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Effect of Energy Loss Due to Emitters on the Design of Trickle Irrigation Laterals

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Abstract. The estimation of energy losses due to emitter's connection in trickle irrigation laterals is very important. Since these losses have a direct effect on trickle irrigation system design, the study of these losses will lead to the improvement of system efficiency which will eventually result in conservation of water and energy. In this study, the problem of a lateral pipe with equally spaced emitters and uniform slope is evaluated. A computer program for estimating lateral discharge, emitter discharge and pressure head distribution along a lateral is developed. Individual emitters are considered in discharge and pressure estimations along the lateral starting from the downstream reach of the pipe. The friction head loss between successive emitters is estimated using the Darcy-Weisbach formula. The change of the velocity head, the changes of momentum along the lateral and the loss due to emitter are also considered. As the emitter discharge and energy losses are evaluated, the corresponding pressure head at each emitter is estimated accordingly. The output results from the program are in close agreement with the experimental data obtained from published work. The developed program is found to be simple and accurate as compared to previously presented programs. The program provides a simple and direct method to design trickle laterals taking into account all energy losses including emitter's connection losses.

Keywords: Trickle Irrigation; Laterals; Friction loss; and Emitter's connection loss.

Notations

The following symbols are used in this paper:

A	cross-sectional area lateral pipe;
a	spacing between emitters;
a_1	distance from main, or submain and the first emitter;
B	quantity defined by Eq.14;
C	emitter constant contained in Eq.1;
D	lateral diameter;
DIF	$Q_{max} - Q_o$;

E	quantity defined by Eq.15;
E_o	quantity defined by Eq.22;
f	coefficient of friction;
fi	coefficient of frictions for the lateral reach downstream from emitter i ;
g	acceleration due to gravity;
H	pressure head;
H_{av}	average pressure head;
H_i	pressure head at emitter i;
H_n	pressure head at the last downstream emitter;
H_o	pressure head at the main or submain;
h	friction head loss;
h_i	friction head loss at the lateral reach downstream from emitter i;
L	distance between first and last emitters;
L_1	distance from main or submain and the last downstream emitter;
n	number of emitters;
Q	lateral discharge;
Q_i	lateral discharge at the lateral reach downstream from emitter i;
Q_{max}	maximum lateral discharge;
Q_n	lateral discharge downstream from the last downstream emitter;
Q_o	lateral discharge upstream from the first emitter;
q	emitter discharge;
q_{av}	average emitter discharge;
q_i	discharge from emitter i;
q_n	discharge from the last downstream emitter;
R	Reynolds' number;
S_o	lateral longitudinal slope;
U_c	Christiansen uniformity coefficient;
V	average lateral velocity;
y	emitter discharge exponent in Eq.1;
Δ	quantity defined by Eq.30;
ΔH_n	quantity defined by Eq.11;
ε	small quantity in the order of 0.0001;
ν	kinematic viscosity of irrigation water.
he	pressure head loss due to emitter,
K	quantiy defined by Eq.19;
α	constant depend on the size of emitter barb,
β	constant depend on the size of emitter barb,
γ	constant depend on the size of emitter barb.
Ab	the area of the barb protrusion.
e,b,t,j,p and m	dimensions shown in Fig. 2.

Introduction

Trickle irrigation laterals are; generally, polyethylene pipes of constant slope and fitted with similar and equally spaced emitters whose discharges usually decrease in the downstream direction. Many investigators provided approximate solutions for the problem of trickle irrigation lateral design. Among the earlier investigators were Perlod [1]; Watters and Keller [2]; Gellespie *et al.* [3] and Khatri *et al.* [4]. In their treatments they generally used approximate friction equations such as Hazen-Williams and Scobey, neglected the variation of the velocity head along the lateral and assumed initial uniform emitter flow. Warrick & Yitayew [5] and Yitayew & Warrick [6] assumed a lateral with a longitudinal slot and presented design charts based on spatially varied flow. The latter solution has neglected the presence of laminar flow in a considerable length of the downstream part of the lateral. Hathoot *et al.* [7] provided a solution based on uniform emitter discharge but took into account the change of velocity head and the variation of Reynold's number. They used the Darcy-Weisbach friction equation in estimating friction losses. Hathoot *et al.* [8] considered individual emitters with variable outflow and presented a step by step computer program for designing either the diameter or the lateral length. In this study we considered the pressure head losses due to emitters protrusion. These losses occur when the emitter barb protrusion obstructs the water flow. Three sizes of emitter barbs were specified, small, medium and large in which the small barb has an area equal or less than 20mm^2, the medium barb has an area between 21-31mm^2 and the large one has an area equal to or more than 32mm^2 [9].

