IDEAL DESIGN OF LOW-HEAD COILED-TUBE IRRIGATION

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ABSTRACT

In low-head tube irrigation, water is applied to the soil surface as a little stream, typically from a small-diameter tube without filtration. The objective of this study were coiling the tube to overcome its lengths problems and developing mathematical model to design the lateral of low-head coiled-tube irrigation with full water application uniformity. Constructing the model include input data under determined operating conditions to get the optimum design. The design model was developed to identify lateral length (L_ℓ), coiled-tube lengths (C_ℓ) and pressure heads (C_h). by using the input data of lateral inside diameter (L_{ID}), coiled-tube inside diameter (C_{ID}) and discharge (C_q), tube interval distances (C_s), soil surface slope (%), and water temperature (T_w). The optimum design example was presented to three coiled-tube diameters of 3.8, 5.2 and 6.8 mm under upstream low-head pressure ($L_{h.a}$) of 0.5, 1.0 and 1.5m for predetermined tube discharges. The results show that the effect of each parameter in the design output.

Keywords: *Low-head, Tube, Lateral, Design, model, Uniformity.*

INTRODUCTION

Microirrigation includes any localized irrigation method that slowly and frequently provides water directly to the plant root zone. The slow rate of water application at discrete locations with certain operating pressure at only a portion of the soil volume in the field can result in relatively low-cost water delivery systems, with a higher uniformity coefficient, as well as reductions in water diversions compared to other irrigation methods, in addition to, more economical and sustain the increase of both cultivated land and populations (**Lamm et al., 2007 and Amer, 2011**).

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Low-head tube irrigation is a microirrigation technique that enables us to save water, energy, less laborious and more efficient irrigation can be achieved **(Ngigi, 2008)**. The flow rate through the tube is very sensitive to changes of pressure head (**Hull, 1981**). To maintain equal discharge from all tubes, require same pressure head at each tubes outlet. The tube pressure heads can be adjusted according to the pressure distribution along the lateral line. The length of each tube was calculated by subtracting the head friction losses in the pipes and the change in length from the static head (**Rawlins, 1977**). The total frictional head losses produced is inversely proportional to the tube length. The characteristics of tube and the friction losses along the lateral are the main data for optimum lateral design. The objectives of this study are:

1- Overcome the practical problems from the tube lengths and increase lateral length by increasing the pressure losses from coiling the tube .

2- Construct a model to design an optimum lateral of low-head coiled-tube irrigation.

MATERIALS AND METHODS

Hydraulic theory

To solve out the problem of using coiled-tubes with same discharge, related hydraulic calculations are required to be considered in a step-by-step (SBS) manner. The SBS procedure was started from the downstream toward the upstream end of the lateral. Energy conservation in coiled-tube system design is described by **Bernoulli's equation**.

$$\frac{P_1}{\gamma} + Z_1 + \frac{V_1^2}{2g} = \frac{P_2}{\gamma} + Z_2 + \frac{V_2^2}{2g} + \sum h_{fL} + \sum h_{ml} \qquad (1)$$

Where, P is the pressure within the pipe, N/m^2; γ is the specific weight of water (N/m^3); Z is the elevation of pipe centerline with respect to a reference datum (*m*); V is the flow velocity of water in the pipe, *m/s*; g is the gravitational constant, m/s^2; h_{fL} is the friction head loss in lateral pipe, *m* and $h_{m\ell}$ is the minor losses at pipe fittings, *m*.

The Darcy-Weisbach and Blasius equation was used to calculate the friction head loss for small diameter and smooth pipes (**Demir and Uz, 1995; Rashad, 2013**) as:

$$h_f = f \cdot \frac{L}{D} \cdot \frac{V^2}{2g} \tag{2}$$

For laminar flow

$$f = 64/Re \qquad Re \le 2000 \tag{3}$$

For turbulent flow

$$f = 0.3164/Re^{0.25} \quad 2000 \le \text{Re} \le 100000 \tag{4}$$

Where, Re is the Reynold's number, (dimensionless); L and d is the length and diameter of the pipes .*m*; and v is the velocity of flow, *m/s*.

