LATERAL HEAD LOSSES AS AFFECTED BY EMITTER'S FLOW PATH GEOMETRY

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ABSTRACT

Although there are many types of emitters with the same nominal flow, they have different flow path's geometry. However, the head loss due to friction along the lateral is normally calculated based on the number of fitted emitters regardless their flow paths' geometry and homogeneity in the manufacture. Therefore, a field study has been carried out to investigate the effect of the emitter's flow depth geometry on the friction losses along the lateral. Four different flow paths, with the same nominal flow, have been chosen and tested under various operating pressures. The pressures along the lateral were measured using a digital pressure gauge. Total flow rate passes through the lateral was also measured and compared with the corresponding theoretical flow rate. A difference between both values is observed when emitters of spiral flow path type have been used. Consequently, the accuracy of calculating the friction loss along the lateral is greatly affected when such type of flow path is used. A good agreement is noticed between the measured and the calculated pressure distribution using the Darcy-Weisbach equation when the measured flow rate in the lateral is used in the calculation. rather than the assumed values of equal flows of each. The variation of flow regime along the lateral length has presented and a noticeable difference in the flow behaviour has observed when emitters of different flow paths have been used.

Keywords: Laterals. Head loss, Emitters, Friction.

INTRODUCTION

The designer of an irrigation system has to consider and integrate numerous factors. Trickle irrigation design principles are different from these developed for other irrigation systems because flow rates are lower and the number of outlets (submains, laterals, and emitters) are larger than in the case of sprinkler irrigation system. Lateral lines are the hydraulic link between the supply lines (main or submain lines) and the emitters. They are designed to achieve a small pressure variation along their lengths due to friction losses and slope gain (or loss). The difference in pressure between the lateral and atmospheric pressure must be dissipated in the emitter and is expressed as the head loss in the emitter. This process depends mainly on the emitter design and its flow path dimensions, such as its length ℓ, diameters d as well as the friction coefficient f. An emitter with large ℓ is a long path type emitter, and one with very small ℓ is a short path type. It is also possible to introduce losses due to abrupt changes in flow direction, and that principle is used in the tortuous flow path type emitter (Von Bernuth and Solomon, 1986).

Head losses caused by friction in the lateral pipe depend mainly upon the roughness of the inside surface of the pipe, its cross section area and length,

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and velocity at which the water flows. Although there are many formulae used to determine head loss in a length of a pipe, h_f, the Darcy-Weisbach equation is considered the most popular one in the trickle irrigation system design (W_u and Gitlen 1973, Watters and Keller, 1987 and Howell et al, 1983). It takes the form:

$$h_f = 6.377\, f\, D^{-5}\, Q^2 \qquad (1)$$

Where:

h_f = friction loss in m.
l = length of pipe in m.
D = pipe diameter in m.
Q = flow rate in l/h.
f = friction coefficient.

The coefficient of friction f depends on the flow regime (Von Bernuth and Solomon, 1986, and Hathoot et al, 1993). For laminar flow, the friction coefficient is given by:

$$f = \frac{64}{R_e} \qquad (2)$$

in which

$$R_e = \text{Reynold's number} = \frac{4Q}{\pi D \nu} \qquad (3)$$

where ν = the kinematic viscosity in m^2/ sec.
For turbulent flow, the Blasius equation can be used (for smooth pipe):

$$f = \frac{0.316}{R_e^{0.25}} \qquad (4)$$

Equation (1) is used to determine the head loss in a pipe, assuming that all water is carried to its end. For a lateral, the head loss is multiplied by a reduction coefficient F to compensate for the reduction of flow rate caused by trickling water from the emitters. This coefficient depends on number of opening along the lateral as well as the formula used to determine h_f (Vermeiren and Jobling, 1984). W_u and Gitlen (1973) stated that inserting certain types of emitters into the lateral line can create more friction than others can create. This is attributed to the friction caused by pressing-in emitters into the lateral. Karmeli and Keller (1975) reported that typical equivalent length resulted from pressing the on-line emitters with barbed connections ranges from 0.1 to 0.6 m.

