APPRAISAL OF AIR BUBBLES DISCHARGE MEASUREMENT TECHNIQUE FOR DIFFERENT NOZZLE SIZES

Khalida Khan[1], *Muhammad Yaseen[1, 2], Muhammad Afzal[2], Qamar-u-Zaman[2],

[1]Centre for Integrated Mountain Research (CIMR), University of Punjab Lahore.

[2] Centre of Excellence in Water Resources Engineering, University of Engineering and Technology, G.T. Road, Lahore, Pakistan.

**Corresponding author* Muhammad Yaseen, Centre for Integrated Mountain Research (CIMR), University of the Punjab, Lahore, Pakistan.

E-mail: myaseen@cimr.edu.com, Contact No: 0092-333-8975891, Fax: (+92-42) 99230624

ABSTRACT: *Accurate measurement of irrigation water allows its efficient use. In small channels flow depths may not be sufficient for accurate working of current meters. In this study, rising air bubbles technique was used for flow measurement in small irrigation channels. The experimentations were conducted on a tilting flume. Various combinations of air inlet ports and discharges were used in the present study. Four ports of different diameters ranging from 2.6 to 0.65 mm were inserted at the midpoint of the flume. For each experiment six different discharges were used. The results of the study show that there is a direct relationship between discharge and the bubble rise length. More accurate discharge results were observed with the nozzle size ranging from 1.65 to 2.0 mm for laboratory experiments, and 2.0 to 2.6 mm for field experiments. The bubbles which were observed in the present study were of spherical shape ranging from 5 to 8 mm diameter. Air bubbles technique is valid for subcritical flow having Froude number less than 0.3. The water flowing velocity should be less than 1 meter per second and channel should be small, prismatic and having small bottom slope.*

Keywords: Discharge; Air bubbles; Flume; Nozzle size

1. INTRODUCTION

Water is the most important asset of irrigated agriculture. Accurate measurement of irrigation water allows more efficient use of the valuable natural resource. Such measurement reduces unnecessary waste and allows the water to be circulated among users according to their needs and rights. Several methods are available for flow measurement in an open channel such as volumetric method, velocity area method, hydraulic structures (orifices, weirs and flumes), tracer method, slope hydraulic radius area method; air bubbles discharge method, ultrasonic discharge method.

The weirs, orifices and flumes are characterized as hydraulic structures, because they involve installation of physical structures at the proposed site in the channel. Flow measurement with the hydraulic structures not only disturbs the flow conditions but also sometimes damages the channel geometry. Hence a discharge measurement using these devices is time consuming and involves more labour. A simple and economical method is therefore, needed to measure flow in small channels that can overcome the limitations of above discussed devices. In field generally the approximate estimate of flow is required. So the flow measurement by using air bubble technique in open channels can be best suited for these conditions. Moreover it is so simple to operate that a person with little guidance can use it successfully. The main objective of this study was to measure the discharge by using air bubbles technique in an open channel and compare it with other discharge measurement methods and to assess the sensitivity of air bubbles with different nozzle sizes.

The technique has been investigated by Sargent [1 & 2] who concluded that it was 'a viable alternative to traditional methods of producing stage-discharge relationships' but which lacked the means for monitoring flows on a continuous and automated basis. Puleo et al. [3] performed experiments and

concluded that air bubble size in aqueous environments is an important factor governing natural processes ranging from fluid/atmosphere gas transfer to noise production. Chanson and Gonzalez [4] studied that new air-water flow measurements were conducted in two large-size stepped chute facilities with two step heights. Toop and Hawnt [5] described field and laboratory analyses which seek to extend previous work and to assess the potential of the technique as an alternative for conventional methods of spot and continuous gauging. Yannopoulos [6] also studied on discharge measurement using air bubble technique. Descamps et al. [7] performed the experiments and concluded that the effect of changing the bubble size is of particular interest as it has been shown to affect the pressure drop over the pipe.

2. MATERIALS AND METHODS

The experiments were conducted on S6 Tilting Flume in the Hydraulic Engineering Laboratory of Centre of Excellence in Water Resources Engineering, University of Engineering & Technology, Lahore which is shown in Fig.1. The length of Flume is 10 meter and depth is 450 mm. The width of channel is 300 mm. The slope of Flume was adjusted by mechanical lever and can be adjusted up to 1:40. A flow control valve is provided with the pump to control the flow. An overshot weir gate is at the downstream of the flume's channel to control the flow depth in the channel for any discharge. This flume is also provided with the jack assembly to change the bed slope of the channel. The depth of flow was measured with the help of tipping rod which was attached in middle of the flume. Different sizes of holes were drilled in bottom of the flume for air inlet. The air was introduced into the flume in these drilled holes with the help of air pump to produce the bubbles in flowing water. The flow velocity was measured by pitot tube and current meter.

