CONTROL
For the Process Industries

Plumbing The Depths Of Open-Channel Flow Measurement

Developments in Area Velocity Meters, Computerization, and Radar Applications Are Augmenting Traditional Technologies.

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Old World Craftsmanship

Ins and Outs of Wiers and Flumes

A weir resembles a dam placed across an open channel. It is positioned in such a way that the liquid can flow over it. Weirs are classified according to the shapes of their openings. Types of weirs include V-notch, rectangular, and trapezoidal.

Water depth is measured at a specific point upstream from the weir. An equation for determining flowrate is associated with each type of weir.

A flume is a specially shaped portion of the open channel with an area or slope that is different from the channel's slope or area. The velocity of the liquid increases and its level rises as it passes through the flume. Types of flumes include Parshall, Palmer-Bowlus, Leopold-Lagco, H-type, trapezoidal and cutthroat.

To determine flowrate, liquid depth is measured at specified points in the flume. An equation is associated with each kind of flume, taking flume size into account.

The choice of flume depends on the application. Parshall flumes were first introduced in the 1920s to measure the flow of irrigation water. Today, Parshall flumes are used in sewers and in sewage treatment plants. Palmer-Bowlus flumes were developed in the 1930s to measure wastewater flow.
The U.S. Dept. of Agriculture's Soil Conservation Service developed H-type flumes in the same decade to measure runoff from small agricultural watersheds. Today, H-type flumes are used to measure low flow of streams, feedlot runoff, and sewage.

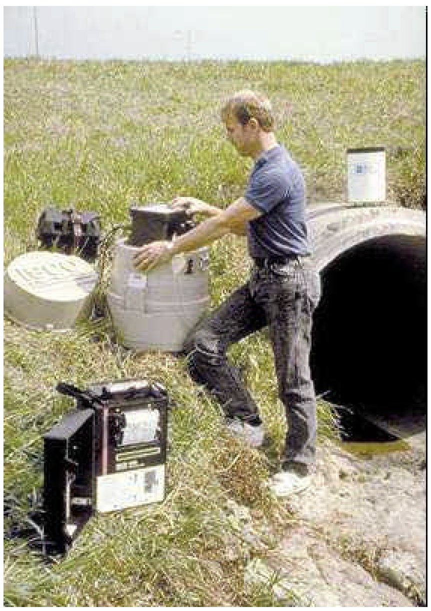
Wiers and flumes each have advantages. Measuring flows with either method requires a secondary device to measure level. Commonly used level technologies include submerged pressure transducer, float, ultrasonic, bubbler, and electrical property instrumentation.

Submerged pressure transducers the hydrostatic pressure of the liquid above the transducer, which is proportional to liquid level. They are not affected by wind, turbulence, or floating debris, but accuracy may be affected by temperature changes.

A float is used with a pivoting arm or a cable and pulley to provide a level measurement. Being mechanical devices, float systems require periodic maintenance. Ultrasonic level meters transmit a pulse to the surface of the liquid and measure the time it takes for the pulse to be reflected back to the meter, which indicates the level of the stream.

Bubblers measure the hydrostatic pressure of the liquid by measuring the gas pressure required to emit a steady flow of bubbles from a tube at the bottom of the flow stream. Liquid level is proportional to this pressure.

Electrical methods measure depth using of the change in an electrical property (capacitance, resistance, etc.) that results from changing levels. Accuracy of these probes can be affected by changing liquid characteristics, or by coatings of solids or grease.



An area velocity flowmeter, sampler, and rain gauge form a system for monitoring storm water runoff.

Clocking Flow by Area Velocity

In area velocity flowmetering, the velocity measurement is made using a variety of technologies, including Doppler, transit time, electromagnetic, and radar instruments.

A Doppler flowmeter transmits high-frequency sound waves into the flowing stream, which are reflected off air bubbles and suspended particles in the flow. A sensor detects the reflected waves and determines their frequencies. By processing the reflected frequencies, the flowmeter determines the velocity of the flowing stream.

Transit-time flowmeters have pairs of transducers that generate sound pulses traveling at an angle to the flow. Sound impulses move faster when travelling with the flow stream and decelerate when traveling against it. By measuring the transit time of the sound pulses, the flowmeter calculates velocity of flow.

Electromagnetic probes use Faraday's principle: when a conductor moves through a magnetic field, it generates a voltage proportional to its velocity. The electromagnetic probes create a magnetic field. When the liquid flows through this field, it creates voltage. The probe measures this voltage by means of electrodes positioned on the surface of the probe, which gives a local velocity. Average flow velocity is calculated using this value, measured depth, and the shape and size of the channel.

