DEVELOPMENT OF A ROLLER-BRUSH PESTICIDE APPLICATOR

By

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Bachelor of Science

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1970

Submitted to the Faculty of the Graduate College
of the Oklahoma State University
in partial fulfillment of the requirements
for the Degree of
MASTER OF SCIENCE
May, 1972

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PESTICIDE APPLICATOR

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PREFACE

The research reported in this thesis was financed in part by the Oklahoma Agricultural Experiment Station Project H-1264 entitled Drift Control of Pesticides. This support is sincerely appreciated.

The author is grateful to Dr. Lawrence O. Roth, the major adviser, for his sound advice and encouragement throughout this study.

I would also like to thank Dr. Bobby Clary of the Agricultural Engineering Department and Dr. Dwayne Suter of the Department of Agricultural Engineering of Texas A&M University for their timely advice and counsel.

The author is grateful to the Department of Agricultural Engineering, headed by Professor E. W. Schroeder, for furnishing the assistantships which made the study possible.

Appreciation is extended to Mr. Clyde Skoch, Mr. Norvil Cole, and Mr. Jesse Hoisington for their valuable assistance to this study.

I would also like to thank Mr. Jack Fryrear and Mr. Sam Harp, draftsmen, for their effort in the preparation of the figures in this thesis. Sincere thanks is extended to Mrs. Eunice LePori for typing the final copy of this thesis.

Finally, I would like to extend my special thanks to Mr. J. W. Tripp of Velsicol Chemical Corporation for his assistance in compiling background information for this study.

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CHAPTER I

INTRODUCTION

Crop spraying has become an important activity in agriculture in recent years. In 1968 alone, over 40 million tons of agricultural chemicals were used in the United States (1). Sprayers were used to apply a considerable amount of these chemicals in the form of insecticides, fungicides, herbicides, defoliants, growth regulators, and plant nutrients (2). This increase in use has emphasized the need for precise control of the spray during application to insure that the chemical will be placed only where desired. A landowner must use his land in a reasonable manner with due regard for the rights and interests of others. If he negligently permits a dangerous substance to pass from his land to that of another, he can be liable for any damages which result (3,4,5). It is, therefore, necessary to keep chemicals where they are desired to prevent injury to adjacent crops and to increase efficient use of chemicals.

Drift control is a problem which has not yet been solved with conventional spray systems. In addition, spray systems have their own inherent problems of operation. Many of the chemicals are highly corrosive to sprayer parts. The pump and lines are difficult to flush out thoroughly and the nozzles frequently become clogged with foreign matter or undissolved powder (6). Sprayers generally deliver a constant amount of liquid regardless of ground speed making uniform coverage difficult.

Most of the research being done is in an attempt to modify and improve conventional spraying systems. However, from conversations with representatives of companies producing agricultural chemicals, it is evident that many new chemicals could be used effectively if only the proper equipment could be developed (7). In other words, perhaps more attention should be given to the investigation of new methods of spray drop formation rather than in modification of existing equipment.

A new method of spray formation is now being investigated. The bristles of a rotating brush contact the wetted surface of a roller and flip drops from the surface of the roller in the direction of motion of the bristles (Figure 1). The roller rotates in a shallow tray of liquid and delivers a layer of liquid to the bristles. Drops are formed by the whipping action of the bristles moving through the liquid after losing contact with the roller surface.

One of the more promising aspects of the new system is that it has been possible to operate the device very near the target areas. In one model spray was applied to a lawn from a height of less than four inches, greatly reducing the exposure time to drift producing winds. The system is simple in design and is gravity fed, thus eliminating the pressure pump. All working parts are easily accessible and may be readily cleaned out. Since the system can be ground driven, it will deliver an amount of liquid in proportion to ground speed. Commercial brushes are available in lengths from several inches up to thirty feet which makes such a system adaptable to both suburban and agricultural use. The device can be constructed entirely out of

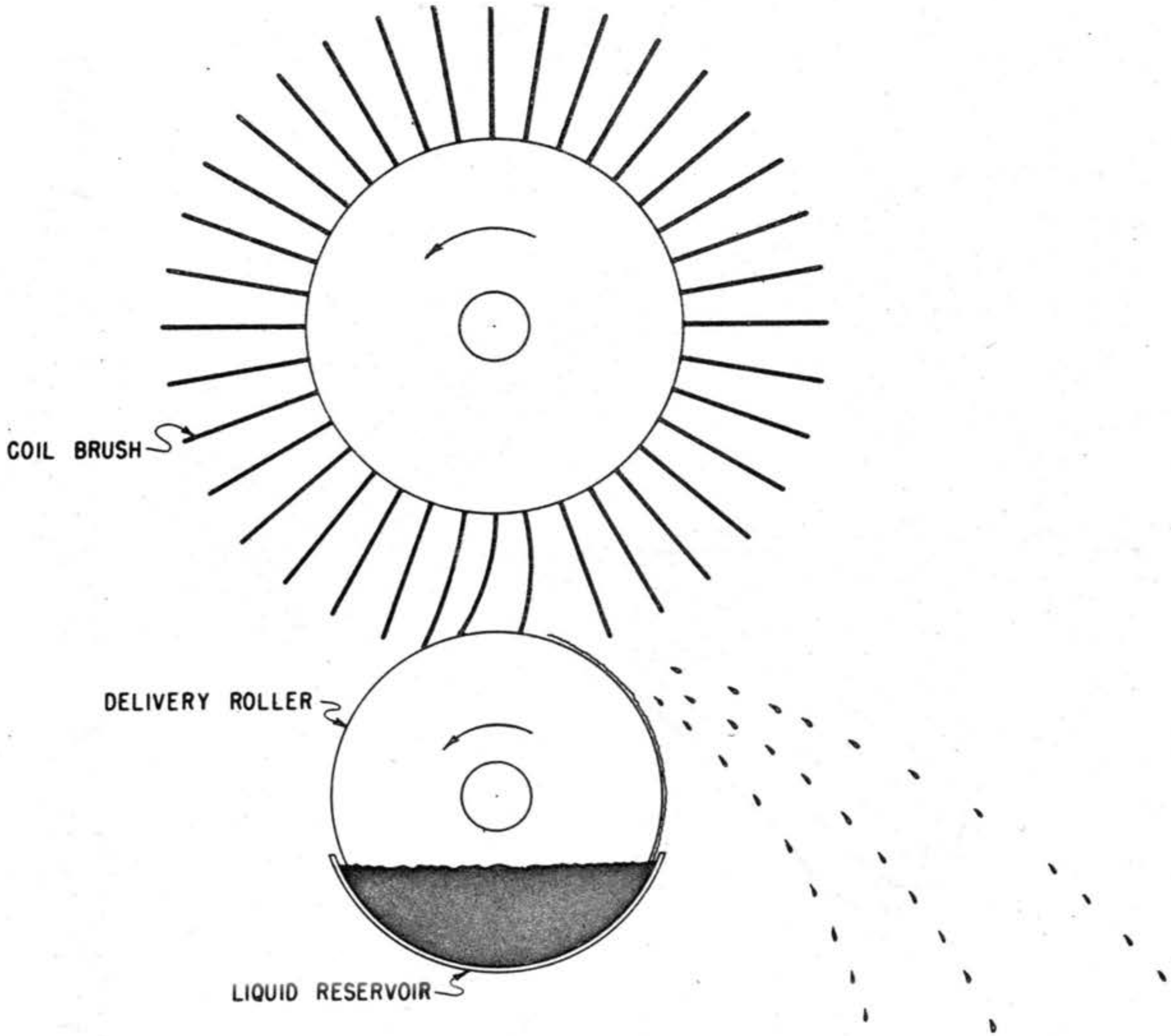


Figure 1. Schematic Diagram of a Roller-Brush System

synthetic materials which are corrosion free. A further advantage is the system's ability to handle viscous liquids. An apparatus of this type has been used to apply liquids which were too viscous to apply through nozzles (8).

CHAPTER II

OBJECTIVES

The primary objective of this study is to describe the drop formation process of removing water from a wetted surface by dragging a resilient bristle over the surface and allowing the whipping action of the bristle to propel drops of water from the surface.

The secondary objective is to determine the effect of some of the design factors of the roller-brush system upon the liquid volume flow rate and the drop size. These factors are: bristle length and diameter, roller-brush overlap, brush density, brush and roller speeds, and the surface conditions of the wetted roller. In addition, the torque requirements for the operation of such a system will be determined.

CHAPTER III

REVIEW OF LITERATURE

Patent Search and Previous Work

Although the idea of a roller-brush applicator is not a new one, very little published information is available for the design of this system. A patent search disclosed that a patent was issued in 1925 for a device called a boll weevil exterminator (9). This device used a roller, running in a shallow tray, to deliver insecticide to a distributing brush for application to cotton plants. The brush was to be made of either natural bristles or feathers and insecticide was to be "applied to the bud of the plant by a wiping or mopping action". Drop formation was not possible due to the nature of the materials used in the construction of the brush.

Another patent was issued in 1967 for a device which applied spatter paint to accoustical tile (8). This device made use of two metering rollers to deliver paint to the brush to apply small beads of paint to the surface of the tile. The owners of the patent claimed the system applied the paint uniformly over the entire surface of the tile and that the beads of paint were uniform in size.

Reeves, Wilkes, Ridgway, and Lindquist (10) have done work using a rotary brush system to apply systemic insecticides directly to the stems of cotton plants. This device differs from the system under study, in that the brush makes actual physical contact with the plant and transfers the insecticide to the stems without drop formation.

Few attempts have been made, previously, to determine the performance characteristics of a roller-brush system. The owners of the spatter paint device have stated in their claims that the paint clings to the bristles and is flipped off by the whipping action of the bristles as they lose contact with the roller. They have further stated that a change in the relative speeds of the brush and roller will change the size of the drops formed with an increase in the roller speed causing a larger drop to be formed. A brush having a diameter of three inches with nylon bristles one inch in length and 0.011 inches in diameter was recommended. No indication was given that any other size of brush was tested. The speed of the tiles passing beneath the applicator was adjusted until an attractive pattern was obtained.

CHAPTER IV

EXPERIMENTAL EQUIPMENT

Design and Function of the Test Apparatus

The test apparatus consisted of two separate units. The first unit was the brush assembly and its power source (Figure 2). The second unit was made up of the knurled roller with its power source, the tray of liquid, and the fluid reservoir (Figures 3 and 8).

The brush assembly was simply a frame supporting a shaft. Brushes were mounted on this shaft above the roller assembly and were driven by a Graham Variable Speed Transmission producing a speed range of 0 to 230 rpm. Two types of brushes were used for this study. The first brush consisted of bristles mounted in a disk four inches in diameter constructed from two 0.25 inch steel plates (Figure 4). Twelve individual bristles were spaced radially around the periphery of the plates and clamped between them. Two sizes of crimped polypropylene bristles were used in this brush. One size had a major diameter of 0.053 inches and a minor diameter of 0.040 inches and was two inches long while the other size had a major diameter of 0.029 inches and a minor diameter of 0.020 inches and was one inch in length. The bristles were oriented in the brush with the major diameter presented to the roller surface. This brush was used for all of the tests except brush density and torque requirements. A small number of bristles was necessary in order to examine the drop formation process and to simplify obtaining such

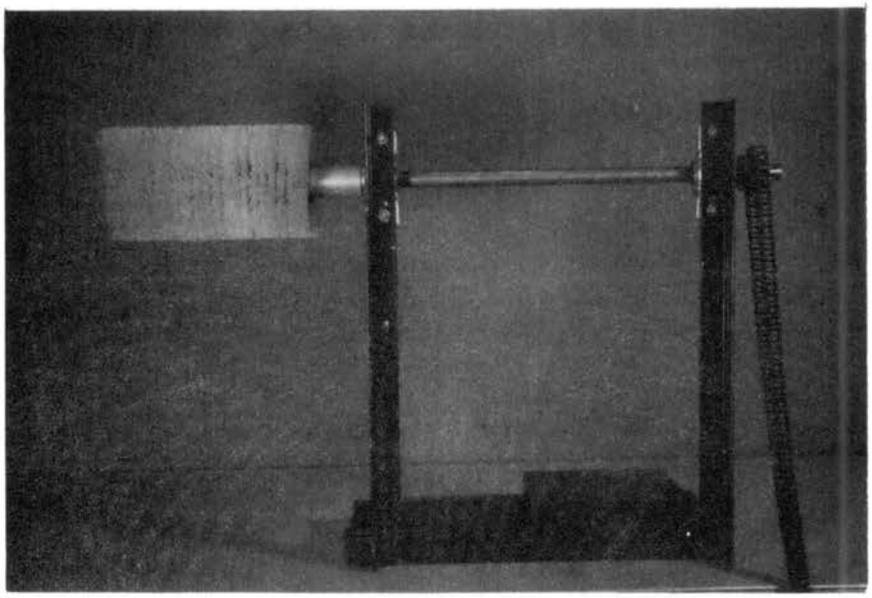


Figure 2. Brush Assembly with Coil Brush

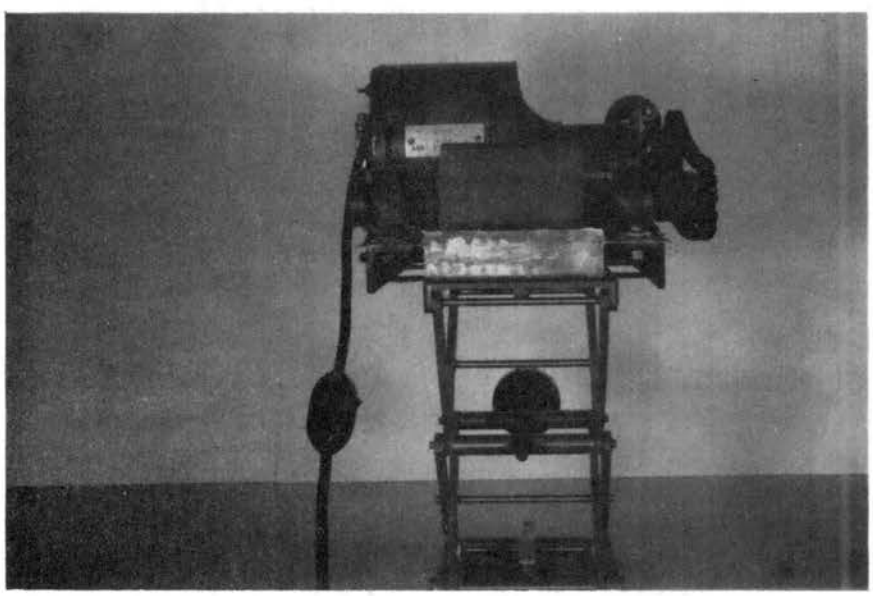


Figure 3. Roller Assembly mounted on Scissors Jack

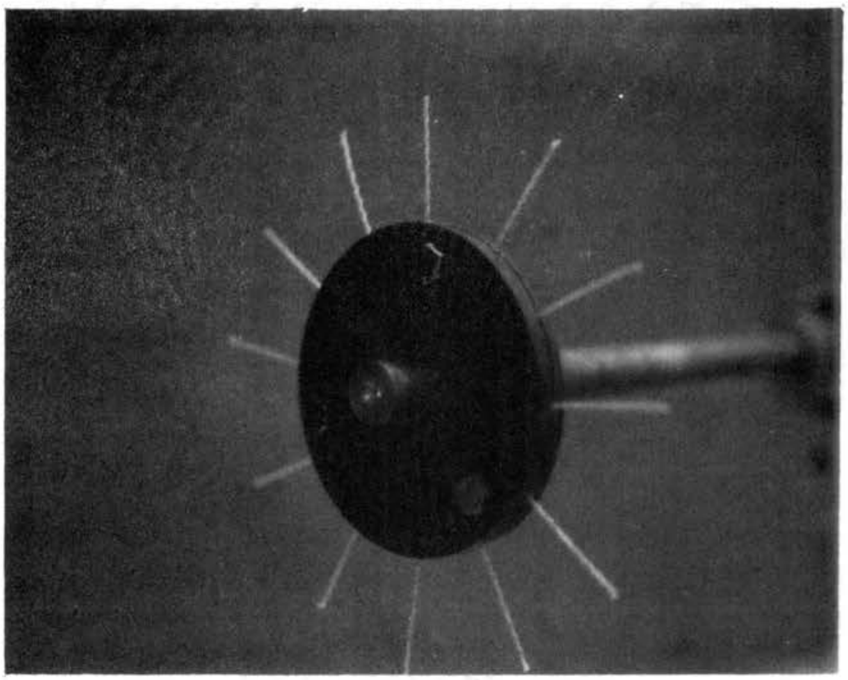


Figure 4. Disk Brush Containing Twelve Bristles

information as bristle wear and bevel, bristle length, roller-brush overlap, and the path of bristle travel.