This study will present a solution, which accounts for the actual flow nature, variation of Reynold's number and the change of velocity head. Also the study will provide a simple and direct method to design the lateral taking into account all losses.

The objective of this study is to develop a new and simple method to design a lateral in trickle irrigation taking in account the energy loss due to emitter and other losses.

Theoretical Development

In trickle irrigation laterals emitters are usually installed at an equal spacing, a, Fig.(1). The first upstream emitter is generally at a different spacing, a_1, from the main or submain. The emitter discharge is a function of the pressure head and the relationship between them may be expressed as

$$q = CH^{y} \tag{1}$$

in which q is the emitter discharge, C is a constant, H is the pressure head acting on the emitter and y is a constant which depends on the state of flow and generally ranges between zero and 1.0 [8,10]. Referring to Fig.1, if there are n emitters, the distance between the first and last ones is given by

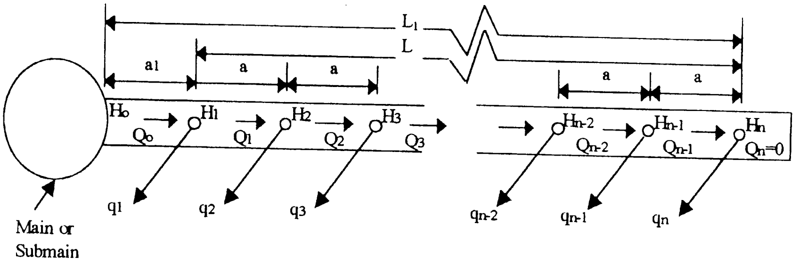

Fig. 1. Lateral pipe and emitters.

$$L = (n-1)a \tag{2}$$

On the other hand the total length of the lateral is

$$L_1 = a_1 + L = a_1 + (n-1)a \tag{3}$$

Stating from the last downstream emitter, its discharge is given by

$$q_n = CH_n^y \tag{4}$$

The lateral discharge downstream from the emitter n should be zero and hence

$$Q_n = 0 \tag{5}$$

On the other hand the lateral discharge upstream from emitter n should equal the emitter discharge:

$$Q_{n-1} = q_n \tag{6}$$

Applying the energy equation between emitters n and n-1:

$$H_{n-1} + Z_{n-1} + \frac{Q_{n-1}^2}{2gA^2} = H_n + Z_n + \frac{Q_n^2}{2gA^2} + h_{n-1} + \Delta H_n \tag{7}$$

in which Z_{n-1} and Z_n are position heads at emitters n-1 and n, respectively, A is the cross-sectional area of lateral, g is the acceleration due to gravity, h_{n-1} is the friction head loss at the lateral reach downstream from emitter n-1 and ΔH_n is the change of pressure head due to the change of momentum at emitter n [11]. Solving Eq.7 for H_{n-1}:

$$H_{n-1} = H_n + Z_n - Z_{n-1} + \frac{\left(Q_n^2 - Q_{n-1}^2\right)}{2gA^2} + h_{n-1} + \Delta H_n \tag{8}$$

For a lateral having a uniform longitudinal slope S_o:

$$Z_n - Z_{n-1} = \pm aS_o \tag{9}$$

the positive sign corresponds to laterals sloping upwards and vice versa.
For accurate estimation of frictional head loss for smooth irrigation laterals, the Darcy Weisbach equation is the most reliable [2,12]. Therefore:

$$h_{n-1} = \frac{8f_{n-1}aQ_{n-1}^2}{\pi^2 gD^5} \tag{10}$$

in which f_{n-1} is the coefficient of friction for the reach n-1, and D is the lateral diameter. The change of pressure head due to the change of momentum [13] is given by:

$$\Delta H_n = \frac{\left(Q_n^2 - Q_{n-1}^2\right)}{gA^2} \tag{11}$$

Substitution from Eqs. 9,10 and 11 into Eq.8:

$$H_{n-1} = H_n + \frac{\left(Q_n^2 - Q_{n-1}^2\right)}{2gA^2} + \frac{8f_{n-1}aQ_{n-1}^2}{\pi^2 gD^5} + \frac{\left(Q_n^2 - Q_{n-1}^2\right)}{gA^2} \pm aS_o \tag{12}$$

