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A New Droplet Generator

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A new droplet generator developed for laboratory use at NAE is described. A loud speaker driven extractor needle is immersed in a pendant drop. Pulsing the speaker extracts the needle forming a fluid ligament which will decay into a droplet. The droplets are sized by stroboscopic photographs. The droplet's size can be changed by varying the amplitude of the speaker pulses and the extractor needle diameter. The mechanism of droplet formation is discussed and photographs of ligament decay are presented. The droplet generator works well on both oil and water based pesticide formulations. Current applications and results are discussed.

Introduction

The NAE Droplet Generator is a device designed to produce and photographically record for subsequent sizing discrete droplets in a laboratory environment. It is also a useful instrument for observing the breakup or collapse of fluid ligaments.

Description of the Droplet Generator

The droplet generator consists of a pendant drop generator, a droplet extractor, a photographic recording system and an electronic control system (Fig. 1).

Pendant Drop Generator

The source of fluid for the droplets is a pendant drop. A syringe pump drives a hypodermic syringe to supply fluid to a central port in a 6.35 millimeter (mm) diameter horizontal disc. It collects on this disc to form a pendant drop. The pendant drop is in the order of 10^6 times the size of the droplets produced and therefore the syringe pump does not need to be operated while generating droplets.

Droplet Extractor

The droplet extractor consists of a horizontal extractor needle which is connected by a drive shaft to the cone of an audio speaker. The needle drive shaft is supported in a bearing to maintain consistent needle tracking. By controlling the polarity and amplitude of electrical pulses to the speaker, the tip of the extractor needle can be driven into or pulled out of the pendant drop. Any audio speaker capable of taking continuous direct current loads and producing large cone deflections could be used. The speaker currently being used is a 25 watt 8 inch diameter speaker. With positive and negative pulses of 8 volts (6.5 watts), it produces an extractor needle movement of ±4.23 mm (Fig. 2).

Power for the speaker is supplied by a dual variable voltage power supply. One half of the power supply provides the positive pulses to immerse the needle in the pendant drop while the other half provides the negative pulses to extract the needle. A conventional multimeter is used to set the amplitude of the pulses accurately.

The extractor needles are removable from the needle drive shaft and needles of various diameters, ranging in size from 98 microns (μm) to 700μm, have been used.

Photographic Recording System

The droplet generator includes a photographic recording system to record photographic images of the droplets for subsequent sizing. The camera being used with the droplet generator is a conventional 35 mm Pentax Spotmatic with a motor drive film advance and a remotely operated shutter attachment. Since the droplets being photographed are small, considerable photographic magnification is required before they can be accurately sized. This requirement is met by using a 38 mm microscope objective lens in lieu of the conventional photo-optics and it is mounted on an appropriate extender tube to achieve a magnification of 10.

The formation of a droplet is a dynamic event and short photo exposures are required to obtain sharp droplet images. In addition there is a requirement for a high light level due to the extender tube. A strobotac and a stroboslave, operating in a single flash mode have been adequate. The strobes are aligned to bounce light off a white backdrop and provide a 3 microsecond (μsec) exposure.

Droplet Generator Controller

The controller was developed specifically for the NAE Droplet Generator and its function is to control and sequence all the events associated with generating and photo-recording a droplet (Fig. 3). It can be operated in a "single droplet" mode or in a "continuous" mode generating droplets at various preset rates of up to 3 droplets per second. The portion of the controller which operates the strobe lights contains an adjustable digital delay timer (1000 50 μsec steps) to operate the lights at the appropriate instant.

Operation of the NAE Droplet Generator

Adjusting the Extractor Needle Position

The criterion used to set the extractor needle position relative to the pendant drop is an arbitrary one but one which has provided consistent results. The needle is positioned vertically 1.0 mm below the pendant drop base so that it will enter the relatively flat side of the drop. It is positioned laterally so that the tip of the needle will be centered in the pendant drop when a full amplitude (8 volt) "IN" pulse is applied to the speaker.

Generating Droplets

For any given extractor needle a range of droplet sizes may be generated by varying the amplitude of the "IN" and "OUT" pulses to the speaker. The range of droplet sizes (Fig. 4) which can be expected is

$$D_n/3 < D_d < D_n$$

where D_d - diameter of the droplet

D_n - diameter of the extractor needle

The time required to form a droplet varies considerably with changes in the "IN" and "OUT" pulse amplitudes and the delay timer must be set to photo record at the appropriate time.