The second brush was a three inch section of coil brush with an outside diameter of five inches (Figure 5). The bristles of this brush were crimped polypropylene 1.09 inches long and 0.029 inches in diameter. There were approximately 714 bristles per single coil. This brush was mounted in such a way as to permit it to be stretched out to a length of ten inches in order to vary the brush density with respect to the roller (Figure 6). Brush density is defined as the number of bristles per square inch of brush surface.

The roller assembly consisted of a roller constructed from a four inch section of steel pipe 3.5 inches in diameter. The roller was turned on a lathe and five surface conditions were applied to the roller in bands around the periphery of the roller (Figure 7). These surfaces were: coarse straight knurl with 0.08 inches between ridges and 0.04 inches deep, medium straight knurl (0.05 inches by 0.02 inches), coarse diamond knurl (0.07 inches by 0.04 inches), medium diamond knurl (0.04 inches by 0.02 inches), and the smooth surface left by the lathe tool. For the brush density tests, the entire roller surface was changed to that of the coarse straight knurl. The finished diameter was 3.375 inches.

The roller rotated in a tray of liquid to a depth of one inch. The liquid level was maintained by means of a point gage at the reservoir connected to the tray (Figure 8). When the twelve bristle brush was being used, the reservoir was refilled from a 50 ml. burette. For tests resulting in a large flow, a 475 ml. spirometer graduated by 50 ml. was used. The roller was driven by a Zero-Max Variable Speed Transmission.

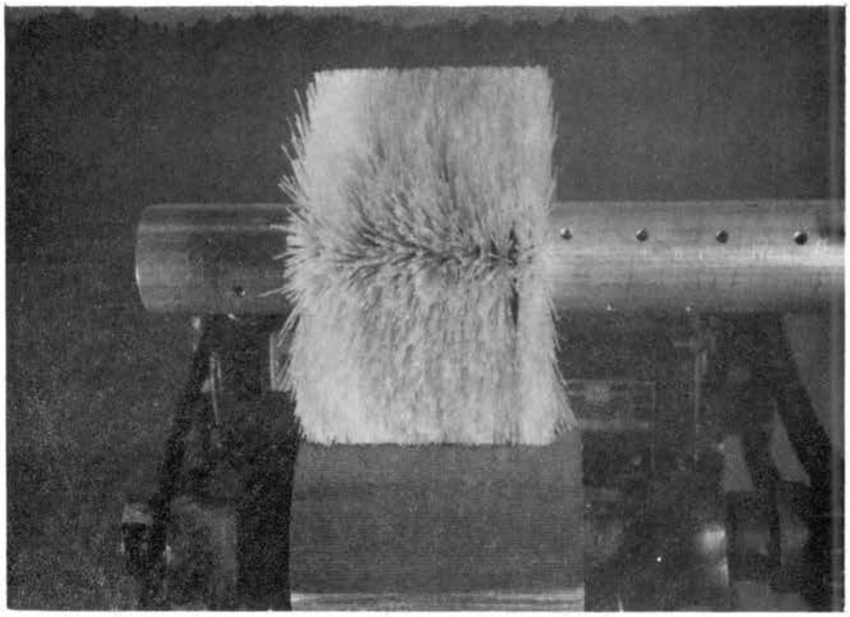


Figure 5. Coil Brush in the Closely Packed Configuration

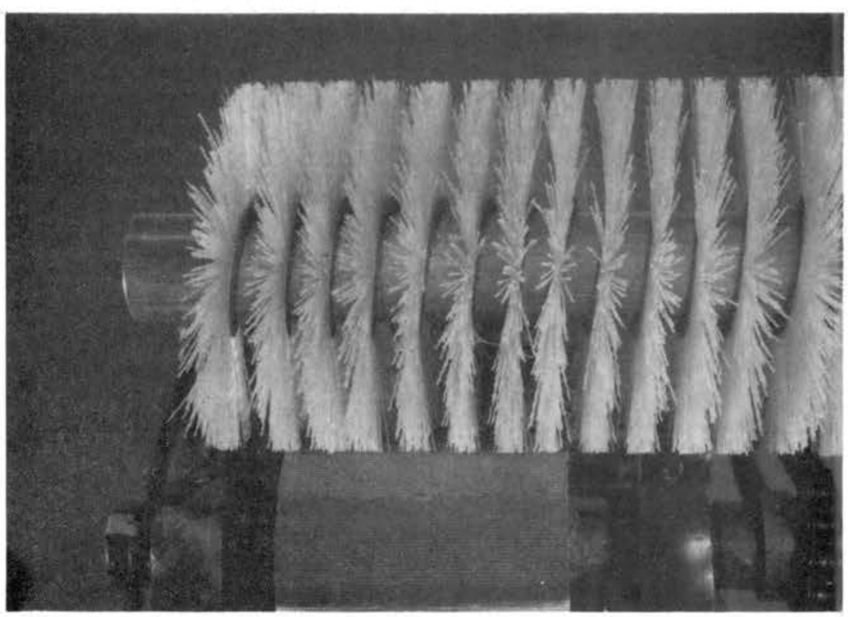
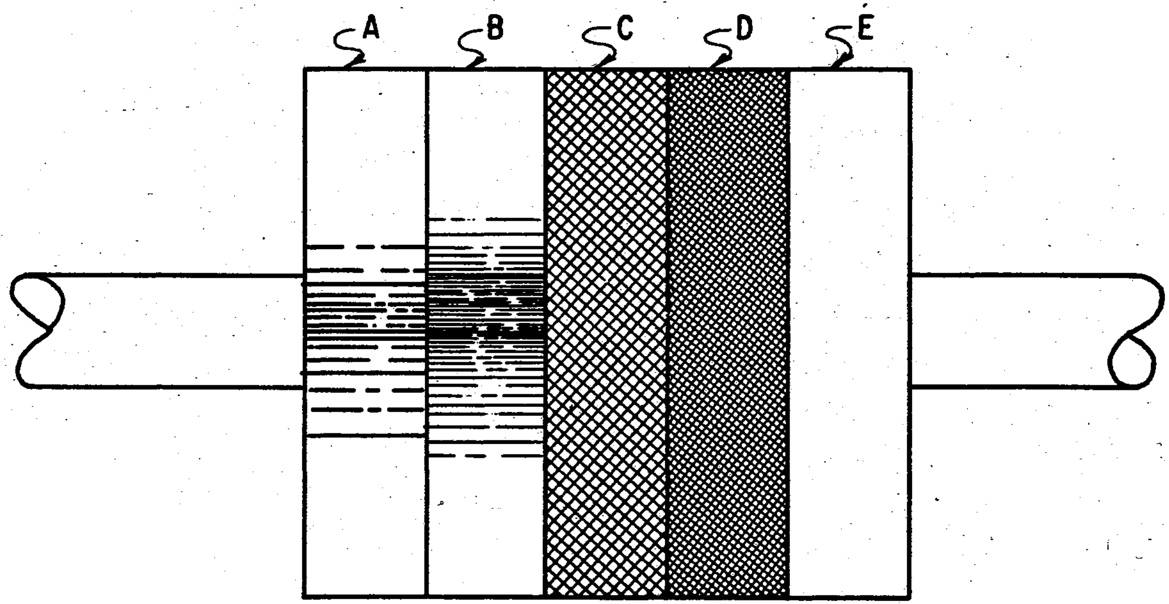


Figure 6. Coil Brush in the Stretched Out Configuration



A – Coarse Straight Knurl

B – Medium Straight Knurl

C – Coarse Diamond Knurl

D – Medium Diamond Knurl

E – Smooth Surface

Figure 7. Surface Conditions of the Roller

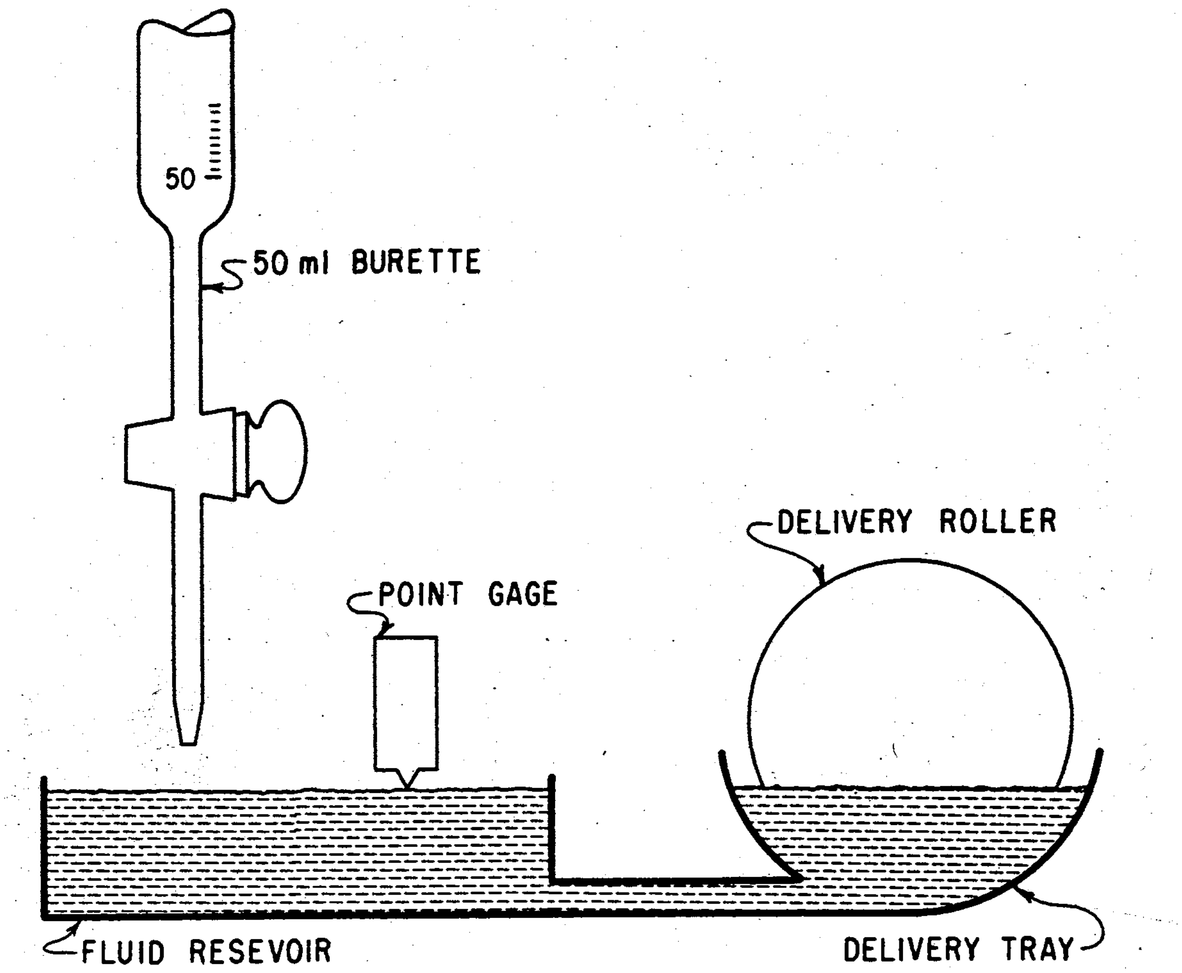


Figure 8. Schematic Diagram of Fluid Reservoir and Delivery Tray

The entire roller assembly was mounted on a scissors jack so that the unit could be raised or lowered under the brush assembly in order to vary the amount of overlap between the roller and the brush. Overlap is defined as the difference between the undeformed bristle length and the distance between the surface of the roller and the base of the brush where the bristles are fastened.

Photographic Equipment

The photographic equipment used was: a Graflex Graphic View II camera for still pictures and a Wollensak Fastax WF-3 high speed movie camera. Other electronic equipment included a General Radio Strobotac Model 1531-A electronic stroboscope with a Model 1536-A photoelectric pickoff unit and a Model 1531-P2 flash delay unit.

CHAPTER V

EXPERIMENTAL PROCEDURE

Examination of Drop Formation

In order to more readily observe the drop formation process, the disk having twelve bristles was used (Figure 4). The bristles were 1.5 inches long and 0.053 inches in diameter. The brush and roller were operated at 25 rpm with an overlap of 0.25 inches.

Photographic Techniques for Still Pictures

The stroboscope was synchronized with the brush speed by means of the photoelectric pickoff unit which was triggered by light reflected from a thin strip of silver foil affixed to the shaft of the brush assembly. The flash duration of the stroboscope was approximately one microsecond. In this way motion was stopped and with the flash delay unit it was possible to examine the individual bristles in different positions during the drop formation process.

