DEVELOPMENT AND EVALUATION OF A PESTICIDE INDUCTION SYSTEM FOR A FIELD SPRAYER

By

DONALD RAY PECK

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Oklahoma State University

Stillwater, Oklahoma

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DEVELOPMENT AND EVALUATION OF A PESTICIDE INDUCTION SYSTEM FOR A FIELD SPRAYER

Thesis Approved:

Lawrence O. Roth

Thesis Adviser

Jay G. Porterfield

David G. Batchelder

N N Durham

Dean of the Graduate College

PREFACE

The research reported in this thesis was conducted as a part of Oklahoma Agricultural Experiment Station Project H-1264.

I would like to express my appreciation to Dr. Lawrence O. Roth, my thesis adviser, for his counsel and encouragement during the course of the entire project. I am also grateful to the other members of my committee, Professor Jay G. Porterfield and Associate Professor David G. Batchelder for their assistance and constructive suggestions.

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INTRODUCTION

Recently the agricultural industry has experienced great turmoil concerning the relative effects of pesticidal residues in the environment. This increased awareness of the possible hazards of these deposits of pesticides continues to increase the demands placed on spraying equipment. The problems associated with the application of these pesticides are therefore further diversified. The present trend indicates that these agricultural chemicals will continue to play an important role in the control of undesirable insects, vegetation, and diseases.

Due to the production and other commercial factors which presently dictate the choice of formulation of pesticides, the past few years have shown a marked increase in the use of wettable powders. Although this change has occurred, very little work has been done to provide spraying equipment that handles wettable powders efficiently. Almost all of the sprayers presently being used to apply wettable powders are modifications of sprayers designed for the application of water-soluble pesticides. These adaptations generally include only the addition or improvement of the mechanical or hydraulic agitation for the sprayer tank.

The problems associated with the use of wettable powders in the converted conventional sprayer systems are numberous and include:

1. Direct physical contact of operator with pesticides.
2. Corrosive action of chemicals on spray system components.
3. Settling of the wettable powder suspension in the sprayer storage tank and other parts of the system.
4. Obstruction of screens, filters, and nozzles by incompletely wetted and dispersed powder particles or by agglomerates of particles which have been rewetted.
5. Excessive pump wear.
6. Difficulty and inaccuracy of calibration.
7. Difficulty in cleaning after use.

This study involved the development and evaluation of a field sprayer unit in an attempt to eliminate or minimize many or all of the previously stated problems. The unit developed employed a pesticide induction system, for both liquids and wettable powders, which metered and introduced the pesticide from a shipping container into the boom supply line.

CHAPTER II

OBJECTIVES

The objectives of this study are:

1. To design and construct a field sprayer capable of handling pesticides formulated as either wettable powders or emulsifiable concentrates directly from their shipping containers using a jet pump to induce and mix the pesticide into the diluent stream.
2. To evaluate the designed system under appropriate field and laboratory tests.

CHAPTER III

REVIEW OF LITERATURE

Problems with Conventional Sprayers

It is estimated that the sale of herbicides and insecticides will increase from their 1969 sale of nine hundred million dollars to nearly one and one-half billion dollars by 1975 (8). With this expected increase, the efficient use of pesticides will continue to play an important economic role in agriculture.

The basic function of an agricultural sprayer is to apply the necessary quantity of toxic materials to control undesirable insects, vegetation, or diseases at the desired points with a minimum of wastage. To be economically feasible, an agricultural sprayer must be capable of handling the pesticides in their various formulated states. The basic formulations of these pesticides which are suitable for spraying are:

1. the concentrated solution which has the active ingredient dissolved in water.
2. emulsifiable concentrates with the active ingredient dissolved in oil and emulsified in water.
3. wettable powders which are finely divided water-insoluble particles.

The chemical activity of the active compound often restricts the choice of formulations of these pesticides. The pesticide must not only be convenient to use when freshly prepared, but also after packaging, transport, and storage. In addition, the formulator must analyze the economic and biological efficiencies involved with the various formulations.

The conventional field sprayer is operated by mixing the pesticide, however formulated, with the diluent in the storage tank. The problems associated with the use of these conventional systems are numerous. One of the more important problems is the direct physical contact of the operator with the concentrated pesticide while measuring the material and filling the storage tank.

The chemical and physical characteristics of the pesticide formulation used should dictate the material used in the construction of the various component parts of the sprayer. The wide range of chemical activities necessitates the use of a storage tank material which is resistant to the corrosive attack of the active ingredients in the pesticide (5). Excessive wear on most rotary pumps is caused by the abrasive action of wettable powder suspensions. This wear can be reduced by using pumps constructed of new wear-resistant materials.

If proper care is not taken in the mixing process to completely wet the powder, poor dispersion of the chemical results. To aid in the dispersion of wettable powder suspensions in the storage tank, various hydraulic and mechanical continuous agitation systems are employed. Often these added agitation systems prove to be inadequate in that they do not keep the powders suspended and dispersed uniformly. Another problem often introduced by poor agitation systems is excessive foaming caused by air entrainment into the system (5). If the material is allowed to settle, re-establishing the suspension requires a much higher degree of agitation (9). Tests which have been conducted indicate that the pesticides do not completely disperse when resuspended after settling. The resulting agglomerates were large enough to cause plugging of the 50-mesh screen used in the tests (10). This settling and agglomeration occurs in the spray tank if adequate agitation is not provided. Spray booms and supply lines are frequently too large to provide sufficient flow velocities to maintain the pesticides in suspension. Settling also occurs in these booms and supply lines when the flow is stopped, trapping a portion of the suspension in the lines.

Many calibration procedures for field sprayers are used. One common practice is to catch the output of one nozzle for a given distance and compute the rate applied according to the area covered by that nozzle. This procedure, assuming the pesticide is uniformly distributed, calibrates the sprayer for that particular nozzle, nozzle flow rate and sprayer speed. Any variations in these parameters result in a change of application rate. If a toxicant mixture is used during this calibration procedure, an actual unknown rate is being applied to the calibration area and this amount of spray and chemical is not recoverable.

Failure to properly clean a sprayer following use, results in reduced reliability and a shorter sprayer life. To properly clean a conventional spraying system, the entire spray mixture must be removed from the storage tank and clean water or an appropriate solvent added. The cleaning liquid is pumped through the system until the desired degree of cleanliness is accomplished. This time consuming task often results in the system going uncleaned.

Another problem frequently encountered is that of being unable to complete a spray job immediately due to an interruption. This prevents the complete use of the mixed tank load of chemicals until the following day. Most chemicals deteriorate somewhat when left in water solutions for extended periods of time. Even greater problems are encountered when an emulsifier deteriorates and is unable to disperse the solvent which contains the active ingredient, even under severe agitation (3).

Analysis of the many problems enumerated here reveals that the limiting factor in many of these areas is the use of wettable powders in the conventional systems. For this reason a sprayer was developed which could handle both wettable powders and liquid concentrates and eliminate or minimize many of these problems.

Lower Volume Sprays

Since a given amount of pesticide contains the required amount of toxic material to control certain plants or animals, it is not feasible to apply less actual pesticide in an attempt to economize on a spraying operation. However, it is economically feasible to apply lower volume sprays in higher concentrations. This could be accomplished by spraying the same amount of actual toxic material in a smaller volume of inert carrier liquid. The logistics involved in supplying the liquid for a normal 180 to 380 l/ha spraying operation represents a sizeable portion of the operation costs (1).

On the basis of inertness, safety, and an enormous advantage in cost, the carrier liquid is almost invariably water. The first function of the carrier is to enable the spray drops to spread out and cover the target area (4). Therefore, the carrier rate may be reduced until an optimum rate for a given pesticide formulation is reached.

A great deal of work has been done in this area resulting in low-volume and ultra-low-volume spraying (2). In the ultra-low-volume spraying the pesticides were formulated in a different manner than those formulated for use in conventional systems. In tests run on these sytems it was reported that these sprays were as effective and possibly more effective than the conventionally diluted application.

Previous Work

Nelson (6) developed and tested a wettable powder induction system that adequately mixed and induced wettable powders into the sprayer boom supply line. A jet pump was used to draw in a slurry of the wettable powder and mix it with water pumped from the supply tank. The powder was metered with a screw feeder and wetted with a small amount of water before entering the suction inlet of the jet pump.

The suspension characteristics that he tested did not indicate significant differences in the suspension produced due to differences in turbulence in the jet pump or differences in the powder metering rate. However, he found that the formulation of the wettable powder can influence the degree of dispersion produced by the induction system.

CHAPTER IV

DESIGN AND CONSTRUCTION OF THE UNIT

A field sprayer unit was designed and built to readily accomodate the handling of wettable powders while not hampering the efficiency of using liquid pesticides. Based upon Nelson's (6) results, the use of a jet pump to induce and mix the wettable powder into the diluent stream seemed to be a feasible method for applying wettable powders. For this reason the jet pump was used as a foundation for the development of the induction system. A mixing chamber was used in the induction system to wet the powder with diluent before the pesticide entered the jet pump.

The spraying system was mounted on a Hagie high-clearance chassis as shown in Figure 1. The pesticide induction system and controls were attached to the tractor frame and positioned adjacent to the operator's station so the operation of the system could be visually monitored.

Diluent System

The diluent system in the unit was basically similar to that used in a conventional sprayer. Figure 2 schematically shows the paths of flow through the system.

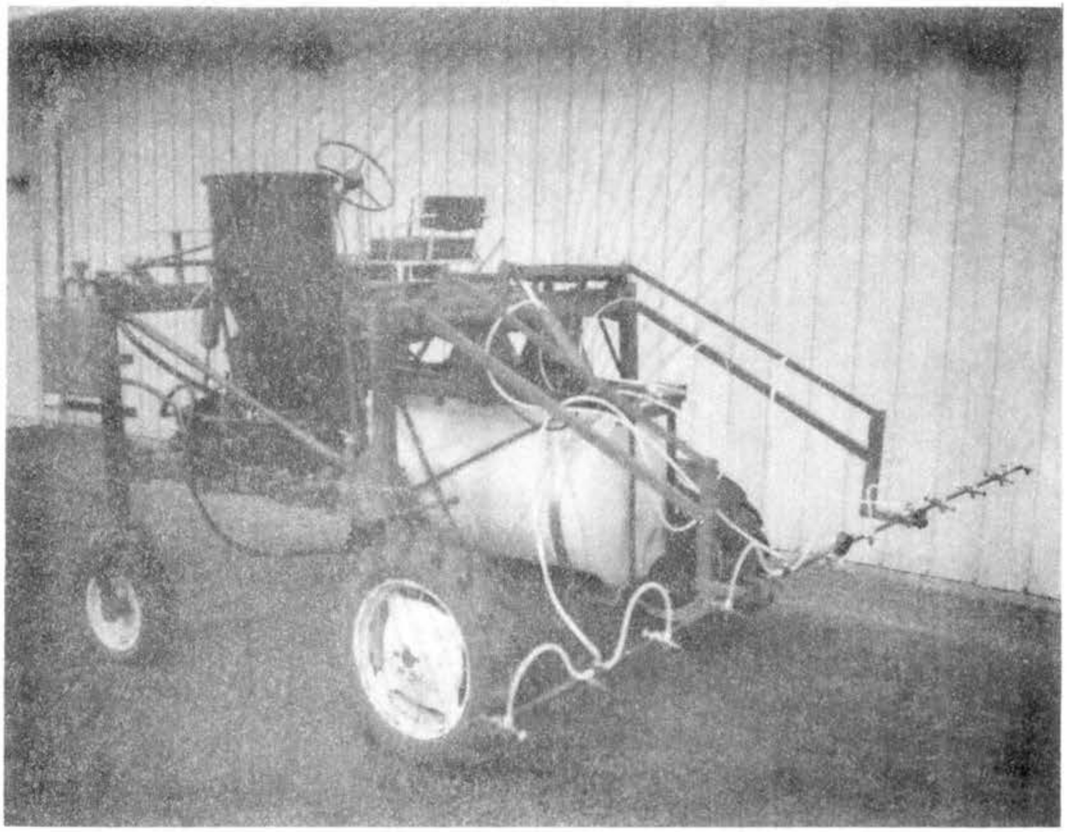

Figure 1. Pesticide Induction Field Sprayer

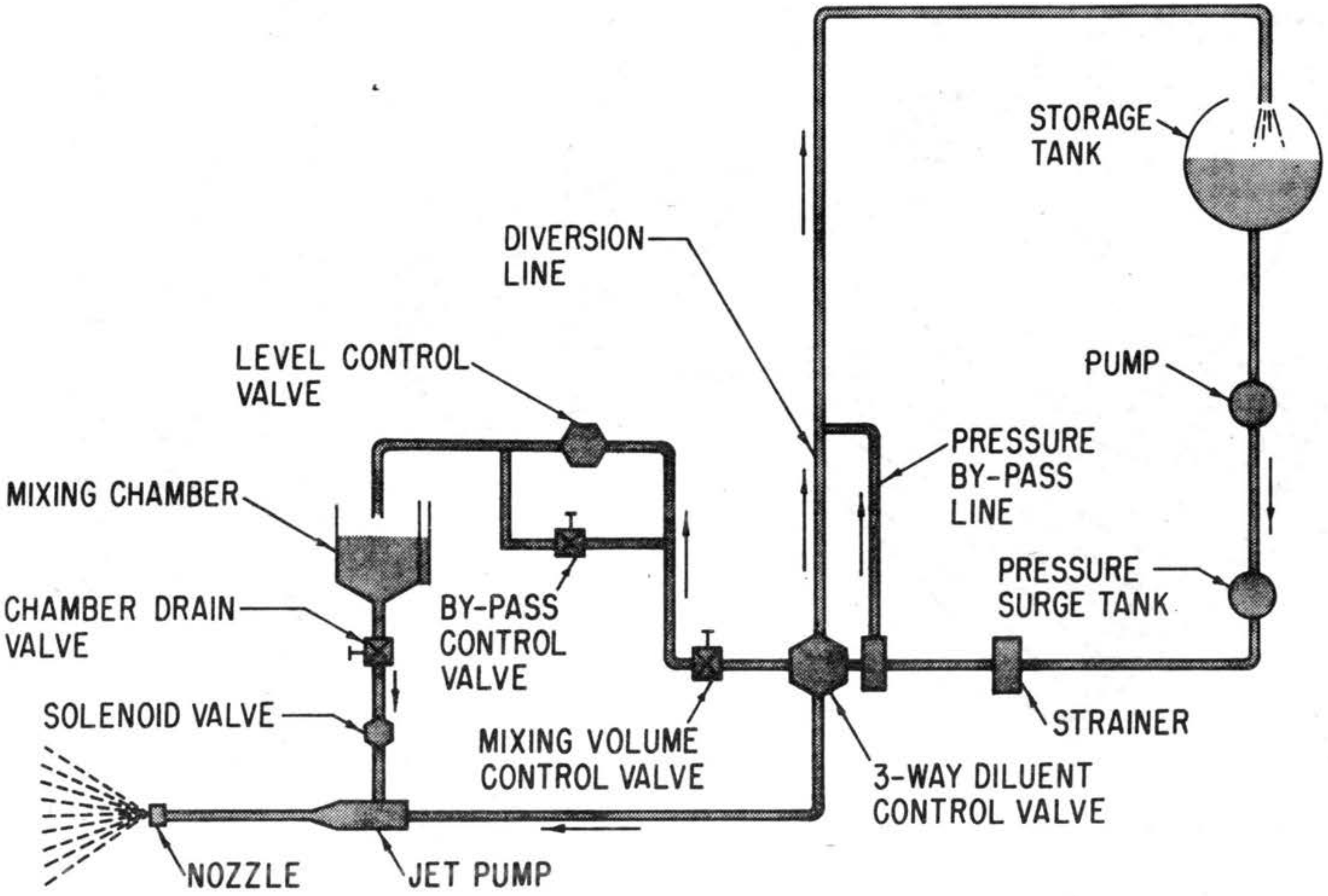

Figure 2. Schematic Diagram of Diluent Flow Path

The diluent was stored in a 760 l storage tank mounted toward the rear and on the underneath side of the tractor. A seven-roller Delavan pump with Nylon rollers was used to draw the diluent from the storage tank and to produce the necessary pressure for the operation of the system. Nylon, rather than rubber, rollers were used in the pump, since operating pressures often exceeded 690 kN/m^2. The roller pump was driven through a V-belt drive directly from the engine crankshaft. The tractor was equipped with a variable ground speed drive, allowing a constant engine and pump speed independent of the tractor ground speed.

A surge tank was placed in the pressure line to minimize pressure fluctuations. The diluent then passed through a 100-mesh strainer, a pressure regulator and into a three-way control valve assembly. This control valve assembly allowed the diluent (1) to be simultaneously directed to the pressure side of the jet pump and to the mixing chamber, (2) to be directed to the mixing chamber with the excess flow diverted back to the storage tank, and (3) to be diverted back to the storage tank.

A switch which controlled a solenoid valve between the mixing chamber and the suction inlet of the jet pump was positioned on the control valve assembly. The switch was positioned so that when the diluent flow was directed to the mixing chamber the solenoid valve was also open. When the diluent was diverted back to the storage tank the solenoid valve was closed. This arrangement insured that the mixing chamber would not continue to fill when the diluent was not being released to the suction side of the jet pump. The switch however, did not control the flow of diluent to the pressure side of the jet pump.

Metering System

The metering unit was designed to be driven proportional to the sprayer ground speed. As indicated schematically in Figure 3, the system would meter either liquid or wettable powder formulations. The metering unit is shown in Figure 4. To accommodate the majority of recommended pesticide rates, the unit was designed to meter wettable powders at rates from 0.6 to 28 l/ha.

