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Flow Measurements in Open Channels Using Integrating-Floats

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ABSTRACT

The flow measurements have increased importance in the last decades due to the shortage of water resources resulting from climate changes that request high control of the available water needed for different uses. The classical technique of open channel flow measurement by the integrating-float method was needed for measuring flow in different locations when there were no available modern devices for different reasons, such as the cost of devices. So, the use of classical techniques was taken place to solve the problem. The present study examines the integrating float method and defines the parameters affecting the acceleration of floating spheres in flowing water that was analyzed using experimental measurements. The method was investigated theoretically, as well as many experimental tests in a fixed floor laboratory flume were conducted. Different sizes of solid plastic spheres with different weights were used as floats to measure velocities and then discharge computation. The results indicate that the integrating-float technique is feasible and accurate for measuring low flow velocity in open channels. It was desirable to use small floats with specific gravity closer to unity to get more accurate results. The measured velocities and the estimated discharges were compared with discharges obtained using some other common laboratory measuring techniques. Good agreement was obtained between the integrating-float method results with the results of velocities obtained using other measurement techniques, with an error of less than 2.5%.

Keywords: Hydrodynamics, Integrating floats, open channels.

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قياس الجريان في القنوات المفتوحة باستخدام العوامات التفاضلية

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الخلاصة

ازدادت أهمية قياسات الجريان في العقود الماضية بسبب نقص الموارد المائية الناتج عن التغيرات المناخية التي تتطلب تحكمًا كبيرًا في المياه المتاحة اللازمة للاستخدامات المختلفة. كانت هناك حاجة إلى التقنية الكلاسيكية لقياس تصاريف القنوات المفتوحة بطريقة الطوافات التكاملية لقياس الجريان في مواقع مختلفة عندما لا تكون الأجهزة الحديثة متاحة لأسباب مختلفة ، منها تكلفة الأجهزة. لذلك ، تم استخدام التقنيات الكلاسيكية لحل تلك المشكلة. تهدف الدراسة الحالية إلى فحص طريقة العوامات التفاضلية وتحديد العوامل المؤثرة في تسريع الكرات العائمة في المياه المتدفقة والتي تم تحليلها باستخدام القياسات التجريبية. تم دراسة الطريقة نظريًا ، كما تم إجراء العديد من الاختبارات التجريبية في قناة مختبرية ذات أرضية ثابتة. تم استخدام أحجام مختلفة من الكرات البلاستيكية الصلدة ذات الأوزان النوعية المختلفة كعوامات لقياس السرع ثم تم حساب التصريف. اشارت النتائج إلى أن تقنية العوامات التفاضلية كانت مجدية ودقيقة لقياس سرعة الجريانات المنخفضة في القنوات المفتوحة ، وكان من المستحسن استخدام عوامات صغيرة ذات اوزان نوعية أقرب مايمكن إلى الواحد للحصول على نتائج أكثر دقة. تمت مقارنة السرعات المقاسة والتصاريف المقدرة بطريقة العوامات التفاضلية مع التصاريف التي المقاسة باستخدام تقنيات مختبرية شائعة اخرى. كان التوافق بالنتائج جيدا ونسبة الخطأ اقل من 2.5٪.

الكلمات الرئيسية: الديناميكا المائية ، دمج العوامات ، القنوات المفتوحة.

1. INTRODUCTION

Reliable measurement of velocities and discharges under natural conditions have been continued to be of importance to many aspects of water resources development and utilization. They are essential in many ways, i.e., supplying and regulating water for domestic, industrial, irrigation uses. The measurement will also provide information on streamflow and its variability in time and space, be used in planning and design surface water-related projects, and manage and operate such projects after they have been built (**Deneves 1953, Liue 1970**). There is no single one universally applicable from many methods and devices used for measuring streamflow. Still, one of the widely used for an open channel is a current meter method. And due to difficult economic limitations and conditions that the country suffers from, the cheap alternative methods were preferred to handle.

Moreover, the standard and the common, more accurate devices are not often easy to provide for the measurement stations. The surface floats have been usually used to determine the mean velocity over a given depth. Still, the relationship between the mean velocity and the surface velocity is quite unpredictable for a given reach of a river. Also, surface floats are easily affected by winds, eddies, and secondary currents (**Troskolansk, 1980**).

