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SENSOR FOR MEASURING LOW VOLUME SPRAY DEPOSIT

by

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SUMMARY:

A spray deposit sensor, circuit and data acquisition system was developed. The sensor provides a voltage output proportional to the number of spray drops deposited on the sensor. Spray deposits ranging from 1 to 10 ul were measured. The ability to accurately measure deposit volume was evaluated for various nozzles over a range of pressures. Constant line spacing sensors and variable line spacing sensors were used to determine spray volumes and droplet size ranges. The sensors and data acquisition system provided quick, accurate results of spray deposits under 10 ul.

KEYWORDS:

Drift, Droplets, Measurement, Spray, Transducers

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INTRODUCTION

Numerous methods are available to measure low volume spray deposits. Common uses for low volume spray measurements include canopy deposit or drift measurement. No method is presently available which offers fast, simple and inexpensive measurement of low volume spray deposit. Methods commonly used include fluorescent tracer deposits, gas chromatography, fluorometer measurements, air samples and rotorods. Most common methods are either subjective, time consuming or expensive. Common methods of low volume spray deposit measurement have been extensively outlined (Saunders et al. (1976), Smith et al. (1981), Grover (1978) and Yoshida (1973)).

Researchers have investigated methods to increase ease of sampling, reduce lab analysis time and reduce costs. Laue (1984) invented an electronic device using a multifinger transducer that could sense the presence of water droplets and actuate a simple alarm circuit. Salyani and Serdynsky (1990) attempted to expand on the multifinger transducer by etching parallel lines on a printed circuit board. The use of a similar printed circuit board sensor has been studied by a variety of researchers (Fisher et al. (1992), Davis and Hughes (1970), McCoy et al. (1972), Gillespie and Kidd (1978) and Weiss and Hagan (1983)).

This study outlines the design and evaluation of a cost effective sensor for low volume spray deposit. Calibration curves from 1 to 10 ul were made using 4 sets of nozzles at 5 pressures.

EQUIPMENT AND METHODS

SENSOR DESIGN

The initial single output sensor design involved the same type of grid transducer developed by Salyani and Serdynski (1990). The initial design used two sets of parallel lines etched on a printed circuit board. A 5 volt supply voltage was applied across the two sets of parallel lines. A current limiting resistor was placed between one of the sets of parallel lines and ground. When a water droplet contacted a 5 volt line and a ground line, current flowed. In effect, water acted as a resistor set across the voltage lines, completing the circuit. The water droplets, acting as resistors, caused a voltage drop across the parallel line sets. A sensor reading was made by finding the voltage drop using a voltage divider. The sensor displayed a linear relationship between droplets and output. However, increasing the number of droplets applied reduced the linear coefficient of determination (R^2) between droplets and output.

Loss of linearity was caused by droplets on the sensor acting like parallel resistors. The equivalent resistance of parallel resistors is found using Equation 1.

Equation 1

$$1/R_{eq} = 1/R1 + 1/R2 = ... + 1/Rn$$

As outlined by Equation 1, increases in equivalent resistance are related to the number of resistors already in parallel. Adding parallel resistors reduces the effects of subsequent parallel resistors on equivalent resistance. Similarly, after a limited number of parallel droplets, additional droplets had little effect on output. Figure 1 illustrates the equivalent resistance of the sensor relative to droplets placed on the sensor. The absence of a linear relationship between droplet and resistance makes correlation between volume applied and sensor output difficult, especially at higher droplet counts.

