

DEVELOPMENT OF A SENSOR FOR SPRAY DEPOSITION ASSESSMENT

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ABSTRACT

A sensor was developed that provides a voltage signal proportional to the amount of spray deposit. Design features of this sensor and its supporting hardware and software are described. Response of the sensor to individual drops of tap water showed an increasing trend as the size and number of drops increased. The magnitude of the signal was different for different drop solutions. It increased as concentration of the ions in the solution decreased. Response of the sensor to tap water spray was linear when the amount of deposit was plotted on the log scale. In general, the system could generate a useful signal; however, it needs some improvement in order to obtain a more reliable method for spray deposition assessment.

INTRODUCTION

Research and development work to test the performance of sprayers in the field suffers from lack of a fast, easy, and inexpensive method for assessment of spray deposition on the plant canopy. Commonly used methods, such as visual judgment of fluorescent tracer deposits on sprayed leaves (Edwards et al., 1961), gas chromatography of pesticide residues on plant parts (Yates et al., 1974), and colorimetry or fluorometry of mineral or fluorescent spray deposits on artificial targets (Salyani and Whitney, 1988), are either very subjective or are too time-consuming and expensive. Therefore, several researchers have investigated procedures to automate part of the process and increase the speed and reduce the cost of spray deposition assessment.

For a continuous measurement of spray deposition across an aerial application swath, Liljedahl and Strait (1959) developed an instrument that could scan fluorescent spray deposits on a paper strip and record the fluorescent signals on a strip-chart recorder. Whitney and Roth (1985) modified a fluorometer to use a cotton string as the spray collector. Carlton et al. (1985) developed a colorimeter that could wash and measure spray deposits on 35 mm film.

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Later, Carlton and Bouse (1987) explored the use of plastic tubing as a spray collector. Because of errors associated with fluorescence of the tracer material and errors due to the geometric and surface dissimilarity of the spray collectors compared to natural targets, the above systems could only provide relative and sometimes questionable results.

Brazee et al. (1968), Sistler et al. (1982), and Penneton (1989) developed various image analysis systems that could provide more detailed information on particle or droplet size distribution and percent coverage of spray images on deposition targets. These were also indirect methods of deposition assessment and their results could be affected by droplet size, image contrast on sampling surface, and operator familiarity with images.

Laue (1984) invented an electronic device composed of a multifinger transducer that could sense the presence of water droplets (due to condensation or rain) to actuate a simple alarm circuit. However, the device could not quantify the amount of water. Göhlich (1988) developed an instrument that correlated evaporative cooling of a temperature sensor with the concentration of water droplets in a drifted spray cloud. The size and number of droplets in the cloud could affect the performance of the instrument and the sensor could more appropriately be utilized in drift studies for comparative measurements.

In view of the apparent shortcomings in the aforementioned methodologies and instrumentation, the objective of the research was to develop a fast, accurate, and low cost system for spray deposition assessment. Therefore, a system was conceptualized where spray deposition patterns, within the tree or plant canopy, could directly be monitored during or immediately after spray application. The system consisted of spray sensors, data acquisition hardware and software, and a microcomputer. Initial steps involved identifying and/or developing a sensor that could detect the presence of spray droplets and give a response proportional to the amount of material on the sensor.

Attempts to use a humidity sensor (General Eastern, RH-8) within the tree canopy to correlate the change in relative humidity with the presence of water droplets on or near the sensors did not show promising results (due to slow and temperature-dependent response). Also, the use of a piezoelectric film (Pennwalt, KYNAR Piezo Film) to transform the mechanical stress (due to the impact of spray droplets) to electrical signal did not provide a desired response. The film was not responsive to small droplets (approximately <1000 μm) and static measurements. However, a sensing circuit comprised of a pair of open-ended wires, a resistor, and a battery was found to give a



useful response when the circuit was closed by a drop of tap water as the water was deionized. Therefore, with the objective of obtaining a viable system for fast, easy, and inexpensive assessment of the spray deposition, this latter concept was further investigated and its corresponding hardware and software were developed. The objectives of this article are to:

- Describe design features of the developed ionized water sensor and its supporting components,
- Discuss responses of the sensor to individual drops and spray droplets of few selected liquids, and
- Reveal the problems associated with the performance of the sensor.

