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SQUEEZER: A DEVICE FOR INDIRECT PRESSURE MEASUREMENT IN THIN–WALLED MICROIRRIGATION TUBING

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ABSTRACT. *A simple device was developed for measuring pressure in thin–walled collapsible emitting hose or tubing in the field. The device, called a "Squeezer," senses pressure by measuring the force necessary to compress a short section of tubing between two parallel plates to 50% of its original diameter. The force can be measured by either an electronic load cell or a spring balance, and the output, calibrated for a particular size of tubing, read directly in pressure units. The device provides a convenient, non–intrusive and low–cost means for irrigators to assess pressure variations within their microirrigation laterals without installing special fittings or puncturing the tubing.*

Keywords. *Pressure measurement, Microirrigation, Drip irrigation, Thin–walled tubing.*

Miroirrigation is increasing worldwide as a means of improving irrigation efficiency. Micro or drip irrigation systems can be adapted to hilly terrain and a wide variety of soils and crops. The emitting tubing can be buried or laid on the soil surface. Most field crop drip systems use thin wall (4 to 15 mil), collapsible polyethylene tubing, also called "drip tape" with integral emitters. Tubing is manufactured in several diameters, and the 16–mm (5/8–in.) diameter tubing is the most popular (Hanson et al., 2000). Emitters are usually tortuous–path and uniformly spaced such that the tubing emits a "nominal" discharge per unit length of tubing, the actual discharge varies with pressure. Pressures of 55 to 83 kPa (8 to 12 psi) are commonly used. The length of lateral is limited by the pressure loss and elevation variation. Pressure levels and variations in drip systems must be known to assess water distribution uniformity. Allowable pressure variations depend on the target emission uniformity (*ASAE Standards*, 2000), but typically the pressure in a lateral should not vary by more than 20%. Unlike sprinkler nozzles, drip emitter pressure cannot be easily measured with a pitot–tube type insertion gage. Irrigators sometimes assess pressure by squeezing the tubing with their fingers. There is a need for a convenient, low–cost means to measure drip tubing pressure in the field, without disturbing or puncturing the tube. Field crop drip tubing is laid on the surface or buried from 2 to 40 cm. Shallow buried tubing is easily exposed for testing. Even when placed under plastic mulch, the tubing is often exposed at the upstream and downstream ends. Deeply buried tubing would need to be exposed by digging a hole. In either case, a non–intrusive pressure measurement is preferable to punching and repairing a hole in the tubing for direct pressure measurement.

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"SQUEEZER" PRINCIPLES AND DESIGN

The "squeezer" device compresses or partially flattens a short section of inflated circular tube to sense the pressure within the tube. The device measures the force required to compress the tube by a standard, repeatable amount between two parallel flat plates. The force is the product of the pressure and the area of tube contacting one of the plates. It is important to avoid excessive flow restriction, because the resulting increased flow velocity will reduce the piezometric pressure being measured (calculated by Bernoulli's equation). Figure 1 shows the plates and compressed tube and the parameters involved. Neglecting the tube wall thickness and elasticity, the plate force, F, can be calculated as

$$F = P\,L\,w \tag{1}$$

and

$$w = d\,(1-h_r)\,\pi/2 \tag{2}$$

therefore

$$F = C\,P\,L\,d\,(1-h_r)\,\pi/2 \tag{3}$$

where

F = the force, N (lb)
w = the width of the tubing contacting the plate m (in.)
P = piezometric pressure in the tube, kPa (psi)
L = length of compressed tube, m (in.)
d = tube diameter, m (in.)
h = distance between plates, m (in.)
h_r = the compression ratio (h/d)
C = a coefficient = 1.0 for English and 1000 for metric units

Equations 1 through 3 are approximate because they neglect the effect of the tension in the tube wall at the upstream and downstream edges of the plate, which tends to increase the force. Thus, the effective length is slightly greater than the plate length, L. The plate edges can be beveled (fig. 1c) to eliminate a sharp bend in the tube wall, and reduce the head loss through the contraction. The force, and thus the potential sensitivity increases as the tube is compressed (h_r decreases). However, as the tube is compressed, the cross–sectional area of flow decreases by

$$A_r = h_r\,(2 - h_r) \qquad (4)$$

where A_r is the ratio of the area in the compressed section to the full circle area.

