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*Full Length Research Paper*

# Study of the influence of venturi weir type on air bubble entrainment

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**Aeration is a natural or mechanical process of increasing the contact between water and air for the purpose of releasing entrained gases, adding oxygen, and improving the chemical and physical characteristics of water. Hydraulic structures can be accepted as the key components in improving aeration efficiency because of the strong turbulent mixing associated with substantial air bubble entrainment at these structures. Weir is the most classic example of a hydraulic structure where aeration occurs and the aeration properties of such a structure has been widely studied in the laboratory and field over a number of years. The present paper investigates the effect of the venturi weir type on air−demand ratio. The results indicate that the venturi weirs are highly effective in terms of air−demand ratio but however, the venturi weir type do not have a significant effect on air−demand ratio. Moreover, regression equations are obtained for the venturi weirs relating air−demand ratio to jet Froude number.**

**Key words:** Aeration, air−demand ratio, venturi, weir.

## INTRODUCTION

Aeration is the process of bringing water and air into close contact in order to add dissolved oxygen, remove un-wanted dissolved gases such as carbon dioxide, and to oxidize dissolved metals such as iron. It can also be used to remove volatile organic chemicals in water. Because of the large interfacial area generated by entrained bubbles, air−water flows in hydraulic structures have great potential of aeration enhancement. The most classic example of a hydraulic structure where aeration occurs is a weir.

The flow over a weir is defined as a free overfall jet, as shown in Figures 1 and 2. The mechanisms by which air is entrained and transferred into water because of the jet are extremely complex and vary with the jet velocity, shape and roughness. Receiving pool geometry also dictates turbulent mixing within the receiving pool and the movement of air bubbles. Moreover, the depth of the receiving pool affects aeration efficiency, because mass transfer is to some degree, dependent upon the residence time of the bubbles in the water. If the receiving pool depth is less than the bubble penetration depth, the bubbles' flow path through the water will be curtailed by the bed of the pool and residence time and hence, aeration efficiency will be limited. The aeration efficiency is relatively unaffected by the receiving pool depth when it is greater than the bubble penetration depth (Wormleaton and Tsang, 2000).

Recently, Avery and Novak (1978), Tsang (1987), Nakasone (1987), Chanson (1995), Tang et al. (1995), Labocha et al. (1996), Watson et al. (1998), Wormleaton and Soufiani (1998), Wormleaton and Tsang (2000), Baylar and Bagatur (2000; 2001a, b; 2006), Baylar et al. (2001a, b; 2008; 2009), Baylar and Emiroglu (2002), Baylar (2003), Emiroglu and Baylar (2003a, b; 2005; 2006) and Baylar and Ozkan (2006) studied on air−demand ratio (ratio of volume flow rate of air to that of water) and aeration efficiency in weirs. Baylar (2003) determined that the air bubble entrainment in the throatless venturi weir was significantly better than that in the rectangular notch weir. The present study investigates the effect of the venturi weir type on air−demand ratio. The venturi weirs are placed at the upstream channel end

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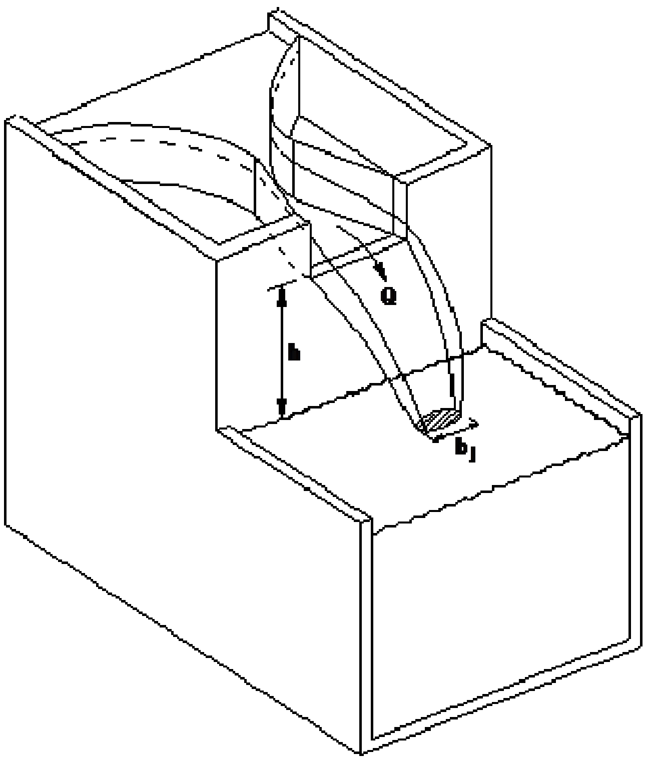