EQUIPMENT AND METHODS

SENSOR DESIGN AND HARDWARE

The first version of the sensor was made of two single conductors of a stranded, hook-up wire spaced about 2.5 mm apart and strapped around a piece of circuit board (with existing notches 2.5 mm apart). The wires were connected to the terminals of a dry cell battery via a variable resistor. A digital multimeter was used to monitor voltage across the resistor when drops of water connected the wires and were deionized. Subsequent versions with increased number of wire loops and less spacing between the wires increased the voltage read-out per water drop and extended the capability of the sensor for smaller drops. Later, a comparatively advanced version was made by etching the parallel lines of the conductor on a printed circuit board. Figure 1 shows the latest version that had 46 pairs of parallel copper conductors, about 0.4 mm wide and 0.35 mm apart. The width and spacing of the sensor conductors were determined by capability of our plotting equipment which was used to plot the conductor grid on the printed circuit board. Finer grids required more sophisticated equipment.

Figure 2 shows the components and circuitry used with the sensor including a battery (6/9 VDC), voltage regulator (5 V), resistor selector switch (100-IM Ω), A/D converter screwboard (Data-Translation, DT-707), and data acquisition board (DT-2801-A) inside the computer (Zenith 151). A digital multimeter, connected in parallel with the sensor, was used to monitor the activity of the sensor and a micro-switch was employed to start the scanning of the voltage. The variable measuring resistors provided a range

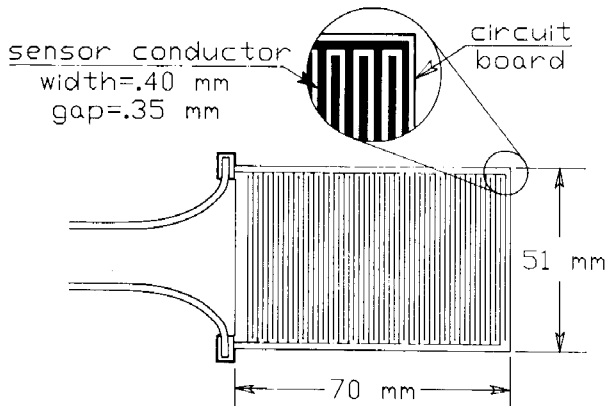


Figure 1—Spray sensor design.

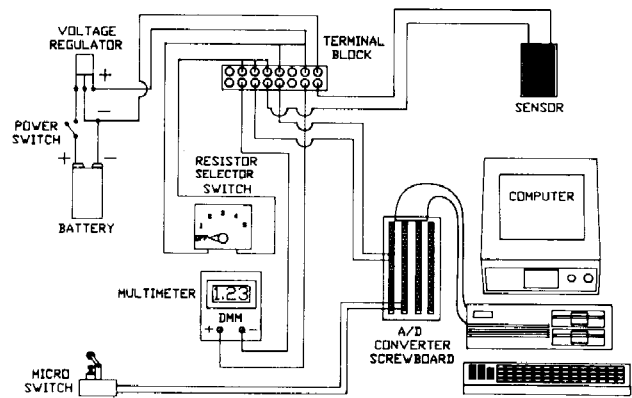


Figure 2—Sensor system hardware.

of sensitivities so different amounts of deposits could be detected.

SENSING SOFTWARE

Using Turbo Pascal V3.0 (Borland International) and PCLAB Machine Language Routines V3.0 (Data Translation, Inc.), a program was used to integrate the voltage signal (positive slope only). It provided a 4000-element array for scanning the signal and operator capability (for setting the scan frequency) to obtain the desired duration for the scan. The acceptable noise level (noise limiter) could be set as percent of the least significant bit (LSB). The signal range could be changed interactively to obtain the desired graphics for the voltage and integral signals. After setting the scan frequency and noise limiter, the user started the scan with a signal from the micro-switch. This gave the operator a chance to synchronize the scanning process with droplet deposition and insure scanning the desired section of the voltage signal within the scan period. Following the graphic representation of the voltage and integral signals, the integration value was displayed on the screen of the computer.

SENSOR TESTS

To test the response of the sensor to individual drops of spray liquids, a microdispenser (Drummond, 10 μL ; $\pm 1\%$) and a dispenser (Eppendorf, 100 μL ; $\pm 1\%$) were used to place 1, 5, 10, and 20 μL drops on the sensor. The liquids of the drops were tap water (about 135 ppm total ions), deionized water, deionized water plus sodium hydroxide (24, 48, and 96 ppm NaOH), and deionized water plus sodium chloride (58,500 ppm NaCl). One to six drops were deposited at different locations on the sensor and the responses were recorded. After each run, the sensor was wiped dry and clean and the run was replicated four times. The data were analyzed using the ANOVA procedure (SAS Institute, Inc., 1985).