As the area decreases, the velocity head increases and the piezometric head decreases (by a factor = $1/A_r^2$). Typical drip laterals are designed to limit flow velocities to well below 1 m/s (3 ft/s) [e.g. a 200–m (600–ft) lateral discharging 6.2 Lpm/100 m (0.5 gpm/100 ft)] to limit friction losses, yielding a velocity head of about 0.7 kPa (0.1 psi). For example, at $h_r = 0.5$ the velocity head increases by a factor of 1.8, to about 1.4 kPa (0.2 psi). At a typical operating pressure of 70 kPa (10 psi), this velocity head effect would be negligible.

Another concern is the pressure loss due to contraction and expansion of the flow. At $h_r = 0.5$ the contraction loss is about 5% of the velocity head in the contraction, and the expansion loss can be estimated by (Rouse, 1946):

$$H_L = H_v\,(1 - A_r)^2 \qquad (5)$$

where H_v is the velocity head in the contraction.

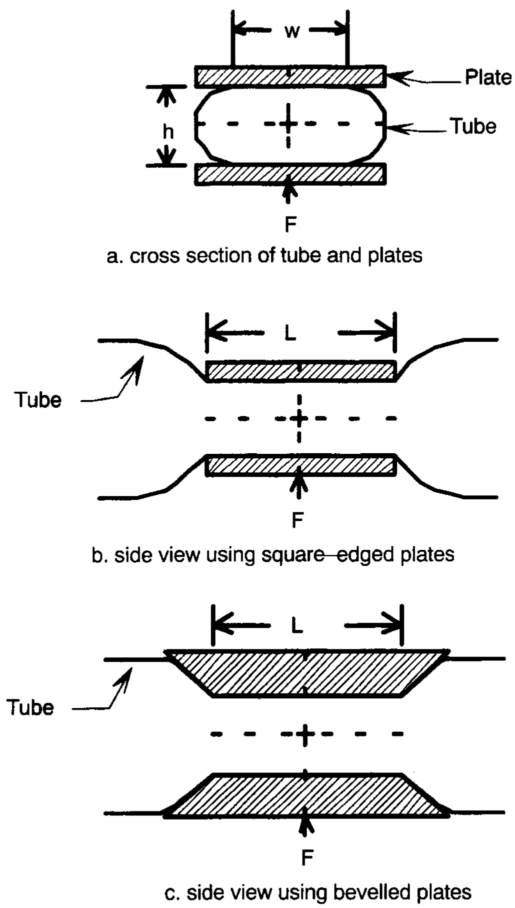

Figure 1. Definition sketch of tube compressed between two plates.

With $h_r = 0.5$, $H_v = 1.4$ kPa, $A_r = 0.75$, and $H_L = 0.06 \times 0.2 = 0.08$ kPa. Thus, the effects of head loss should be negligible at $h_r \geq 0.5$. Smaller compression ratios would give better sensitivity to pressure, but will cause some error at higher flows. Thus, we recommend compressing the tube to approximately one–half its original diameter. The desired sensitivity or compressed area can be obtained by simply increasing the compressed length. We recommend a compressed length, L, of two to three times the tube diameter to reduce the end effects and to obtain a linear response to pressure.

Construction of the Prototypes

The device was designed to compress the tube to a constant, repeatable distance between the plates, to have easily opened jaws, and to be easily adjustable. Two methods of measuring the force were used in prototype devices. An electronic load cell provided an accurate and reliable laboratory test unit (fig. 2). In this unit, the plates are opened by rotating the pivoting lever to raise the upper plate while the tube is positioned between the plates. As the levers are squeezed together, the load cell forces the upper plate downward until the pivoting lever contacts a preset stop, where the plates are parallel and spaced at 8 mm (for use with 16–mm tube). The load cell output device then displays a reading in mV (or other units after calibration). The load cell used here was an interface model SML (www.interface-force.com, INTERFACE, Scottsdale, Ariz., $295) with a full–scale capacity of 113 N (25 lb). The output was read with a Campbell Scientific 21X data logger. This unit, although expensive, was used as a laboratory test device to evaluate the potential accuracy of the method.