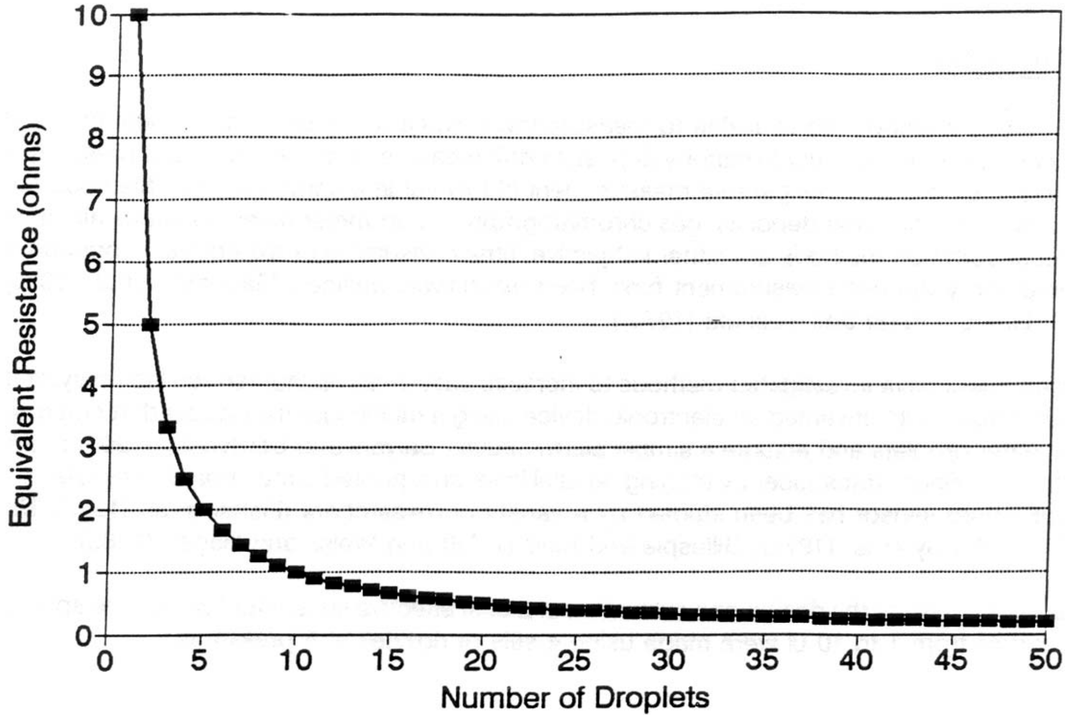

Figure 1. Parallel Line Sensor Equivalent Resistance and Droplet Number

Due to the linearity problems of the single output sensor, 2 sensors with multiple signal inputs and outputs were developed. The printed circuit board sensors developed used 15 sets of lines which were connected to inputs of a 16 channel multiplexer. Multiple outputs from the sensors increased both range and accuracy by reducing the parallel droplet effects.

A constant width sensor and a variable width sensor were constructed by printed circuit board manufacturers (Figure 2 and 3). The constant line width sensor (Figure 2) used line spacing of 254 um and line sizes of 254 um. The total sensing area of the constant width sensor was 15.24 mm x 20.32 mm or 309.68 mm^2. The variable width sensor (Figure 3) had a minimum line spacing of 254 um. The line spacing increased by 100.8 um, to a maximum line spacing of 965.2 um. Line sizes of the variable width sensors were 254 um, for a total sensing area of 25.78 mm x 17.53 mm or 451.92 mm^2.

After tap water was applied to the sensor, current flow caused oxidization of the copper and water. Copper oxidation caused a build-up of copper oxide between the sensor lines. Oxidization build-up caused errors in the voltage outputs of the sensors. To reduce copper oxidation between the lines of the two sensors, a solder mask was applied to the sensor by the board manufacturers. Gold plating was also used on the sensor, however the solder mask provided the same benefit in reducing the oxidation, at a lower cost.