Once the head loss due to friction along the lateral length ($F.h_f$) is determined using Eq. (1), the pressure distribution along a constant diameter lateral on flat terrain is calculated using the Solomon and Keller formula (1987). It was empirically developed based on various pressure measurements along the lateral. It takes the form:

$$H(L) = H(l) + E(L)\,(F.h_f) \qquad (5)$$

in which:

$$E(L) = \exp\left\{-4.38815 \frac{L^{1.9086}}{(1-L)^{0.05555}}\right\} \qquad (6)$$

where:
H(L) = pressure heat at relative position L on lateral in which L = 0.0 at inlet and L = 1.0 at the end.
H(l) = pressure head at lateral end.
H(0) = pressure head at lateral inlet.
E(L) = Constant depends upon values of "L".

However, the effect of emitter's flow path geometry is not considered in the reduction coefficient F, although each type of emitter offers a different local resistance to the flow in the lateral. Moreover, the total flow Q in equation (1) is equal to number of emitters *n* along the lateral multiplied by the nominal flow of emitter q_n, regardless their actual flows and their homogeneity in the manufacture.

The objective of this research is to investigate experimentally the effect of the emitter's flow path geometry on the head loss due to friction along the lateral.

MATERIALS AND METHODS

The field experiments were conducted at the Agricultural Research Station, King Saud University, Buraidah, Saudi Arabia. A complete irrigation network was already existing on a leveled area and one connection between submain and a lateral was chosen to carry out the experimental work. A valve followed by a calibrated pressure gauge were fixed at the lateral inlet to control the operating pressure.

Four different types of emitters' geometry have been chosen to represent different flow paths plate (1). They are (1) tortuous flow path; (2) flat internal spiral path; (3) spiral long path; and (4) spiral short path. The chosen emitters have also the same barbed inlet of 4 mm so that their local losses due to pressing-in connections will be the same. The nominal flows of the tested emitters under various operating pressures (p) are listed in Table (1). Each type of emitter was fixed on a new polyethylene lateral with an inner diameter of 12 mm and a total length of 100 m. The first emitter was fitted at 2 meters away from the lateral inlet and then emitters were spaced every 4 meters, making the total number of emitters 24. For measuring flow rate of each emitter q_i along the lateral, catch cans with a capacity of one liter were placed in small dug holes underneath each emitter to receive the trickled water. The temperature of the received water was also measured and it ranged from 17 °C to 18 °C. A scaled tube and a stop watch were used to measured the emitter flow rate q_i. Then, the measured total flow rate passing through the lateral Q_m equals:

Table (1). Nominal Flow of the Tested Emitters' Flow Paths under Different Operating Pressures.

Flow path type	q_n (l/h)		
	P = 1 bar	P = 2 bar	P = 2.5 bar
Tortuous	3.52	5.1	5.3
Flat internal spiral	4.0	5.6	6.0
Spiral long path	3.9	6.2	6.9
Spiral short path	4.2	6.5	7.45

*** For the reader's convincing only, the commercial name of the used gauge is RS Manometers (Model No. 255-828).

$$Q_m = \sum_{i=1}^{24} q_i \tag{7}$$

while the assumed total flow rate passing through the lateral Q_t, based on equal q_n, equals:

$$Q_t = 24\, q_n \tag{8}$$

in which q_n is the nominal emitter flow rate at a specific operating pressure (Table (1)).

In order to measure the pressures along the lateral, a small hole was made close to each emitter and a plastic tube of 3 mm ID and 10 cm length was fixed into the hole by glue. A digital pressure gauge*** with an accuracy of 0.1 m bar was used by connecting it to the tube end. Then the pressures were measured along the lateral length at the five relative positions L where equation (5) was developed

(L = 0.0, 0.21, 0.39, 0.56 and 1.0). Three operating pressures P (1.0, 2.0 and 2.5 bars) were applied at the lateral inlet. The previous procedures were repeated for the four chosen types of emitters.