**Figure 1.** Free overfall jet over a venturi weir.

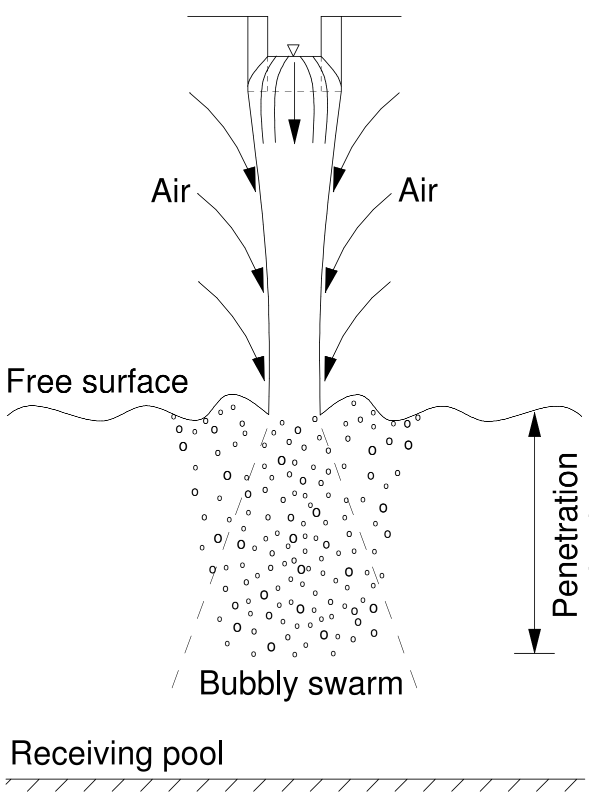



**Figure 2.** Air entrainment by free overfall jet from a venturi weir.

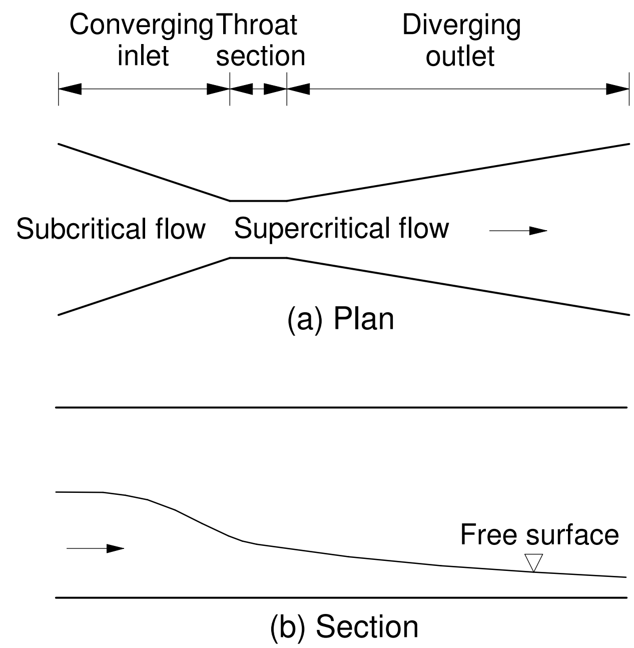



**Figure 3.** Venturi weir (a) plan; (b) section.

in order to increase flow velocity of the free overfall jet and hence to increase air bubble entrainment.

## BACKGROUND

### Venturi principle

Venturi weir consists of three sections: a converging section, a throat section, and a diverging section (Figure 3). In venturi weirs, the venturi effect is achieved by way of a horizontal constriction of the channel cross section. Such geometric change results in flow transition from a subcritical to supercritical state under free flow conditions. Venturi weir operates on the same principle of venturi tube where the constriction of the flow cross−sectional area culminates to an energy conversion, which then accelerates the fluid in the region of the constriction. Since the water level upstream of the venturi weir inlet exists in the subcritical regime, the water at the venturi weir upstream is quiet. This occurs automatically as the damming of water causes velocity decline resulting in subcritical flow conditions. The critical depth develops in the throat section. The flow downstream of the throat is supercritical.

### *Air bubble entrainment mechanisms*

As shown in Figure 4, aeration occurring over weirs involves three mechanisms. Aeration directly to the jet of water flowing over the weir is considered relatively small while aeration on the surface of the pool from the jet

