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STRUCTURING AND CHARACTERISATION OF THE MEDICAL INFUSION SET AS EMITTER FOR LOW-COST DRIP IRRIGATION SYSTEM

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Abstract

The medical infusion set was re-structured to serve as a point source emitter for low-cost drip irrigation systems. The re-structured device, here referred to as 'medi-emitter', was subjected to laboratory tests to evaluate its hydraulic characteristics. A calibration experiment, relating flow rate and level of emitter opening, gave a discharge range of 0-533 $l\text{hr}^{-1}$ as the emitter flow regulator was gradually opened to its maximum. The peak discharge of 533 $l\text{hr}^{-1}$ was recorded under a pressure of only 49.05 kPa. This makes the medi-emitter particularly suitable for low-cost drip systems that operate under gravity flow with low pressures often less than 58.86 KPa. The exponent values of the emitter flow functions ranged from 0.610 to 1.038, thus characterising the device as a laminar emitter. The laminar characteristic increases progressively with closure of the flow regulator. Manufacturer's coefficient of variation of the medi-emitter was 0.065. Measured coefficient of variation and deviation from nominal flow were between 5 and 19%. The energy head loss coefficient of the emitter ranged from 1.48 to 28.25, which is within the range of common water outlets widely in use. Discharge through the medi-emitter was found to increase with rise in water temperature, although these variations were insignificant at 95% probability level. The influence of temperature on discharge was stronger at lower levels of emitter opening. The emitter gave average soil wetting diameters of 0.679, 0.924 and 1.07 m for sand, loam and clay soils respectively, under a discharge of 2 $l\text{hr}^{-1}$. These values are comparable to those of conventional emitters. Results from this research reveal the potential of the medical infusion set to adequately serve as emitter for low-cost drip irrigation systems, particularly because it is widely available even in most rural communities.

1. Introduction

Drip irrigation is the slow and frequent application of water to plants through mechanical devices called emitters, and at rates approximating the crop consumptive use. This method of irrigation is becoming increasingly favoured as there is the need for more efficient use of water in areas of scarcity. Emitters are the terminal components of a drip system and they perform the crucial role of delivering a near exact irrigation water requirement directly to the crop root zone. This way, losses through evaporation, deep percolation and surface run-off are minimised, causing drip systems to offer high efficiencies of up to 90% (Or, 1985; Dawood and Hamad, 1985; Brouwer *et al.,* 1989; Donay *et al.,* 1997). The success of a drip system in achieving high irrigation efficiencies hinges on the performance of its emitters. Today, a number of manufacturing companies have accordingly specialised in the production of emitters that can satisfy most demands.

In many developing countries, however, drip irrigation is not popular among peasant farmers. This is due to two principal reasons. Firstly, unavailability of emitters and other system components in the local markets, and secondly, the low purchasing power of peasant farmers.

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Attempts have been made to introduce low-cost and accessible drip components with a view to making drip irrigation affordable by small-holder farmers. In the Philippines for instance, Baqui and Angeles (1995) used bamboo for drip laterals, and further improvised a low-cost emitter by inserting polyethylene cordage into a narrow (3 mm diameter) plastic tube. In Nigeria, Yohanna (1997) used canvas material with varying lengths to obtain specified flow rates. Unfortunately, these low-cost emitters do not have provisions for flow regulation, which restricts the range of irrigation regimes for which they could be used. Besides, the cordage and canvas emitters are apparently difficult to reproduce in large numbers and with precision using present day low-cost simple procedures. The medical infusion set used in hospitals has a flow regulator, and is widely available even in most communities of developing countries, giving it a potential to be used for varied water application to crops. This research therefore, investigated the hydraulic characteristics of the medical infusion set and examined the suitability of using this device as emitter for low-cost drip irrigation.

2. Materials and methods

The medical infusion set also referred to as intra- venous administration set is the device used in hospitals to dose liquid medications to patients. Figure 1 shows the main components of the infusion set according to the manufacturer, *Zhejiang Kindly Medical Devices and Plastics* Co. Ltd, China. The original configuration of this device was amended for it to serve as emitter for drip irrigation. Firstly, the needle was discarded to eliminate possibilities of operational injuries. Then, the discharge monitor was cut off because it is apparently of little use when the device is used for watering crops. With these alterations, water was observed to discharge directly out of the contrivance. The length of the tubing was shortened to 450 mm, taken to be one half the inter-row spacing of a hypothetical crop. The spike was removed and replaced with the luer adapter to function as connector (nipple) between the emitter and the lateral. This left the latex flash bulb injection site to serve as the emitter exit with an aperture of 5 mm. All these modifications transformed the infusion set to what would henceforth be called “medi-emitter”. The roller clamp is movable, and may be placed anywhere along the length of the tubing. The medi-emitter and associated parts re-named using conventional emitter nomenclature is shown in Figure 2.