2.1. Experimental setup in field

The experiments were conducted in the Model Tray Hall of Centre of Excellence in Water Resources Engineering, University of Engineering and Technology, Lahore. The experimental channel was a rectangular lined channel which represented the field conditions (Fig.1). The length of channel is 40 meter and depth of 0.60 meter. Bed width of the channel is 0.72 meter and bed slope is 0.35 percent. To measure the flow depths, water measuring scales

2.2. Measurement of discharge

Following methods were used to measure discharge in all experiments:

2.2.1. Current meter method

In this method the velocity was measured by current meter and cross sectional area was measured by tipping rod and at head, middle and tail end of the channel.

measuring scale. The water discharge was measured by using the following relation [8 and 9].

$$Q = AV \quad (1)$$

Where
Q = Water flowing discharge (m3/sec)
A = Cross sectional Area of flume (m2)
V = Water flowing velocity (m/sec)
were installed


Figure 1. S6 Hydraulic tilting flume and field experiment set up.

2.2.2. Pitot tube method

From this method the discharge was calculated by using the following relation.

$$Q = AV \quad (2)$$

Where
Q = Water flowing discharge (m^3/sec)
A = Cross sectional Area of flume (m^2)
V = Water flowing velocity (m/sec)

The water flowing velocity was calculated by using the following relation.

$$V = \sqrt{2gh} \quad (3)$$

Where
V = velocity of water (m/sec)
g = Acceleration due to gravity (m/sec^2)
h = Head difference (m)

2.2.3. V-Notch weir method

To measure discharge in the experimental channel, a 900 v-notch weir of length 0.60 meter long at upstream of the experimental channel was installed. The discharge through the V- Notch weir was computed by using Francis formula [10 and 11]:

Q=0.0138 H5/2 (4)

Where
Q = Discharge (liter per second)
H = Head over the V-Notch weir (cm)

2.2.4. Air bubbles technique

From this method the discharge can be computed by using the following relation [6 and 12]:

$$q = aW_x L \quad (5)$$

Where
Q = Discharge per unit width (cm3/sec/cm)
a =Function of hydraulic and geometric characteristics of flow and air bubbles (0.85)
Wx = Air bubbles terminal velocity (cm/sec)
L = Air bubbles rise length (cm)

A graduated pipette (1ml) was fitted with a funnel at one end and was immersed in the water near the point of bubble release. Bubbles were collected in the funnel, while their number was counted. These bubbles were coalesced at the throat of the funnel and would then be moved into the graduated portion of the pipette by suction.

Their volume was then recorded by inspection. Division by the number of collected bubbles determined the average volume of each bubble. Measure the average diameter of bubbles by using the following equations.

$$Vol = \frac{4\pi r^3}{3} \quad (6)$$

Where
D = diameter of bubble (cm)
Vol = volume of bubble (cm^3)
Measure the air bubbles rise length (it is length from air inlet hole to where the bubble appears on water surface. Measure the air bubbles terminal velocity by the following relationship [6].

$$W_x = \left(\frac{3\sigma}{\rho d} + \frac{gd}{2} \right)^{0.5} \quad (7)$$

Where
Wx = Air bubbles terminal velocity (cm/sec)
Ρ = Density of water (kg/m^3)
Σ = Air water surface tension (kN/m^2)
g = Acceleration due to gravity (m/sec^2)
d = diameter of bubble (cm)

2.3. Experimental scenario

For achievement of the objectives various combinations of air inlet ports and discharges were used in the present study. Four ports of different diameters having size of 0.65, 1.65, 2.0 and 2.6 mm were inserted at the middle point of the flume. With this setup, six different discharges were released in the flume. Average discharge was taken of three data set of air bubbles discharge at each air inlet ports for each water run. An air pump was used to produce air bubbles in water. The size of the pump used in experimentation was $139 \times 84 \times 49$ mm, weighing 440 grams and having capacity of 3.5 liter per min. It has the capability to change the flow rate of air.

3. RESULTS AND DISCUSSIONS

To calibrate the physical model for discharge measurement by air bubbles technique, the discharge was also measured by pitot tube and current meter for laboratory experiments. For field experiments the results of air bubbles technique was compared with V-notch weir. The comparison of discharge measured with these methods is given in Tables 1 to 4 respectively. There is more variation between discharge measured with air bubbles method using 2.6 mm and 0.65 mm nozzles and that measured with other methods for laboratory experiments. The results with 2.0 mm and 1.65 mm nozzles correlate well with the results of current meter and pitot tube in laboratory experiments. The results with 2.0 mm and 2.6 mm nozzle sizes correlate well with V-notch weir.