Flow regimes can be characterized by the Reynolds's number (*Re*), which may be expressed in terms of the water temperature that is given by **(Boor *et al*. 1968)**, as follows:

$$Re = 198.7\ Q\ (1 + 0.03368 T_w + 0.000221 T_w^2)/d \tag{5}$$

Where Q is the total flow rate, ℓ/*h*; T_w is the water temperature (^oC) and *d* is the internal pipe diameter, *mm*. Equations (2) can be combined to obtain the equations for laminar Eq (3) and turbulent Eq (4) flows, respectively as follows:

For laminar flow

$$h_f = 408.4479 \ \frac{LQ^2}{R_e\ d^5} \tag{6}$$

For turbulent flow

$$h_f = 2.01926 \frac{LQ^2}{R_e^{0.25}\ d^5} \tag{7}$$

Where, h_f is the frictional head loss, *m; L* is the length of pipe, *m; Q* is the discharge, *ℓ/h; d* is the inside pipe diameter, *mm; Re* is the Reynolds number.

The entrance; coil and Velocity head losses can be written as follows:

$$h_e = 0.0077 \frac{C_q{}^2}{C_{ID}{}^4} \tag{9}$$

$$h_v = 0.0064 \frac{C_q{}^2}{C_{ID}{}^4} \tag{10}$$

$$h_{co} = 0.0083 Co \ \frac{C_q{}^2}{C_{ID}{}^4} \tag{11}$$

Watters and Keller (1978) presented the applicator barb friction minor losses *(E_ℓ)* in terms of a length of lateral as follows:

$E_\ell = 0.25\ C_{ID}\ (19\ L_{ID}^{-1.9})$ (12)

Where, E_ℓ is the equivalent length of pipe, *m;* C_{ID} is the coiled-tube inside diameter, *mm;* L_{ID} is the lateral inside diameter, *mm.*

Model development

The developed model was designed to obtain the optimum design of low-head coiled-tube lateral. So, the hydraulic gradient line (*HGL*) of coiled-tubes must be parallel to the lateral, as shown in Fig (1).

The length of coiled-tube decreased gradually along the horizontal lateral from upstream toward downstream end ... $C_{\ell 1} \rangle C_{\ell 2} \rangle \ldots \rangle C_{\ell.min}$ while $C_{q1} = C_{q2} = \ldots = C_{qn}$. The total head of the coiled-tube *(H_n)* at lateral downstream end could be calculated as follows:

$$h_e + h_v + h_{c(n)} + h_{co(n)} = H_n \qquad (14)$$

The minimum coiled-tube length ($C_{\ell.min}$) as follows:

- For laminar coiled-tube flow

$$h_e + h_v + 408.4479 \frac{C_{\ell n} C_q^2}{R_{e(C)} C_{ID}^5} + h_{co(n)} = H_n \qquad (15)$$

- For turbulent coiled-tube flow

$$h_e + h_v + 2.01926 \frac{C_{\ell n} C_q^2}{R_{e(C)}^{0.25} C_{ID}^5} + h_{co(n)} = H_n \qquad (16)$$

Where, $C_{\ell n}$ *is* the coiled-tube length, *m.*

The balance of energy heads between two successive outlet points (*n -1*) and *(n)* could be written as:

$$h_{e(n-1)} + h_{v(n-1)} + h_{fC(n-1)} + h_{co(n-1)} = h_{e(n)} + h_{v(n)} + h_{fC(n)} + h_{co(n)} + h_{f\ell(n)} \pm S\, C_s \qquad (17)$$

Where, *S* is the slope of lateral and C_s is the distance between coiled-tubes. Since the entrance, velocity head losses and discharges are same in all the coiled-tubes, so Eq (17) can be written as

$$h_{fC(n-1)} + h_{co(n-1)} = h_{fC(n)} + h_{co(n)} + h_{fL(n)} \pm S\, C_s \qquad (18)$$

Calculate the coiled-tube length $C_{\ell(n-1)}$ as shown in Eq. (3.19).

$$C_{\ell(n\text{-}1)} = C_{\ell(n)} + h_{fL(n)} + S\,C_s \tag{19}$$

- The lateral flow regime is laminar.

