SELECTING A SUITABLE OPEN CHANNEL FLOWMETER

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SELECTION OF A SUITABLE FLOW MEASUREMENT TECHNOLOGY FOR OPEN CHANNELS

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ABSTRACT

This paper discusses a variety of methods used for the measurement of flow rates in open channels. It examines the principal of measuring flow using a primary device, or calibrated flow restriction, paired with a level sensor. The various types of level sensing techniques used including ultrasonic, bubbler and pressure transducer are explained and the installations most suited to each technique discussed.

The paper then examines the "Area Velocity Measuring Technique" which utilises a Doppler velocity probe paired with one of the standard level measuring techniques to measure flow in open channels which don't have a primary device located in them.

The paper closes with an examination of how a number of difficult applications may be overcome and how recent advances in flow measuring devices are helping to solve these applications and overcome other problems with existing systems.

1.0 INTRODUCTION

There are a variety of flow measurement technologies available for the determination of flow through an open channel. The various techniques can be divided into two broad categories.

2.0 DISCUSSION

2.1 Level Measurement techniques

This technique uses some form of pressure sensor or an ultrasonic sensor to determine the level of liquid as it passes through a primary device.

A primary device is a calibrated restriction, placed in an open channel, having a known head (depth or level) to flow relationship. In other words the flow rate through a primary device is proportional to the head in the primary device.

A secondary device is an open channel flow meter. The flow meter directly measures the head in a primary device and converts the reading into a flow rate based on the characteristics of that primary device. The primary and secondary devices work together as a team to provide an accurate measurement of flow in open channels. However even a perfect flow meter cannot make up for deficiencies in the installation of the primary device. The best primary devices typically have an uncertainty of +/- 5% with the average primary device having an uncertainty greater than 10%.

There is a direct relationship between the depth of the liquid and the flow rate. If a primary device which has a known flow to depth relationship is used then it is possible to determine the flowrate through that channel at any given point in time by knowing the depth of the liquid.

The depth or level of the effluent is determined either directly through the use of an ultrasonic sensor which sits above the surface of the effluent and focuses a beam of energy (sound) and records the amount of time it takes to leave the sensor, reflect off the effluent and return to the sensor.
As the speed of sound is known in air the distance between the effluent's surface and the sensor can easily be determined. If the distance between the sensor and the bottom of the channel is known then the difference between the two values is the depth of the effluent.

As all electronics have a certain response time it is essential that the ultrasonic beam is capable of travelling a certain distance before hitting the effluent surface. Most ultrasonic sensors require 15 - 25 cm clearance above the effluent surface. One supplier of flowmeters has recently designed a zero deadband sensor designed for use in pipes where level measurement to the top of the pipe is desired. The unique design patented by American Sigma allows the measurement to within 4 cm from the top of the pipe (the diameter of the sensor) by containing the entire deadband horizontally within the sensor body.

The other two commonly used methods are a pressure transducer which is mounted directly into the effluent stream and measures the pressure of the effluent above it. As in many instances depth is directly proportional to pressure then the depth of the effluent can be determined.

The pressure transducer is mounted in the flow stream at the proper location for head measurement. As the level in the channel increases and decreased, the pressure at the submerged probe varies proportionately. The pressure transducer converts the water pressure to a voltage which tis then used by the flowmeter to calculate the liquid level in the channel. After calculating the level, the flowmeter then converts the level reading to a flow rate based on the user defined characteristics of the primary device.

The other common method employed to measure depth is bubbler technology. A small air line is affixed in the flow stream. A small amount of air is continuously pushed through the outlet and bubbles are emitted slowly. The back pressure pushing against the bubbling air changes in proportion to the liquid level in the flow stream. This pressure is then determined by the flowmeter and converted to a level reading.

The selection of a suitable level measuring technology will depending on a variety of factors which include the size of the channel, flow properties of the channel and composition and physical properties of the effluent.

Table 1 highlights what level measuring technology should be used where in level measurement technology.

Table 1: ***Level measuring technology and applications.***

Application Suitability	**Standard Ultrasonic**	**Zero Deadband Ultrasonic**	**Submerged pressure**	**Bubbler**
Small round pipe 8”-10”	Not recommended	Excellent	Very good	Excellent
Medium round pipe 12-120”	Good	Excellent	Excellent	Excellent
Large Round Pipes>120”	Not recommended	Not recommended	Excellent	Not recommended

Application Suitability	**Standard Ultrasonic**	**Zero Deadband Ultrasonic**	**Submerged pressure**	**Bubbler**
Performance under adverse conditions				