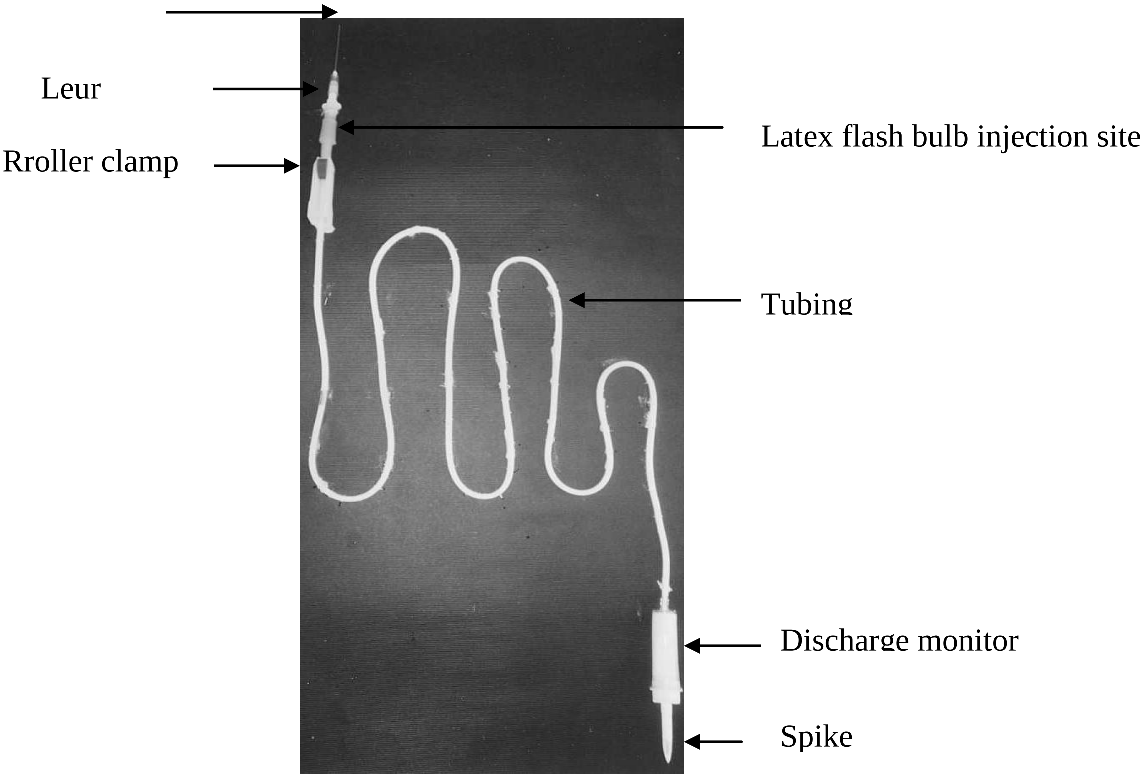

Figure 1: Main components of the medical infusion set

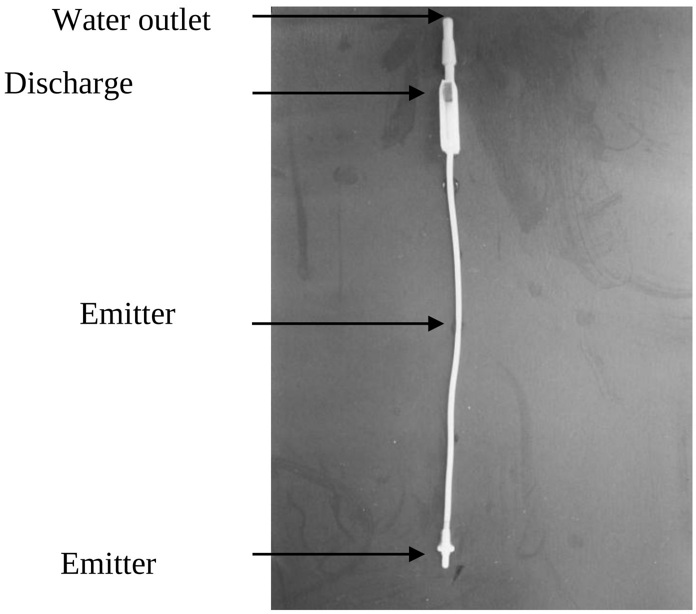

Figure 2: Main components of the medi-emitter

The first hydraulic experiment was a calibration exercise between emitter discharges over a range of emitter openings. Discharge measurements were made under pressures of 5.0 – 58.86 kPa at increments of 5kPa. This pressure range was chosen because the medi – emitter was conceptualised to be used for low-cost drip irrigation systems, which are operated mainly under gravity. Pressure variation was achieved by raising a 40 *l* plastic water container to heights corresponding to the desired pressure head. A float valve in a second 30 *l* pressure stabilization tank was used to maintain a constant pressure head during measurements. The scale of the emitter flow regulator was graduated, delineating ten levels of emitter openings. Discharge was measured at each level of emitter opening and pressure head using the volumetric method according to Merriam *et al.* (1980). The experiment was conducted at temperatures of 20-25 ^{o}C, which is regarded as the optimum temperature range for such tests (Ozekici and Sneed, 1995).