Radar has traditionally been a means to measure level, but is now also being used to measure flow velocity. Radar flowmeters determine flow velocity in much the same way that police radar guns measure the speed of an automobile. The radar flowmeter transmits a radar signal to the flowing stream, which is reflected back at a different frequency. Analyzing the difference in transmitted and reflected frequencies yields flow velocity.

The other component of area velocity measurement is the depth, which is determined by a level measurement. This value, together with values relating to the geometry of the conduit, is used to determine area.

Comparison of Open Channel Flow Methods

Method
Area velocity
Dilution
Flume or Weir
Manning formula
Timed-gravimetric

Description
Mean flow velocity multiplied by flow area yields flowrate
Measures flow by dilution of tracer solution
Flowrate is determined from fluid level over or through a hydraulic structure
Flowrate calculated from area, slope, and roughness of conduit
Flow is collected for a fixed period of time, then weighed
Primary Uses
Temporary on large-channel applications where installation of a weir or flume is not practical
To verify correct operation of flumes
To determine the relation between level and flowrate in a stream
Occasional flow measurement or calibration
Flow in manholes, water and wastewater treatment plants, agricultural runoff, and irrigation channels
Round pipes in manholes
Calibrate other meters

Advantages
Works under submerged, surcharged, full pipe, and reverse flow conditions
Works with a variety of pipe or channel shapes; More accurate than slope-hydraulic radius method
No moving parts
Minimal flow obstruction
No pressure loss
No flow obstruction
More accurate than slope-hydraulic radius method
No weir or flume
High accuracy
Low cost

Disadvantages
Requires measurements of both flow depth and mean velocity
More complex than weir or flume
Not practical for continuous use
Concentration instruments are costly and fragile
Requires trained operators
Sensitive to upstream debris
Some parameters hard to measure;
Less accurate than other methods
Not suited for continuous record of flowrate;
Limited to low flowrates

Weirs vs. Flumes

Advantages
Lower cost;
Easier to install;
Quite accurate
Less head loss;
Less affected by approach velocity;
More tolerant of debris, sediment, or solids

Disadvantages
Significant head loss
Accuracy is affected by approach velocity of liquid
Not suitable for liquids with solids
More costly
More difficult to install

Today's Watersheds

Though much of the technology for open-channel flow measurement was developed in past decades, there are new developments on several fronts, including more application of radar both for level and velocity measurement, greater computerization of open-channel flowmeters, and increased use of area velocity meters.

While radar is traditionally a level technology, it is now being introduced into open-channel flow measurement. In one example, radar replaces an electromagnetic sensor to measure velocity. Larry Marsh, president of Marsh McBirney, believes the non-contact nature of radar makes it attractive to users. "Over time, prices will drop and non-contact area-velocity flowmeters will become the method of choice for most open-channel flow monitoring," he says.

Radar technology is also being used by the Swiss National Hydrological Service to monitor the water level in rivers and streams around the country. One purpose of this is to provide an early warning system for flash floods that occur in the mountains when rivers and streams overflow.

The Swiss have 330 measuring stations throughout the country that record water levels and flowrates (Figure 1). This monitoring was originally done with mechanical float systems, then pressure sensors and bubble sensors were introduced using drum recorders. Later, ultrasonic sensors were installed that required less maintenance than earlier systems, but were somewhat sensitive to temperature. Now the Swiss have installed radar sensors, which are largely unaffected by temperature and pressure changes.

The use of area velocity meters has increased over the past five years as technologies have improved and prices have become more affordable. For example, significant improvements have been made in the Doppler technology used to measure velocity. In addition, improvements have occurred in signal processing and algorithms.

Typical applications for area velocity technology include collection systems monitoring and inflow and infiltration studies (Figure 2). "Progress in area velocity meters is driven by the needs of the market. Customers are looking to fix inflow and infiltration problems, and manufacturers have responded to that need," says Brian Dawson, flowmeter product manager for Isco, Lincoln, Neb.

Increased use of microprocessor technology continues to drive enhancements in open-channel flow technology and bring down prices. "Eight years ago, customers paid $6,000 to $7,000 for area velocity meters. Today they can be bought for $3,000 to $3,500," says Jim McCrone, marketing director for American Sigma, Medina, N.Y. "Flowmeters today are more stable and powerful than in the past. If you haven't updated your flowmeter in the past five years, you're missing a lot," he adds.

