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Hydraulic performance of manually operated drip irrigation system

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ABSTRACT

In drip irrigation system the hydraulic parameters such as pressure discharge relationship, manufacturing coefficient of variation, mean flow rate deviation, coefficient of discharge, emitter discharge exponent, field emission uniformity and absolute emission uniformity can be used for the design, operation and selection of the irrigation system. The field experiment was conducted to evaluate the performance of manually operated drip irrigation system for different types of emitters. For the experiment three different types of emitter's *viz*. 2 lph, 4 lph and 8 lph were fitted on three laterals each of 10 m length. The emitters and lateral spacing was 1 m. The system was operated at varying pressures between 0.4 to 1.4 kg/cm^2 with an increment of 0.2 kg/cm^2. The emitter flow rate was measured in the catch cans. Results show that the emitters based on the hydraulic parameters were characterized as average. The field and absolute emission uniformity was above 90 %. The system performed better in the range of 0.6 to 1.0 kg/cm2 with highest emission uniformity. The overall quality of emitters was better for high nominal discharge rates. These hydraulic parameters of emitters evaluated can be used for the design, operation and selection of the irrigation system. The manually operated system thus can be used form small farms.

Key words : Emission uniformity, Emitting devices quality, Pressure-discharge relationship, Mean flow rate deviation and emitter discharge exponent

Agriculture sector contributes nearly 35 per cent of national income and engages 70 per cent of Indian population. Water is the most vital input in agriculture and has made a significant contribution in providing stability to food grain production and self-sufficiency. Efficient utilization of available water resources is crucial for a country like India, which shares 17 % of the global population with only 2.4 % of land and 4 % of water resources. In Maharastra while 80 % cultivable land depends on rainfall, efficient utilization of available water resources in the state is crucial for its agricultural development (Anonymous, 2006). Irrigation meets the water demands of plants by replenishment of root zone when natural rainfall is inadequate or poorly distributed. Within a field, irrigation water needs to be distributed uniformly to all plants. However, in most cases non-uniformity in irrigation water supply is the major source of reduced crop yields (Wu, 1987; Bhatnagar and Srivastava, 2003).

On the contrary, drip irrigation system can apply frequent and small amounts of water at many points in the field with minimum losses and maintaining steady moisture in the soil profile. In addition, drip irrigation system is best suited for difficult topography (Decroix and Malaval, 1985; Youngs *et al*., 1999 and Wei *et al*., 2003) and offers the highest irrigation uniformity compared to other irrigation methods. A successful uniform drip irrigation system application depends on the physical and hydraulic characteristics of the drip tubing (Al Amound, 1995). Efficiency of drip irrigation system depends on application uniformity which can be evaluated by direct measurement of emitter flow rates. According to Mizyed and Kruse (1989), the main factors affecting drip irrigation uniformity are manufacturing variations in emitters and pressure regulators, pressure variations caused by elevation changes, friction head losses throughout the pipe network, emitter sensitivity to pressure, irrigation water temperature changes and emitter clogging. Similarly, Capra and Scicolone (1998) indicated that the major sources of emitter flow rate variations are emitter design, the material used to manufacture the drip tubing and precision.

The uniformity and general performance of drip irrigation systems are affected by hydraulic design, emitter manufacturer's coefficient of variation, grouping of emitters, and emitter clogging amongst other factors (Mofoke *et al.,* 2004). Coefficient of variation gives more critical interpretation of hydraulic characteristics as compared to emission uniformity (Mokashi *et al*., 1998). Most of the time actual coefficient of variation was higher than those claimed by manufacturers for pressure compensating emitters (Ozenkici and Sneed, 1995) hence the design should be base on reliable test data and not on data supplied by manufacturers.

Many different systems for drip irrigation are in use in the modern agriculture. Their main advantages are that they permit the economical usage of water (up to 50% reduction in the quantity of water used), the automation of the irrigation processes and the ability to make local water irrigation in steep terrain. Although major part of irrigation is surface irrigation, in recent years farmers have slowly accepted drip irrigation technology for irrigating vegetables and horticulture crops. More than 70 per cent of Indian farmers are small-scale operators cultivating plots of less than one hectare. Erratic rainfall pattern plays an important role for small farmers who do not have any alternate supply of water (Florov, 2002). The studies on evaluation of the hydraulic characteristics of drip irrigation tubing sold in the region are limited. Therefore, the study was aimed at comparing the manufacturers' reported discharge rate and the coefficients of manufacturing variation values of popular drip tubes widely used in the region with measured values.