For convenience, Eq.12 is put in the form:

$$H_{n-1} = H_n + B\left(Q_n^2 - Q_{n-1}^2\right) + Ef_{n-1}Q_{n-1}^2 \pm aS_o \tag{13}$$

in which

$$B = \frac{3}{2gA^2} \tag{14}$$

and

$$E = \frac{8a}{\pi^2 gD^5} \tag{15}$$

If two successive intermediate emitter i and i-1 are considered it is easy to apply the above procedure to get the following equation:

$$H_{i-1} = H_i + B\left(Q_i^2 - Q_{i-1}^2\right) + Ef_{i-1}Q_{i-1}^2 \pm aS_o \tag{16}$$

It is worthy to note that emitter and lateral discharges are interrelated by:

$$Q_{i-1} = Q_i + q_i \tag{17}$$

To estimate the pressure loss due to emitter barb, empirical formulas were developed based on the statistical analysis of some experimental data. Al-Amoud has used three sizes of emitter's barb which are small, medium and large[14], Fig.(2).
These losses can be estimated by:

$$he = EXP\left(K + \alpha \times \ln(R)\right) \tag{18}$$

in which he the pressure head losses due to emitters, K is a constant. It depends on the diameter of the lateral and the type of barb. It is equal:

$$K = \beta + \gamma \times D \tag{19}$$

α, β and γ are constants that depend on the type of emitter's barb, Table (1), and D is the diameter of the lateral.

Now the pressure head at the first emitter from upstream, H_{11} can be calculated from:

$$H_{11} = H_1 + he \tag{20}$$

and the pressure head at the main or submain, H_o can be calculated from:

$$H_o = H_{11} + B\left(Q_1^2 - Q_o^2\right) + E_o f_o Q_o^2 \pm a_1 S_o \tag{21}$$

in which H_{11} is the pressure head at the first upstream emitter, Q_1 is the lateral discharge downstream from the first emitter, Q_o is the maximum lateral discharge, f_o is the coefficient of friction for the first upstream reach of the lateral and E_o is given by:

$$E_o = E\frac{a_1}{a} \tag{22}$$

Table 1. Constants CB, CE and CF for different barb sizes

Barb size	α	β	γ
Small barb	1.749171	-17.042141	-0.278794
Medium barb	1.748461	-16.747641	-0.276917
Large barb	1.749507	-16.216389	-0.279445

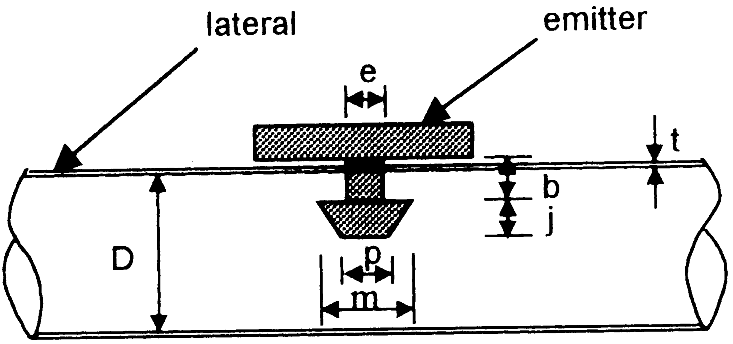

Fig. 2. Section through pipe showing an on-line emitter.

The area of the barb protrusion, A_b can be evaluated from:

$$Ab = e(b - t) + 0.5 \times j(p + m) \tag{23}$$

in which e, b, t, j, p and m are dimensions shown in Fig. 2.