Applications of the Droplet Generator

The NAE Droplet Generator was developed specifically for biological applications. It is being used as a calibration tool in assessing aerial spray deposits and to treat insect larvae with specific dosages of pesticide. The droplet generator also appears to be suitable for studies on liquid ligament breakup or collapse.

Spread Factor Calibrations

For aerial spraying, it is customary to place sampling cards in the area to collect a sample of the pesticide. The cards retain the stains produced by the droplets and for subsequent pesticide accounting it is necessary to know the relationship between the size of the stain and the droplet that produced it. The droplet generator is used to produce and size droplets of the appropriate pesticide. The droplets are collected on sampling cards and the stains are sized by the NAE Flying Spot Scanner Analyzer. The computer outputs for the droplet and stain sizes are combined to produce a mathematical relationship between the size of a droplet and the size of the stain it will produce on a particular type of sampling surface. The mathematical relationships developed are typically

$$D_d = C + bD_s$$

where D_d - droplet diameter (μm)

D_s - stain diameter (μm)

C - a constant

b - the slope of the curve

The slope confidence at the 90% interval is typically ±0.3%

Dispensing Minute Quantities of Fluid

The droplet generator can be used as a tool to dispense minute quantities of fluid (i.e. in the order of 10^{-6} microlitres). It has been used to treat spruce budworm larvae with specific dosages of pesticide to determine required spray parameters for adequate insect control.

Studying Ligament Collapse

Figures 5, 6 and 7 are a series of photographs showing the formation of droplets. The process of forming a ligmament and its collapse to form a droplet is extremely consistent. These photographic series are not high speed movies; they are, in each case, 20 photographs of 20 different droplets. In each case the photo exposure has been delayed by the time shown on each photograph.

Figures 5 and 7 show that with different combinations of "IN" and "OUT" pulse amplitudes the ligament may break free at one end first. In Figure 5 it breaks free from the needle first and the needle end of the ligament starts collapsing to form the droplet. This portion of the ligament starts moving towards the pendant drop. When the pendant drop end of the ligament finally breaks free, it too starts collapsing to form a droplet and this portion of the ligament moves away from the pendant drop. Since the needle end of the ligament started forming a droplet first, its mass is greater than the other portion of the ligament and the resulting droplet has a horizontal velocity towards the pendant drop. Figure 7 shows the ligament breaking free from the pendant drop first and the resulting droplet is given a horizontal velocity away from the pendant droplet.

Figure 5 also shows that if the droplet contacts the pendant drop, both the droplet and the pendant drop distort but the droplet will bounce free from the elastic pendant drop surface. Figure 7 is an example of the droplet having sufficient horizontal velocity to overtake the extractor needle. Although the extractor needle is covered with fluid it cannot distort as the pendant drop did and the droplet is "captured" by the needle.

Figure 6 shows another phenomenon which is evident, to lesser degrees, in Figures 5 and 7; namely, the instability of a cylindrical liquid jet or ligament. In Figures 5 and 7 there is evidence that the ligament was trying to break up; however, each ligament did collapse into a discrete droplet before the break up could occur. In Figure 6 the separation of the ligament was delayed and the ligament did break up before it could collapse to form a single droplet.

These 3 figures show that varying the amplitude of the "IN" and "OUT" pulses varies the droplet formation process as well as the droplet size.

Results with the Droplet Generator

Droplet Sizes Produced

The parameters which have a significant effect on the size of the droplets are:

- The diameter of the extractor needle
- The amplitude of the "IN" pulse to the speaker (i.e. the immersion depth of the needle in the pendant drop)
- The amplitude of the "OUT" pulse to the speaker (i.e. the velocity at which the needle is extracted from the pendant drop).

The viscosity of the fluid has very little effect on the size of the droplets produced.

Using extractor needles ranging from 98 μm to 700 μm has produced droplets ranging in size from 30 μm to 800 μm.

Droplet Size Consistency

Current applications of the NAE Droplet Generator have required the sizing of discrete droplets and the consistency of the droplet sizes has been of minor interest. Some tests have been carried out to determine the size consistency of the droplets and typical results are listed in Table 1.

TABLE 1

Droplet Size Consistency

Number of droplets sized	24
Mean drop diameter	179.34 μm
Range	5.3 μm
Standard deviation	1.20 μm

Accuracy of Droplet Sizing

The source of errors in sizing droplets and their estimated magnitude are listed in Table 2.

