



Development and evaluation of low head and minimum pressure drop equipment for fertilizer application through drip irrigation system

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ABSTRACT

The different methods of fertilizer application through drip irrigation system are By-pass tank, Venturi and pump system and the venturi is most commonly used for fertilizer application through drip irrigation system, the main limitations of venturi are large pressure drop and high head requirement for its operation. So equipment called as orifice meter was developed for the fertigation purpose in the drip irrigation system which operates at inlet pressure below 1 kg/cm². Six different sizes of orifice meters developed and evaluated at the Research farm, Department of Soil and Water Engineering, Punjab Agricultural University, Ludhiana. Four orifices having diameter 3.18 mm and thickness 25.4 mm, 19.05 mm, 12.7 mm and 9.53 mm and two orifices of diameters 2.38 mm and 1.59 mm with thickness 12.7 mm. were evaluated in the range of 0.42 to 0.944 kg/cm². The maximum injection rate was of 45 lph of orifice meter having diameter 3.18 mm and thickness 12.7 mm operating at inlet pressure 0.702 kg/cm² found to be best. The developed equipment is also suitable for farmers having small land holdings or in greenhouse.

Key words: Drip irrigation, Fertigation, Orifice meter, Venturi

Drip irrigation offers several advantages like higher irrigation efficiency, labour and energy savings, improvement in quality and yield of produce, opportunity to manipulate inputs as per the crop demands etc. over the conventional irrigation techniques. Black (1976), Miller *et al.* (1976) and Kaneworthy (1979) and Smith *et al.* (1979) indicated that up to 50 per cent fertilizer can be saved when applied through drip irrigation system.

Fertigation is the technique of supplying water soluble fertilizers to crops through an irrigation system. It has become a common practice in modern agriculture. Fertigation through drip irrigation can yield a fertilizer savings in the range of 25 to 50 per cent (Haynes 1985). Fertilizers can be injected into irrigation systems by the three principal methods: (i) By-pass tank (ii) Venturi and (iii) Pumps, and venturi is considered as the best mechanism for fertigation. The main limitations of venturi are large pressure drop and high head requirement for its operation, ie Lewitt (1952) gave the mathematical equation for measurement of flow by pipe orifice. Ree (1977) conducted experiment on accuracy of shop made orifice plates. The result indicated that shop-built orifices, when

used without correcting to true diameter, may yield errors in a discharge estimate as large as 15% for the 2.54 cm diameter orifice and 6% for the three larger (4.44, 6.35, 8.89 cm) orifices. Eisenhauer and Bockstadter (1990) studied on injection pump flow considerations for center pivots with corner watering systems and concluded that injecting chemicals at constant rates into center pivots equipped with either guns or swing-booms results in systematic chemical application rate errors due to the variable wetted radius of the irrigation system. Replogle and Wahlin (1994) constructed special venturi meter from plastic pipe fitting attempted to address these economic limitations, fouling problems and water management requirements. Thirty venturi meters were constructed. It was established that individual calibrations are not required for effective application in irrigation practice. Camp *et al.* (2000) conducted experiment to develop a variable rate, digitally controlled metering device to permit variable flow of a fluid. The device consists of a reservoir that was alternatively filled and emptied at a rate dependent upon a digital pulse from an external source. The above review shows that there are number of methods such as by-pass tank, venturi, pumps etc. for fertilizer application through drip irrigation system. The most commonly used device for fertilizer application is venturi. But it needs high pressure head, ie 1 kg/cm² to 4 kg/cm² for its operation. So, it was thought of to develop another equipment which can operate

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at low head for fertilizer application through drip irrigation system. It will also be useful for farmers having small land holdings or in greenhouses.

MATERIALS AND METHODS

As the water was flowing through the orifice meter the velocity in the orifice is increased due to decrease in the area of flow. This increase in velocity is accompanied by a consequent reduction of pressure. This pressure and velocity are related through Bernoulli's theorem. Hence the orifice meter was developed on the basis of Bernoulli's theorem.

Where, a_1 , cross-sectional area of inlet pipe (mm^2); a_2 , cross-sectional area of orifice meter (mm^2); D , diameter of inlet pipe (mm); d , diameter of orifice meter (mm); V_1 , Velocity of water approaching orifice meter (m/s); V_2 , Velocity of water through orifice meter (m/s); p_1 , pressure of fluid before orifice meter (kg/cm^2); p_2 , pressure of fluid after orifice meter, (kg/cm^2); h , measured difference of pressure (cm); w , unit weight of water (kg/cm^3).