The Coefficient of friction

Flow of water through smooth trickle irrigation laterals is generally turbulent. In some cases flow is laminar for a considerable length of the downstream reach of the lateral pipe [8]. For laminar flow where $R \leq 2000$ the coefficient of friction is given by:

$$f = \frac{64}{R} \tag{24}$$

in which R, Reynolds number is given by:

$$R = \frac{VD}{\nu} \tag{25}$$

in which V is the average velocity and ν is the kinematic viscosity of water.
For turbulent flow $(3000 < R \leq 10^5)$ the Blasius equation can be used:

$$f = 0.316R^{-0.25} \tag{26}$$

For fully turbulent flow, $10^5 < R < 10^7$, Watters and Keller [2] recommended the following equation:

$$f = 0.13R^{-0.172} \tag{27}$$

Emission uniformity

Uniformity design constraint

In designing trickle irrigation laterals it is of practical importance to have a high degree of emission uniformity. In general emission uniformity is defined as the relationship between the minimum (or maximum) emitter discharge and the average emitter discharge within a lateral. The Christiansen uniformity coefficient, U_c is a good measure of the uniformity [15]. And is given by:

$$U_c = 1 - \left(\frac{1}{nq_{av}}\right) \sum_{i=1}^{n} \left| q_i - q_{av} \right| \qquad (28)$$

The Computer Program

The flow chart of the main computer program is shown in Fig. (3). The objective of the program is to provide pressure, lateral discharge, emitter discharge distributions along the lateral and uniformity. The program is designed to be simple and accurate and the main steps of the program are as follow:

1. The essential data such as the lateral length, diameter, slope, spacing between emitters, the average emitter discharge, the average pressure head, the constant C, the exponent y, should be known in advance.
2. The maximum lateral discharge at the upstream end of the lateral is to be calculated from:

$$Q_{max} = n \times q_{av} \qquad (29)$$

in which q_{av} is the average emitter discharge and n is the number of emitters.

3. The constants CB, CE and CF are defined according to the size of emitter barb, which is small, medium or large, Table (1).
4. Calculations are to be started at the downstream end of the lateral and the last emitter discharge, q_n , is assumed equal to the average discharge, q_{av} as a first trial cycle. The pressure head, H_n is then evaluated by using Eq.4.
5. The pressure head at the emitter n-1 is estimated according to Eq.12 taking into account that the discharge $Q_{n-1} = q_n$, Eq.6.
6. The pressure loss due to emitter barb is estimated according to Eq. 18.
7. The emitter discharge of the second emitter from the downstream, q_{n-1}, is estimated according to Eq.1.
8. The pressure head at the third emitter is estimated according to Eqs.16 and 18 taking into account Eq.17 and then the emitter discharge is evaluated according to Eq.1.
9. Calculation similar to those performed in step no. 8 are repeated for other emitters in the upstream direction until the first emitter close to the main or submain is reached.
10. The pressure head at the mainline end of the lateral, H_o is evaluated by using Eqs.20 and 21.

11. If the assumption $q_n = q_{av}$ is correct, which is not expected in the first trial, the estimated lateral discharge will be equal to, Q_{max}, otherwise correction should be made.
12. The difference Q_{max} - Q_o is estimated and the corrective emitter discharge to be added to the assumed q_n is given by:

$$\Delta = \frac{Q_{max} - Q_o}{n} \tag{30}$$

13. Steps 4 through 10 are to be repeated with the new downstream emitter discharge given by:

$$q_n = q_n + \Delta \tag{31}$$

14. Trial cycles are continued until the difference DIF = Q_{max} - Q_o becomes practically small such that:

$$\frac{|100 \times \mathrm{DIF}|}{Q_{max}} \le \varepsilon \tag{32}$$

in which ε is a small quantity in the order of 0.0001.

15. Evaluation of Uc from Eq. 28.

Design criteria

In designing trickle irrigation laterals it is necessary to determine either the diameter or the length of lateral with the other variable known. In determining the diameter or length of lateral U_c should be equal to or greater than an acceptable level of uniformity U_{cc}, which is taken herein 0.95.

In designing lateral pipe for a trickle irrigation system it is assumed that the pressure-head discharge relationship, allowable head loss, discharge and acceptable level of uniformity are known a priori. It remains to design either the pipe length or the diameter with the other variables known.

The following are examples based on each concept.

Example 1

Design the proper length of a lateral pipe for the following:

q_{av}=4 Lh^{-1} (= 1.1111×10^{-6} m^3s^{-1}); a = 1m; $U_c \ge 95\%$; D=13mm ; H_{av}=9.6 m ; y=0.2 and $S_o = 0\%$.