The use of an integrating-float method for discharge measurements has been an apparent advantage over the surface and other float apparatus. The integrating-float method actually integrates the entire longitudinal velocity distribution of a perpendicular section in a single measurement (**Reginald and Herschy, 1999**). Also, this method cannot be affected by air currents, which are detrimental when using other floats.

The present study was conducted based on multi-laboratory experiments in the Hydraulic Laboratory in the Technical Institute-Baghdad, using a fixed floor flume, shown in **Fig.1**.

The present study aims to experimentally determine the feasibility and the accuracy of the integrating-float method for measuring flow velocities and discharges in open channels and defining the parameters affecting the present method's accuracy.

Figure 1. The Laboratory flume used in the present study.

2. THEORY

A one-dimensional, steady, open channel flow will be considered, with uniform velocity in the streamwise x-direction. A lighter than water sphere is released from the bottom of the channel using a releasing device, as illustrated in **Fig. 2**. This scheme was designed and manufactured to neglect turbulence effects (**Chow, 1970, and Douglas, 2001**).

The sphere will travel with a trajectory as illustrated in **Figure 3**, determined by the local flow velocity, Vx, where this velocity of the sphere (float) is assumed to be the same as the flow velocity at the same location. The trajectory of the float at any time may be described by (**Acheson 1990, Chorin 1993**);

$$x = \int_0^t v_x \, dt \qquad (1)$$

and

$$y = \int_o^D v_y \, dt \qquad (2)$$

The actual discharge per unit width of the channel is defined as;

$$q_t = \int_0^D v_x \, dy \qquad (3)$$

Where D is the depth of flow, and the variation in flow velocity along with the depth with respect to time can be simulated by;

$$dy = v_y \, dt \qquad (4)$$

By substituting equation (4) into equation (3), gives;

$$q_t = \int_0^t v_x \, v_y dt \qquad (5)$$

Where *t*= time of the rise of float to reach the water surface. If it is assumed that the float will reach its terminal velocity v_t in a time t_o (the time lapsed for the float to reach its terminal velocity " V_f " in a time which is nearest the total time), $t_o < t$ (**Liue 1970**), Equation 5 can be written as;

$$q_t = v_t \int_0^t v_x \, dt - \int_0^{t_o} v_x \left(v_t - v_y\right) dt \qquad (6)$$

The horizontal distance traveled by the float L will be;

$$L = \int_o^l v_x \, dt \qquad (7)$$

Substituting eq. (7) into eq. (6) gives;

$$q_t = v_t L - \int_0^{t_o} v_x \, (v_t - v_y) \qquad (8)$$

From the definition of velocity and rewriting of equation (8) in terms of time;

$$q_t = v_t L - \int_0^{D_o} v_x \left(\frac{v_t}{v_y} - 1\right) dy \qquad (9)$$

The order of magnitude of the integral term will be very small if $\frac{t_o}{t}$ or $\frac{D_o}{D}$ approach zero, where D_o=depth at which the float reached its terminal velocity, thus;

$$q = v_t L \qquad (10)$$

Or $$q = \frac{DL}{t} \qquad (11)$$

Where; q=the discharge per unit width using the float technique. Accordingly, it needs to gather the travel distance and time for a float up to reach its terminal velocity in experimental work.

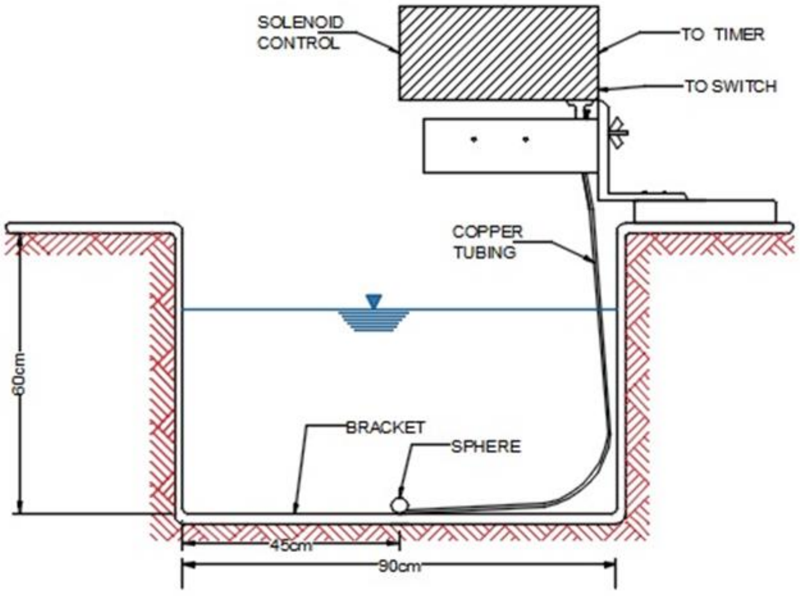

Figure 2. Laboratory Apparatus and release device mechanism.