3.1. Relationship between nozzle size and discharge

The results of discharge with air bubbles technique with different nozzle sizes for laboratory and field experiments are given in Tables 6 and 7 respectively. It is apparent from these tables that discharge was measured for only two data sets with 0.65 mm nozzle size in laboratory experiments and no discharge was measured for this nozzle size in field experiments. The relationship between discharge and nozzles size are plotted in Figures 2 and 3 for laboratory and field experiments respectively.

3.2. Sensitivity of air bubbles with different nozzle sizes

The water discharges by air bubbles are shown in Table 8 for each nozzle size. In first four data sets, the nozzle size of 0.65 mm did not produce bubbles and thereby no discharge was possible for this nozzle size due to very high velocity of flowing water for both laboratory and field experiments. The 2.0 and 1.65 mm nozzle sizes produced valid results for all data sets in laboratory experiments whereas the 2.0 and 2.6 mm nozzle sizes produced valid results for all data sets in field experiments.

4.0. CONCLUSIONS

The present study was conducted that there is more variation between discharge measured with air bubbles method using 2.6 mm and 0.65 mm nozzles and that measured with other methods for laboratory experiments. The results with 2.0 mm and 1.65 mm nozzles correlate well with the results of current meter and pitot tube in laboratory experiments. The present study shows that more accurate results were produced by 1.65 mm and 2.6 mm nozzle sizes. Different geometric cross section of the channel may be introduced in the experimental scenarios for a broader vision of effect of geometric cross section on discharge measurement by air bubbles technique in sediment free water. The sediment effect should be studied on air bubbles technique in the future studies. The effect of air blower velocity and temperature of water on bubbles size and visibility should be tested while measuring discharge with air bubbles technique. Air bubbles technique is valid for subcritical flow having Froude number less than 0.3 and the flow velocity of water should be less than 1 meter per second. Channel should be small, prismatic and having less bottom slope.

Table 1. Comparison of discharge with 2.6 mm nozzle size in laboratory.

Data set	Pitot Tube (m^3/sec)	Current Meter (m^3/sec)	Air Bubbles Technique (m^3/sec)	Percent error w.r.t current meter %
1	0.0267	0.0252	0.0300	16
2	0.0252	0.0241	0.0291	17
3	0.0220	0.0218	0.0273	20
4	0.0218	0.0216	0.0267	19
5	0.0205	0.0207	0.0254	18
6	0.0180	0.0200	0.0242	17

Table 2. Comparison of discharge with 2.0 mm nozzle size in laboratory.

Runs No	Pitot Tube (m^3/sec)	Current Meter (m^3/sec)	Air Bubbles Technique (m^3/sec)	Percent error w.r.t current meter %
1	0.0267	0.0252	0.0261	3
2	0.0252	0.0241	0.0250	3
3	0.0220	0.0218	0.0230	5
4	0.0218	0.0216	0.0221	2
5	0.0205	0.0207	0.0208	1
6	0.0180	0.0200	0.0197	1

Table 3. Comparison of discharge with 1.65 mm nozzle size in laboratory.

Runs No	Pitot Tube (m^3/sec)	Current Meter (m^3/sec)	Air Bubbles Technique (m^3/sec)	Percent error w.r.t current meter %
1	0.0267	0.0252	0	0
2	0.0252	0.0241	0.0249	3
3	0.0220	0.0218	0.0235	7
4	0.0218	0.0216	0.0228	5
5	0.0205	0.0207	0.0221	6
6	0.0180	0.0200	0.0208	4

Table 4. Comparison of discharge with 0.65 mm nozzle size in laboratory.

Runs No	Pitot Tube (m^3/sec)	Current Meter (m^3/sec)	Air Bubbles Technique (m^3/sec)	Percent error w.r.t current meter %
1	0.0267	0.0252	Bubbles did not appear	
2	0.0252	0.0241		
3	0.0220	0.0218		
4	0.0218	0.0216		
5	0.0205	0.0207	0.0273	24
6	0.0180	0.0200	0.029	31

Table 5. Comparison of discharge by V-Notch weir and with different nozzle sizes in field.

Data Set	V-Notch Weir	Discharge Measurement by Air Bubbles Technique with nozzle sizes					
		Nozzle Size 2.6 mm	Percent Error	Nozzle Size 2.0 mm	Percent Error	Nozzle Size 1.65 mm	Percent Error
1	0.0190*	0.019*	1.6	0.018*	4	0.016*	17
2	0.0247	0.023	6.8	0.022	10	0.021	16
3	0.0296	0.028	4.7	0.027	9	0.026	12
4	0.0350	0.032	8.3	0.031	11	0.030	13
5	0.0389	0.039	0.9	0.035	10	0.034	13
6	0.0453	0.043	5.3	0.042	8	0.039	14

*Discharge in m^3/sec unit.