The drip irrigation is one of the methods that can help to increase irrigation potential by optimizing the use of limited available water resources. However, the farmers of Konkan region of Maharashtra are marginal farmers having terrain and sloping small fields with limited water available for irrigation. In addition there are other problems in adopting drip systems in the region such as high initial cost, high operational and maintenance cost, irregular supply of electricity in rural areas. The pumps for regular drip systems are not economical and effective for small fields. A manually operated drip irrigation system can overcome these limitations, which does not need electricity or any fuel energy and can be operated with available man power. Studies on hydraulic performance of such manually operated systems are also lacking. The present study therefore is aimed at developing a manually operated drip irrigation system and testing its hydraulic performance for a small field.

METHODOLOGY

The study was carried out at the Research Farm of Dr. Budhajirao Mulik College of Agricultural Engineering and Technology, Mandki-Palvan. The emitters with rated flow rates of 2, 4 and 8 lph were selected for the performance tests of manually operated drip irrigation system. The experimental field consisted of three laterals each of 10 m length on which 10 emitters spaced at 1 m were placed. Similarly the laterals were also placed at 1 m. Emitter flow rates were measured at the operating pressure range of 0.4 to to 1.4 kg/cm^2 with an increment of 0.2 kg/cm^2. The pressure was maintained in the laterals by adjusting ball valves located at mainline. The catch cans were placed below the emitter for discharge measurements (Fig.1).

Fig. 1 : Experimental set up for catch cans

The prime mover was rocker sprayer which creates the pressure in the system. The pressure chamber made up of brass with pressure guage was attached to the system. The handle of the regular rocker sprayer was replaced by the pedal operated cycle mechanism. The chain is made up of number of rigid links which are hinged together by pin joints in order to provide the necessary flexibility for wrapping round the driving and driven wheels. These wheels have projecting teeth of special profile and fit into the corresponding recesses in the links of the chain. The power transmission to the sprayer was given by reciprocating motion. The main frame of M.S. angle of size 89x84x90 cm was fabricated and a stand of 54x27x40 cm was made on which the pressure chamber of rocker sprayer was placed (Fig.2). The pedal of the rocker sprayer was replaced by the chain and gear mechanism. The velocity ratio of chain was estimated as:

Fig. 2 : Power transmission system for manually operated drip system

$$VR = N1 / N2 = T2 / T1 \quad (1)$$

where, VR= velocity ratio; N_1 = speed of rotation of smaller sprocket, rpm; N_2 = speed of rotation of larger sprocket, rpm; T_1 = Number of teeth on the smaller sprocket = 18 and T_2 = Number of teeth on the larger sprocket = 44.

The length of chain was 136 cm and the center distance between sprockets was 47 cm. The revolutions per minutes of the sprocket reduce as the chain pitch increases for a given number of teeth. The performance of system was tested using the following parameters:

Manufacturing coefficient of variation (Cv):

The manufacturing coefficient of variation describes the quality of process used to manufacture them and can be estimated using following equation (Keller and Karmeli, 1974):

$$Cv = SD / q_a \quad (2)$$

where, Cv = manufacturing coefficient of variation, SD= Standard deviation, q_a = average discharge in lph.

$$SD = \frac{(q_1^2 + q_2^2 + q_3^2 + \ldots\ldots + q_n^2 - n \times q_a^2)^{1/2}}{(n-1)^{1/2}} \quad (3)$$

where, q_1, q_2, q_3 are discharges of emitter 1, emitter2, emitter 3; q_n = discharge of n[th] emitter, lph; q_a = average emitter discharge, lph and n = total number of emitters.

Mean flow rate deviation:

$$Qd = \frac{(q_r - q_a)}{q_r} \times 100 \quad (4)$$

where, Qd = Mean flow rate deviation (%), q_r = Rated emitter discharge, lph and q_a = Average emitter discharge, lph.

The quality of emitter based on the values of manufacturing coefficient of variation suggested by ASAE (ASAE, 1985) is presented in Table 1.