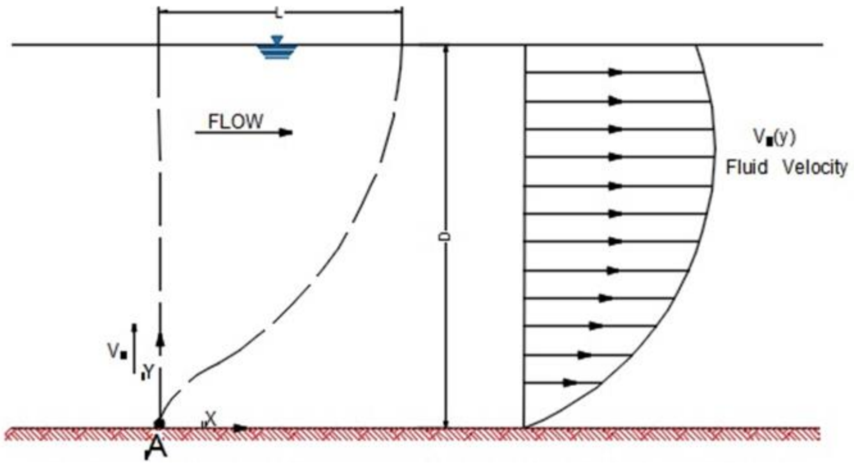

Figure 3. The rise of a lightweight float and velocity distribution of flow.

3. HYDRAULICS ANALYSIS OF INTEGRATING-FLOAT MOVEMENT

The drag force (FD) on a submerged spherical object is dependent on the diameter of the sphere (D), the relative velocity between the sphere and the fluid (V), the fluid density (ρ), and the fluid viscosity (μ). In other words, FD = f (D, V, ρ, μ), where f indicates a functional relationship, which just gives another way of saying that FD (ML/T^2) depends on D (L), V(L/T), ρ(M/L^3), and μ (M/LT). The dimensions (indicated by the square brackets) of each variable are as follows. Since there are 5-dimensional variables and three dimensions, there are two dimensionless parameters (π-terms) for this problem. The units can be canceled in steps, beginning with the parameter with the largest number of dimensions. In this case, the process will begin with the drag force, which has the largest number of dimensions when expressed in terms of mass (**Cameron et al. 2019, Esam and AL-Turaihi 2017**). First, the force is divided by the density to cancel the mass dimension. Since the result is dimensionless, and the dimensionless parameters are;

$$\pi_1 = \frac{F_D}{\rho V^2 D^2} \quad , \tag{12}$$

$$\pi_2 = \frac{\mu}{\rho V D} \tag{13}$$

$$\frac{F_D}{\rho V^2 D^2} = f\left(\frac{\mu}{\rho V D}\right) \tag{14}$$

4. EXPERIMENTAL WORK

The Experimental investigations were conducted in a fixed floor flume of 40 cm depth, 40 cm width, and 6.6 m long. Many runs were conducted to investigate the relationship between measurements of velocities and discharges using integrating-floats and current meter method as well as the volumetric method (**Hassan et al. 2020, Elisabetta et al. 2019**).

Four sizes of ball float 1, 1.5, 2, and 3 cm in diameter with a specific gravity of 0.98, 0.95, 0.92, and 0.85 were manufactured from polyethylene material with some modification for achieving the required specific gravity. For releasing the floats from the bottom of the channel, a special device was manufactured. The device consists of, solenoid control unit, timer, cooper tubing bracket, and switch. If one switched the device on, the bracket's small shaft would pull, and the float (ball) will release as well as the timer start counting simultaneously. When the device is switched off, that done when the float reaches the water surface, the timer will stop counting.

