Development of a Low-cost Metering Device for Automatic Mixing of Nutrient-Solution

K. H. RYU, K. C. LEE and J. H. LEE
Department of Agricultural Engineering
Seoul National University
Suwon 441-744, Korea

ABSTRACT

A low-cost and precise metering device, which is suitable to automatic mixing of nutrient-solution for hydroponic culture, was developed for small-scale growers. The metering accuracy of the metering device developed was compared with commercial metering pumps. The mixing performance through the control of EC and pH was also evaluated.

The accuracy of the metering device in terms of the full-scale error was ±0.3 %, which was much better compared to ±2.45 % and ±1.38 % for the two types of commercial metering pumps. The mixing system of nutrient-solution with the metering device showed a satisfactory control performance with the accuracies of ±0.05 mS/cm and ±0.2 pH for EC and pH, respectively.

Key Word : metering device, nutrient-solution, automatic mixing, hydroponics

INTRODUCTION

In hydroponics accurate mixing of nutrient-solution is very important since nutrients for plants must be supplied without deficiency or excess. There are two methods to control the concentration of nutrient-solution. One is to use venturi tube, which drafts concentrated nutrient-solution into the water stream flowing in. The other is to use metering pumps or dosing feeders to mix concentrated nutrient-solution with water.

Metering pumps are more precise and convenient to control nutrient-solution than dosing feeders. Therefore, it is common to use metering pumps for an accurate control of nutrient-solution. However, metering pumps are expensive and the variation in discharge rate is rather significant among the individual pumps and the variation tends to increase with the time of operation.

The objective of this study was to develop a low-cost and precise metering device, which can replace metering pumps.

MATERIAL AND METHODS

Metering Device

Supply pump Supply pumps were used to supply concentrated nutrient-solution into metering cylinders. A simple impeller pump, which is inexpensive, chemical resistive and endurable, was selected. The pumps selected are shown in Fig. 1, and their specifications are listed in Table 1.

Metering cylinder Metering cylinders were used to measure and discharge the amount of concentrated nutrient-solution flown into themselves by the supply pumps. They consisted of the three parts, i.e., cylinder, level sensor, solenoid valve. A float-type level sensor, which has a float moving up and down as fluid level changes and a magnet in the float making a reed switch charged electrically, was selected. Fig. 2 shows the overview of the metering cylinders.

The pressure in the metering cylinder increases with depth in fluid. The level sensor gives an electric signal to make the level of fluid constant while the fluid is being discharged. It is possible to get the exact amount of flow by controlling the time of opening solenoid valves.

Venturi Tube A venturi tube was used to prevent the nutrient-solution from flowing backward into the metering cylinder by reducing the fluid pressure instead of increasing the fluid velocity in the tube. The Bernoulli's equation along the center streamline was applied to determine the diameter of the throat as follows.

$$\frac{p_1}{\rho g} + \frac{v_1^2}{2g} + z_1 = \frac{p_2}{\rho g} + \frac{v_2^2}{2g} + z_2 \qquad (1)$$

where p = pressure,
ρ = the density of fluid,
g = gravitational acceleration,
z = elevation.

The flow rate through the tube is given by

$$Q = A \times V = \frac{\pi D^2 V}{4} \qquad (2)$$

where Q = the flow rate through the pipe,
A = the area of the pipe,
V = the average velocity of the fluid,
D = the diameter of the pipe.

From Eq. (1) and (2), the diameter of the throat in the venturi tube can be determined for the given flow rates through the pipe. Fig. 3 shows the diameter of the venturi with respect to the flow rate of fluid, and Fig. 4 shows the shape of the venturi tube developed, assembled with the inlet tubes from the metering cylinder.