In another test, the sensor was placed horizontally on a test stand and moved on a conveyor belt across the stream of tap water spray droplets. The droplets were generated by a vibrating orifice droplet generator (Salyani, 1988). They were not uniform in size and may have ranged from few μm to few hundred μm in diameter (estimates from experience). The speed of the conveyor belt, thereby the exposure time of the sensor to the spray cloud, was varied

so that different amounts of spray could be deposited on the sensor. For each speed setting, the sensor was sprayed four times.

The ranges of the liquid temperature, ambient temperature, and relative humidity during the test were 21-24.3° C, 21-24.3° C, and 34-69%, respectively.

RESULTS AND DISCUSSION

When the sensor was dry and its circuit was open, a zero voltage was displayed on the multimeter or computer, but when the sensor terminals were jumpered with a resistor, a voltage signal was observed. For a particular size of the measuring resistor in the circuit, the voltage signal was constant. As the resistance of the sensor jumper increased, the voltage signal decreased. Similarly, deposition of individual drops or a mass of droplets on the sensor generated a voltage signal. However, due to the electrochemical process of deionization and dynamic conductance of the electrolytic solution on the sensor, the voltage signal did not remain constant. After a quick rise to a peak, it gradually decreased with time. Summation of the discrete values of the voltage signal (positive slope only) generated a corresponding integral signal. Typical voltage and integral signals for two drops of 10 μ L tap water are shown in figure 3. The measuring resistance, scan frequency, scan duration, and noise limiter were 10 k Ω , 100 Hz, 40 s, and 10%, respectively. The two short rises on the curves coincide with the deposition of the first and second drops. The reason for the two small steps near the end of the integral signal is not known. They may have originated from a minor change of the drop contact area (due to the bubble formation) or other noise sources in the system.

The peak voltage, end voltage, and voltage integral values were significantly affected (at 5%) by the size and number of water drops. However, the voltage signals did not provide a reliable response to the deposition of multiple, individual drops, since they could give erroneous read-out due to the momentary noise spikes. The integral signal was less susceptible to the spikes and provided a response clearly related to number of drops (fig. 4). While the voltage signal peaks from the first and second drops of the NaOH solution were nearly the same, their corresponding integral showed a pronounced step for each drop. The comparison of the signals from the tap water and NaOH solution revealed the difference in the shape of the

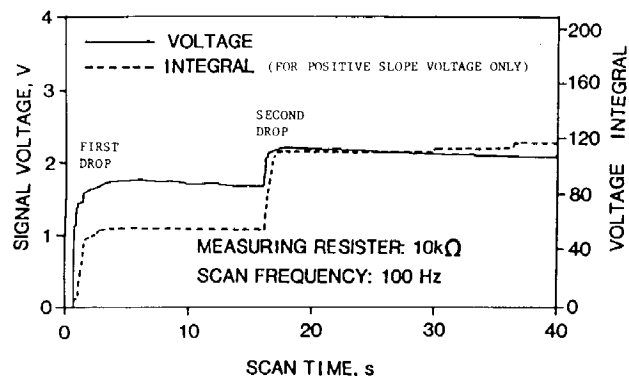


Figure 3—Typical voltage and integral signal resulting from deposition of two 10 μ L drops.

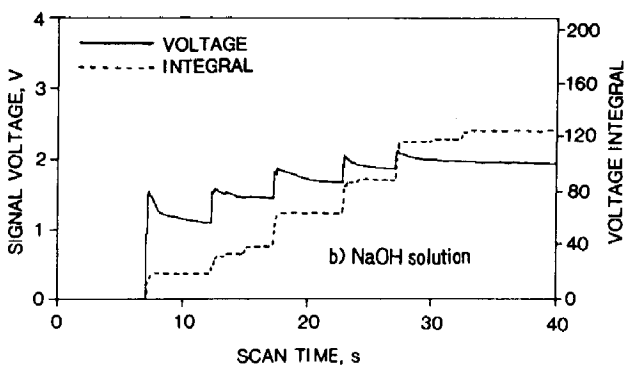
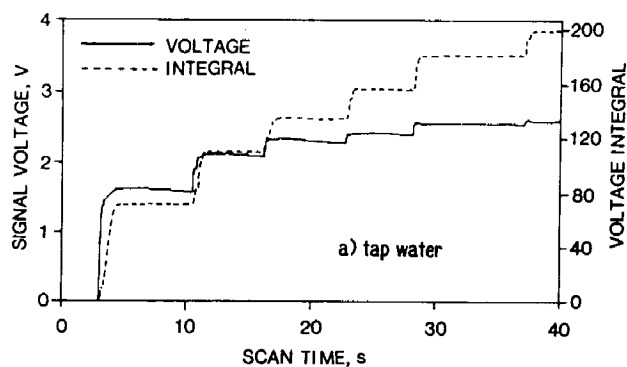