The influence of pressure head on discharge for the medi-emitter was investigated at the ten principal levels of emitter opening – 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100%. Pressure was varied from 5 kPa at increments of 2.5 kPa to a maximum of 49.05 kPa. Measured values of discharge and pressure were fitted into Equation 1 (Karmeli *et al.*, 1985), and the values of x and k determined using regression analysis.

$$q_e = k\left(p_e\right)^x \qquad 1$$

Where:
q_e = emitter discharge, m^3/hr or l/hr
p_e = pressure at emitter ,m
k = coefficient of proportionality that characterises an emitter, and depends on the emitter diameter and shape.
x = emitter discharge exponent that expresses the emitter flow regime, and classifies the emitter as either long path (or laminar) emitter, orifice (or turbulent) emitter, vortex emitter, or pressure compensating emitter.

The discharge uniformity of the medi-emitter was assessed using two standards – The standard of the American society of Agricultural Engineers (ASAE), and that of the International Standard Organisation (ISO). The ASAE reflect differences in emitter performance due to manufacturing variations in a parameter known as manufacturer's coefficient of variation defined as (ASAE Standards, 1990):

$$c_v = \frac{s_q}{q_{avg}} \qquad 2$$

Where:
c_v = manufacturer's coefficient of variation
q_{avg} = mean emitter flow rate, $l$hr^{-1}
s_q = standard deviation of flow rates of the emitter in a sample, $l$hr^{-1}

The recommended guidelines (ASAE Standards, 1990) for classifying emitters based on their c_v values is given in Table 1.

Table 1: Recommended classification of coefficient of manufacturing variation (ASAE EP 405.1)

C_v Range	Classification
< 0.05	Excellent
0.05-0.07	Average
0.07-0.11	Marginal
0.11-0.15	Poor
> 0.15	Unacceptable

The International Standard Organisation (ISO 9260) uses two indicators of the uniformity of emitter discharge. These are: coefficient of variation and deviation from the nominal flow rate (*Dev*) defined in Equation 3 (ISO, 1991).

$$Dev = 100\left[\frac{(qm - qn)}{qn}\right] \qquad 3$$

Where:
qm = average flow rate
qn = nominal flow rate

The $\boldsymbol{C_v}$ and *Dev* were calculated from 100 emitters using Equations 2 and 3.

The effect of temperature on discharge for the medi-emitter was also studied. This was done by raising the temperature of water to 60°C and taking the flow rate as the water cooled down. Discharge measurements were made at 10°C intervals to a minimum of 10°C. Temperatures below 20°C were obtained through immersion of ice pellets into the water tank, and constantly monitoring the fluid temperature as it reached the desired temperature mark.

The energy head loss coefficient of the medi-emitter was calculated using Equation 4 (Dake, 1983). This was done at the principal levels of emitter opening.

$$k_n = \frac{1}{v_c^2} - 1 \qquad 4$$

Where:
v_c = coefficient of velocity
v_c is given by Equation 5 (Lal, 1963)

$$v_c = \sqrt{\frac{x^2}{4yh}} \qquad 5$$

Where:
x and y are respectively horizontal and vertical co-ordinates of the jet of water issuing from the emitter. h is the pressure head of water, causing flow.

Another measured emitter characteristic was the soil wetting diameter as affected by emitter discharge. This parameter is essential in determining the irrigation time, the intra-crop spacing and the number of point source emitters to use. The wetted diameter was determined for the three major textural groups: clay, loam and sand. The volume of water required to saturate one square meter of soil was calculated for each soil type based on the soil physical properties. This quantity of water was then applied to the soil at different discharges from the medi-emitter. The diameter of the wetted area was measured with a meter rule. The values were fitted to the linear function and their trendline equations determined using regression analysis.

3. Results and discussion

Figure 3 shows the calibration curves of the medi-emitter. The emitter flow functions are presented in Figures 4 and 5. Table 2 contains values of the energy loss coefficients and manufacturer's coefficient of variation of the medi emitter. The discharges through the medi-emitter measured at different temperatures are given in Table 3, while Table 4 contains the soil wetting diameters under different discharges from the medi-emitter.