A spring balance device was developed as a low–cost unit for 16–mm tubing (figs. 3 and 4) An ell–shaped scissors–type arrangement is used with the compression plates on one side of a pivot and the spring balance on the other side. The spring is compressed until the plates are parallel and the spring force balances the pressure force. Levers are provided to open the plates while the tube is positioned between the plates. The levers are released and the wing nut is then adjusted until the alignment indicator shows that the plates are parallel (fig. 4). As the wing nut is adjusted, the spring length changes and the pointer bar moves relative to the pressure scale. A linear scale calibrated in pressure units measures the spring length, and thus the spring force and fluid pressure.

The compression springs used in the prototype had an outside diameter of 32 mm (1.25 in.), a free length of 100 mm (4 in.), and a wire diameter of 2 mm (0.08 in.). The length of the lever arm of the device (vertical height) was designed to accommodate this spring. The lever arm length can be changed and the scale adjusted to utilize different springs. To accommodate different tubing sizes, the plate spacing, lever arm, or length of the plates (compression length) can be changed or made adjustable. The device shown is sized for 16–mm (5/8–in.) diameter tubing, and was constructed primarily from 38– × 4.8–mm (1.5– × 3/16–in.) flat steel bar stock. The cost of materials to build the spring balance prototype was less than $10 (US). Figures 5 and 6 show the spring device in field use. The lower plate assembly is painted white and the upper plate assembly is black for clarity [Note that there are minor differences in placement of the

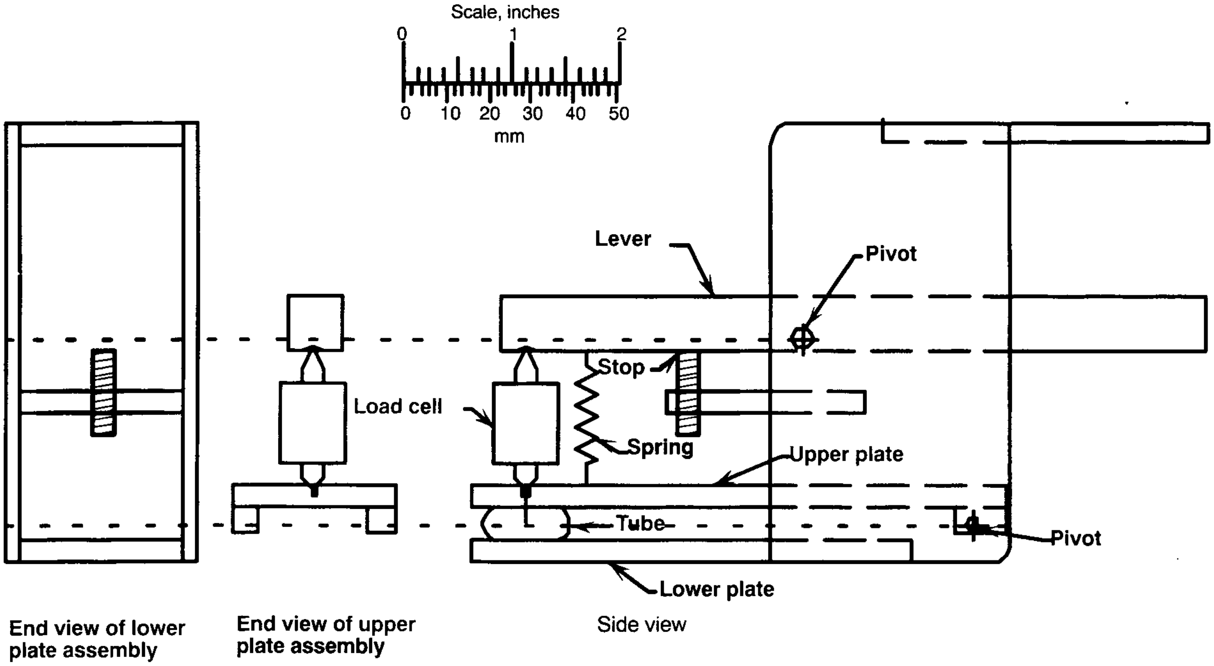

Figure 2. Laboratory test device using an electronic load cell.

pressure scale and pointer between the schematics (figs. 3 and 4) and the photos (figs. 5 and 6)]. The user squeezes the levers to open the plates (fig. 5), slides the lower plate under the tube, aligns the outside tube edge with the outer edge of the plates, and releases the levers. The wing nut is then adjusted until the alignment pointer indicates that the plates are parallel. The pressure is then read from the scale at the pointer position (fig. 6 indicates a reading of 10.5 psi). Normally, only small adjustments of the wing nut are needed between successive readings.

