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Development of Pressure Discharge Relationship for Rotary Sprinkler Irrigation System

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Abstract

Sprinkler irrigation is an advance method of irrigation through which water can be used effectively. However in the field or during the design of sprinkler irrigation system, sprinkler is associated with the problems like fixation of nozzle size, nozzle elevation and operating pressure to suit the demand of water requirement of crop and other for high water discharge and better performance of sprinkler for high yield of crop. As a step to explore proper solution for above problem, a field investigation was conducted to study the effect of operating pressure on discharge at different nozzle sizes and elevations and for developing prototype sprinkler and designing of sprinkler irrigation system. The discharge was measured at different operating pressure i.e. 0.75, 1.00, 1.25, 1.50, 1.75, 2.00, 2.25, 2.50, 2.75, 3.00, 3.25, 3.50, 3.75 and 4.00 kg/cm^2 with three nozzle elevation i.e. 150, 110 and 75 cm for different nozze sizes i.e. 5.6, 4.7 and 3.1 mm. A pressure discharge relationship for sprinkler irrigation system was used to determine pressure-discharge relationship of sprinkler. It was found that discharge increased with an increase in operating pressure and nozzle size but decreased with an increase in nozzle elevation. Also the pressure had significant effect on discharge than sprinkler nozzle size and nozzle elevation.
Key words : Rotary sprinkler, Pressure-discharge relationship.

Sprinkler irrigation is defined as an irrigation system which distributes water as discrete droplets through the air. Sprinkler irrigation play an important role for efficient utilization of scarce resources like water and save the energy. Sprinkler system having many form of applying water to the field as a spray or rain. The spray is developed by the flow of water under pressure through orifice or nozzle. The pressure is usually obtained by pumping. Sprinkler is affected by wide range of flow rates and pressures. The pressure discharge relationship affects the design and operational efficiency of a sprinkler system. Because irrigation uniformity relates to crop yield and the efficient use of resources, engineers regard it as an important factor to be considered in the selection, design and management of sprinkler irrigation systems (1—9). The specific design requirements of sprinkler irrigation system involve the water application rates based on the infiltration for optimum design and efficient operation of sprinkler irrigation system. Other than this pressure discharge relationship for the sprinkler nozzle is also essential for developing new sprinkler prototypes and designing sprinkler irrigation system. Therefore, a study was undertaken with objective to understand the effect of operating pressure, nozzle elevation and nozzle size on discharge and development of pressure discharge relationship for rotary sprinkler.

Methods

The pressure-discharge relationship was determined at the operating pressure heads of 0.75 to 4.0kg/cm^2 and nozzle elevation of 75, 110 and 150 cm for nozzle sizes 5.6 mm, 4.7 mm and 3.1 mm. The desired pressure was maintained in the system with the help of bypass arrangement and gate valve. The discharge of each nozzle was measured for specified duration of 5 min. Initially, a particular pressure head was maintained in the system. The discharge through the nozzle was collected in container by connecting a flexible tube to the mouth of nozzle. The collected

Table 1. Discharge through different nozzles at different operating pressures and nozzle elevations.