Table 2: Measured values of manufacturer's coefficient of variation (C_v) from nominal flow rate (*Dev*), and the energy head loss coefficients of the medi-emitter

Level of emitter opening (%)	C_v	Dev (%)	**K_n**
10	◘	◘	◘
20	◘	◘	◘
30	0.078	15.10	♀
40	0.075	15.10	♀
50	0.069	14.81	28.25
60	0.070	14.62	25.32
70	0.068	14.52	13.52
80	0.068	14.50	13.00
90	0.069	14.47	1.500
100	0.062	14.45	1.480

◘ There was no flow at these levels of emitter opening.

♀ The flow at these levels did not produce jets to enable calculation of K_n using Equations 4 and 5.

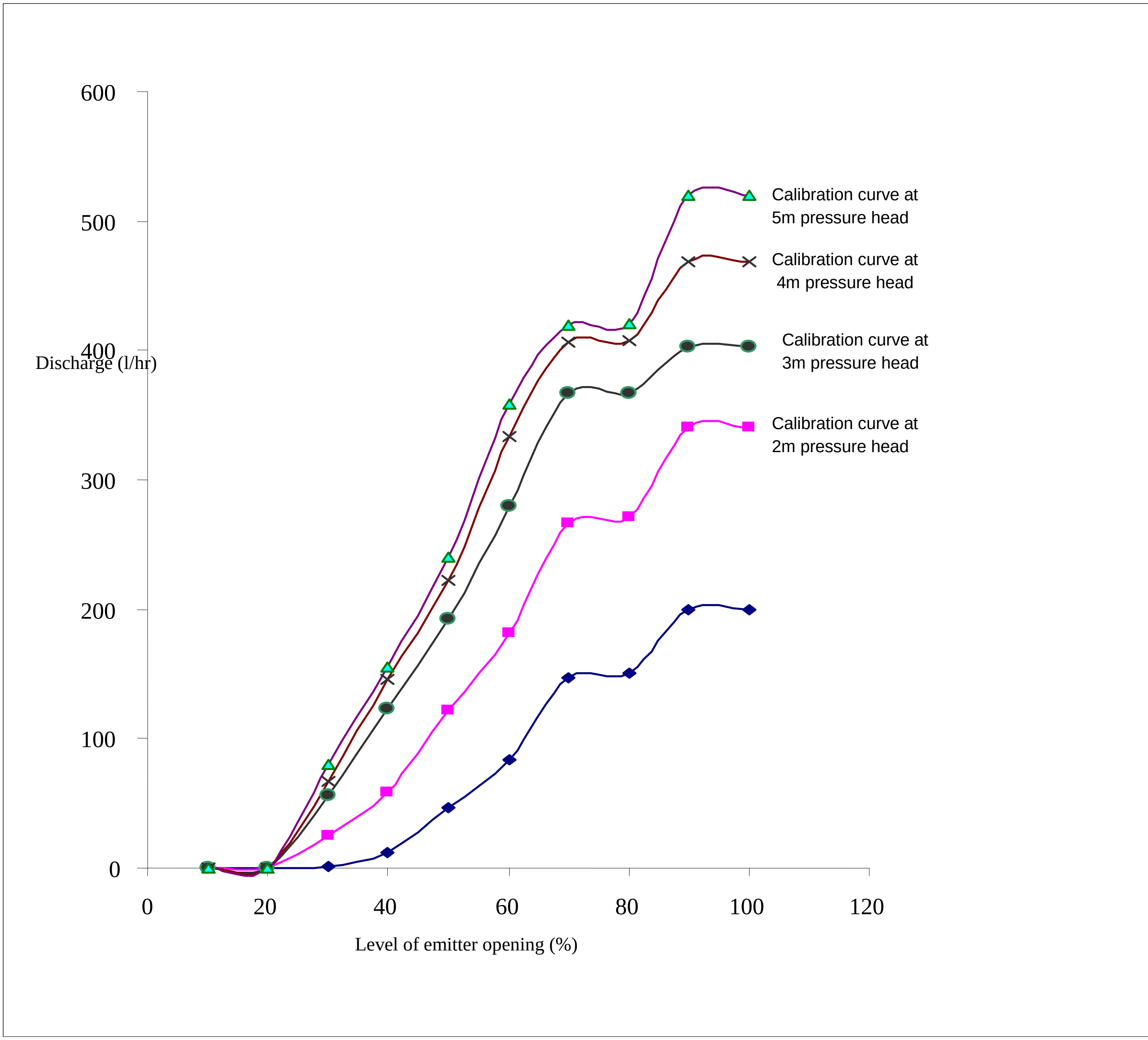

Figure 3: Calibration curves of the medi-emitter at various pressure heads