Extreme flow turbulence	Good	Good	Excellent	Very Good
Standing wave	Not recommended	Not recommended	Excellent	Excellent
Very high flow velocity >3ms	Excellent	Excellent	Good	Not recommended
Occasional surcharge	Not recommended	Good	Excellent	Excellent
Frequent surcharge	Not recommended	Not recommended	Excellent	Excellent
High Turbulence	Not recommended	Not recommended	Excellent	Excellent
Liquid Temp. above 30 deg C	Excellent	Excellent	Not recommended	Excellent

Maintenance Requirements caused by adverse conditions				
High Grease Concentrations	None	None	Occasional	1 week
Nutrient rich flow	None	None	None	1 week
Silting	None	None	Occasional	Occasional
High ragging	None	None	Occasional	Occasional
Surcharge	Occasional	Occasional	None	None

In many instance submerged pressure sensors aren't recommended for applications where effluent temperature is highly variable. Variations in temperature can create up to a +/- 2.8% error in some sensors. American Sigma has overcome this with an error variation of +/-0.4% of reading.

In certain instances flowmeters will be used in a wide variety of applications and installation sites. It is essential that the flowmeter used for such a purpose has the ability to measure level in all applications. Naturally using the one level technique will not allow this. There is at least one flowmeter on the market which offers the ability to have three level measuring techniques on the one meter as well as an area velocity Doppler probe.

2.2 Area Velocity measurement techniques

In applications where a primary device is unavailable, inconvenient or greater accuracy is required the area and velocity of the stream can be determined directly.

If the cross sectional area of the stream and the velocity of the stream are known then the flow in the stream can be determined.

$$\text{Flow} = \text{Area x Velocity}$$

The cross sectional area is determine by measuring the level of the flow (as discussed above) and knowing the cross sectional area of the channel at any given depth. For instance in a square channel the cross sectional area will be equal to the width of the channel multiplied by the level of the effluent.

$$\text{Area} = \text{depth x width}$$

Once the cross sectional area of the stream is known the only other requirement is to determine the velocity of the stream.

There are two common means of determining velocity.

The first is to induce a magnetic field in the stream. Physics principles then dictate that as a conductor moves through a magnetic field a current is generated. The current generated is directly proportional to the velocity at which the conductor moves through the magnetic field. The conductor in this case is the effluent and the magnetic field is generated by a probe located in the effluent. The current generated is then measured by the flowmeter and the velocity determined.

The disadvantages with this technique is that the current generated is very small and thus the electronics must be very accurate and stable to accurately measure velocity. This means that the electromagnetic probe is dedicated to the flowmeter and can't be replaced in the field. The second disadvantage is that the electromagnetic sensor is easily upset by grease or oil in the effluent and this may create inaccuracies in the measurement of velocity.

The other widely used method to determine velocity in a stream uses a technique known as Doppler.

The Doppler effect is named after Christian Doppler (1803 - 1853) and describes the apparent change in the frequency of waves, such as sound or light, occurring when the source and the observer are in motion relative to one another, the frequency increases when the source and observer approach one another and decreasing when they move apart.

A Doppler flowmeter transmits high frequency sound waves into the flow stream. The sound waves reflect off particles in the flow stream and are reflected back to the velocity probe. The frequency of the returning sound waves is 'shifted' slightly either higher or lower(depending on the flow direction) than the original frequency. This is due to the movement of the particles in the flow stream speeding up or slowing down the frequency. The amount of frequency shift is proportional to the speed of the particles and is used by the flowmeter to calculate the velocity of the flow stream.

The frequency shift is proportional to three things - the original sound frequency, the speed of sound in the fluid and the speed of the moving objects. Doppler systems owe their drift free operation to the fact that a frequency, not a voltage, is being measured. In an analog system (such as an electromagnetic velocity probe) virtually every circuit component (in particular the probe) has a significant effect on the measurement drift of the system.

In a Doppler system only one component has any effect on the frequency being measured - the master oscillator. It is straightforward to construct this oscillator so that no significant drift (<0.01%) can be measured. The remaining components in the system (and again, in particular the probe) have no effect on measurement drift.

One of the disadvantages with some Doppler style flowmeter is that in clean effluents there may be insufficient particles to generate a return signal and thus a 'drop out' of the signal results. However the higher the Doppler frequency (strength) the greater the ability of the Doppler to detect particles in a clean stream.(frequency measurement is a squared function) For instance a Doppler which uses a 250 khz frequency will be a factor of 16 times less sensitive than a Doppler which uses a 1 MHZ frequency. Thus a 1 MHZ Doppler is actually capable of measuring flows in streams where there is less than 50 ppm of suspended solids.

Many area velocity flow meters require the velocity probe to be directly matched and calibrated to the flowmeter. In many instances a replacement probe needs to be calibrated to the flowmeter in a workshop environment. This is due to the precise impedance balancing of a bridge circuit. If it isn't matched precisely inaccuracies occur.