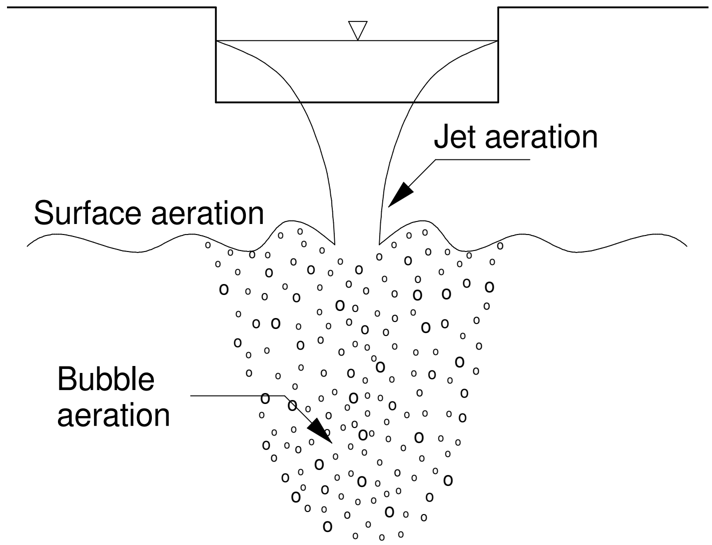



**Figure 4.** Weir aeration mechanisms (Mueller et al., 2002).

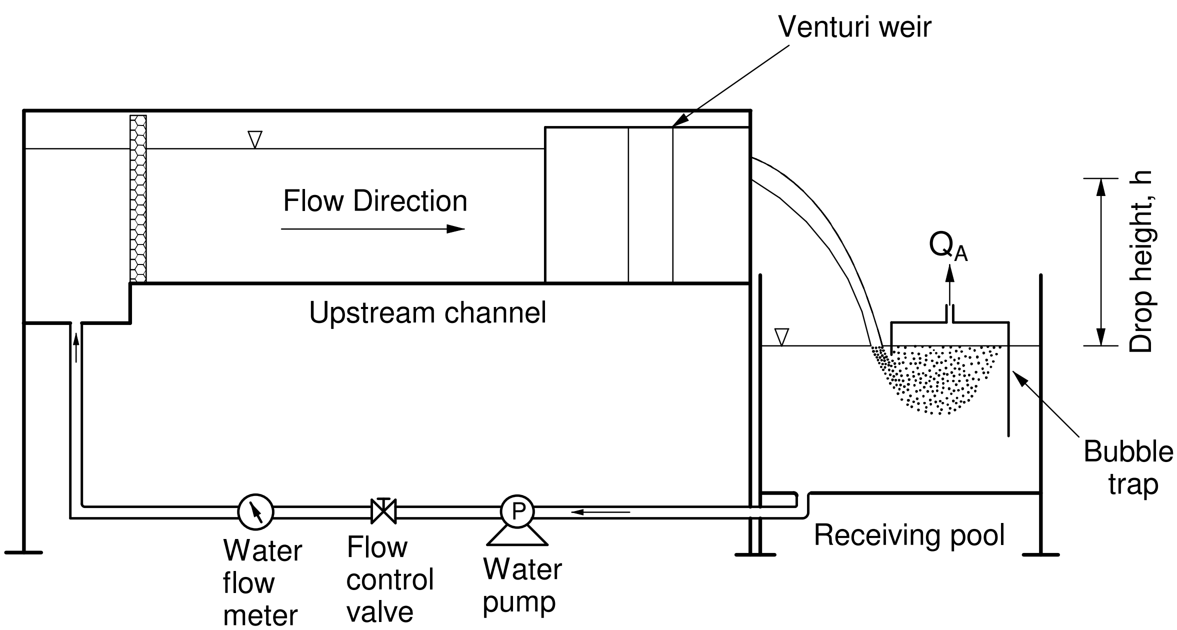



**Figure 5.** Experimental apparatus.

impact depends on the intensity of surface agitation. Bubble aeration from air entrained in the jet and pool, to which the jet is discharging, is the most significant contributor to the oxygenation process (Gameson, 1957). With increasing drop height over the weir, the jet characteristics change from smooth to rough jets, then to oscillating jets, and finally to jet breakup (Wormleaton and Soufiani, 1998). Aeration efficiency increases with jet height, with the rough and oscillating jets providing significant surface agitation and a large amount of closely packed bubbles entrained in the pool. Although a drop height causing jet breakup has the highest efficiency, the rate of increase with drop height is significantly lower than that of the rough and oscillating jets (Mueller et al., 2002).

## MATERIALS AND METHODS

All experiments were conducted using an experimental apparatus in the Hydraulic Laboratory at the Engineering Faculty of Firat University, Elazig, Turkey (Figure 5). The free overfall jets from the venturi weirs plunged into a receiving pool. The plan–view dimensions of the receiving pool were 1.20 × 1.20 m and the depth

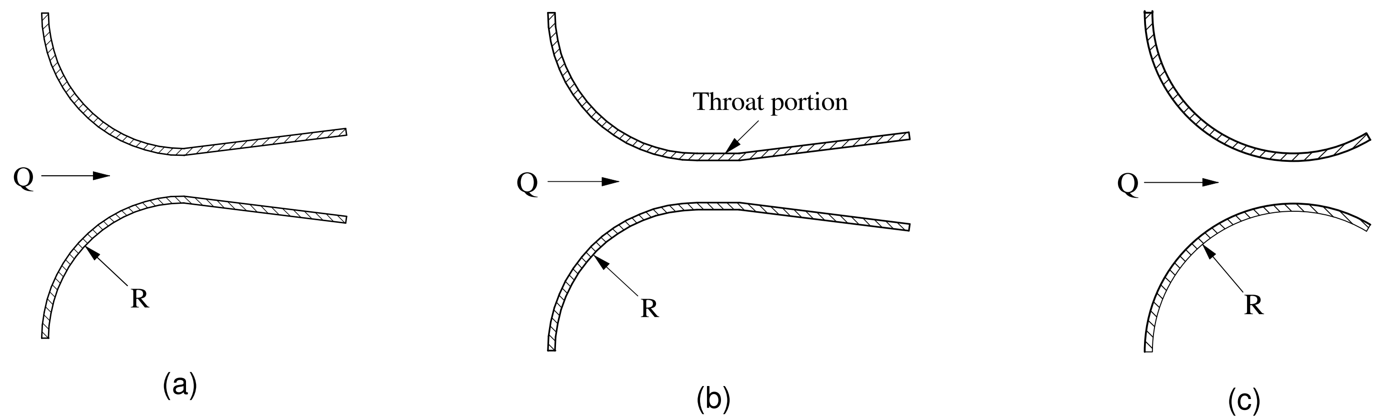



**Figure 6.** Venturi weir types used in the experiments: (a) throatless venturi weir; (b) throated venturi weir; (c) circular venturi weir.

of the receiving pool was 1.50 m. The upstream channel used in this study was 3.40 m long, 0.60 m wide and 0.50 m deep. The crest widths of the venturi weirs were kept constant at 0.15 m in all experiments.