RESULTS AND ANALYSIS

Using the Darcy-Weisbach equation, the head losses due to friction along the lateral length are calculated twice, based on equations (7) and (8), and are indicated by $h'_{f(1)}$ and $h'_{f(2)}$ respectively. Since the number of emitters is 24, the corresponding reduction coefficient F equals 0.37 (Vermeiren and Jobling, 1978). A summary of the collected and calculations for the tested flow paths is listed in Table (2). It can be noticed that the difference $\Delta h'_f$ between the calculated head loss based on the measured emitters flows $h'_{f(1)}$ and the corresponding calculated head loss based on the nominal emitters flow $h'_{f(2)}$ varies from a flow path to another. The minimum $\Delta h'_f$ values are noticed in the tortuous and the flat internal spiral flow paths and ranged from

1.6 % to 18.0 %. The maximum value of $\Delta h'_f$ is noticed in the spiral short flow path type and ranged from 77.0 % to 85.0 %, where the corresponding Q_m/Q_{th} is about 0.37 to 0.46, respectively. This is may be attributed to the sensitivity of such flow path type to clogging by accumulating of small particles in its narrow flow path. The minus sign of $\Delta h'_f$ values means that applying the Darcy-Weisbach equation (Eq.1), using the nominal emitters flows, is underestimating the actual head loss along the lateral. Consequently, the accuracy of the design of laterals as well as the whole trickle network will be affected. On the other hand, positive sign of $\Delta h'_f$ values means that equation (1) is overestimating the actual values of h'_f. Consequently, uneconomic design of the trickle network is expected.

Figures (1) to (3) show the distribution of the pressure along the lateral length for P = 1.0, 2.0 and 2.5 bar, respectively, using equations (5) and (6). Dashed curves represent the calculated pressure distribution based on Q_m while continuous curves represent the calculated pressure distribution based on Q_{th}. Black ovals represent the measured pressure using the digital pressure gauge. A very good agreement between the measured pressure and the corresponding calculated pressure distribution using Q_m (dashed curves) is noticed rather than in the case of using Q_t. However, small discrepancies are noticed at some locations, especially at the lateral end. This is may be attributed to the local losses caused by pressing-in emitters into the lateral that are not included in the equation of Darcy-Weisbach and it may be also attributed to the variation of emitters' manufacture.

Table 2. A Comparison between The Calculated Head Losses along The Lateral Using the Measured and Nominal Emitters' Flows.

P = 1 bar

Flow path type	Q_m (l/h)	f	$h'_{f(1)}$* (m)	Q_{th} (l/h)	f	$h'_{f(2)}$** (m)	$\Delta h'_f$%***
Tortuous	74.46	0.033	0.0144	84.48	0.029	0.013	-9.7
Flat internal spiral	85.05	0.046	0.02297	96	0.0447	0.028	18
Spiral long path	104.24	0.0438	0.033	93.6	0.045	0.027	-22.2
Spiral short path	40.6	0.0608	0.007	100.8	0.044	0.031	77.42

P = 2 bar

Tortuous	121.53	0.033	0.043	115.2	0.029	0.0393	-9.4
Flat internal spiral	128.38	0.0416	0.047	134.4	0.041	0.051	7.84
Spiral long path	175.88	0.0385	0.082	148.8	0.04	0.061	-34.4
Spiral short path	58.35	0.0423	0.01	156	0.039	0.067	85.07

P = 3 bar

Tortuous	141.22	0.042	0.056	127.2	0.0427	0.05	-12
Flat internal spiral	152.58	0.0398	0.064	151.2	0.04	0.062	-1.6
Spiral long path	212.54	0.0367	0.114	163.68	0.039	0.073	-56.12
Spiral short path	79.9	0.03	0.014	172.32	0.039	0.067	82.23

* Head loss using the measured emitter's flow.