Operating pressure, (kg/cm^2) Elevation (cm)	Observed discharge from 5.6 mm nozzle size (1ph)			Observed discharge from 4.7 mm nozzle size (1ph)			Observed discharge from 3.1 mm nozzle size (1ph)		
	75	110	150	75	110	150	75	110	150
0.75	1370.07	1360.00	1352.41	820.13	720.00	715.23	449.00	428.98	423.29
1	1522.00	1502.21	1479.41	890.00	820.01	807.12	493.12	388.90	484.10
1.25	1648.62	1628.83	1607.82	913.00	902.04	890.27	541.32	534.60	524.21
1.5	1798.00	1778.22	1755.81	999.18	987.98	974.93	591.21	584.70	580.01
1.45	1931.00	1913.30	1890.34	1078.00	1066.46	1053.27	609.70	609.62	602.78
2	2049.00	2031.17	2011.85	143.71	1132.38	1119.35	673.39	664.50	652.80
2.25	2174.00	2152.91	2133.31	1214.00	1203.07	1188.63	738.40	731.17	723.34
2.5	2292.00	2280.54	2262.29	1294.53	1281.06	1267.93	746.50	737.50	725.57
2.75	2407.00	2392.55	2375.80	1369.00	1358.92	1345.60	775.16	790.01	764.03
3	2522.00	2499.30	2477.05	1439.59	1430.95	1419.50	810.25	809.21	800.12
3.25	2605.00	2587.76	2572.23	1503.0	1495.18	1484.56	840.42	832.39	813.28
3.5	2716.00	2700.01	2684.88	1587.29	1579.51	1569.87	865.36	859.23	850.06
3.75	2801.00	2784.19	2770.26	1634.0	1626.48	1616.56	885.21	879.01	870.12
4	2990.12	2889.10	2872.92	1694.79	1686.82	1678.72	910.12	904.12	896.08

volume was measured with the help of graduated measuring cylinder and then was converted into liter per hour.

The pressure discharge relationship for nozzle as proposed by Keller and Karmeli (10) was used which is expresses as

$$Q = KP^X \quad \text{... (1)}$$

Where,Q = flow rate, 1ph, K = characteristics nozzle discharge coefficient, X = nozzle exponent characterizing the nozzle flow regime, P = pressure applied, kg/cm^2.

The value of k and x may be determined by fitting power curve to field data and also analytically by using following equation (10).

$$x = \frac{\log (q_1 / q_2)}{\log (P_1 / P_2)} \quad \text{...(2)}$$

Where, q_1 and q_2 expresses discharge at the pressure P_1 and P_2 respectively. By using the value of x from above equation, the value of K was determined with the help of equation (1).

Similar procedure was adopted for different combinations of above mentioned nozzle elevations and pressures for all above mentioned nozzles sizes. The experiment was repeated three times in each case.

Results and Discussion

Determination of Pressure-Discharge Relationship

For determination of pressure-discharge relationship, the three rotary sprinklers of size 5.6, 4.7 and 3.1mm were run at different operating pressures ranging from 0.75 to 4 kg/cm^2 with nozzle elevation ranging from 75 to 150 cm. The corresponding discharges through different nozzles were determined to develop the pressure discharge relationship.The observed discharge, at different operating pressure and nozzle elevation for different nozzle sizes are given in Table 1 and also shown in Figures 1, 2 and 3. The discharge through the nozzle increases with an increase in nozzle size from 3.1 to 5.6 mm and operating pressure from 0.75 to 4 kg/cm^2 but decreased with an increase in nozzle elevation from 75 to 150 cm due to head loss (Table 1).

Figures 1, 2 and 3 show that the discharge increased with an increase in nozzle size and pressure for a range of 5.6, 4.7 and 3.1 mm and for 0.75 to 4 kg/cm^2 respectively. It is observed that rate of increase of discharge during the range of operating pressure from 3.75 to 4.0 kg/cm^2 for 5.6 mm nozzle, 2.75 to 3.0 kg/cm^2 for 4.7 mm nozzle size and1.75 to 2.0 kg/cm^2 for 3.1 mm nozzle size and is lowest from 3 to 3.25 kg/cm^2, 3 to 3.25 kg/cm^2 for 5.6, 4.7 mm nozzle size respec-

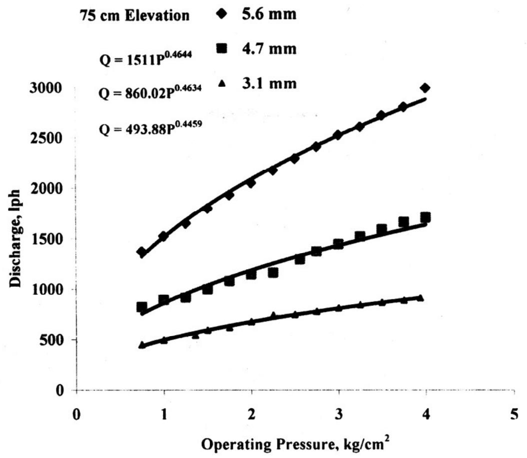

Figure 1. Effect of operating pressure on nozzle discharge at 75 cm nozzle elevation.