Table 1 : ASAE recommended classification of manufacturers coefficient of variation

Emitter type	Cv	Interpretation
Point Source	< 0.05	Excellent
	0.05 - 0.07	Average
	0.07 - 0.11	Marginal
	0.11 - 0.05	Poor
	> 0.15	Unacceptable
Line Source	< 0.10	Good
	0.10 - 0.20	Average
	> 0.20	Marginal to unacceptable

The manufacturing coefficient of variation (Cv) and mean flow rate deviation (Qd) at a nominal pressure of 1.0 kg/cm^2 for all tested emitters were estimated.

Hydraulic characteristics:

Over the range of discharge the flow characteristics of emitters can be characterized by:

$$Q = K_d H^x \quad (5)$$

where, q = emitter discharge, lph; K_d = constant of proportionality that characterizes each emitter; H = working pressure head at the emitter; m and x = emitter discharge exponent characterized by the flow regime.

To determine K_d and x, the discharges at different operating pressure heads must be known. The exponents x may be determined by measuring the slope of log-log plot of pressure head (H) vs discharge (q) or analytically by,

$$X = \frac{\log\left[\frac{q_1}{q_2}\right]}{\log\left[\frac{H_1}{H_2}\right]} \quad (6)$$

where, x = emitter discharge exponent, q_1 = Emitter discharge at H_1, lph. q_2 = Emitter discharge at H_2 , lph and H_1, H_2 = Pressure heads in m.

The value of x can be used in equation 5 to solve for K_d. the value of x characterizes the flow regime and discharge verses pressure relationship of the emitter. The lower the value of x, the less discharge will be affected by pressure variations. In fully turbulent flow x = 0.5 and in laminar flow x = 1.0. Non-compensating orifice and nozzle emitters are always fully turbulent with x = 0.5. However, the exponent of long-path emitters may range anywhere between 0.5 and 1. For different flow regime expected values of x are given in Table 2.

Table 2 : ASAE recommended Emission device classification (1985)

Flow regime	X – value	Emitter type
Variable flow path	0.1	Pressure
	0.2	compensating
	0.3	
Vortex flow	0.4	Vortex
Fully turbulent flow	0.5	Orifice, Tortuous
Mostly Turbulent flow	0.6	Longer spiral path
	0.7	
	0.8	
Mostly laminar flow	0.9	Micro tube
Fully laminar flow	1.0	Capillary

Operational characteristics:

To define uniformity of water application of a micro irrigation system, Keller and Karmeli (1974) suggested two parameters namely Field Emission Uniformity and Absolute Emission Uniformity characterized by,

$$Euf = \frac{q_n}{q_a} x 100 \quad (7)$$

where, q_a = Average emitter flow rate, lph and q_n = average emitter flow rate of n^{th} emitter, lph.

$$Eua = \frac{1}{2} x \left[\frac{q_{min}}{q_a} + \frac{q_a}{q_{max}}\right] x100 \quad (8)$$

where, Euf = Field emission uniformity, %; Eua = Absolute emission uniformity, %; q_a = Average emitter flow rate, lph; q_{min} = Average of lowest ¼ of emitter flow rate, lph and q_{max} = Average of highest $^1/_8$ of emitter flow rate.

RESULTS AND DISCUSSION

Manufacturing coefficient of variation (Cv) and mean flow rate deviation (Qd) at nominal pressure (1 kg/cm^2) for all the tested emitters is shown in the Table 3. Data indicate that the average discharge (Qa) of emitters at nominal operating pressure (1 kg/cm^2) is higher than the rated discharge. The manufacturing coefficient of variation decreases with increase in its nominal discharge for same type of emitters whereas mean flow rate deviation for tested emitter was minimum for 4 lph emitter and maximum for 8 lph emitters.

The tested emitters were found to be average in quality as per ASAE (1985) recommendations, at operating pressure of 1 kg/cm^2.

The relationship between operating pressure and corresponding emitter discharge for all tested emitter is depicted in Fig. 3. With increase in operating pressure, emitter discharge increases and show a linear trend for the range of pressures used in this study (Fig.3). Theoretically the coefficient of discharge of an emitter should remain constant. However there exists a slight variation with pressure (Table 3). It was observed that the K_d is greater than its nominal value because of improper punching of laterals.