In order to obtain still pictures, the Graflex Graphic View II was placed near the surface of the roller where the bristles were flipping and perpendicular to the direction of motion of the bristles (Figure 9). The distance from the camera lens to the bristles was approximately one inch. The stroboscope was placed on the opposite side of the bristles and the light of the stroboscope was directed into the camera lens. With the aperature set wide open and the shutter

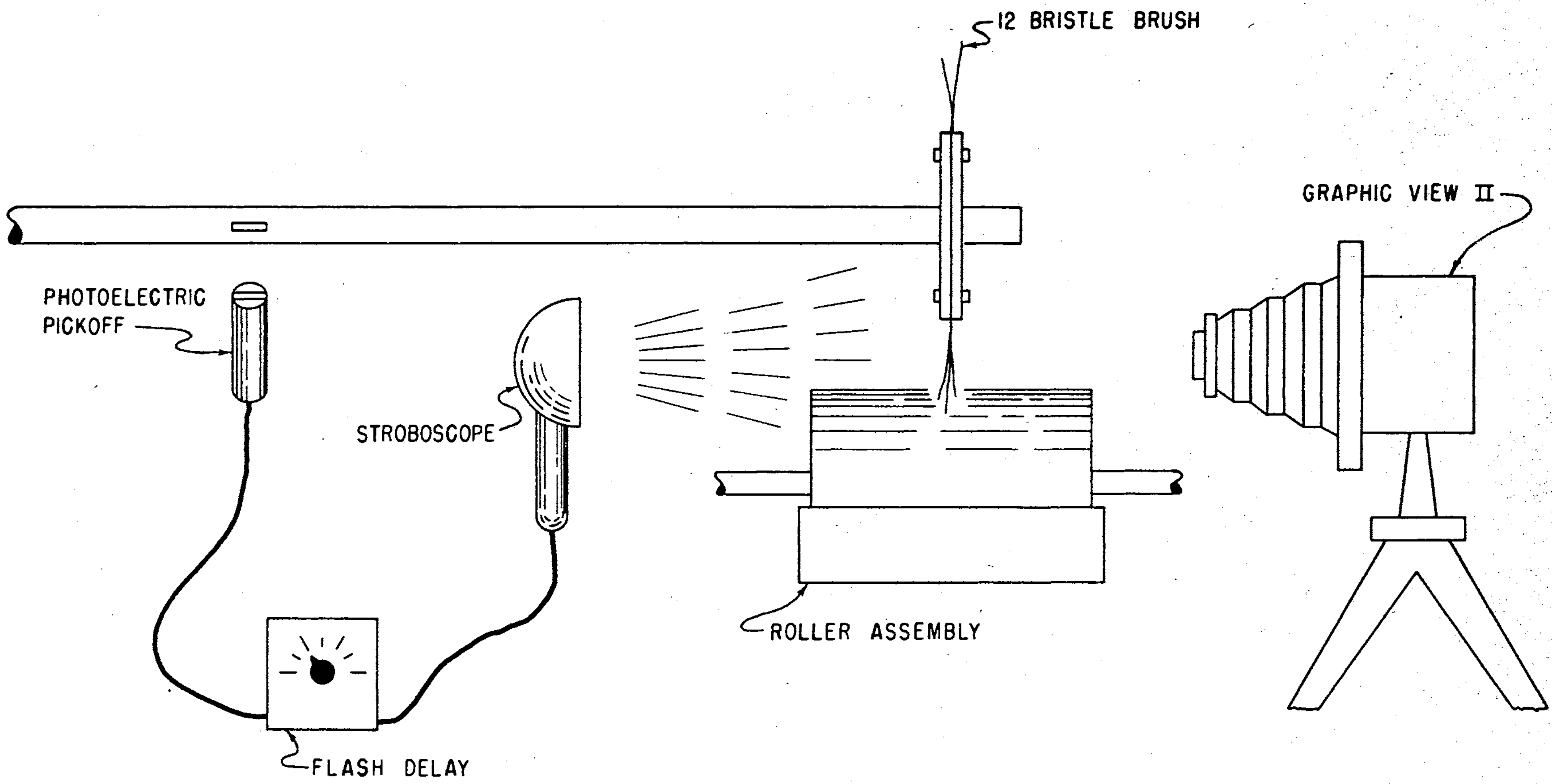


Figure 9. Schematic Diagram of Photographic Equipment Arrangement

locked open, the bristles were observed through the viewfinder. Using a 65 mm. lens mounted on an extension tube 12.5 inches long, a magnification of 5.5 was obtained. With the flash delay, it was possible to view the bristles in the various stages of the whipping motion. In order to obtain a clear picture, only one strobe flash could be allowed to expose the film. The operating instructions for the photoelectric pickoff stated that the method for finding the correct dial setting for the stroboscope was to turn the stroboscope dial clockwise to the limit of its travel and then to rotate the dial slowly counterclockwise until the stroboscope started to flash. At these low brush speeds, it was possible to turn the dial until the strobe flashed once and then quickly rotate the dial clockwise before the second flash. The flash would occur at the desired moment due to the photoelectric pickoff and the flash delay.

To get a picture, the following step by step procedure was used:

1. Turn on the Strobotac and the flash delay and allow to warm up. Fill the reservoir and turn on the brush and roller power sources.
2. With the aperature of the camera wide open and the shutter locked open, adjust the flash delay until the desired event is observed in the viewfinder.
3. Set the proper aperature. Set the shutter in the position where the shutter remains open as long as the shutter cord is depressed.
4. Cock the shutter and load one packet of Polaroid Type 55 P/N film.
5. Turn off the lights in the room.

6. Turn the stroboscope dial clockwise until the strobe flashes stop.

7. Open the shutter and hold it open while the stroboscope dial is slowly turned counterclockwise until the first flash occurs.

8. Immediately rotate the stroboscope dial clockwise before the second flash and release the shutter.

9. Turn on room lights and process the picture.

Due to the short duration of the flash, the aperature setting was obtained by trial and error. Photographs shown on page 23 were obtained in this manner.

Photographic Techniques for Motion Pictures

Because of the method required to obtain still pictures, it was not possible to acquire sequential pictures of a single bristle pass. In addition, the direction of travel of the drops could not be determined by an examination of still photographs. It was therefore necessary to obtain motion pictures of the drop formation process.

An attempt was made to film the drop formation process at 64 frames per second with a Bolex Paillard H-16 Reflex movie camera. However, the whipping motion of the bristles was too rapid for the action to be stopped at this filming rate.

Suitable high speed motion pictures were obtained in the following manner with the Wollensak Fastax movie camera. The Fastax was placed near the roller and aimed at the bristles in the same manner as with the still photographs (Figure 9). A 35 mm. lens was used and the distance from the camera to the bristles was approximately one foot.

The width of field at the plane of the bristles was approximately six inches. Two floodlights were placed opposite the Fastax and their light was directed into the camera lens. The Fastax was set for 4000 frames per second and loaded with Kodak TRI-X Reversal Type 7278 film. The aperature of the camera was set by using the recommended setting obtained from the light meter. With the roller and brush operating at 25 rpm, the high speed movies were taken.

Measurement of the System Volume Flow Rate

Six sets of tests were conducted to determine the effect of bristle length, bristle diameter, bristle overlap with the surface, brush density, brush and roller speeds, and the surface conditions of the roller upon the volume flow rate.

The following procedure for obtaining the measurement of the volume flow rate was adopted so as to insure consistency of sampling:

1. Start the roller running at the desired speed.
2. Fill the reservoir up to the point gage.
3. Start the brush rotating at the desired speed and simultaneously start the stopwatch.
4. Allow apparatus to run for ten minutes.
5. At the ten minute mark, stop the brush.
6. With the roller operating, fill the reservoir back up to the level of the point gage using a 50 ml. burette.
7. Record the amount of liquid required to refill the reservoir.

The roller was rotated during the filling of the reservoir in order to keep the same amount of liquid on the roller at all times, and so that no liquid would be used to wet a dry roller. By recording the amount of liquid used over a ten minute interval, it was possible to obtain a measurement of the volume flow rate.

Due to the large volumes of liquid produced during the density tests, it was necessary to depart from the above sampling procedure. The amount of liquid produced in the density tests was measured in the following manner:

1. Fill the reservoir up to the point gage.
2. Operate the system at the desired speed until the liquid leaves the point gage and immediately stop the brush.
3. Refill the reservoir with 50 ml. of liquid from the 475 ml. graduated spirometer.
4. Start the brush rotating at the desired speed and simultaneously start the stopwatch.
5. Allow the system to run until the liquid again leaves the point gage.
6. Stop the stopwatch immediately and then stop the brush.
7. Record the time required to remove 50 ml.

In this way a measurement of the volume flow rate can be calculated.

CHAPTER VI

PRESENTATION AND ANALYSIS OF DATA

Drop Formation Process

From an inspection of the still photographs and the high speed motion pictures, it was possible to determine the sequence of events in the drop formation process. A few small drops with a range of diameters of approximately 0.007 inches to 0.015 inches were formed while the bristle was still in contact with the surface of the roller as shown by the still photograph of Figure 10-a. By observing the high speed motion pictures, it was determined that these drops appeared in the area of the wake created by the bristle moving through the liquid and immediately fell back to the surface of the roller. As the bristle left the surface of the roller and began to accelerate, the small amount of liquid clinging to the trailing edge of the bristle was cast off (Figure 10-c). As the bristle moved through the liquid, it hurled drops into the air from the area immediately before the bristle (Figure 10-e). These drops had a range of diameters of approximately 0.007 inches to 0.025 inches. The high speed motion pictures revealed that the bristle, after leaving the surface of the roller, traveled in an oscillating pattern which quickly damped out after approximately a half dozen oscillations. When the bristle reached the limit of its first forward oscillation, it was ahead of the bulk of the liquid thrown off (Figure 10-f). In addition, the small amount of liquid on

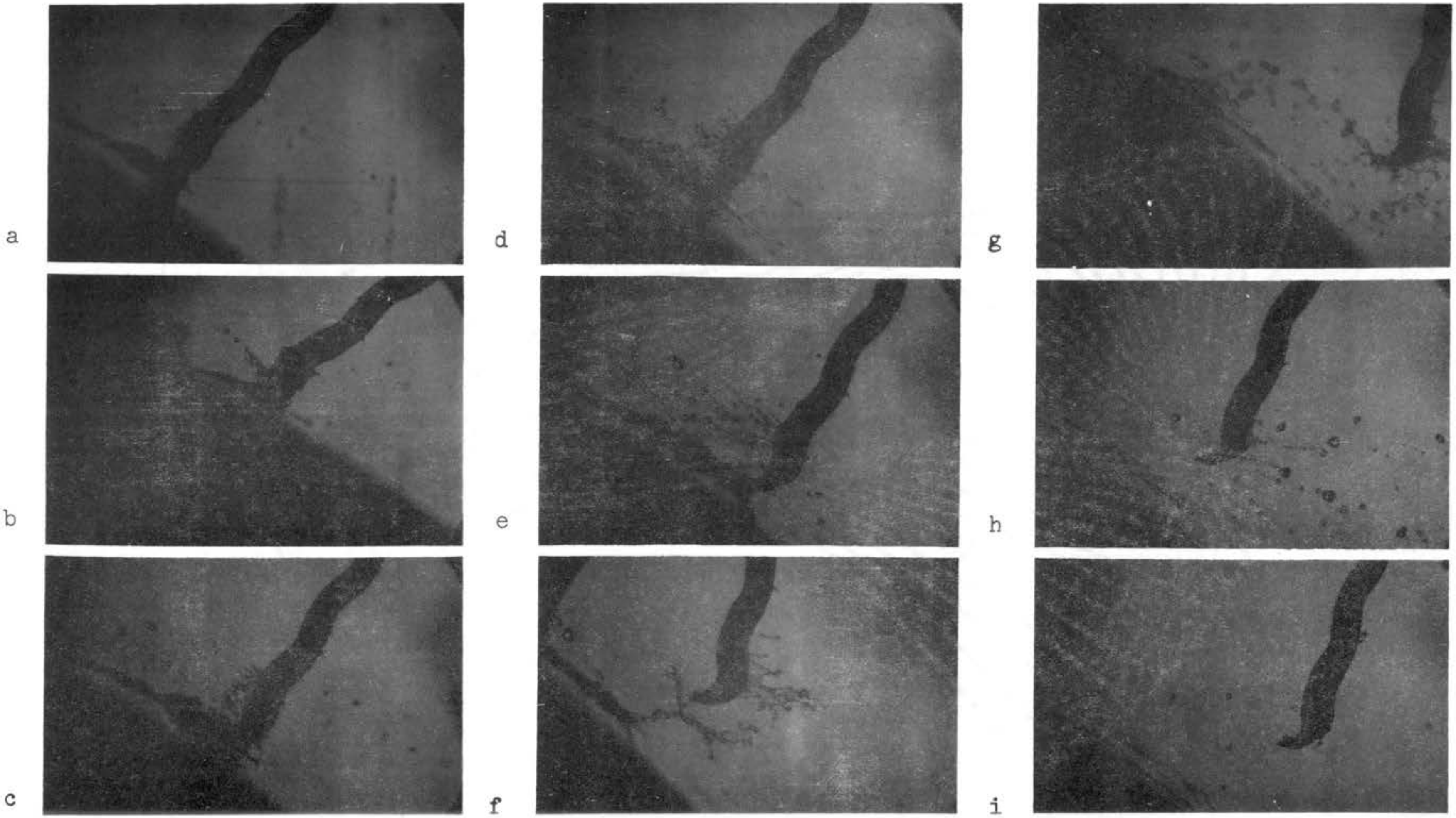


Figure 10. Sequential Still Photographs of Drop Formation Process

the leading edge of the bristle was cast off at the end of this forward travel. As the bristle continued its first backward oscillation, the drops caught up with and passed the bristle (Figures 10-g and 10-h). The drops were thrown forward in a spreading pattern with a heavy concentration of drops along the line tangent to the roller surface at the intersection of the brush and the roller.

Analysis of Individual Tests

The data for each of the length, speed, overlap, and density tests were analyzed by means of a step-wise, multiple regression computer program with double precision. The factors in the equations indicated by the program are presented in the order of their importance rather than in the standard notation.

After individual analysis, all of the data was combined and the step-wise regression program was used to determine the significant factors in order of their importance. In this way, it was possible to evaluate analytically the significance of each design factor upon the volume flow rate.

Surface Condition Results

The test of surface conditions was conducted with the brush and roller speeds at 100 rpm, bristle length of 2.05 inches, bristle diameter of 0.053 inches, overlap of 0.15 inches, and the number of bristles in the brush was twelve.

