SENSITIVITY OF THIN-WALLED DRIP TAPE EMITTER DISCHARGE TO WATER TEMPERATURE

G. A. Clark, F. R. Lamm, D. H. Rogers

ABSTRACT. *One of the primary goals in the design of microirrigation systems is to have a hydraulic balance to ensure uniform emitter discharge. However, while most design processes focus on pressure distributions and changes associated with friction and elevation differences, elevated water temperatures will change the physical properties of the water and may change the physical properties of some emitters. Laboratory studies were conducted to measure the effects of water operating temperature on the sensitivity and discharge rate of emitters from thin-walled drip tape (collapsible emitting hose) products. Two different product types (Robert's Ro-Drip, RD; and T-Tape, TT,) each with two wall thicknesses, were evaluated. The RD product included wall thicknesses of 0.20 mm (8 mil, RD-08) and 0.38 mm (15 mil, RD-15), whereas the TT product included wall thicknesses of 0.25 mm (10 mil, TT-10) and 0.38 mm (15 mil, TT-15). Additional characterization tests included a standard operating pressure/emitter discharge rate test and a tubing tensile stress (elongation) test. All tests were conducted in accordance with ASAE Standard S553, "Collapsible Emitting Hose (Drip Tape) — Specifications and Performance Testing." Increases in water operating temperature from 21°C to 50°C resulted in an 18%, 44%, and 97% increase in emitter discharge from the RD-08 product at operating pressures of 55, 69, and 83 kPa, respectively. Emitter discharge rate changes in the RD-15 product were not as great (10 to 12% increase) for similar water temperature changes. Effects of water temperature on the discharge rate from the TT products were quite different from the RD products. Emitter discharge rate increased slightly(<5%) with water temperature at 55 kPa, but decreased by up to 7% at 83 kPa. TDR values (also referred to as a "temperature flow rate index") relate the emitter discharge at each measured temperature value (q_t°) to the emitter discharge at the initial base temperature (q_{20}°) [TDR = (q_t°)/(q_{20}°)]. In this work, the RD-08 product had a quadratic relationship between temperature discharge ratio and water temperature, while the RD-15 product and both TT-10 and TT-15 products had more linear relationships.*

Designers of microirrigation systems need the hydraulic performance characteristics of the products that they are considering in a system design. Such information should come from the manufacturers of the various collapsible emitting hose (drip tape) products. Product information should clearly provide physical characteristic data such as the emitter exponent "x," constant of proportionality "k," temperature discharge ratio values, and maximum recommended operating temperature.

Keywords. *Drip irrigation, Drip emitter, Microirrigation.*

Designers of microirrigation systems need to know how specific products will perform under conditions experienced in the field. The goal is to design a system that will have a hydraulic balance such that a subunit within the system has a known and uniform emitter discharge. Because substantial variations in operating pressure can occur in a field system due to elevation changes and friction loss, most design concerns focus on the operating pressure/emitter discharge relationships of the emitters. However, emitter discharge rates and the uniformity of a microirrigation system are also influenced by other factors such as manufacturing variability, temperature of the emitters, and clogging of the emitters (Solomon, 1985; Wu et al., 1986; Keller and Bliesner, 1990; Wu et al., 2003). While the designer cannot control manufacturing variability, it is usually small (<0.10) for labyrinth type emitters (Solomon, 1979; Von Bernuth and Solomon, 1986) and can be incorporated into the design. Emitter clogging can be controlled by proper water filtration, chemical treatment, and system maintenance. However, temperature is often an uncontrolled and variable parameter that can influence the discharge of individual emitters and the emission uniformity of a microirrigation system (Keller and Karmelli, 1975; Von Bernuth and Solomon, 1986).

Parchomchuk (1976) measured lateral line temperature increases from 26°C to 42°C on a bright sunny day in British Columbia, Canada for surface positioned polyethylene pipe laterals. Buried laterals (15-cm deep) had a peak measured temperature of 32°C. Similar results were reported by Nakayama and Bucks (1985) for 14.5 mm black polyethylene

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lines in Phoenix, Arizona. Peak water temperatures for surface positioned laterals were measured at 42°C in May, whereas empty lines had a peak temperature of 48°C. Furthermore, higher temperatures can exist under polyethylene mulch. Temperatures in May exceeded 50°C at the soil surface under plastic mulch in Guam and exceeded 40°C at a depth of 5 cm (Singh, 2004). Bell and Laemmlen (1991) reported that under clear polyethylene mulch, diurnal temperatures ranged from 24°C to 66°C at a depth of 2 cm whereas temperatures ranged from 23°C to 53°C at a soil depth of 15 cm. Abu-Gharbieh (1997) also reported soil temperatures of 50°C at 10- to 15-cm depth and 38°C at 30 cm. Even under these conditions, buried drip irrigation laterals can act as a heat exchanger and absorb heat from the soil, thereby increasing the temperature of the water and emitter chambers.