$$C_{\ell(n\text{-}1)} = C_{\ell(n)} + 408.4479\ \frac{LQ^2}{R_g\ L_{ID}{}^5} \pm\ S\,C_s \tag{20}$$

- The lateral flow regime is turbulent.

$$C_{\ell(n\text{-}1)} = C_{\ell(n)} + 2.01926\ \frac{LQ^2}{R_g{}^{0.25}\ L_{ID}{}^5} \pm S\,C_s \tag{21}$$

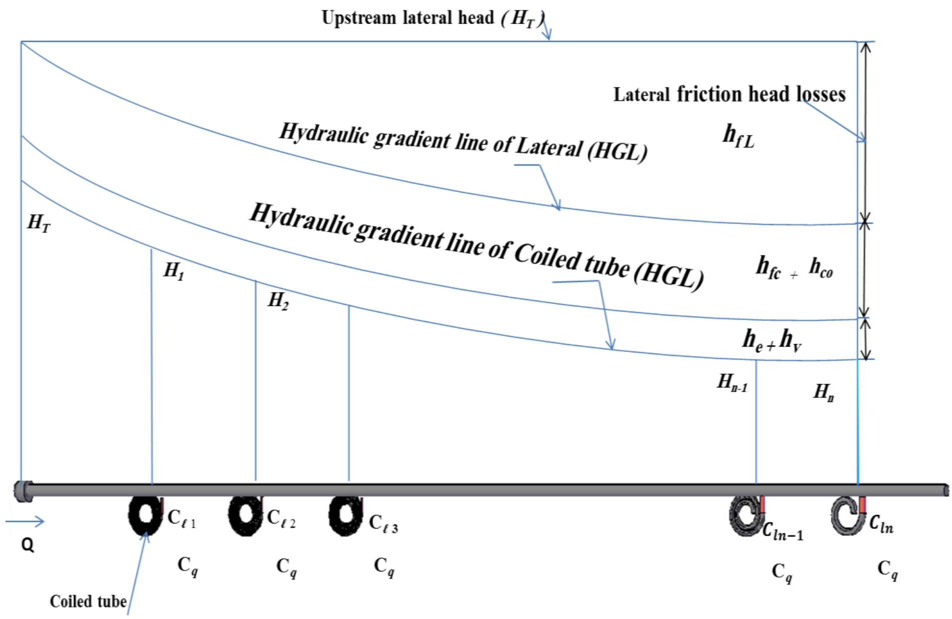

Fig (1): Hydraulic gradient line and head losses along the lateral

Therefore, proceeding in this manner up to the lateral upstream, all the coiled-tube lengths will be calculated to deliver equal discharges (C_q). The unknown $C_{\ell(n-1)}$, $C_{\ell(n-2)}$, $C_{\ell(n-3)}$, ... $C_{\ell\ (max)}$ can be calculated directly from the above equations. Fig (2), illustrate the model calculation steps to obtain the optimum design of coiled-tube lateral length. There are two points to ending the mathematical models' calculations whichever is earlier. When the coiled-tube length $C_{\ell\ (1)}$ would be equal to the maximum coiled-tube length $C_{\ell(max)}$, or the lateral upstream pressure head H_T (the head at last coiled-tube calculated) reach the allowable pressure head $L_{h.a}$.