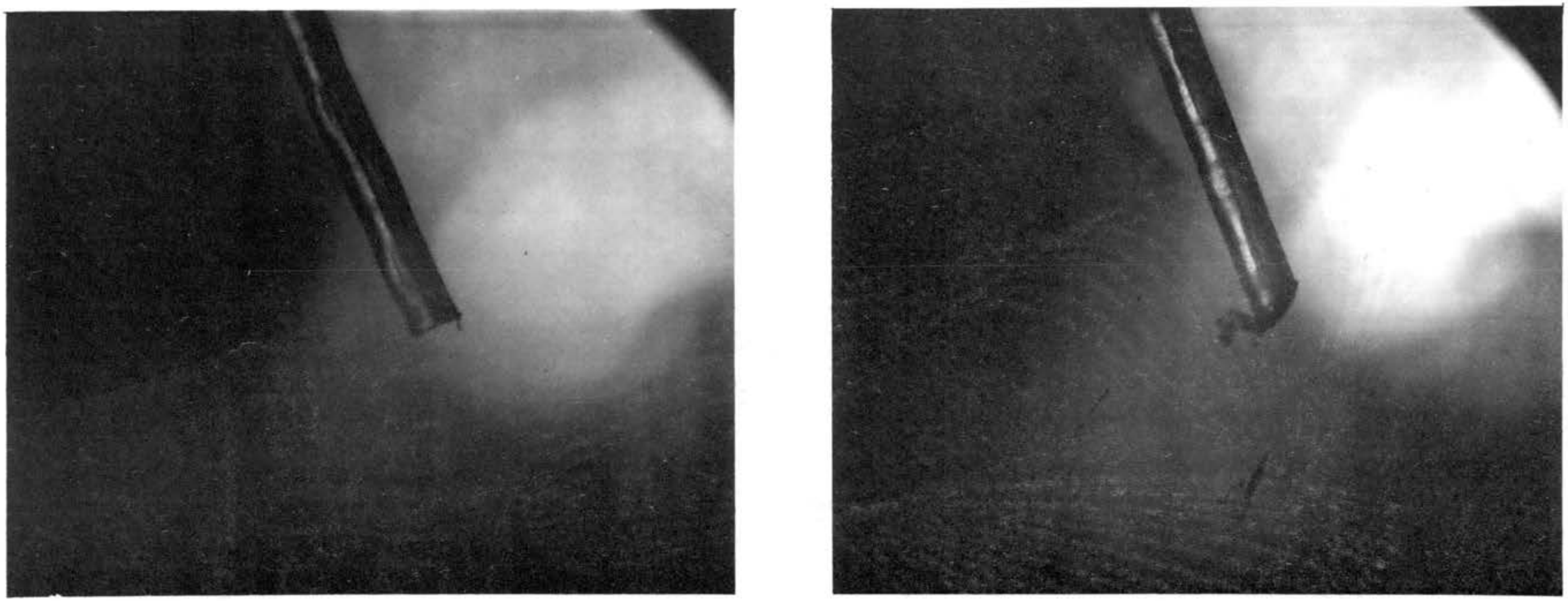
A single factor approach to testing was used for the surface condition test. Tests were run by moving the brush to each of the surfaces and operating the system for ten minutes. At the end of ten minutes, the volume of liquid removed was recorded. The surfaces tested were: medium straight knurl, smooth, and coarse diamond knurl. This sequence of testing was repeated until the three surfaces had been tested three times each. These three surfaces were tested because they represented the most variation among the surfaces available.

The data from the surface condition test were evaluated using an analysis of variance. Applying the variance ratio, f, as a criterion for testing the hypothesis that the treatment means are the same, the hypothesis is accepted at the five percent level of significance. The results of the analysis of variance for the roughest and the smoothest are given in Table I. The original data from the surface condition test are given in Table II of the Appendix.

Bevel and Wear Results

It was discovered early in the surface condition test that the degree of bevel of the bristle ends had a great effect upon the volume flow rate. For this reason the effect of beveling was studied next. A single factor approach was again used for the testing of bevel and wear. Bristles having straight ends were placed in the brush. The apparatus was operated until the bristles reached the fully beveled condition (Figure 11). The test was interrupted every ten minutes while the volume of liquid discharged was measured and the amount and nature of wear was examined. After the fully beveled condition was reached, the test was continued for several hours to determine the rate of wear of a beveled bristle. Wear was determined by recording the reduction in bristle length over a period of time.

The time required to obtain the fully beveled condition shown in Figure 11 was approximately three hours. The volume flow rate decreased



Straight Bristle

Beveled Bristle

Figure 11. Comparison of Bristle End Conditions

steadily until the fully beveled condition was reached as shown by Figure 12. The step-wise, multiple regression computer program was utilized resulting in the equation given in Figure 12. The proportion of sum of squares reduced was 0.932 with a standard deviation of 1.615 and a correlation coefficient of 0.965. The rate of wear of a beveled bristle 1.45 inches long and 0.053 inches in diameter was found to be 0.01 inches per hour of operation at 100 rpm brush and roller speeds and 0.15 inches overlap. However, there was no reduction in the volume flow rate at this rate of wear (Figure 13). The proportion of sum of squares reduced was 0.001 with a standard deviation of 0.548 and a correlation coefficient of 0.039 for the 0.053 inch diameter bristle. The original data for the bevel and wear test are given in Table III of the Appendix.

Roller-Brush Overlap Results

The single factor approach was used for the overlap test. Twelve beveled bristles were installed in the brush. The bristle lengths were 1.44 inches and the diameters were 0.053 inches. The brush was operated at 125 rpm while the roller was operated at 100 rpm. The roller assembly was then raised until the amount of overlap was 0.05 inches. At this point all of the bristles were making good contact with the roller and flipping properly. Three samples of the volume flow rate were taken at this setting. The overlap was then increased consecutively to 0.10, 0.15, 0.20, 0.25, 0.30, 0.40, and 0.50 inches and three samples were taken at each setting. At an overlap of 0.50 inches, the bristles were being deformed so severely that they swept across the roller sidewise. The test was therefore concluded at that point.

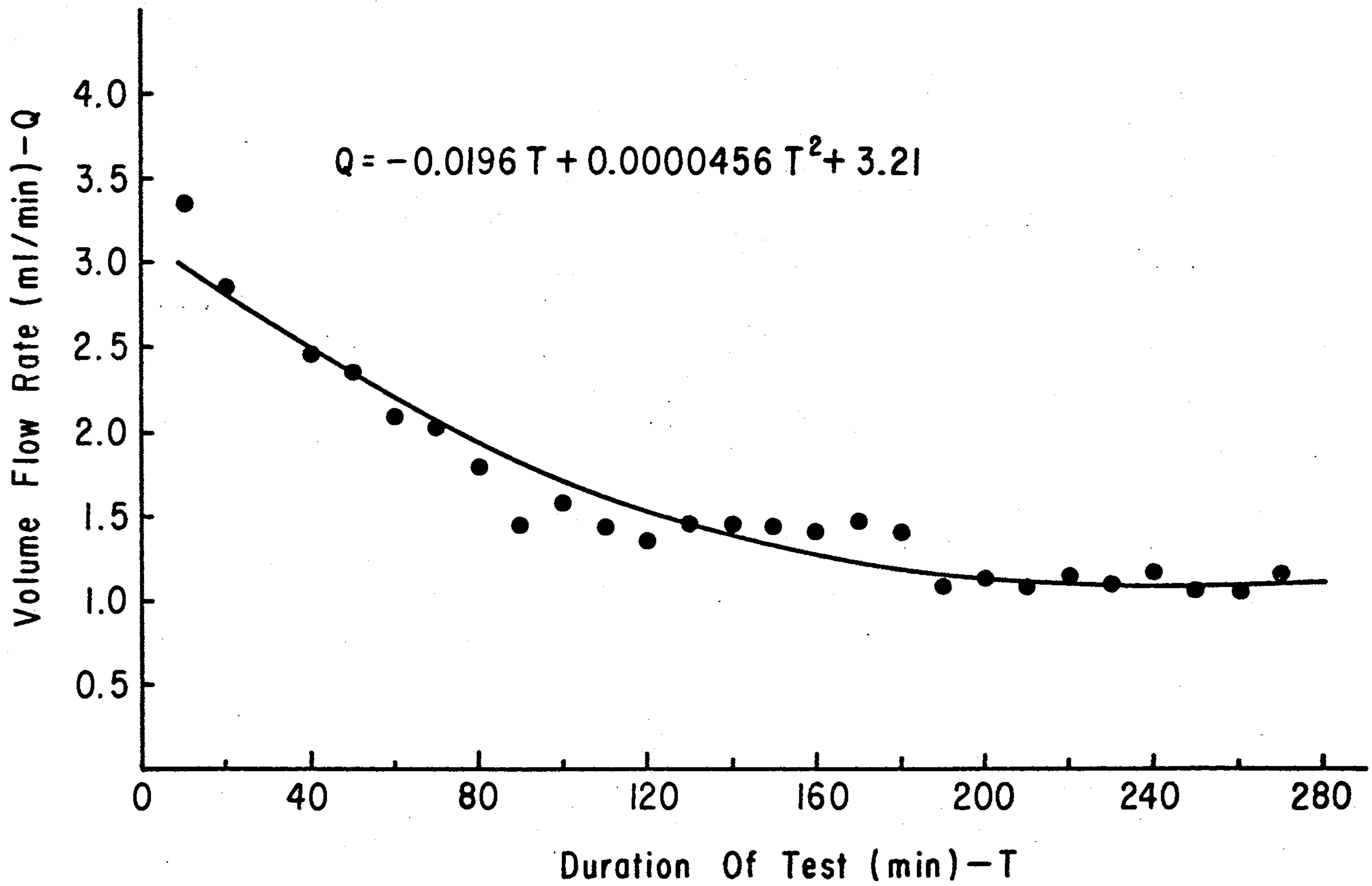


Figure 12. Volume Flow Rate vs. Duration for the Beveling Process

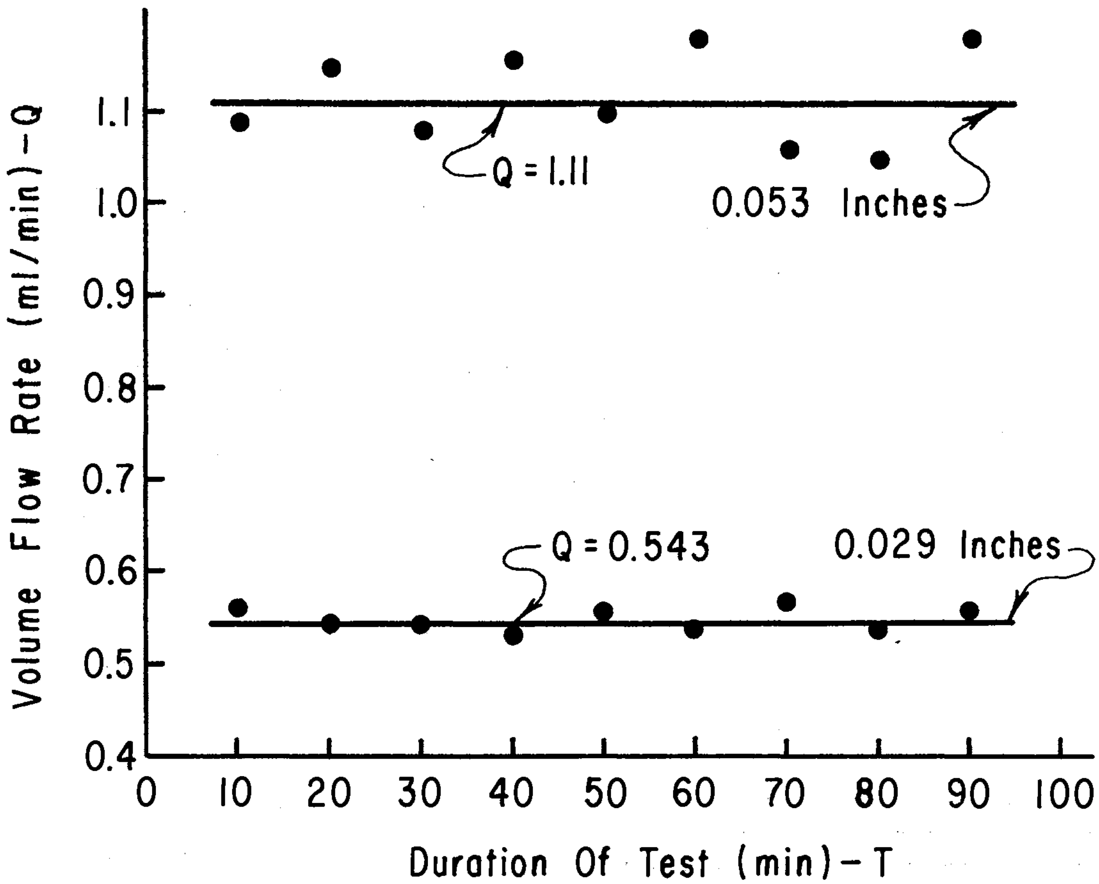


Figure 13. Volume Flow Rate vs. Duration for Bristle Wear for Beveled Bristles with Diameters of 0.053 inches and 0.029 inches

The data for the overlap test were evaluated by means of the step-wise program giving the equation shown in Figure 14. The proportion of sum of squares reduced was 0.923 with a standard deviation of 0.146 and a correlation of 0.961. The volume flow rate increased only slightly as the overlap was increased. The regression curve was not forced through the origin. The original data from the overlap test are given in Table IV of the Appendix.

Roller-Brush Speed Results

A factorial approach to testing with two factors was used for the speed tests. Twelve beveled bristles 1.72 inches long and 0.053 inches in diameter were installed in the brush. The overlap was maintained at 0.15 inches.

The tests were performed by setting the roller speed at 50 rpm and the brush speed at 50 rpm and taking three samples at this setting. The brush speed was then increased consecutively to 100, 200, 300, 400, and 500 rpm while three samples were taken at each setting. The procedure was then repeated consecutively for roller speeds of 100, 200, and 300 rpm.

The brush speed was stopped at 500 rpm because of increased vibration beyond this brush speed. The roller speed was stopped at 300 rpm because the liquid was thrown off by centrifugal force above this speed for the 3.375 inch diameter roller.

