Hydraulic evaluation of locally modified emitter under laboratory conditions

Harby Mostafa and Wael Sultan

ABSTRACT

Drip irrigation systems have become a major part of developing agriculture in Egypt and the aim of this research was to obtain the best performance from irrigation systems management using locally modified and original emitters. The experiments were carried out at the National Irrigation Laboratory of the Agricultural Engineering Research Institute. The emitters were tested and calibrated under different operating pressures (0.50, 0.75, 1 and 1.25 bar) to determine emitter flow rates and emitter emission uniformity (EU) and manufacturing variation coefficient (CV). The original emitter performance was determined using the relationship between emitter flow rate (2 lh^{-1}) and operating pressure, with data indicating that the EU was 98.5%, at a CV of 2.3% and actual flow rate was 1.8 lh^{-1} for the original emitter. The EU was 93.8% with a CV of 5.2% and actual flow rate of 2.02 lh^{-1} for the modified emitter. For original emitter performance at 4 lh^{-1}, data indicated that the EU was 96%, with a CV of 4.8% and actual flow rate of 3.78 lh^{-1}. The EU for the modified emitter was 95% with a CV of 2.7% and actual flow rate of 4.5 lh^{-1}. The emitter exponent values were 0.41 to 0.44 for modified and 0.37 to 0.38 for original emitters.

Key words | characteristics, emitters, hydraulic performance

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INTRODUCTION

During recent years, numerous drip irrigation emitters with varying characteristics have become available in the market. To have the best emission uniformity (EU) and minimum flow rate fluctuation due to pressure distribution, some of the emitters have been designed as 'pressure compensating' emitters. Some of them are self-cleaning or 'flushing' to reduce the clogging but others can be clogged easily and require sophisticated water filtration (Keshtgar 2012).

With a specific end goal to upgrade the water system effectiveness, small-scale water system strategies, for example, drip, sprinkler, and bubbler water systems, are being utilized in developed countries. Among these, the trickle water system technique is considered as the most proficient strategy requiring just 20 to 30% of water required for ordinary strategies (Tagar *et al.* 2010).

In a drip irrigation system, the uniformity of water application from emitters depends on lateral line lengths, emitter design, operating pressure, friction losses, the manufacturing variation of emitters and emitter tendency to clogging. The uniformity of water is related to the pressure variation along the lateral line. The friction losses and the lateral line inclination largely affect the pressure variation (Sinobas & Rodríguez 2012).

The hydraulic analysis necessary to obtain the discharge from any kind of emitter is another concern in drip irrigation design. Resolution of this problem is important to determine the efficiency of the system, which is called EU. Different methods are discussed to calculate the emitter discharge throughout the system and each one has its own advantages and disadvantages.

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Ideally, each emitter would convey the same quantity of water regardless of where it is situated in the field. Truly, emitter discharge is variable along a line in a trickle water system. Gil *et al.* (2008) revealed that assembling variation, head differences, emitter clogging, frictional head losses, water temperature changes, and emitter affectability result in stream rate variation even between two indistinguishable emitters. Also, the emitter operating characteristics have a tendency to change over time. Thus flow may change even with a constant pressure. In a poorly designed system, the operator may not be able to get a uniform distribution of water, which may result either in lower irrigation or over irrigation. Under each case, plants will either suffer dry stress or experience wet stress.

Through a properly designed drip system, a uniformity coefficient of at least 85% is considered appropriate for standard design requirements. Such a high uniformity coefficient is only possible through properly designed emitters (Al-Amound 1995; Evans 2000) that provide steady discharge to all emission points. The distribution uniformity (DU) substantially decreases at slopes steeper than 30% (Ella *et al.* 2009). In a hydraulic performance analysis on various kinds of emitters, Hezarjaribi *et al.* (2008) calculated the manufacturing variation coefficient, emitter discharge coefficient and emitter discharge exponent in order to establish flow sensitivity to pressure and compare manufacturers' specifications. Their results indicated that for the chosen emitters the manufacturer's supplied data are not reliable for design purposes. Reliable, field tests are required prior to the design of a drip system. In fact, using the manufacturer's data will lead to non-uniformity of discharge throughout the system (Singh *et al.* 2009; Keshtgar 2012).

The performance of a drip irrigation system depends on the best possible design of emitters, spacing of emitters and proper spacing between delivery lines, etc. But the design of emitters plays a prime role in uniform distribution of water on the field. Thus, focusing on the importance of the design of emitters, the present study was conducted on the hydraulic performance of some locally modified emitters comparing with the original emitter (imported) to evaluate emitter discharge and EU.