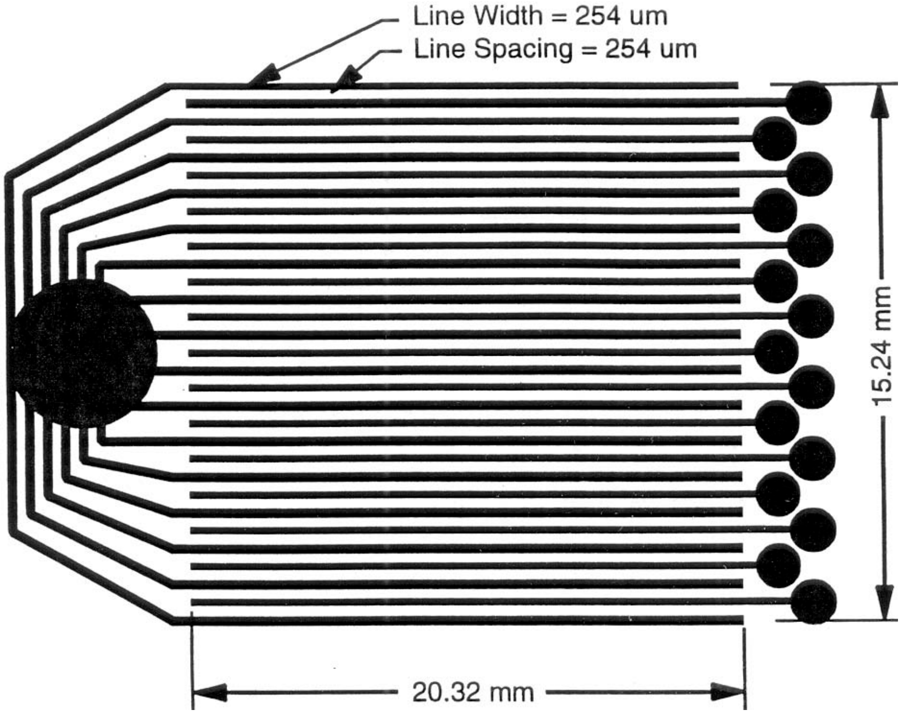

Figure 2. Constant Width Sensor

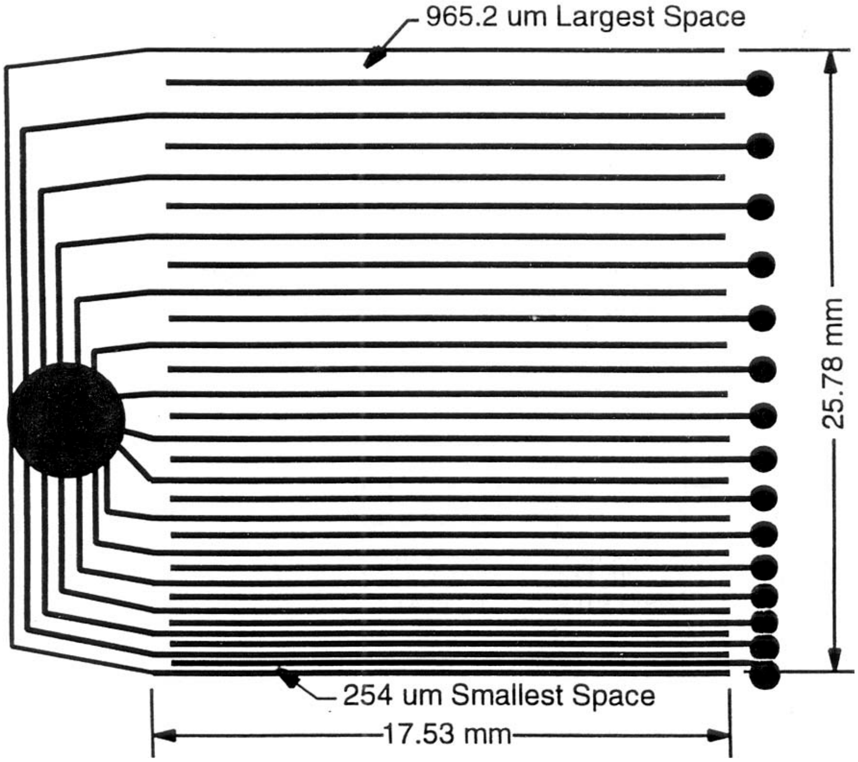

Figure 3. Variable Width Sensor

CIRCUIT DESIGN

The measurement circuit consisted of a sensitivity circuit, multiplexer and timing circuit. The sensitivity circuit used voltage dividers and parallel resistors to adjust the sensor's 15 line output sensitivities and linearities. Output from the sensitivity circuit was wired into input channels of a multiplexer. The 16 channel multiplexer allowed the 15 sensor line inputs to be put into a single serial output. The 16th channel of the multiplexer was connected to a known voltage for a reference output. A single serial output was used to allow numerous sensors to be recorded with a data acquisition system. The circuit design is outlined in Figure 4.

The multiplexer was driven by a timing circuit consisting of a binary counter and a frequency generator. A programmable crystal oscillator was used to generate a frequency to control the binary counter connected to the channel select lines of the multiplexer. The multiplexer input channels were switched at 1000 Hz. By switching at 1000 Hz, each of the fifteen lines on the sensor was sampled 62.5 times per second.