A gear box with a 6:1 increase was driven by the chain drive from the counter shaft of the ground wheel drive. The gearbox output shaft was coupled directly to the input shaft of the reversible Zero-Max variable speed drive. This provided sufficient input speed for reaching the maximum desired output speed of 6.67 rps. The input necessary to obtain this speed was 26.67 rps. Directional roller clutches were positioned on the separate metering unit drive shafts in opposite operational directions. This directional placement allowed either the wettable powder metering unit or liquid metering unit to be operational at one time, but not both at the same time. A removable handle was supplied to fit over the shaft leading to the peristaltic pump. This crank allowed metering units to be operated by hand for priming, cleaning, and calibration purposes.

The component of the metering unit which regulated the flow of wettable powder into the system was patterned after the volumetric auger-type metering system used in Nelson's work (6). The horizontal discharge outlet of the wettable powder metering device was fitted into a hole in the top of the mixing chamber.

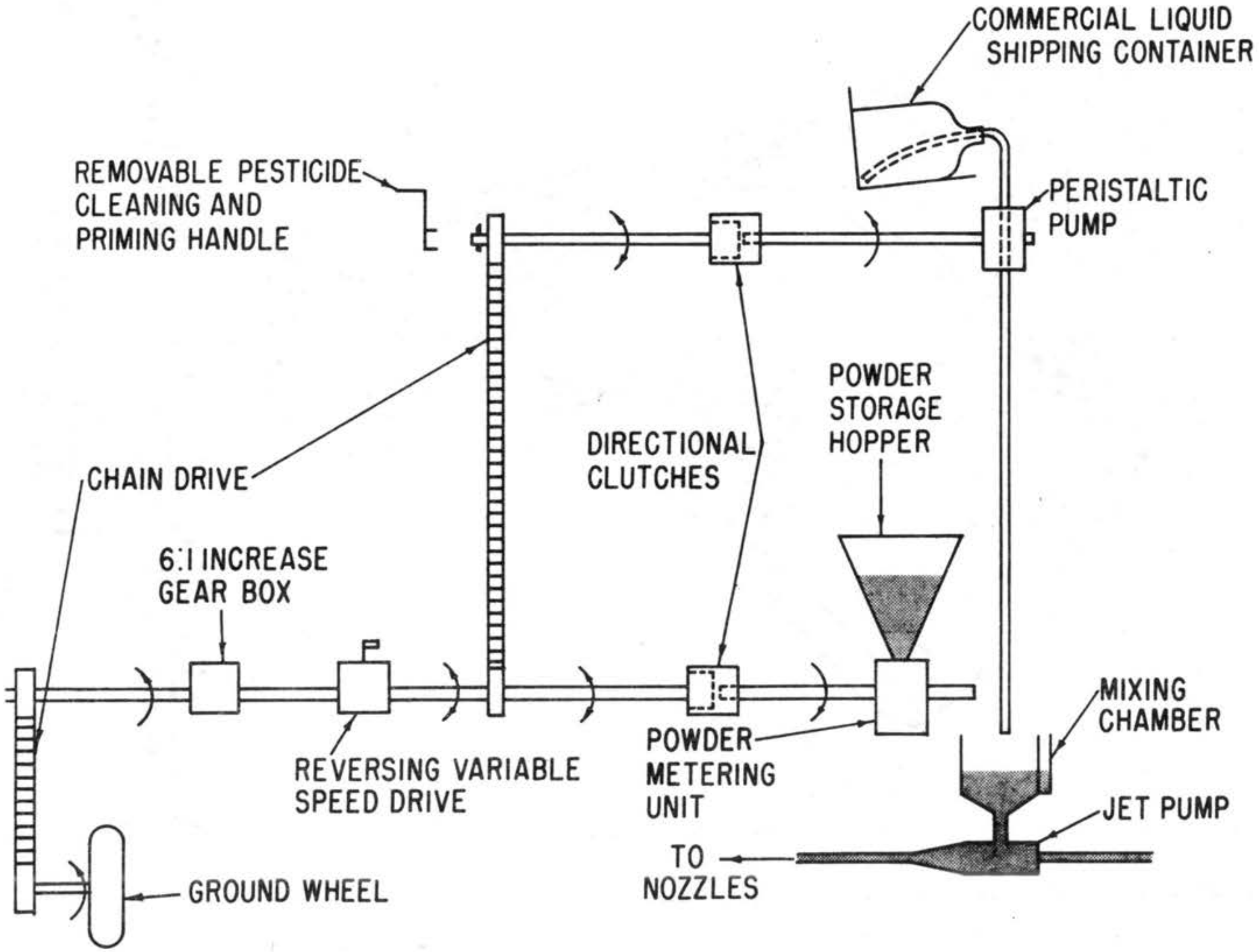

Figure 3. Schematic Diagram of Pesticide Metering System

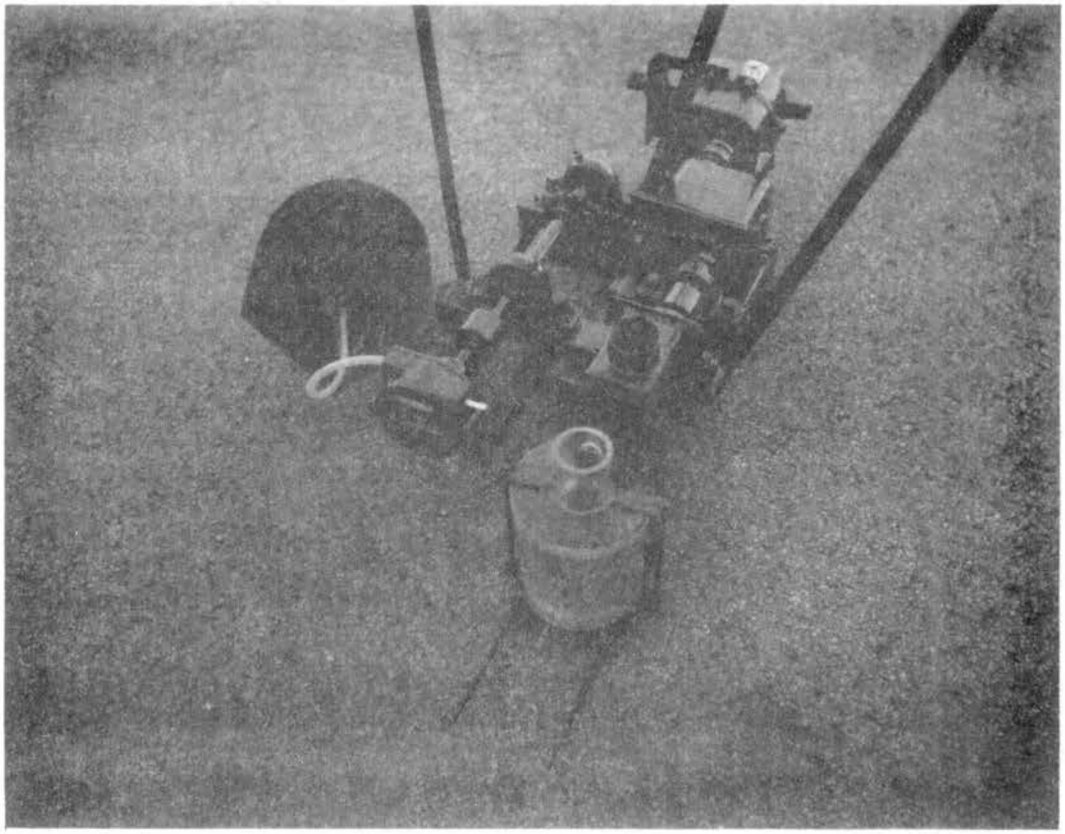

Figure 4. Pesticide Metering System

Rotating fingers within the wettable powder metering housing were used to reduce the effect of powder depth in the storage hopper on the bulk density of the metered wettable powder. For emptying and cleaning the powder storage hopper, the metering unit was constructed with a hinged wrap-around bottom.

To store the wettable powder prior to entrance into the metering unit, a storage hopper was constructed of galvanized sheet metal and suspended directly over the metering unit with coil springs. This method of suspension was used to reduce tractor vibrations which would compact the powder in the hopper. As shown in Figures 1 and 5, the upper portion of the hopper was cylindrical and the lower portion conical and provided a maximum storage volume of 0.24 m^3. The two sections were separated by a horizontal rod grid that could support four 2.27 kg bags of powder at one time without blocking the flow of wettable powder to the lower section. The entire inner surface of the hopper was coated with an air dried Teflon finish to reduce the friction between the wettable powder particles and hopper walls. A clear plastic lid was clamped to the top of the hopper and sealed with weather stripping. Holes were drilled in the lid to facilitate the placing of eight separate cords and alligator clamps to be attached to the bottom of as many as four wettable powder pesticide sacks. Hooks were provided on the outside of the storage hopper to provide a means of attaching the cords while suspending the sacks in an inverted position within the hopper.

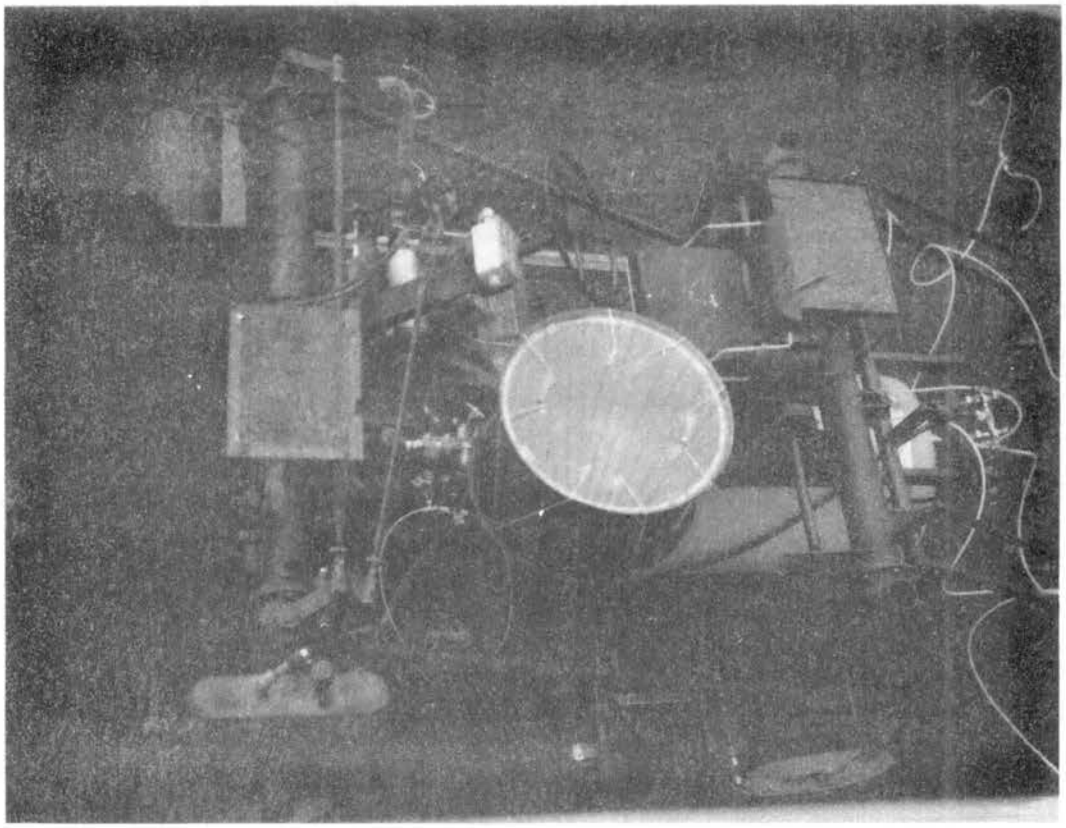

Figure 5. Overhead View of Powder Storage Hopper

The remaining portion of the metering system included a liquid pesticide metering device. The liquid pesticides were metered directly out of the 3.78 l liquid shipping container with the aid of an EP-500 Hardman peristaltic pump. In this pump, the peristaltic pumping action was produced by the rotating of an eccentric roller which squeezed a resilient flexible tube against the inside finished surface as shown in Figure 6. Rate changes were made possible by altering the speed of rotation. Different sizes of tubing were available to provide various ranges of metering rates. The tubing on the suction side of the pump was passed through a rubber stopper, capable of sealing a 25.4 to 38.1 mm opening to a liquid pesticide container. The rubber stopper held the tubing in place within the pesticide container. The pesticide container was supported at a 45° angle to allow a smaller collecting volume for the last portion of liquid in the pesticide container. The tubing was directed from the peristaltic pump to an opening above the annular nozzle ring of the mixing chamber.

Wetting and Mixing System

To furnish the mixing capability in this induction system, a 12.7 mm type 264 eductor manufactured by Schutte and Koerting Company was installed. This jet pump was a bronze casting with an overall length of 92.074 mm. The diameter of the venturi throat was 5.97 mm and the diameter of the motive nozzle exit was 3.02 mm.

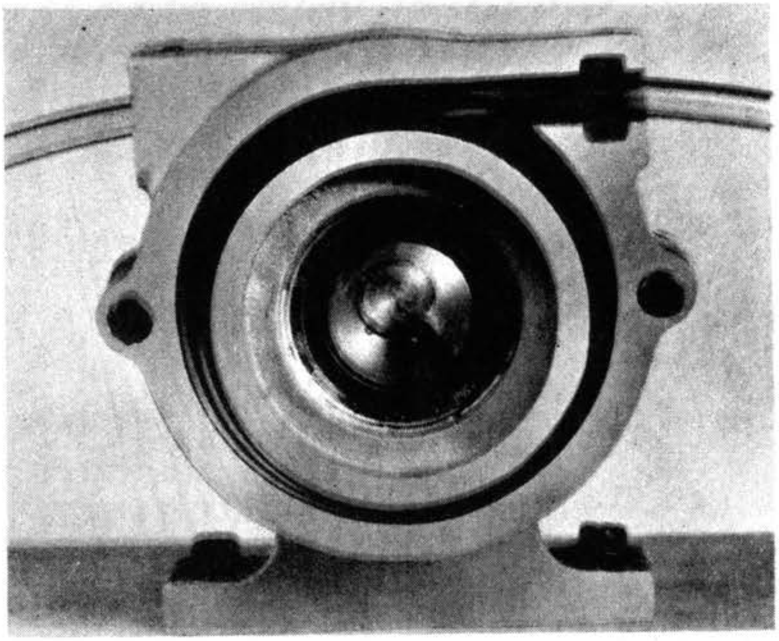

Figure 6. Interior View of Hardman
Peristaltic Pump

Jet pump operating characteristics of suction rate, discharge rate, and motive pressure are critical to the induction system performance. The relationships of both the suction rate and discharge rate to the motive pressure, as presented by Nelson (6), work ideally in initial jet pump analysis. Since the flow through a set of nozzles, Q, is directly proportional to the square root of the nozzle pressure P, the ratio $Q\sqrt{P}$ is constant for a given set of nozzles. This information enables one to plot the motive pressure versus the discharge rate and the motive pressure versus the jet pump suction rate. From these curves the performance of the jet pump over a prescribed range of motive pressures for a particular set of nozzles can be examined.

A mixing chamber, as schematically illustrated in Figure 7, was designed to provide the necessary liquid seal over the suction inlet of the jet pump to prevent air entrainment. The diluent that had been tapped off of the main supply line was directed into the mixing chamber where the wetting of the wettable powder or diluting of the liquid concentrate occurred. This chamber was constructed of 127 mm inside diameter, 6.35 mm wall thickness transparent plastic tubing. It was 127 mm deep with a tapered bottom. The chamber was mounted on two parallel rods extending from a bracket mounted on the wettable powder metering device (Figure 4). During calibration procedures the mixing chamber was moved to or from the powder metering unit on these rods.