Results and Discussion

A series of lab tests were conducted to test the effect of different tube wall thicknesses, manufacturers, etc., on the

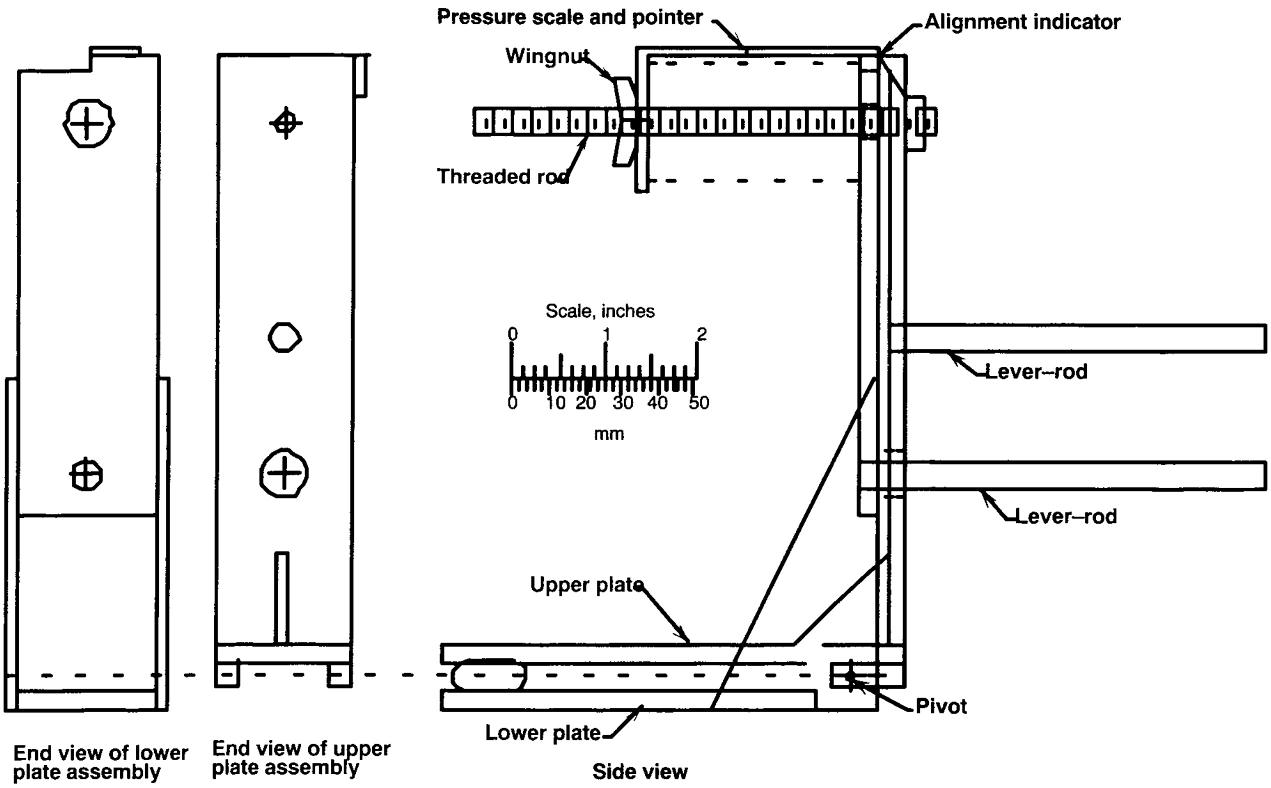

Figure 3. Squeezer spring device.

