a current of 11.58 amperes and a total power of 7.64 kw.

The outside dimensions of the furnace are 4 x 17-1/2 x 45 inches.

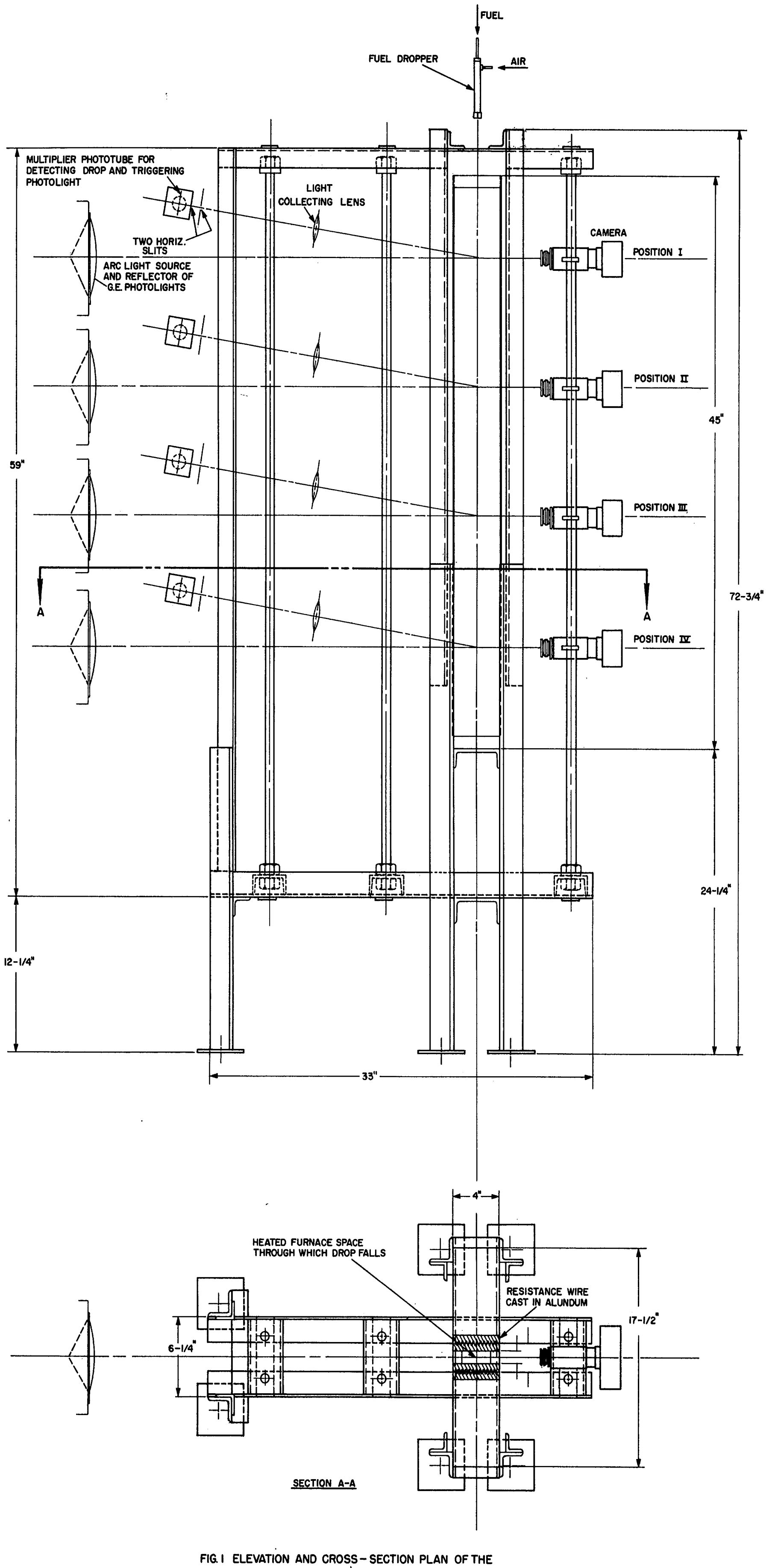


FIG. I ELEVATION AND CROSS-SECTION PLAN OF THE VERTICAL FURNACE

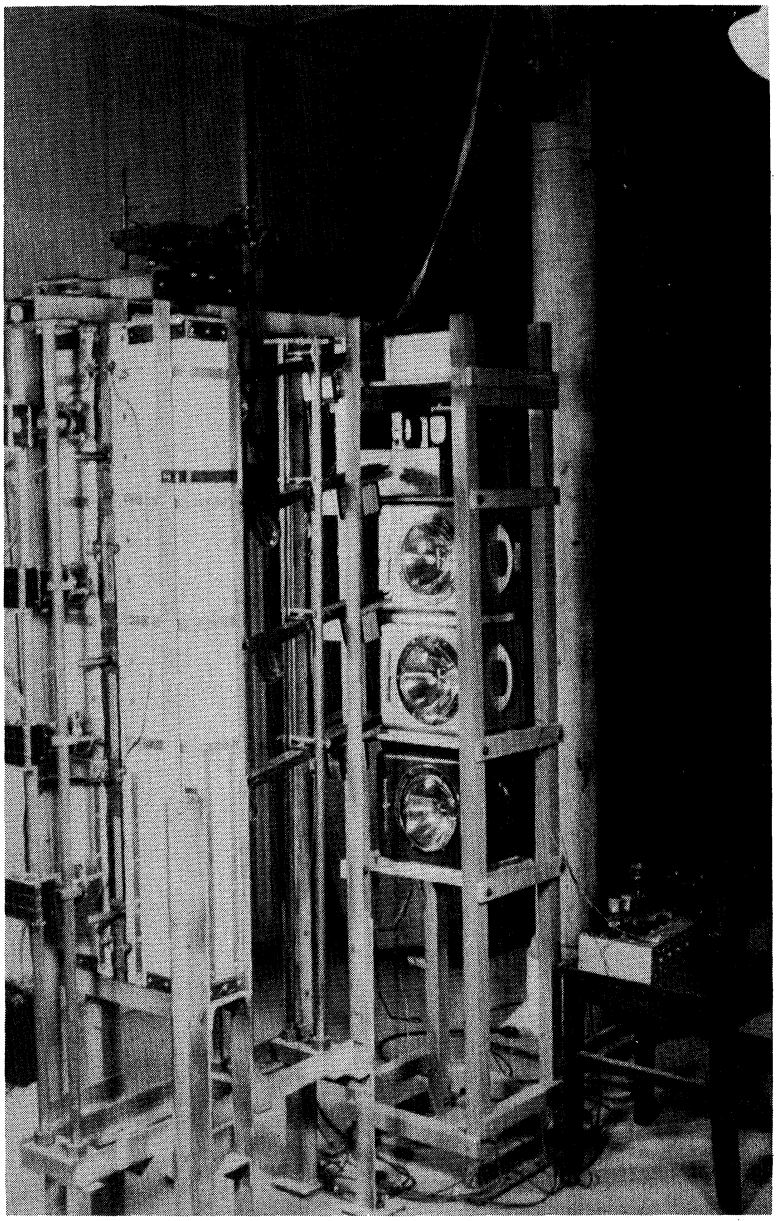


Fig. 2. Vertical furnace for burning and observing falling drops of fuel.

The insulation is made up of two layers of materials: 2-1/2 inches of firebrick and 5 inches of vermiculite. The whole insulation is contained within a steel shell made of 1/16-inch steel sheet. The lid and bottom pieces, which are removable, are clamped by sheet metal screws.

The entire furnace length is provided with two opposite continuous glass windows which allow the drop to be photographed at any position in the furnace, and the entire burning process can be observed. The glass windows are made of pieces of high-temperature Pyrex glass, 3 x 1-1/4 x 1/8 inches.

Three iron-constantan thermocouples are used to determine the temperature within the furnace, their tips being shielded by platinum foil 0.01 inch thick. The thermocouple wire is passed through 1/8-inch twin-bore ceramic tubing, which in turn is inserted in a stainless steel tube and clamped to it by a setscrew. A Leeds and Northrup potentiometer is used to read the temperature.

The furnace is mounted on a platform made of 2-inch angle iron so that the bottom of the furnace was 2 feet above the floor. An angle-iron frame was attached to this platform to provide a stand for mounting other pieces of equipment.