The temperature of the water in a microirrigation lateral will influence the Reynolds number (R_e) due to changes in the kinematic viscosity of the water (CRC Press, 1973; Daily and Harleman, 1966). These changes can also impact the friction coefficients of the lateral lines (Peng et al., 1986) and of the emitters, and subsequent water discharge (Keller and Karmelli, 1975; Keller and Bliesner, 1990). In laminar and unstable flow regimes ($R_e < 4000$), emitter discharge is very dependent upon the viscosity of the water. However, in partially and fully turbulent flow regimes ($R_e > 4000$), the friction coefficient changes very little with R_e and is almost independent of temperature (Keller and Karmelli, 1975; Keller and Bliesner, 1990; Nakayama and Bucks, 1985). Thus, water temperature and viscosity do not have much of an effect on the discharge from turbulent flow emitters (emitters with a discharge exponent = 0.5). However, many of the collapsible emitting hoses (drip tape) have tortuous (labyrinth) path emitters with emitter discharge exponents that range from 0.5 to 0.7 and will have emitter flows in the laminar and unstable flow regimes resulting in possible sensitivity to water temperature.

Parchumchuk (1976) found that microtube and spiral path emitters with R_e values in the laminar and unstable flow regime had measured discharge variations up to 53% for water temperatures between 20°C and 60°C. Orifice type emitters had very little change in emitter flow with water temperatures ranging from 7°C to 38°C. However, vortex emitters had an 8% decrease in discharge as water temperature changed from 8°C to 38°C. Similar results were reported by (Decroix and Malaval, 1985) for long path ($x > 0.5$) emitters (increasing discharge with increasing water temperature) and vortex ($x < 0.5$) emitters (decreasing discharge with increasing water temperature). Zur and Tal (1981) measured the discharge sensitivity of three labyrinth-type emitters to water temperature. One of the emitters had relatively small discharge sensitivity to temperature, which increased with line pressure. The other two emitters had minimal discharge sensitivity to temperature. However, emitters in that study were molded as individual emitters, unlike the embossed emitters that are formed as part of the extrusion process in many types of drip tape.

Several types of drip tape products are available on the market with a wide range of wall thicknesses (0.10 to 0.38 mm [4 to 15 mil]), different polymers, and different emitter designs involving some form of tortuous (labyrinth) flow path. Because many of these products are used in surface or near surface conditions and in warm to hot climates with full and/or partial exposure to the sun, information is needed to address the effects of water temperature on the discharge rate. The objective of this work was to evaluate the effect of elevated water temperature on the discharge rate performance of thin-walled drip tape (collapsible emitting hose) emitters from different wall-thickness products and different manufacturers.

Methods and Materials

Performance tests were conducted on four different thin-walled drip tapes (collapsible emitting hose) listed in table 1. These products represented two manufacturers (Roberts Irrigation Products Inc., San Marcos, Calif., http://www.robertsirrigation.net/; and T-systems International, San Diego, Calif., http://www.tsystemsinternational.com/) with different types of plastic. Drip products were selected with two different wall thicknesses from each manufacturer (table 1). All products came from the manufacturer on standard rolls. Each drip tape had a reported inside diameter of 15.9 mm. Products were also selected that had labyrinth design emitters with similar rated emitter discharge rates that were also typical for drip tapes.

All tests were conducted in the hydraulics lab of the Department of Biological and Agricultural Engineering at Kansas State University, and followed procedures as outlined in ASAE Standard S553 (*ASAE Standards*, 2003). As part of the testing and characterization process, a test on the resistance to tensile stress (Section 8.7, S553, *ASAE Standards*, 2003) was conducted to measure differences in plastic composition through product elasticity. A standard test on the emitter discharge rate response to pressure (Section 8.3, S553, *ASAE Standards*, 2003) was conducted to develop baseline data and for comparison with manufacturer provided performance data. The final set of performance tests focused on the response of drip emitter discharge to water temperature (Section 8.4, S553, *ASAE Standards*, 2003). These tests will be described in detail below.

Resistance to Tensile Stress

Three 152-cm samples of drip tape were cut from the stock roll. A mid-sample section of 102 cm was marked. The upper end of a sample was secured around a pipe for support, and a bucket was attached to the lower end to hold water that was added to increase applied weight. The upper end pipe

Table 1. Drip tape products tested in this study along with general characteristic data.

Product Code	Manufacturer[a]	Wall Thickness (mm/mil)	Emitter Spacing (cm)	Nominal Discharge[b] (L/h)
RD−08	Roberts Irrigation, Inc	0.20/8	30.5	0.91
RD−15	Roberts Irrigation, Inc.	0.38/15	20.3	1.02
TT−10	T−Systems International	0.25/10	40.6	1.02
TT−15	T−Systems International	0.38/15	20.3	1.02

[a] Mention of specific products or manufacturers does not imply endorsement or criticism by the authors or by Kansas State University.
[b] Manufacturer reported discharge at a nominal pressure of 55 kPa.

support was hung from anchors attached to a vertical support column in the hydraulics lab. Water was added to the bucket in 2.0-kg increments. After each addition of weight, the tubing was allowed to stabilize for 2 min. Elongation was then measured between the originally marked points by using a tape measure. Weight was added until a sample ruptured or elongated more than 25% of the original length. Each test was repeated for three samples of each tubing type.