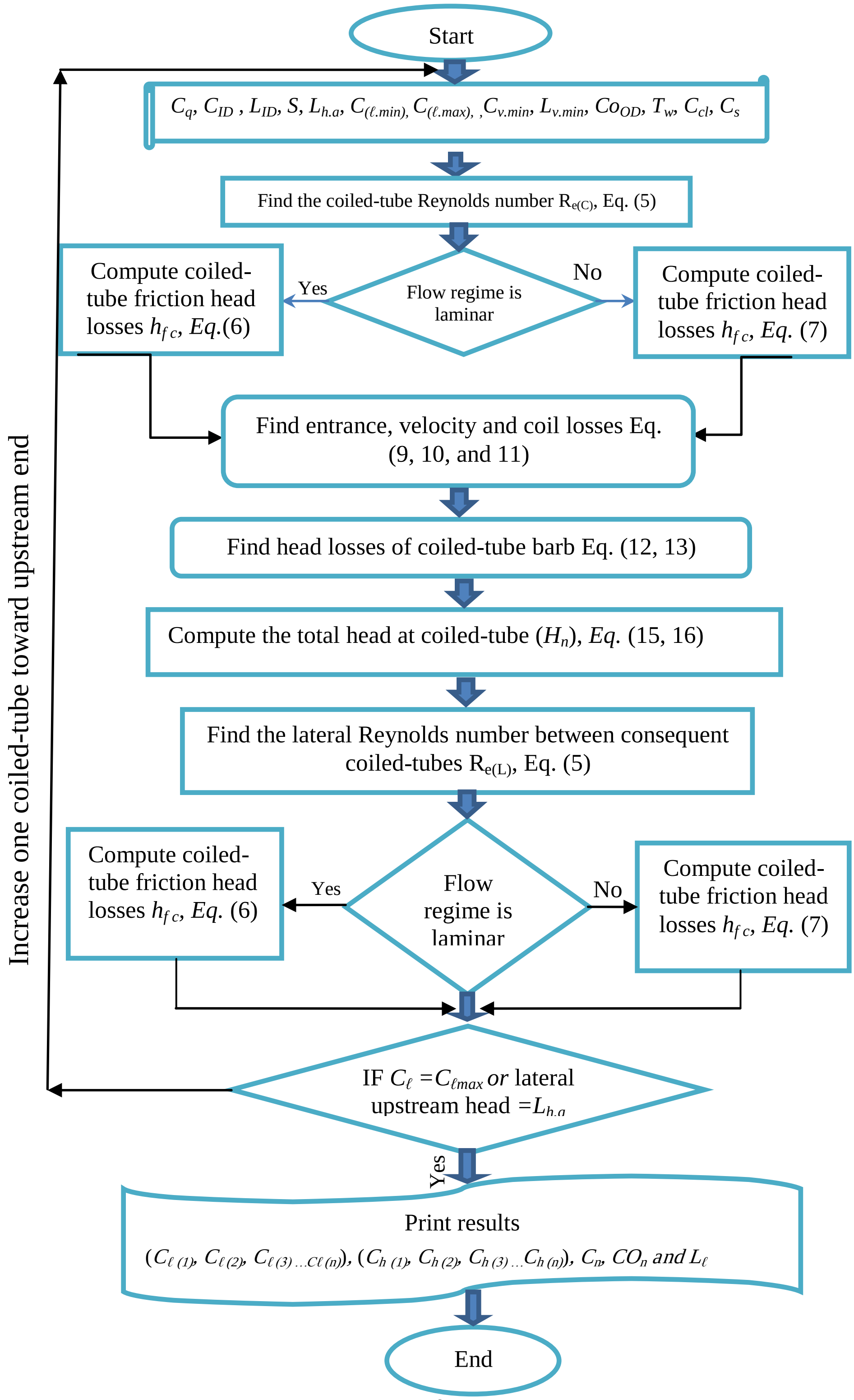

Fig (2): Flowchart of the developed program

Design Example

A design example by the developed model is presented using three coiled-tube diameters. The design was for three coiled-tube diameters (C_{ID} 3.8, 5.2 and 6.8*mm*) at one lateral diameter (L_{ID} *18 mm*), time's 3 pressure levels, at 3*m* distance between coiled-tubes and a half distance from upstream end. Operating pressures were set at (0.5, 1.0 and 1.5 *m*). The example was executed on level ground surface, minimum coiled-tube length (0.25*m*), maximum length (2.25*m*), and coiled-tube discharges C_q of 20 to 120 *ℓ/h* with water temperature of (20^0C), coiled-tube connector length (0.1*m*), and coils outside diameter (75 *mm*).

RESULTS AND DISCUSSION

The success key of the proper design for a low-head coiled-tube system is achieving full application uniformity. The design example shows how can be introducing the available design solutions for the required low head irrigation lateral by the model. Summarized results in Table (1), shows the results for different inputted data. Relating to available lateral input pressure head ($L_{h.a}$), maximum coiled-tube length ($C_{\ell.max}$). Developed model prints up the details of these results for each outlet point.