Fuel Dropper.—The first attempt to form drops was accomplished with a small-bore tube from which the drops are thrown off by a concentric air jet. Experience shows that the drop size can be controlled by capillary bore size and the pressure of the concentric air jet. It is difficult to form a drop of diameter less than that of the outside diameter of the capillary tube.

A hypodermic needle was welded to a 1/4-inch copper tube to form the fuel supply line. This tube is centered into a 4-1/2 inch long, 1/2-inch-outside-diameter brass tube which serves as the air jacket. The tip of the needle passes through a small hole drilled at the center of a circular brass plate at the end of the brass tube. The plate is held in position by a cap nut. The centering of the needle in the orifice is done by two sets of centering screws which also hold the needle in position.

The hypodermic needle tip gives relatively large drops; a glass tube with a much smaller tip could be substituted to give smaller droplets.

Compressed air is introduced into the dropper and is controlled by a needle valve. The velocity of the concentric air is not high because violent turbulence will occur, which causes the drops to fall in a non-vertical path.

The dropper is shown in Fig. 3.

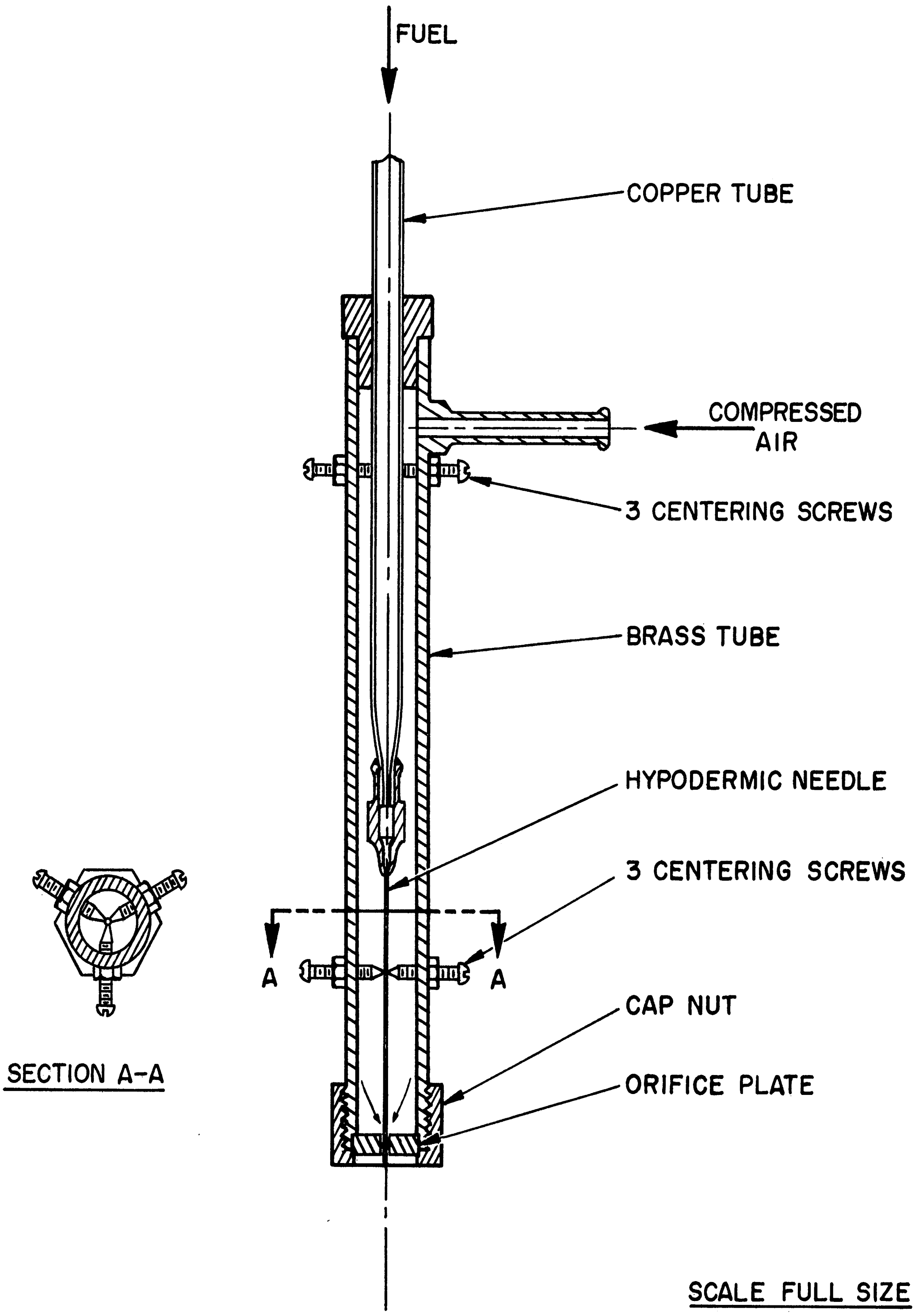


FIG. 3 FUEL DROPPER

B. PHOTOGRAPHIC EQUIPMENT

Pictures of a falling drop are taken at four positions along the furnace and the time is recorded at each position. Each position has an Argus C-3 camera box with an extension tube 4 inches long attached. The inside of the extension tube is painted dull black to prevent light reflections. On the other end of the tube a Schneider Coponar lens with a focusing mount is attached. In front of the lens a circular piece of heat-absorbing glass is placed to protect the lens from the heat of the furnace. On the other side of the furnace, a high-speed General Electric photolight is used to provide a high-intensity light source. The photolight