Figure 4—Comparison of two typical signals: a) six 10 μ L drops of tap water; b) five 10 μ L drops of 24 ppm NaOH solution. The integral values correspond to the positive slope voltage only.

voltage signal apparently due to the differences in their electrochemical processes. While there was a comparatively gradual increase in voltage right after dispensing the tap water, there was a sharp peak with NaOH solution. However, this difference in the response was detected by the integral signal and resulted in larger integral values for the tap water.

The effect of number and size of tap water drops on the signal is shown in figure 5. Generally speaking, there was a larger mean signal as the size and number of drops increased. The 20 μ L drops showed a more pronounced response; however, overall repeatability was poor and suggested additional investigations. Measurements of the drop-sensor contact area (with a microscope) revealed some disproportionality in the contact areas as compared to the drop volumes. The mean and standard deviation of four

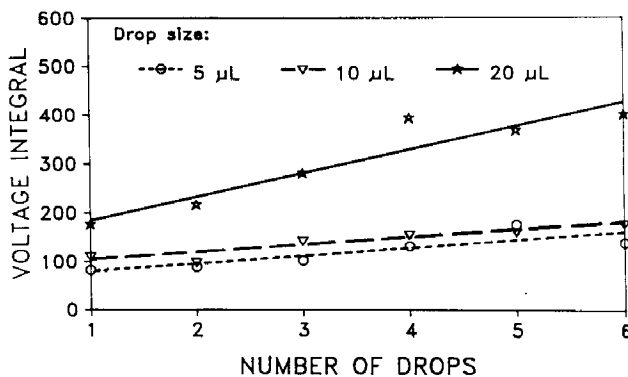


Figure 5—Trends of the sensor response vs. number of different sized drops of tap water.

measurements for the 1, 5, 10, and 20 μL tap water drops were 1.39 (0.15), 4.31 (0.17), 7.22 (0.60), and 24.03 (0.39) mm^2 , respectively. Therefore, part of the reason for poor repeatability of data for individual drops could be associated with the differences in contact areas. Although drop contact area and volume of drops showed much higher Pearson Correlation Coefficients (with the integral values) than number of drops (0.93, 0.89, and 0.43, respectively), the latter was used to show the comparative results for various solutions.

When two different sized drops (5 and 20 μL) were deposited one after another at different orders, there was no significant difference in the integral values (t-test at 5%) and the response depended on the total amount of deposition. The type of liquid, however, had a significant effect (at 5%) on the sensor response (fig. 6). The highest mean values of response was observed with the tap water and the lowest mean response corresponded to the NaCl solution (58,500 ppm). A further look at the effect of ion concentration revealed that as concentration of the NaOH (electrical conductivity of the solution) increased, the mean value of the integral signal decreased (fig. 7). The 24, 48, and 96 ppm concentrations showed significantly different signals (at 5%) and 24 ppm gave the highest integrals. It should be noted that the trends shown in figures 5-7 represent only a small portion of the sensor response and are linearized for that range.

All the results shown in figures 5-7 were obtained at the scan frequency of 100 Hz which gave a scan duration of 40 s. Using lower scan frequencies (or higher scan durations) resulted in hardware noise that made the value of integral signal unreliable. The noise problem became more serious when ion concentration of the solutions was decreased. When deionized water was placed on the sensor, the problem was intensified. Observing the sensor with a lens and microscope revealed that when deionized water or a solution with low ion concentration (low electrical conductivity) was used, some black particles were generated between the sensor conductors. As the scan time proceeded, the particles or precipitation increased and grew like tree branches. When these precipitation branches bridged the adjacent sensor conductors, the noise problem started; the voltage signal increased and integral signal no longer became reliable. Study of these black deposits with electron microscopy showed that they were made of copper oxide. Increasing the scan frequency (decreasing the scan