The water in the upstream channel was circulated by a water pump. The water discharge over the venturi weirs, Q, was measured using an electromagnetic water flow meter. Q was varied from 1 to 5 L/s in 1 L/s steps. Drop height (h) defined as the difference between the weir crest and receiving pool surface was varied between 0.20 to 1.00 m in 0.20 m steps. Constriction ratio (ratio of throat width to weir crest width β) was selected as 0.50 and 0.75. A bubble trap for which the plan−view dimensions were 0.75 m x 0.60 m, was used to obtain the entrained air discharge $Q_A$ using a Testo 435 anemometer.

Venturi weirs used in the experiments were made of metal. The physical sizes of the weirs were determined in accordance with maximum discharge, 5 L/s. Three different venturi weir types were used in the experiments.

1. Throatless venturi weir: It consists of a converging level inlet section with rounded sidewalls and a diverging level outlet section also with vertical sidewalls. It does not have any parallel walls forming a straight throat (Figure 6a).
2. Throated venturi weir: It resembles throatless venturis but, it comprises a throat of which the invert is truly horizontal in the direction of flow. The throat is prismatic (Figure 6b).
3. Circular venturi weir: It consists of a converging level inlet and diverging level outlet sections with rounded sidewalls. It does not have any parallel walls forming a straight throat (Figure 6c).

## RESULTS AND DISCUSSION

The present paper investigates the effect of the venturi weir type on the air−demand ratio (ratio of volume flow rate of air to that of water $Q_A/Q$). The values of air−demand ratio are obtained depending on drop height (h), water discharge (Q), constriction ratio (β) and venturi weir type. The following sections present and discuss experimental results.

### Effect of jet Froude number on air−demand ratio

Due to the complicated and conflicting effects of bubble contact time and the quantities of air entrained, a jet Froude number was defined by Avery and Novak (1978) as:

$$F_j = \left[ gh^3 / 2q_j^2 \right]^{0.25} \tag{1}$$

where $F_j$ is jet Froude number, g is the acceleration of gravity ($m/s^2$), h is drop height (m) and $q_j$ is discharge per unit perimeter of the jet at the point of impact ($m^2/s$). For a free falling jet, $q_j$ is defined as:

$$q_j = Q/2b_j \tag{2}$$

where Q is water discharge over the entire weir ($m^3/s$) and $b_j$ is free overfall jet width at the point of impact (m).

Figure 7 (a − f) show the variation in the air−demand ratio ($Q_A/Q$) with the jet Froude number ($F_j$). For all venturi weir types, the $Q_A/Q$ increases with increasing $F_j$ and water discharge (Q). This increase can be explained with the increased drop height.

### Effect of drop height on air−demand ratio

The change in the $Q_A/Q$ with drop height (h) is given in Figure 8 (a − f). It is observed from these figures that for all venturi weir types, the $Q_A/Q$ increased with increasing h. The reason for this increase in the $Q_A/Q$ can be found by the increased momentum of the jet flow.

### Effect of constriction ratio on air−demand ratio

Figures 7, 8, and 9 show that β has no significant effect on the $Q_A/Q$. However, the venturi weir type (especially circular venturi weir) has a small effect when Q takes values around 1 L/s.