TABLE 2

Errors in Droplet Sizing

Source of Error	Magnitude of Error
Photographic magnification	± 0.38%
Lens resolution	± 0.9 μm
Film resolution	± 1. μm
Measuring accuracy	± 0.1 μm

Tests to determine the error due to the sum of the last three items in Table 2 indicate an error of slightly over ± 1. μm.

Figure 8 shows the optical layout for the droplet generator. An error in the distance from the lens to the droplet would induce a magnification error; however the optical depth of field is very limited and droplets which are off the focal plane sufficiently to produce a 0.38% error create a very badly out of focus image. If out of focus droplet images are deleted then the magnification error will be less than 0.38 percent.

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

SUMMARY

The NAE Droplet Generator is a device which will produce discrete droplets with fluids of various viscosities (i.e. heavy fuel oils or water). It has been used to generate droplets ranging in size from 30 µm to 800 µm. Images of the droplets produced are photographically recorded and can subsequently be sized to ± 1.5 µm. Once the generator has been set to generate a specific size of droplet it will continue to produce droplets with a standard deviation of less than 1%.

The consistency of the droplet formation process also [illegible] the generator a suitable instrument for observing fluid ligament break up or collapse.

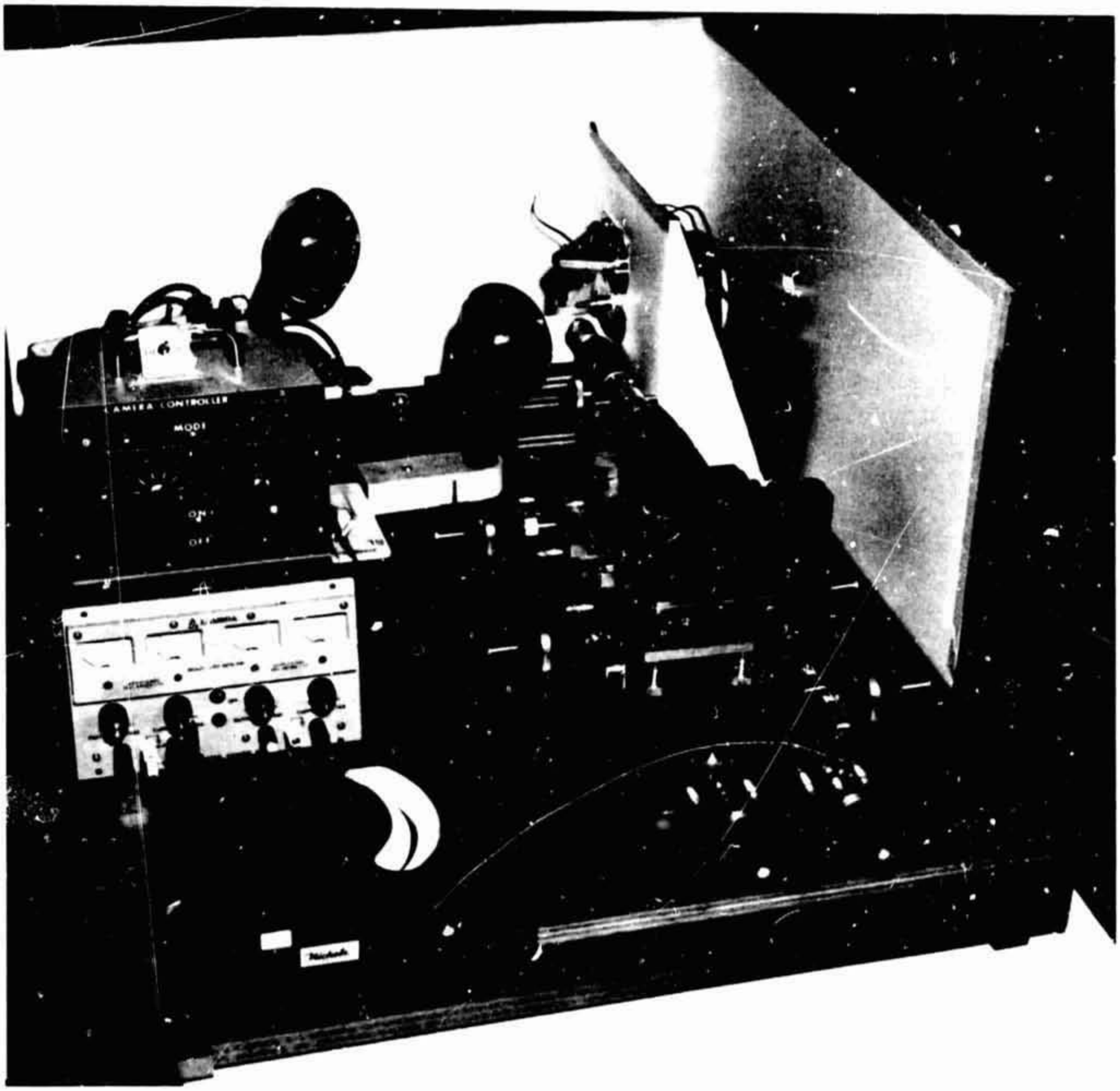

Figure 1: N A E droplet generator

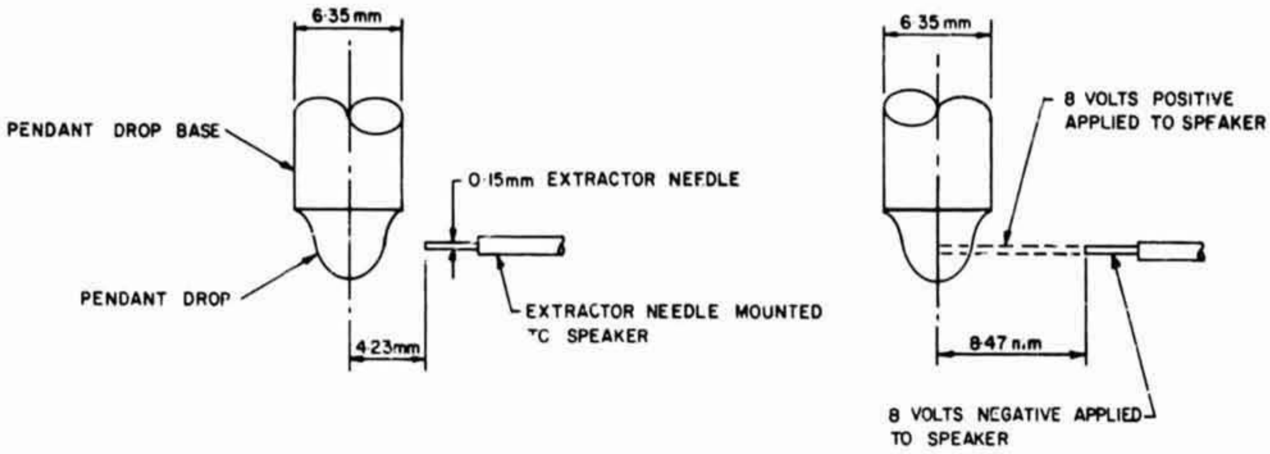

Figure 2: Pendant drop and droplet extractor

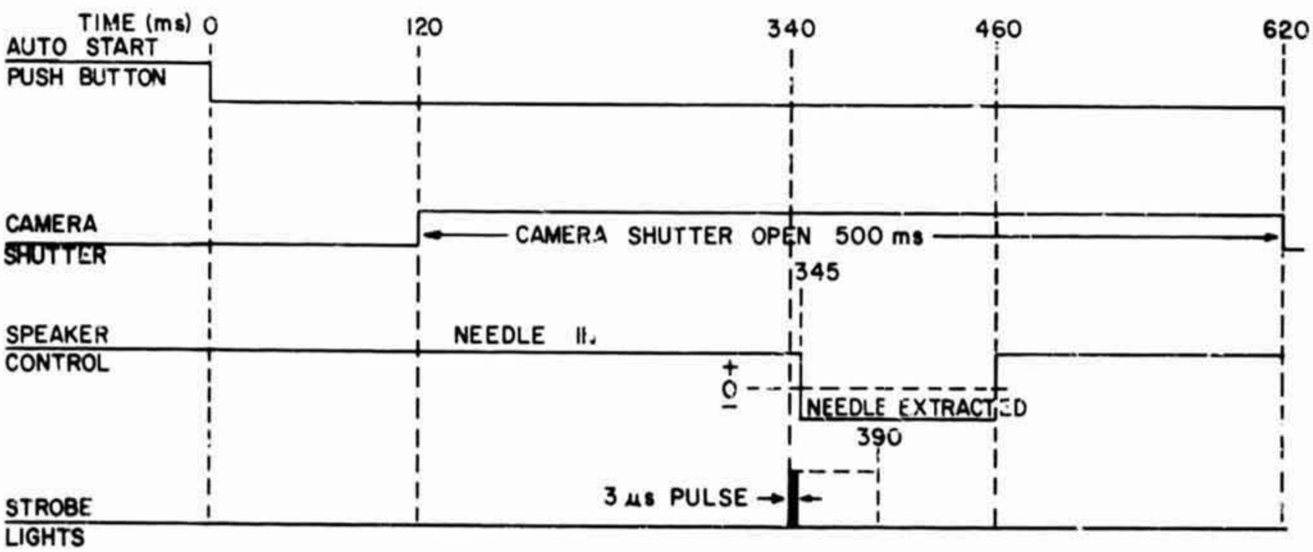

Figure 3: Droplet generator timing sequence

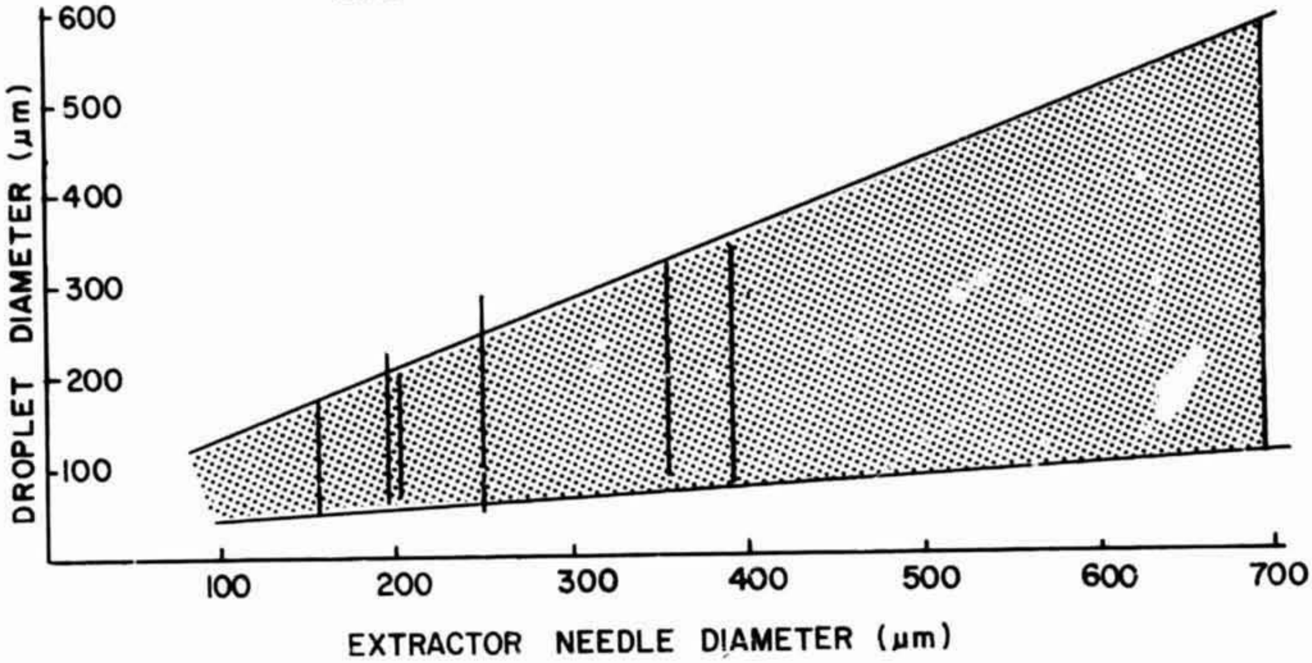

Figure 4: Droplet sizes vs extractor needle diameter