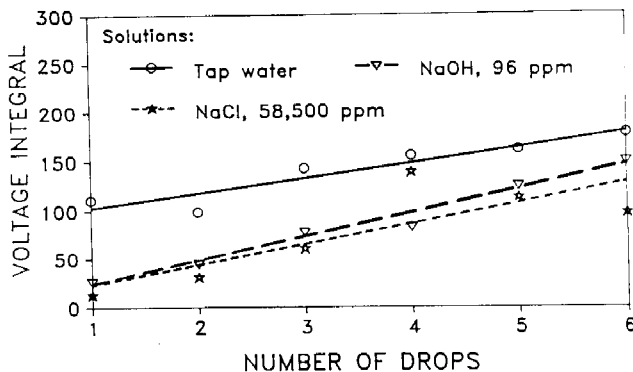


Figure 6—Trends of the sensor response vs. number of 10 μL drops for three solutions.

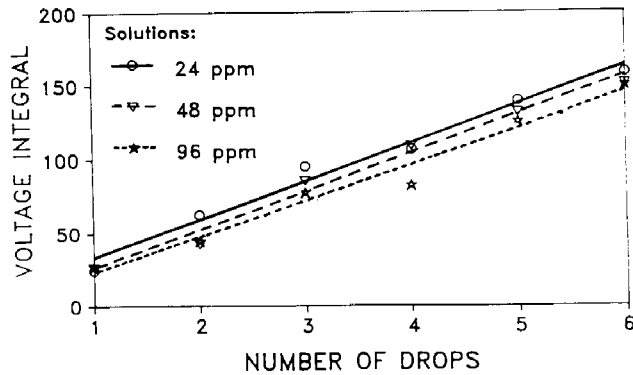


Figure 7—Trends of the sensor response vs. number of 10 μL drops of three NaOH solutions.

duration or sensor activity time) could alleviate this problem for the tap water and other solutions used in the test.

The response of the sensor to tap water spray is shown in figure 8. As the conveyor speed increased (amount of water deposit on the sensor decreased), the magnitude of the voltage integral decreased. This response, obtained at 400 Hz and with a measuring resistance of 1 $\text{k}\Omega$, showed a linear relationship ($R^2 = 0.98$) with \log_{10} of the conveyor speed (conveyor speed on logarithmic scale).

The above results indicated that the sensor could generate a useful signal (integral value) which, in general, was proportional to the amount of deposit on the sensor. The sensor with its supporting hardware and software could provide a viable system for spray deposition assessment. The smallest droplet to which the sensor responds depends on the resolution of its conductor grid. In addition to practical limitations in making very fine grid, there may be some unforeseen limitations to sensor performance as the spacing of the conductors decreases. For the existing system, development of the copper oxide precipitation, material build-up and plating of the sensor conductors, and hardware noise were the main problems. The test liquids were selected from available materials to represent different ion concentrations. They were not intended to represent pesticide spray properties since only tap water (or well water) is expected to be used with the completed system. The sensor is rugged and can be cleaned easily with either common detergents and/or an ultrasonic cleaner.

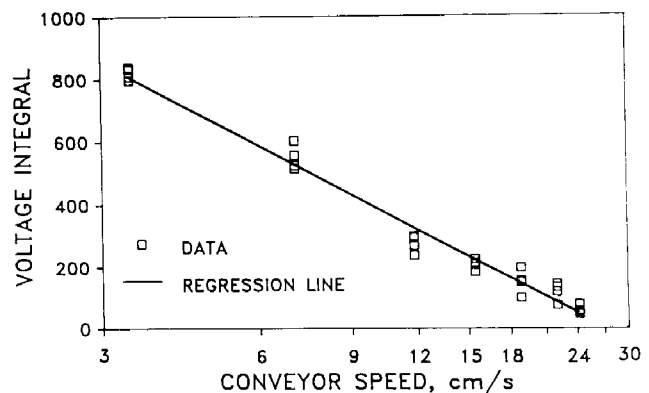


Figure 8—Sensor response to water spray.

Further work is under way to plate the sensor with gold. This may minimize or eliminate copper oxide development. A multisensor system is under development to be employed in field conditions.

CONCLUSIONS

1. The sensor generated a signal (integral value) proportional to spray deposit.
2. The magnitude of the signal was different for different solutions.
3. Development of copper oxide was the major problem for the system.
4. The system needs improvement to provide a fast and reliable method for automatic assessment of spray deposition in the field.

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