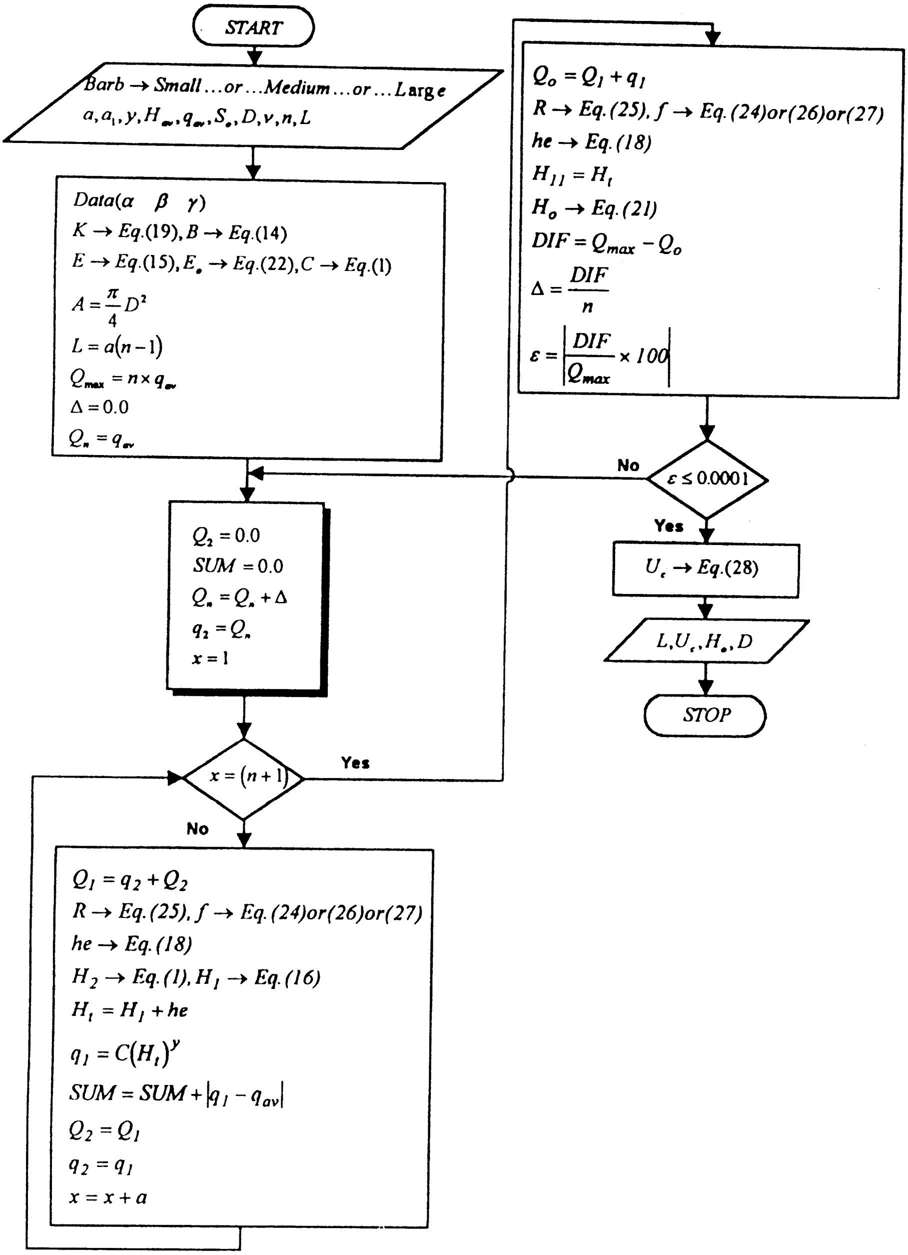

Fig. 3. Flow chart for the computer program.

In four cases:

I. Not taking the loss due to emitter barb in account.
II. Taking the loss due to emitter barb in account for:
  (i) Small barb.
  (ii) Medium barb.
  (iii) Large barb.