The data for the roller-brush speed test were evaluated by the step-wise program to give the plane surface shown in Figure 15. The proportion of sum of squares reduced was 0.971 with a standard deviation of 1.446 and a correlation coefficient of 0.986. The original

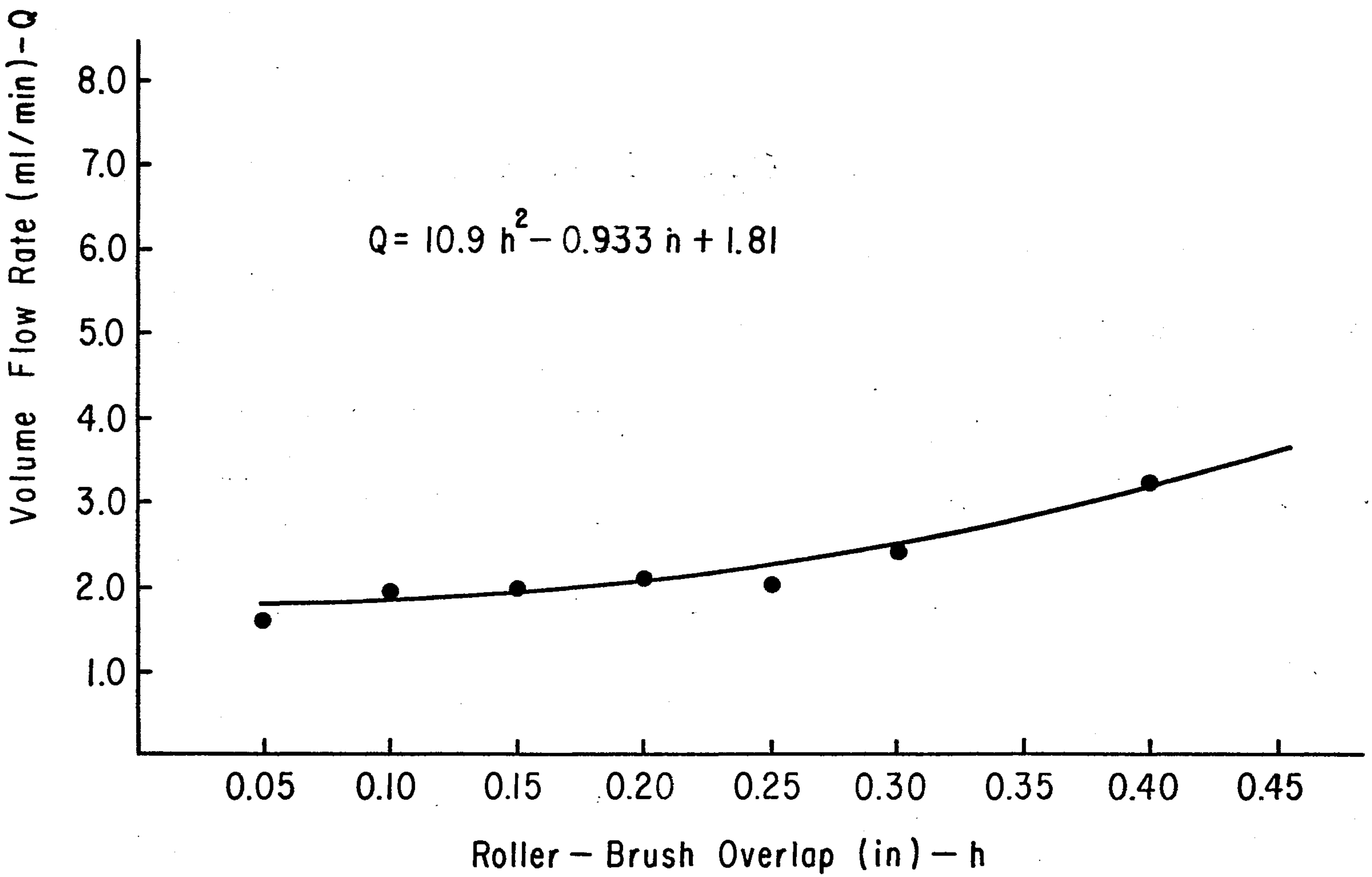


Figure 14. Volume Flow Rate vs. Roller-Brush Overlap

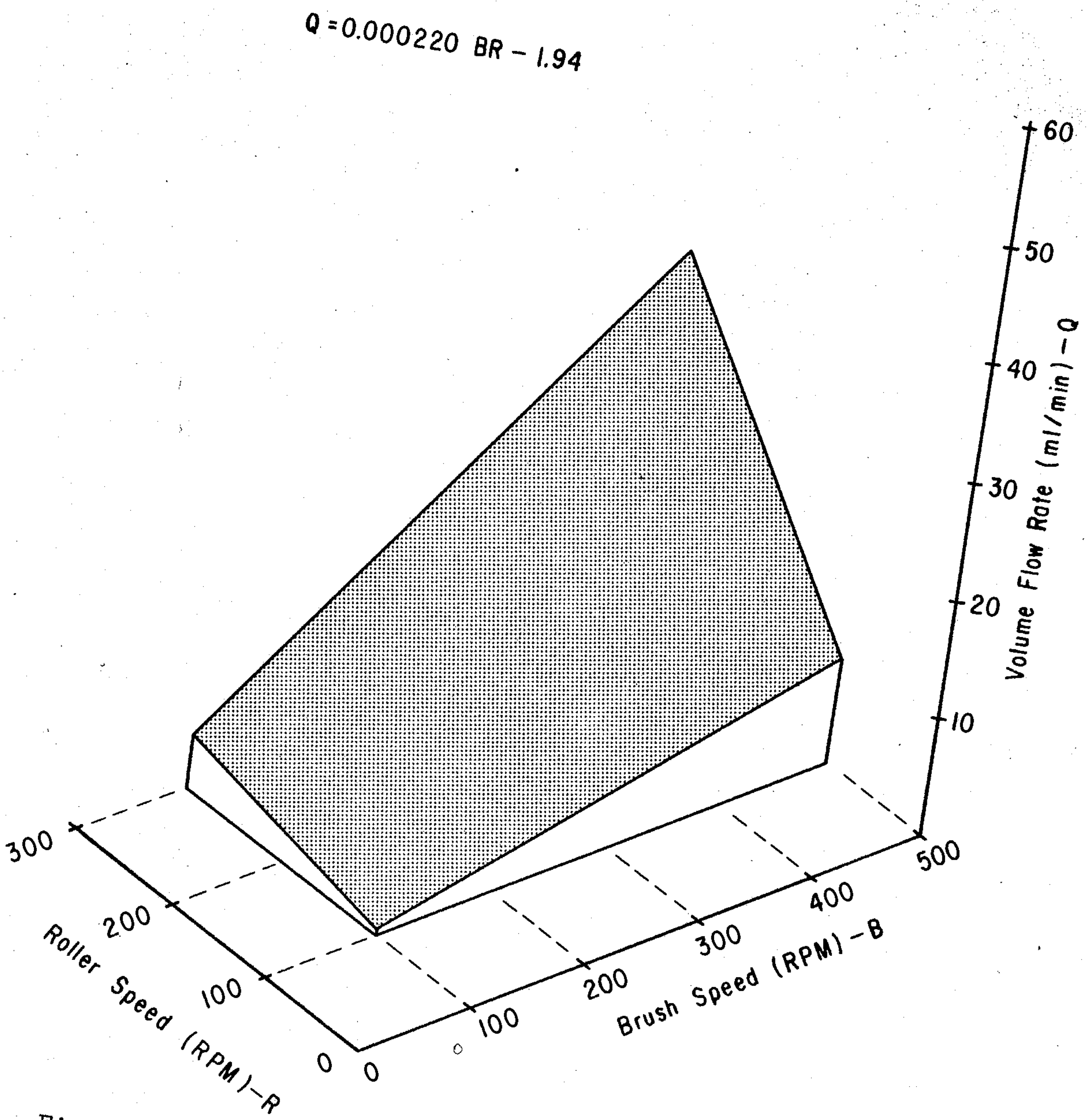


Figure 15. Volume Flow Rate vs. Brush and Roller Speeds

data from the roller-brush speed tests are given in Table V of the Appendix.

Bristle Length Results

The single factor approach was used for the length test. Six beveled bristles having diameters of 0.053 inches were installed in the brush. The overlap was maintained at 0.15 inches and the brush and roller speeds were 100 rpm each. Six bristles were used in order to simplify the length shortening process.

The bristles were initially 1.93 inches long. Three samples were taken at this length. The lengths were shortened consecutively to 1.75, 1.50, 1.25, 1.00, 0.75, and 0.50 inches and three samples were taken at each setting.

Sampling was stopped after a length of 0.75 inches because the bristles were permanently deformed backward when an attempt was made to sample a bristle 0.50 inches long.

The data for the length test were evaluated by the step-wise program to give the relationship shown in Figure 16. The proportion of sum of squares reduced was 0.598 with a standard deviation of 0.094 and a correlation coefficient of 0.774. The volume flow rate increased slightly as the bristle length was reduced. The original data from the length test are given in Table VI of the Appendix.

Bristle Diameter Results

Seven bristle diameters were available for the diameter test. Three were made of nylon and had diameters of 0.005, 0.010 and 0.015 inches. Four bristles were made of polypropylene and had diameters of

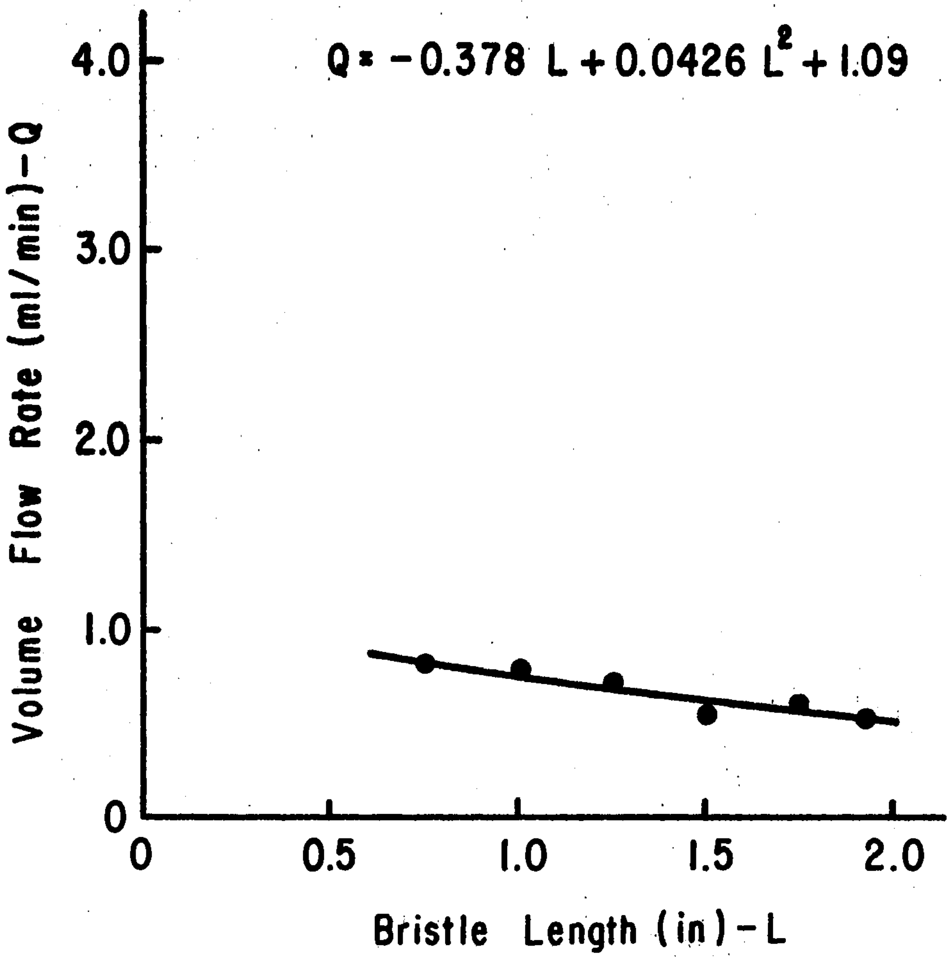


Figure 16. Volume Flow Rate vs. Bristle Length

0.012, 0.020, 0.029 and 0.053 inches. Of these bristles, only the polypropylene bristles having diameters of 0.029 and 0.053 inches had sufficient stiffness to produce drops in measurable volumes in the twelve bristle brush.

Since only two bristle sizes were suitable for testing it was not possible to determine a functional relationship for diameters. All of the previous tests had been conducted with bristles having 0.053 inch diameters. In order to get a comparison, all of the tests of wear, length, overlap, and brush and roller speeds were repeated using the 0.029 inch diameter bristles.

A comparison of the data for the two bristle sizes indicates the smaller bristles removed smaller amounts of liquid than did the larger bristles. Figure 13 gives an example of the effect that bristle diameter has upon the volume flow rate. The proportion of sum of squares reduced was 0.089 with a standard deviation of 0.139 and a correlation coefficient of 0.239. The original data are presented in Table VII of the Appendix.

Brush Density Results

A factorial approach to testing with three factors was used for the brush density tests. These tests were performed with a coil brush having 14.2 coils and approximately 714 bristles per coil. The bristles were 1.09 inches long and 0.029 inches in diameter. The overlap was 0.15 inches. The number of bristles was determined by counting the number of bristles in a 60° arc of the coil and then calculating the number of bristles for a full 360° coil. In this way the coil brush could be stretched out and the number of coils and fractions of coils in contact with the roller could be counted. The brush densities were calculated by dividing the number of bristles by the cylindrical surface area of the brush in contact with the roller. Brush densities of 128, 96, 64, and 32 bristles per square inch were tested by stretching out the coil brush and running 50 ml. through the system and recording the time.

Three samples were taken at each density for consecutive brush speeds of 25, 50, and 100 rpm for consecutive roller speeds of 25, 50, and 100 rpm.

The brush density of 128 bristles per square inch represented the closely packed configuration of the coil brush (Figure 5). The bristle density of 64 bristles per square inch represented the configuration having the coil brush stretched out completely (Figure 6). The brush density of 32 bristles per square inch was achieved by removing half of the bristles from the brush and operating the brush in the same position as with the 64 bristles per square inch test.

The data for the density test were evaluated by the step-wise program. The data was grouped by brush and roller speeds. Two examples of the results are given in Figure 17 for brush and roller speeds of 25 rpm each and 50 rpm each. The proportion of sum of squares reduced was 0.472 with a standard deviation of 4.042 and a correlation coefficient of 0.687 for the brush and roller speeds of 25 rpm. The proportion of sum of squares reduced was 0.902 with a standard deviation of 6.431 and a correlation coefficient of 0.948 for the brush and roller speeds of 50 rpm. In each case an increase in bristle density resulted in an increase in the volume flow rate. The original data for the density test are given in Table VIII of the Appendix.