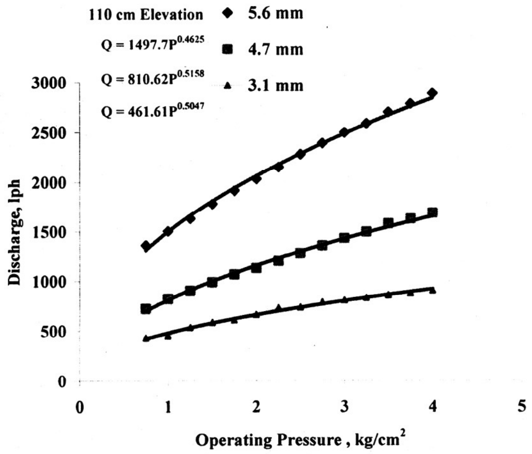

Figure 2. Effect of operating pressure on nozzle discharge at 110 cm nozzle elevation.

tively and 3.5 to 3.75 kg/cm^2 for 3.1 mm nozzle size.

The results show that an operating pressure increased from 0.75 to 4.0 kg/cm^2 (433 per cent) the discharge increased from 1370.07 to 2990.12 1ph (118.24%), 820.13 to 1703.01 1ph (107.65%) and 449 to 910.00 1ph (102.67 per cent) for 5.6, 4.7 and 3.1 mm nozzle sizes respectively. As the nozzle size increased from 3.1 to 5.6 mm (80.64%), the dischage increased 449.00 to 820.13 (82.65%) at 0.75 kg/cm^2 operating pressure, 820.13 to 1370.07 (67.05%) at 0.75 kg/cm^2 operating pressure for 3.1 to 4.7 mm nozzle size respectively. Similar trend followed by various measured operating presure range with their respective sizes. Table 1 shows that an increase in nozzle elevation causes a reduction in discharge at all operating pressure between 0.75 to 4.0 kg/cm^2, however a change in nozzle elevation results more variation in discharge at lower values of operating pressures.

There was no significant difference in average discharge rate at all operating pressures with nozzle elevation 75, 110 and 150 cm, for 5.6 mm, at 150 cm for 4.7 mm and 75 and 110 cm for 3.1 mm nozzle sizes. The decrease in discharge was found to be 0.23 to 1.80% for 5.6 mm nozzle size, 1.36 to 4.00% for 4.7 mm nozzle size and 2.08 to 4% for 3.1 mm nozzle sizes as the nozzle elevation is changed from 75 to 110, 110 to 150 and 75 to 150 cm for 5.6, 4.7 and 3.1 mm nozzle sizes respectively for operating pressure increased from 0.75 to 4.0 kg/cm^2. To derive mathematical relationship between operating pressure and discharge, equation 1 was used. The resulting pressure discharge relationship for 5.6 mm nozzle size (Table 2 equation 1.1 to 1.3), for 4.7 mm nozzle size (equation 1.4 to 1.6) and for 3.1 mm nozzle size (1.7 to 1.9) at different elevation are derived (Fig. 1, 2 and 3 and Table 2).