"The communication level is also important," McCrone continues. "Ten years ago, people were using chart recorders. Now they want to tie in with radios, cell phones, SCADA systems, and pagers. You have to give people data in a useful format."

While pressurized, closed-pipe flowmetering technology has grabbed much of the attention, advances in open-channel flow measurement are not standing still. As is the case with closed-pipe flow, many of the recent developments revolve around electronic enhancements and improvements in communication, but there is also room for new sensor technologies and improvement of existing sensors. Some improvements of this type have already occurred with Doppler technology. Watch for further developments as vendors vie for a growing market.

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Cool, Clear Water

Applications for open-channel flowmetering are on the increase, as populations expand and the demand for clean water for drinking and recreational purposes grows. This demand can be expected to increase not only in the United States, but also in other countries that are becoming accustomed to an improved standard of living.

Wakefield, Mass., is an example of a town that is analyzing and measuring water flow to enhance water quality. Lake Quannapowitt sits adjacent to the center of town, fed by more than 20 inlets, most of them storm drains. Another major inlet feeds into the lake from the west, where wetlands provide a source of water. A weir has been installed at this inlet to measure flow into the lake. The level of phosphorus in the lake is a major concern, as it leads to excessive weed and algae growth in the summertime.

Quannapowitt Lake Monitoring Group was formed to determine what corrective action to take. When it rains, surface water flows into the lake through the storm drains. This surface runoff is a possible source of phosphorus, which is contained in fertilizer and detergents. By analyzing and measuring the water flow through storm drains, the Lake Monitoring Group hopes to identify which drains bring the most phosphorus into the lake. Those drains could be diverted to a central area for treatment.

Across the country in Portland, Ore., a water treatment plant is measuring open-channel flow for a different reason-so it can report it to the EPA. The channel is 12 ft. wide and 10 ft. deep. The city has chosen the Big Dipper, an open-channel flowmeter from MSR Magmeter Manufacturing of Edmonton, Alberta, to measure the flow.

The Big Dipper uses the area velocity method to calculate flow, with an ultrasonic level transducer and an electromagnetic velocity sensor. The meter computes average velocity with a novel method-instead of simply measuring velocity at a point, it takes velocity measurements at one-inch increments from the bottom of the channel to the top. By taking velocity profile into account, this method has the potential for higher accuracy than meters that make a single velocity measurement.

Ever-increasing environmental regulations and the growing importance of water as a natural resource are generating new interest in measuring flow in open channels. Open-channel flow occurs when liquid flows in a conduit or channel with a free surface: common examples include rivers, streams, canals, and irrigation ditches.

But the flow of liquids in partially filled pipes, when not under pressure, is also considered open-channel flow, for example, water flowing through a culvert running underneath a street. Other examples of open-channel flow include flow in water treatment plants, storm and sanitary sewer systems, industrial-waste applications, sewage treatment plants, and irrigation systems.

A Sea of Options

A variety of methods are used to measure flow in open channels (Table I). The best method for a given situation depends on many factors, among them the nature of the application, budget, accuracy needs, and reporting requirements. Choices include:

- Dilution: A tracer such as a radioactive solution or
  fluorescent dye is added to the flow. Downstream, the tracer concentration is measured and used to

calculate flow-rate, based on a theoretical formula. Two techniques are the total-recovery method and the constant-rate injection method.

- Timed-gravimetric: The liquid is captured in a container for a specified period of time, then weighed using a mass or force measuring device such as a beam scale or load cell. A variation of this method uses a container with a known volume and a stopwatch to capture the flow and spot-check the flowrate. Timed-gravimetric methods give high accuracy, but are not suited to continuous flow measurement.

- Weirs and flumes: This common method uses a hydraulic structure such as a weir or flume, called a primary device. A primary device is a restriction placed in an open channel that has a known depth-to-flow relationship. Mathematical relationships or charts are used to correlate water depths with flowrates for different types and sizes of weirs and flumes.

- Area Velocity: The mean velocity of the flow is calculated at a cross-section, and this value is multiplied by the flow area. Flowrate Q is determined according to the continuity equation $Q = V \times A$.
  The area velocity method is used when it is not practical to install a weir or flume, and for temporary flow measurements. Examples include influx and infiltration studies and sewer flow monitoring.

- Manning formula: Proposed in 1889 by Robert Manning, an Irish civil engineer, and modified in the 1930s, the Manning formula calculates flow based on cross-sectional area, slope of the water surface, and roughness of the conduit. No primary device is required, but the method is less accurate than area velocity because flow velocity is calculated using assumed rather than measured values. The Manning formula is also called the slope-hydraulic radius method.