provides a flash of light of an extremely short duration (approximately one microsecond). The photolight combines a short-gap, high-pressure, inert-gas-filled flash tube with an energy storage capacitor, a high-voltage transformer, a rectifier, and a trigger circuit which releases the energy from the capacitor into the flash tube at the proper time.

The lenses used are Schneider Coponar F/4.5 of 75-mm focal length. The magnification ratio is about 1:1. The cameras are mounted in such a way that they can move upward or downward along the furnace, and can move inward and outward from the furnace.

C. DETECTION EQUIPMENT

At each photographing position and on an inclined axis, a multiplier phototube is used for the detection of the falling drop. The multiplier phototube is totally enclosed except for a small horizontal slit. A 5-inch focal length lens is used to collect the light from the droplet flame and collimate it on the multiplier phototube. A 1/32-inch slit is placed in front of the phototube box so that the light from the burning droplet has to pass through the two slits in order to reach the phototube.

The camera shutters are kept open during the entire time of fall of the drop. The actual function of the multiplier phototubes and the triggering circuit is to flash the G.E. photolight at the instant when the droplet is in the field of the camera.

Figure 4 shows the detection-circuit diagram of the four identical stages. The photo-multiplier tube, which is type 931A manufactured by RCA, has 9 stages and is capable of multiplying a feeble photoelectric current produced at the cathode by an average value of 1,000,000 times when operated at 100 volts per stage. The applied potential is 1,000 volts DC from 5 90-v dry cells and a 550-v power supply connected in series. The triggering coil of the photolight is connected to the plate of the thyratron tube. The thyratron tube is made to flash the photolight, and the total delay between the detection of the falling droplet