The Sigma velocity probe doesn't need precise matching because the probe is an independent device from the rest of the system and is controlled by the area velocity board. The crystals in the probe are highly stable and accurate devices and sufficient analog signal processing is done within the probe to allow interchangeability.

2.3 Installation and Set up Time

Another factor to consider when selecting an area velocity flow meter is the amount of time it takes to install it. Many area velocity flowmeters use a "reference based" system where one velocity measurement is made and then the pipe is profiled manually by the operator, this takes considerable time and introduces errors. However, there is at least one Doppler flowmeter which measures the spectrum of velocities in the entire flow profile. This eliminates the need to profile the pipe drastically reducing the setup time of the flowmeter. Furthermore, as manual profiling is no longer required the errors that are put in during profiling are eliminated.

Rapid installation can also be facilitated by the use of a single sensor which measures velocity and depth. Some flowmeters require the installation of up to three sensors to measure a single streams flowrate.

2.3 Difficult Applications

Most flowmeters on the market are more than capable of measuring flow in the easy applications ie where the channel is more than half full and levels aren't widely fluctuating and there is plenty of time for installation. Where many flowmeters have trouble are during storm events, in low flows and under high flow velocity rates.

Application 1 - Environment where effluent level is changing dramatically such as during a storm event.

In this type of environment the flowmeter must be able to respond quickly to changing flowrates. For instance the longer the response time the greater the likelihood that a flow peak may be missed. It is not rare to find area velocity flowmeters with a 2-5 minute response time. However as response time is a function of signal processing speed and algorithm efficiency, the faster the signal processing speed and the stronger the algorithm the quicker the response time.

The easiest way to determine the response time of a flowmeter is to remove it from a flow stream and measure the time to respond. There is at least one Doppler AV flowmeter available which has a response time typically better than 5 seconds.

Application 2 - Low flow levels

In applications where there is consistently low flow levels a significant amount of flow can be missed if the water level is less than 8 cm. This could cause significant inaccuracies especially in pipes with a 10 - 15 cm diameter (which are common). To overcome this problem some flowmeter manufacturers insert a fudge factors to ensure that there is at least some measurement of flow when the level is less than 8 cm. Other manufacturer overcome this problem through designing a very low profile probe. For instance the Sigma AV probe is able to measure flows in streams with a depth of less than 2.0 cm.

Application 3 - High Velocity flow rates

High velocity flow rates will have an effect on the accuracy of flow measurement unless compensation is used. As the stream is diverted slightly over the probe, the velocity of the stream across the probe increases, creating a local region of lower pressure. The degree to which the pressure is lower than undisturbed flow pressure is proportional to the velocity of the stream. In many cases this phenomenon is ignored by flowmeter manufacturers or in some cases the probes shape is designed to minimise this effect. American Sigma's embedded software applies a correction to the indicated level, based on the velocity of the stream at that instant, thereby cancelling the effective error.

2.5 Recent advances in flow measurement technology

There are a number of advances occurring with flowmeters.

These include increasing the Doppler frequency and thus its strength which results in its ability to be used in clean effluents. American Sigma currently have the highest frequency at 1 MHZ which facilitates measurement in effluents with > 50 ppm of suspended solids.

2.6 Communication

Flowmeters are becoming more advanced in their communication options. Many flowmeters are now available with integral modems and some are even capable of sending a status alarm over a phone line or to a pager. Modem speed is gradually increasing a 14.4 bps is available in at least one brand of flowmeters.

2.7 Probe Construction

The construction of velocity sensors is continually being examined in order to develop a probe which is resistant to wear and has fast response and high accuracy. American Sigma have pioneered the use of embedded circuitry in an epoxy probe which is exceptionally resistant to wear and intrusion of liquids.

2.8 Increased number of flow sensors

Some of American Sigma's flowmeters offer the ability to measure 3 different flows from the one flowmeter or the ability to have three different level sensing techniques in the one flowmeter.

2.9 Memory Size

The available memory in flowmeters is being increased with 512 kbytes available allowing up to 116,000 data points to be logged.

2.10 Battery life

The use of extremely low power electronics and improved battery design is allowing some flowmeters to be operated continuously for 1 year off the same battery with 15 minute averaging periods.

2.11 Multiple Sensors

Flowmeter manufacturers are examining ways of measuring other water quality parameters with their flowmeters. For instance one flowmeter on the market is now capable of measuring not only level and velocity but pH, ORP, temperature, conductivity, dissolved oxygen, rainfall and is also capable of logging an addition seven discrete analog inputs from external devices such as a turbidity meter.

3.0 CONCLUSION

This paper has examined a variety of different measurement techniques used for monitoring flow rates in open channels. It has highlighted some of the main sensors used and in which applications they are most suited. It has illustrated a few of the more difficult applications and has closed with an examination of recent advances in flow monitors.