Tapered Lateral Design for Subsurface Drip Irrigation [1]

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Abstract

A stepwise tapered lateral design was evaluated for drip tape laterals that are used in High Plains subsurface drip irrigation systems. Spreadsheet models were developed to simulation drip irrigation lateral hydraulics to determine flow requirements, emission uniformity, and chemical travel times for tapered and non-tapered laterals. Models were run for a straight 11/8-inch lateral, a 11/8-inch to 7/8-inch tapered lateral, and a 11/8-inch to 9/8-inch tapered lateral. Each of these lateral combinations were simulated for nominal flow rates of 0.20, 0.25, and 0.25 gpm/100ft, and slopes of 0%, -0.5%, and –1.0.

Tapered laterals reduced the travel time of injected chemicals and reduced required flow rates during the flushing process. The 11/8-inch to 7/8-inch combination was generally not desirable due to low emission uniformities. However, the 11/8 to 9/8-inch combination was acceptable for most simulation scenarios. . Reduced fitting costs associated with smaller laterals, also reduced system costs for the tapered lateral design.

Introduction

Subsurface drip irrigation (SDI) systems are increasing in acceptance and use throughout the Great Plains. However, these production systems are concentrated with field crops (i.e. corn, soybean, alfalfa) that need to maintain low production costs. As these SDI systems have evolved, longer lateral run lengths result in the most economical designs. Because many of the agricultural production fields were divided into quarter sections and flood irrigated with runs of 2640 ft, larger diameter drip laterals have been developed to accommodate these long runs by maintaining acceptable emission uniformities.

System maintenance is essential to ensure longevity and continued performance of the irrigation system. This generally requires injection of chlorine, acid, and/or other water treatment chemicals to treat the laterals. In addition liquid fertilizers can be injected to provide essential crop nutrients on an as needed basis. While some dispersion can occur, these injected chemicals travel with the water and are thus dependant upon the flow velocity of the water in the lateral and pipe network. Flow velocities in drip laterals are typically very low, starting at 1 to 2 ft/s at the inlet end and decreasing to zero at the distal end. Therefore, injected chemicals will move very slowly in the lower sections of a drip lateral. When lateral diameter is increased, but the emitter spacing and discharge remain the same, flow velocities are even lower. Some chemical travel time analyses will not consider the last 10, 20 or 30 feet of the lateral because the water is moving so slow and that section represents less than1-2% of the lateral length. For example, in a plug flow analysis of a 0.875-inch diameter lateral that is 1320 feet long with an average flow rate of 0.25 gpm/100ft, the

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travel times for injected chemical to get to the end of the lateral and within 10 feet of the end are 103 and 64 minutes, respectively. In a similar analysis for a 1.375-inch diameter lateral that is 2640 feet long, the travel times are 274 and 179 minutes, respectively, while for a 1.375-inch diameter lateral that is 1320 feet long the times are 241 and 150 minutes. Thus, it can take almost 90 minutes for chemical to travel the last 10 feet in a 1.375-inch diameter lateral. Therefore, it is evident that lateral diameter is a significant factor that influences chemical travel times and that the analysis position is also very important.

Flushing of drip laterals is an essential maintenance practice. In order to properly flush a lateral, it is recommended to have a minimum flush velocity of 1 ft/s. The required volumetric flow rate during a flushing cycle will be dependant upon the size of the laterals, the emitter discharge characteristics, the number of laterals in a flushing zone, and the average lateral pressure during the flushing cycle. larger diameter laterals require greater volumetric flow rates. For example, a 1 ft/s flow velocity in a 0.875-inch diameter lateral corresponds to a flow velocity of 1.9 gpm while that same flow velocity in a 1.375-inch diameter lateral requires 4.6 gpm.

A tapered lateral that steps from a larger diameter lateral to a smaller diameter lateral could improve chemical travel times and reduce required flush cycle flow rates. However, the appropriate location of the taper split needs to be analyzed. In addition, the hydraulic performance of the resultant lateral needs to be assessed for uniformity of emitter discharge. Thus, the objectives of this work were to design and analyze tapered laterals that use a discrete size change.