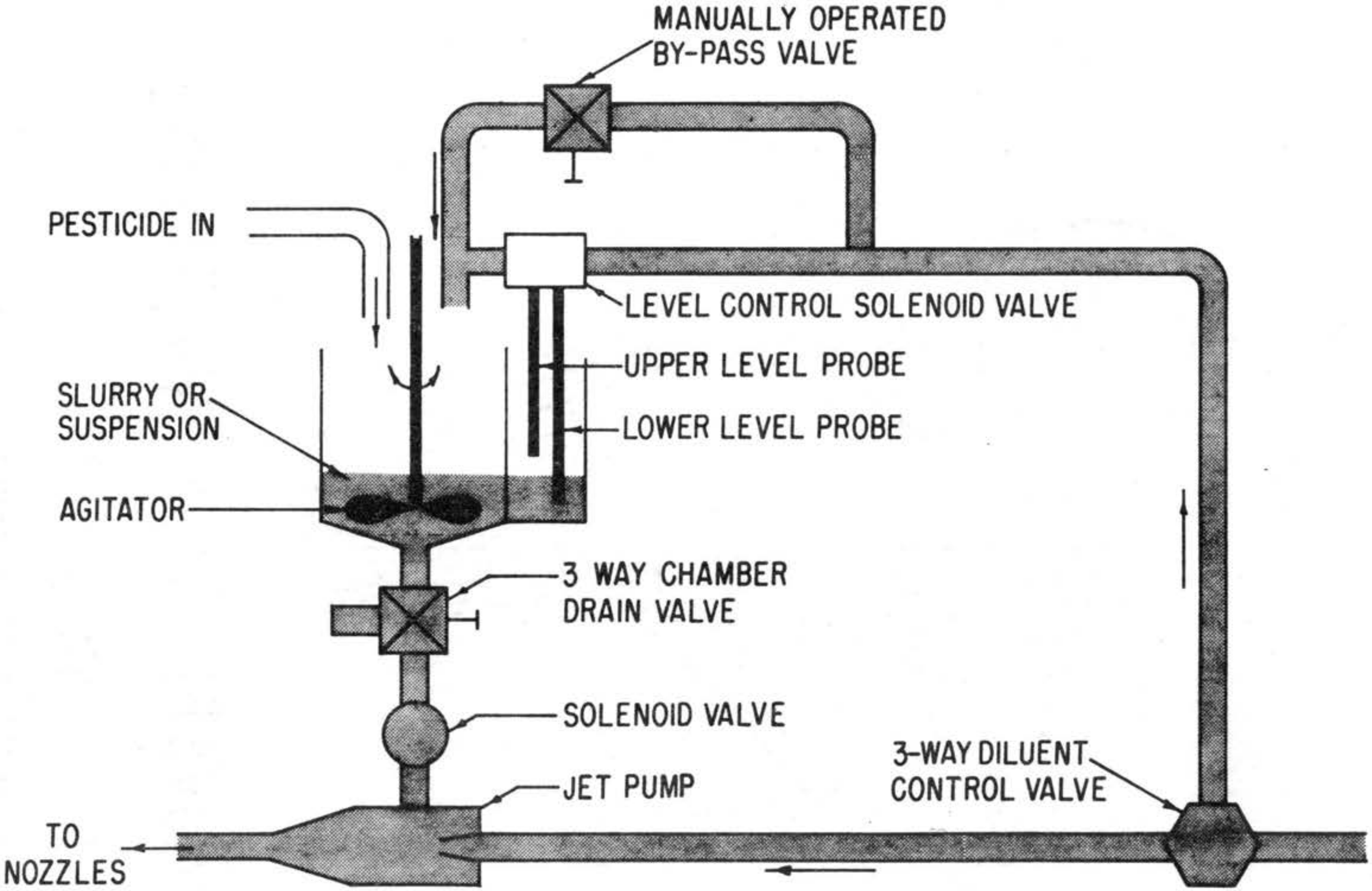

Figure 7. Schematic Diagram of Pesticide Mixing System

A removable 8-mesh screen trap was constructed to rest below the normal liquid surface in the mixing chamber. This prevented any large pieces of foreign matter from entering the spray system and possibly blocking the jet pump. The mixing chamber was also equipped with a 6-blade propeller-type agitator. This agitator was used to break the surface tension of the liquid in the mixing chamber and to keep the pesticide uniformly dispersed while in the mixing chamber. The agitator shaft had approximately a 15° angular oscillation when driven by the oscillating motor mounted to the top of the chamber.

To further assist the agitator in more complete wetting of the wettable powder, the diluent added to the mixing chamber passed through an annular nozzle ring as illustrated in Figure 8. This ring was part of the removable lid to the mixing chamber and contained 12 holes directed downward with alternating holes drilled at 0°, 6°, and 12° from the vertical.

Uninterrupted diluent flow into the mixing chamber to provide constant agitation of the liquid surface was deemed desirable. To accomplish this continuous flow and to help decrease the cyclic rate of the solenoid valve, a manually adjustable by-pass flow route around the controlling solenoid valve was provided.

A manually operated three-way valve was placed between the mixing chamber and solenoid valve. This enabled the contents of the mixing chamber to be drained without the concentrate passing through the supply line.

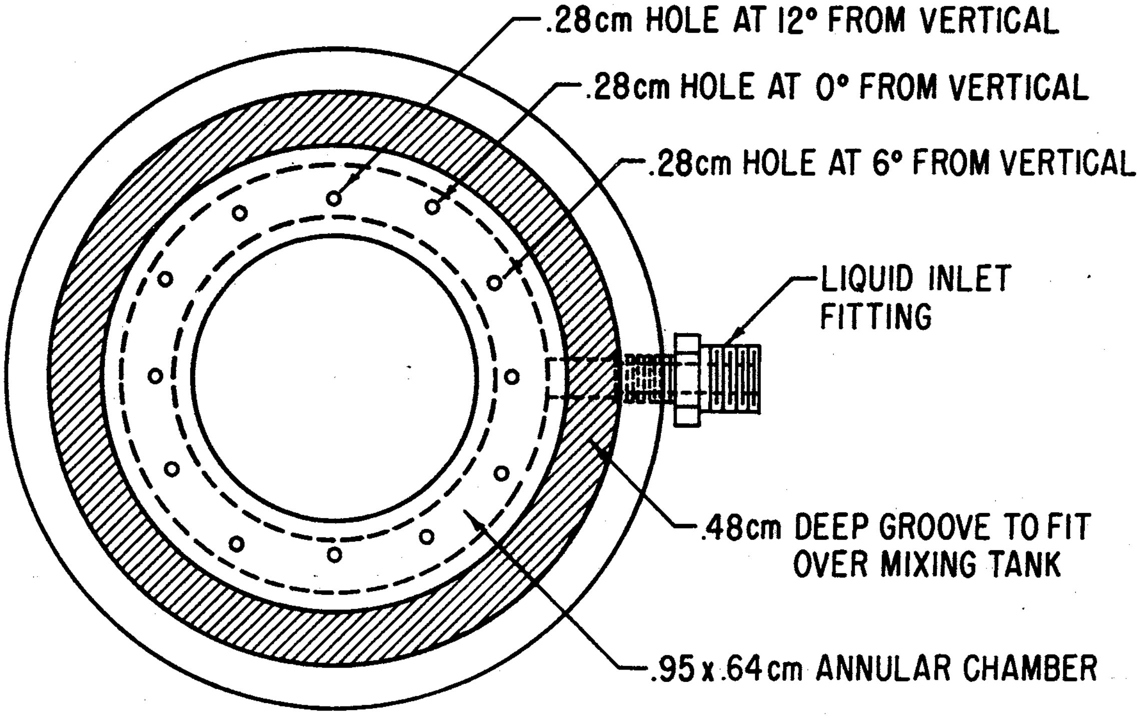

Figure 8. Bottom View of Annular Nozzle Ring

Liquid Level Control Unit

In the final design, the flow of diluent through the nozzle ring was controlled using a solenoid valve. The solenoid valve was controlled by two variable position probes which sensed the liquid level in the small stilling well of the mixing chamber. The schematic diagram of this controlling unit is shown in Figure 9.

The controlling system consisted of two interrelated circuits, the switching circuit and the sensing circuit. The primary source of power for the switching circuit came from the 6 V tractor battery in series with a 6 V dry cell battery. This circuit was initially controlled by switch A, a SPST switch, and contained an auxilliary circuit with visible lights to indicate the operational status of the solenoid valve. Relay A (4PDT), which diverted the flow of current within the switching circuit, was activated by coils, C, within the sensing circuit.

This sensing circuit consisted of separate circuits for both the upper and lower probe with a common ground between the two circuits and switch B, a 4PST switch. A 1.5 V dry cell battery was used as the power source for both probe circuits. The diluent inside the stilling basin acted as the switch. A NPN transistor was used in the low probe circuit to provide directional current sensing. This opposite current flow for the two circuits was used to eliminate feedback in the system which would have resulted in the transmission of false signals. The transistors were incorporated with the probe circuits to amplify the signal sufficiently to activate the linking coil relays.

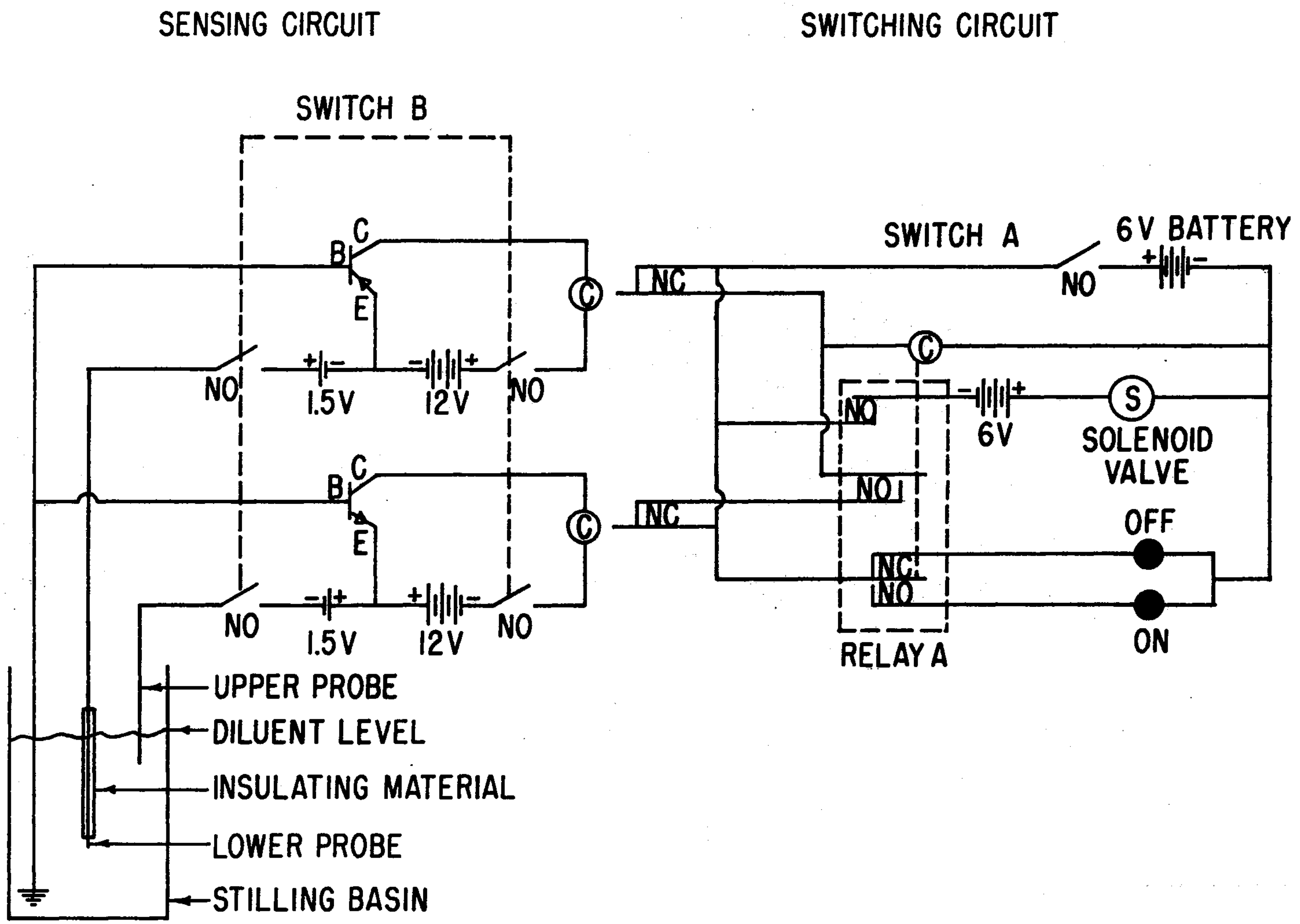

Figure 9. Schematic Diagram of Liquid Level Control

Distribution System

The spray concentration leaving the jet pump entered a modified manifold-boom distribution system with four feeder lines as shown in Figure 10. Each of these four feeder lines of equal length and of 7.09 mm inside diameter Nylon tubing led to the center nozzle of a three-nozzle boom. These three nozzles were connected by Nylon tubing of 5.91 mm inside diameter. The standard velocity for 0.15 mm particles was calculated to be approximately 15.24 cm/s using Orr's method (7). Using the lowest expected flow through the system, the tubing sizes were determined and selected.

The tractor's hydraulic lift was used to operate a 6.1 m length of pipe to which the nozzle bodies were clamped. A 0.207 KN/m^2 pressure gauge was installed in the center nozzle of the boom so that the nozzle pressure could be monitored by the operator.

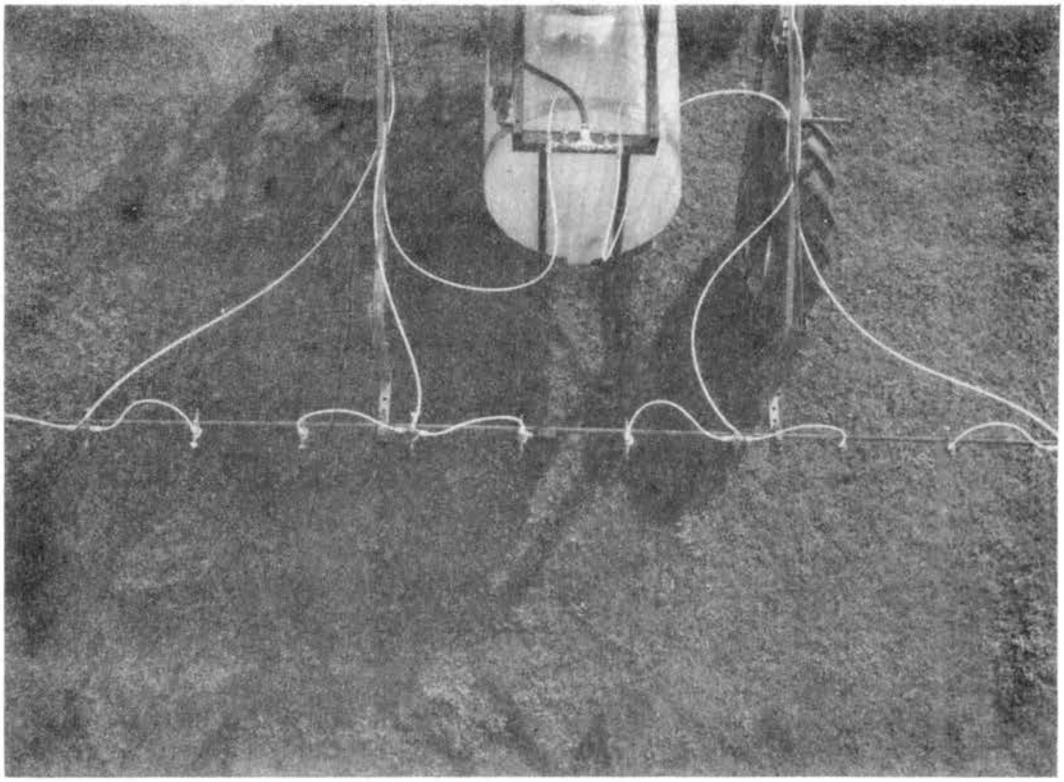

Figure 10. Overhead View of Sprayer Distribution System

CHAPTER V

OPERATION AND OPERATING PROCEDURES

Prior to operation, the sprayer system required adjustment to provide the desired pressure at the nozzles. The diluent which was being pumped and diverted back to the storage tank was redirected to both the mixing chamber and the pressure side of the jet pump. As the control valve to the mixing chamber was opened, a switch opening the solenoid valve between the mixing chamber and the suction side of the jet pump was activated. The desired pressure at the nozzles was obtained by adjusting the pressure regulator attached to the control valve assembly.

In order to automatically control the liquid level within the mixing chamber, the liquid level control unit was activated and operated as follows:

1. The two switches on the control box were turned on to activate both basic internal circuits and open the solenoid valve leading to the mixing chamber.
2. The upper and lower level probes in the stilling basin were positioned an equal distance above and below the desired level of operation within the mixing chamber.
3. The manually operated by-pass valve was opened to allow some flow into the mixing chamber at all times.

4. When the liquid level reached the upper probe, the circuit within the sensing circuit was completed and caused the solenoid valve to be closed. This allowed only diluent passing through the by-pass circuit to enter the mixing chamber.
5. The solenoid valve remained closed until the liquid level dropped below the lower probe position. This opened the sensing circuit and caused the solenoid valve to be reopened.
6. The manually controlled by-pass valve was adjusted so that sufficient diluent entered the mixing chamber to wet the entering powder. Care was taken to insure that the rate of diluent entering the mixing chamber through the by-pass valve did not exceed the rate at which the mixture was leaving the chamber.
7. The total flow through both the solenoid valve and by-pass valve was adjusted by the manually operated globe valve located at the control valve assembly allowing further control of the diluent flow into the chamber.

Depending on the formulation of the pesticide the following procedures were followed to add the active chemicals to the system in the correct quantities.

1. If the pesticide was formulated as a liquid concentrate the following steps were followed:
    A. The liquid pesticide shipping container was secured in the holding bracket.

B. The rubber stopper with the feeder tubing replaced the pesticide container lid.

C. For calibration purposes, the tubing end suspended above the mixing chamber was inserted into a graduated cylinder.

D. With the reversible variable speed drive engaged in the proper direction to activate the peristaltic pump and adjusted to a trial setting, the sprayer was driven through a predetermined distance, i.e., 30 m. The metered pesticide was collected and measured.

E. For the given boom width and rate of application, the amount of pesticide collected was compared to the desired amount to be applied by the sprayer for 30 m of travel. The desired amount of pesticide was determined from the nomograph in Figure 11.

F. If the compared figures differed, the variable speed drive was adjusted to a new trial setting. Following a calibration trial, the collected pesticide was returned to the storage chamber.

G. This procedure was continued until the collected amount was equal to the desired amount.

H. When the system was calibrated, the tubing from the peristaltic pump was placed in the opening of the mixing chamber above the annular nozzle ring.