As seen in Table (1), the coiled-tube diameter (C_{ID}) and discharge (C_q), had the main effect on lateral length. The small C_{ID} couldn't be used to meet relatively large discharges due to the increase in coiled-tube friction loss. The increase in the allowable pressure heads ($L_{h.a}$) from 0.5 to 1.5m had different effects on lateral length for different diameters. The $L_{h.a}$ had a slight effect on lateral with coiled-tube diameter (5.2 and 6.8*mm*); meanwhile, it had a great influence with small diameters (3.8 *mm*). Use small coiled-tube diameter of 3.8 mm with the lower discharges as 20 and 30 *ℓ/h*, to obtain acceptable lateral lengths. It is couldn't be use diameter 5.2 mm with lower discharges as 20 *ℓ/h* but it was desirable with 30 to 60 ℓ/h. The minimum discharge could be used with diameter 6.8 mm is *40 ℓ/h*, and the maximum discharges could be excess than 120 *ℓ/h*.

However, the information contained in this example contributes to a better understanding of how and why the low-head coiled-tube irrigation needs to be adopted on more and more of the irrigated area each year. It is hoped that this information will serve as a pattern to guide those who are interested in adopting and managing coiled-tube systems on fruit trees, and spurs research.

Table (1): Design of lateral length (L_ℓ), coiled-tube number (C_n) and required pressure (C_h) at different of: coiled-tube discharges (C_q), available lateral pressures ($L_{h.a}$) and coiled-tube diameters (C_{ID}) with distance (C_s) 3*m*.

C_q (ℓ/h)	$L_{h.a}$ (m)	C_{ID} (mm)								
		6.8			5.2			3.8		
		C_n (n)	C_h (m)	L_ℓ (m)	C_n (n)	C_h (m)	L_ℓ (m)	C_n (n)	C_h (m)	L_ℓ (m)
20	0.5	...	...	...	...	...	...	24	0.47	70.5
	1.0	...	...	...	...	...	...	26	0.53	76.5
	1.5	...	...	...	...	...	...	...	...	...
30	0.5	...	...	...	21	0.43	61.5	9	0.49	25.5
	1.0	...	...	...	...	...	...	18	0.95	52.5
	1.5	...	...	...	...	...	...	22	1.25	64.5
40	0.5	19	0.31	55.5	16	0.49	46.5	2	0.47	4.5
	1.0	...	...	...	19	0.62	55.5	11	0.98	31.5
	1.5	...	...	...	...	...	...	15	1.3	43.5
50	0.5	17	0.39	49.5	11	0.46	31.5	...	...	...
	1.0	...	...	...	17	0.84	49.5	6	0.92	16.5
	1.5	...	...	...	...	...	...	10	1.37	28.5
60	0.5	15	0.47	43.5	8	0.48	22.5	...	...	...
	1.0	16	0.52	46.5	14	0.95	40.5	3	0.99	7.5
	1.5	...	...	...	16	1.17	46.5	7	1.46	19.5
70	0.5	12	0.45	34.5	6	0.49	16.5	...	...	...
	1.0	15	0.64	43.5	11	0.93	31.5	...	...	...
	1.5	...	...	...	14	1.33	40.5	4	1.4	10.5
80	0.5	10	0.49	28.5	3	0.47	7.5			
	1.0	13	0.72	37.5	8	0.90	22.5			
	1.5	...	...	...	11	1.36	31.5			
90	0.5	8	0.43	22.5	...	...	...			
	1.0	13	0.88	37.5	7	0.93	19.5			
	1.5	...	...	...	10	1.44	28.5			
100	0.5	7	0.48	19.5	...	...	...			
	1.0	11	0.89	31.5	5	0.90	13.5			
	1.5	12	1.03	34.5	8	1.43	22.5			
110	0.5	5	0.43	13.5	...	...	...			
	1.0	9	0.85	25.5	4	0.98	10.5			
	1.5	11	1.17	31.5	6	1.34	16.5			
120	0.5	5	0.44	13.5	...	...	...			
	1.0	9	0.91	25.5	3	0.92	7.5			
	1.5	11	1.28	31.5	6	1.43	16.5			