** Head loss using the nominal emitter's flow.

*** $\Delta h'_f = \{h'_{f(2)} - h'_{f(1)}\} / h'_{f(2)}$

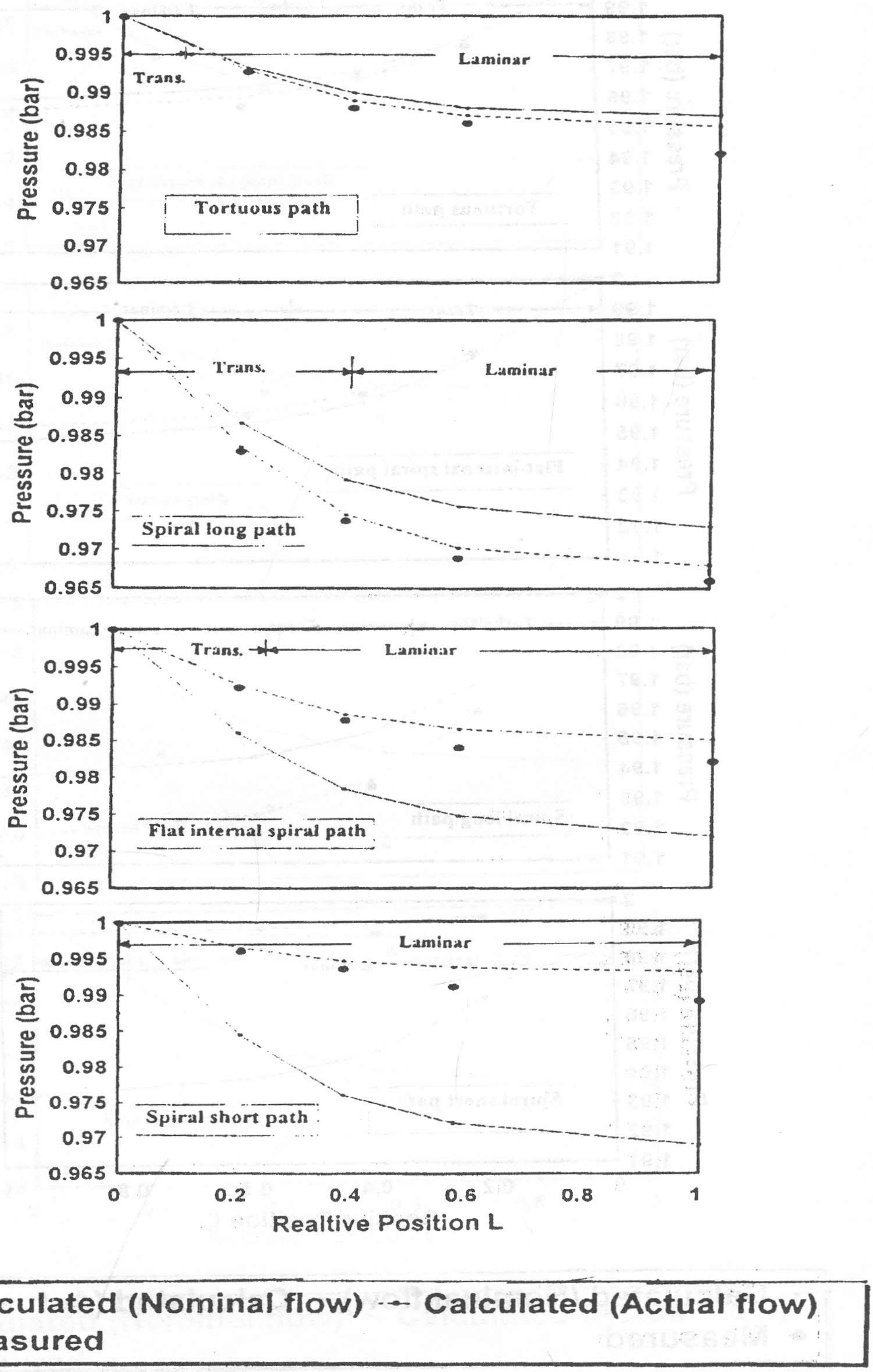

Figure 1. Pressure distribution along the lateral using different flow paths (operating pressure = 1 bar).