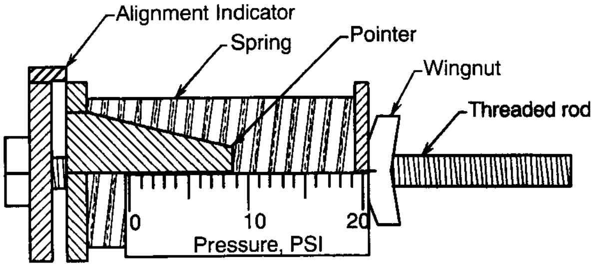

Figure 4. Top view of spring and pressure scale.

calibration and to determine the accuracy and optimum configuration of the devices. The 16–mm (5/8–in.) diameter tubes were used in these tests. Short lengths of tube were pressurized with air. The load cell device was first calibrated in force units. Using tubes from one manufacturer, we tested the effect of tube wall thickness (4 to10 mil = 0.1 to 0.25 mm) and plate length (20 and 40 mm) on the response curve (fig. 7). The output was found to be practically linear from 13.8 to 138 kPa (2 to 20 psi), with either plate length. Theoretical force curves calculated by equation 3 are shown in figure 7 for comparison. The actual force is greater than the theoretical force because of the plate end effects, as previously discussed. The end effects decrease as plate length increases. The force increased slightly with tube wall thickness at a given pressure. The ratio of actual to theoretical force was about 1.8 and 1.5 for the 20 mm and 40 mm plates, respectively, at the midrange pressures.

Tubes from a number of different manufacturers were also tested (fig. 8). These tests indicate that there is enough difference due to wall thickness or variation in diameter from different manufacturers that for 5% or better accuracy, the device should be calibrated with the tube that will be used in the field. However, for many cases where growers simply need to assess pressure differences, 10% accuracy will be sufficient, and a fixed calibration can be used for most tubing of the same nominal size.

The load cell device tests were also conducted with water flowing in the tubes, at a constant piezometric pressure of 69 kPa (10 psi). As the flow velocity increased from 0 to 1 m/s, the load cell force decreased about 3%. A further increase in velocity to 2 m/s resulted in a 15% decrease in force. This decrease is larger than would be predicted by the velocity head, and is likely due to the curvature of the flow at the contraction.

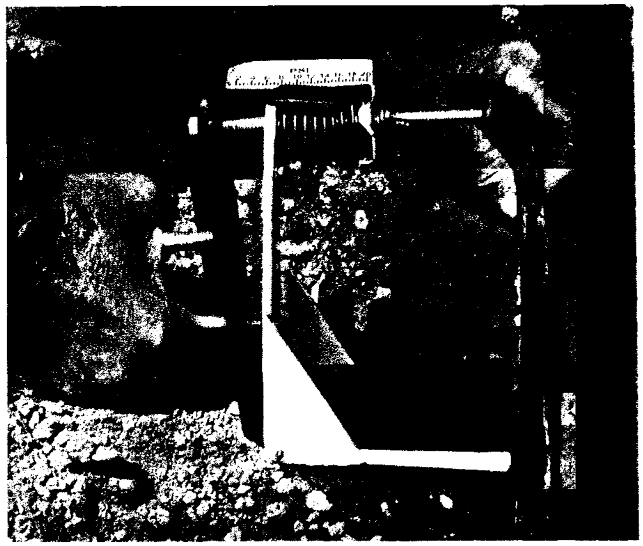

Figure 5. Squeezer being placed on tube in the field.

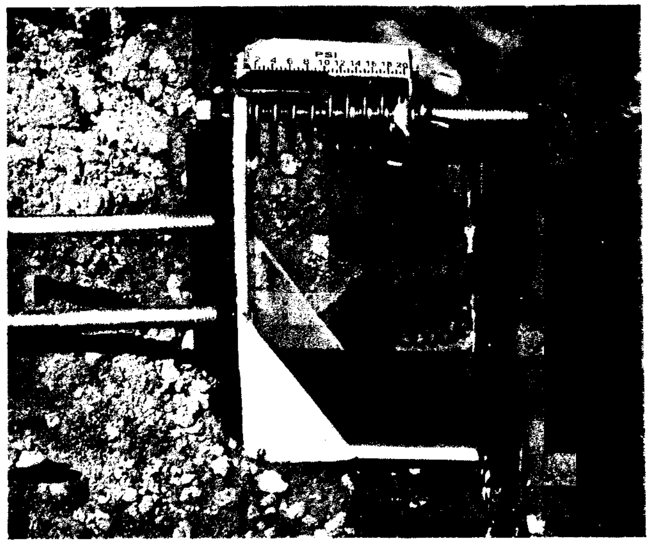

Figure 6. Squeezer on tube ready for pressure reading.