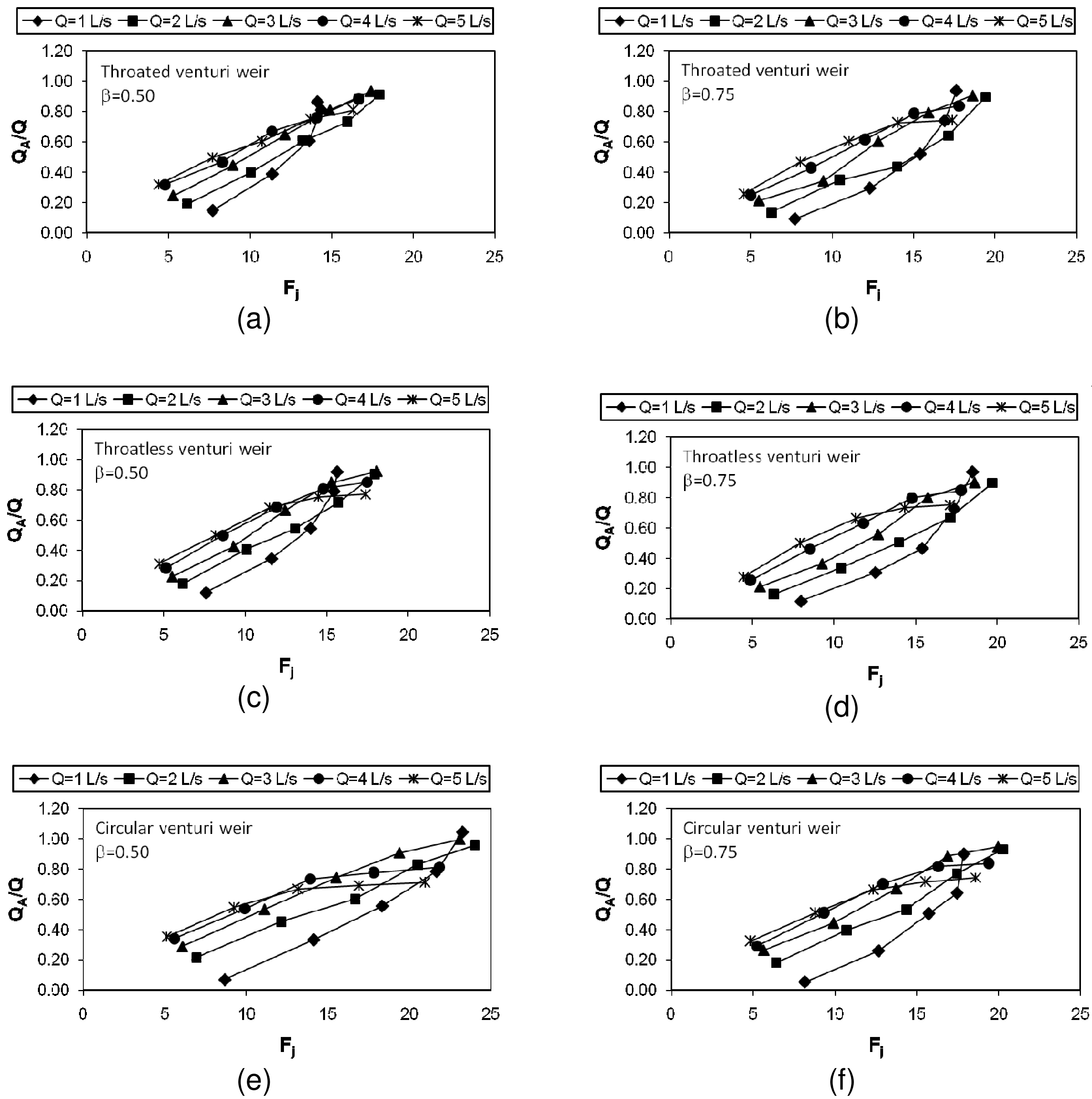



**Figure 7.** Variation in air−demand ratio with jet Froude number and water discharge for different weir types and constriction ratios.

**Effect of drop height on free overfall jet width at the point of impact**

It is apparent from the results in Figure 10 (a - f) that for low water discharges, the free overfall jet width at the point of impact ($b_j$) decreases as drop height increases. However, for high water discharges, $b_j$ increases as drop height increases. The reason for this is that for low water discharges, jet contraction occurs in lower drop heights.

**Effect of weir type on air−demand ratio**

The results reveal that venturi weir type does not have a significant influence on air−demand ratio (Figure 11; a - j). For low water discharges, the increasing tendency in

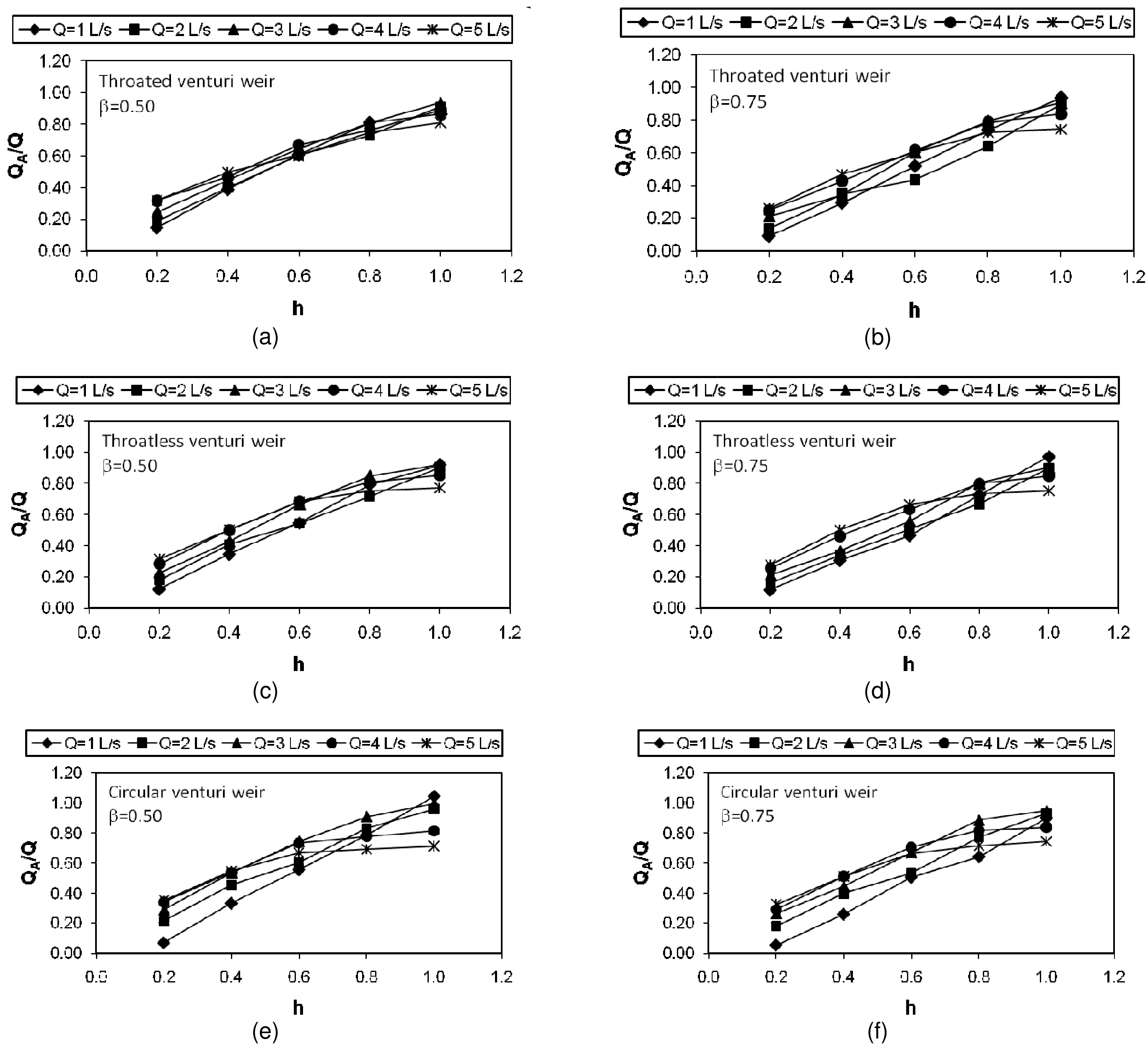



**Figure 8.** Variation in air–demand ratio with drop height and water discharge for different weir types and constriction ratios.