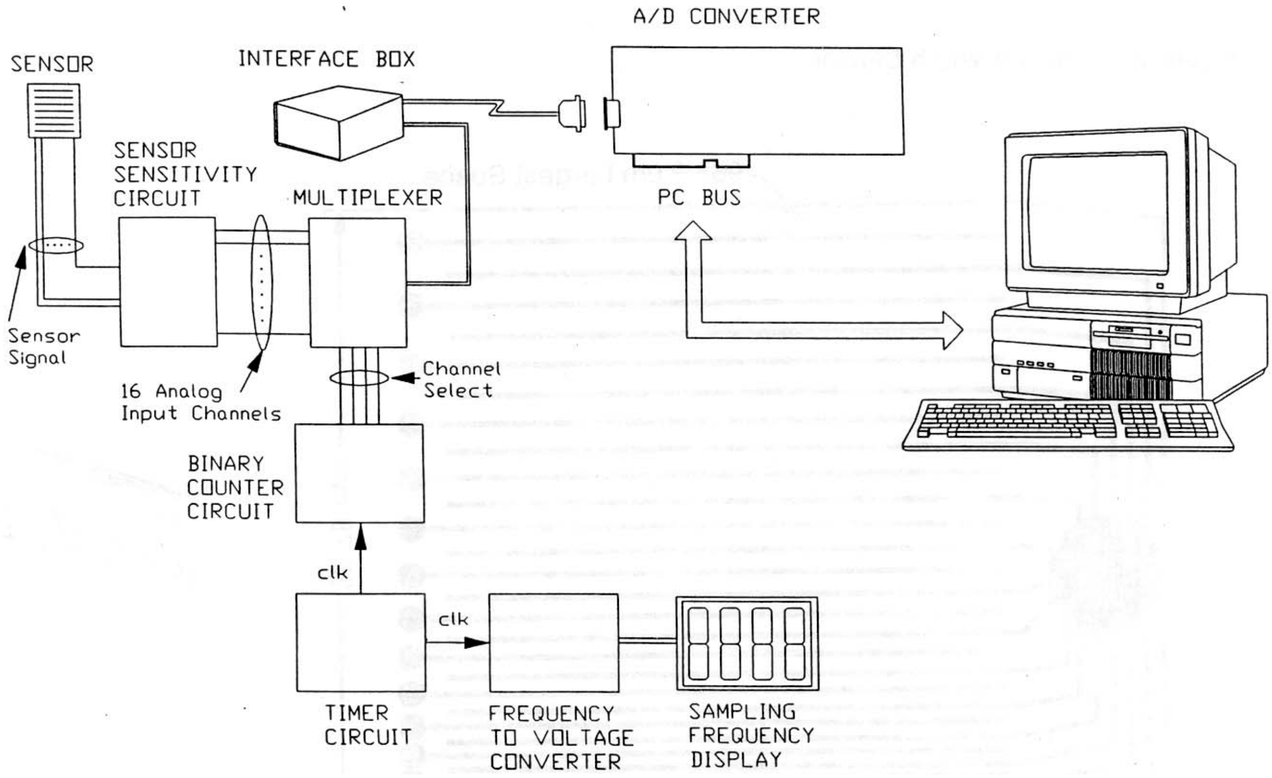

Figure 4. Measurement System

DATA ACQUISITION

The outputs of each multiplexer were recorded using a high speed analog to digital (A/D) converter board. The A/D board was in a 386 PC computer equipped with data acquisition software developed by the Alberta Farm Machinery Research Centre (AFMRC). The A/D board sampled at the multiplexer switching rate, allowing synchronization between the sampling of the multiplexer and the A/D board conversion. To ensure synchronization, the 16th channel of the multiplexer was set to a reference voltage. A computer program was used to check the 16th channel reference voltage of the stored data for each test. If the program indicated an error in reference voltage value, the test was repeated.

CALIBRATION PROCEDURES

Before sensor calibration, nozzle flow rates and spray patterns were determined. Row rates were measured at boom pressures ranging from 200 to 500 kPa using a graduated cylinder and a stopwatch. The AFMRC spray patternator table was used to find nozzle spray pattern distributions. The pattemator table consists of 256 slotted plastic collection sections. Each section is 16 mm wide by 2.44 m long. A spray boom and nozzle are supported above the table. The boom is driven over the table using a variable speed DC motor. Nozzle pressure is maintained electronically with a pressure controller. Once a nozzle passed over the table, the table is tilted 90º. The height of the water columns in each collection section is measured. The spray table nozzle height was recorded and used dudng sensor calibration tests. The data acquisition software allowed for statistical analysis and graphing of the data. From the water height measurements, the spray pattern was determined.