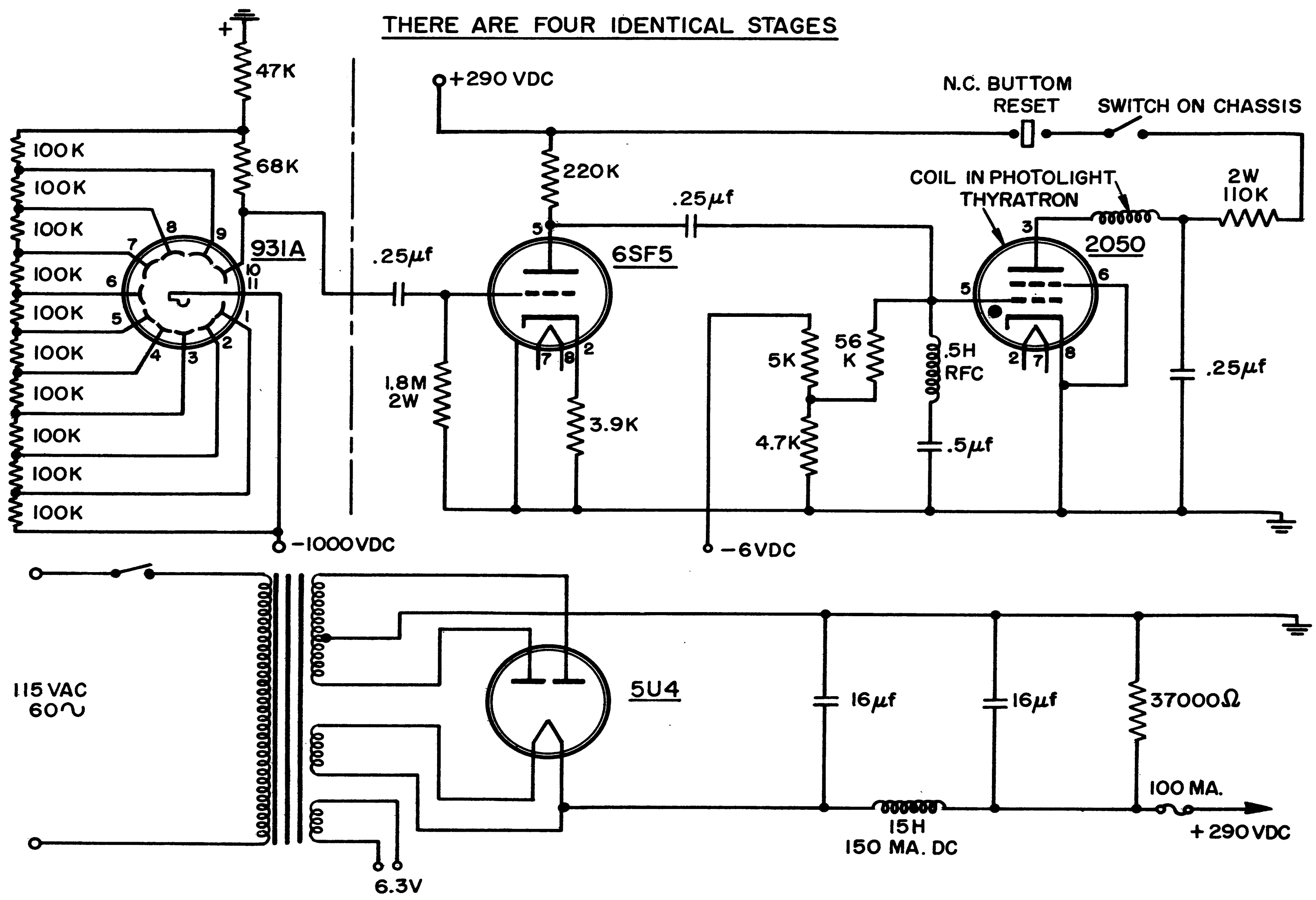


FIG. 4 DETECTION CIRCUIT DIAGRAM

and the flashing of the light is in the microseconds range.

D. THE TIMING EQUIPMENT

The elapsed time between the pictures must be accurately established to permit the determination of the rate of burning. This was accomplished by recording the instant when the photolights flash, in the manner described below.

The plate of each thyratron tube is connected to the input of a Tektronix cathode-ray oscilloscope. The sweep of the scope is made to run triggered by the first thyratron tube, and each sweep is started independently of the preceding sweep. When the first thyratron tube triggers, the beam goes linearly to the right at a rate determined by the sweep generator, and the triggering of the remaining thyratrons gives pips or pulses on the screen. At the end of the sweep the beam returns to the left side again to await another trigger. The sweep rate of the scope ranges from 0.3 second/cm to 3 microseconds/cm.

The output of a square-wave generator is fed to the scope. The function of the generator is to give pulses on the screen at exactly equal intervals. These pulses are used as a check of the sweep rate. After setting the sweep rate at the required value, the pulses of the square-wave generator were too close to each other and, to overcome this difficulty, a crystal diode was connected to the output of the generator before it is fed to the scope. The crystal diode acts as a rectifier, eliminating every other pulse. The screen shows that the square-wave generator gives pulses upwards only, spaced at equal intervals of 1/60 second. The triggering of the thyratron tubes gives pulses downwards. A polaroid camera mounted on the screen is used to photograph the timing pips; a typical photograph is shown in Fig. 5.