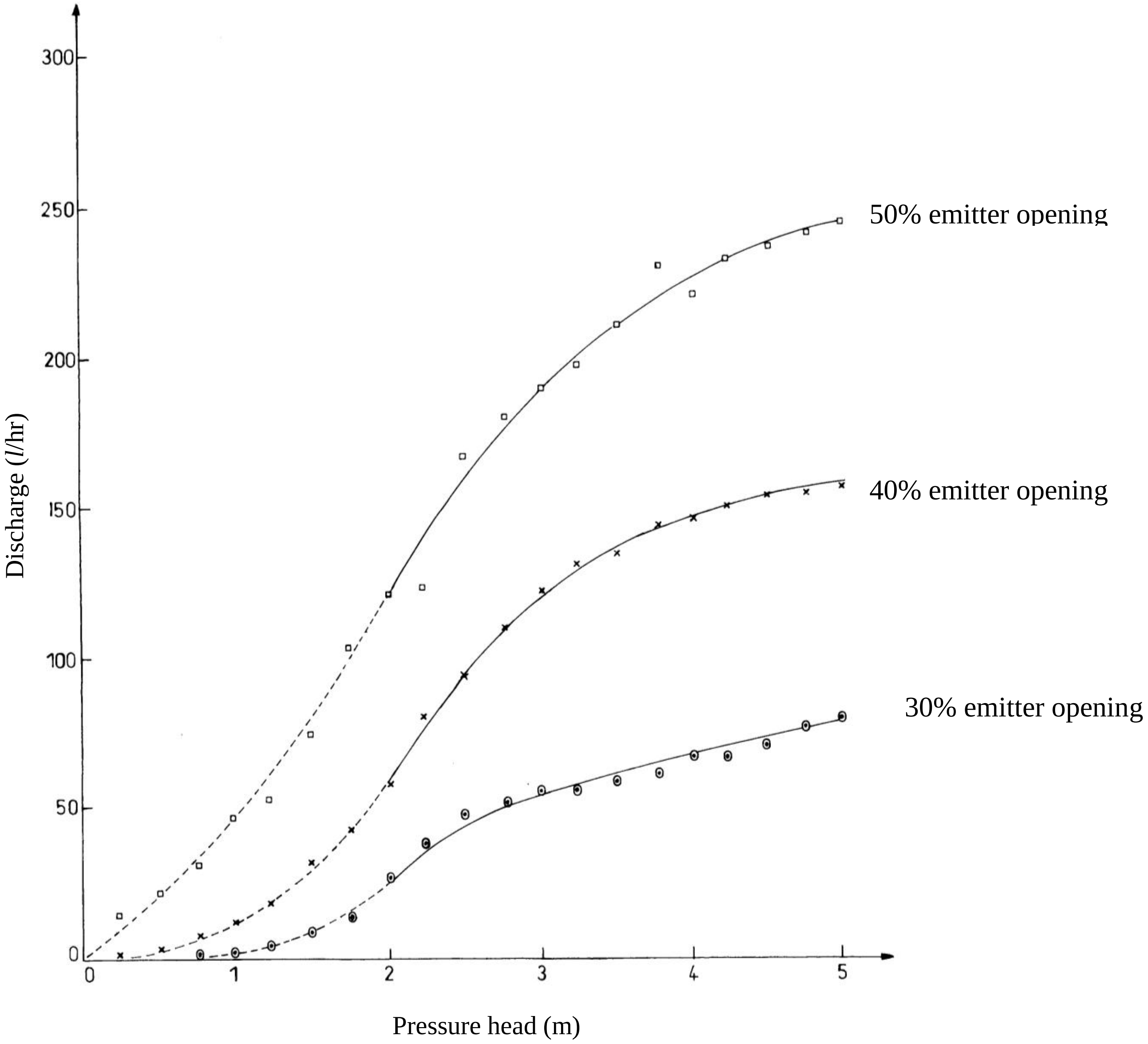

Figure 4: Emitter flow functions at 30 –50 % emitter opening

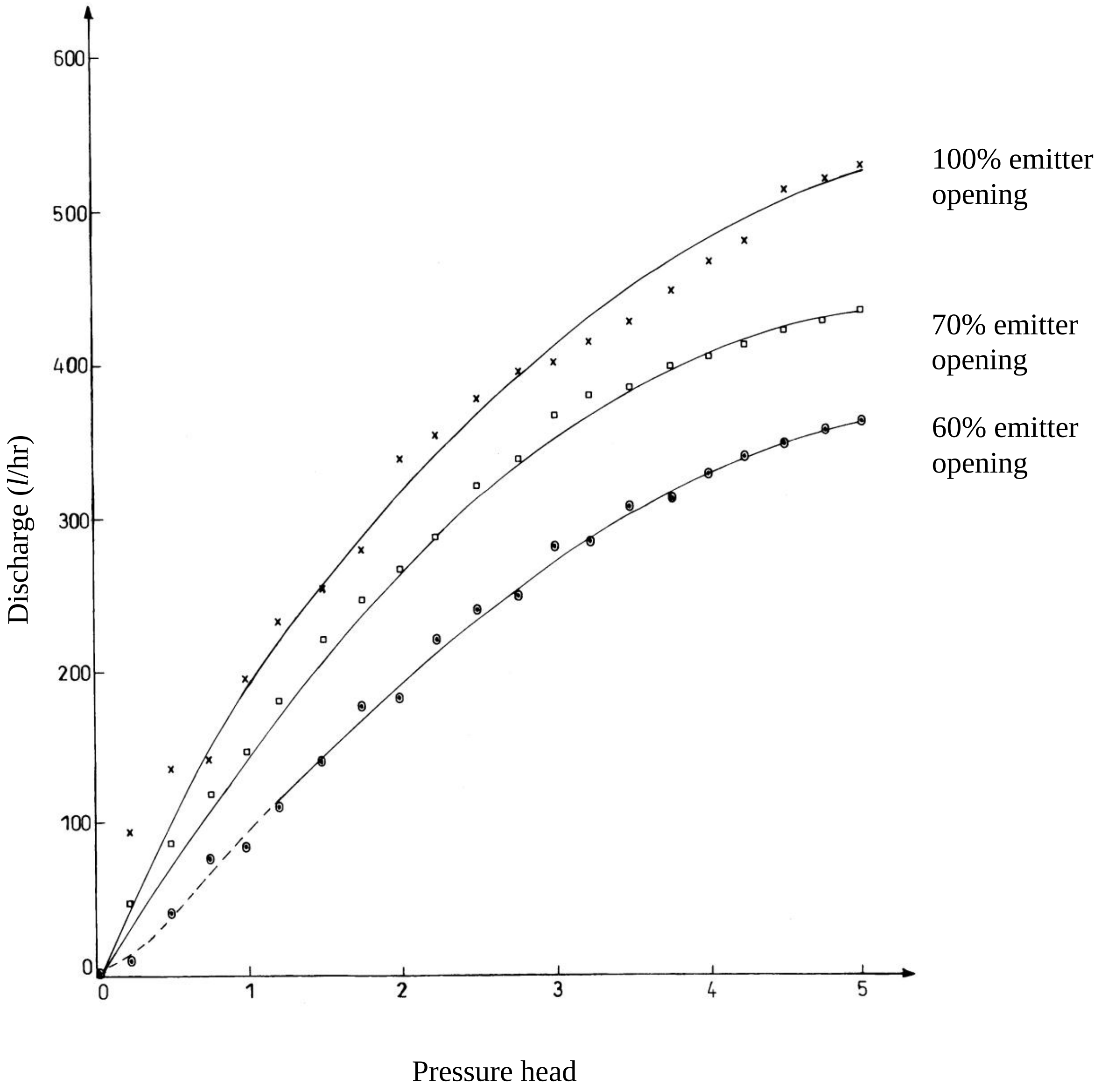

Figure 5: Emitter flow functions at 60 –100% emitter opening

Table 3: Discharge (lh^{-1}) through the medi-emitter at different water temperatures

Pressure head (m)	Level of emitter opening (%)	Temperature (°C)					
		10	20	30	40	50	60
1	30	0.80	0.83	0.82	0.87	0.88	0.92
	50	46.72	47.00	47.18	47.30	47.30	47.38
	70	146.76	146.77	146.71	146.76	146.76	146.77
	100	200.00	200.00	200.01	199.99	200.10	200.14
2	30	25.00	25.10	25.42	25.41	25.83	25.88
	50	120.99	121.00	121.12	121.50	121.59	121.59
	70	266.0	266.60	266.70	266.61	266.64	266.61
	100	340.12	340.10	340.11	340.10	340.11	340.12
3	30	56.10	56.00	56.81	57.32	57.62	57.91
	50	191.98	192.80	193.00	193.32	193.85	194.41
	70	366.99	367.10	367.20	367.20	367.21	367.22
	100	402.80	402.80	402.81	402.80	402.80	402.80
4	30	66.52	66.70	67.100	68.00	67.81	67.98
	50	222.50	222.50	222.54	222.59	222.58	222.59
	70	405.98	406.10	406.11	406.33	406.11	406.14
	100	468.88	468.90	468.92	468.80	468.91	468.91
5	30	79.00	79.00	79.89	80.00	80.62	80.84
	50	244.86	245.00	245.31	245.31	245.62	245.84
	70	426.65	427.00	427.01	427.00	427.02	427.02
	100	533.20	533.21	533.21	533.22	533.22	533.22