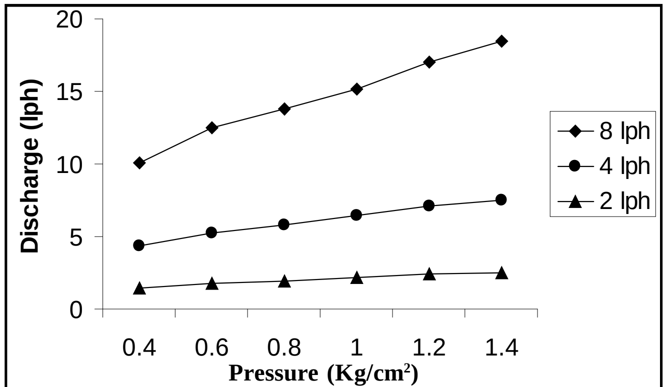

Fig. 3 : Relation between operating pressure and corresponding emitter

Similarly the emitter discharge exponent value (x) should be constant for an emitter hoverer, for some emitter the variations in the value of x are observed (Table 4). Emitter having minimum (K_d) value may be suitable for use in pressure range but, here it can be seen that for most of emitters, x value lies from 0.3 to 0.7 *i.e.* from vortex flow to mostly turbulent flow range according to ASAE -emission device classification. When the value of x is less than 0.30 then the flow is variable and pressure compensating. Remaining tested emitter's lies in fully turbulent flow to mostly turbulent flow regime according to exponent x.

Table 4 : Emitter discharge exponent of the tested emitter for different pressure range

Emitter	Pressure range (kg/cm^2)				
type	0.4-06	0.6-0.8	0.8-1.0	1.0-1.2	1.2-1.4
2 lph	0.42	0.40	0.39	0.60	0.26
4 lhp	0.46	0.36	0.47	0.50	0.39
8 lph	0.34	0.32	0.39	0.71	0.67

The field emission uniformity and absolute emission uniformity of the emitters at different operating pressures is presented in Table 5 and 6, respectively. The data indicate that the value of emission uniformity of all the emitters under study remains above 90 per cent (Table 5). All the emitters performed better at the pressure range of 0.6 to 1.4 kg / cm^2 with the emission uniformity of above 95 %. It can also be seen that variations in absolute

Table 3 : Coefficient of discharge of emitter at different pressure ranges

Emitter	Pressure range (kg/cm^2)				
type	0.4-06	0.6-0.8	0.8-1.0	1.0-1.2	1.2-1.4
2 lph	2.17	2.15	2.14	2.15	2.286
4 lhp	4.40	4.18	4.31	4.29	4.385
8 lph	7.78	8.55	8.70	8.7	8.80

Table 5 : Field emission uniformity, Euf (%) of emitters at different operating pressures

Emitter	Operating pressure (kg/cm^2)					
type	0.4	0.6	0.8	1.0	1.2	1.4
2 lph	92.29	96.46	96.54	94.90	93.75	94.40
4 lhp	90.09	98.56	95.33	97.43	96.23	96.40
8 lph	93.33	97.10	95.00	96.32	98.58	95.64

Table 6 : Absolute emission uniformity Eua (%) of emitters at different operating pressures

Emitter type	Operating pressure (kg/cm^2) 0.4	0.6	0.8	1.0	1.2	1.4
2 lph	95.54	96.09	94.38	95.89	93.75	93.49
4 lhp	90.56	98.02	96.06	97.02	96.54	96.36
8 lph	93.93	97.88	94.88	96.65	98.20	94.02

emission uniformity with pressure were similar to the field emission uniformity. However the values of field emission uniformity are lower than the absolute emission uniformity.

The results thus indicate that the hydraulic parameters such as manufacturing coefficient of variation, mean flow rate deviation, coefficient of discharge, emitter discharge exponent, field emission uniformity and absolute emission uniformity can be used for design and operation of manually operated drip irrigation system. The study indicated that the operating pressure affects flow rates of emitters and their relationship is linear. The operating pressure of 1.0 kg/cm^2 is optimum for average emitter performance.

Conclusion:

Based on the hydraulic characteristics of the manually operated drip irrigation system it can be concluded that such system operated by the rocker sprayer can successfully to be used in small farm.

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