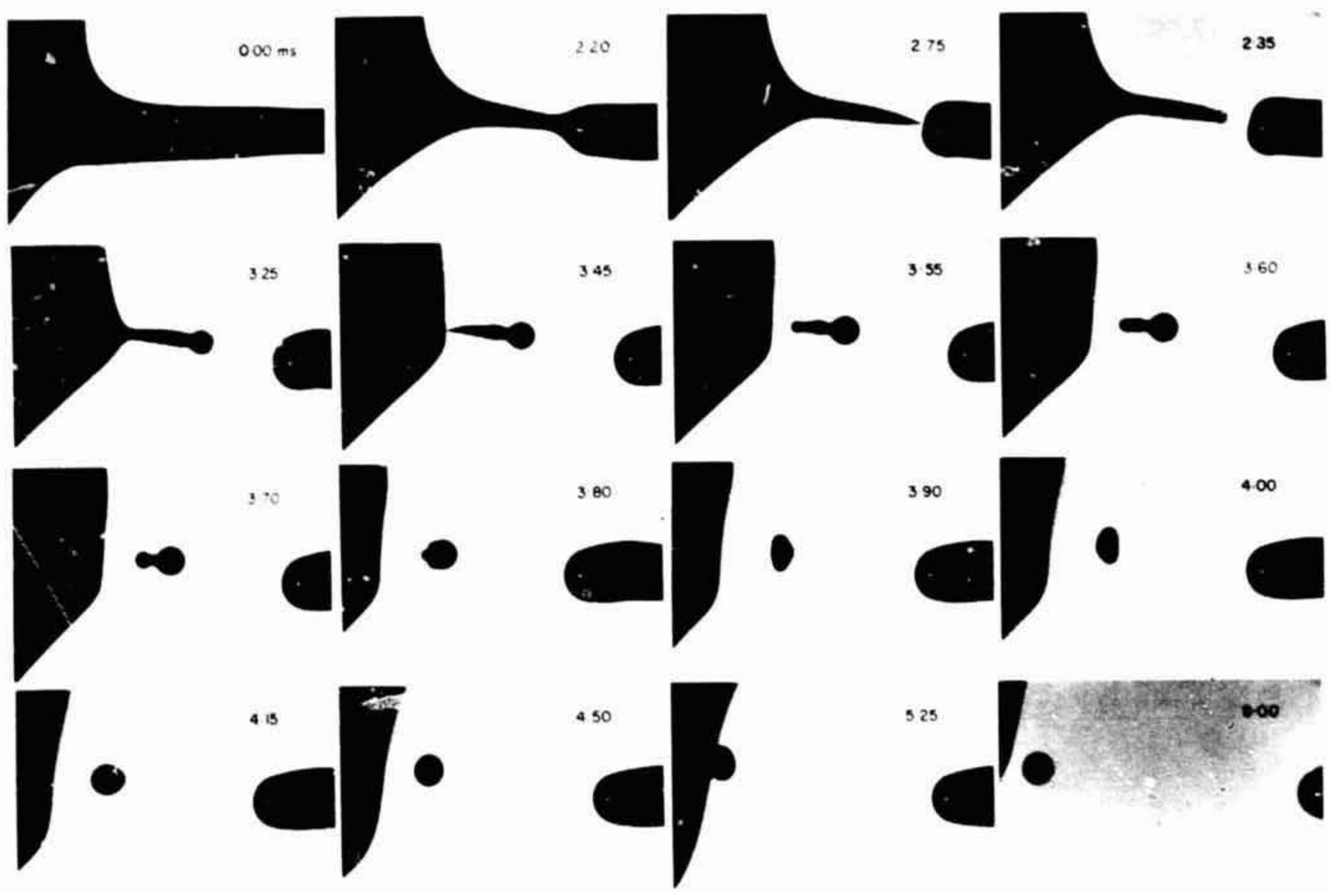

Figure 5: Ligmant collapse to form a droplet

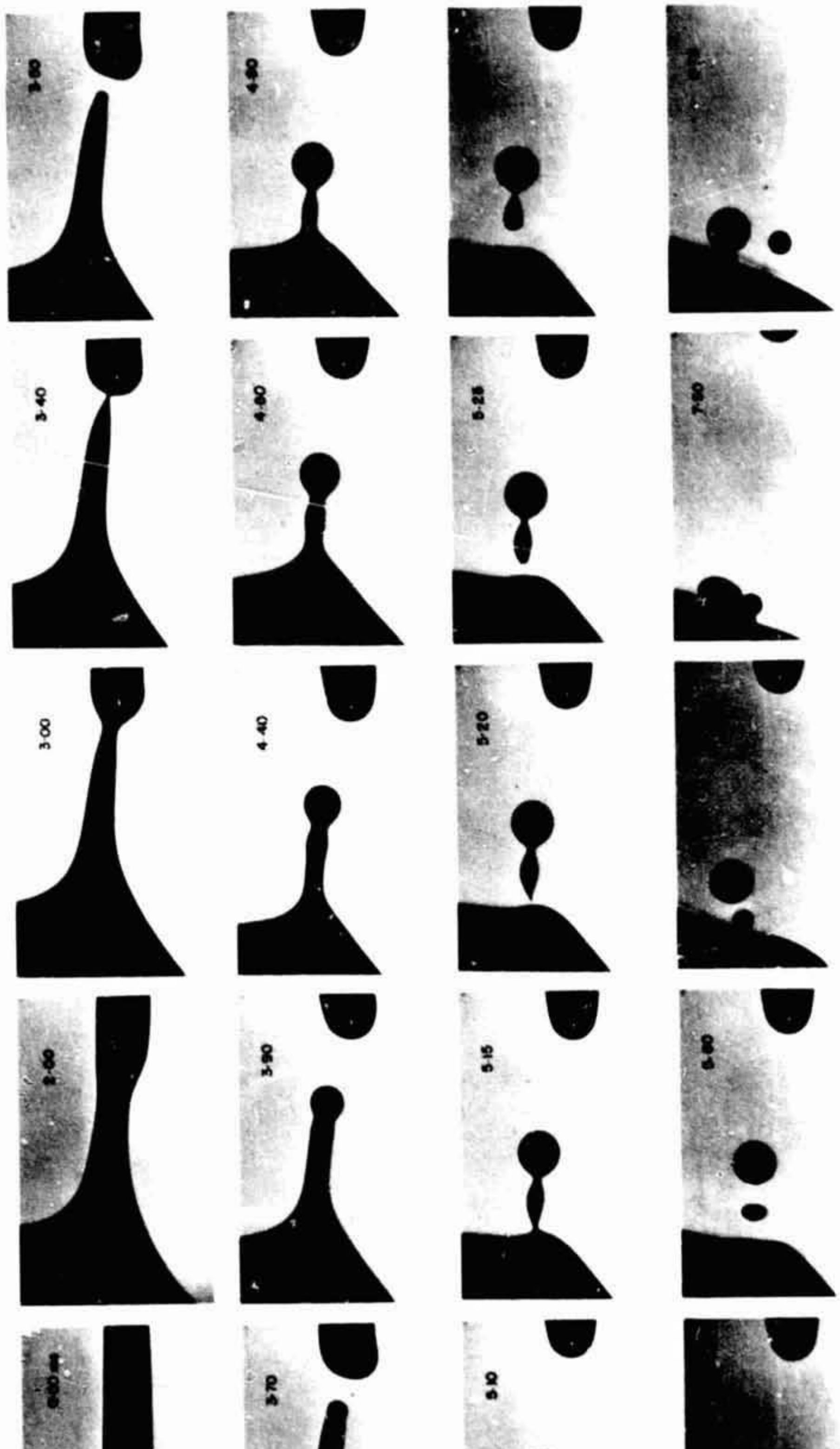

Figure 6: Ligmant fission to form two droplets

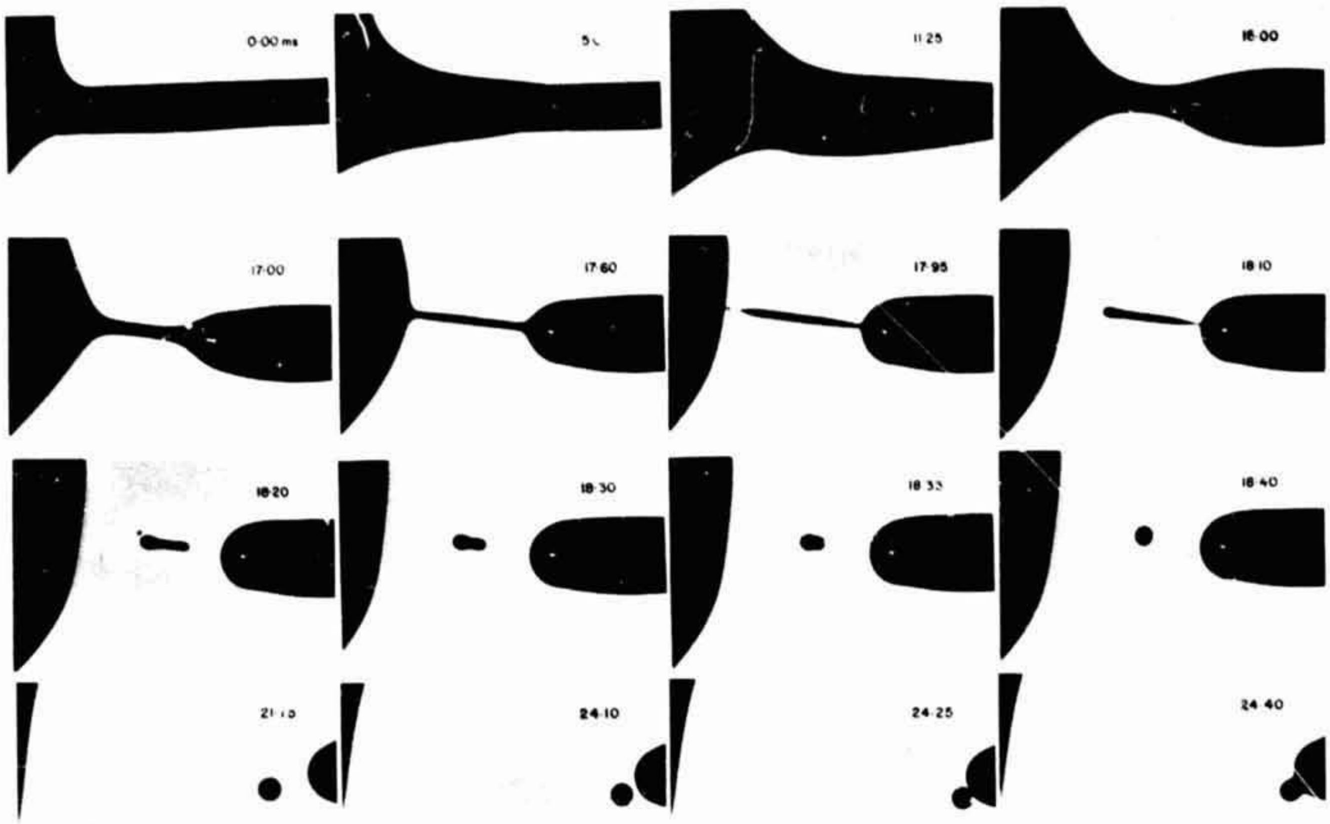

Figure 7: Needle–captured droplet

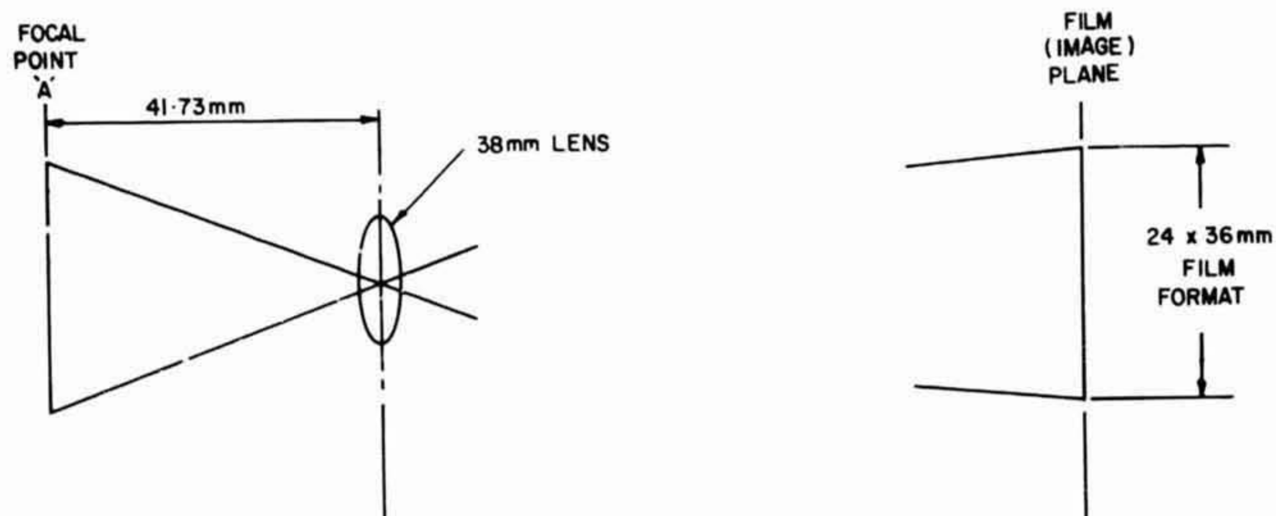

Figure 8: Photo–optical layout