Parshall Flume Submergence

Parshall flumes, like all flumes, require a minimum head loss to ensure that free-flow exists and that only a single upstream head measurement is needed to determine the discharge rate. When the downstream water surface rises above a critical point, the resistance to flow in the downstream channel becomes sufficient to reduce the upstream velocity, increase the upstream flow depth, and cause a backwater effect in the flume.

Unlike free-flow conditions where only one head measurement is required, submerged flow requires the measurement of both the upstream head (H_a) and the downstream head (H_b) (located in the throat for a Parshall flume). The crest (flat upstream floor) of the flume is the reference level for both measurements.

Determining Submergence

The ratio of the downstream head to the upstream head, H_b/H_a, expressed as a percent, is defined as the submergence ratio. Research has shown that the discharge rate of a Parshall flume is not reduced (that is the flume operates under free-flow conditions) until the submergence ratio exceeds a critical value (the submergence transition, s_t).

The submergence transition, s_t, (H_b/H_a) ratios for Parshall flumes are as follows:

50%	1-3 inch flumes
60%	6-9 inch flumes
70%	1-8 foot flumes
80%	10-50 foot flumes

OPENCHANNELFLOW

East Coast: Atlanta, Georgia | West Coast: Boise, Idaho

V: 866.435.8637 | F: 855.331.6457 | www.openchannelflow.com

At, and above, these ratios, submerged flow conditions exist. Two head measurements must be taken with the information then applied to special submerged flow discharge tables. Care should be taken not use free-flow discharge tables as they will overstate the actual discharge rate.

As the submergence in a Parshall flume increases, the strong, backward-rolling hydraulic jump in the discharge section decreases and a series of smooth standing waves form in the discharge section (approximately at a submergence ratio of 90%). The change from the rolling jump to the standing waves is abrupt, and once formed, will persist even as the submergence level decreases. The submergence at which this change occurs can be defined as the "critical submergence".

Difficulties Measuring Submergence Values

For high submergence, where the submergence ratio exceeds 0.95 (95% submergence), little faith can be placed on the resultant value as very minor errors in determining the H_a or H_b levels become critical. Practically speaking, a submergence ratio of 90% should be considered the upper end of correctable flow.

In addition to the obvious effects of increasing the complexity of determining the reduced discharge rate and raising the upstream flow depth (which could lead to overtopping the upstream channel), the decrease in the upstream velocity may lead to or aggravate sedimentation problems.

It is important to remember in evaluating existing installations that downstream water levels can change with changes in downstream flow resistance, which frequently varies with sediment deposits, debris, canal checking operations, and aging. Increased downstream flow resistance can result in flumes originally designed for free-flow conditions to experience submergence.

Advantages of Submerged Flow

When compared with a Parshall flume operating under free-flow conditions, a Parshall flume operating under submerged flow conditions does offer two primary advantages:

(1) There is less energy loss
(2) The inlet floor of the flume can be placed at the same elevation as the channel bottom

Typically, to insure free flow, the inlet floor of a Parshall flume is set above the grade of the channel resulting in greater upstream depths. In natural channels this may cause additional silting and increased upstream seepage losses. A Parshall flume submerged from the outset could minimize these conditions.

Disadvantages of Submerged Flow

Keep in mind, though, that since the flow in the throat is quite turbulent, causing the water level to fluctuate considerably, it is difficult to accurately measure Hb with a staff gauge. Consequently, a stilling well is typically required for an accurate measurement of Hb.

The addition of a secondary stilling well creates its own problems, though, as silting and clogging (and the associated maintenance) become issues on solids / debris laden flows. Additionally, the cost and complexity of secondary meters or methods used to determine the submerged flow rate typically outweigh any benefits that submerged flow metering might convey.

Correcting For Submergence

After submergence has been confirmed by measuring the submergence ration (determined by the H_a and H_b levels and comparing them), two options exist to determine the actual flow rate through the flume:

- Submergence correction tables
- Submergence correction equations

Traditionally, submergence correction tables have been used. Tables, however, do not lend themselves to spreadsheet data manipulation and analysis and have fallen out of favor for anything other than spot use.

In utilizing submergence corrections equations, two general forms are available:

Wahl (12"-96" Flumes):

$$Q_{net} = Q_{free} - Q_{correction}$$

$$Q_{correction} = M\left(0.000132\, H_a^{\,2.123}\, e^{9.284S}\right)$$

Where:

- Q_{net} = net submerged flow rate, in cfs
- Q_{free} = free flow rate, in cfs
- $Q_{correction}$ = discharge reduction in flow rate, in cfs
- H_a = depth at the primary point of measurement, in feet
- H_b = depth at the secondary point of measurement, in feet
- M = multiplying factor
- e = natural logarithm
- S = submergence ratio

$$S = \frac{H_b}{H_a}$$

Size of Flume	Multiplying Factor, M
1'	1.0
1.5'	1.4
2'	1.8
3'	2.4
4'	3.1
5'	3.7
6'	4.3
7'	4.9
8'	5.4

ISO 9826:1992(E):

$$Q_{dr} = Q - Q_e$$

Where:

- Q_{dr} = submerged discharge, in m3/s
- Q = free flow discharge, from above, in m3/s
- Q_e = reduction in discharge as a result of submergence, in m3/s

$$Q_e = 0.07\left(\left[\frac{H_a}{0.305\left(\left\{\frac{1.8}{S}\right\}^{1.8} - 2.46\right)}\right]^{4.57-3.14S} + S\right) W^{0.815}$$

- H_a = depth at the primary point of measurement, in meters
- H_b = depth at the secondary point of measurement, in meters
- S = submergence ratio

$$S = \frac{H_b}{H_a}$$

- W = throat width, in meters

Further Reading:

Wahl, T., Equations for Computing Submerged Flow in Parshall Flumes.

ISO 9826:1992 Measurement of Liquid in Open Channels – Parshall and SANIIRI Flumes.