Methods and Materials

A spreadsheet model was developed to conduct a hydraulic analysis for a microirrigation lateral. The model analysis was designed to first determine the optimal taper step position on a microirrigation lateral based upon minimum flow velocity criteria during a flushing event. The model analysis was designed to determine normal flow hydraulic characteristics and chemical travel times using a plug flow analysis.

The lateral model hydraulics were based upon a Bernoulli energy head balance

$$h_1 + \frac{v_1^2}{2g} + z_1 = h_2 + \frac{v_2^2}{2g} + z_2 + h_f \quad (1)$$

where h_1 and h_2 represent the pressure head (ft) at two positions in the lateral, v_1 and v_2 are the flow velocities (ft/s) at those locations ($v^2/2g$ is the velocity head), z_1 and z_2 are the elevation heads (ft) at those locations, and h_f is the friction head (ft) between locations 1 and 2. This analysis was conducted between adjacent emitters in a stepwise manner from the last (distal) emitter on a lateral to the first (inlet) emitter on that lateral. Because the flow velocities in a microirrigation lateral are low and the differences between flow velocities (and associated velocity heads) are very small, the velocity head terms were negligible and were removed from Eq. 1.

The friction head, h_f, was determined using the Darcy-Weisbach equation

$$h_f = 1000(F_f)\frac{L}{D}\left(\frac{v^2}{2g}\right) \tag{2}$$

where L is the length (in.) of the lateral section that is being analyzed (in this case the distance between emitters), D is the inside diameter (in.) of the lateral, and F_f is the friction factor. The friction factor was determined using the following relationship for Reynold's numbers (R_y) below 2000

$$F_f = \frac{64}{R_y} \tag{3}$$

The Blasius equation was used for Reynold's numbers that exceeded 2000

$$F_f = 0.316 \bullet \left(R_y^{-0.25}\right) \tag{4}$$

The Reynold's number was determined from

$$R_y = (3214)\left(\frac{Q}{D}\right) \tag{5}$$

where Q is the flow rate (gpm) and D is the inside diameter of the lateral (in.). Emitter discharge was determined using the emitter equation

$$q_e = k\,p^x \tag{6}$$

where q_e is the emitter discharge (gph), k is the emitter flow constant, p is the emitter pressure (psi) and x is the emitter discharge exponent. An emitter discharge exponent of 0.5 was used in all calculations.

Lateral emission uniformity (EU) and emitter flow variation (q_{var}) were used to quantify the "quality" of a design. Emission uniformity was calculated as:

$$EU = 100\left(1.0 - 1.27\frac{C_v}{\sqrt{n_p}}\right)\frac{q_{min}}{q_a} \tag{7}$$

where C_v is the manufacturers coefficient of variation (a value of 0.03 was used in all analyses), n_p is the number of emitter per plant (1 for these analyses), q_{min} is the minimum emitter discharge on the lateral, and q_a is the average emitter discharge for the lateral. The emitter flow variation (q_{var}) was calculated as

$$q_{var} = \left(\frac{q_{max} - q_{min}}{q_{max}} \right)(100) \tag{8}$$

where q_{max} is the maximum emitter discharge along the lateral and q_{min} is the minimum emitter discharge along the lateral.

The previously described relationships were programmed into a spreadsheet model (fig. 1). That model and a companion model were used to determine the optimal location of the split junction from larger to smaller lateral based upon maintaining a minimum flow velocity of 1 ft/s in all portions of the lateral during a “flushing” operation. Flushing operation criteria used a distal pressure of 3 psi with nominal tubing flow rates of 0.20, 0.25, and 0.25 gpm/100 ft (based on a nominal pressure of 8 psi), and slopes of 0, –0.5%, and –1%. While the “optimal “ junction location varied with the three lateral design flow rates and distal pressure, most were close to the midpoint of the lateral. Thus, subsequent design runs were conducted using a midpoint junction position. Flushing operation simulations generated values for inlet pressure, lateral flow rate, and time to completely flush the lateral.