Mixing System

Hardware The mixing system consisted of the metering device developed, sensors, supply pumps, solenoid valves, filters, tanks, microcomputer-based data acquisition system. The schematic diagram of the mixing system and the overview of the automatic nutrient-solution mixing system are shown in Fig. 5 and Fig. 6, respectively. Temperature, electric conductivity, pH were selected to measure the performance of nutrient-solution mixing system. The specifications of the sensors used in the experiment are listed in Table 2. A centrifugal pump was selected to supply nutrient solution and agitate it in mixing tank during the time of mixing solutions. Solenoid valves were attached to the outlet of the metering cylinder in order to prevent the fluid in the tube from flowing backward into the metering cylinder while the solutions are not being discharged and in order to stop solutions passing through until the metering cylinder is filled up to the desired level. The size of mixing tank was selected from considering the amount of water to supply for plants and the area of cultivation.

Software The software for the operation of the mixing system was developed by the borland C/C++ developed by Borland Co. The temperature, EC, pH of nutrient-solution were measured and displayed on CRT monitor, the control performance was analyzed with the data processing packages such as EXCEL. The flow chart of the nutrient-solution control program with time-based operation is shown in Fig 7.

RESULTS AND DISCUSSION

Metering Device Fig. 8 shows the regression result between the discharge rate and operating time for the metering device developed. The correlation coefficient between the flow rate and operating time was almost 1, and the linear regression equation computed was $y=21.759x$. The metering device was tested for 600 hours(equivalent to the use of about 4 months), and there was no significant difference in the accuracy of metering. Fig. 9 shows the deviation in flow rate for the metering devices developed, and the deviation between two metering devices tested was ± 0.33 %FS. Fig. 10 and Fig. 11 show the deviation in flow rate for the two types of commercial metering pumps, and the deviation between two metering pumps for each type were ±2.45 % and ±1.38 % respectively, which are much larger compared to the metering device developed.

Mixing System

Electric Conductivity Fig. 12 shows the response of EC control when the EC of nutrient-solution was changed from 1.0 to 1.4 mS/cm with the deadband of ±0.05 mS/cm. It is noticed that EC was controlled step by step and the settling time was about 15 min. The algorithm for EC control was first to raise EC to about 50 % level of the desired, and then to determine the next level according to the previous response. This algorithm for feedback control made the system stable even if users made a mistake in preparing concentrated solutions.

pH Fig. 13 shows the response of pH control. The control algorithm was the same as the EC control except the regression equation was a second-order nonlinear function. The settling time for pH control from 6.4 to 6.0 pH was about 15 min, with the deadband ±0.02 pH. Fig. 14 shows the responses of EC and pH controls for multiple steps of operation.

CONCLUSIONS

A low-cost and precise metering device was developed for the automatic nutrient-solution mixing system for small hydroponic growers. The results of this study are summarized as follows,

1. The correlation coefficient between the flow rate and operating time for the metering device developed was almost 1. The deviation between two metering devices was very low with ±0.33 %FS, while the deviations

between two metering pumps for the two types of commercial metering pumps were ±2.45 % and ±1.38 %, respectively.

2. The mixing system with the metering devices showed an excellent control performance for EC and pH controls. The settling time for EC to change from 1.0 to 1.4 mS/cm was about 15 min. with the deadband of ±0.05 mS/cm. The settling time for pH to change from 6.4 to 6.0 pH was about 15 min. with the deadband of ±0.02 pH.

REFERENCES

1. Benjamin C. KUO. 1995. Automatic Control System. Prentice-Hall, N. J.
2. Frank M. White. 1986. Fluid Mechanics. McGraw-Hill, N.Y.
3. M. Heinen. 1992. Control of the composition of the nutrient solution in an automated NFT system: A Simulation Study. Acta Horticulturae 304: 281-289.
4. P. G. Cook and G. R. Walker. 1992. Depth Profiles of Electrical Conductivity from Linear Combinations of Electromagnetic Induction Measurements. Soil Sci. Soc. Am. J. 56:1015-1022.
5. Thomas G. B., Roy D. M. and John H. L. V, 1993. Mechanical Measurements. Addison-Wesley, N.Y.

Table 1 Specifications of the supply pumps seclected.