For describing the influence of the size (diameter) of the integrating floats and the influence of the specific weight of these float on the velocity measurements of the flowing water, two sets of tests were conducted, the first set of tests was implemented using the different size of floats for fixed specific gravity at (0.98). In contrast, the second set of tests was conducted using a floating ball having 1 cm in diameter and various specific gravity.

5. RESULTS AND ANALYSIS

Numerous tests were conducted to study the factors that may affect the accuracy of flow measurement using the integrating-float technique.

5.1. Influence of float size

Fig. 4 shows the influence of float size (diameter) on velocities measured by these floats. It is seen that indirect relation was obtained between the float size and the accuracy of velocities measured. It was also noticed that the reliable and accurate results obtained when using floats having the smallest diameter, so it was desired to use the floats of small size than the bigger one due to the influence of the bigger one by air and water current as well as the effect of turbulence.

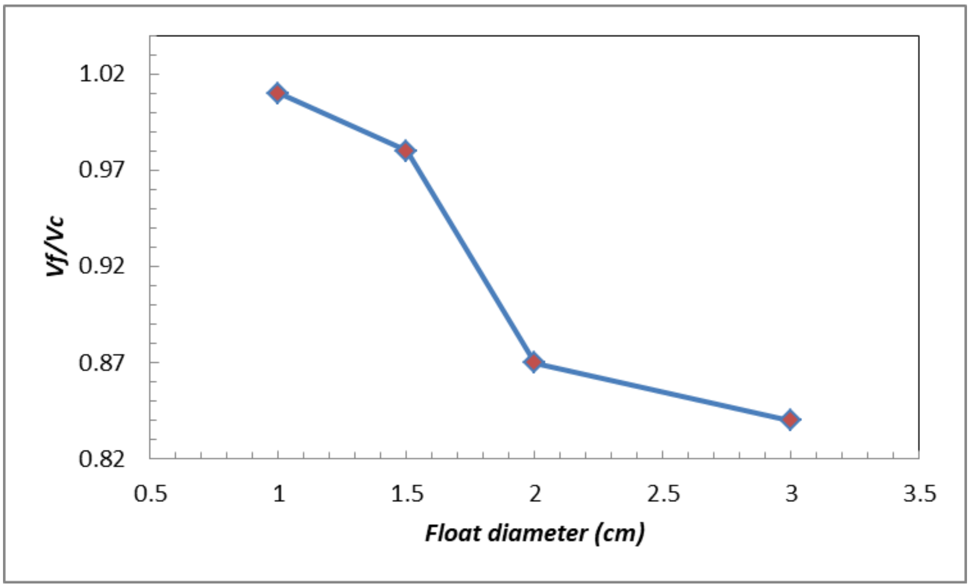

Figure 4. The influence of integrating-floats diameter, D, having 0.98 specific weight, upon the velocity measurement.

5.2. Influence of specific weight

Fig. 5 shows the influence of the specific weight of the floats on the velocity measurements. It is seen that the balls (floats) of unity value of the specific weight produce accurate results. So, it desirable to use floats with specific gravity approaching unity to obtain more accurate results for velocity measurements.