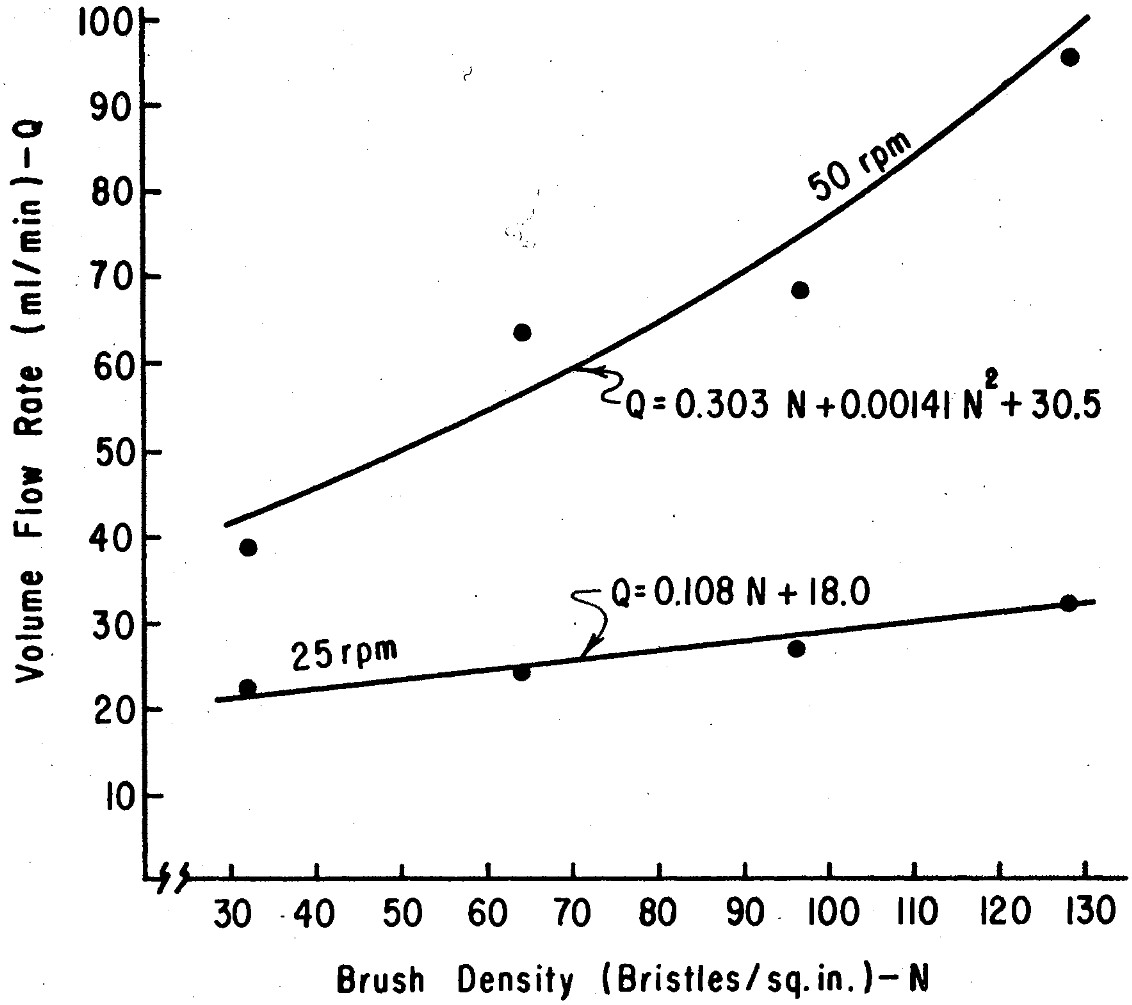


Figure 17. Volume Flow Rate vs. Brush Density for Brush and Roller Speeds of 25 by 25 and 50 by 50 rpm

Torque Requirement Results

Maximum torque requirements to operate the system were determined by using a spring scale graduated in ounces and a lever arm attached to the shafts of the roller and the brush. The overlap was 0.15 inches and the brush density was 128 bristles per square inch. Bearing torques for the roller and the brush were determined by rotating the shafts at approximately 50 rpm by pulling on the spring scale at the end of the lever arm. Five replications were recorded in this manner. The brush and roller were not in contact at this time. The system was then set up with the coil brush in contact with the roller. The roller was then rotated by its power source at 100 rpm while the torque required to turn the brush at 50 rpm was measured in the manner described above. The brush shaft was then powered by its source at 100 rpm while the roller torque was determined at 50 rpm. The torque required to operate the system was then the observed torque minus the bearing torque.

The torque required to rotate the brush was found to be 1.46 pound-feet for a three inch section of brush with a density of 128 bristles per square inch and a 0.15 inch overlap. This reduces to 0.486 pound-feet per linear inch of brush. The torque required to rotate the roller against this brush was 0.99 pound-feet. This torque reduces to 0.33 pound-feet per linear inch of brush.

Drop Size Analysis

Representative drop samples were collected throughout the tests in the following manner. Fluorescent powder was placed in the liquid in the reservoir. A white cardboard strip four inches wide and 22 inches long was passed under the apparatus at two miles per hour with the 22 inch side perpendicular to the direction of travel. The vertical distance from the roller surface to the cardboard was 24 inches. After the drops had dried, the cardboard strips were examined under an ultraviolet lamp.

Two design factors were found to have an effect upon the size of the drops produced by this system. The first factor was the degree of bevel of a bristle end (Figure 18). Drops produced by bristles with straight ends were larger than those produced when the bristles became beveled.

These samples were collected during the bevel test. The brush and roller speeds were 100 rpm, bristle length was 1.45 inches, bristle diameter was 0.053 inches, overlap was 0.15 inches, and the number of bristles was twelve.

The other factor affecting drop size was the speed of the roller when the coil brush was used (Figure 19). When the roller speed increased, the drop size increased markedly.

The samples shown in Figure 19 were taken with a brush speed of 10 rpm, a bristle length of 1.09 inches, a diameter of 0.029 inches, an overlap of 0.15 inches, and a brush density of 64 bristles per square inch.

Analysis of the Significant Factors

After determining the effect upon the flow rate of each of the design factors separately, it was necessary to determine the significance of each factor and investigate the effects of interaction.

The step-wise, multiple regression program was used to test the significance of each factor. All of the data for bristle length,

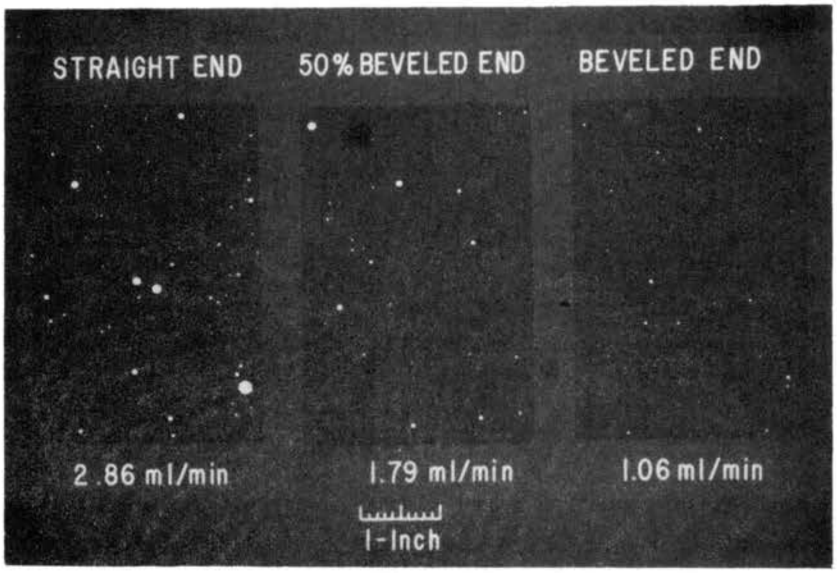


Figure 18. Effect of Bristle End Conditions Upon Drop Size

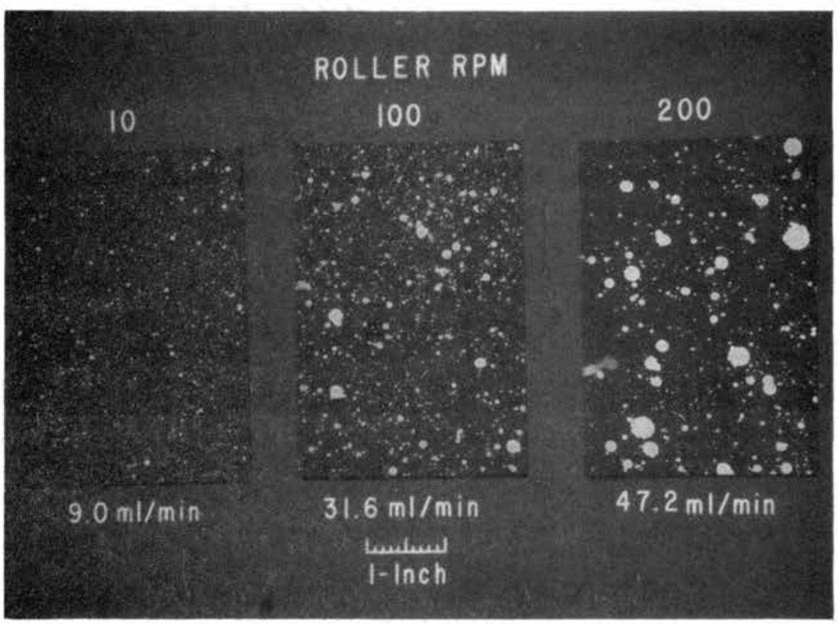


Figure 19. Effect of Roller Speed Upon Drop Size

bristle diameter, roller and brush speeds, overlap, and density were combined and the step-wise program indicated the significant factors in order of their importance. The choices given the program were the factors, their squares, and their cross products.

The prediction equation given by the step-wise regression program, where each factor appears at least once, was:

$$Q = 0.024\ RN - 0.50\ R - 0.0056\ N^2 + 36\ RD + 0.010\ BN - 0.51\ B + 7.5\ BD + 1200\ D + 0.00029\ BR - 99\ DN - 1.0\ LN + 290\ L - 0.00046\ R^2 + 3.8\ N - 3600\ LD - 0.97\ RL - 0.98\ Nh - 200$$

where

Q = the volume flow rate (ml./min.)

R = the roller speed (rev./min.)

B = the brush speed (rev./min.)

N = the brush density (bristles/sq. inch of brush surface)

D = the bristle diameter (inches)

L = the bristle length (inches)

h = the roller-brush overlap (inches)

The proportion of cumulative sum of squares reduced by this equation was 0.877 with a standard deviation of 21.2. However, the last eight terms of this equation increased the proportion of sum of squares reduced by only 0.008. The effect of length and overlap is therefore very slight. The equation was carried out to the twenty-third term, but there was no further increase in the proportion of sum of squares reduced.

CHAPTER VII

SUMMARY AND CONCLUSIONS

Summary

A test apparatus of the roller-brush atomizing system was designed and constructed so that the drop formation process and some of the design factors could be studied. The apparatus consisted of a brush assembly and a roller assembly each having their own power sources.

Drop formation was recorded by the use of still and high speed motion pictures. An analysis of these pictures determined the method of drop formation.

The effect of eight design factors upon the volume flow rate were evaluated. These factors were: surface condition of the roller, bristle bevel and wear, roller-brush overlap, brush speed, roller speed, bristle length, bristle diameter, and brush density.

In addition, an indication of the torque required to operate such a system was obtained. Drop size samples were also taken periodically throughout the tests in order to detect a noticeable change in drop size.

Conclusions

The following conclusions are presented from the results of this study:

1. Drops are formed by the bristles bursting through the layer of liquid on the roller surface. As the observed depth of the liquid is increased, more liquid is thrown off and larger drops are formed.
2. The surface conditions of the roller had no apparent effect upon the volume flow rate of the system.
3. The amount of bevel of the bristle ends had a great effect on both the volume flow rate and the drop size. Unbeveled bristles delivered greater amounts of liquid in the form of larger drops than did beveled bristles. Beveling became complete in a few hours. Fully beveled bristles wore slowly and had no measured effect upon the volume flow rate.
4. Overlaps below 0.05 inches were not satisfactory due to the fact that not all of the bristles made sufficient contact for flipping. Above 0.40 inches, the bristles were deformed sidewise and the bristles swept across the roller and failed to flip properly.
5. An increase in the speed of either the roller or the brush caused an increase in the volume flow rate. At roller speeds above 300 rpm, the liquid was cast off the roller by centrifugal force for the 3.375 inch diameter roller. A particular volume flow rate could be achieved by any of several combinations of brush and roller speeds.
6. Bristle length had slight effect upon the volume flow rate. As the bristle was shortened the volume flow

rate increased slightly due to an increase in bristle stiffness.

7. Bristles having larger diameters produced more liquid than did bristles of small diameters. Bristles below 0.029 inches in diameter lacked sufficient strength to produce drops.
8. As the brush density was increased, the volume flow rate would increase. However, the torque required to operate the system also increased when the brush density increased.
9. Drop sizes could be increased effectively by increasing the roller speed.
10. The most significant factors affecting the volume flow rate were: the product of the roller speed and the brush density, the roller speed, the square of the brush density, the product of the roller speed and the bristle diameter, and the product of the brush speed and the brush density.

Suggestions for Future Research

1. The system should be tested with several liquids with different viscosities and surface tensions in order to determine their effect upon the volume flow rate and the drop size.
2. A system made with a roller of synthetic material should be tested to determine the effect of a synthetic surface upon the volume flow rate and the drop size.

3. Field tests of a prototype roller-brush system should be conducted in order to evaluate its performance under the adverse conditions found in the field.
4. A study should be made to evaluate the ability of the system to control the drifting of the spray.