Table 4: Soil wetted diameters at different discharges through the medi-emitter

Discharge (lh^{-1})	Wetted diameter (m)		
	Sand	Loam	Clay
0.06	0.13	0.25	0.29
0.08	0.18	0.28	0.37
0.10	0.21	0.39	0.42
0.24	0.30	0.43	0.54
0.27	0.38	0.46	0.62
0.50	0.40	0.57	0.88
0.70	0.43	1.06	1.17
1.00	0.56	1.18	1.23
2.00	0.82	1.20	1.42
3.00	0.95	1.22	1.50
4.00	1.06	1.46	1.64
5.00	1.64	1.72	11.89
6.00	1.68	1.74	1.89
9.00	1.76	1.86	1.98
10.00	1.83	2.01	2.24

Figure 3 exhibits a wide range of emitter discharge, stretching from 0 to 533 lh^{-1}. The fact that there was no flow when the emitter was completely closed denotes a 100% flow control of the medi-emitter. The increase in discharge resulting from increase in emitter opening progressed in four stages from 1- 4m pressure head. Between 20 – 70% and 80 – 90% emitter opening, discharge increased exponentially and remained constant between 70 – 80% and 90 – 100%. Same discharge trend observed at 5m pressure head would likely be obtainable for pressure heads greater than 5m.

The shapes of the calibration curves serve as a guide when adjusting the device to obtain desired flow rates. Most conventional emitters are rated at 2-16 lh^{-1}. The medi-emitter could satisfactorily operate within this discharge range by simply adjusting the emitter flow regulator. The required level of emitter opening may be obtained through extrapolation from Figure 3, or by solving for E_{lev} from the appropriate equation in Table 5. Partitioning of the flow regulator scale could be done visually and then fine tuned to precision.

Table 5: Trendline equations of the calibration curves relating emitter discharge (q_e) and level of emitter opening (E_{lev}) of the medi-emitter

Pressure head (m)	Range of emitter opening (%)	Regulatory function	R^2
1	0-20	$q_e = 0$	1.00
	20-70	$q_e = 0.0475e^{0.123(Elev)}$	0.941
	70-90	$q_e = 51.74e^{0.0145(Elev)}$	0.919
	90-100	$q_e = 200.00$	1.00
2	0-20	$q_e = 0$	1.00
	20-70	$q_e = 5.15e^{0.05(Elev)}$	0.983
	70-80	$q_e = 270.00$	1.00
	80-90	$q_e = 7.57(E_{lev}) - 338.55$	0.995
	80-100	$q_e = 340.43$	1.00
3	0-20	$q_e = 0$	1.00
	20-70	$q_e = 17.03e^{0.045(Elev)}$	0.978
	70-80	$q_e = 367.00$	1.00
	80-90	$q_e = 188.61e^{8.297E-10(Elev)}$	0.993
	90-100	$q_e = 402.76$	1.00
4	0-20	$q_e = 0$	1.00
	20-70	$q_e = 21.32e^{0.044(Elev)}$	1.00
	70-80	$q_e = 406.70$	0.974
	80-90	$q_e = 6.19(E_{lev}) - 86.45$	0.998
	90-100	$q_e = 468.88$	1.00
5	0-20	$q_e = 0$	1.00
	20-90	$q_e = 0.234(E_{lev})^{1.755}$	0.986
	90-100	$q_e = 533.3$	1.00

Figures 4 and 5 demonstrate that the flow functions of the medi-emitter do not completely follow a power curve from 30-60 % emitter opening. The flow functions have two segments within this range of emitter opening. The first part from 0 to about 2 m pressure heads is an exponential relationship indicated by broken lines, while the power curve represented with solid lines starts from about 2 to 5 m pressure heads and beyond. The two portions of the flow functions are presented mathematically in Table 6.

The exponents of the flow power curves in Table 6 range from 0.610 to 1.038, which classifies the medi-emitter as a laminar emitter (James, 1988; Karmeli *et al.*, 1985). Based on the trend of the exponent values, the degree of laminar flow characteristic of the medi-emitter increases as the emitter regulator is progressively closed. The exponent value of this device at 100% emitter opening (0.610) is close to that (0.638) of the 4 $l\text{h}^{-1}$ Toro E-2 flag style drip emitter. The medi-emitter therefore offers a comparable flow regime with standardized emitters. The fact that the medi-emitter operates within the laminar regime prevents it from offering the advantage of self-flushing which is a characteristic of the turbulent flow emitters. At higher levels of emitter opening (80 – 100%), however, the flow characteristic of the medi-emitter tends towards the labyrinth type with x values of 0.724 and 0.610, approaching the 0.4-0.5 range for turbulent emitters. The medi-emitter may therefore provide this self flushing advantage to some extent when the device is regulated towards full opening. Nevertheless, use of the medi-emitter for low-cost drip irrigation should be complemented with appropriate cheap filtration units to prevent introduction of sediments into the laterals.