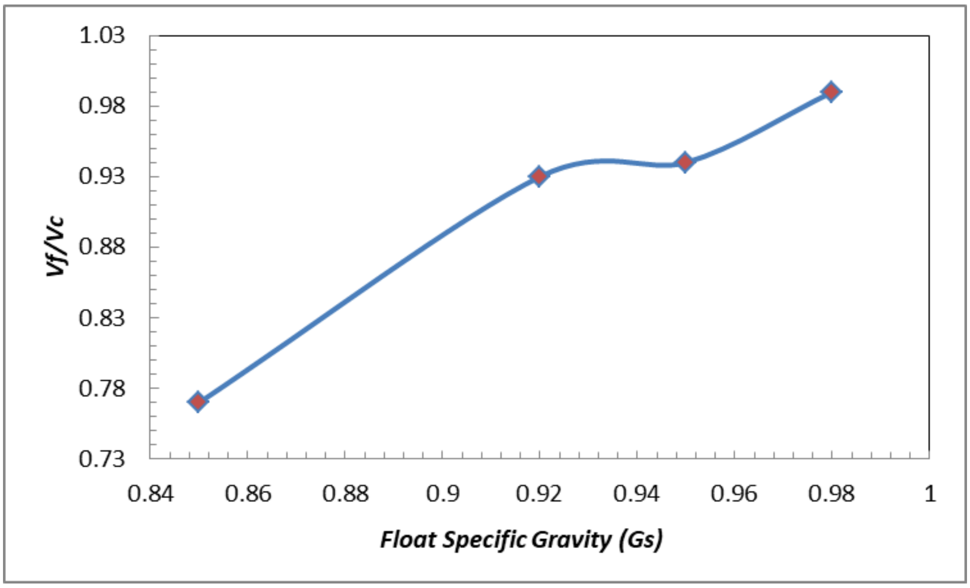

Figure5. The influence of the Specific weight of integrating-floats, G_s, having *1cm* diameter, upon the velocity measurement.

5.3 Measurement of velocity

For the purpose of obtaining the feasibility of using integrating floats to measure the mean velocity in an open channel, several runs were conducted, and the results were compared with the mean velocity measured by the current meter at the sixths of the flow depth as well as with the mean velocity that is computed by volumetric method. **Fig. 6 and Fig.7** illustrate that the results of that test refer to the accuracy of the integrating-float method compared with the current meter method and the mean velocity resulted from the volumetric method. These figures show that the new method is well correlated with the two common methods due to the high determination coefficients (R^2). The floats used here having 1 cm in diameter and a specific gravity of 0.98.

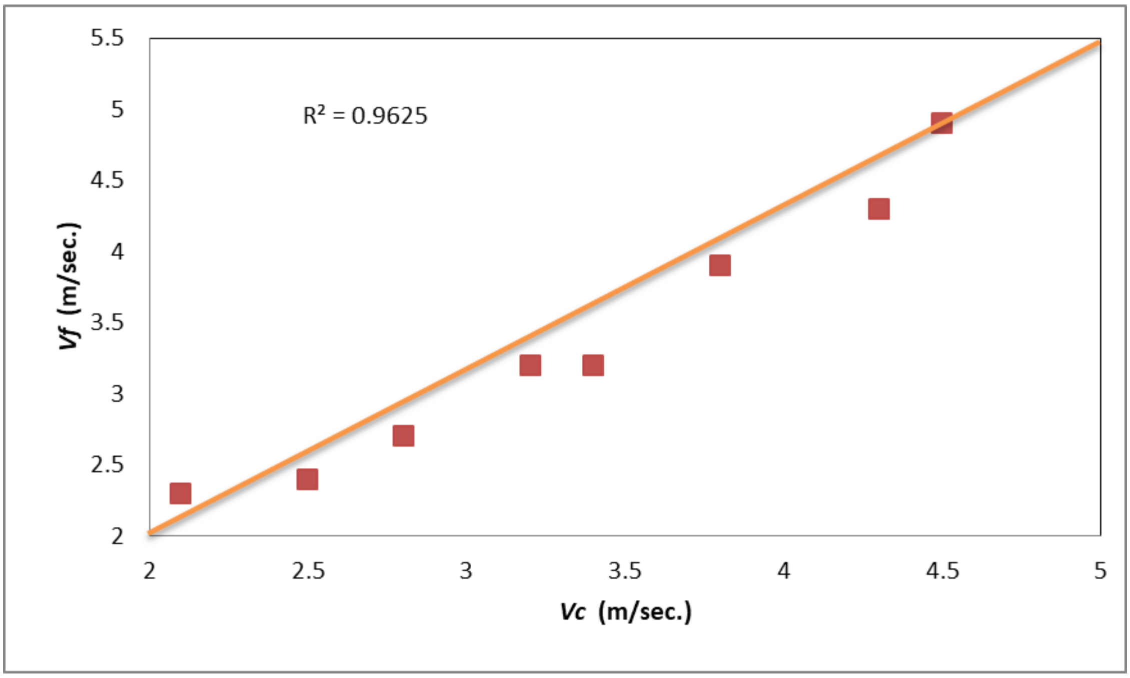

Figure 6. The relationship between the flow velocities measured by integrating-floats V_f and current meter method *Vc*.