MATERIALS AND METHODS

This research was conducted at National Irrigation Laboratory of the Agricultural Engineering Research Institute (AEnRI), Dokki, Giza, Egypt. The target of this work was to evaluate the performance of a local modified emitter that was developed by the authors and manufactured by 'Arab Drip Egypt Co.' compared with the original emitter performance (Netafim Co.). The local modified emitter was developed by changing the water path map for lines with flowrates of 2 and 4 lh^{-1} (Figure 1).

The drip irrigation systems test facility (Figure 2) was used to evaluate hydraulic characteristics of drippers. The pressure drop test facility (Figure 3) was used to measure friction losses at pressure of 1 bar.

On-line turbo emitter types of 2 and 4 lh^{-1} discharge and 5 mm barb outer diameter were selected in this experiment. Flow rates were measured for 50 new emitters of each flow rate (2 and 4 lh^{-1}) under 0.50, 0.75, 1 and 1.25 bar operating pressure. Characteristic curves of tested emitters were logarithmically found for emitters under the foregoing different pressures. Pressure was measured using a Bourdon-tube gage which was calibrated with a pressure transducer device.

Poly-ethylene laterals (LDPE) of 16 mm outer diameter, 1.3 mm thickness, 25 m length, and 0.5 m emitter spacing

Figure 1 | Comparison between water path map for the standard and modified emitter.

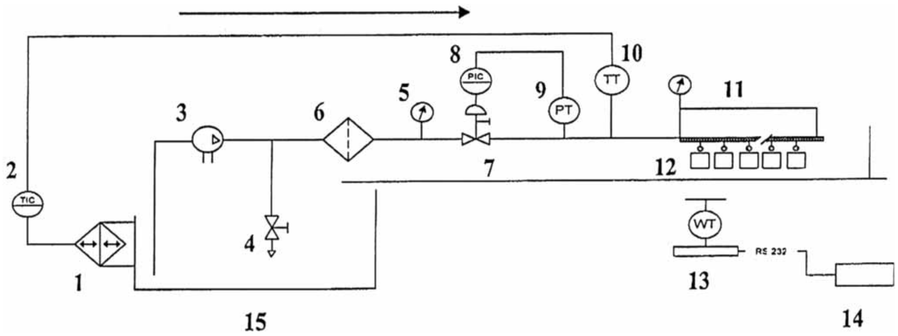

Figure 2 | Drip irrigation test facility. 1. Temperature conditioning; 2. Temperature regulator; 3. Multi stage pumping unit; 4. Manual discharge valve; 5. Direct reading pressure gage; 6. Screen filter; 7. Pressurized air regulating valve; 8. Pressure regulator; 9. Pressure transmitter; 10. Temperature transmitter; 11. Lines of pipes including tested emitters; 12. Water collectors for each emitter in test; 13. Weighing scale; 14. Computer; 15. Water tank.

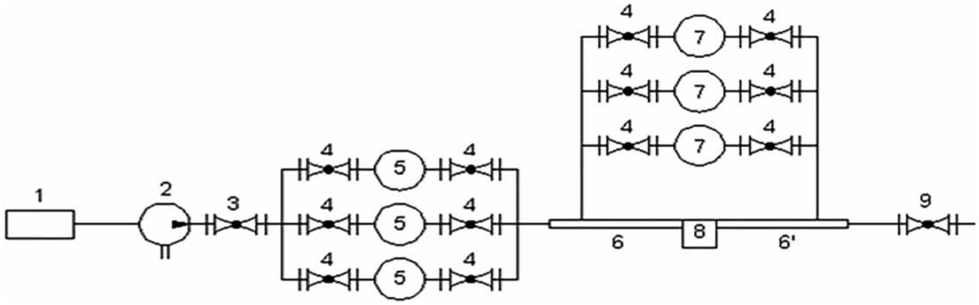

Figure 3 | General sketch showing pressure drop test facility. 1. Water source; 2. Pump; 3. Discharge valve; 4. Manual isolating valves. 5. Electromagnetic flow meters; 6 and 6′. Set of straight pipes; 7. Differential pressure gauges. 8. Device to be tested; 9. General ball valve.

were alternatively laid on zero-slope soil surface and tested in the laboratory. Inlet pressures were regulated by measuring them and adjusting the regulator pressure.

The emitter flow rates are usually characterized by the relationship between flow rates, and pressure. Equation (1) for emitter flow rates can be expressed as (Keller & Karmeli 1974):

$$q = kp^x \tag{1}$$

where

q: the emitter flow rate, (lh^{-1});
k: a dimensionless constant of proportionality that characterizes each emitter;
p: operating pressure, (bar); and
x: a dimensionless emitter flow rate exponent that is characterized by the flow regime.

The manufacturing coefficient of variation 'CV' was calculated by measuring the flow rates from a sample of the new emitters according to American Society for Agricultural Engineers (ASAE) standard (ASAE 2005), Equation (2):

$$CV = (s/q_a) \times 100 \tag{2}$$

where

CV: manufacturer's coefficient of emitter variation, (%);
q_a: average flow rate, (lh^{-1}); and
s: standard deviation of emitter flow rates at a reference pressure head.