From the flow rate pattern (Figure 5) an equation representing the flow rate over the sensor calibration location was found. The centre of the sensor was calibrated at 100 mm from the nozzle centre. The equation representing the flow rate distribution over the sensor was then integrated over the width of the sensor. The result of the integration was divided by the sensor width to find the average flow rate on the sensor. This calculated average flow rate was used to calibrate the sensor.

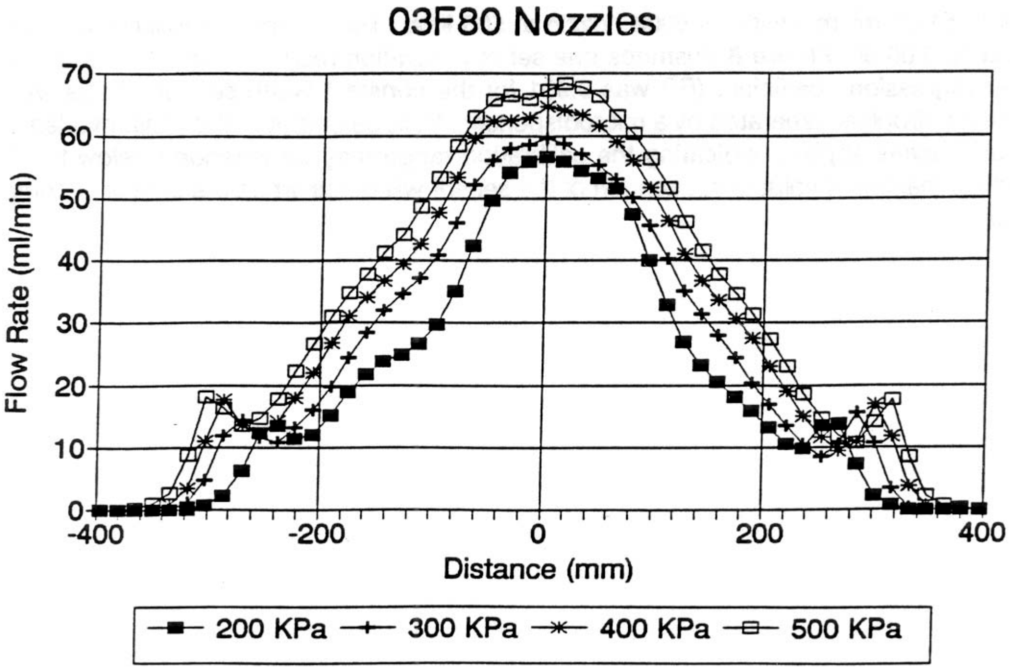

Figure 5. Spray Pattern Distribution

Sensor calibration was completed using a direct drive three nozzle spray boom and electronic pressure controller. Tee-Jet 8001, 80015, 8002 and 8003 stainless steel flat fan nozzles were used at pressures of 200, 300, 400 and 500 kPa (29, 44, 58 and 73 psi). The spray boom consisted of a 3.8 cm boom mounted under a carriage frame which was propelled down a track by a chain drive and gear assembly. A magnetic pick-up rpm sensor was mounted to one of the gears to determine boom speed. Boom pressure was electronically controlled using a pressure controller.

Spray deposit on the sensor was calculated using boom speed and sensor width. From the time the boom was over the sensor and the volume of spray per unit time, the spray deposited was calculated.

Sensor calibration was completed using 4 sets of Tee-Jet nozzles, 5 pressures and a boom speed of 6.85 km/h (4.1 mph). The range of nozzles and pressures used allowed for the deposit of a range of droplet sizes and velocities on the sensors during calibration. Three replications of nozzle type and pressure were completed.

RESULTS AND DISCUSSION

As water droplets were applied to the sensor, voltage output from each line was recorded. The voltage output on a specific line was proportional to the number of droplets applied to the line. After a maximum increase in voltage due to droplet deposit, the voltage of the line started to decrease due to water deionization on the lines. For determining volume deposit, the maximum line voltages minus initial line voltages were used. The initial voltage on the lines before spray application was due to a parallel resistor used with the line output in the circuit.