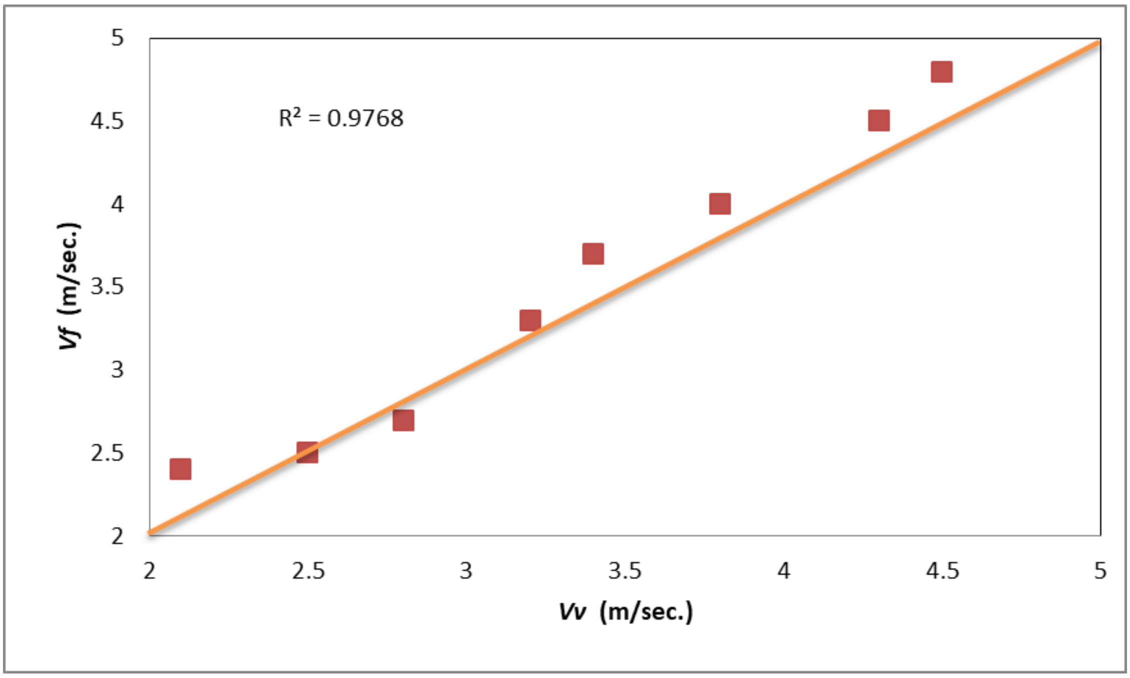

Figure 7. The relationship between the flow velocities measured by integrating-floats V_f and computed using volumetric method *Vv*.

5.4 Computation of discharges

More than one float was used for a given discharge, and ten tests per float were implemented. By applying eq.11, the equation recommended for the integrating-float method, the measured discharges using 1 cm diameter float with a specific energy of 0.98 was calculated and compared with the discharge measured using other methods, **Fig. 8 and Fig.9**.

The results indicate that good agreement between discharges computed according to the new method and that of the other two common methods, and the relations have higher determination coefficients.