Specifications	Supply-Pump
Manufacutrer	KUMIL
Overall Dimensions	200(L)×100(W)×150(H) mm
Pump Casing	Polypropylene
Weight	Approx. 3 kg
Power Required	110/220 V; 50/60 Hz

Table 2 Specifications of the sensors used.

Specifications	Temperature	EC	pH
Manufacturer	KONICS Co.	HANNA Inst.	HANNA Inst.
Range	-200~600 ℃	0~19.99 mS/cm	0~14 pH
Resolution	0.1 ℃	0.02 mS/cm	0.01 pH
Accuracy	±0.1 ℃	±2 %F.S.	±0.02 pH
Sensor Type	Resistance detector	Impedance type	Combination electrode type
Output	4~20 mA	4~20 mA	4~20 mA

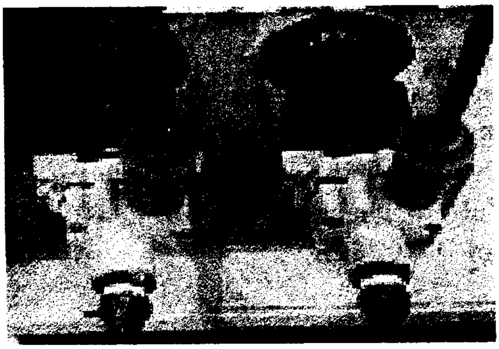

Fig. 1 Supply pumps used.

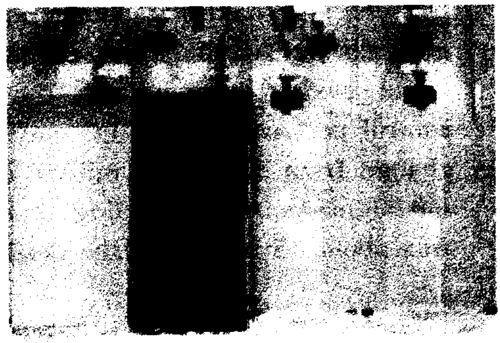

Fig. 2 Metering cylinders developed.

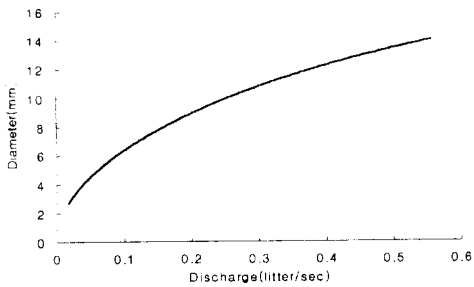

Fig. 3 Relationship between venturi tube diameter and flow rate.

Fig. 4 Venturi tube developed.