Standard Operating Pressure/Emitter Discharge Tests

Emitter discharge tests were conducted at four pressure settings (28, 56, 69, and 83 kPa) using five drip tape lateral lines that each had five emitters (fig. 1). Each lateral was attached to an inlet and distal manifold system. All drip tapes were suspended on a support rack made of 25-mm (1-in.) nominal PVC pipe. Emitters from each drip lateral were aligned so that a collection cup rack could be used to simultaneously collect emitter discharge. Small pieces of kite string were attached to the drip tape at each emitter extending approximately 15 cm below the drip tape. The strings were saturated during the conditioning periods, and directed water into the collection cups. Supply water was provided by a 190-L reservoir (fig. 1, item 1) that had a small pump used to pressurize the water. Water temperature during these tests was maintained at (or near) 23°C (±2°C). Adjustable pressure regulating valves (fig. 1, item 3) were used to adjust operating pressure. Water operating pressures were incrementally increased between discharge tests, from a minimum pressure of 28 kPa, up to 83 kPa. Water pressure was measured by using a series [0-104, 0-207, and 0-414 kPa (0-15, 0-30, and 0-60 psi)] of precision Bourdon Tube pressure gauges (fig. 1, item 2) that were on an adjustable rack so that the gauge level could be consistent with the drip tubing level to eliminate elevation head effects. Water temperature was measured during each test sequence with both a bimetallic temperature sensor and an electronic thermistor connected to a data logger. Both temperature sensors were inserted into the applied water stream by using modified PVC pipe fittings (fig. 1, item 4). A small nozzle was also attached to the discharge manifold to discharge approximately 113 L/h of water. This nozzle discharge was used to maintain flow through the suspended drip tapes, and minimize slow internal flow velocities and entrapped air.

During the first test sequence, all drip tapes were conditioned for 15 min at the minimum pressure setting (28 kPa). Water discharge amounts from all emitters were collected into small plastic cups over a 6-min collection period. After the conditioning period, the collection cup racks were simultaneously slid under the dripping strings. At the end of six minutes, collection cups were simultaneously slid out from under the dripping strings. Collected water volumes were weighed on an electronic balance and converted to volumetric units. Collected amounts typically weighed between 90 and 120 g, and the balance had an accuracy of ±0.1 g. All cups were emptied and shaken dry between tests. The water pressure was adjusted to the next setting and drip tubes were then conditioned for 3 min at each successive pressure setting before collecting discharge volumes.

Drip Tubing Temperature Response

Three drip tape lateral lines with five emitters each were tested at each temperature and pressure setting by using the previously discussed lab setup (fig. 1). Each sequence of tests evaluated each product at the operating pressures of 55, 69, and 83 kPa with five water temperature settings (20°C, 29°C, 38°C, 48°C, and 52°C). In order to avoid potential bias from possible physical changes to drip tape products from test conditions, new sections of drip tape were used for each operating pressure setting. Operating pressures were established and measured by using procedures as described previously.

The specified water temperature values were target levels. Actual water temperatures were measured and recorded during each test. Hydraulics lab tap water temperature ranged between 19°C and 21°C. This temperature was used as the starting point (T_{min}) in all temperature tests. For the first

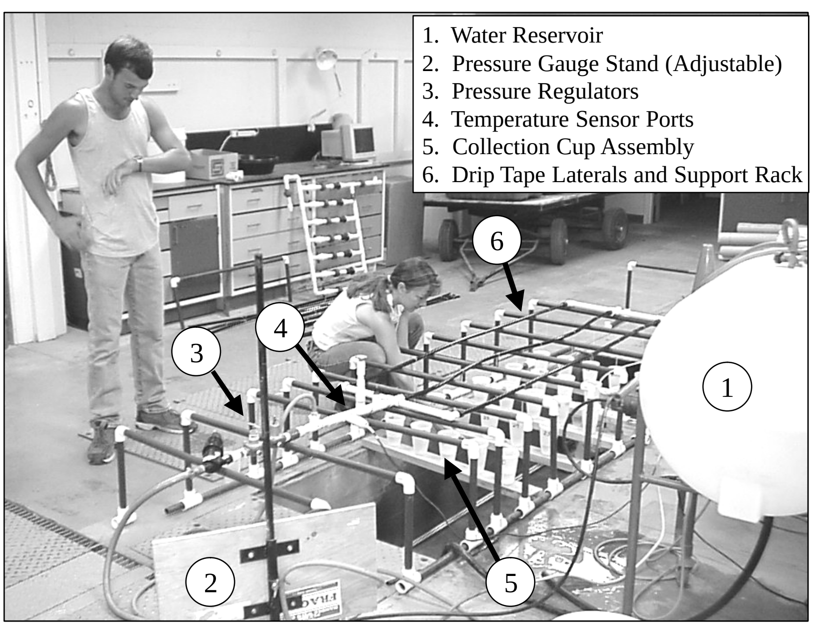


Figure 1. Lab setup to measure drip tape emitter discharge rates.

temperature setting in all tests, the 190-L reservoir was filled with the lab tap water. Temperature sensors were positioned in the reservoir, in the supply pipe to the test manifold, and on the discharge manifold of the testing system. Water temperature readings were digitally and manually recorded during each test to ensure consistent temperatures throughout the drip tape laterals. For the tests with elevated water temperatures, water was heated in a standard electric water heater, and approximately 76-L was added to the 190-L reservoir. Cooler tap water and heated water were then added and stirred to obtain a water temperature close to the next higher target temperature. Because each water temperature test sequence lasted for less than 30 min, the thermal mass of the water in the supply reservoir was sufficient to maintain the elevated water temperature during the test sequence to within 1°C of the test temperature.