Applying Bernoulli's equation to both sides of orifice connected horizontally.

$$\frac{p_1}{w} + \frac{V_1^2}{2g} + Z_1 = \frac{p_2}{w} + \frac{V_2^2}{2g} + Z_2 \quad (3.2)$$

Since it was horizontal, hence $Z_1=Z_2$

The equation (3.2) becomes

$$\frac{p_1}{w} + \frac{V_1^2}{2g} = \frac{p_2}{w} + \frac{V_2^2}{2g}$$

$$\text{or} \quad \frac{p_1}{w} - \frac{p_2}{w} = h = \frac{V_2^2 - V_1^2}{2g}$$

By applying continuity equation

$$\text{The rate of discharge} = Q = a_1 V_1 = a_2 V_2 \quad (3.3)$$

$$\text{or} \quad V_1 = \frac{a_2 V_2}{a_1}$$

Substituting for V_1 from equation (3.3)

$$h = \left(V_2^2 - V_2^2 \frac{a_2^2}{a_1^2} \right) \times \frac{1}{g}$$

$$= \frac{V_2^2}{2g} \left[1 - \left(\frac{a_2}{a_1} \right)^2 \right]$$

$$\text{or } h = \frac{V_2^2}{2g} \left[1 - \left(\frac{d}{D} \right)^4 \right]$$

$$\text{or } V_2 = \sqrt{\frac{2gh}{1 - \left(\frac{d}{D} \right)^4}}$$

Then

$$Q_{th} = a_2 V_2$$

$$= a_2 \sqrt{\frac{2gh}{1 - \left(\frac{d}{D} \right)^4}}$$

Where, Q_{th} , Discharge rate without the equipment (lph).

Owing to losses due to passage of the fluid through the orifices, this equation multiplied by a constant known as coefficient of discharge

$$Q_{act} = C_d a_2 \sqrt{\frac{2gh}{1 - \left(\frac{d}{D} \right)^4}}$$

Where, Q_{act} , Discharge rate with equipment (lph); C_d , coefficient of discharge.

Due to drop in pressure in the orifice meter, water soluble fertilizer was injected into the orifice meter. Then it was mixed with the water flowing through the orifice meter.

The discharge rate at the outlet, ie from the emitters was given by the following equation.

Calculation of coefficient of discharge (C_d)

$$C_d = Q_{act}/Q_{th}$$

$$Q_{act} = Q_e * N$$

Where N , Total no. of emitters in the given area of fertigation; Q_e , emitter discharge rate (lph); Q_{th} , discharge rate without the equipment (lph).

Calculation of number of emitters in a given area

I. Area of fertigation = 450 m^2

No. of emitters present per an emitter line = 17

Total no. of emitter lines for this area = 54

Total no. of emitters = 17*54 = 918

$$Q_{act} = 918 * Q_e$$

II . Area of fertigation = 300 m^2

No. of emitters present per an emitter line = 17

Total no. of emitters lines = 36

Total no. emitters = 17 * 36 = 612

$$Q_{act} = 612 * Q_e$$

III. Area of fertigation = 150 m^2

No. of emitters per an emitter line = 17

Total no.of emitter lines = 18

Total no. of emitters = 17 * 18 = 306

$$Q_{act} = 306 * Q_e$$

Design of equipment for fertilizer application

Orifice meters having various thicknesses and diameters which were fabricated are given in Table 1. The figures of different thicknesses of the developed orifice meter are given in Fig 1.

Table 1 Various sizes of the developed orifice meters

Orifices	Thickness (mm)	Diameter of orifice (mm)	Diameter of fertilizer injection hole (mm)
O ₁	25.40	3.18	1.59
O ₂	19.05	3.18	1.59
O ₃	12.70	3.18	1.59
O ₄	9.53	3.18	1.59
O ₅	12.70	2.38	1.59
O ₆	12.70	1.59	1.59