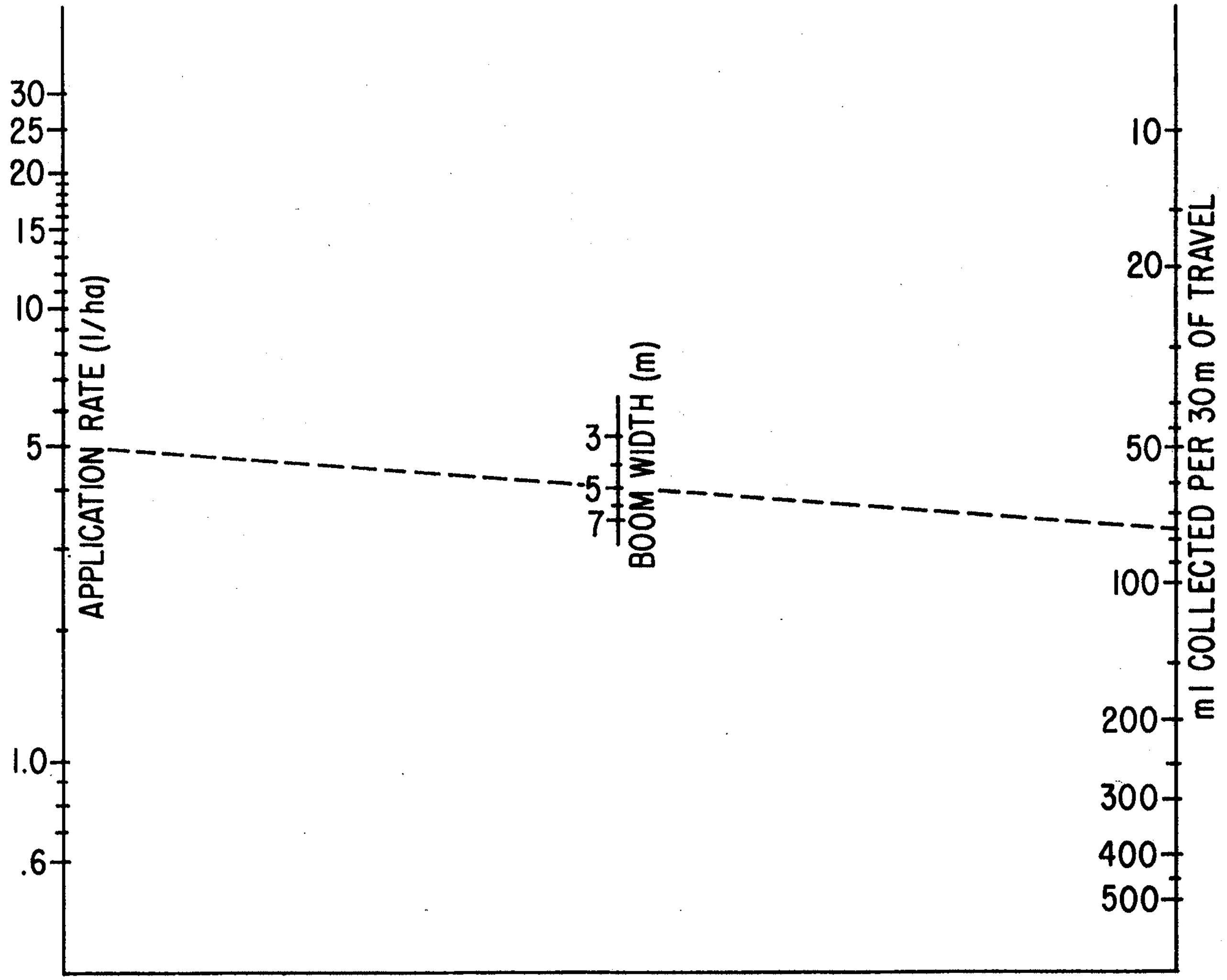

Figure 11. Liquid Pesticide Calibration Nomograph

2. If the pesticide was formulated as a wettable powder the following procedure was followed:

   A. The wettable powder metering unit was retracted from the annular nozzle ring. A pre-weighed collection container was placed to catch the wettable powder as it was metered.

   B. The seal on each bag of wettable powder was broken and two alligator clamps were fastened to opposite sides of the bottom of each bag. The bags were aligned on the grid within the storage hopper.

   C. The plastic hopper lid was replaced and the cord ends to which the alligator clamps were attached were hooked to the outside of the hopper. This action dumped and suspended the bags in an inverted position.

   D. With the variable speed drive engaged in the proper direction to activate the wettable powder metering unit and adjusted to a trial setting, the sprayer was driven through a predetermined distance, i.e., 30 m. The amount of wettable powder metered was collected and weighed.

   E. The weight of collected wettable powder was compared to the weight of wettable powder that was to be metered as determined from the nomograph in Figure 12.

   F. If the compared weights were different, appropriate adjustment of the variable speed drive was made and another trial was run. The collected powder was returned to the storage container following calibration.

   G. The procedure was continued until the collected amount was equal to the desired amount.

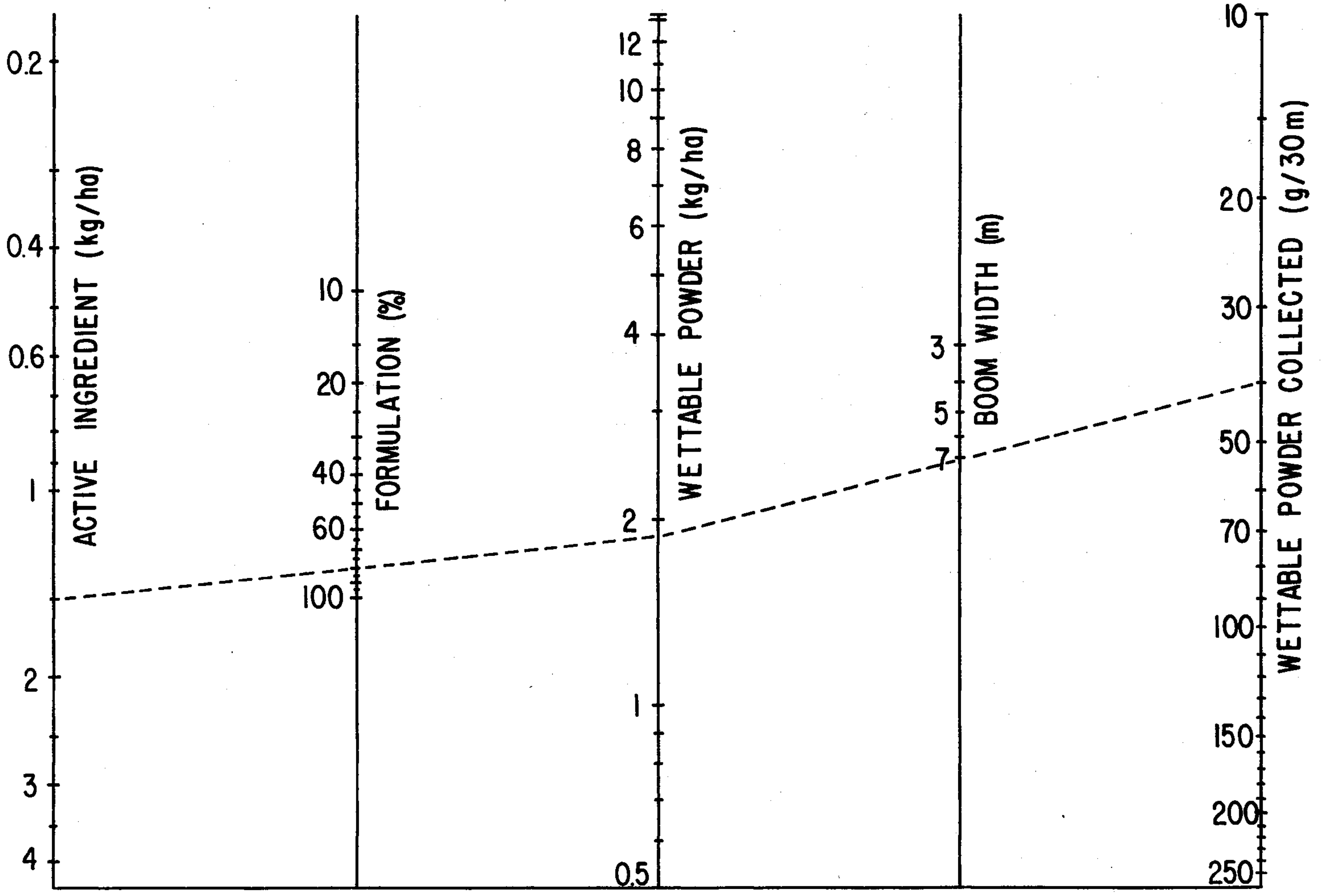

Figure 12. Wettable Powder Calibration Nomograph

H. When the calibration was completed, the wettable powder metering device outlet was repositioned in the mixing chamber in the opening above the annular nozzle ring.

To aid in reducing the time required for the mixing chamber to reach the initial desired pesticide concentration, the mixing chamber was primed before starting the spraying operation in the following manner:

1. Using the control valve assembly, diluent was collected in the mixing chamber until the desired operating level was reached. The agitator in the mixing chamber remained in operation.
2. The nomographs in Figures 13 and 14 were prepared and used to determine the required number of revolutions of the liquid and powder metering units drive shafts to initially prime the mixing chamber to the desired pesticide level.
3. A handle was attached to the slotted shaft and turned the desired number of turns in the appropriate direction to prime the system.

When the sprayer was put into operation the liquid level control valve switches were on, the mixing chamber was primed, and the diluent control valve assembly directed flow to the jet pump and nozzles. When pesticide was to be applied, the control valve assembly directed a portion of the overall flow to the mixing chamber and the suction side of the jet pump.

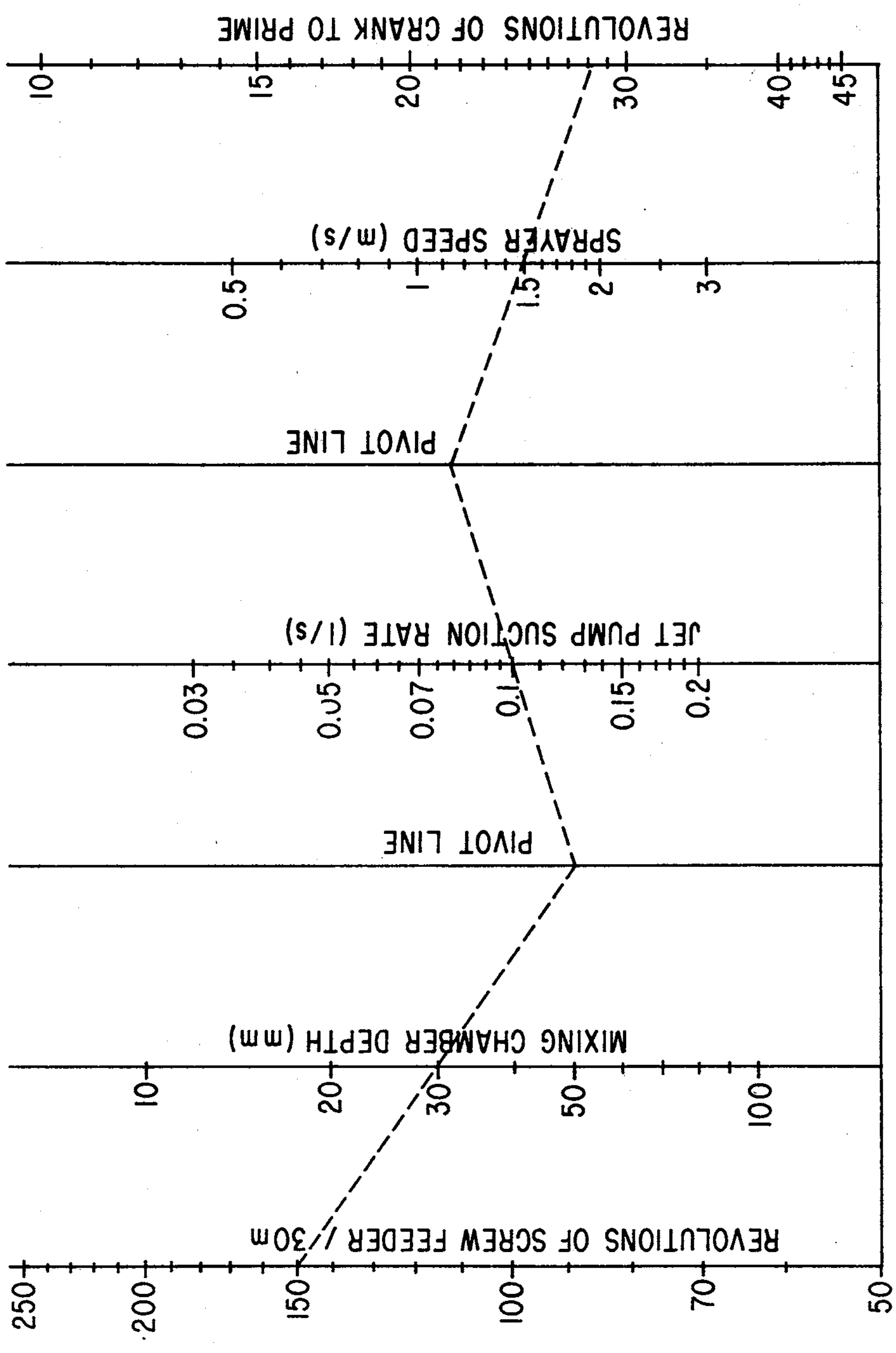

Figure 13. Nomograph for Priming of Mixing Chamber with Wettable Powder

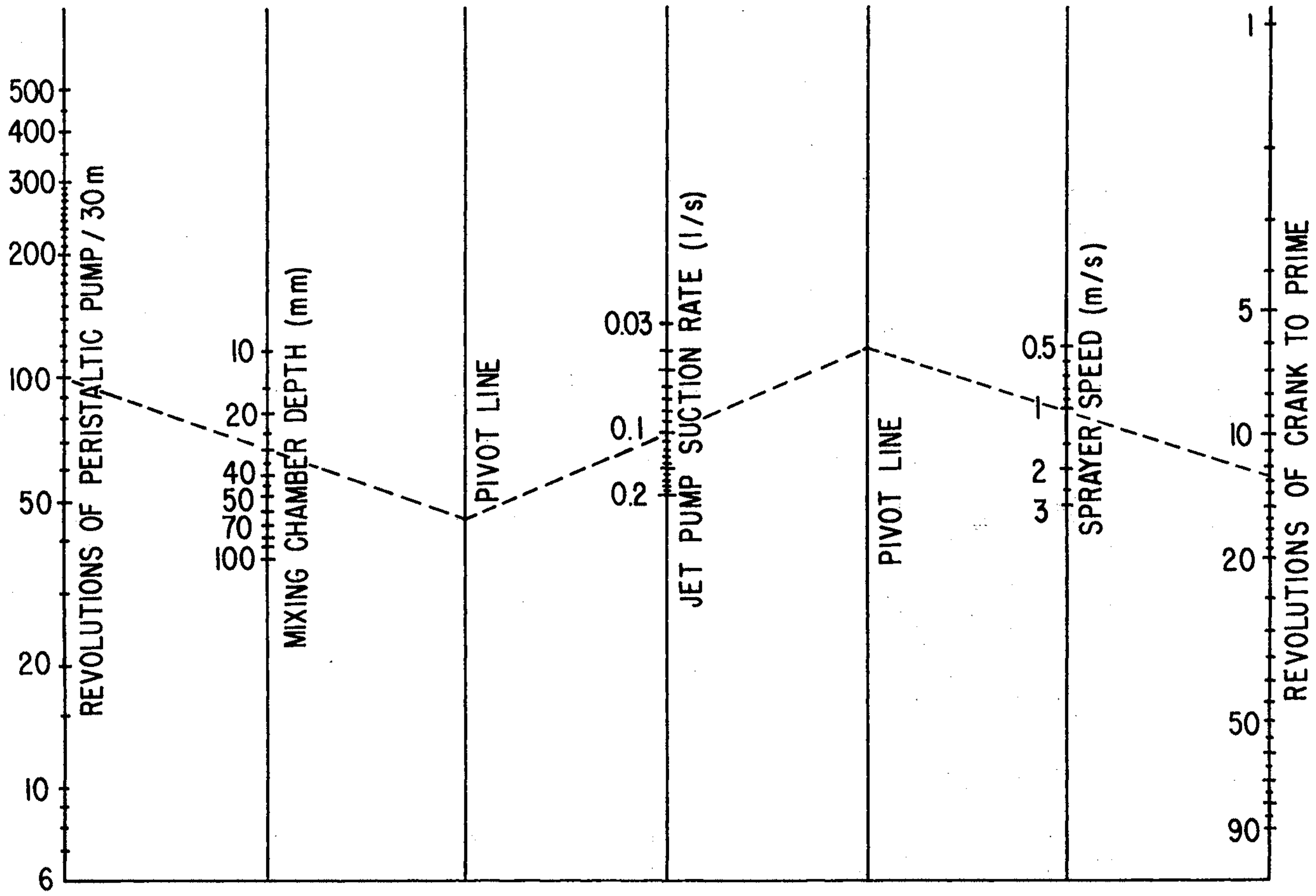

Figure 14. Nomograph for Priming of Mixing Chamber with Liquid Pesticides

During normal field spraying operations, delays are often encountered. The procedure outlined below was followed to simulate delays of less than five minutes, i.e., turning at the end of a row:

1. The variable speed drive was placed in neutral to stop the flow of pesticide during travel.
2. The diluent control valves to the mixing chamber and to the pressure side of the jet pump were closed. All diluent was diverted back to the storage tank. This kept the reservoir of diluted pesticide in the mixing chamber at the same level as when the operation ceased.
3. The agitator within the mixing chamber was allowed to continue the agitation process to keep the pesticide uniformly distributed throughout the mixing chamber.