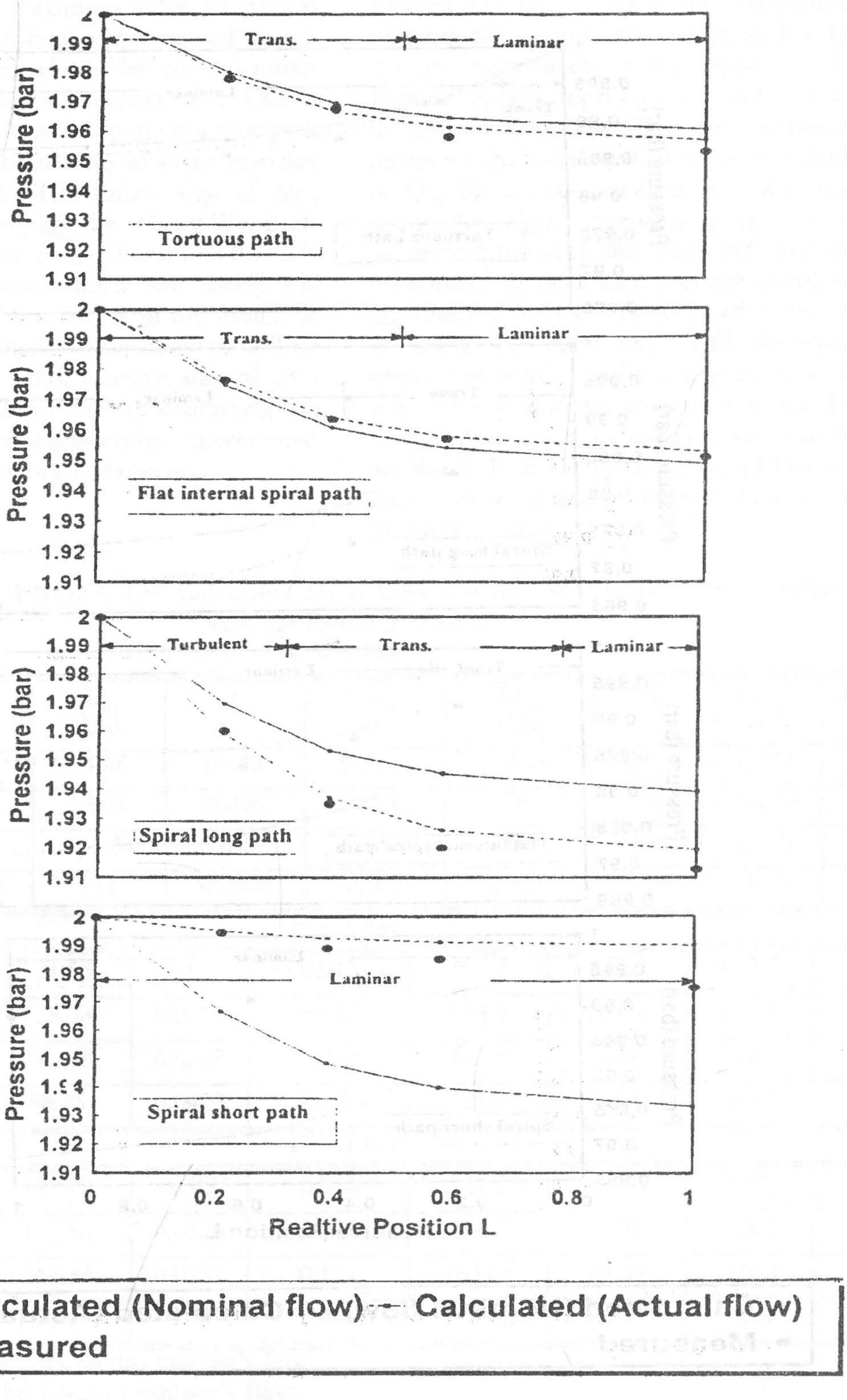

Figure 2. Pressure distribution along the lateral using different flow paths (operating pressure = 2 bar).