SENSOR RESULTS

For the constant width sensor, the spray volume flow rate ranged from 10.91 mL/min with an 8001 nozzle at 200 kPa to 51.60 mL/min with an 8003 nozzle at 500 kPa. The volume deposited on the sensor ranged from 0.93 ul to 8.00 ul. Figure 6 illustrates one set of calibration results for the constant line width sensor. The linear regression coefficient (R^2) was 0.901 for the constant width sensor. Tests were also completed using single droplets generated by a microdispenser. Voltage output of the sensor varied linearly with the number of droplets applied, indicating the calibration range may be extended below the 0.93 ul deposit. The practical maximum volume application of the sensor will occur when the sensor is completely covered with water.

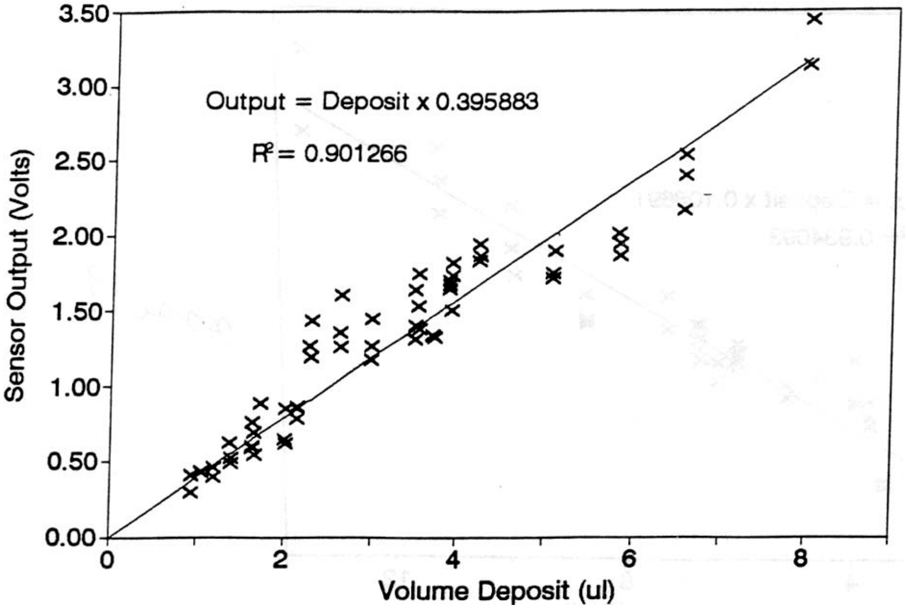

Figure 6. Constant Width Sensor Outputs

The flow rate applied to the variable width sensor ranged from 10.90 to 51.59 mL/min. The 10.90 mL/min flow rate was obtained using an 8001 nozzle at 200 kPa. An 8003 nozzle at 500 kPa produced a flow rate of 51.59 mL/min.

The volume deposit on the sensor ranged from 1.57 to 13.53 ul. Figure 7 illustrates one set of calibration results for the variable width sensor. The linear regression coefficient (R^2) was 0.934 for the variable line sensor.