The medi-emitter gave a maximum flow rate of 533 $l\text{h}^{-1}$ at 5 m pressure head, whereas most customized emitters can deliver a maximum of only about 150 $l\text{h}^{-}$ at exceedingly high pressure heads of 40-70 m. High emitter discharges are desirable when irrigating orchard crops having high consumptive use like banana, mangoes and citrus. The medi-emitter would easily release water at typical high rates of 150 $l\text{h}^{-1}$ under a pressure head of only 1 m. This discharge is obtainable under 1 m pressure head when the flow regulator opening is between 80-85%. Such a low operating head for the medi-emitter permits its use for low-cost trickle systems that operate mainly under gravity flow with pressure heads between 1-6 m. This also provides possibility of designing precision low-cost drip systems not only for vegetable crops (as is currently the case), but also for orchards.

Table 2 contains calculated values of manufacturer's coefficient of variation, deviation from nominal flow rate, and the energy head loss coefficients of the medi-emitter at increasing levels of emitter opening. From the table, C_v ranges from 0.062 at 100% emitter opening to 0.078 at 30% emitter opening. Up to 75% of the calculated C_v fall within 0.05-0.07. This classifies the medi emitter as average in terms of discharge uniformity according to the standards of the American society of Agric. Engineers (ASAE Standards, 1990). The reduction in C_v with decrease in the emitter opening is probably due to differential compression of the emitter tube by the control knob, and human inability to regulate all the 100 emitters used to exactly equal levels of emitter opening. Also, the calculated *Dev* values are all between 5 and 15%, characterising the device as category B emitter according to the International Standards Organisation (ISO, 1991). From these two perspectives, the discharge uniformity of the medi-emitter is considered satisfactory. The energy head loss coefficient (K_n) increased from 1.48 at full emitter opening to 28.25 at 50% emitter opening. The increase in K_n with successive closure of the emitter opening depicts that much energy is lost by water flowing through the device at lower levels of opening. From Equation 4 therefore, K_n would be tend to infinity when the flow through the emitter approaches zero. The same trend in K_n was recorded for gate valves (Brater and King, 1976). The authors reported K_n values ranging from 1.00 for a 0.5 inch gate valve at full opening to as high as 60 at 25% valve opening. Adoption of the medi-emitter for drip systems is therefore not expected to introduce exit losses out of the range already presented by existing pipe fittings.

Table 3 shows discharges through the medi-emitter at six different temperatures. From the table, discharge increases with temperature. Statistical analysis, however, indicated that difference in discharge due to temperature variation for the medi-emitter was not significant at 95% probability level. The effect of temperature on discharge was more pronounced at lower levels of emitter opening (30 and 50 % opening) because the nature of flow at these levels of opening was laminar with x values of 1.038 and 0.791 respectively (Table 6). Flow through the emitter approached the turbulent range at 100% opening with x values of 0.610, causing the temperature effect on discharge to be minimal at this level of opening.

Table shows that the wetting diameters of the medi-emitter increase with emitter discharge. The increase was found to be linear with the following trendline equations:

$$WD_s = 0.1796q_e + 0.32 \; ; \; r^2 = 0.91 \qquad 6$$
$$WD_l = 0.1670q_e + 0.59 \; ; \; r^2 = 0.81 \qquad 7$$
$$WD_c = 0.175q_e + 0.72 \; ; \; r^2 = 0.0.79 \qquad 8$$

Where WD_s ,WD_l and WD_c are the wetted diameters for sand, loam and clay soils respectively.

Using Equations 6, 7 and 8 with a typical emitter discharge of 2 lhr^{-1}, the medi emitter would wet soils to projected average diameters of 0.679, 0.924 and 1.07 m for sand, loam and clay respectively. These values are comparable to those derived from generalised wetting diameter functions (0.54, 0.920, and 0.924) given by Karmeli *et al.* (1985) for the three major soil types in same order.

4. Conclusion

It has been shown that the medical infusion set can serve as a point source emitter for low-cost drip irrigation if properly re-configured. The infusion set was re-structured by removing its needle and other minor components. The modified device known as ‘medi-emitter’ can deliver water with discharges of up to 533 lhr^{-1}under a pressure head of 5 m. The emitter flow regulator offers precise discharge regulation making it possible to obtain a very wide range of flow rate between 0-533 lhr^{-1}. Flow through the medi-emitter is mainly laminar. The influence of temperature on discharge is insignificant at 95% probability level within water temperatures of 10-60 ^{o}C. The medi-emitter offers uniform discharge and produces satisfactory wetting diameters. This medical infusion set is widely available and from the results of this study, it could be easily modified and used as emitter for low-cost drip irrigation systems.

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