RESULTS OF PRELIMINARY TESTS

Some pictures of drops falling in the furnace have been taken at three successive stages with a furnace temperature of 1400°F. Examples of these pictures are shown in Fig. 6. The reduction in size is appreciable with small drops, and in some cases no pictures were obtained at the third position, either because the flame around the drop was too weak to affect the multiplier phototube or because the drop was completely burned before reaching the third position. On the other hand, with large drops small diameter changes are noted as the drop falls through the furnace. This is due to the fact that the rate of reduction of diameter is larger for small drops than for big ones. Also, in the case of big drops

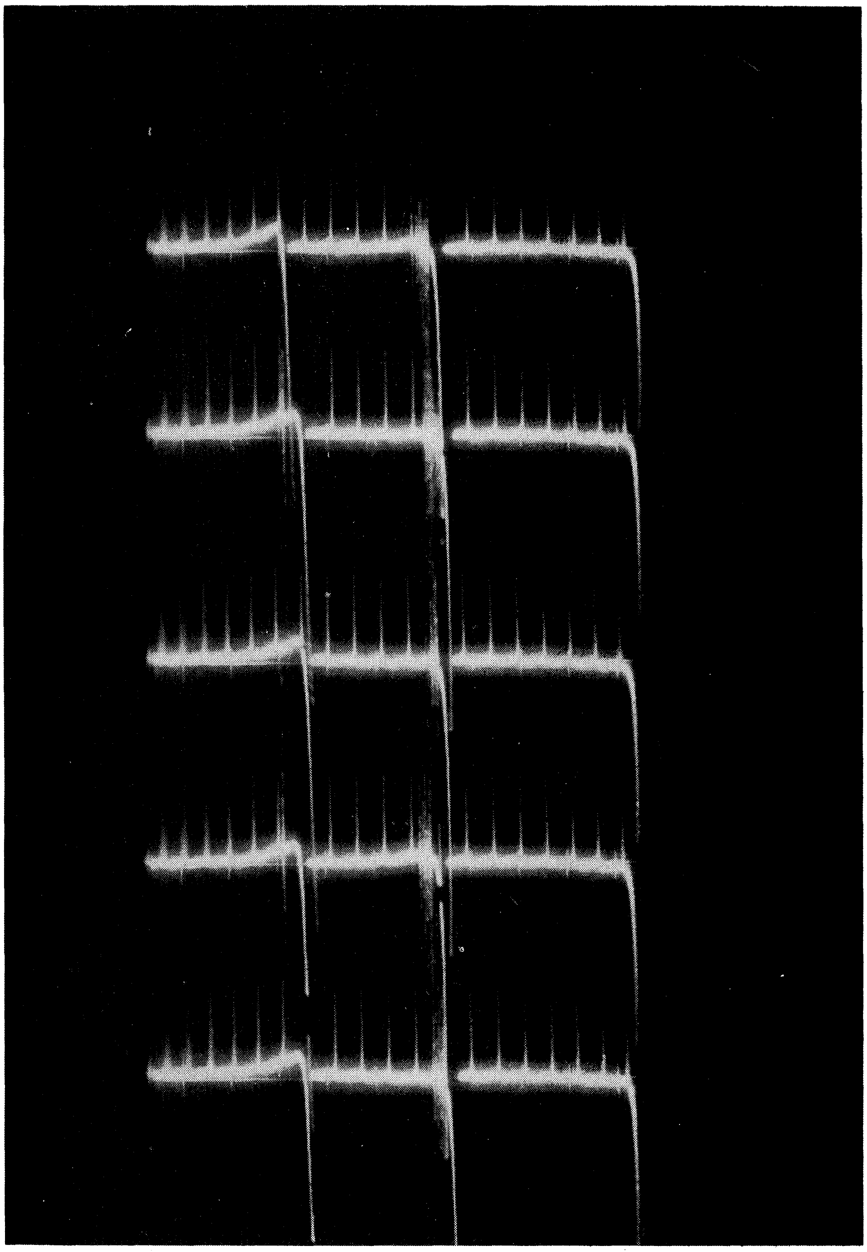
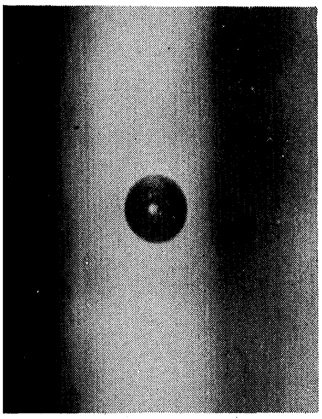
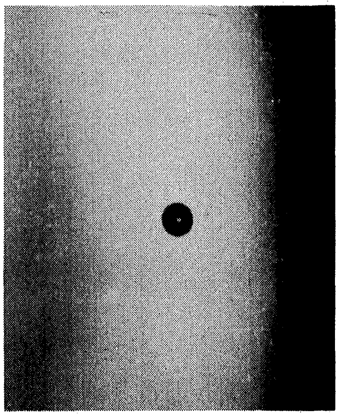