Table 6. Air bubbles discharge with different nozzle sizes of laboratory experiments.

Nozzle Size	Discharge (m^3/sec)					
	Data Set 1	Data Set 2	Data Set 3	Data Set 4	Data Set 5	Data Set 6
0.65	0	0	0	0	0.0273	0.029
1.65	0	0.0249	0.0235	0.0228	0.0221	0.0208
2	0.026	0.025	0.023	0.0221	0.0208	0.0197
2.6	0.03	0.0291	0.0273	0.0267	0.0254	0.0242

Table 7. Air Bubbles Discharge with different nozzle sizes of field experiments.

Nozzle	Discharge (m^3/sec)					
Size	Data Set 1	Data Set 2	Data Set 3	Data Set 4	Data Set 5	Data Set 6
1.65	0.016	0.021	0.026	0.03	0.034	0.039
2	0.018	0.022	0.027	0.031	0.035	0.042
2.6	0.0187	0.023	0.0282	0.0321	0.0386	0.0429

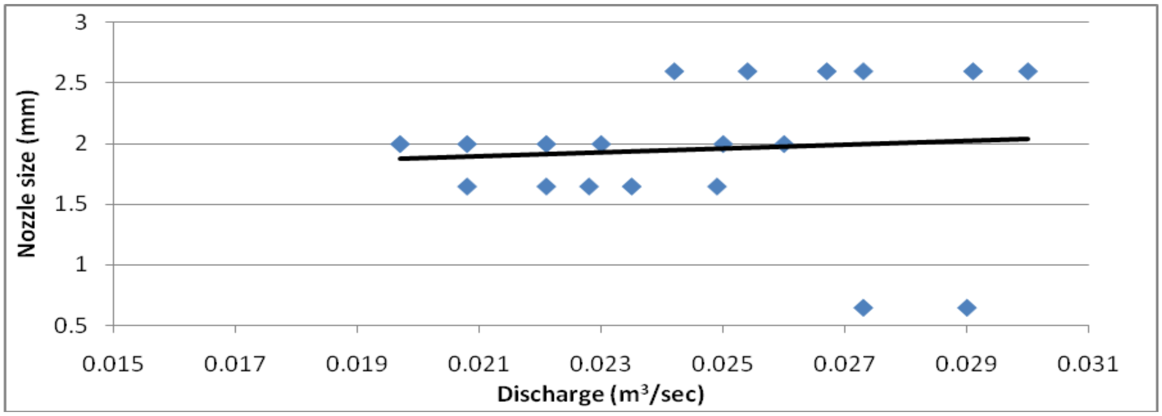

Fig. 2. **Relationship between nozzle size and discharge for each data set of laboratory experiments**

Table 8. Air bubbles discharge with different nozzle sizes.

Data Set	Nozzle Size 2.6 mm	Nozzle Size 2.0 mm	Nozzle Size 1.65 mm	Nozzle Size 0.65 mm
1	0.0300*	0.0261*	No bubble	No bubble
2	0.0291	0.0250	0.0249*	No bubble
3	0.0273	0.0230	0.0235	No bubble
4	0.0267	0.0221	0.0228	No bubble
5	0.0254	0.0208	0.0221	0.0273*
6	0.0242	0.0197	0.0208	0.0290

*Discharge in m^3/sec unit.

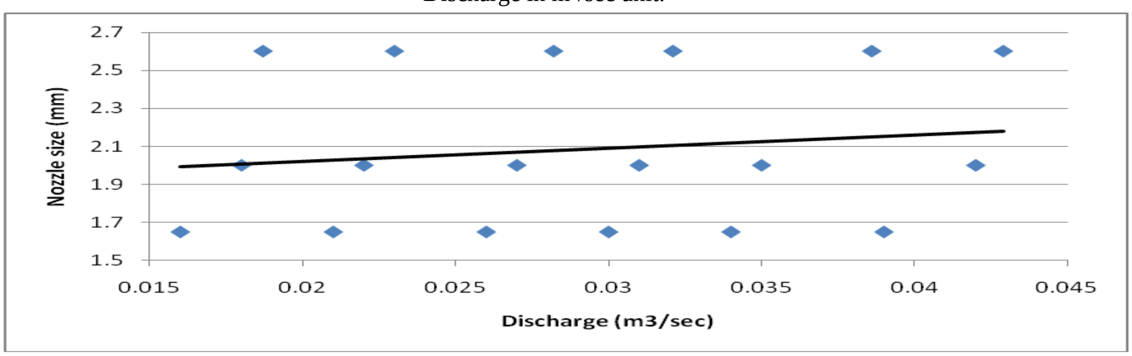

Fig 3. Relationship between nozzle size and discharge for each data set for field experiments.

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