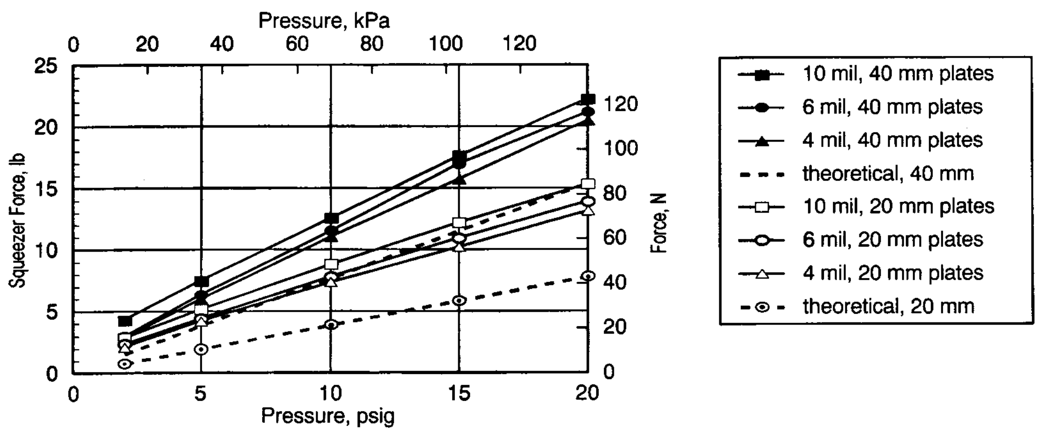

Figure 7. Load cell response curves with various wall thickness from one manufacturer (Tiger Tape).

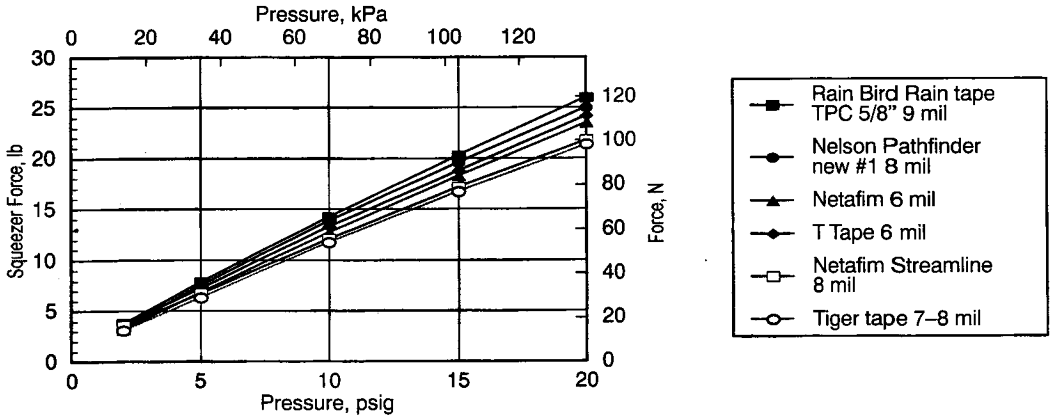

Figure 8. Load cell response curves with 16–mm tubes from various manufacturers (40–mm plates).