The value of discharge exponent obtained for 5.6, 4.7 and 3.1 mm nozzle sizes were between 0.44 to 0.51 which, is with in the range of 0.4 to 0.6 for sprinkler nozzles. Based on discharge exponent values,

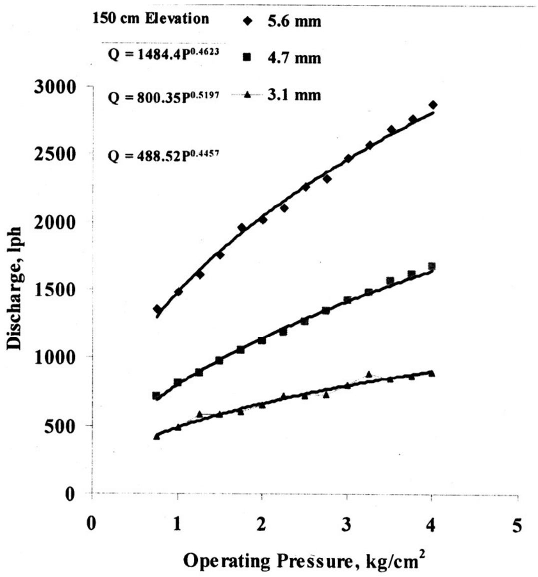

Figure 3. Effect of operating pressure on nozzle discharge at 150 cm nozzle elevation.

Table 2. Equations showing pressure-discharge relationship at different nozzle elevation.

Equation no.	Developed equation	Value of correlation coefficient (r^2)	Nozzle elevation (cm)
1.1	$Q = 1511\ P^{0.4644}$	0.98	75
1.2	$Q = 1497.7\ P^{0.4625}$	0.98	100
1.3	$Q = 1484.4\ P^{0.4623}$	0.98	150
1.4	$Q = 860.02\ P^{0.4634}$	0.98	75
1.5	$Q = 810.62\ P^{0.5158}$	0.98	100
1.6	$Q = 800.35\ P^{0.5197}$	0.98	150
1.7	$Q = 493.88\ P^{0.4459}$	0.98	75
1.8	$Q = 461.61\ P^{0.5047}$	0.96	100
1.9	$Q = 488.52\ P^{0.4457}$	0.97	150

the hydraulic performance of each nozzle was characterized as suggested by Keller and Karmeli (10) which indicated that all sprinkler nozzle sizes have turbulent flow. The value of correlation coefficient for developed pressure relationship was in the range of 0.96 to 0.98 and the correlation was found to be significant at a level of 1 and 5% level of significance. Thus, it can be very well infer that, the developed pressure discharge relationship may be used for predicting the discharge through 5.6 mm, 4.7 and 3.1 mm nozzle size respectively at different operating pressure and nozzle elevations.

A pressure discharge relationship was developed as described by Keller and Karmeli (10) of the form $Q = KP^x$ where Q, is discharge in 1ph, K is coefficient of proportionality, P is pressure in kg/cm^2 and x is nozzle discharge exponent. The discharge was measured with the help of flexible tubes connecting to nozzle mouth and stored it in a container.

The discharge was measured for a specified duration of 5 minutes. The value of characteristics nozzle discharge coefficient (K) and nozzle exponent (x) were estimated for all three nozzle at different pressure and nozzle elevation. The values of x so estimated were used to represent the mathematical relationship between pressure and discharge. It value of discharge exponent (x) was found in the range of 0.41 to 0.566 which is within the range recommended by Keller and Karmeli (10).

The developed pressure-discharge relationship for different nozzle size, at different pressure and different nozzle elevation may well be used for prediction of discharge as the value of discharge exponent (x) was found in the range of 0.41 to 0.566 which is within the range recommended by Keller and Karmeli (10) for sprinkler nozzle and the value of r^2 ranged from 0.96 to 0.98.

Conclusion

The developed presure-discharge relationship for different nozzle size, at different pressure and different nozzle elevation may well be used for prediction of discharge as the value of discharge exponent (x) was found in the range of 0.41 to 0.566 which is within the range recommended by Keller and Karmeli (10) for sprinkler nozzle and the value of r^2 ranged from 0.96 to 0.98.

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