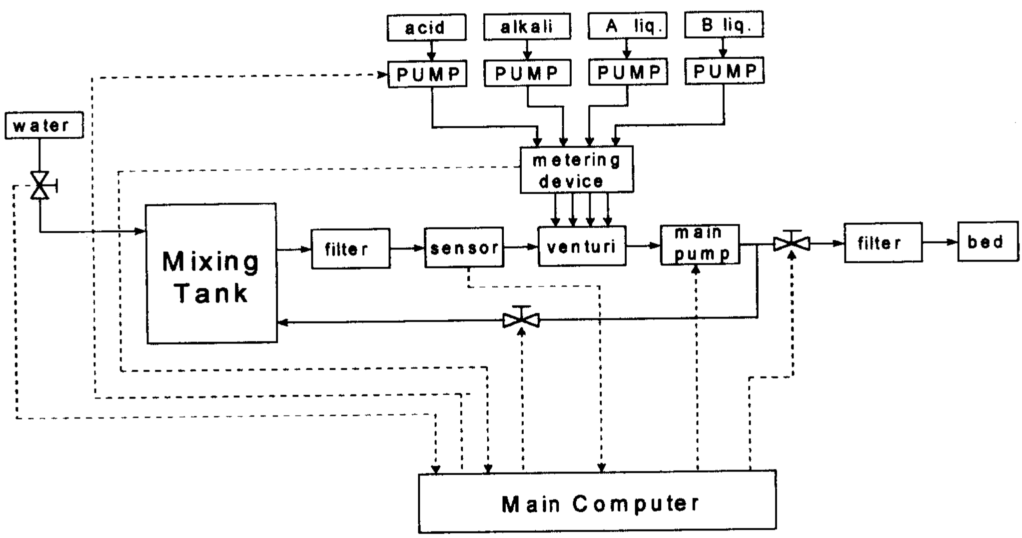

Fig. 5 Schematic diagram of the automatic nutrient-solution mixing system.

Fig. 6 Overview of the automatic nutrient-solution mixing system.

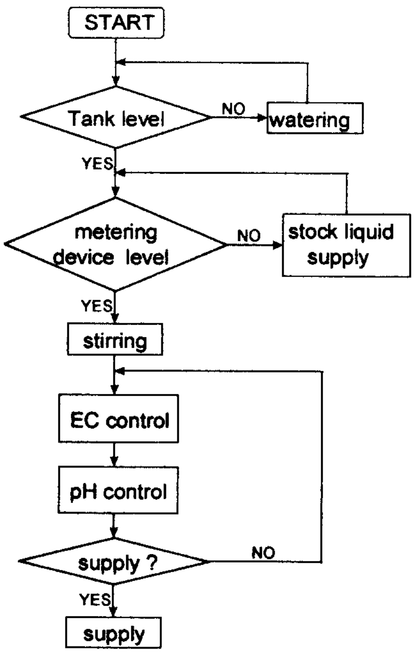

Fig. 7(a) Flow chart of the program for operating the automatic mixing system.

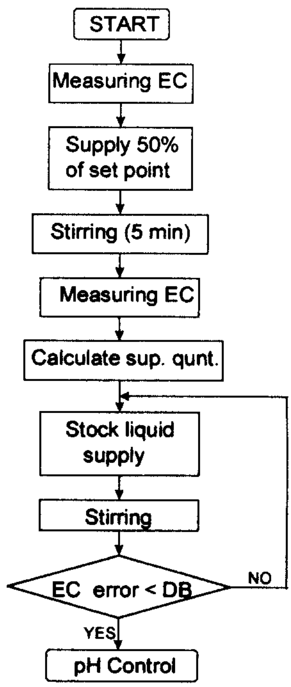

Fig. 7(b) Flow chart of the EC control.

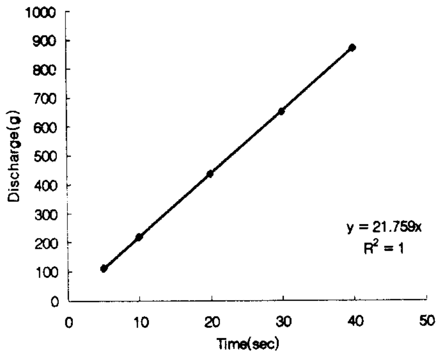

Fig. 8 Regression curve of the metering device developed.

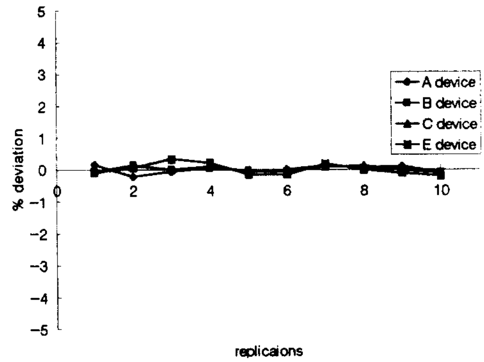

Fig. 9 Deviation in flow rate between the metering devices.