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APPENDIX

ORIGINAL DATA FOR ALL TESTS

TABLE I

ANALYSIS OF VARIANCE OF SMOOTH AND COARSE DIAMOND KNURLED SURFACES

Source	df	ss	ms	f
Total	5	2.05		
Treatment	1	0.13	0.13	0.27
Error	4	1.92	0.48	

TABLE II

SURFACE CONDITION TEST DATA

SAMPLE NO.	BRUSH SPEED (RPM)	ROLLER SPEED (RPM)	BRISTLE LENGTH (IN)	BRISTLE DIAMETER (IN)	BRUSH DENSITY (BRISTLES / SQ IN)	BRISTLE OVERLAP (IN)	VOLUME FLOW RATE (ML / MIN)	SURFACE
1	100.0	100.0	2.05	0.053	9.03	0.15	0.83	MEDIUM STRAIGHT KNURL
2	100.0	100.0	2.05	0.053	9.03	0.15	0.60	SMOOTH SURFACE
3	100.0	100.0	2.05	0.053	9.03	0.15	0.56	COARSE DIAMOND KNURL
4	100.0	100.0	2.05	0.053	9.03	0.15	0.64	MEDIUM STRAIGHT KNURL
5	100.0	100.0	2.05	0.053	9.03	0.15	0.51	SMOOTH SURFACE
6	100.0	100.0	2.05	0.053	9.03	0.15	0.47	COARSE DIAMOND KNURL
7	100.0	100.0	2.05	0.053	9.03	0.15	0.67	MEDIUM STRAIGHT KNURL
8	100.0	100.0	2.05	0.053	9.03	0.15	0.63	SMOOTH SURFACE
9	100.0	100.0	2.05	0.053	9.03	0.15	0.62	COARSE DIAMOND KNURL

TABLE III

BEVEL AND WEAR TEST DATA

SAMPLE NO.	BRUSH SPEED (RPM)	ROLLER SPEED (RPM)	BRISTLE LENGTH (IN)	BRISTLE DIAMETER (IN)	BRUSH DENSITY (BRISTLES / SQ IN)	BRISTLE OVERLAP (IN)	VOLUME FLOW RATE (ML / MIN)
1	100.0	100.0	1.47	0.053	10.6	0.15	3.35
2	100.0	100.0	1.47	0.053	10.6	0.15	2.46
3	100.0	100.0	1.47	0.053	10.6	0.15	2.35
4	100.0	100.0	1.47	0.053	10.6	0.15	2.08
5	100.0	100.0	1.47	0.053	10.6	0.15	2.03
6	100.0	100.0	1.47	0.053	10.6	0.15	1.79
7	100.0	100.0	1.47	0.053	10.6	0.15	1.45
8	100.0	100.0	1.47	0.053	10.6	0.15	1.59
9	100.0	100.0	1.47	0.053	10.6	0.15	1.43
10	100.0	100.0	1.47	0.053	10.6	0.15	1.37
11	100.0	100.0	1.47	0.053	10.6	0.15	1.46
12	100.0	100.0	1.47	0.053	10.6	0.15	1.46
13	100.0	100.0	1.47	0.053	10.6	0.15	1.45
14	100.0	100.0	1.47	0.053	10.6	0.15	1.42
15	100.0	100.0	1.47	0.053	10.6	0.15	1.47
16	100.0	100.0	1.47	0.053	10.6	0.15	1.42
17	100.0	100.0	1.47	0.053	10.6	0.15	1.09
18	100.0	100.0	1.47	0.053	10.6	0.15	1.15
19	100.0	100.0	1.47	0.053	10.6	0.15	1.08
20	100.0	100.0	1.47	0.053	10.6	0.15	1.16
21	100.0	100.0	1.47	0.053	10.6	0.15	1.10
22	100.0	100.0	1.47	0.053	10.6	0.15	1.18
23	100.0	100.0	1.47	0.053	10.6	0.15	1.06
24	100.0	100.0	1.47	0.053	10.6	0.15	1.05
25	100.0	100.0	1.47	0.053	10.6	0.15	1.18

TABLE IV

ROLLER-BRUSH OVERLAP TEST DATA

SAMPLE NO.	BRUSH SPEED (RPM)	ROLLER SPEED (RPM)	BRISTLE LENGTH (IN)	BRISTLE DIAMETER (IN)	BRUSH DENSITY (BRISTLES / SQ IN)	BRISTLE OVERLAP (IN)	VOLUME FLOW RATE (ML / MIN)
1	125.0	100.0	1.44	0.052	10.9	0.05	1.68
2	125.0	100.0	1.44	0.052	10.9	0.05	1.59
3	125.0	100.0	1.44	0.052	10.9	0.05	1.62
4	125.0	100.0	1.44	0.052	10.9	0.10	1.85
5	125.0	100.0	1.44	0.052	10.9	0.10	2.06
6	125.0	100.0	1.44	0.052	10.9	0.10	1.85
7	125.0	100.0	1.44	0.052	10.9	0.10	1.97
8	125.0	100.0	1.44	0.052	10.9	0.10	1.98
9	125.0	100.0	1.44	0.052	10.9	0.10	1.88
10	125.0	100.0	1.44	0.052	10.9	0.15	2.06
11	125.0	100.0	1.44	0.052	10.9	0.15	1.90
12	125.0	100.0	1.44	0.052	10.9	0.15	1.95
13	125.0	100.0	1.44	0.052	10.9	0.20	2.09
14	125.0	100.0	1.44	0.052	10.9	0.20	2.01
15	125.0	100.0	1.44	0.052	10.9	0.20	1.97
16	125.0	100.0	1.44	0.052	10.9	0.20	2.19
17	125.0	100.0	1.44	0.052	10.9	0.20	2.17
18	125.0	100.0	1.44	0.052	10.9	0.20	1.95
19	125.0	100.0	1.44	0.052	10.9	0.25	2.04
20	125.0	100.0	1.44	0.052	10.9	0.30	2.40
21	125.0	100.0	1.44	0.052	10.9	0.30	2.49
22	125.0	100.0	1.44	0.052	10.9	0.30	2.38
23	125.0	100.0	1.44	0.052	10.9	0.40	3.10
24	125.0	100.0	1.44	0.052	10.9	0.40	3.03
25	125.0	100.0	1.44	0.052	10.9	0.40	3.51
26	125.0	100.0	1.44	0.052	10.9	0.40	3.31

TABLE V

BRUSH AND ROLLER SPEED DATA

SAMPLE NO.	BRUSH SPEED (RPM)	ROLLER SPEED (RPM)	BRISTLE LENGTH (IN)	BRISTLE DIAMETER (IN)	BRUSH DENSITY (BRISTLES / SQ IN)	BRISTLE OVERLAP (IN)	VOLUME FLOW RATE (ML / MIN)
1	50.0	50.0	1.72	0.053	9.8	0.15	0.35
2	50.0	50.0	1.72	0.053	9.8	0.15	0.31
3	50.0	50.0	1.72	0.053	9.8	0.15	0.33
4	100.0	50.0	1.72	0.053	9.8	0.15	0.61
5	100.0	50.0	1.72	0.053	9.8	0.15	0.50
6	100.0	50.0	1.72	0.053	9.8	0.15	0.60
7	200.0	50.0	1.71	0.053	9.9	0.15	0.91
8	200.0	50.0	1.71	0.053	9.9	0.15	0.92
9	200.0	50.0	1.71	0.053	9.9	0.15	0.96
10	300.0	50.0	1.69	0.053	9.9	0.15	1.37
11	300.0	50.0	1.69	0.053	9.9	0.15	1.15
12	300.0	50.0	1.69	0.053	9.9	0.15	1.22
13	400.0	50.0	1.69	0.053	9.9	0.15	1.64
14	400.0	50.0	1.69	0.053	9.9	0.15	1.48
15	400.0	50.0	1.69	0.053	9.9	0.15	1.64
16	500.0	50.0	1.67	0.053	10.0	0.15	1.95
17	500.0	50.0	1.67	0.053	10.0	0.15	2.16
18	500.0	50.0	1.67	0.053	10.0	0.15	2.14
19	50.0	100.0	1.64	0.053	10.1	0.15	0.62
20	50.0	100.0	1.64	0.053	10.1	0.15	0.58
21	50.0	100.0	1.64	0.053	10.1	0.15	0.60
22	100.0	100.0	1.64	0.053	10.1	0.15	1.10
23	100.0	100.0	1.64	0.053	10.1	0.15	1.07
24	100.0	100.0	1.64	0.053	10.1	0.15	1.19
25	200.0	100.0	1.63	0.053	10.1	0.15	2.40
26	200.0	100.0	1.63	0.053	10.1	0.15	2.39
27	200.0	100.0	1.63	0.053	10.1	0.15	2.30
28	300.0	100.0	1.63	0.053	10.1	0.15	3.86
29	300.0	100.0	1.63	0.053	10.1	0.15	3.71
30	300.0	100.0	1.63	0.053	10.1	0.15	3.60
31	400.0	100.0	1.62	0.053	10.1	0.15	4.84
32	400.0	100.0	1.62	0.053	10.1	0.15	4.70
33	400.0	100.0	1.62	0.053	10.1	0.15	4.64
34	500.0	100.0	1.62	0.053	10.1	0.15	6.54
35	500.0	100.0	1.62	0.053	10.1	0.15	6.42
36	500.0	100.0	1.62	0.053	10.1	0.15	6.38

TABLE V (Continued)

SAMPLE NO.	BRUSH SPEED (RPM)	ROLLER SPEED (RPM)	BRISTLE LENGTH (IN)	BRISTLE DIAMETER (IN)	BRUSH DENSITY (BRISTLES / SQ IN)	BRISTLE OVERLAP (IN)	VOLUME FLOW RATE (ML / MIN)
37	50.0	200.0	1.60	0.053	10.2	0.15	1.13
38	50.0	200.0	1.60	0.053	10.2	0.15	0.90
39	50.0	200.0	1.60	0.053	10.2	0.15	1.06
40	100.0	200.0	1.60	0.053	10.2	0.15	2.25
41	100.0	200.0	1.60	0.053	10.2	0.15	2.21
42	100.0	200.0	1.60	0.053	10.2	0.15	2.25
43	200.0	200.0	1.59	0.053	10.2	0.15	5.66
44	200.0	200.0	1.59	0.053	10.2	0.15	5.56
45	200.0	200.0	1.59	0.053	10.2	0.15	5.66
46	300.0	200.0	1.59	0.053	10.2	0.15	10.66
47	300.0	200.0	1.59	0.053	10.2	0.15	10.44
48	300.0	200.0	1.59	0.053	10.2	0.15	10.34
49	400.0	200.0	1.58	0.053	10.2	0.15	14.13
50	400.0	200.0	1.58	0.053	10.2	0.15	13.86
51	400.0	200.0	1.58	0.053	10.2	0.15	14.26
52	500.0	200.0	1.58	0.053	10.2	0.15	24.22
53	500.0	200.0	1.58	0.053	10.2	0.15	24.62
54	500.0	200.0	1.58	0.053	10.2	0.15	23.20
55	50.0	300.0	1.57	0.053	10.3	0.15	1.65
56	50.0	300.0	1.57	0.053	10.3	0.15	1.74
57	50.0	300.0	1.57	0.053	10.3	0.15	1.65
58	100.0	300.0	1.57	0.053	10.3	0.15	3.96
59	100.0	300.0	1.57	0.053	10.3	0.15	3.80
60	100.0	300.0	1.57	0.053	10.3	0.15	3.88
61	200.0	300.0	1.57	0.053	10.3	0.15	9.82
62	200.0	300.0	1.57	0.053	10.3	0.15	10.60
63	200.0	300.0	1.57	0.053	10.3	0.15	9.78
64	300.0	300.0	1.57	0.053	10.3	0.15	16.34
65	300.0	300.0	1.57	0.053	10.3	0.15	16.67
66	300.0	300.0	1.57	0.053	10.3	0.15	17.06
67	400.0	300.0	1.57	0.053	10.3	0.15	23.98
68	400.0	300.0	1.57	0.053	10.3	0.15	25.30
69	400.0	300.0	1.57	0.053	10.3	0.15	25.73
70	500.0	300.0	1.56	0.053	10.3	0.15	33.65
71	500.0	300.0	1.56	0.053	10.3	0.15	33.37
72	500.0	300.0	1.56	0.053	10.3	0.15	30.98
73	50.0	50.0	1.56	0.053	10.3	0.15	0.46
74	100.0	50.0	1.56	0.053	10.3	0.15	0.52
75	200.0	50.0	1.56	0.053	10.3	0.15	0.84
76	300.0	50.0	1.56	0.053	10.3	0.15	1.38
77	400.0	50.0	1.56	0.053	10.3	0.15	1.82
78	500.0	50.0	1.56	0.053	10.3	0.15	2.46

TABLE VI

BRISTLE LENGTH DATA

SAMPLE NO.	BRUSH SPEED (RPM)	ROLLER SPEED (RPM)	BRISTLE LENGTH (IN)	BRISTLE DIAMETER (IN)	BRUSH DENSITY (BRISTLES / SQ IN)	BRISTLE OVERLAP (IN)	VOLUME FLOW RATE (ML / MIN)
1	100.0	100.0	1.93	0.053	4.7	0.15	0.61
2	100.0	100.0	1.93	0.053	4.7	0.15	0.54
3	100.0	100.0	1.93	0.053	4.7	0.15	0.41
4	100.0	100.0	1.75	0.053	4.9	0.15	0.69
5	100.0	100.0	1.75	0.053	4.9	0.15	0.55
6	100.0	100.0	1.75	0.053	4.9	0.15	0.57
7	100.0	100.0	1.50	0.053	5.2	0.15	0.61
8	100.0	100.0	1.50	0.053	5.2	0.15	0.49
9	100.0	100.0	1.50	0.053	5.2	0.15	0.54
10	100.0	100.0	1.25	0.053	5.6	0.15	0.71
11	100.0	100.0	1.25	0.053	5.6	0.15	0.73
12	100.0	100.0	1.25	0.053	5.6	0.15	0.75
13	100.0	100.0	1.25	0.053	5.6	0.15	0.65
14	100.0	100.0	1.00	0.053	6.1	0.15	0.83
15	100.0	100.0	1.00	0.053	6.1	0.15	0.76
16	100.0	100.0	1.00	0.053	6.1	0.15	0.79
17	100.0	100.0	0.75	0.053	6.7	0.15	0.99
18	100.0	100.0	0.75	0.053	6.7	0.15	0.63
19	100.0	100.0	0.75	0.053	6.7	0.15	0.82

TABLE VII

SMALL BRISTLE DIAMETER DATA

SAMPLE NO.	BRUSH SPEED (RPM)	ROLLER SPEED (RPM)	BRISTLE LENGTH (IN)	BRISTLE DIAMETER (IN)	BRUSH DENSITY (BRISTLES / SQ IN)	BRISTLE OVERLAP (IN)	VOLUME FLOW RATE (ML / MIN)
1	100.0	100.0	1.09	0.029	21.7	0.15	0.56
2	100.0	100.0	1.09	0.029	21.7	0.15	0.54
3	100.0	100.0	1.09	0.029	21.7	0.15	0.54
4	100.0	100.0	1.09	0.029	21.7	0.15	0.53
5	100.0	100.0	1.09	0.029	21.7	0.15	0.56
6	100.0	100.0	1.09	0.029	21.7	0.15	0.54
7	100.0	100.0	1.09	0.029	21.7	0.15	0.57
8	100.0	100.0	1.09	0.029	21.7	0.15	0.54
9	100.0	100.0	1.09	0.029	21.7	0.15	0.56
10	100.0	100.0	1.09	0.029	21.7	0.05	0.39
11	100.0	100.0	1.09	0.029	21.7	0.15	0.46
12	100.0	100.0	1.09	0.029	21.7	0.25	0.64
13	100.0	100.0	1.09	0.029	21.7	0.35	0.60
14	100.0	100.0	1.08	0.029	21.8	0.15	0.50
15	100.0	100.0	1.08	0.029	21.8	0.15	0.55
16	100.0	100.0	1.08	0.029	21.8	0.15	0.53
17	100.0	100.0	0.75	0.029	24.5	0.15	0.68
18	100.0	100.0	0.75	0.029	24.5	0.15	0.60
19	100.0	100.0	0.75	0.029	24.5	0.15	0.67
20	100.0	100.0	0.50	0.029	27.0	0.15	1.18
21	100.0	100.0	0.50	0.029	27.0	0.15	1.07
22	100.0	100.0	0.50	0.029	27.0	0.15	1.13