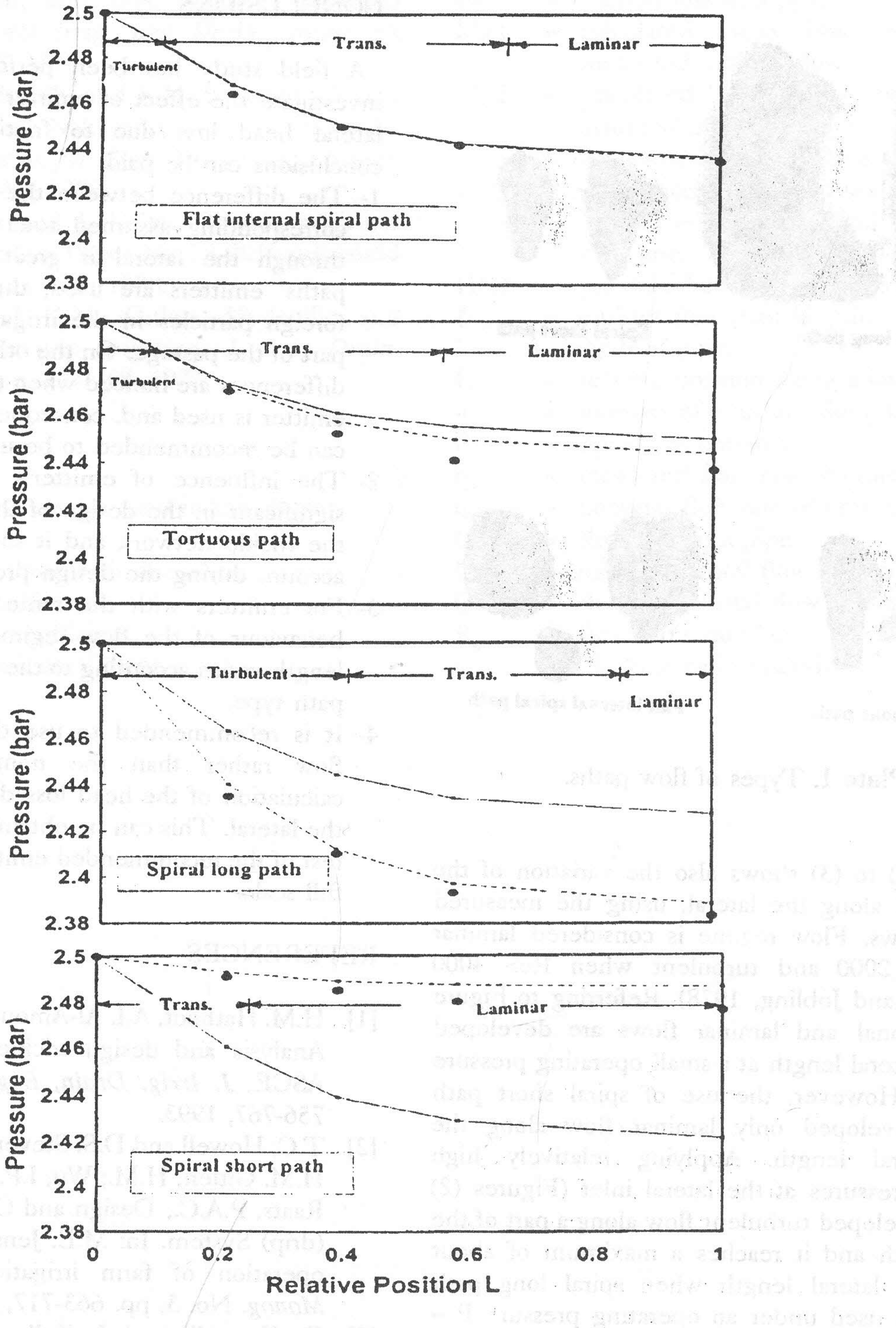

Figure 3. Pressure distribution along the lateral using different flow paths (operating pressure = 2.5 bar).