Solution

Variable	Taking the loss due to emitter barb in account			Not taking
	Small barb	Medium barb	Large barb	
L (m)	153	151	145	159
Uc (%)	95.1	95.0	95.1	95.2

Example 2

For the same data as *example 1*, design the diameter for a lateral pipe if:
L = 100 m.

Solution

Variable	Taking the loss due to emitter barb in account			Not taking
	Small barb	Medium barb	Large barb	
D (mm)	13	13	13	10
Uc (%)	98.30	98.26	98.10	95.30

For the sake of comparison with other published work, the computer program was used to solve two examples, which were used by Warrick and Yitayew [5] and Hathoot *et al.* [8]. In the following two examples, these data are common:
$D=13\text{mm}$; $a=1\text{m}$; $S_o=0\%$ and $\nu=1.01 \times 10^{-6}\,\text{m}^3.\text{sec}^{-1}$.

Example 3

$L=150\text{m}$; $q_{av}=2\ \text{L.h}^{-1}$ ($= 5.5555 \times 10^{-7}\ \text{m}^3\text{s}^{-1}$); $H_{av}=7.2\text{m}$ and $y=0.54$.

Solution

Paper	Uc
Warrick and Yitayew (1988)	0.97
Hathoot *et al.* (1993)	0.97
This paper	0.964

Example 4

$L=250\text{m}$; $q_{av}=4\ \text{L.h}^{-1}$ ($= 1.1111 \times 10^{-6}\ \text{m}^3\text{s}^{-1}$); $H_{av}=9.6\text{m}$ and **a.** $y=0.2$ or **b.** $y=0.53$.

Solution

	a.	**b.**
Paper	Uc	Uc
Warrick and Yitayew (1988)	0.9	0.76
Hathoot *et al.* (1993)	0.9	0.76
This paper	0.896	0.758

Conclusion

Although the computer program is simple and logic, it provides an accurate result, which are close to results of other recognized programs and to experimental data.

When comparing the results of the program which takes the effect of loss due to emitter barb with the other one which dose not take the effect of those losses, in the design of the lateral, we found that there is a significant difference between the two programs specially for small lateral diameter and large barb area, in which the design will change.

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تأثير فواقد الطاقة الناتجة عن المنقطات على تصميم الخطوط الحاملة للمنقطات في ري التنقيط

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ملخص البحث : يعد تقدير فواقد الطاقة الناتجة عن تركيب المنقطات في نظم الري بالتنقيط ذو أهمية كبيرة ، ونظرا لكون هذه الفواقد لها الأثر المباشر في تصميم نظم الري بالتنقيط لذا فأن دراسة هذه الفواقد قد تؤدي إلى تحسين كفاءة نظام الري بالتنقيط مما يؤدي بالتالي إلى التوفير في المياه و الطاقة .

تم في هذا البحث دراسة حالة خط حامل للمنقطات مثبتة علية المنقطات على مسافات متساوية وميل منتظم للأنبوب . حيث تم تطوير برنامج لنموذج رياضي يقوم بحساب التصرف و الضغط لكل منقط خطوة بخطوة عند الانتقال من منقط لآخر بدءا من نهاية الخط إلى بدية الخط الحامل للمنقطات . يتم حساب فاقد الاحتكاك بين كل منقطين متتاليين بواسطة معادلة دارسي - وايسباخ و يتم الأخذ بالاعتبار التغير في ضاغط السرعة و كمية التحرك أمام وخلف كل منقط كما اخذ في الاعتبار فقد الطاقة الناتج عن تركيب المنقطات . ويقوم البرنامج بتقدير تصرف المنقط وفاقد الطاقة وبناءا على ذلك يتم حساب ضاغط الضغط عند المنقط التالي و هكذا .وفي برنامج الحاسب الآلي يتم حساب تصرف الخط الحامل للمنقطات و تصرف المنقطات و توزيع الضغط على طول الخط الحامل للمنقطات . و النتائج المتحصل عليها من هذا البرنامج وجدت بأنها قريبة من نتائج تجارب عملية عديدة ، ويعد هذا البرنامج أسهل من البرامج المنشورة سابقا ، حيث يقدم هذا البرنامج المطور طريقة سهلة و دقيقة و مباشرة لتصميم الخط الحامل للمنقطات مع الأخذ بالاعتبار الفواقد الناتجة عن تركيب المنقطات.