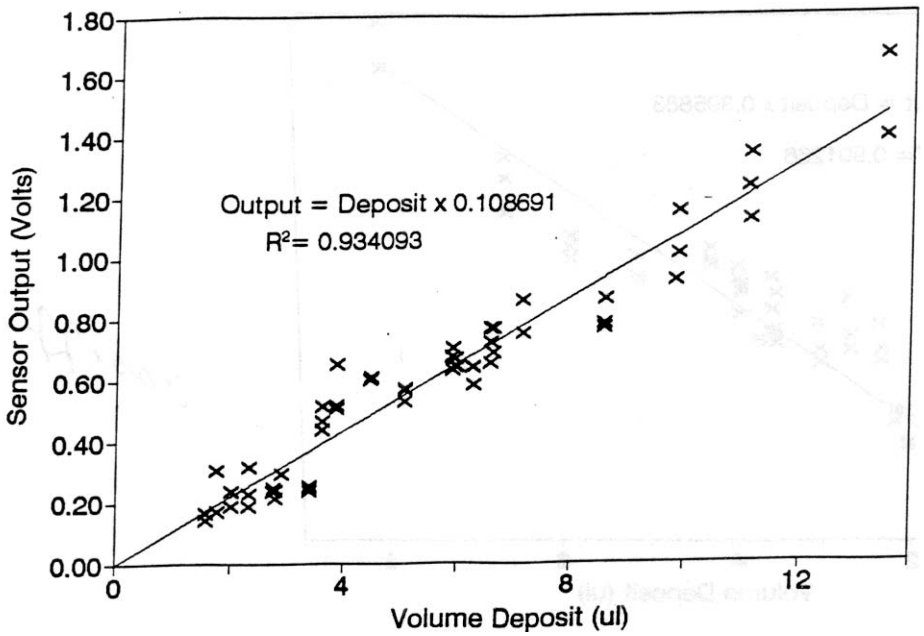

Figure 7. Variable Width Sensor Outputs

CALIBRATION ERRORS

The values of the R^2 for the regression coefficient of the constant and variable line sensor varied from 0.9 to 0.97 for the calibration sets completed. The variation in R^2 was attributed to water temperature changes, boom vibration and spray deposit uniformity. Equations obtained from nozzle distribution patterns may have caused some calibration error since regression lines were used to calculate flow. The effects of water temperature on voltage output are illustrated in Figure 8. Raising water temperature increased voltage output on the sensor.

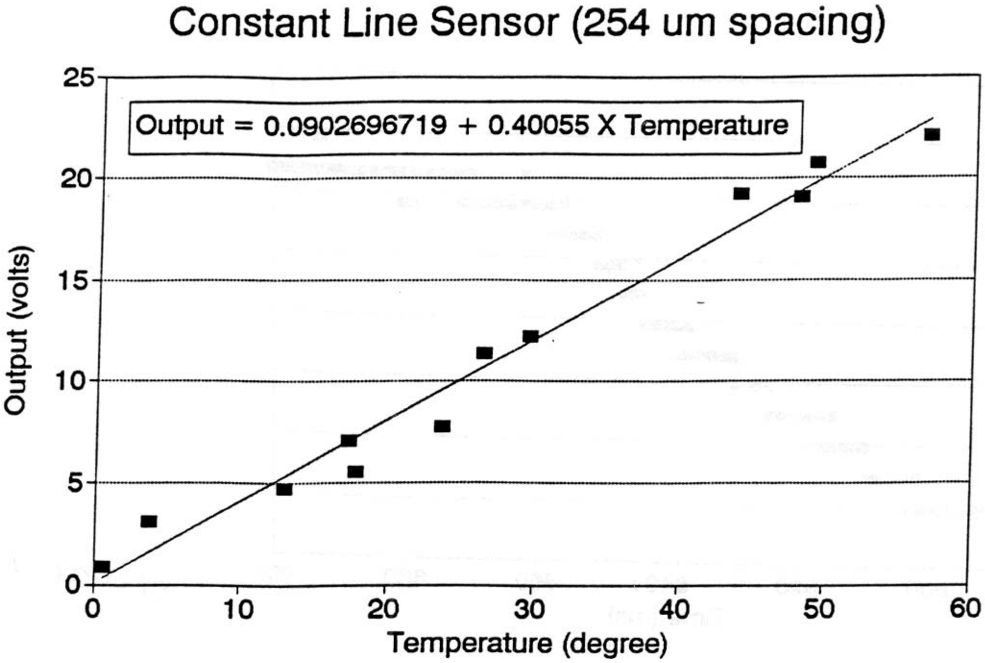

Figure 8. Temperature Correction Curve

A maximum coefficient of variation (CV) of 7.28 percent occurred in the test replications. The high CV illustrated the variation of droplet numbers over the constant sensor with the same nozzle at the same pressure.

Tests were not completed to determine if water properties such as pH or ion concentration would affect results. Further testing should be completed to determine the effects of changing water properties. Salyani and Serdynski (1990) indicated changing water properties affected voltage outputs of a sensor similar to the sensors used in these tests.

DROPLET COUNTS

A test was completed sampling a single line at a rate of 1000 samples per second (Figure 9). The results illustrate the deposit of individual drops on the line. An increase in voltage of 49 mv occurred with each drop applied to the line. The number of droplets landing on each line was determined by dividing the voltage of the line by 49 mv. With the variable line width sensor, an indication of range of droplet size was found (Figure 10). Increasing number and size range of the lines may increase the potential for accurate measurement of droplet size distributions. However, the effects of droplet overlap, large droplets falling on small lines and small droplets combining to contact large lines should be addressed.