During a temperature sequence of tests, drip tapes were initially conditioned at the specified pressure setting (55, 69, or 83 kPa) and T_{min} (~20°C) for at least 1 h. During the test, pressure was maintained at the treatment setting. After each test run, the water temperature was increased to the next level as previously described, and tubing was conditioned at that temperature for 15 min. Water discharge amounts from all emitters were collected into small plastic cups over a 6-min collection period by using procedures as previously described.

Temperature discharge ratio (TDR) values (Von Bernuth and Solomon, 1986; Keller and Bliesner, 1990) were calculated for each product at each temperature and pressure setting. TDR values (also referred to as a "temperature flow rate index;" *ASAE Standards*, 2003)

$$TDR = (q_t°)/(q_{20}°) \tag{1}$$

relate the emitter discharge at each measured temperature value ($q_t°$) to the emitter discharge at the initial base temperature ($q_{20}°$). Those data were further analyzed using simple regression analysis. Both linear and quadratic functions were fit to the TDR/temperature data and the R^2 correlation terms were used to determine the best fit.

Results

Resistance to Tensile Stress

Resistance to tensile stress (fig. 2) followed a similar trend for all products, however, wall thickness and material composition affected the elongation response. A load of 16 kg resulted in a 25% elongation of the RD-08 product whereas 24 kg was required for the thicker-walled RD-15 product. Thus, as expected the thicker wall increased the resistance to tensile stress. Similar responses were measured between the TT-10 and TT-15 products (fig. 2). However, while the TT-10 product (0.20 mm) is thinner than the RD-15 product (0.38 mm), a load of 26 kg was required to reach 25% elongation of the TT-10 product compared to the 24 kg required for the RD-15 product. In comparison, the TT-15 product (also 38 mm) was the stiffest, requiring 32 kg of load to elongate by 25%. These results demonstrate the difference associated with product material composition.

Standard Operating Pressure/Emitter Discharge Tests

Emitter discharge/pressure relationships for the RD (fig. 3) and TT (fig. 4) products were fitted to a standard power function that takes the form:

$$q_e = kP^x \tag{2}$$

where q_e is the emitter discharge (L/h), P is the operating pressure (kPa), x is the emitter discharge coefficient, and k is a constant of proportionality. Values of "k" and "x" for the test data relationships in figures 3 and 4 were determined using the power function regression analysis tool in Microsoft Excel. These power function regression relationships all had very high R^2-values (>97%). Power function values for the "Mfg Eqn" relationships in figures 3 and 4 were obtained from the manufacturer literature for these products. The RD-08 and RD-15 measured discharge rates at the nominal pressure (55 kPa) were very close (within 0.01 L/h) to the reported manufacturer values (fig. 3). However, measured nominal pressure discharge rates for the TT-10 and TT-15 products (fig. 4) were substantially higher than reported manufacturer values (to be discussed further below).

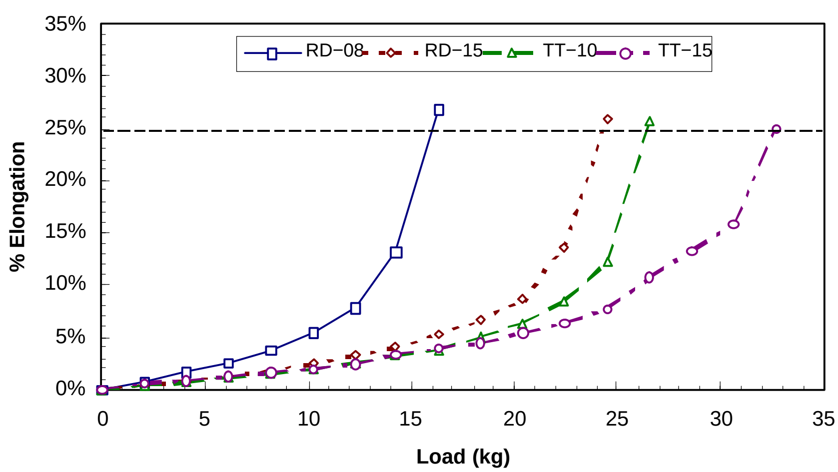
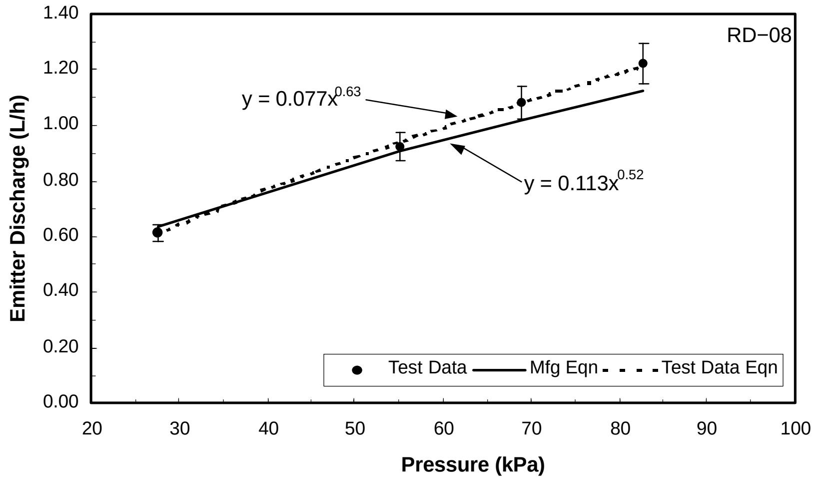
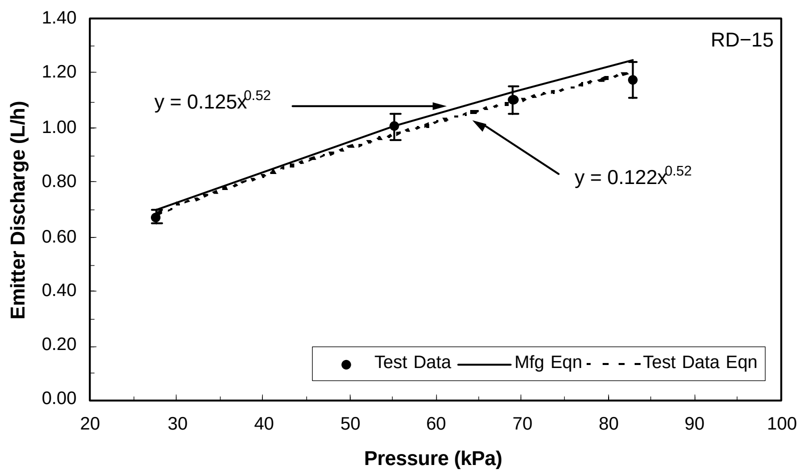