	A	B	C	D	E	F	G	H	I	J	K	L	M
1			Specify				Initial Flow Rate		189.12384	gph			
2	Lateral length		1320	feet			Must Be 0		0.000	gph			
3	Initial Pressure		12	psi									
4	k		0.0379				Initial P.	12	psi				
5	x		0.5										
6	Emitter Spacing		12	in.			Distal P.	2	psi				
7	Slope		0	%									
8	Flush "q"		1.0	gpm									
9	Larger Diameter		0.875	in.									
10	Smaller Diameter		0.625	in.									
11	Minimum Flushing Velocity		1	ft/s									
12													
13													
14	Position	Emitter	D	Pres	qe	qtube	vtube	Ry	Ff	hf	z	h	Diameter
15	Feet	No.	in.	psi	gph	gph	ft/s			ft	ft	ft	Size
648	632	632	0.875	8.6	0.1	113.4	1.008	6940	0.0351	0.008	0.000	19.76	Larger
649	633	633	0.875	8.6	0.1	113.2	1.007	6933	0.0351	0.008	0.000	19.75	Larger
650	634	634	0.875	8.5	0.1	113.1	1.006	6926	0.0351	0.008	0.000	19.74	Larger
651	635	635	0.875	8.5	0.1	113.0	1.005	6919	0.0351	0.008	0.000	19.74	Larger
652	636	636	0.875	8.5	0.1	112.9	1.004	6913	0.0351	0.008	0.000	19.73	Larger
653	637	637	0.875	8.5	0.1	112.8	1.003	6906	0.0351	0.008	0.000	19.72	Larger
654	638	638	0.875	8.5	0.1	112.7	1.002	6899	0.0351	0.008	0.000	19.71	Larger
655	639	639	0.875	8.5	0.1	112.6	1.001	6892	0.0351	0.007	0.000	19.71	Larger
656	640	640	0.875	8.5	0.1	112.5	1.000	6885	0.0351	0.007	0.000	19.70	Larger
657	**641**	641	0.875	8.5	0.1	112.4	**0.999**	6879	0.0351	0.007	0.000	19.69	**Larger**
658	**642**	642	0.625	8.5	0.1	[illegible]	**1.957**	9621	0.0323	0.037	[illegible]	[illegible]	**Smaller**
659	643	643	0.625	8.5	[illegible]	112.1	1.955	[illegible]	[illegible]	0.037	0.000	19.65	Smaller
660	644	644	[illegible]	[illegible]	[illegible]	[illegible]	1.953	9602	0.0323	0.037	0.000	19.61	Smaller
661	645	645	[illegible]	[illegible]	[illegible]	111.9	1.951	9592	0.0323	0.037	0.000	19.57	Smaller
662	646	646	[illegible]	[illegible]	[illegible]	111.8	1.949	9583	0.0323	0.037	0.000	19.54	Smaller
663	647	647	[illegible]	[illegible]	[illegible]	111.7	1.947	9573	0.0324	0.037	0.000	19.50	Smaller

Velocity Change

Figure 1. Display of the “Split” spreadsheet that was used to determine the split junction between larger and smaller diameter laterals.

Simulations were next conducted on those laterals for “normal” operation. Under the normal operation simulations, the inlet pressure was set at 10 psi for each of the design lateral flow rates and lateral slopes. These simulation runs provided data on distal pressure, actual lateral flow rate

(q_{lat}), emission uniformity (EU), emitter flow variation (q_{var}), and time for an injected chemical to travel to the end of the tube ($Time_{end}$) and to 10 ft from the end of the tube ($Time_{end-10}$). Both models were run for a straight 11/8-inch lateral, a 11/8-inch to 7/8-inch tapered lateral, and a 11/8-inch to 9/8-inch tapered lateral.