The procedure followed for delays of longer duration than five minutes was similar to the procedure for the short delay. The only procedural change was that when the control valve to the mixing chamber was closed, the control valve to the pressure side of the jet pump remained open for at least 30 s. When the flow of diluted pesticide from the mixing chamber halted, the distribution lines were cleared of the spray mixture.

Once the spraying operation was completed, the sprayer was cleaned by observing the procedures for a long delay with the following additions:

1. The mixing chamber was drained by opening the manually operated 3-way valve between the mixing chamber and the solenoid valve.

2. The control valve to the mixing chamber was opened with care being taken not to trip the switch which would have opened the solenoid valve on the suction side of the jet pump. Opening the control valve diverted clean diluent into the mixing chamber to aid in flushing the pesticide from the chamber.
3. When the liquid pesticide metering system was used, the suction tubing was retracted from the commercial shipping container and submerged in the diluent in the mixing chamber. The peristaltic pump was operated using the hand crank, flushing the liquid pesticide from the tubing.
4. When the wettable powder metering unit was used, the empty pesticide bags were removed from the upper storage element. These bags were then used to catch the unused wettable powder as it fell from the hinged door at the bottom of the wettable powder metering device. The small amount of powder contained within the auger chamber of the wettable powder metering device was removed by turning the metering device by hand until clean.

CHAPTER VI

ANALYTICAL PREDICTION OF SYSTEM BEHAVIOR

In an attempt to better describe the functioning of the basic sprayer and to determine ranges for certain sprayer parameters, the system was analyzed mathematically. Although the pesticide formulation was metered into the system directly proportional to the ground travel of the sprayer, the changes of pesticide concentration of the applied spray did not occur instantaneously. This time delay was due to the buffering action of the mixing chamber. Lag time was defined as the elapsed time from the instant of speed change until the infinitesimal pesticide application rate had changed 95 per cent of the amount required to equilibrate for the new sprayer speed. An illustration of the defined lag time is given in Figure 15.

Development of Governing Equation

An equation was derived to indicate the amount of pesticide present within the mixing chamber as a function of time. This equation also represented the amount of pesticide applied by the sprayer. The derived equation was based on the following assumptions:

1. The mixing of the pesticide and diluent within the mixing chamber occurred the instant the pesticide entered the mixing chamber.

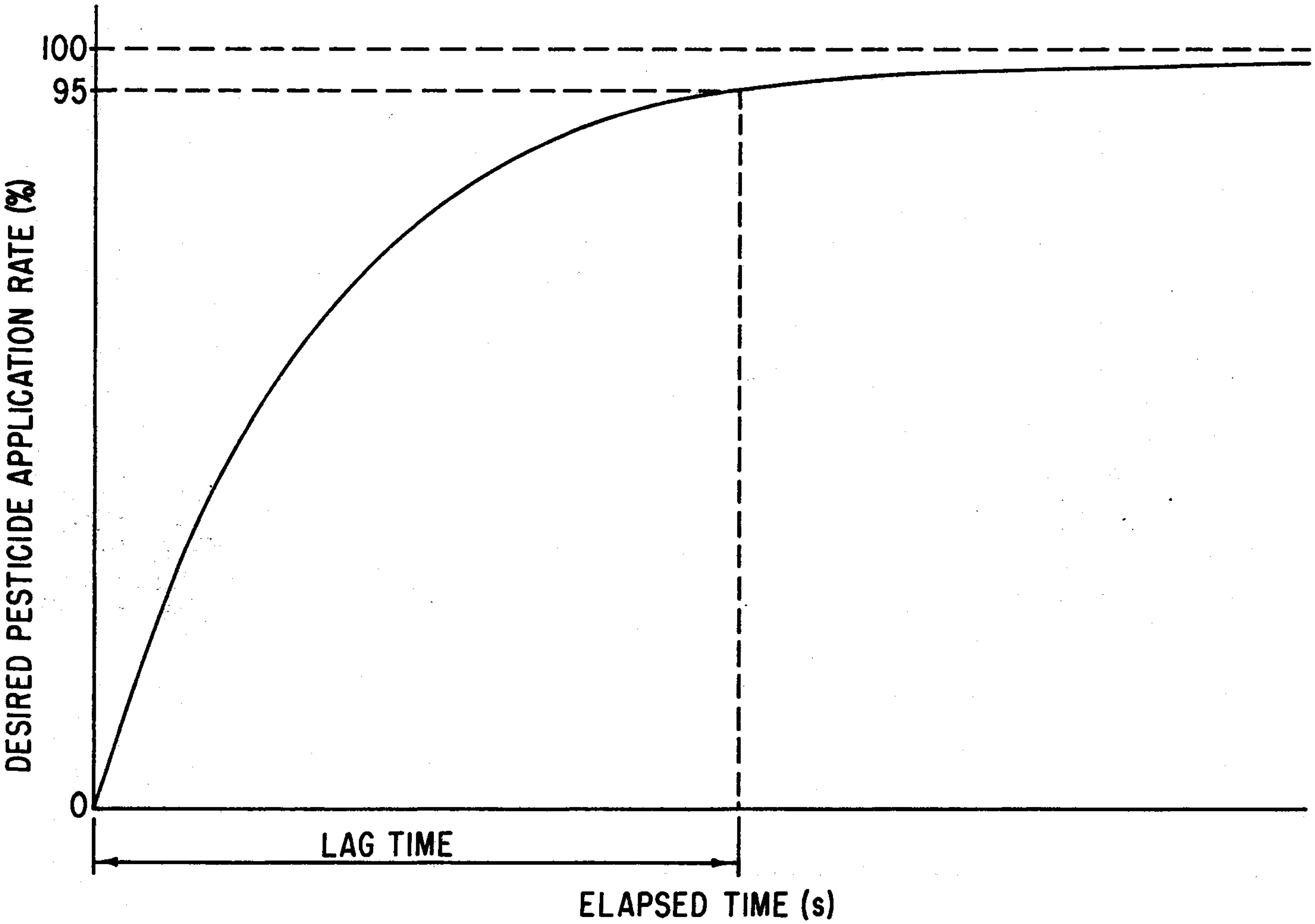

Figure 15. Graphical Determination of Sprayer Lag Time

2. No concentration gradients existed within the mixing chamber.

3. Instantaneous sprayer speed changes were encountered.

The change in the amount of pesticide within the mixing chamber was equal to the difference between the amount of pesticide entering and leaving during the specified time interval. The amount of pesticide leaving the chamber was represented by the term $\frac{MQ}{V}$. The following first order differential equation resulted:

$$\frac{dQ}{dT} = P - \frac{MQ}{V}$$

where:

Q = amount of pesticide in mixing chamber, g

Q_o = initial amount of pesticide in mixing chamber, g

T = time, s

P = rate of pesticide entering chamber, g/s

M = jet pump suction rate, l/s

V = volume of diluent in chamber, l

$\frac{dQ}{dT}$ = change of pesticide amount with respect to time, g/s

Integrating between the limits of amounts of pesticide Q_o and Q, and with the limits of time 0 to T, the equation became

$$Q = \frac{PV}{M} + Q_o e^{\frac{-MT}{V}} - \frac{PV}{M} e^{\frac{-MT}{V}}$$

As seen from this equation, after an infinite amount of time has passed the amount of pesticide in the mixing chamber reaches an equilibrium value of $\frac{PV}{M}$. At this point the amount of pesticide metered into the mixing chamber was equal to the amount entering the jet pump.

Analysis of Theoretical Parameters

To quantify the lag time and to study the effects of the various parameters on this time interval, the system equation was mathematically modeled on a TR-20 analog computer. The output was recorded with the aid of model 1130 Variplotter. Plots of different combinations of design variables for the sprayer operation were obtained. By examining the effects of the variables the ranges of lag time and performance were determined. The range of variables considered for the pesticide metering rate were 0.15 to 25.0 g/s and 0.03 to 0.19 l/s for the jet pump suction rate. The sprayer speed was varied from 0 to 3.13 m/s and the mixing chamber volume from 0.5 to 4.1.

A function switch was used to study lag times and to simulate the change of sprayer ground travel in the field. The computer output for changes to three different speeds was recorded as shown in Figure 16. The conditions governing the results shown in Figure 16 were a pesticide metering rate of 25 g/s at 3.13 m/s, jet pump suction rate of 0.190 l/s, and a mixing volume of one l. With the amount of pesticide in the mixing chamber at equilibrium for a sprayer speed of 3.13 m/s, the sprayer speeds were instantaneously reduced to 0.447 m/s, 1.79 m/s, and 2.68 m/s at point 1 in Figure 16. The decreasing functions represented the recovery and stabilization of the amount of pesticide in the mixing chamber. Points 2, 3, and 4 mark the points where the sprayer speed was increased from the slower speed back to the original speed of 3.13 m/a. The speed changes were followed by the exponential functions that approached equilibrium. Comparison of the curves in Figure 16 indicates that the time required to reach 95 per cent of the equilibrium level after a speed change was the same,

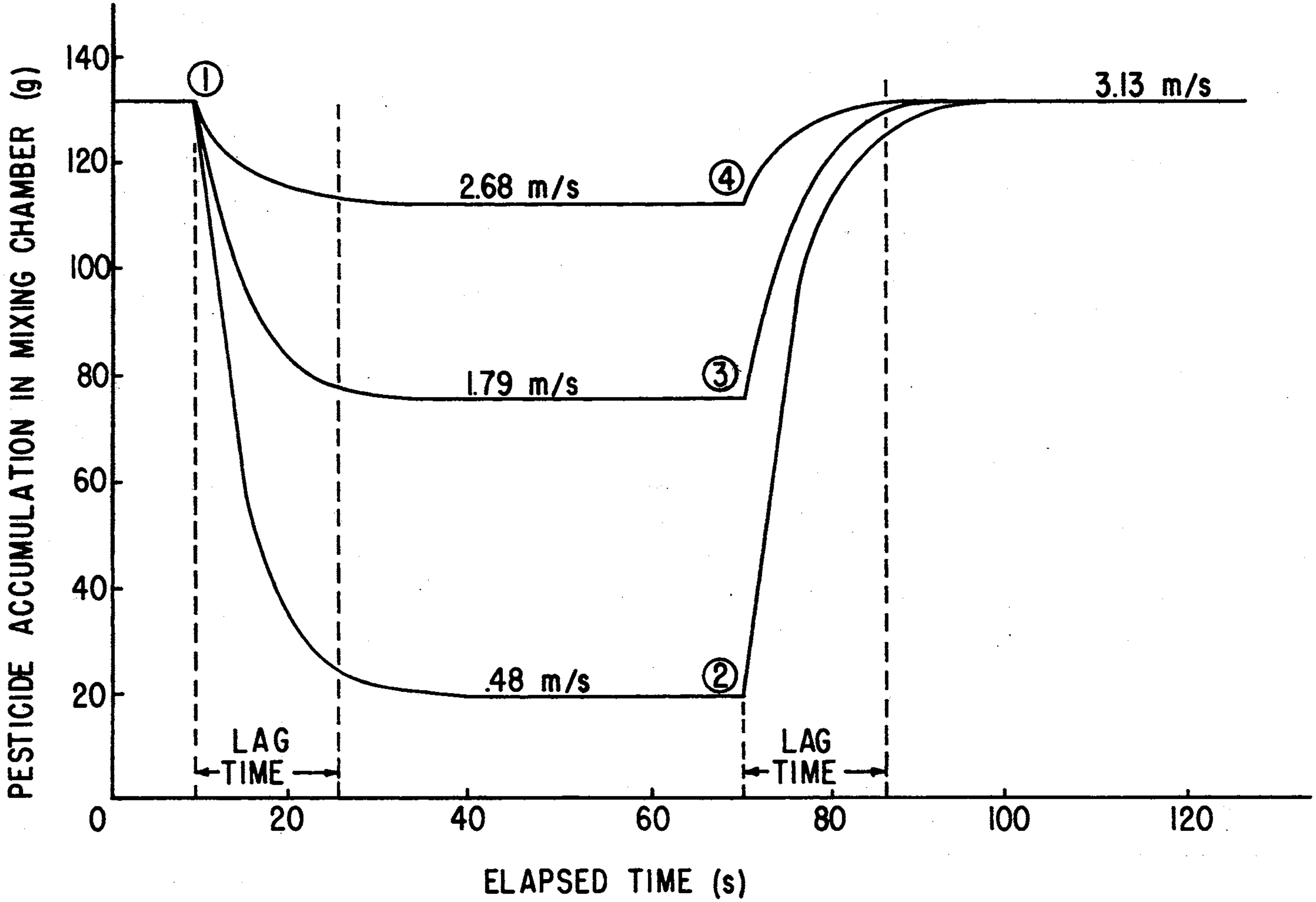

Figure 16. Computer Predicted Pesticide Accumulation in Mixing Chamber for Varying Sprayer Speeds

regardless of the change in pesticide level caused by the speed change. In this particular instance the lag time for all three curves was approximately 16 s.

As compiled from several analog computer traces, Figure 17 illustrates the effect of the diluent volume in the mixing chamber on the lag time. With a constant pesticide rate of 25 g/s and a jet pump suction rate of 0.19 l/s, the mixing chamber volumes of one, two, three, and four l were used with no initial pesticide concentration. The dotted lines on each curve indicate the time where the pesticide accumulation in the mixing chamber reached a level of 95 per cent of the equilibrium level. The lag times L1, L2, L3, and L4 increased directly as the diluent volume in the mixing chamber.

Figure 18 represents the computer output and illustrates that the lag time in the sprayer system was also dependent upon the jet pump suction rate. The two curves represent pesticide accumulations for the high and low jet pump suction rates of 0.19 and 0.031 l/s with a mixing chamber volume of 0.5 l and a pesticide metering rate of 20 g/s. With the dotted lines marking the 95 per cent equilibrium points, the lag time L1 and L2 varied inversely as the rate at which the suspension or solution was drawn from the mixing chamber. This relationship was expected since the jet pump suction rate was located in the numerator of the negative exponent in the time term.

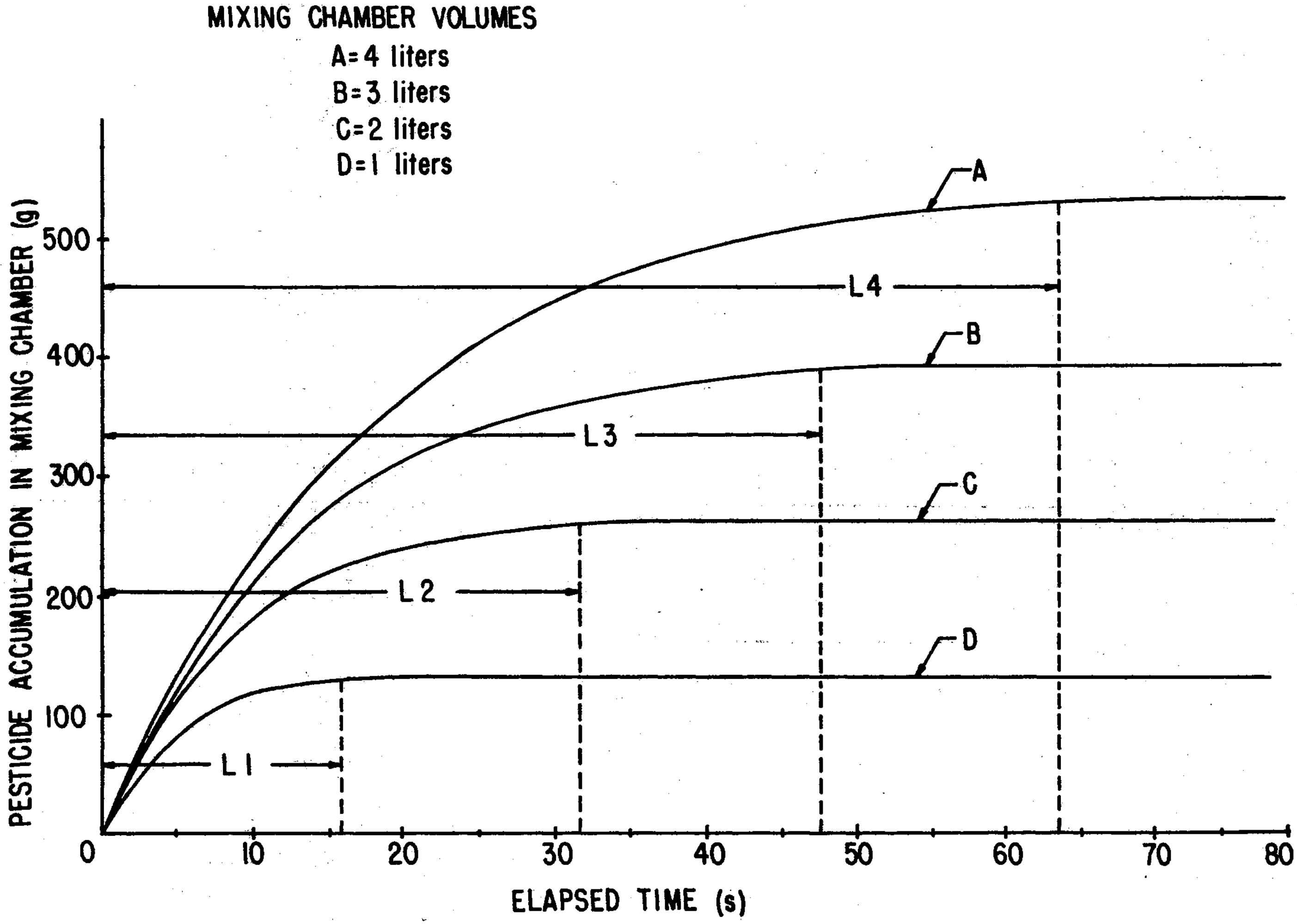

Figure 17. Pesticide Accumulation Versus Time for Different Mixing Chamber Volumes