Figure 2. Resistance to tensile stress expressed as percent elongation of 152-cm long sample of product in response to loading. Loading was ceased at 25% elongation. Average results for each of the four tested products are shown.



(a)



(b)

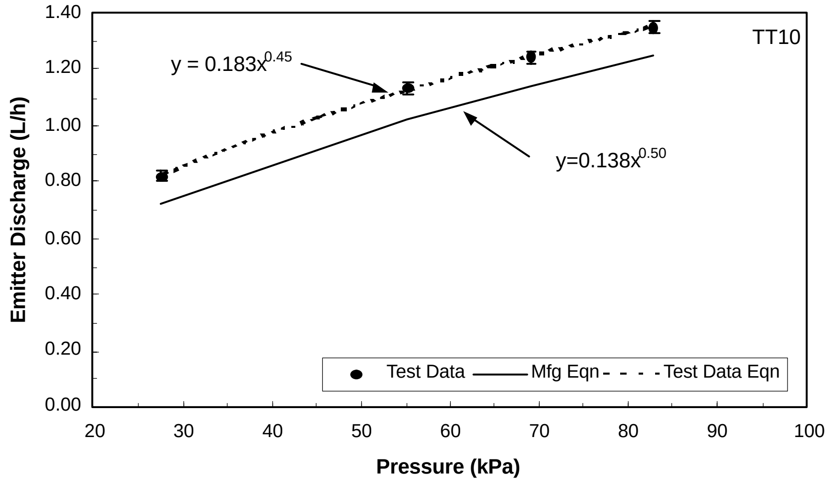
Figure 3. Emitter discharge/pressure relationships for the RD-08 product (a) and RD-15 product (b). The original discharge/pressure test data are displayed with error bars (±1 std dev) and the power function of those data. The discharge function from the manufacturers data is also displayed with that relationship.

The measured discharge/pressure relationship for the RD-08 product (fig. 3a) was very close to the manufacturer data at the lower end of the pressure scale. However, the calculated emitter discharge exponent “x” of 0.63 from measured data was greater than the manufacturer reported value of 0.52. Additionally, the measured discharge data continued in a more increasing linear trend at pressures above 55 kPa. However, the measured discharge/pressure relationship for the RD-15 product (fig. 3b) was very close to the manufacturer data throughout the range of measured data. Similarly, the calculated and manufacturer reported “x” values were identical at 0.52 (fig. 3).

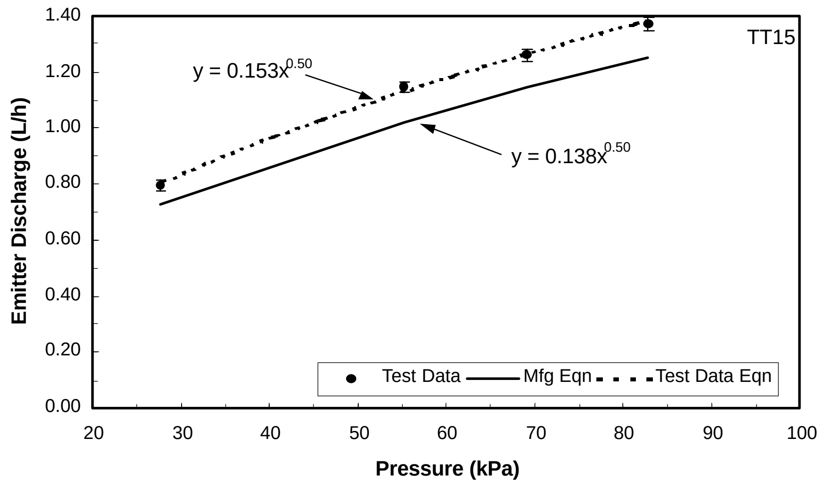
Measured discharge/pressure relationship data for the TT-10 and TT-15 products consistently tracked higher than manufacturer data (fig. 4). TT-10 measured data were about 0.10 L/h higher while TT-15 data were up to 0.12 L/h higher. Differences between measured and manufacturer data may be associated with the level of the “data” obtained from the manufacturer literature. While Roberts Irrigation Inc. provides both “k” and “x” values for their products, T-Systems does not. The T-Systems manufacturer-based “k” and “x” values were obtained by using the “nominal” flow and pressure information in their literature. A single tubing discharge value at a single pressure is provided as an average for the tube, along with an “average x” value of 0.5. If specific “k” and “x” values are not provided, it is better to provide discharge data for several operating pressure so that appropriate “k” and “x” values can be derived.