CONCLUSION

Forming mathematical model using main and minor head losses can help to determine the optimum lateral design. Furthermore, the model helps to use a different operational condition such as required coiled-tube discharges, the lateral upstream pressure allowable head $L_{h.a}$, effects of water temperature T_w, coiled-tube diameters, lateral diameter, and soil surface slope. A design example was presented by using the developed model to estimate the optimal coiled-tube lengths which give full water application uniformity. Coiled-tube diameters of 3.8, 5.2 and 6.8*mm* were examined with different coiled-tube discharges in this example. The small coiled-tube diameters (C_{ID}) couldn't be used to meet relatively large discharges due to the increase in coiled-tube friction loss. The increase in the allowable pressure heads ($L_{h.a}$) from 0.5 to 1.5*m* had different effects on lateral length for different diameters.

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الملخص العربي

التصميم النموذجي للري منخفض الضاغط بالأنابيب الملفوفة

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مع تزايد الحاجة لزيادة كفاءة استهلاك المياه والطاقة تبرز اهمية نشر نظم الري ذات الكفاءة العالية في توزيع المياه بضاغط منخفض. نظام الضاغط المنخفض بالأنابيب الملفوفة يلبي تلك الاحتياجات ولكن لم يقدم بصورة مناسبة للمزارعين وهناك نقص في برامج التصميم لهذه المنظومة. لذلك يهدف هذا البحث لتطوير تصميمي رياضي يعمل على انتظامية اضافة مياه الري بنسبة *١٠٠%* عند الأقطار والتصرفات المحددة للأنابيب الملفوفة كذلك قطر الماسورة الجانبية المركب عليها الانبوب الملفوف آخذاً في الحسبان تأثير فواقد الضغط الثانوية الناتجة عن نتوءات تثبيت الانبوب الملفوف وفاقد الدخول من الماسورة الجانبية الى الانبوب الملفوف بالإضافة لدرجات حرارة الماء السائدة في منطقة التصميم واستواء التربة. ويلبي التصميم امكانيات ورغبات المزارع من حيث ضاغط التشغيل الذي سيتم الامداد به عند بداية الخط الجانبي للري. تم تقديم مثال للتصميم باستعمال البرنامج لثلاثة اقطار داخلية الانبوب الملفوف (C_{ID})٣.٨، ٥.٢ و6.8 مم على مسافة٣ م ما بينها ومركبة على ماسورة جانبية بقطر داخلي (L_{ID}) *١٨*مم موضوعة على تربة مستوية وكانت درجة حرارة ماء الري *(T_w)*، ٢٠ درجة مئوية بحيث يقدم التصميم عند ضاغط كلي متاح ($L_{h.a}$)، ٠.٥، ١.٠ و ١.٥م. وعرض خلال هذا المثال ملخص لأهم النتائج. يستخدم القطر الصغير للأنابيب الملفوفة ٣,٨ مم مع التصرفات صغيرة مثل ٢٠ و٣٠ لتر\ساعة، للحصول على طوال الخط جانبي مقبولا يمكن استخدام قطر٥.٢ مم مع التصرفات الصغيرة مثل ٢٠ لتر\ساعة ويفضل استخدامها مع تصرفات من ٣٠إلى ٦٠ لتر\ساعة. اقل تصرف يمكن استخدامه مع قطر ٦.٨ مم هو ٤٠ لتر\ساعة، ويمكن استخدام تصرفات أكبر قد تزيد عن ١٢٠ لتر\ساعة.ويتضح من النتائج انه عند التصرفات الصغيرة الانبوب الملفوف يكون الفقد بالاحتكاك صغير ويصبح تأثير قطر الأنبوب صغير وهناك تشابه كبير ما بين الأقطار المتقاربة لذا لا ينصح اقتصادياً باستعمال الأقطار الكبيرة للأنابيب الملفوفة مع التصرفات الصغير.

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