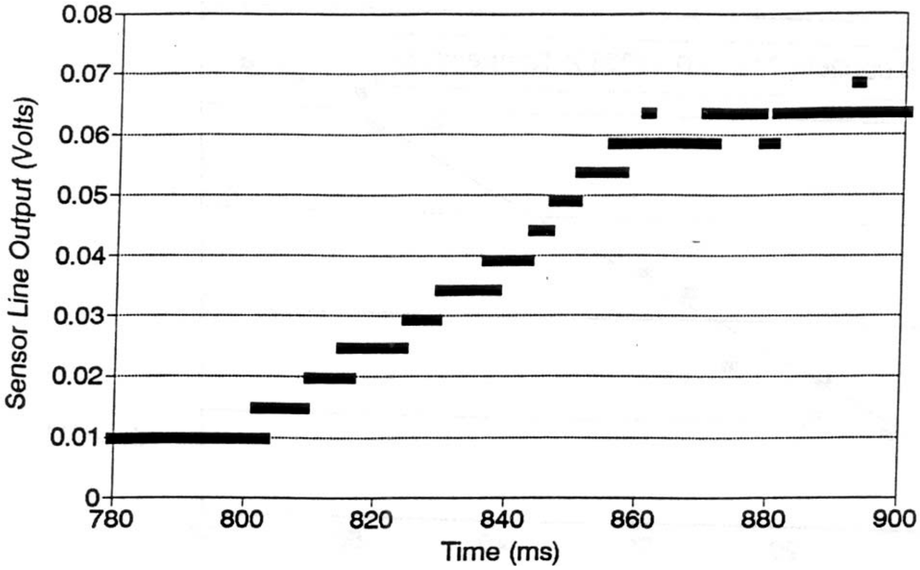

Figure 9. 1000 Samples Per Second Test

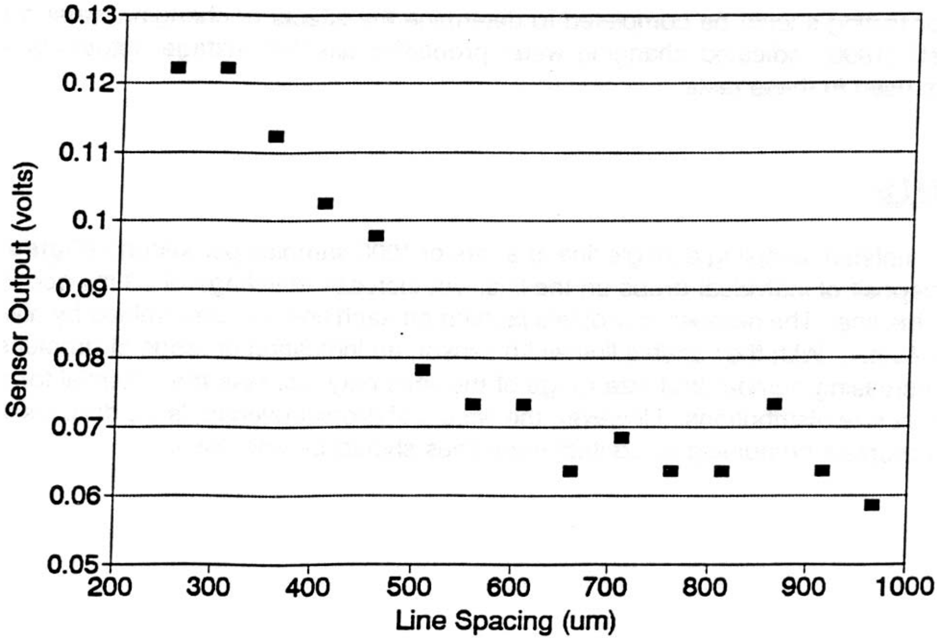

Figure 10. Variable Line Sensor Output

CONCLUSIONS

The sensors developed provided a fast, low cost and accurate method for measuring low volume spray deposit for a range of droplet sizes and velocities.

The calibration curves for the constant width line sensor indicated an R^2 of 0.901 for volumes ranging from 0.93 ul to 8.00 ul. The R^2 for the variable width sensor was 0.934 for volumes of 1.57 ul to 13.53 ul.

The number of drops applied to the sensor was calculated for the sensors. Output from the variable width sensor indicated the range of droplet sizes applied to the sensor.

Errors in calibration may have occurred when calculating flow rates and spray deposits. Errors could have been due to variations in flow rate regressions and spray pattern distributions. Increasing the accuracy of application volumes on the sensor may have improved regression coefficients.

The variable line width sensor gave an indication of range of droplet size deposited. Increasing the number and size range of the lines may increase the potential for accurate measurement of droplet size distributions.

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