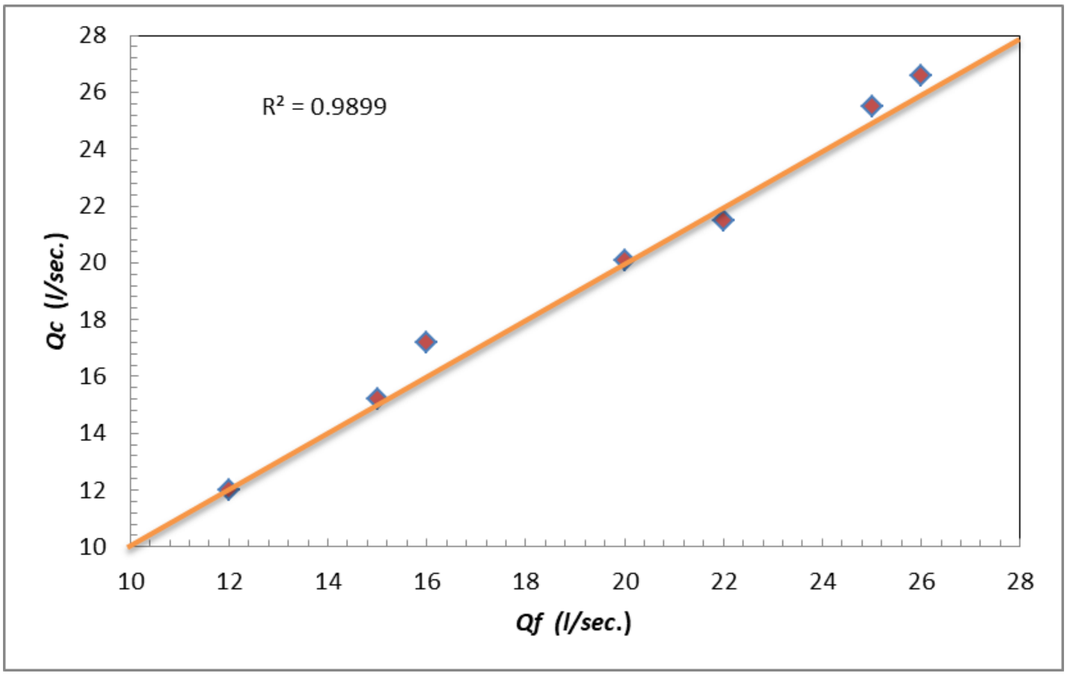

Figure 8. Comparison between the computed flowrate using integrating-floats, Q_f, and the current meter method, Q_c.

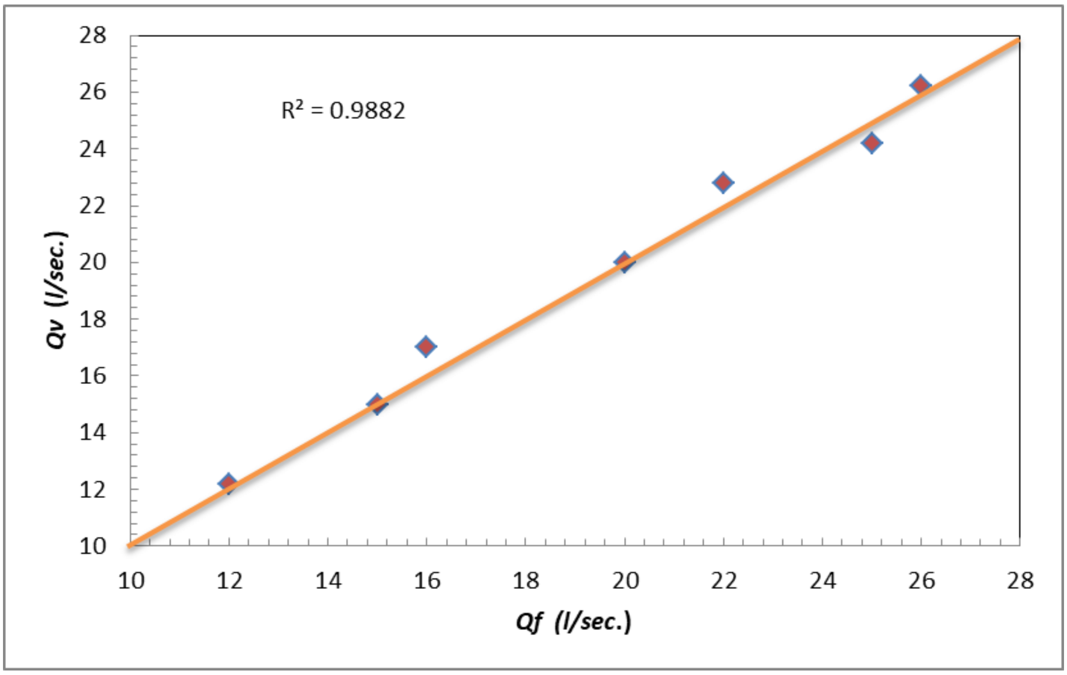

Figure 9. Comparison between the computed flowrate using integrating-floats, Q_f, and the volumetric method, Q_v.

6. CONCLUSIONS

The following conclusions were drawn up that obtained based on the results from the present study; The integrating-float method was feasible to measure mean velocity and computing discharge in an open channel. Accurate results obtained when using the integrating-float method for measuring mean velocity (with determination coefficient greater than 0.96), and computing discharge compared with current meter and volumetric methods (with determination coefficient greater than 0.98). The comparison gives a high correlation coefficient, especially for low flow velocity. More accurate results were obtained with the smaller size (diameter) floats and specific gravity close to unity. The integrating-float method was feasible to measure velocity and discharges in the natural Iraqi channel due to its low costs, ease in handling, ease in applications, and availability of apparatuses required.

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