Results

Example emitter discharge profiles on a level (05) slope for all three lateral combinations are shown in fig. 2. The 11/8 to 7/8 combination has a more substantial emitter discharge variation due to friction losses than the 11/8 to 9/8 combination. The 11/8 to 7/8 combination would not be acceptable for a zero slope condition.

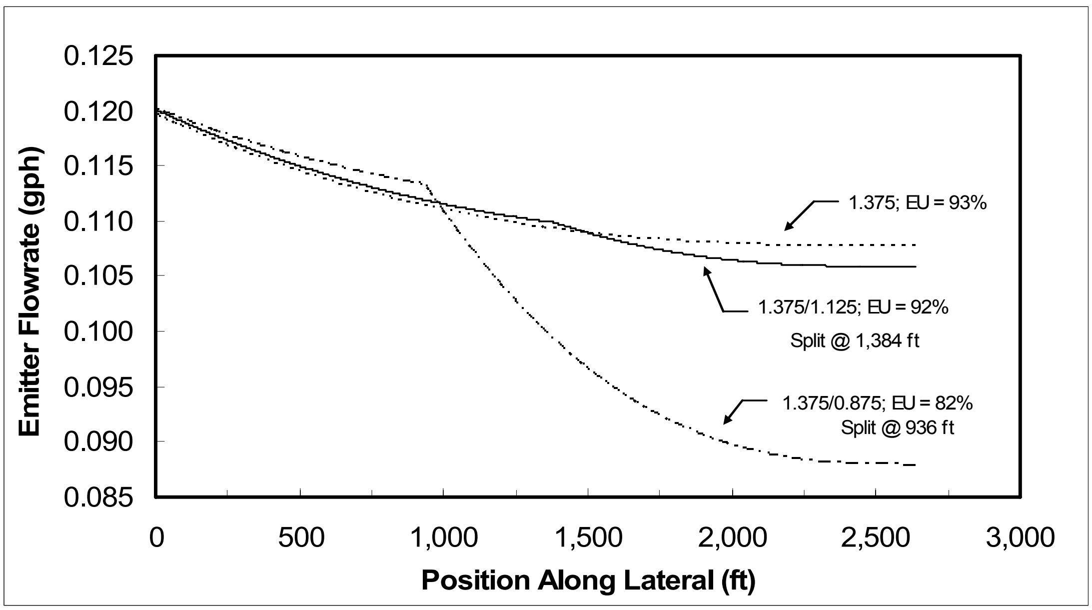

Figure 2. Emitter discharge along the length of a 2,640-ft-long lateral under normal operating conditions for a standard 1.375-in. lateral, a tapered 1.375 – 1.125-in. lateral, and a 1.375 - 0.875-in. lateral.

Summary tables of the hydraulic performance of all lateral and nominal flow combinations are shown in tables 1, 2, and 3. The non-tapered 11/8-inch lateral with a nominal flow of 0.20 gpm/100 ft (tab. 1a) resulted in distal pressures of 7.8, 12.8, and 17.8 psi for slopes of 0, -0.5%, and –1%, respectively. Associated emission uniformities were 93, 92, and 84%. Thus the steeper slope reduced the performance level of the lateral. Travel times to the end of the lateral ranged from 223 to 330 minutes while travel times to a position 10 feet upstream from the lateral ranged from 147 to 215 minutes. It is probably more realistic to use the $Time_{end-10}$ data which substantially reduces the travel time. However, the travel times can average 3 hours or more. Similar results exist for the other nominal flowrates of 0.25 and 0.30 gpm/100 ft (tab. 1b and 1c).