the $Q_A/Q$ is high. However, as the water discharge increases, the increasing tendency in the $Q_A/Q$ decreases.

## Regression analyses

Regression analyses were performed using the nonlinear regression module. Empirical correlations predicting air–demand ratio ($Q_A/Q$) were developed for the venturi weirs. For β=0.50 and 0.75, the resulting correlations are given in Equations 3 and 4. The correlation coefficients for Equations 3 and 4 are 0.86 and 0.87, respectively.

$$\frac{Q_A}{Q} = 0.086\,(F_j - 1)^{0.791} \quad \text{for } \beta = 0.50 \tag{3}$$

$$\frac{Q_A}{Q} = 0.048\,(F_j - 1)^{0.996} \quad \text{for } \beta = 0.75 \tag{4}$$

where $Q_A/Q$ is air–demand ratio, $F_j$ is jet Froude number and β is constriction ratio in the horizontal. The measured air–demand ratios were compared with those predicted with Equations 3 and 4. Good agreements between the

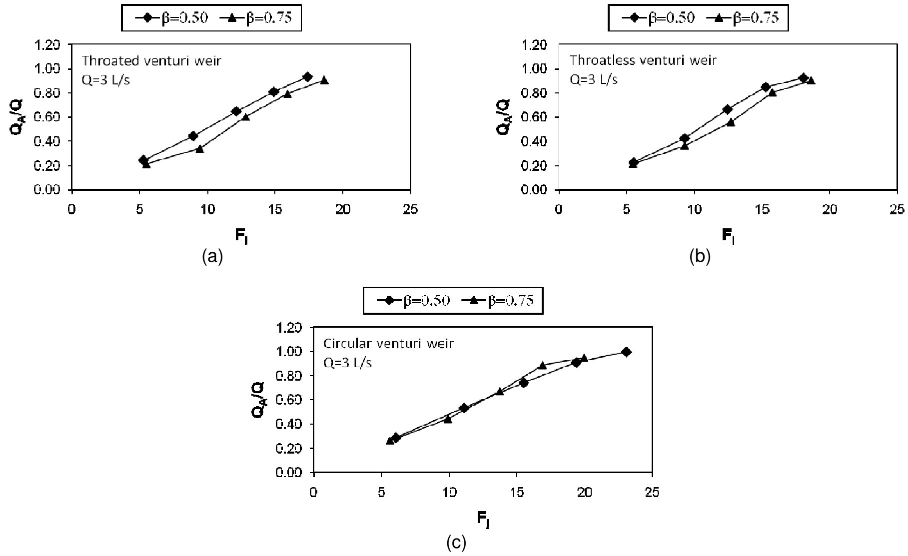



**Figure 9.** Variation in air−demand ratio with jet Froude number and constriction ratio for different weir types.

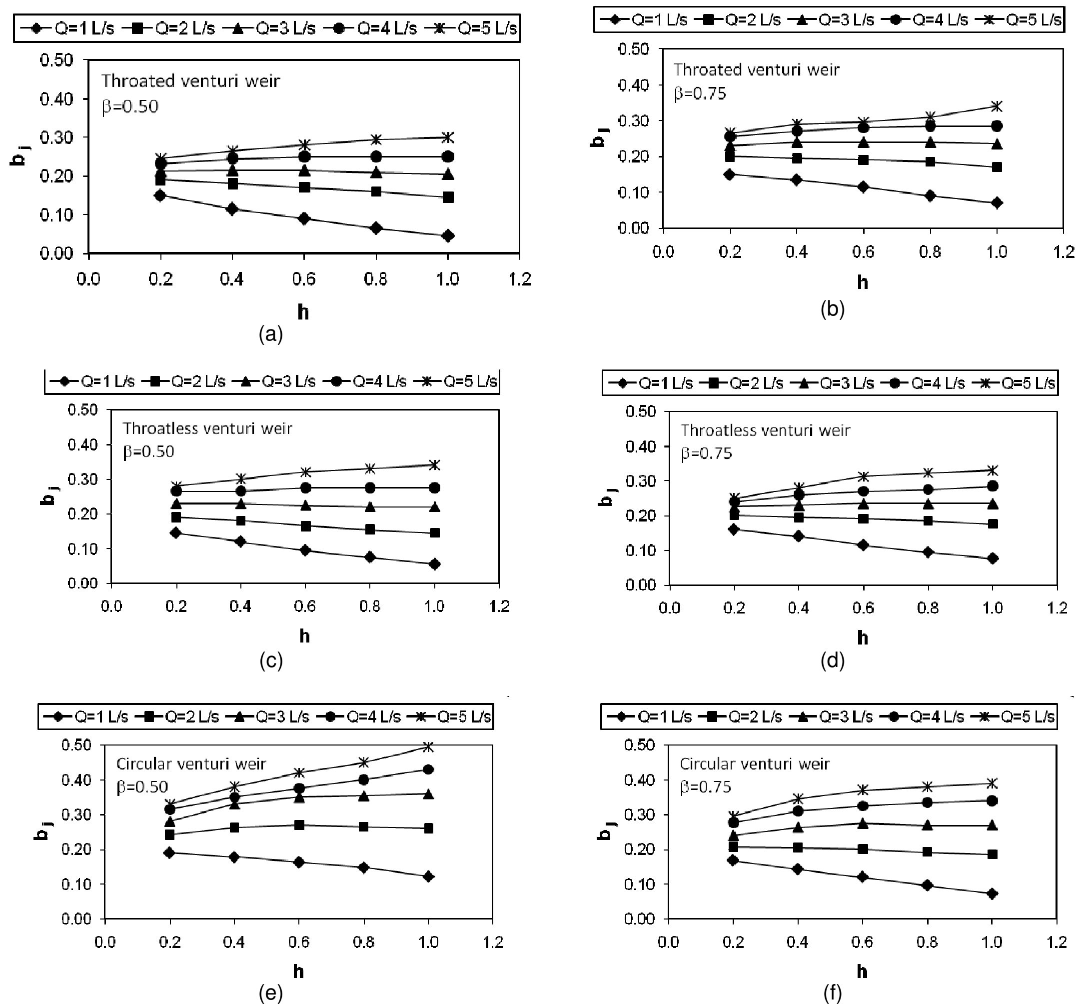
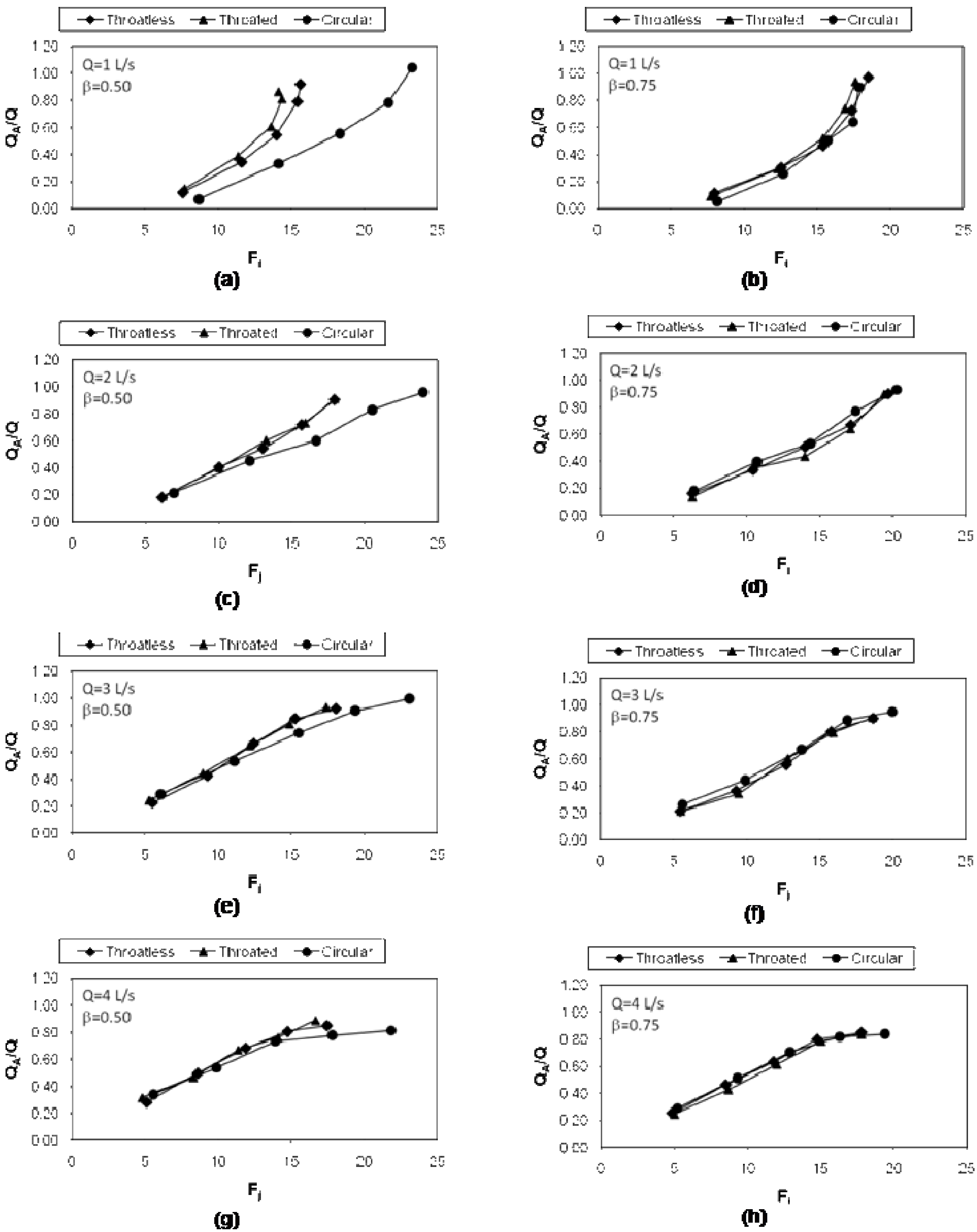
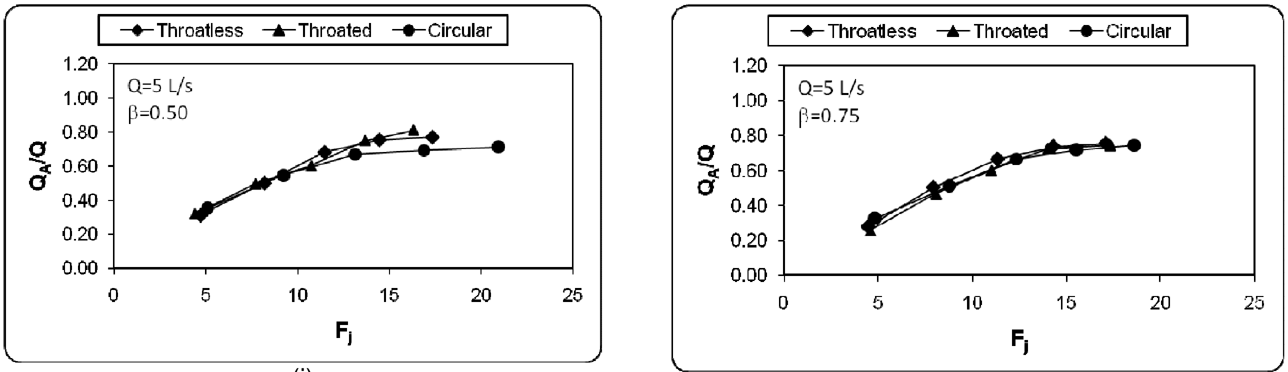