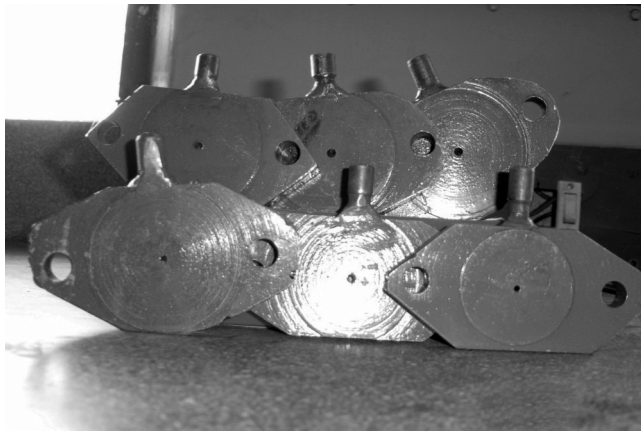


Fig 1 Different thicknesses of fabricated orifice meters

From the experiment it was found that as the diameter decreases, the injection rate increases. By keeping that diameter of orifice meter constant, i e 3.18 mm, then the thickness of the orifice meter was varied to reduce to get the optimal value. For fertilizer injection a hole of diameter 1.59 mm was drilling just at the edge of the orifice meter. A plastic tube was connected from the orifice meter to the fertilizer tank which was placed at a height of one meter above the ground. The amount of pressure drop and the amount of fertilizer injection rates were recorded. The difference between the inlet pressure and outlet pressure was measured by the difference in height of mercury of two limbs of the V-tube manometer. This pressure gradient is related by the following equation.

$$h = R \left(\frac{S_m}{S} - 1 \right)$$

where, h, Water head in cm; R, reading of the U-tube manometer (cm); S_m, specific gravity of mercury, S, Specific gravity of water.

The equipments studies were conducted to determine the injection rate through the different sizes of the orifice meters. After preparing the fertilizer solution into the water flowing through orifice meter was applied to the area under fertigation. All developed equipments were tested under

Table 2 Maximum injection rates and the corresponding operating pressures for different orifice meters (O₁-O₆)

Orifice meter	Size (mm)		Maximum injection rate (lph)	Operating pressure (kg/cm ²)	
	Thickness (mm)	Diameter (mm)		Inlet pressure	Outlet pressure
O ₁	25.4	3.18	24.82	0.772	0.117
O ₂	19.05	3.18	12.00	0.784	0.124
O ₃	12.7	3.18	45.00	0.702	0.037
O ₄	9.53	3.18	27.70	0.795	0.102
O ₅	12.7	2.38	15.00	0.830	0.108
O ₆	12.7	1.59	27.67	0.944	0.078

various inlet discharges, rate of fertilizer injection. All orifice meters were tested for areas 450 m², 300 m², 150 m².

RESULTS AND DISCUSSION

The developed orifice meters were evaluated in the range of 0.42 kg/cm² to 0.944 kg/cm² of inlet pressure and the areas under fertigation were 150 m², 300 m², 450 m². The orifice meter having maximum injection rate and the corresponding operating pressure for different orifice meters are given in the Table 2.

It was revealed from the study that the maximum injection rate depends upon the outlet pressure for a particular inlet pressure. The best fit equation of average injection rate and outlet pressure for orifice meters (O₁-O₆) are given by the following equations:

For orifice meter O₁
 $S = 2292.1 P^2 - 924.74 P + 99.326$
 $R^2 = 0.9448$

For orifice meter O₂
 $S = 45937 P^2 - 12322 P + 833.65$
 $R^2 = 1$

For orifice meter O₃
 $S = 1498.1 P^2 - 573.94 P + 64.788$
 $R^2 = 0.9778$

For orifice meter O₄
 $S = 1541.7 P^2 - 519.09 P + 58.239$
 $R^2 = 0.9956$

For orifice meter O₅
 $S = 1061.9 P^2 - 409.21 P + 47.007$
 $R^2 = 0.9517$

For orifice meter O₆
 $S = 4610.1 P^2 - 1105.1 P + 84.857$
 $R^2 = 0.9952$

where, S, Average injection rate (lph); P, Outlet pressure (kg/cm²)

Cost estimation of the best developed orifice meter

The material used are, two pieces of flanges with thickness 12.7 mm (₹ 150), 900 mm length of GI pipe with

diameter 12.7 mm (₹ 30), and two elbows with diameter 12.7 mm (₹ 100). The total cost of the system including the best developed orifice meter is ₹ 300.

CONCLUSIONS

The performance of all the developed orifice meters are tested at a pressure less than 1 kg/cm², while venturi operates at 1 kg/cm² to 4 kg/cm². The orifice meter having thickness 12.7 mm and diameter 3.18 mm is best with maximum fertilizer application rate 45 lph at inlet pressure 0.72 kg/cm². The orifice meter is cheaper than most commonly used device, i.e. venturi. The cost of orifice meter is around ₹ 300 whereas the cost of the venturi is ₹ 1 048 for same purpose of fertigation.

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