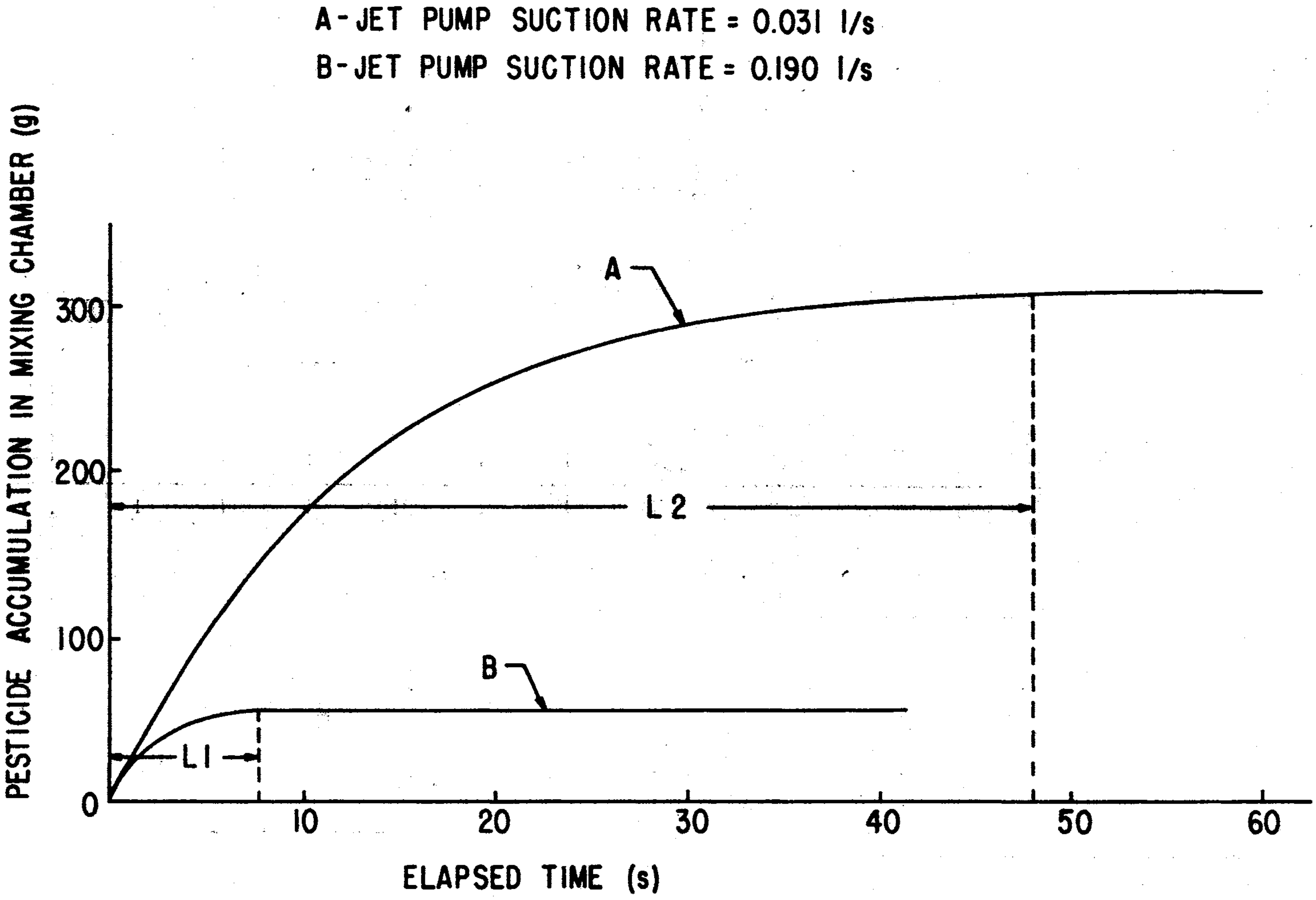

Figure 18. Pesticide Accumulation in Mixing Chamber Versus Time for Limiting Jet Pump Suction Rates

From the computer output, Figures 19 and 20 illustrate that the lag time for the upper and lower extremes of the pesticide metering rates were the same. The two curves represent the concentration levels for the high and low pesticide metering rates of 25 and 0.3 g/s with a constant mixing chamber volume of one 1 and a jet pump suction rate of 0.19 1/s. The 95 per cent equilibrium dotted line occurred at the same time for the two curves although the pesticide accumulation levels differed.

For comparison between the induction system and the conventional sprayer performance during a sprayer speed variation, Figure 21 is presented. This comparison was based on the per cent of the two systems from the actual desired rate. The induction system curve represents the analog output with 0.5 1 of mixing chamber volume and 0.19 1/s jet pump suction rate. With each system applying the desired amount of pesticide and traveling at 2.24 m/s the speed was instantaneously reduced to 0.45 m/s. Since the same amount of pesticide was being sprayed from the conventional system, the actual application rate was increased five fold due to the reduction in ground travel. This higher rate continued until the speed was instantaneously increased to the original speed of 2.24 m/s at which the sprayer had been calibrated. The rate applied by the induction system at the instant of the speed decrease was also five fold. However, this application rate decreased from this level until the speed was increased to 2.24 m/s. Then the rate of pesticide application was less than that desired. Again the system exponentially increased until the desired steady rate was obtained.

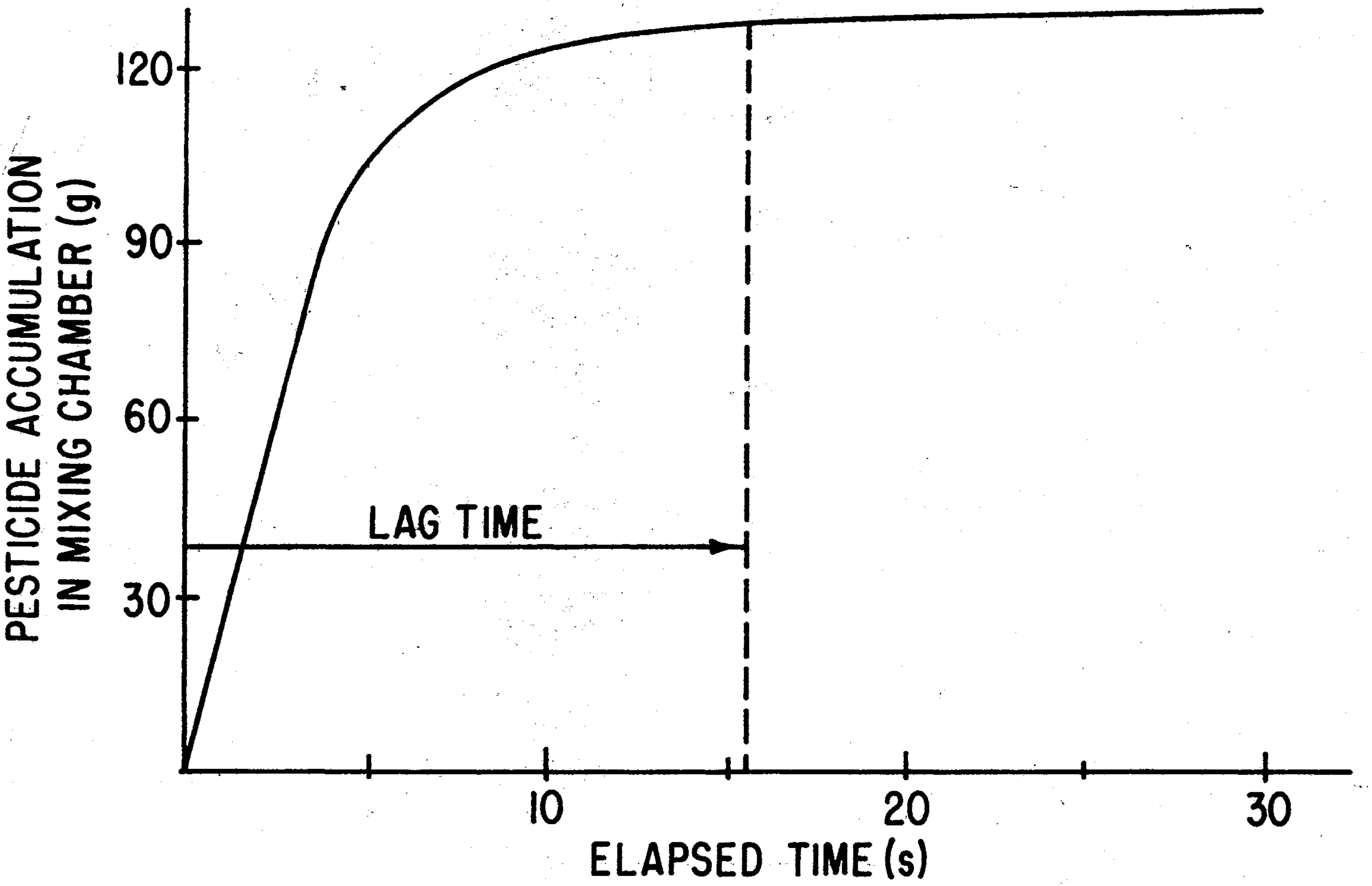

Figure 19. Pesticide Accumulation in Mixing Chamber Versus Time for Pesticide Metering Rate of 25 g/s

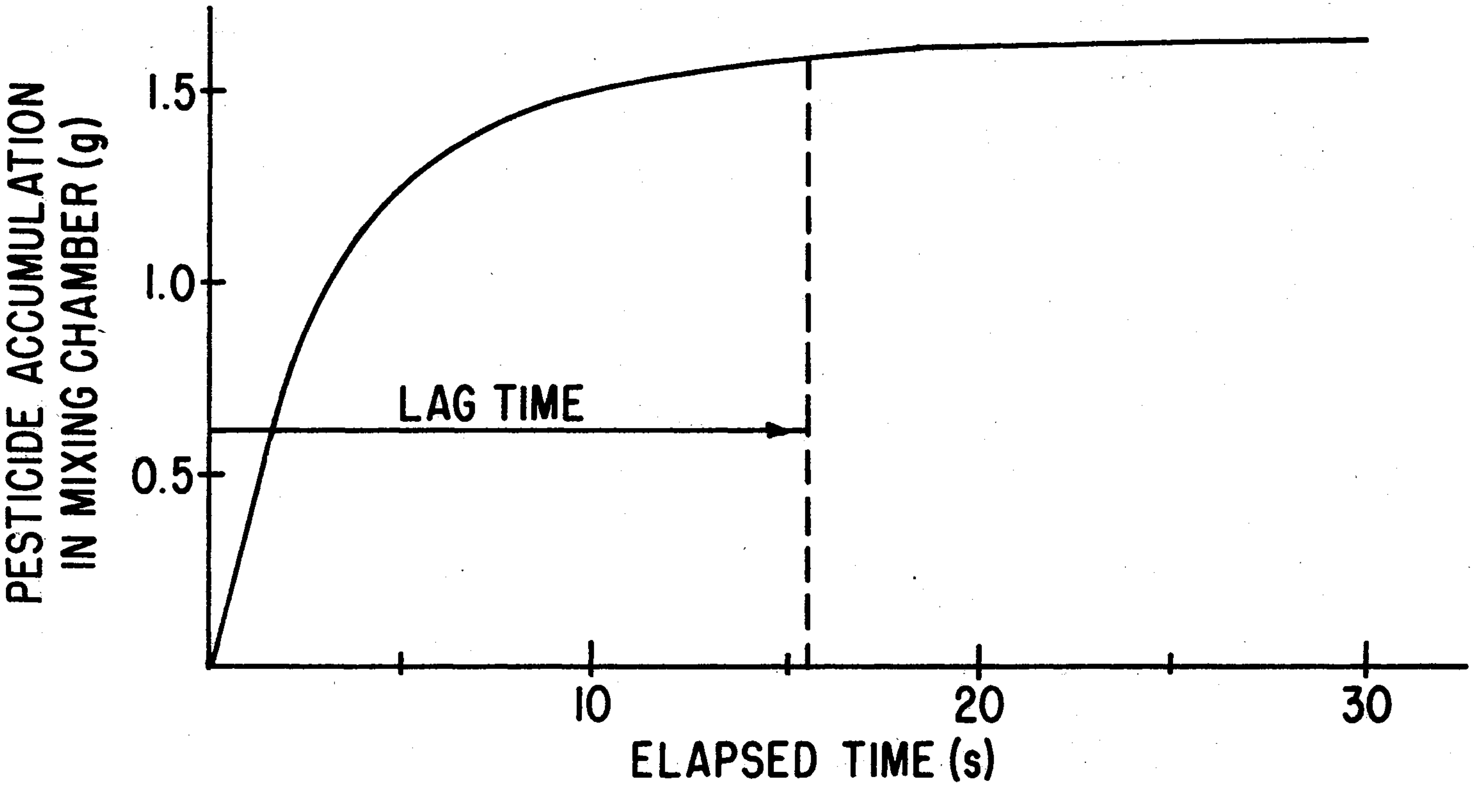

Figure 20. Pesticide Accumulation in Mixing Chamber Versus Time for Pesticide Metering Rate of 0.3 g/s

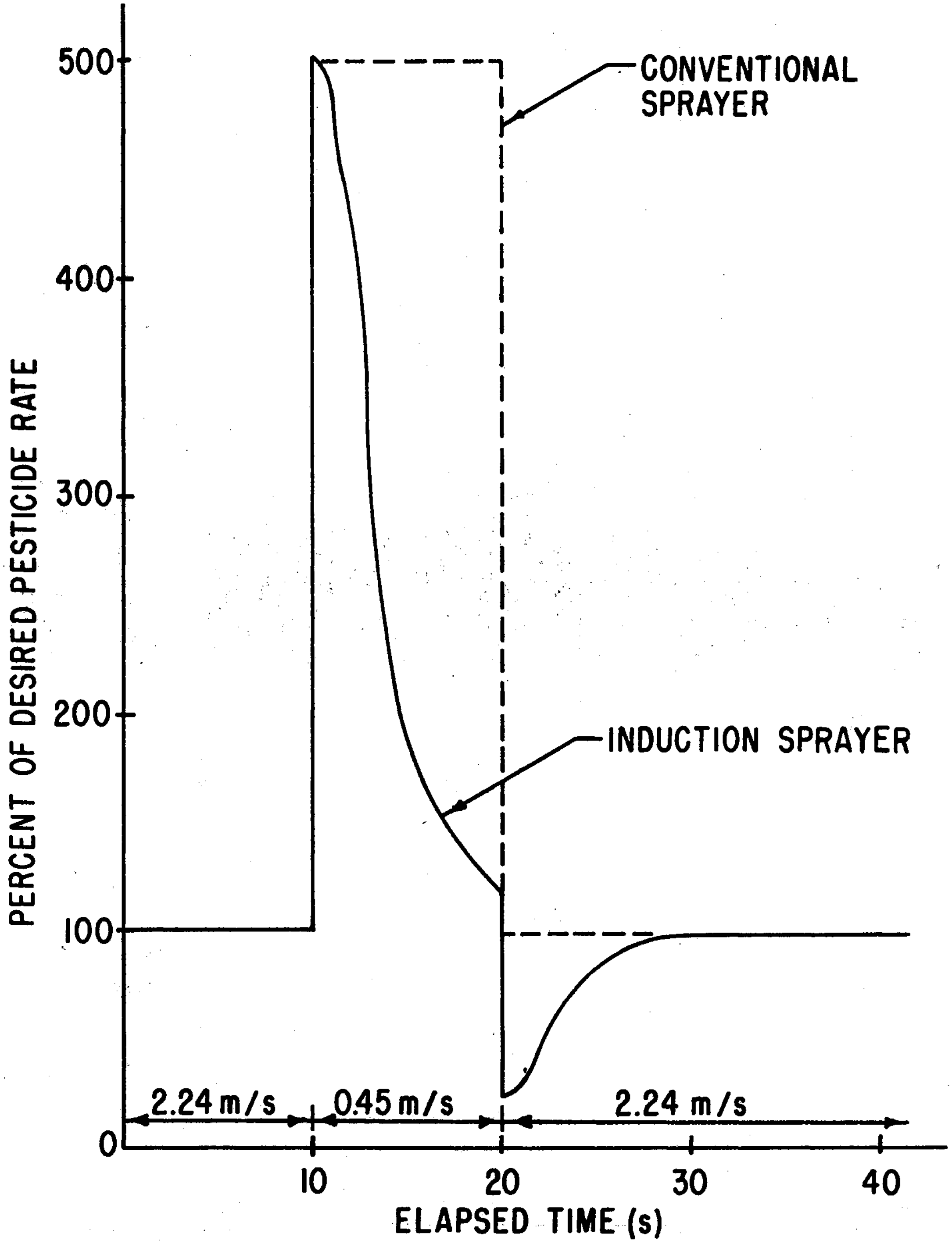

Figure 21. Comparison of Pesticide Accumulation Response for Conventional and Induction Sprayer

To compare the relative error in application rate involved with the theoretical operation of the conventional and induction sprayers, the areas between the individual accumulation curves and the desired accumulation were compared. With the systems operating as indicated in Figure 21, the area under the conventional curve was approximately twice that under the induction curve. Although the ratio of the areas vary with different operating conditions the conventional system will always have the greater error. The shorter the time interval between speed changes, the less difference in the errors between the conventional and induction systems.