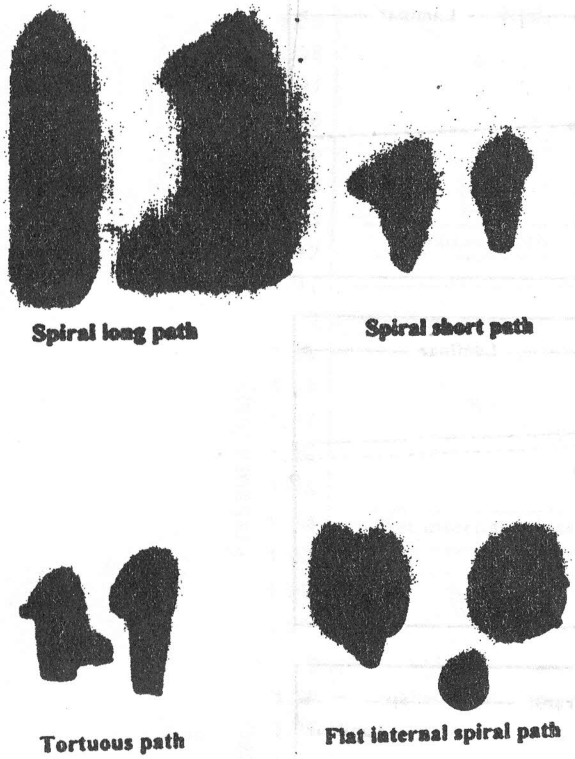

Plate 1. Types of flow paths.

Figures (1) to (3) shows also the variation of the flow regime along the lateral, using the measured emitters flows. Flow regime is considered laminar when $R_e < 2000$ and turbulent when $Re > 4000$ (Vermerien and Jobling, 1978). Referring to Figure (1), transitional and laminar flows are developed along the lateral length at a small operating pressure (P=1 bar). However, the use of spiral short path emitters developed only laminar flow along the whole lateral length. Applying relatively high operating pressures at the lateral inlet (Figures (2) and (3)) developed turbulent flow along a part of the lateral length and it reaches a maximum of about 0.40 of the lateral length when spiral long path emitters are used under an operating pressure P = 2.5 bar. However, turbulent flow is not absolutely developed when spiral short path emitters are used, although high operating pressure is applied. This is attributed to the very small value of the measured flow rate Q_m as indicated in Table (2).

CONCLUSIONS

A field study has been performed in order to investigate the effect of emitter's flow path on the lateral head loss due to friction. the following conclusions can be paid:

1- The difference between the measured and the corresponding assumed total flow rates passing through the lateral is great when spiral flow paths' emitters are used, due to the fact that foreign particles in the irrigation water block a part of the passage. On the other hand, minimum differences are noticed when tortuous flow path's emitter is used and, consequently, the later type can be recommended to be used.

2- The influence of emitter's flow path type is significant in the design of the lateral as well as the trickle network and it should be taken into account during the design procedure.

3- For emitters with the same nominal flow, the behaviour of the flow regime along the lateral length varies according to the used emitter's flow path type.

4- It is recommended to use the actual emitter's flow rather than the nominal flow in the calculation of the head loss due to friction along the lateral. This can be obtained by performing a test of the recommended emitters before using in full scale.

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NOTATIONS

The following symbols are used in this paper:

- d = emitter flow path diameter.
- D = pipe coefficient.
- f = friction coefficient.
- F = reduction coefficient.
- h_f = friction loss in a pipe.
- $h'_f(1)$ = calculated head loss based on the measured emitter flow
- $h'_f(2)$ = calculated head loss based on the assumed emitter flow
- h'_f = head loss in a lateral due to friction.
- $\Delta h'_f$ = difference in head losses along a lateral using the measured and assumed total flow rate.
- H(1) = pressure head at lateral end.
- ℓ = emitter flow path length.
- l = length of pipe.
- L = relative position along a lateral.
- n = number of emitters along the lateral.
- P = operating pressure.
- q_i = measured flow rate of emitter.
- q_n = nominal flow rate of emitter.
- Q = flow rate in a pipe.
- Q_m = measured total flow rate in a lateral.
- Q_t = theoretical total flow rate in a lateral
- R_e = Reynold's number.
- υ = the kinematic viscosity.