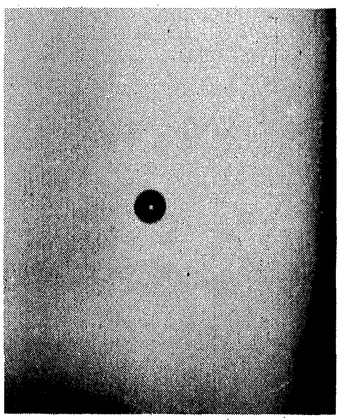
Fig. 5. A typical photograph of the timing pulses.



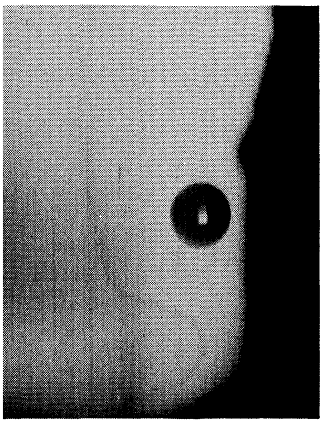
Position I



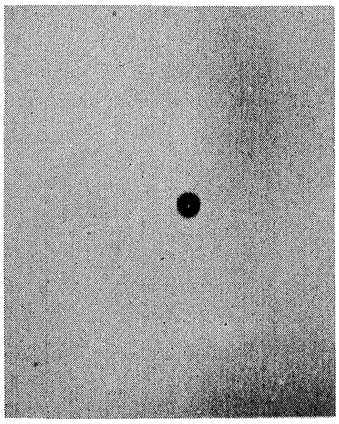
Position I



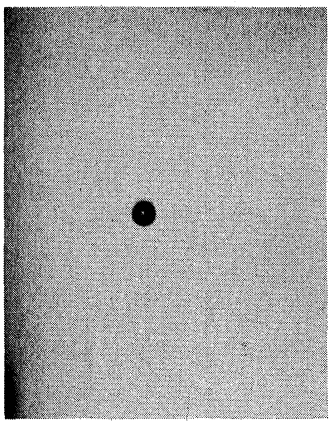
Position I



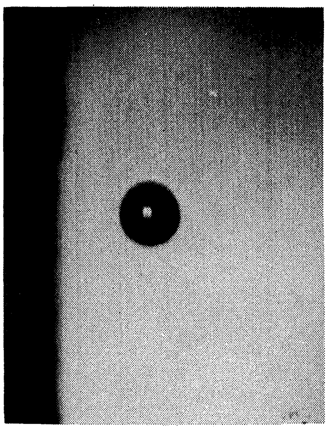
Position II



Position II



Position II



Position III

Fuel: n-heptane
Furnace temperature 1400°F
Magnification ratio about 4:1

Fig. 6. Series of photographs taken in sequence of burning fuel drops falling freely in a hot atmosphere.

a large portion of the heat transferred to the surface of the drop is used up in the internal heating of the drop.

Some data has been taken of drops of about 1000-microns initial diameter, and the timing between the photolights' flashes has been measured by comparing the distance between the pips and the equal distances between the pulses of the square-wave generator.

An attempt was made to solve the equation of a burning drop falling in a hot atmosphere. The solution of such equation is very complicated, and more simplified and reasonable assumptions are necessary.

The investigation of this problem will continue as a graduate study thesis, and without further cost to this project, with the hope of getting significant quantitative data concerning the burning rates of fuel drops.