Drip Tubing Temperature Response

Emitter discharge rates and associated TDR values for the RD-08 product at an operating pressure of 55 kPa consistently increased with increases in water temperature (table 2) from a discharge rate of 0.95 L/h at 19°C (TDR = 1.0) to 1.13 L/h at 52°C (TDR = 1.18). Similar results with even higher TDR values were measured with the higher operating pressures of 69 and 83 kPa (table 2). Measured emitter discharge rates appeared to increase exponentially with



(a)



(b)

Figure 4. Emitter discharge/pressure relationships for the TT-10 product (a) and TT-15 product (b). The original discharge/pressure test data are displayed with error bars (±1 std dev) and the power function of those data. The discharge function from the manufacturers data is also displayed with that relationship.

temperature. Resultant TDR values at the 51°C and 50°C temperatures for the 69 and 83 kPa pressures reached 1.44 and 1.97, respectively. Even in the middle of the temperature range (37°C to 40°C), TDR values were 1.06, 1.13, and 1.23 for the operating pressures of 55, 69, and 83 kPa. Such characteristics could provide highly undesirable flow rate distributions in a microirrigation subunit with drip tape exposed to sunlight and/or very warm water conditions.

Increased wall thickness (RD-15) reduced the sensitivity of the RD product to water temperature (table 2). The greatest sensitivity to water temperature with the RD-15 product occurred at the lowest operating pressure of 55 kPa with a peak TDR value of 1.12 at both 46°C and 49°C. Furthermore, the TDR value only dropped by 0.01 to 1.11 at 40°C. Lower sensitivity to water temperature at the higher pressures may be associated with the thickness of the plastic along the emitter pathway. The RD products have a “self-flushing” emitter design that allows the emitter pathway to enlarge under elevated “back-pressure” associated with a clogged or partially clogged pathway. This self-flushing design along with the elasticity of the plastic in these products may be contributing to the high and somewhat variable emitter discharges associated with elevated water temperatures.

Emitter discharge rate changes in the TT products (table 3) were quite different from the RD products (table 2). The TT-10 product (table 3) had a 5% increase in emitter discharge with a temperature rise from 20°C to 52°C at an operating pressure of 55 kPa. Surprisingly, emitter discharge rate decreased with increased water temperature at operating pressures of 69 and 83 kPa. While, decreasing emitter discharge rates were also reported by Parchomchuk (1976) for vortex type emitters, the emitters in this study had a labyrinth style, which would typically have a positive to nearly negligible change in emitter discharge with temperature. However, the labyrinth emitters in these products are formed from the drip tape as part of the extrusion process (the are not preformed/molded emitters). Therefore, wall thickness may vary such that thinner sections may be more susceptible to temperature-related property changes that result in a slight constriction of the emitter path (at elevated pressures) and reduced emitter discharge. The greatest decrease in emitter discharge rate occurred at 83 kPa, with a

Table 2. Emitter discharge response to water temperature at 55, 69, and 83 kPa of operating pressure for the Ro-Drip products.

Operating Pressure (kPa)	RD-08				RD-15			
	Temp[a] (°C)	q[b] (L/h)	cv[c]	TDR[d]	Temp (°C)	q (L/h)	cv	TDR
55	19	0.95	0.069	1.00	20	0.96	0.056	1.00
	28	0.97	0.065	1.01	31	1.04	0.055	1.08
	37	1.01	0.071	1.06	40	1.07	0.058	1.11
	45	1.06	0.078	1.12	46	1.07	0.062	1.12
	52	1.13	0.076	1.18	49	1.07	0.063	1.12
69	22	1.09	0.055	1.00	19	1.06	0.052	1.00
	30	1.15	0.053	1.06	30	1.09	0.073	1.04
	37	1.22	0.053	1.13	38	1.08	0.057	1.03
	48	1.41	0.048	1.30	48	1.11	0.056	1.05
	51	1.56	0.053	1.44	52	1.12	0.063	1.06
83	21	1.20	0.056	1.00	21	1.14	0.058	1.00
	29	1.27	0.054	1.06	29	1.17	0.055	1.03
	40	1.47	0.053	1.23	37	1.18	0.055	1.04
	47	1.95	0.069	1.63	47	1.21	0.053	1.07
	50	2.36	0.065	1.97	53	1.25	0.050	1.10

[a] Water temperature.
[b] Emitter discharge rate.
[c] Coefficient of variation.
[d] Temperature discharge ratio.

reduction in emitter discharge of 0.10 L/h and an associated TDR value of 0.93 as water temperature increased from 19°C to 52°C.