TABLE VII (Continued)

SAMPLE NO.	BRUSH SPEED (RPM)	ROLLER SPEED (RPM)	BRISTLE LENGTH (IN)	BRISTLE DIAMETER (IN)	BRUSH DENSITY (BRISTLES / SQ IN)	BRISTLE OVERLAP (IN)	VOLUME FLOW RATE (ML / MIN)
23	100.0	50.0	1.08	0.029	21.8	0.15	0.30
24	100.0	50.0	1.08	0.029	21.8	0.15	0.32
25	100.0	50.0	1.08	0.029	21.8	0.15	0.34
26	300.0	50.0	1.08	0.029	21.8	0.15	0.59
27	300.0	50.0	1.08	0.029	21.8	0.15	0.72
28	300.0	50.0	1.08	0.029	21.8	0.15	0.59
29	500.0	50.0	1.08	0.029	21.8	0.15	1.00
30	500.0	50.0	1.08	0.029	21.8	0.15	1.06
31	500.0	50.0	1.08	0.029	21.8	0.15	1.08
32	100.0	100.0	1.08	0.029	21.8	0.15	0.50
33	100.0	100.0	1.08	0.029	21.8	0.15	0.55
34	100.0	100.0	1.08	0.029	21.8	0.15	0.53
35	300.0	100.0	1.08	0.029	21.8	0.15	1.65
36	300.0	100.0	1.08	0.029	21.8	0.15	1.83
37	300.0	100.0	1.08	0.029	21.8	0.15	1.48
38	500.0	100.0	1.08	0.029	21.8	0.15	2.70
39	500.0	100.0	1.08	0.029	21.8	0.15	2.76
40	500.0	100.0	1.08	0.029	21.8	0.15	2.23
41	100.0	200.0	1.08	0.029	21.8	0.15	1.13
42	100.0	200.0	1.08	0.029	21.8	0.15	1.08
43	100.0	200.0	1.08	0.029	21.8	0.15	0.96
44	300.0	200.0	1.08	0.029	21.8	0.15	3.86
45	300.0	200.0	1.08	0.029	21.8	0.15	4.10
46	300.0	200.0	1.08	0.029	21.8	0.15	4.23
47	500.0	200.0	1.08	0.029	21.8	0.15	7.90
48	500.0	200.0	1.08	0.029	21.8	0.15	8.65
49	500.0	200.0	1.08	0.029	21.8	0.15	8.31

TABLE VIII

BRUSH DENSITY DATA

SAMPLE NO.	BRUSH SPEED (RPM)	ROLLER SPEED (RPM)	BRISTLE LENGTH (IN)	BRISTLE DIAMETER (IN)	BRUSH DENSITY (BRISTLES / SQ IN)	BRISTLE OVERLAP (IN)	VOLUME FLOW RATE (ML / MIN)
1	25.0	25.0	1.09	0.029	128.0	0.15	32.10
2	25.0	25.0	1.09	0.029	128.0	0.15	32.50
3	25.0	25.0	1.09	0.029	128.0	0.15	32.10
4	50.0	25.0	1.09	0.029	128.0	0.15	40.60
5	50.0	25.0	1.09	0.029	128.0	0.15	34.40
6	50.0	25.0	1.09	0.029	128.0	0.15	31.40
7	100.0	25.0	1.09	0.029	128.0	0.15	39.20
8	100.0	25.0	1.09	0.029	128.0	0.15	44.10
9	100.0	25.0	1.09	0.029	128.0	0.15	36.50
10	25.0	50.0	1.09	0.029	128.0	0.15	62.00
11	25.0	50.0	1.09	0.029	128.0	0.15	62.40
12	25.0	50.0	1.09	0.029	128.0	0.15	65.30
13	50.0	50.0	1.09	0.029	128.0	0.15	95.70
14	50.0	50.0	1.09	0.029	128.0	0.15	92.80
15	50.0	50.0	1.09	0.029	128.0	0.15	98.40
16	100.0	50.0	1.09	0.029	128.0	0.15	108.80
17	100.0	50.0	1.09	0.029	128.0	0.15	100.40
18	100.0	50.0	1.09	0.029	128.0	0.15	92.40
19	25.0	100.0	1.09	0.029	128.0	0.15	128.00
20	25.0	100.0	1.09	0.029	128.0	0.15	141.60
21	25.0	100.0	1.09	0.029	128.0	0.15	135.70
22	50.0	100.0	1.09	0.029	128.0	0.15	242.00
23	50.0	100.0	1.09	0.029	128.0	0.15	216.60
24	50.0	100.0	1.09	0.029	128.0	0.15	236.70
25	100.0	100.0	1.09	0.029	128.0	0.15	296.40
26	100.0	100.0	1.09	0.029	128.0	0.15	252.60
27	100.0	100.0	1.09	0.029	128.0	0.15	278.40

TABLE VIII (Continued)

SAMPLE NO.	BRUSH SPEED (RPM)	ROLLER SPEED (RPM)	BRISTLE LENGTH (IN)	BRISTLE DIAMETER (IN)	BRUSH DENSITY (BRISTLES / SQ IN)	BRISTLE OVERLAP (IN)	VOLUME FLOW RATE (ML / MIN)
28	25.0	25.0	1.09	0.029	96.0	0.15	23.50
29	25.0	25.0	1.09	0.029	96.0	0.15	23.10
30	25.0	25.0	1.09	0.029	96.0	0.15	21.90
31	50.0	25.0	1.09	0.029	96.0	0.15	22.20
32	50.0	25.0	1.09	0.029	96.0	0.15	23.30
33	50.0	25.0	1.09	0.029	96.0	0.15	19.60
34	100.0	25.0	1.09	0.029	96.0	0.15	24.90
35	100.0	25.0	1.09	0.029	96.0	0.15	26.00
36	100.0	25.0	1.09	0.029	96.0	0.15	24.00
37	25.0	50.0	1.09	0.029	96.0	0.15	56.00
38	25.0	50.0	1.09	0.029	96.0	0.15	58.80
39	25.0	50.0	1.09	0.029	96.0	0.15	55.20
40	50.0	50.0	1.09	0.029	96.0	0.15	70.40
41	50.0	50.0	1.09	0.029	96.0	0.15	72.00
42	50.0	50.0	1.09	0.029	96.0	0.15	72.80
43	100.0	50.0	1.09	0.029	96.0	0.15	98.00
44	100.0	50.0	1.09	0.029	96.0	0.15	86.40
45	100.0	50.0	1.09	0.029	96.0	0.15	82.00
46	25.0	100.0	1.09	0.029	96.0	0.15	81.60
47	25.0	100.0	1.09	0.029	96.0	0.15	124.80
48	25.0	100.0	1.09	0.029	96.0	0.15	109.20
49	50.0	100.0	1.09	0.029	96.0	0.15	152.40
50	50.0	100.0	1.09	0.029	96.0	0.15	179.40
51	50.0	100.0	1.09	0.029	96.0	0.15	159.00
52	100.0	100.0	1.09	0.029	96.0	0.15	240.00
53	100.0	100.0	1.09	0.029	96.0	0.15	232.60
54	100.0	100.0	1.09	0.029	96.0	0.15	251.70

TABLE VIII (Continued)

SAMPLE NO.	BRUSH SPEED (RPM)	ROLLER SPEED (RPM)	BRISTLE LENGTH (IN)	BRISTLE DIAMETER (IN)	BRUSH DENSITY (BRISTLES / SQ IN)	BRISTLE OVERLAP (IN)	VOLUME FLOW RATE (ML / MIN)
55	25.0	25.0	1.09	0.029	64.0	0.15	23.20
56	25.0	25.0	1.09	0.029	64.0	0.15	26.60
57	25.0	25.0	1.09	0.029	64.0	0.15	22.80
58	50.0	25.0	1.09	0.029	64.0	0.15	32.60
59	50.0	25.0	1.09	0.029	64.0	0.15	31.30
60	50.0	25.0	1.09	0.029	64.0	0.15	32.80
61	100.0	25.0	1.09	0.029	64.0	0.15	37.10
62	100.0	25.0	1.09	0.029	64.0	0.15	40.20
63	100.0	25.0	1.09	0.029	64.0	0.15	35.40
64	25.0	50.0	1.09	0.029	64.0	0.15	38.20
65	25.0	50.0	1.09	0.029	64.0	0.15	41.10
66	25.0	50.0	1.09	0.029	64.0	0.15	42.30
67	50.0	50.0	1.09	0.029	64.0	0.15	60.40
68	50.0	50.0	1.09	0.029	64.0	0.15	66.40
69	50.0	50.0	1.09	0.029	64.0	0.15	64.10
70	100.0	50.0	1.09	0.029	64.0	0.15	90.30
71	100.0	50.0	1.09	0.029	64.0	0.15	85.80
72	100.0	50.0	1.09	0.029	64.0	0.15	91.20
73	25.0	100.0	1.09	0.029	64.0	0.15	82.20
74	25.0	100.0	1.09	0.029	64.0	0.15	89.40
75	25.0	100.0	1.09	0.029	64.0	0.15	108.00
76	50.0	100.0	1.09	0.029	64.0	0.15	118.20
77	50.0	100.0	1.09	0.029	64.0	0.15	118.40
78	50.0	100.0	1.09	0.029	64.0	0.15	113.40
79	100.0	100.0	1.09	0.029	64.0	0.15	145.80
80	100.0	100.0	1.09	0.029	64.0	0.15	198.00
81	100.0	100.0	1.09	0.029	64.0	0.15	195.60

TABLE VIII (Continued)

SAMPLE NO.	BRUSH SPEED (RPM)	ROLLER SPEED (RPM)	BRISTLE LENGTH (IN)	BRISTLE DIAMETER (IN)	BRUSH DENSITY (BRISTLES / SQ IN)	BRISTLE OVERLAP (IN)	VOLUME FLOW RATE (ML / MIN)
82	25.0	25.0	1.09	0.029	32.0	0.15	22.80
83	25.0	25.0	1.09	0.029	32.0	0.15	21.30
84	25.0	25.0	1.09	0.029	32.0	0.15	21.70
85	50.0	25.0	1.09	0.029	32.0	0.15	23.60
86	50.0	25.0	1.09	0.029	32.0	0.15	26.40
87	50.0	25.0	1.09	0.029	32.0	0.15	31.40
88	100.0	25.0	1.09	0.029	32.0	0.15	43.20
89	100.0	25.0	1.09	0.029	32.0	0.15	45.10
90	100.0	25.0	1.09	0.029	32.0	0.15	40.40
91	25.0	50.0	1.09	0.029	32.0	0.15	25.10
92	25.0	50.0	1.09	0.029	32.0	0.15	24.80
93	25.0	50.0	1.09	0.029	32.0	0.15	26.20
94	50.0	50.0	1.09	0.029	32.0	0.15	34.10
95	50.0	50.0	1.09	0.029	32.0	0.15	40.40
96	50.0	50.0	1.09	0.029	32.0	0.15	42.10
97	100.0	50.0	1.09	0.029	32.0	0.15	76.50
98	100.0	50.0	1.09	0.029	32.0	0.15	74.40
99	100.0	50.0	1.09	0.029	32.0	0.15	77.60
100	25.0	100.0	1.09	0.029	32.0	0.15	48.60
101	25.0	100.0	1.09	0.029	32.0	0.15	49.20
102	25.0	100.0	1.09	0.029	32.0	0.15	47.20
103	50.0	100.0	1.09	0.029	32.0	0.15	87.50
104	50.0	100.0	1.09	0.029	32.0	0.15	91.20
105	50.0	100.0	1.09	0.029	32.0	0.15	97.20
106	100.0	100.0	1.09	0.029	32.0	0.15	159.20
107	100.0	100.0	1.09	0.029	32.0	0.15	162.60
108	100.0	100.0	1.09	0.029	32.0	0.15	165.70

TABLE VIII (Continued)

SAMPLE NO.	BRUSH SPEED (RPM)	ROLLER SPEED (RPM)	BRISTLE LENGTH (IN)	BRISTLE DIAMETER (IN)	BRUSH DENSITY (BRISTLES / SQ IN)	BRISTLE OVERLAP (IN)	VOLUME FLOW RATE (ML / MIN)
109	25.0	25.0	1.09	0.029	96.0	0.15	36.40
110	25.0	25.0	1.09	0.029	96.0	0.15	30.20
111	25.0	25.0	1.09	0.029	96.0	0.15	34.60
112	50.0	25.0	1.09	0.029	96.0	0.15	39.40
113	50.0	25.0	1.09	0.029	96.0	0.15	42.80
114	50.0	25.0	1.09	0.029	96.0	0.15	39.80
115	100.0	25.0	1.09	0.029	96.0	0.15	45.20
116	100.0	25.0	1.09	0.029	96.0	0.15	46.60
117	100.0	25.0	1.09	0.029	96.0	0.15	42.10
118	25.0	50.0	1.09	0.029	96.0	0.15	49.60
119	25.0	50.0	1.09	0.029	96.0	0.15	46.80
120	25.0	50.0	1.09	0.029	96.0	0.15	54.80
121	50.0	50.0	1.09	0.029	96.0	0.15	60.20
122	50.0	50.0	1.09	0.029	96.0	0.15	69.60
123	50.0	50.0	1.09	0.029	96.0	0.15	65.20
124	100.0	50.0	1.09	0.029	96.0	0.15	91.60
125	100.0	50.0	1.09	0.029	96.0	0.15	91.80
126	100.0	50.0	1.09	0.029	96.0	0.15	91.60
127	25.0	100.0	1.09	0.029	96.0	0.15	89.40
128	25.0	100.0	1.09	0.029	96.0	0.15	93.60
129	25.0	100.0	1.09	0.029	96.0	0.15	82.20
130	50.0	100.0	1.09	0.029	96.0	0.15	157.20
131	50.0	100.0	1.09	0.029	96.0	0.15	151.80
132	50.0	100.0	1.09	0.029	96.0	0.15	147.00
133	100.0	100.0	1.09	0.029	96.0	0.15	210.10
134	100.0	100.0	1.09	0.029	96.0	0.15	213.60
135	100.0	100.0	1.09	0.029	96.0	0.15	211.20

VITA 1

Gary Warren Tripp

Candidate for the Degree of

Master of Science

Thesis: DEVELOPMENT OF A ROLLER-BRUSH PESTICIDE APPLICATOR

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