Uniformity plays a vital role in selection, design, and management of irrigation systems. One measure of drip irrigation uniformity is to calculate the uniformity coefficient of a system using Equation (3) (Mosh 2006):

$$U_C = 100 - \left(80\frac{S}{q_a}\right) \tag{3}$$

where

U_C: uniformity coefficient (%);
s: standard deviation of observed emitter flow; and
q_a: average volume collected (ml).

EU is typically used to evaluate manufacturing quality of emitters. It is used to describe the predicted emitter flow variation along a lateral line and can be assumed as synonymous to that of DU. Equation (4) was used to calculate EU (Ortega *et al.* 2002).

$$EU = (q_n/q_a) \times 100 \tag{4}$$

where

EU: the emission uniformity, (%);
q_n: the average of the lowest ¼ of the emitter flow rate, (lh^{-1}); and
q_a: the average of all emitter flow rates, (lh^{-1}).

Measurements were taken according to ISO 9621 and ASAE standard (ASAE 1996) for evaluating local emitter performance.

Due to the small geometry and path of the emitters, it is not easy to observe and measure the flow state of the fluid. Computational Fluid Dynamics (CFD) was used to investigate the fluid inside paths not always accessible using experimental techniques (Zhang & Zhao 2013).

RESULTS AND DISCUSSION

As shown in Figure 4, the relationship between emitter flow rates and operating pressure indicated that once the operating pressure increases the emitter flow rates also increase. The EU was 96.8% (excellent) with a CV of 5.4% (good) according to ASAE (2005) and actual flow rate (average) was 2.03 lh^{-1} for the modified emitter with a 2 lh^{-1} manufacturer's value. Similar results were obtained for the original emitter with a correlation of 99.4%. At 98.2%, the EU for the original emitter was a little better than that of the modified emitter, but emitter flow rate was lower (1.7 lh^{-1}) than the manufacturer's value.

The emitter exponent (x) was calculated for all the emitters. The flow types for modified and original emitters were fully turbulent, due to $x = 0.41$ for the modified emitter indicating it to be sensitive to pressure variation compared with $x = 0.37$ for the original emitter.

Data presented in Figure 5 indicate that the modified emitter (4 lh^{-1} manufacturer's value) has better hydraulics classification, with CV = 2.79% (excellent), EU = 95% (excellent) and the type of flow was fully turbulent due to $x = 0.44$, compared with original emitter with flow 4 lh^{-1} with CV = 2.83%, EU = 96% and the type of flow being turbulent ($x = 0.38$).

Data in Table 1 present the theoretical and actual friction loss results for the 2 and 4 lh^{-1} emitters affected by lateral length. The data show that the actual measurement of the friction losses closely agrees with the Hazen–Williams equation displaying the same trend for both modified and original emitters. The data show non-significant differences between modified and original emitters for both 2 and 4 lh^{-1} with 25, 50 and 75 m lateral length.

The flow field in the flow path and pressure of the emitters is extremely hard to examine by traditional methods because of the tiny path, so the profile of pressure and velocity in the flow path of the labyrinth emitter was numerically simulated by the CFD method using the emitter data at inlet and outlet for pressure and water velocity at the outlet.

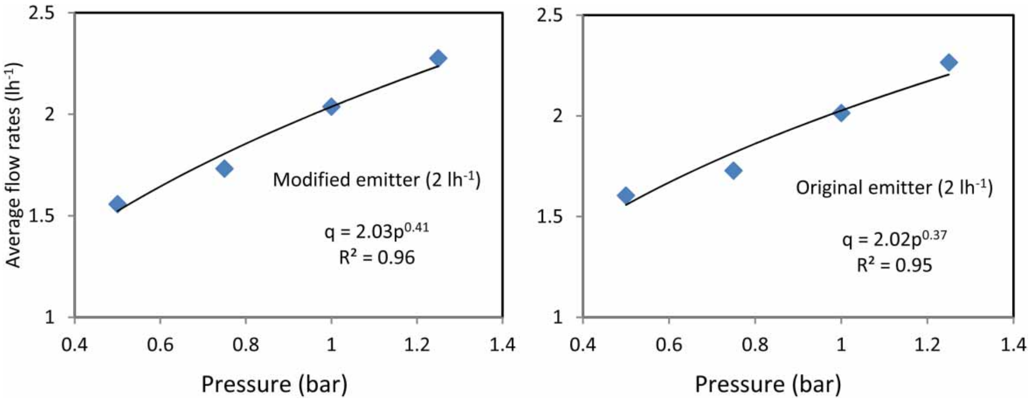

Figure 4 | Average flow rates vs. pressure for modified and original emitter (2 lh^{-1}).