An increase in wall thickness with this product (TT-15) also reduced the effects of water temperature on emitter discharge (table 3). Emitter discharge changes at pressures of 55 and 69 kPa were minimal with peak TDR values of 1.02; however, at 83 kPa, emitter discharge rate decreased by 0.07 L/h (TDR = 0.94) with a water temperature change from 21°C to 52°C. Thus, it also appears with the TT products that increasing wall thickness reduces the sensitivity to water temperature. Different plastics will have different values for the modulus of elasticity, tensile strength, and coefficient of linear thermal expansion (CRC Press, 1973). These properties will affect the response of the product to variations in pressure and temperature. While the test on resistance to tensile stress evaluates the linear stress properties and linear elasticity of the tubes, it also appears that perhaps that material property (fig. 2) may provide an indication of sensitivity to water temperature. The RD products were more elastic (a characteristic of their design that has other benefits) with lower resistance to tensile stress than the TT products, and discharge rates of their emitters were more sensitive to increased water temperature.

Most water temperature/emitter discharge data have been shown to be linear (Parchomchuk, 1976; Zur and Tal, 1981; Von Bernuth and Solomon, 1986). However, those studies focused on more rigid emitter designs such that the primary influence of water temperature was from the changes in viscosity of the water. Data from this study include both linear and quadratic (fig. 5, table 4) relationships. The RD-08 product had positively increasing quadratic relationships for each pressure setting over the temperature range in this study (table 4). Yet, while the RD-15 product also had a quadratic

Table 3. Emitter discharge response to water temperature at 55, 69, and 83 kPa of operating pressure for the T-Tape products.

Operating Pressure (kPa)	TT-10				TT-15			
	Temp[a] (°C)	q[b] (L/h)	cv[c]	TDR[d]	Temp (°C)	q (L/h)	cv	TDR
55	20	1.18	0.026	1.00	20	1.14	0.036	1.00
	29	1.20	0.025	1.02	28	1.14	0.029	1.00
	38	1.22	0.029	1.03	35	1.14	0.033	1.00
	47	1.23	0.025	1.04	44	1.14	0.032	1.00
	52	1.23	0.023	1.05	50	1.14	0.028	1.01
69	19	1.21	0.015	1.00	21	1.16	0.024	1.00
	29	1.19	0.017	0.98	30	1.18	0.019	1.02
	38	1.19	0.018	0.98	37	1.18	0.025	1.02
	48	1.18	0.014	0.97	46	1.19	0.020	1.02
	52	1.16	0.015	0.96	51	1.17	0.018	1.01
83	20	1.36	0.018	1.00	21	1.37	0.020	1.00
	29	1.30	0.017	0.96	30	1.35	0.020	0.98
	38	1.28	0.016	0.95	38	1.34	0.018	0.97
	48	1.26	0.018	0.93	46	1.31	0.017	0.95
	52	1.26	0.016	0.93	52	1.30	0.016	0.94

[a] Water temperature.
[b] Emitter discharge rate.
[c] Coefficient of variation.
[d] Temperature discharge ratio.

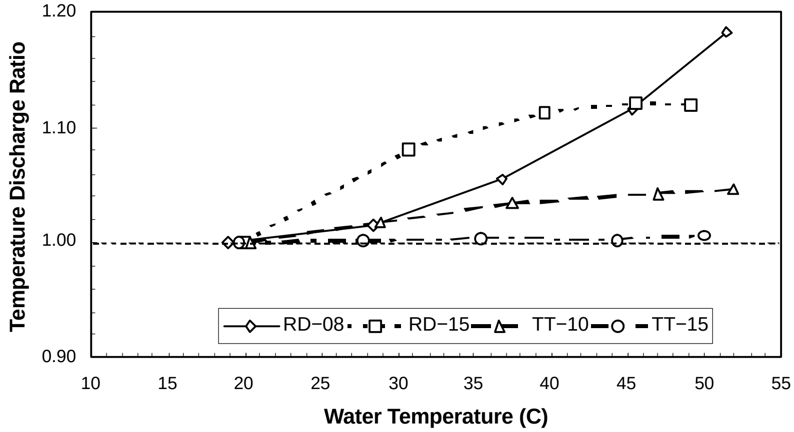


Figure 5. Temperature discharge ratio (TDR) values as affected by water temperature for the RD-08 , RD-15 , TT-10, and TT-15 products when operated at a pressure of 55 kPa.

relation at the 55 kPa pressure setting, the 69 and 83 kPa pressure settings had strong linear relationships. Similarly, strong linear relationships exist for the TT products. While the TT-10/55 kPa and TT-15/69 kPa best fit functions are quadratic, the quadratic term coefficients are very small. Thus, these results also imply that the elasticity and perhaps the self-flushing (expanding) emitter design of the RD-08 product changes the temperature function from linear to quadratic. As wall thickness associated with the RD-15 product reduced elasticity, it also tended to provide a more linear temperature response.

Some variation in emitter response from the RD-08 product was noted with coefficients of variation (cv) ranging from 0.065 to 0.078, 0.047 to 0.055, and 0.053 to 0.069 at the 55-, 69-, and 83-kPa levels, respectively (table 3). While measured emitter variation with the RD-15 product was similar to that of the RD-08 product (table 3), both TT products (TT-10 and TT-15) had lower cv values (0.014 to 0.036) indicating greater consistency among emitters (table 4). Furthermore, even though cv values for individual products were different from each other, neither water temperature nor operating pressure appears to have had any substantial effect on emitter discharge variation for any given product.