Tapering of the laterals from 11/8-inch to 7/8-inch (tables 2a, 2b, and 2c) and from 11/8-inch to 9/8-inch (tables 3a, 3b, and 3c) reduced both distal pressures and travel times for injected chemicals. In general the 11/8 to 7/8 inch combination was not desirable due to low (<90) emission uniformities. However, the 11/8 to 9/8 inch combination had acceptable (>90) or near acceptable emission uniformities for most nominal flow rates and slopes. This lateral combination reduced the end-10 chemical travel time ($Time_{end-10}$) times by 40 to 60 minutes for the 0.20 gpm/100 ft laterals. This situation can enhance the discharge and application uniformity of injected chemicals. This tapered lateral combination also reduced the required flowrate during flushing by 1.0 to over 1.5 gpm per lateral while maintaining similar lateral inlet pressures during the flushing operation. The times to purge the lateral during flushing were minimally increased. These are desirable design and operational conditions.

Summary and Conclusions

Spreadsheet models were developed to simulation drip irrigation lateral hydraulics to determine flow requirements, emission uniformity, and chemical travel times for tapered and non-tapered laterals. Models were run for a straight 11/8-inch lateral, a 11/8-inch to 7/8-inch tapered lateral, and a 11/8-inch to 9/8-inch tapered lateral. Each of these lateral combinations were simulated for nominal flow rates of 0.20, 0.25, and 0.25 gpm/100ft, and slopes of 0%, -0.5%, and –1.0%.

Tapered laterals reduced the travel time of injected chemicals and reduced required flow rates during the flushing process. The 11/8-inch to 7/8-inch combination was generally not desirable due to low emission uniformities. However, the 11/8 to 9/8-inch combination was acceptable for most simulation scenarios.

Table 1. Normal and flushing operation data for an 11/8-inch diameter, 2,640 ft lateral at nominal flowrates of (a) 0.20, (b) 0.25, and (c) 0.30 gpm/100 ft.

a. 11/8-inch --- 0.20 gpm/100ft			**Slopes (%)**		
Operation	**Parameter**	**Unit**	**0%**	**-0.50%**	**-1.00%**
Normal	Distal P	psi	7.8	12.8	17.8
	q_{lat}	gpm	5.40	6.11	6.73
	EU	%	93	92	84
	qvar	%	12	12	25
	$Time_{end}$	min	330	261	223
	$Time_{end-10}$	min	215	172	147
Flushing	Inlet P	psi	12.6	5.8	3.6
	q_{lat}	gpm	9.41	8.20	9.27
	Time	min	32	33	27

b. 11/8-inch --- 0.25 gpm/100ft			**Slopes (%)**		
Operation	**Parameter**	**Unit**	**0%**	**-0.50%**	**-1.00%**
Normal	Distal P	psi	7.0	11.7	16.4
	q_{lat}	gpm	6.48	7.35	8.08
	EU	%	91	93	87
	qvar	%	17	11	22
	$Time_{end}$	min	279	219	186
	$Time_{end-10}$	min	182	144	123
Flushing	Inlet P	psi	14.2	7.0	3.1
	q_{lat}	gpm	10.77	9.28	9.33
	Time	min	30	31	27

c. 11/8-inch --- 0.30 gpm/100ft			**Slopes (%)**		
Operation	**Parameter**	**Unit**	**0%**	**-0.50%**	**-1.00%**
Normal	Distal P	psi	6.2	10.6	15.1
	q_{lat}	gpm	7.46	8.45	9.32
	EU	%	90	93	89
	qvar	%	22	11	21
	$Time_{end}$	min	247	192	162
	$Time_{end-10}$	min	161	126	107
Flushing	Inlet P	psi	16.0	8.3	3.5
	q_{lat}	gpm	12.21	10.44	9.80
	Time	min	28	30	27

Table 2. Normal and flushing operation data for a tapered 11/8-inch to 7/8-inch diameter, 2,640 ft lateral at nominal flowrates of (a) 0.20, (b) 0.25, and (c) 0.30 gpm/100 ft.