CALIBRATION AND USE OF THE "SQUEEZER"

The Squeezer can be calibrated by using a short length of tube pressurized with air or water, with an accurate pressure gage to measure the supply pressure. There is normally no need to calibrate the devices for force units. The spring device was calibrated using the Nelson Pathfinder 8–mil tubing. A pressure scale of the proper length was constructed (a computer drawing program or hand drawing and reducing copier could be used), and clamped under a sheet of clear Plexiglas (the plastic was removed in figures 5 and 6 for clarity). This allowed the scale to be adjusted laterally to "zero" the scale at the midrange of pressure. Alternatively, the pointer could be made adjustable. A linear scale reading in psi was constructed to read accurately between 28 to 110 kPa (4 to 16 psi), as shown in figure 4. When this same scale was used for other manufacturer's tubing, and adjusted to read accurately at 69 kPa (10 psi), errors of about 5% occur at the high and low ends of the pressure range (fig. 9). Thus, if higher accuracy over a wide pressure range is required, the scale length (slope of the calibration) may need to be changed for different types of tube. However, the accuracy remains within 3% for pressures within 20% of midrange pressure. Pressure variations of 50% or more from nominal design pressure indicate serious design or maintenance problems that need to be addressed before the measurement accuracy is a concern. A grower could install a pressure gage at a convenient location in the system as a "known pressure point" at which to check and adjust the Squeezer.

Another accuracy issue is the possible temperature effect on pressure measurement. Increased temperature should increase the resiliency of the tubing, effectively decreasing the wall thickness, which decreases the force (and indicated pressure) as shown in figure 7. Water temperature can increase considerably in surface tubing near the ends of laterals, but the resulting error in pressure is probably minor relative to the temperature affect on flow rate through the emitters. These effects need to be explored further.

CONCLUSIONS AND RECOMMENDATIONS

The plates should be designed such that the compressed length of tubing is about twice the tube diameter. The use of beveled plates is probably not necessary since tube wall tension tends to eliminate a sharp bend at the plate edge. The mechanism should be designed such that the plates are nearly parallel at the recommended compression of 50% of the tube nominal diameter. For optimum accuracy, the pressure scale should be designed to read near the design operating pressure at its midrange, and have a range of 50 to 150% of midrange pressure.

This article deals only with thin–walled resilient tubing up to about 15–mil polyethylene. Pressure in thicker walled tubing could be measured by this method wherever pressure levels are high enough and the material is resilient enough so that the properties of the tubing would have relatively minor

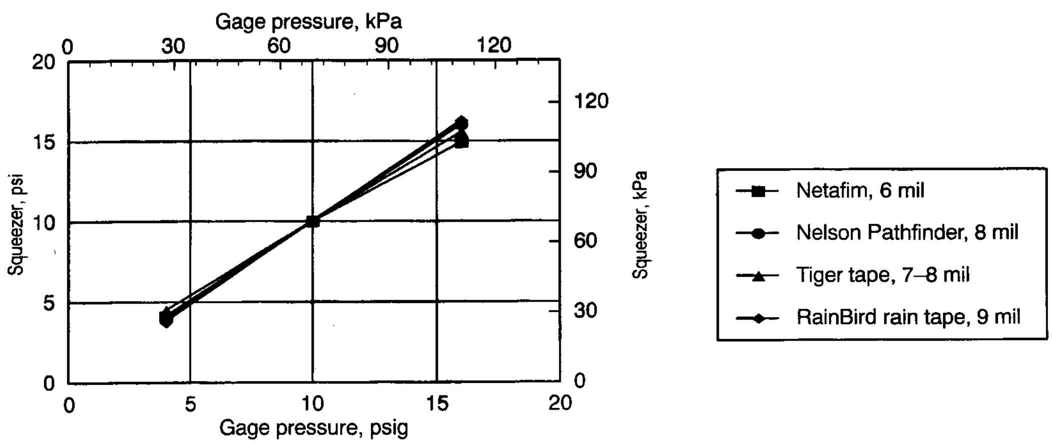

Figure 9. Spring device calibration at 69 kPa (10 psi).

influence. The optimum percent compression may be different for thick–walled tubing.

The Squeezer is a viable method for measuring pressure in thin–walled flexible drip irrigation tubing and may be useful for other applications. The low–cost spring balance unit can measure pressures within 10% for a reasonable range of tube wall thicknesses and manufacturers, or within 5% when calibrated for specific tubes. Small errors may occur near the inlet of laterals where velocities may be high. This device provides growers with a convenient means of assessing pressure variations in drip irrigation systems. A low–cost electronic version of the Squeezer is also being developed.

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