Summary and Conclusions

Characterization tests on Robert's Ro-Drip (RD) and T-Tape (TT) drip tape products included resistance to tensile stress, emitter discharge response to operating pressure, and emitter discharge response to water temperature. The RD product included wall thicknesses of 0.20 mm (8 mil, RD-08) and 0.38 mm (15 mil, RD-15), whereas the TT product included wall thicknesses of 0.25 mm (10 mil, TT-10) and 0.38 mm (15 mil, TT-15). These two product types were made of different plastic materials that also had different material properties; the RD products were more elastic than the TT products. A resistance to tensile stress analysis showed that the required load to result in a 25% increase in length was 16, 24, 26, and 32 kg for the RD-08, RD-15, TT-10, and TT-15 products, respectively.

The emitter discharge response to water pressure results from both Roberts Irrigation products tracked the emitter discharge relationship curve at the lower end of the pressure range based upon "k" and "x" values provided in the manufacturers literature. They both deviated from the manufacturer curve at higher pressures (within the operating range as specified by the manufacturer) with the greatest deviation from the thinner walled RD-08 product. Measured

Table 4. Temperature discharge ratio (TDR) regression functions (related to water temperature, T in °C) for the drip tape products used in this study at each operating pressure of 55, 69, and 83 kPa.

Product	Operating Pressure (kPa)	TDR Regression Function	R^2
RD−08	55	$TDR = 0.0002T^2 - 0.0068T + 1.0662$	1.00
	69	$TDR = 0.0005T^2 - 0.0205T + 1.2294$	0.98
	83	$TDR = 0.0016T^2 - 0.0844T + 2.0841$	0.98
RD−15	55	$TDR = -0.0002T^2 + 0.0166T + 0.7416$	1.00
	69	$TDR = 0.0017T + 0.9719$	0.87
	83	$TDR = 0.0029T + 0.9394$	0.96
TT−10	55	$TDR = -4.0 \cdot 10^{-5}T^2 + 0.004T + 0.9327$	1.00
	69	$TDR = -0.0011T + 1.02$	0.87
	83	$TDR = -0.0021 + 1.0318$	0.92
TT−15	55	$TDR = 0.0002T + 0.9966$	0.86
	69	$TDR = -8.0 \cdot 10^{-5}T^2 + 0.0061T + 0.909$	0.92
	83	$TDR = -0.0018T + 1.0373$	0.99

emitter discharge data for the TT-10 and TT-15 products were consistently 0.10 to 0.12 L/h higher than "estimated" manufacturer data at all pressures within the test range. T-Systems literature did not provide "k" and "x" values for their products and these had to be estimated from a published emitter discharge rate at a specified nominal pressure. Estimation errors could occur because a single point was used to determine the "k" and "x" values rather than a series of operating pressure and discharge rate points.

Water temperatures ranged from 20°C to 50°C and products were tested at 55, 69, and 83 kPa of operating pressure. The RD-08 product had the greatest emitter discharge response to water temperature. Temperature discharge ratio (TDR) values reached 1.97 with a water temperature of 50°C at the 83-kPa operating pressure. Furthermore, all temperature-based emitter discharge responses of this product were quadratic while the other products had very strong linear relationships. The increased wall thickness of the RD-15 product reduced emitter discharge sensitivity to water temperature with peak TDR values at 1.12. Furthermore, both T-Tape products had the lowest emitter discharge rate sensitivity to water temperature. However, emitter discharge rates increased or decreased with increased levels of water temperature at the different pressure settings. Resultant TDR values ranged from 0.93 to 1.05 for the TT-10 product and from 0.94 to 1.02 for the thicker walled TT-15 product.

Results of these studies clearly indicate the need to know basic hydraulic and materials properties characteristics information for collapsible emitting hose (thin-walled drip tape) products. System design currently incorporates acceptable emitter discharge variations associated with pressure variations due to friction and elevation changes. However, emitter discharge variation due to temperature is typically not considered and substantial discharge differences associated with water (or soil) temperature can affect the "as-built" characteristics of the system design, pump output, system/subunit uniformity, and/or pressure distribution.

These tests followed ASAE Standard S553, "Collapsible Emitting Hose (Drip Tape) — Specifications and Performance Testing" that was initiated by and partially developed by the manufacturers of drip tape products. Section 4 states that a "nominal emitting hose discharge rate" should be provided along with the "nominal operating pressure." While several manufacturers provide specific values for the emitter exponent "x" and constant of proportionality "k" (for a specific set of units), this information is not directly available. However, designers need this specific data for use in generic design programs and system analyses. Thus it would be helpful for that data to be directly provided rather than using a single pressure/discharge point for estimation purposes. Manufacturers should also provide temperature response data for their products along with the maximum recommended operating temperature (Section 4.2.5 of ASAE Standard S553, 2003). The results of this research also warrant investigations into thinner wall products such as the 0.10-, 0.13-, and 0.15-mm (4-, 5-, and 6-mil) tubes and to determine if there are any hysteresis effects. In addition, because temperature can have a substantial effect on the discharge rate of some drip emitters, temperature measurements and associated corrections may also be necessary during field performance evaluations of these systems. Emitter discharge rates above and/or below normal may not simply be in response to operating pressure.

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