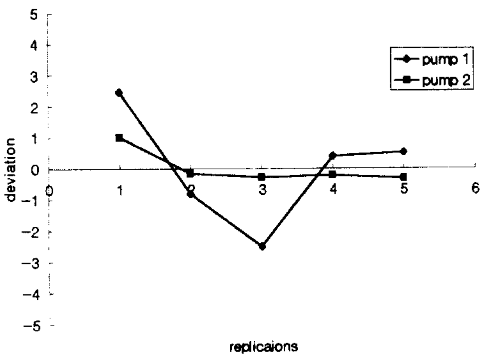

Fig. 10 Deviation in flow rate for the commercial metering pumps A.

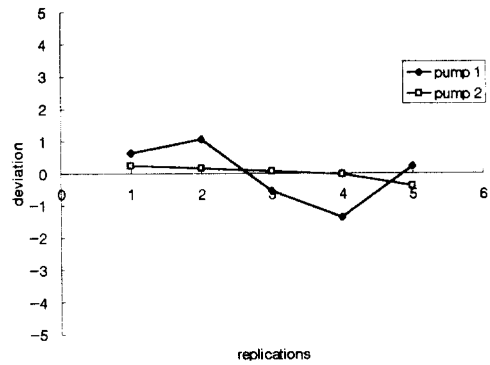

Fig. 11 Deviation in flow rate for the commercial metering pumps B.

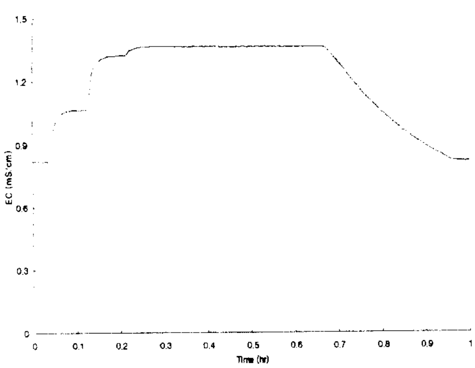

Fig. 12 Performance of the EC control.

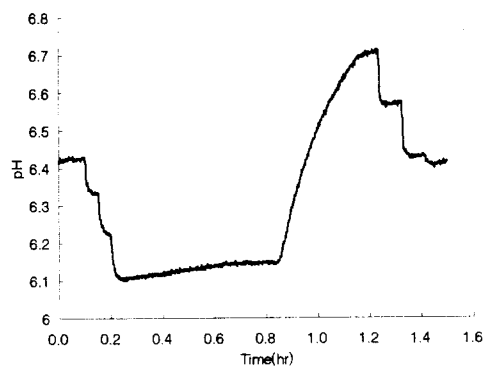

Fig. 13 Performance of the pH control.

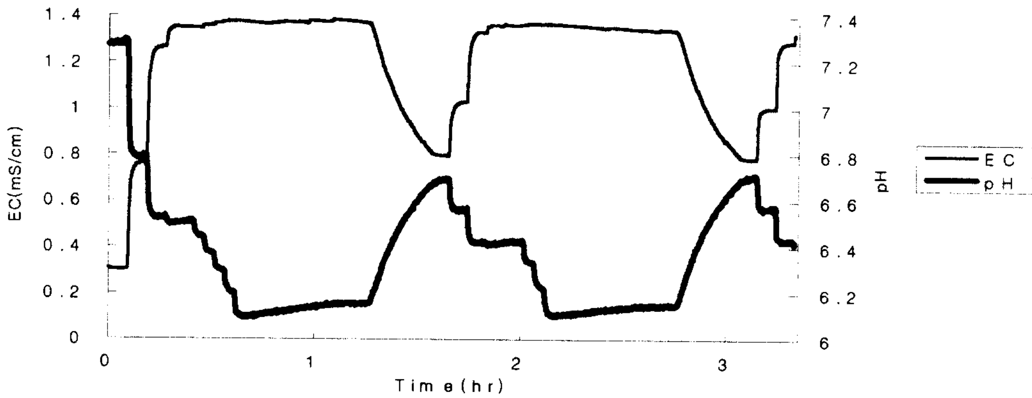

Fig. 14 Responses of the EC and pH control for multiple steps of operation.