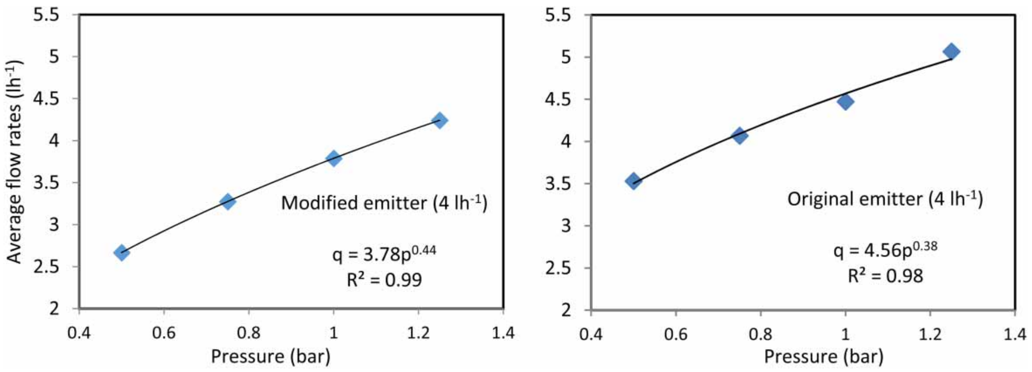

Figure 5 | Average flow rates vs. pressure for modified and original emitter (4 lh^{-1}).

Table 1 | Theoretical and actual friction losses for modified and original emitters

Emitter	Discharge	Lateral length (m)	Theoretical friction losses (m) Hazen–Williams ($C = 140$)	Actual friction losses (m)
Modified emitter	2 lh^{-1}	25	2.19	2.33
		50	4.33	6.5
		75	7.46	8.5
	4 lh^{-1}	25	2.19	2.2
		50	4.33	5.1
		75	7.46	6.5
Original emitter	2 lh^{-1}	25	2.19	2.5
		50	4.33	6.4
		75	7.46	8.6
	4 lh^{-1}	25	2.19	2.3
		50	4.33	5
		75	7.46	6.5

The pressure in the inlet area was higher than in the outlet area and reduced gradually from the inlet to the outlet for all CFD modeling of original and modified emitters, as shown in Figure 6.

Both the modeling results and the measuring results indicated that the pressure reduced linearly with the length of the flow path. The pressure distribution modeling results agreed well with the pressure measuring results. The average difference between the modeling results and the measuring results was less than 2%, which agreed with Sachin *et al.* (2013).

The CFD analysis for emitters shows that modified emitters have better performance than original emitters without any drastic change in velocity flow profile, even at 2 or 4 lh^{-1} rate of discharge, and gave almost the same velocity vortex profile in the outlet area of the emitters (Figure 7).

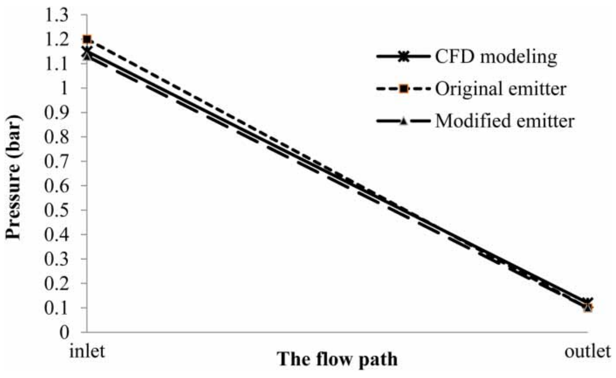

Figure 6 | Pressure curves as a comparison between inlet and outlet of emitters.

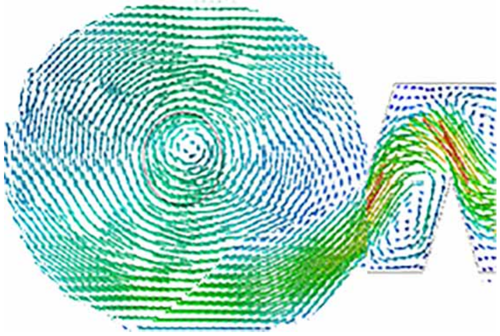

Figure 7 | Velocity vortex profile in the outlet area of the emitters by CFD modeling.

CONCLUSION

From the previous discussion regarding modified and original emitters, it may be summarized as follows:

1. The hydraulic parameters of the modified emitter were comparable to those of the original emitter.

2. The modified emitter path map, which plays a major role in emitter application, matched 100% with the original emitter path map where it gave almost the same pressure distribution and velocity vortex profile in the outlet area of the emitters.
3. Finally, results provided by empirical evidence suggest the modified emitter could improve the water DU of a drip irrigation system similarly to the original emitter.

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