CHAPTER VII

TESTING PROCEDURES

The testing program used in this study was designed to evaluate the performance of the sprayer components, and to compare the mathematically predicted and actual measured pesticide concentration during operation. Due to the problem of disposing of the toxic sprays, only limited tests were conducted by spraying actual pesticide through the system. Wettable powder was used in the system since the powder in suspension was readily visible and could be easily determined by evaporating the water from the samples.

Metering Units

Water was used to test the precision of the liquid metering device. The calibration procedures, as described in Chapter V, were followed in adjusting the liquid concentrate metering system to apply a relatively high rate of 28 l of liquid concentrate /ha. With the metering unit operational, the sprayer traveled over approximately 183 m. The metering unit was then subjected to a 30.5 m calibration trial during which the liquid was collected, measured, and recorded. The entire procedure was repeated five times in 15°C temperature. The metering device performance was also monitored while traversing level pavement and extremely rough terrain in separate tests.

When the water was pumped through the tubing of the peristaltic pump at the slowest pump speed, individual drops of approximately 0.75 ml were formed. At the minimum designed application rate of 0.5 l of concentrate /ha for liquid pesticides, this drop size would result in a drop entering the mixing chamber at about one second intervals, resulting in a cyclic concentration within the mixing chamber. Since the minimum allowable mixing volume was 0.1 l and the maximum concentration cycle period was one second, this cyclic change was considered negligible. No attempts were made to actually measure the change in pesticide concentration with respect to time in the mixing chamber or at the nozzles.

All testing done with the wettable powder metering unit was done using Atrazine 80W provided by Geigy Agricultural Chemicals. The method of transferring the wettable powder from the shipping container to the storage hopper was observed. The operation of the overall metering system was also observed over rough, as well as smooth, terrain. Particular attention was focused on the performance of the screw metering device and the flow of wettable powder within the storage hopper.

Measurements were made to test the precision with which the wettable powder was being metered. The unit was filled with fresh wettable powder, calibrated to meter 9.3 kg of wettable powder /ha and driven 183 m. Following this, the metered wettable powder over a 30.5 m trial run was collected, weighed, and recorded. This procedure was repeated four times.

Mixing Chamber and Liquid Level Control Performance

Performance of the mixing chamber was judged strictly from observation. Since the mixing chamber was necessary in the induction system primarily to accommodate the use of wettable powders, wettable powder was used to examine performance within the chamber. Wettable powder was metered into the mixing chamber at the maximum application rate of 13.5 kg/ha. With the liquid level probes set for 6 mm differential at a liquid depth of 76 mm, the position of the mechanical agitator was varied from the upper level probe to 50 mm below the lower probe. The effect of the jets of liquid from the annular nozzle ring on the dispersion of the wettable powder at the diluent surface was also studied. This study was accomplished by turning the mechanical agitator off and varying the pressure on the jets from 256 to 512 kN/m^2.

Wettable powder that had been exposed to moist air was metered into the chamber at a rate of 8.4 kg/ha with the spraying system in operation for five minutes to test the acceptance of the system to moist wettable powder. The system was then examined for possible deposits of the wettable powder in the mixing chamber, jet pumps, and nozzle tips.

To evaluate the liquid level control performance, the sprayer was operated with an electrode differential of from 3 to 76 mm for periods of twenty minutes each. With the sprayer operating over varying degrees of rough terrain, the effect of the position of the stilling basin relative to the mixing chamber was studied. The fluctuations of the diluent level in the stilling basin due to the sprayer travel were observed with the basin parallel and perpendicular to the line of sprayer travel. Also the distribution system was examined for variations caused by the action of the liquid level control system.

Concentration Tests

In an attempt to compare the performance of the actual field model with the analog computer simulation, two tests were conducted. The tests were designed to establish the concentration of pesticide in the spray coming out of the nozzles as a function of time.

In preparation for the concentration tests, the hopper was filled with wettable powder and calibrated to meter the wettable powder at 7.75 and 7.2 kg/ha, respectively, in two tests. The high clearance chassis was blocked up with the drive wheels off the ground to allow for stationary testing. All nozzles were placed over a 760 l stock tank to catch the spray from the nozzles. One center nozzle from the distribution system was separated from the others for sampling purposes. The diluent flow through the jet pump was adjusted and the volume of liquid in the mixing chamber was stabilized between 0.85 and 0.8 l. Twenty-two wide mouth containers were cleaned, oven-dried, and weighed before being arranged in line with a conveying arrangement. With the tractor operating at 2.1 and 2.05 m/s respectively, and the array of containers prepared to be manually drawn under the sampling nozzle, the metering of the pesticide into the system was initiated. From the instant the pesticide was started into the system, the containers were moved at 2 s intervals, catching the spray for 2 s in each container. At the conclusion of the collection of the spray in the containers, the contents of each container were vigorously stirred and a 20 ml sample withdrawn, placed in a petri dish, dried at 60°C, and weighed. The initial dried container weight was subtracted from the final dried container weight and the weight of powder caught in the 2 s interval was recorded. These two tests were conducted in 10°C weather.

Cleaning Tests

In addition to observing the cleaning procedures for both pesticide metering units, limited tests were conducted on the cleaning effectiveness. Since one of the stated advantages of the induction system sprayer was the recoverability of the unused pesticide, measurements of losses of unused powder were made. The storage hopper was filled with 2.2 kg of wettable powder. The entire metering system was operated 15 s to fill the system with powder. Following the cleaning procedures listed in Chapter V, the wettable powder was removed from the unit, weighed, and recorded. The difference between the initial and final weights represented the amount of wettable powder not recovered. This test was repeated by adding 9 kg of wettable powder to the system to establish the dependency of the amount of wettable powder not recovered on the amount to be cleaned from the sprayer.

It was deemed necessary to evaluate the amount of time a suspension of powder would remain in a closed chamber before a detrimental degree of settling would occur. To measure this, 100 g of wettable powder was suspended in 0.85 l of water, while the mechanical agitator continued to operate. Six tests of five minute duration were conducted to simulate a stop of short duration in the field as described in Chapter V.

The hypothesis that the nozzles and strainers could be cleaned by passing clean diluent through the nozzles immediately after use was tested. Wettable powder was run through the sprayer at 8.75 kg/ha and a sprayer speed of three m/s for 210 s. After 210 s of operation the diluent flow was stopped and the distribution lines were allowed to drain for one minute. Six of the 12 nozzle tips and strainers that had previously been cleaned, dried, and erighed were then removed, dried, and weighed. The difference in these two weights reflected the amount of powder residue if the unit had not been cleaned immediately. These six nozzles were replaced by six others to allow operation of the system with evenly divided flow between nozzles. With the nozzles back in place, diluent was again passed through the system one minute to flush the remaining wettable powder particles from the distribution system. At this time the remaining six previously weighed nozzle tips and strainers were removed, dried, and weighed. The difference in weight of these six nozzle assemblies represented the dried powder remaining in the system after flushing. The two cleaning procedures were then compared.

CHAPTER VIII

PRESENTATION AND ANALYSIS OF DATA

The durability of the components was not established since the unit was operated only during the testing program. However, no mechanical failures of the components occurred during this period.

The effectiveness of the chassis as a high-clearance unit was somewhat reduced since the induction system was positioned low to permit observation from beside the unit. The row clearance was reduced from 1.7 to 0.84 m.

Metering Units

The chain drive that supplied power to the metering devices functioned adequately. The directional clutches also satisfactorily functioned in driving the appropriate metering device.

By metering the liquid pesticide directly from the shipping container the pesticide was mixed for application as required through the spraying operation. A simple means for cleaning the toxic substance from the system was provided by isolating the toxic substance from a major portion of the sprayer. The contact of the operator with the concentrated pesticide was reduced.

The data for testing the precision and consistency of the liquid metering device at the high pesticide rate is given in Table I. The difference in amount of liquid collected did not exceed 0.002 l which represented a variation in application rate of 0.43 l/ha for a 0.14 per cent variation.

TABLE I

CALIBRATION DATA ON LIQUID METERING SYSTEM

Observation Number	Milliliters Collected Per 30.5 Meters	Liters Per Hectare
1	486.0	27.92
2	488.0	28.03
3	486.5	27.95
4	487.0	27.98
5	486.0	27.92
Mean	486.7	27.96

The calibration nomograph for the liquid pesticide provided an accurate and simple means of determining the amount of pesticide required to be collected for a particular application rate. Since the factor determining the application rate was the volume of the chemical, the only measuring device necessary for calibration was a graduated cylinder and tape for the measurement of distance.

While operating over level pavement, the peristaltic pump metered the water out of the 3.8 l shipping container until approximately

0.08 l remained in the container. Over extremely rough terrain, intermittent flow did not occur until all but 0.34 l of the water was metered. These values represent the worse expected conditions since more viscous emulsifiable concentrates would oscillate less freely under similar motion.

The wettable powders were not readily removed from the shipping container. It was difficult to fasten the clamps on the lower edge of the bags. By measurement, the movement of the sprayer over smooth terrain provided adequate jolting action to remove from 60 to 90 per cent of the wettable powder from the bags. The hopper lid provided an adequate seal to prevent the escape of the wettable powder into the air.

Preliminary calibration trials were conducted using an electric motor to drive the wettable powder metering device. During these trials it was discovered that after metering the wettable powder through the system twice, no difference in powder density was observed. After being recycled the third time, the wettable powder became less dense since the volumetric metering device consistently metered less powder by weight. This was believed to be caused by the agglomeration of the finely divided particles into small clusters.

The data obtained from testing the precision and consistency of the powder metering device is shown in Table II. The greatest differential in the amounts collected during each calibration procedure was 0.5 g. This represented a variation in actual application rate of 0.28 kg/ha. This rather large variation was attributed to the change in density of the metered powder since the wettable powder was recycled.

TABLE II

CALIBRATION DATA ON POWDER METERING SYSTEM

Run	Grams Collected Per 30.5 Meters	Kilograms Per Hectare
1	17.3	9.30
2	17.2	9.25
3	16.9	9.08
4	17.4	9.36
Mean	17.2	9.25

Bridging of the powders did not occur when the first batch of wettable powder was passed over the freshly treated smooth surface of the storage hopper. However, after the sides had been exposed to the wettable powder one time, problems were encountered with the wettable powder bridging. Travel of the sprayer over rough terrain aided the powder in overcoming the frictional resistance and reduced the frequency of bridging problems. To further reduce the bridging problems encountered with the wettable powders a rotating agitator driven by a gear reduction from the metering system drive unit could be used.

Mixing Chamber and Liquid Level
Control Performance

With the induction system being operated as described in the testing procedures, the operation of the mixing chamber was observed. It was noted that at the high wettable powder metering rate of 13.5 kg/ha no apparent accumulation of powder occurred on the water surface with the mechanical agitator operating on or 50 mm below the surface. The diluent delivered to the mixing chamber through the annular nozzle ring created enough surface disturbance to rapidly disperse the wettable powder into the mixing chamber liquid. With the surfactant level of the wettable powder used, the velocity with which the jets of liquid entered the liquid surface did not cause excessive foaming. However, as much as 13 mm of foam was observed above the liquid surface level.

After the somewhat compacted powder was metered into the system for five minutes, the mixing chamber was drained and no buildup of agglomerated powder was observed on the mixing chamber's screen trap. However, as expected, a thin coating of powder was observed on the nozzle strainers. This coating of powder was not large enough to restrict flow through the strainers.

The liquid level control system maintained a liquid level within the mixing chamber between two selected levels ranging from 3 to 76 mm.

It was observed that after approximately twenty cycles, a film formed over the insulating material of the lower electrode and the inside surface of stilling basin walls. This same type of malfunction occurred when both electrodes were in direct contact with the stilling basin walls. A continuous film between the two electrodes was formed. When the electrodes were properly adjusted, the malfunctions did not normally occur. However, the problems were encountered more frequently when the difference between the two electrodes was less than 13 mm. The foam that was produced at the surface of the mixing chamber did not enter the stilling well unless the liquid level dropped below the entrance to the stilling well. When this foam did become trapped in the stilling basin, it caused the film to form.

The vibration of the engine did not cause noticeable oscillations within the mixing chamber. Because the stilling well and mixing chamber were positioned in the line of travel, the level in the stilling well was affected directly by all sudden stops and starts. With the stilling well and mixing chamber placed perpendicular to the line of travel, the fluctuations in the stilling well, due to starting and stopping, were minimized. The major motion of the liquid did not fluctuate perpendicular to the line of travel unless a side slope was encountered. When the liquid level in the stilling well did oscillate, the cycling time was varied. However the short duration of the waves did not cause the operating level in the mixing chamber to vary more than 1.5 mm from that desired. Some of the fluctuations surged the water in the stilling well to the top of the chamber.

One undesirable characteristic of the system caused by the level control unit was the instantaneous change in total system pressure. This change was caused when the level control solenoid valve switched on and off. The magnitude of this abrupt pressure variation was dependent upon the diluent flow rate into the mixing chamber and the routing of this liquid. While being operated at a flow rate through the liquid level control valve of approximately 0.1 l/s, the system pressure was observed at the discharge of the jet pump. With all of the liquid forced to travel through the diluent supply solenoid valve, the pressure increase was approximately 34 kN/m^2 when the solenoid valve was closed. The closing of the solenoid valve also caused the motive fluid pressure to increase, thus causing a slight change in the jet pump suction rate. This maximum change was observed to vary the nozzle flow rate four ml/s. The control system was then adjusted such that the by-pass route was carrying nearly all of the 0.1 l/s necessary for equilibrium in the mixing chamber. Under these conditions the pressure increase was 17 kN/m^2 when the solenoid valve closed. It was noted that as the flow through the control system was reduced, the pressure variation decreased. The cyclic fluctuations in the pressures observed at the nozzles could be reduced by using a surge tank. This surge tank should be located in the pressure line between the pressure regulator and the solenoid valve controlling the flow of diluent into the mixing chamber.

Distribution System Performance

The distribution system arrangement distributed the spray solution to the spray nozzles. Pressure losses and resulting variations in nozzle application rates were measured at a system flow rate of 0.3 l/s, motive fluid pressure of 690 kN/m^2, and nozzle pressure of 89 kN/m^2. The pressure drop from the jet pump discharge to the center nozzle of the three nozzles was 13 kN/m^2. Due to the small diameter of tubing used between nozzles, there existed a pressure drop between the center nozzle and the outer nozzles of each group of three nozzles. Using

Delavan FS-10 nozzle tips discharging 25 ml/s per nozzle, the pressure drop from the center nozzle to the outer nozzles was observed to be 10 kN/m^2. This pressure differential accounted for the observed variation of 0.9 ml/s in the individual nozzle flow rate. Using smaller FS-7 nozzle tips at a measured rate of 10 ml/s, the measured pressure differential was 10 kN/m^2 and the change in flow was 0.1 ml/s.

No tests were conducted to determine the degree of dispersion of the suspension. As Nelson (6) reported, the degree of dispersion was dependent upon the formulation of the pesticide used.

Pesticide Concentration Tests

Following the procedures outlined in Chapter VII the actual field model performance was compared to the performance predicted by the mathematical equation. The amount of wettable powder collected in the actual test was plotted on Figures 22 and 23. The test represented by Figure 22 was run at 2.10 m/s with the wettable powder metered at 7.73 kg/ha into a mixing chamber volume of 0.85 l, and a jet pump suction rate of 0.063 l/s. Figure 23 represents the sprayer being run at 2.08 m/s with wettable powder being metered at 7.17 kg/ha into the mixing chamber volume of 0.85 l, and a jet pump suction rate of 0.063 l/s. The amount of wettable powder collected was plotted at the point of average time the collection of spray was made. The theoretical curve represents the analog simulation for the same operating conditions.