a. 11/8 -7/8 inch --- 0.20 gpm/100ft			**Slopes (%)**		
Operation	**Parameter**	**Unit**	**0%**	**-0.50%**	**-1.00%**
Normal	Distal P	psi	6.0	10.2	14.4
	q_{lat}	gpm	5.19	5.85	6.45
	EU	%	85	93	88
	qvar	%	23	7	17
	$Time_{end}$	min	168	133	113
	$Time_{end-10}$	min	115	92	79
Flushing	Inlet P	psi	16.5	9.4	3.9
	q_{lat}	gpm	7.75	6.76	6.04
	Time	min	33	35	35

b. 11/8 -7/8 inch --- 0.25 gpm/100ft			**Slopes (%)**		
Operation	**Parameter**	**Unit**	**0%**	**-0.50%**	**-1.00%**
Normal	Distal P	psi	4.9	8.5	12.3
	q_{lat}	gpm	6.18	6.95	7.65
	EU	%	80	90	93
	qvar	%	31	12	10
	$Time_{end}$	min	148	116	98
	$Time_{end-10}$	min	101	80	68
Flushing	Inlet P	psi	19.9	12.4	4.6
	q_{lat}	gpm	9.68	8.47	6.90
	Time	min	29	30	33

c. 11/8 -7/8 inch --- 0.30 gpm/100ft			**Slopes (%)**		
Operation	**Parameter**	**Unit**	**0%**	**-0.50%**	**-1.00%**
Normal	Distal P	psi	3.9	7.1	10.4
	q_{lat}	gpm	7.04	7.94	8.72
	EU	%	75	86	90
	qvar	%	38	20	13
	$Time_{end}$	min	138	105	88
	$Time_{end-10}$	min	94	73	61
Flushing	Inlet P	psi	24.0	15.9	7.5
	q_{lat}	gpm	11.83	10.40	8.61
	Time	min	25	27	30

Table 3. Normal and flushing operation data for a tapered 11/8-inch to 9/8-inch diameter, 2,640 ft lateral at nominal flowrates of (a) 0.20, (b) 0.25, and (c) 0.30 gpm/100 ft.

a. 11/8 -9/8 inch --- 0.20 gpm/100ft				**Slopes (%)**	
Operation	**Parameter**	**Unit**	**0%**	**-0.50%**	**-1.00%**
Normal	Distal P	psi	7.3	12.1	17.0
	q_{lat}	gpm	5.33	6.04	6.66
	EU	%	91	93	85
	qvar	%	14	10	23
	$Time_{end}$	min	237	187	160
	$Time_{end-10}$	min	158	126	108
Flushing	Inlet P	psi	12.7	5.9	3.0
	q_{lat}	gpm	8.16	7.02	7.42
	Time	min	33	35	30

b. 11/8 -9/8 inch --- 0.25 gpm/100ft				**Slopes (%)**	
Operation	**Parameter**	**Unit**	**0%**	**-0.50%**	**-1.00%**
Normal	Distal P	psi	6.4	10.9	15.4
	q_{lat}	gpm	6.41	7.24	8.00
	EU	%	89	94	89
	qvar	%	20	8	19
	$Time_{end}$	min	202	158	134
	$Time_{end-10}$	min	134	106	91
Flushing	Inlet P	psi	14.6	7.4	3.7
	q_{lat}	gpm	9.66	8.26	8.22
	Time	min	30	32	29

c. 11/8 -9/8 inch --- 0.30 gpm/100ft				**Slopes (%)**	
Operation	**Parameter**	**Unit**	**0%**	**-0.50%**	**-1.00%**
Normal	Distal P	psi	5.5	9.7	13.8
	q_{lat}	gpm	7.34	8.32	9.15
	EU	%	86	94	91
	qvar	%	26	9	17
	$Time_{end}$	min	181	140	118
	$Time_{end-10}$	min	120	94	80
Flushing	Inlet P	psi	16.8	9.2	3.7
	q_{lat}	gpm	11.26	9.62	8.61
	Time	min	28	30	29