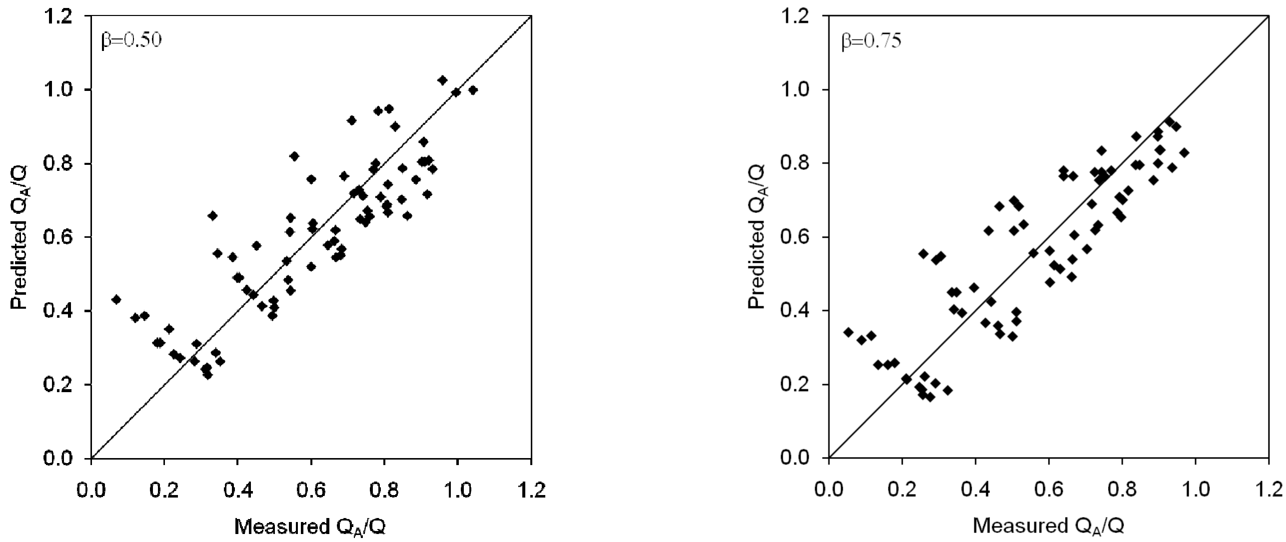

**Figure 10.** Variation in free overfall jet width at the point of impact with drop height and water discharge for different weir types and constriction ratios.


Throatless
Throated
Circular
Q=1 L/s
β=0.50
$Q_A/Q$
$F_i$
(a)
Q=1 L/s
β=0.75
(b)
Q=2 L/s
β=0.50
(c)
Q=2 L/s
β=0.75
(d)
Q=3 L/s
β=0.50
(e)
Q=3 L/s
β=0.75
(f)
Q=4 L/s
β=0.50
(g)
Q=4 L/s
β=0.75
(h)




(i) (j)

**Figure 11.** Variation in air−demand ratio with jet Froude number and weir type for different discharges and constriction ratios.




(a) (b)

**Figure 12.** Comparison of measured air−demand ratio values with those calculated from Equations 3 and 4 for (a) β=0.50; (b) β=0.75.

measured and predicted air−demand ratios were obtained (Figure 12; a - b).

## Conclusions

A series of laboratory experiments was carried out to investigate the effect of the venturi weir type on the air−demand ratio. Empirical equations were obtained for the venturi weirs relating air−demand ratio to jet Froude number. The results demonstrate that the venturi weirs have a high air−demand ratio. The air−demand ratio increases with increasing drop height and water discharge in all venturi weir types. However, the venturi weir type is not an important parameter influencing air−demand ratio. Thus, using a simple venturi weir would significantly increase the air−demand ratio. Future researches should be directed towards the effects of venturi weirs on aeration efficiency.

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