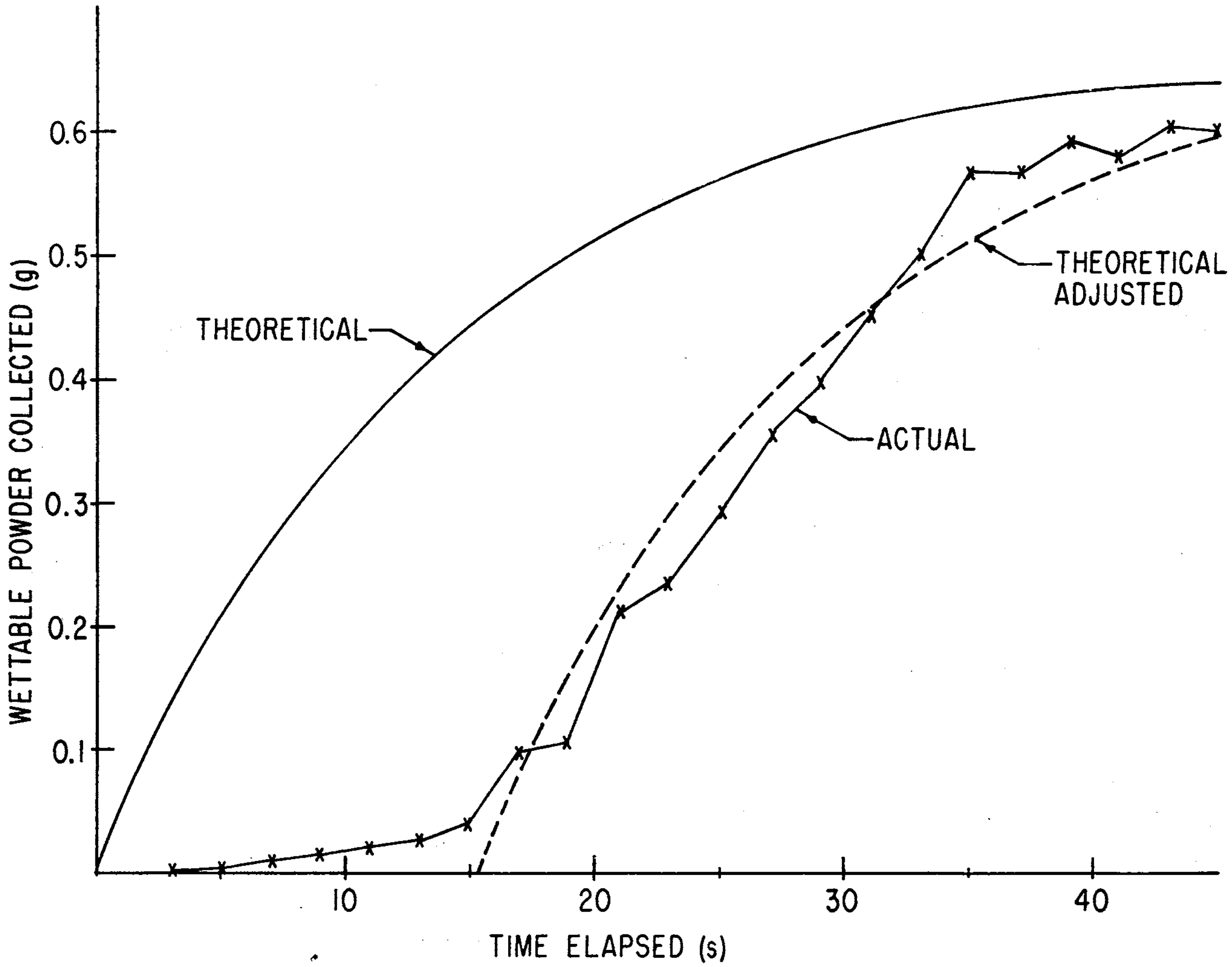

Figure 22. Theoretical Versus Actual Pesticide Accumulation for Powder Rate of 7.73 kg/ha, Volume of 0.85 l, Jet Pump Rate of 0.063 l/s, and Speed of 2.1 m/s

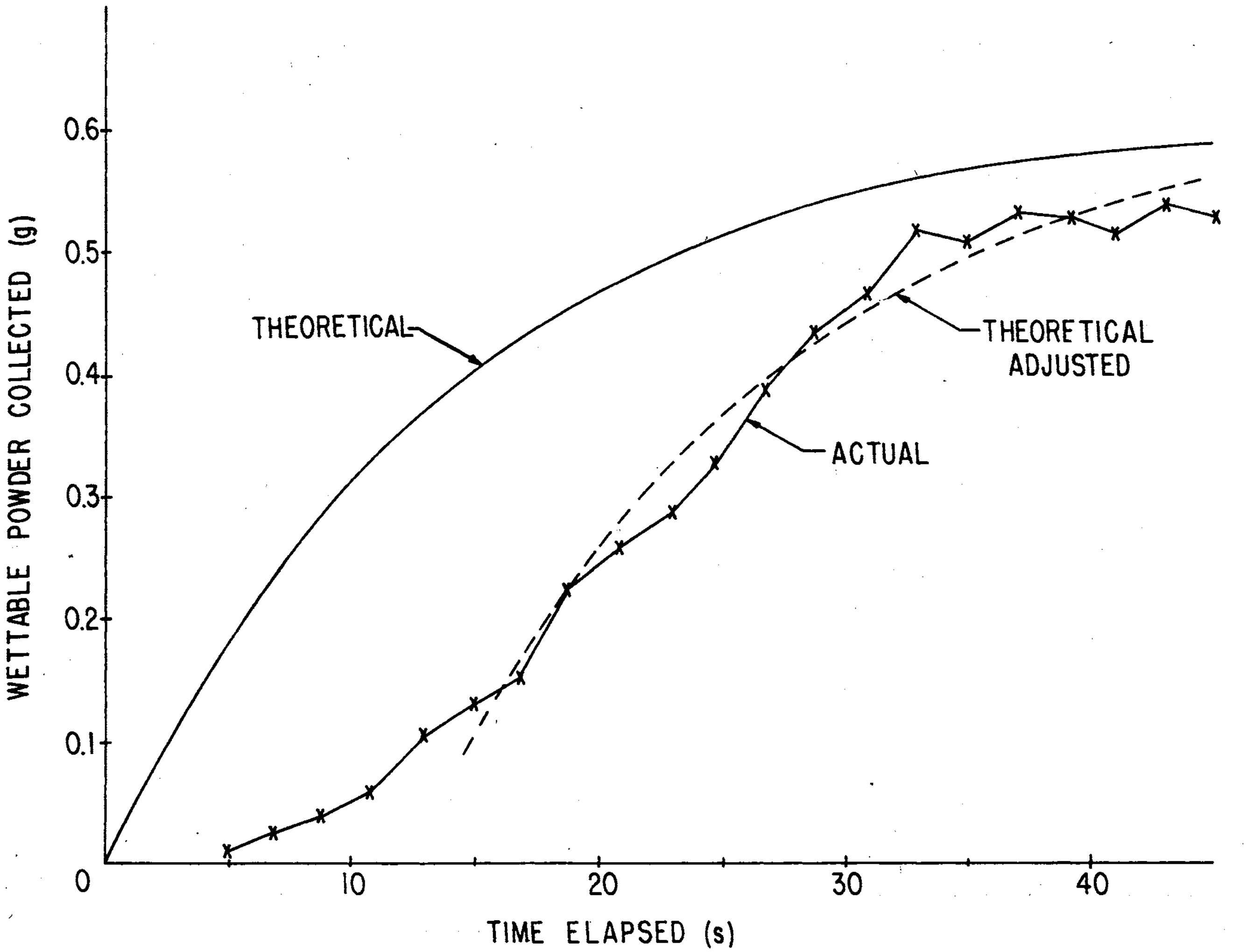

Figure 23. Theoretical Versus Actual Pesticide Accumulation for Powder Rate of 7.17 kg/ha, Volume of 0.85 l, Jet Pump Rate of 0.063 l/s, and Speed of 2.08 m/s

The approximately three second delay in the start of the actual curves indicated the delay in time due to the travel of the spray solution through the distribution lines. The theoretical curves were delayed to compensate for the delay in the response of the actual curve. Both experimental curves signified that the actual pesticide accumulation increased less rapidly than the adjusted mathematical prediction immediately after the spraying operation was started. This slower response was expected since the analog solution assumed instantaneous mixing while in actuality there was a delay in attaining a homogeneous suspension. As indicated from the curves, once the change became established, the rate of change increased roughly as the mathematical model or slightly faster. The lag time for the actual test coincided very closely with the predicted lag time of 40 s. In the time interval examined, the measured wettable powder quantity never reached the magnitude predicted mathematically. This discrepancy may have been due to variations in motive pressure, jet pump suction rate, and pesticide metering rate. Errors such as the spray missed during station changes and the failure of withdrawing a representative homogeneous sample from each collection point may have also contributed to the differences in the two curves.

Cleaning System Tests

The cleaning of the liquid pesticide metering system was accomplished without difficulty. The only losses encountered in the recovery of the unused pesticide was the liquid that remained on the inside surface of the peristaltic pump tubing. That part of the pesticide was diluted and washed from the surface by the hand cranking of the peristaltic pump with the suction end of the tubing submerged in water. No physical contact with the concentrate by the operator was encountered.

The powder hopper and metering device were not as easy to clean as was the liquid metering device. In testing the recoverability of 2.2 kg of wettable powder, it was found that approximately 50 g remained in the system. This 50 g consisted of a thin layer of powder on the inner surfaces of the hopper and metering device. This represented a loss of 2.2 per cent of the total wettable powder introduced to the system. When nine kg of wettable powder was placed in the powder hopper and metering system and then removed, less than 50 g were not recovered. This represented a loss of 0.7 per cent of the original amount of wettable powder in the system. While removing the wettable powder from the metering system as outlined in Chapter V, the operator came in direct contact with the wettable powder. In both test cases, the use of a brush enabled all but approximately four g to be accounted for.

The most complete cleaning of the mixing chamber occurred when the liquid level was controlled manually. When the automatic leveling control was left operational, the time to dilute the suspension within the mixing chamber was in the order of five minutes. During this five minute period, diluent was being passed through the entire spraying system. The method cleaned the mixing chamber below the level of the upper probe level. With the diluent level controlled manually and the liquid discharged through the drain valve, diluent was not circulated through the main supply line. The contents of the chamber was allowed to drain completely and then more clean diluent was added. It was observed that after about five cycles the major portion of the wettable powder had been removed and only a slight powder residue remained at the uppermost liquid level. By manually controlling the level it was possible to remove the collections of powder and powder dust above the upper level probe.

In testing the operation of the solenoid valve at the bottom of the mixing chamber, it was found that after being closed for five minutes with a wettable powder suspension in the mixing chamber, the valve was able to be consistently opened without any assistance. After five minutes the wettable powder in suspension in the chamber was still dispersed well enough that there was no noticeable void of powder in suspension in the upper region of the liquid.

The volume of the distribution lines from the jet pump to the nozzles and a given flow rate was believed to determine the amount of time necessary before the main stream of the pesticide was discharged from the nozzles. From direct calculations, a particle would take 4.7 s to exit the system at a flow rate of 0.31 l/s. In actual operation at 0.31 l/s, the transparent distribution lines remained clouded by the powder-laden diluent up to 32 s after the suspension source had been terminated. This was attributed to the removal of the accumulation of wettable powder in the void area of the jet pump body downstream from the nozzle.

In the test concerning immediate and delayed cleaning of the nozzles after the spraying operation ceased, the mean of the collected wettable powder in each nozzle and strainer was used for comparison. In the two trials which represented the stopping of the sprayer operation without flushing the distribution lines, the mean wettable powder weight collected per nozzle was 0.0176 g. This 0.0176 g represented 8.85×10^{-3} per cent of the projected total quantity of wettable powder that passed through each nozzle. The mean weight of powder residue on each nozzle in the system which was immediately flushed for one minute was 0.0039 g which represented 1.74×10^{-3} per cent of the total amount of wettable powder that was projected to pass through a given nozzle. This quantity of wettable powder was represented by two small, but visible, flakes of wettable powder. The original data from which these means were derived are presented in the Appendix.

CHAPTER IX

DISCUSSION OF RESULTS

The induction sprayer developed for this project was used for the application of both wettable powder and liquid formulations. The ranges of pesticide metering rate, jet pump suction rate, and mixing volume used in this study covered a broad spectrum. The resulting application rates, possible from the combinations of these parameters, encompassed all but a few of the application rates normally used.

The liquid pesticide was metered from the shipping container with virtually no operator contact. However, the operator was exposed to the wettable powder as it was being placed in the storage hopper. To accurately calibrate the liquid system only a graduated cylinder and measuring tape were necessary while a hand held 50 g spring scale and measuring tape were needed to accurately calibrate the wettable powder system. The peristaltic pump allowed the liquid to be metered with a maximum variation from the mean of 0.14 per cent while the wettable powder was metered with a 1.74 per cent maximum variation from the mean.

The mixing chamber provided enough surface area so the wettable powder could be placed in suspension at the high wettable powder metering rates. The mechanical agitator aided getting the wettable powder in suspension and keeping the pesticide dispersed in the liquid while the agitator remained submerged.

Although the operation of the liquid level control unit was cyclic, the control system regulated the liquid level within the mixing chamber. With the stilling basin positioned perpendicular to the line of travel, the wave action of the diluent in the mixing chamber caused by the motion of the sprayer was minimized.

The liquid pesticide metering system was easily cleaned by manually turning the peristaltic pump. More effort was involved in effectively cleaning the wettable powder system. The tests indicated that the recoverability of the unused wettable powder was not dependent upon the total amount of powder placed in the system. Tests also revealed that when the spraying system was flushed immediately after use, consistently less wettable powder was collected on the strainer and nozzle than when the system was shut down without being flushed with clean diluent.

For the limits used in this study and between mixing chamber volumes of 0.5 and 4 l, the lag times varied from 8 to 400 s. The conditions which produced the 8 s lag time were 0.19 l/s suction rate and 0.5 l mixing chamber volume, whereas the conditions which produced the 400 s lag time were 0.03 l/s jet pump suction rate and 4 l mixing chamber volume.

In comparing the actual amounts of sprayed wettable powder to the predicted amounts obtained from the derived equation, it was noted that the initial delay before the wettable powder was being sprayed was actually longer than predicted. Also after this delay, the actual chemical concentration level did not increase as rapidly as the mathematical model. However, the chemical concentration level within the mixing chamber increased rapidly and then proceeded to roughly follow the adjusted theoretical curve. Although the actual pesticide accumulation curves never reached the steady state condition, it was projected that the lag time involved with the actual spraying system would be only slightly higher than the theoretical curve and slightly less than the adjusted theoretical curve.

CHAPTER X

SUMMARY AND CONCLUSIONS

Summary

A field sprayer was designed and constructed utilizing a jet pump to induce pesticide mixtures into the sprayer boom supply line. The pesticide was metered into the mixing chamber proportional to the ground speed of the sprayer and wetted with a small amount of diluent before entering the jet pump. Wettable powders were metered with a screw feeder and a peristaltic pump was used for metering liquid concentrates. A variable-speed drive train was used to regulate pesticide application rates. The liquid level within the mixing chamber was automatically controlled with the use of two manually positioned electrodes and an electronic control system. The jet pump provided a means of continuously drawing a pesticide mixture from the mixing chamber and mixing it with diluent from the supply tank. The resulting spray mixture was then routed into a manifold distribution system with each lead going to separate 3-nozzle boom assemblages.

The performance of the sprayer system was analytically modeled with the aid of an analog computer. The model indicated that the lag time was not dependent upon the pesticide metering rate, but varied directly with the mixing volume and inversely with the jet pump suction rate. The performance and precision of the components of the sprayer were measured and observed using both wettable powders and liquid concentrates. Tests were conducted to compare the modeled system pesticide concentration to the actual sprayer's pesticide concentration as they progressed from an unprimed system to a definite application concentration. It was found that the actual concentration change at the beginning of the time period was less than predicted by the model. However, the concentration later changed more rapidly than predicted and resulted in approximately the same lag time.

Conclusions

1. The induction system sprayer functioned as an integral unit using either powder or liquid formulations.
2. The direct measurement of the pesticide in the calibration procedures allowed simple field operation and achieved consistent results.
3. The cleaning procedures available with this system were simpler and more expedient than for conventional sprayers thereby providing potentially greater reliability in operation.
4. The liquid level control accurately regulated the flow of diluent into the mixing chamber to maintain the level within 3 mm of any electrode differential from 3 to 100 mm, although the control was cyclic in nature.
5. In this study the mathematical model predicted the minimum lag times caused by changes in sprayer speeds.

6. The lag time of the sprayer varied directly as the mixing volume, inversely as the jet pump suction rate, and was not affected by the pesticide metering rate.
7. Modifications to prevent powder bridging in the hopper and to prevent the cyclic pressure changes caused by the operation of the mixing chamber solenoid valve would be necessary for the system to function properly.

Suggestions for Future Studies

1. Modify the existing metering system to eliminate bridging of the wettable powders in the storage hopper for field use.
2. Subject the liquid level control unit to further comprehensive field operation to evaluate the durability of the system.
3. Investigate different shipping containers for wettable powders to find a container which provides acceptable storage characteristics and allows for the wettable powder to be metered directly from the commercial container without being tranferred to a storage hopper.

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APPENDIX

CLEANING TEST DATA

CLEANING TEST DATA

Replication Number	Flushing Time minutes	Powder Weight grams	Per Cent Powder Caught X 1000
I	0	0.0202	9.8
		0.0172	8.3
		0.0165	8.0
		0.0170	8.2
		0.0164	8.0
		0.0194	9.4
	1	0.0036	1.7
		0.0029	1.4
		0.0041	1.9
		0.0040	1.9
		0.0037	1.7
		0.0042	2.0
II	0	0.0178	9.3
		0.0133	6.9
		0.0192	10.0
		0.0176	9.2
		0.0158	8.2
		0.0210	10.9
	1	0.0048	2.5
		0.0061	3.1
		0.0035	1.8
		0.0039	2.0
		0.0040	2.0
		0.0021	1.0

VITA

Donald Ray Peck

Candidate for the Degree of

Master of Science

Thesis: DEVELOPMENT AND EVALUATION OF A PESTICIDE INDUCTION SYSTEM FOR A FIELD SPRAYER

Major Field: Agricultural Engineering

Biographical:

Personal Data: Born in Liberal, Kansas, March 3, 1945, the son of Mr. and Mrs. Raymond A. Peck.

Education: Graduated from Goodwell High School, Goodwell, Oklahoma in May, 1963; received Bachelor of Science degree in Agricultural Engineering from Oklahoma State University in May, 1968; completed requirements for the Master of Science degree in December, 1973.

Professional Experience: Engineering Assistant, School of Agricultural Engineering, Oklahoma State University, 1965-68; Graduate Research Assistant, School of Agricultural Engineering, Oklahoma State University, 1970-71; Graduate Teaching Assistant, School of Agricultural Engineering, Oklahoma State University, 1971; Design Engineer, Dickey Machine Works, 1972; Design Engineer, M. G. Dickey Industries, 1972-73.

Professional and Honorary Organizations: Associate Member, American Society of Agricultural Engineers; Member, Sigma Tau; Engineer in Training, State of Oklahoma.