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Ask Tom! Column

In Control - Considerations for Control Systems
Part Two: Flow Measurement

by Dan Capano, DTS, Inc

Flow is one of the most common process parameters to be measured. Flow measurement choices are numerous, and the application of the correct instrument can have far-reaching effects on system operation and budget. This month I will briefly explain the most common options for flow measurement. Each type of flowmeter is unique in the method used to measure flow. The variety of instruments available allows the application of an instrument with the best fit for a wide range of process fluids, environments and locations.

Nature of Flow

Flow is defined as the movement of a fluid. To measure flow rate is to measure the volume of fluid moving through or past a physical point at a given time.

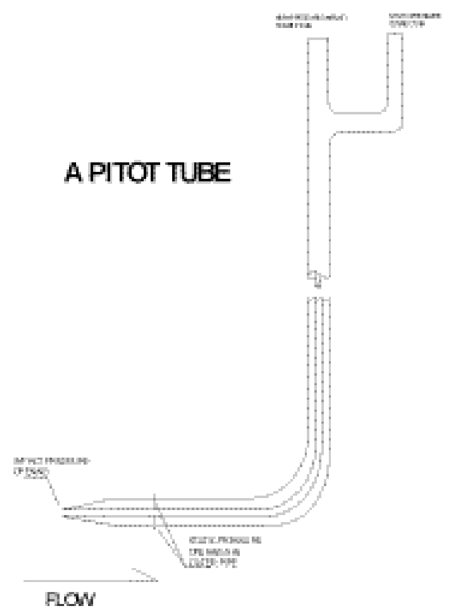
The flowmeters described below measure flow volumetrically, as opposed to Mass Flowmeters which measure the quantity of mass passing through or past a given point. It is desirable to continuously measure the rate of flow of a process stream to allow operators or engineers to determine the state of an operation or process. Flow rate is used to determine if a system is operating within capacity and to automate processes such as the addition of some chemical to the process stream. An example would be the addition of chlorine to plant effluent for disinfection. Monitoring of flow allows planners and engineers to properly assess needs and design systems of the proper capacity or production.

Different methods are used to measure flow. Each method was developed to provide accuracy with minimal process disturbance. Factors to consider when installing or replacing a flowmeter are:

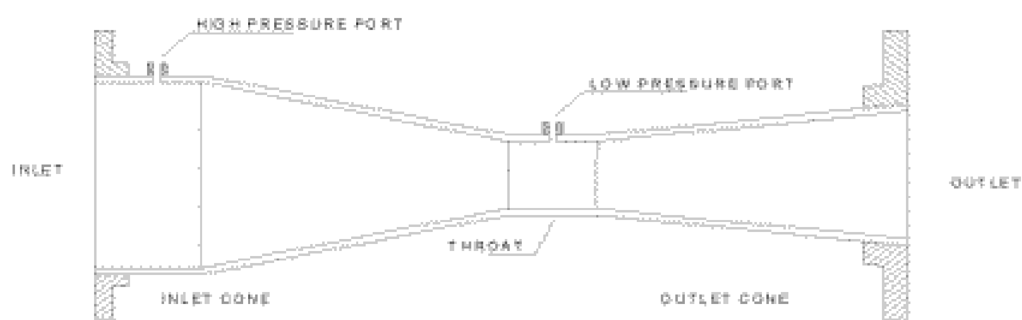
- **Maintenance:** Consider what demands the new device will place on your maintenance resources. If the device must be cleaned, adjusted, filled or overhauled, then adequate resources must be committed to maintain meter accuracy. Also, consider if a pipeline must be discharged or a process interrupted in order to repair or calibrate the instrument.
- **Proper matching:** Matching flowmeter to the process is crucial. If a process stream contains large amounts of solids or debris, restrictions or obstructions then an improperly applied flowmeter will eventually fail. If the meter material is incompatible with the process fluid, premature failure can also be expected. A failure of this type could also endanger personnel. Proper instrument enclosure selection protects personnel, equipment and facilities from damage
- **Power considerations:** Every installation is different. Remote locations may operate on low voltage loops or may not be electrified at all.
- **Cost:** Flowmeter cost varies directly with complexity for a given installation. Shop around. Don’t overlook bargains in the used equipment market.
- **Range and Accuracy:** Flowmeters are available in virtually any range. Accuracy is usually stated as of percentage of full scale. The term turndown ratio is used to describe the range over which a flowmeter will perform at its rated accuracy. A 10: turndown means that a flowmeter having a range of 0-100 GPM is accurate from about 10 GPM through maximum. Repeatability is a term used to describe the percentage of change of successive measurements.

Types of Flowmeters

Differential Pressure producers are a class of flowmeters used extensively. Flowmeters of this type rely on the development of a measurable differential pressure to function. Placing an obstruction at some point in the process stream will artificially produce a Differential Pressure (DP). The pressure before and after this obstruction is measured and compared; the flow rate is calculated from the resulting number. Obstructions in the line interfere with the flow of the process fluid and will cause a loss of system pressure. To maintain flow and pressure, energy in the form of increased flow must be added to the system. This is accomplished by increased pump or compressor cycles with a commensurate rise in energy consumption. It is desirable, in most cases, to minimize the effect of the obstruction, which is exhibited in loss of head in the system. Some devices produce more head loss than others; these are, in order of rising pressure drop:



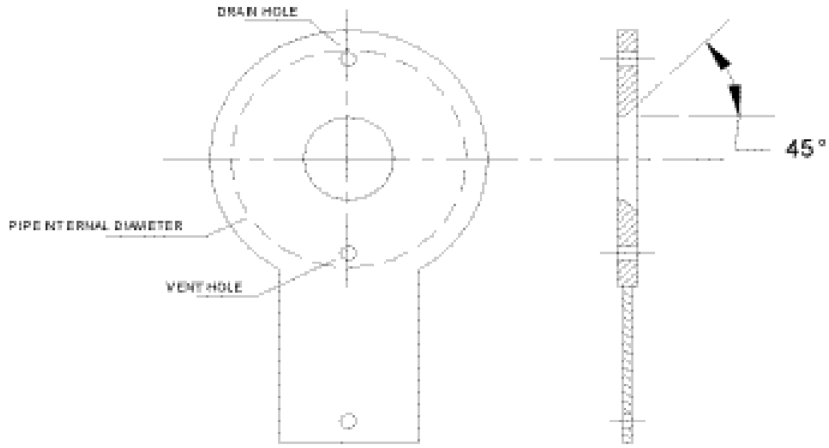
Pitot Tubes: These devices use small diameter concentric tubes to measure upstream and downstream pressures. The tubes are inserted into the stream with the high-pressure port facing upstream and the low measuring static pressure. The impact pressure of the process stream at the high-pressure tube produces a measurable rise in pressure relative to the static pressure measurement point(s). A very small target is presented to the moving fluid and the tube produces a negligible effect on the system pressure. These devices require 10-30 diameters of straight pipe upstream and 5-15 downstream to avoid the effects of turbulence on the meter. The tubes can become fouled and their use in other than clean gases or liquids is not recommended. While reasonably accurate over the middle range of the instrument, accuracy is limited at low flows.



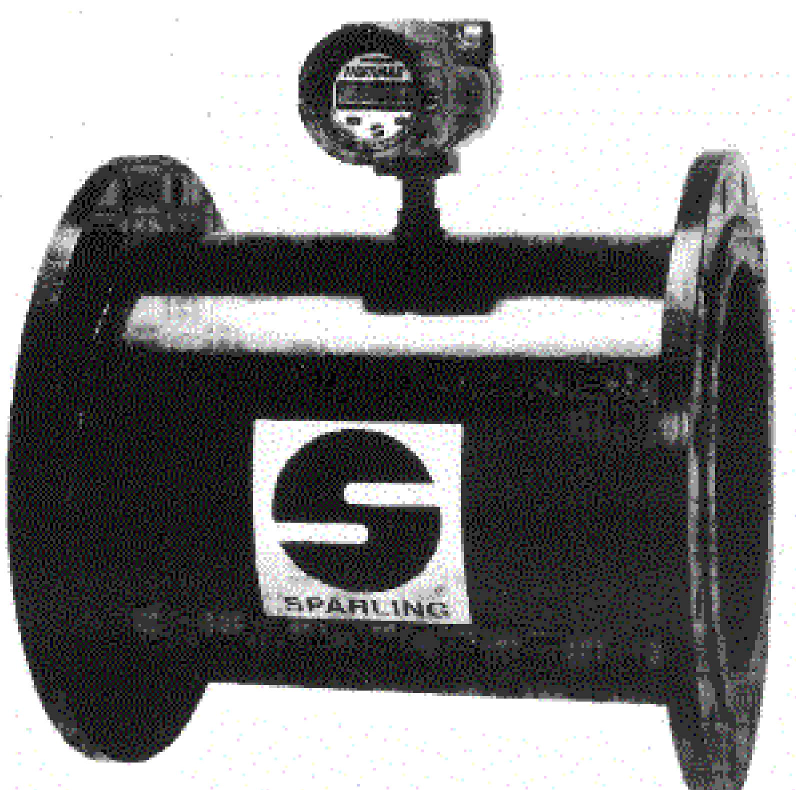
CLASSIC VENTURI TUBE

Venturi Tubes: These devices are inserted into the pipe and become part of the piping system. The upstream side of the device slowly tapers to a narrow throat. Downstream from the throat, the device flares out again, allowing near recovery of lost system pressure. Converging (upstream) angles are between 19 and 23 degrees, 21 degrees being the most common angle used. The diverging (downstream) angle is typically 7.5 degrees, but up to 15-degree divergence angles are used with some sacrifice to system pressure recovery. Venturis require up to ten pipe diameters of straight pipe upstream to avoid turbulence effects from the system. Downstream requirements are not critical to proper operation. This type of DP device presents a moderate head loss to the system and can be used for a wide variety of process fluids in both the liquid and gas phases. Venturis are maintenance free and are cost effective over a large range of flow. Most venturis are designed to return 90 % of lost pressure to the system.

Orifices: These devices employ a flat plate with a precisely ground orifice which may be concentric, eccentric or segmental. The orifice is usually mounted between two pipe flanges. Measurement ports may be integral to the flanges, or may be at some predetermined distance (diameters) upstream and downstream of the orifice. Requirements for straight pipe upstream vary with the ratio of the orifice diameter to the pipe diameter and can exceed fifty pipe diameters. Straight pipe requirements can be reduced with the use of straightening vanes or tubes. Orifices produce the greatest head loss, and are not suitable for slurries or dirty fluids and their use is limited in corrosive duty because of erosion of the orifice edge. Orifice flowmeters are used chiefly for high-pressure gas or liquid applications.



CONCENTRIC
ORIFICE PLATE

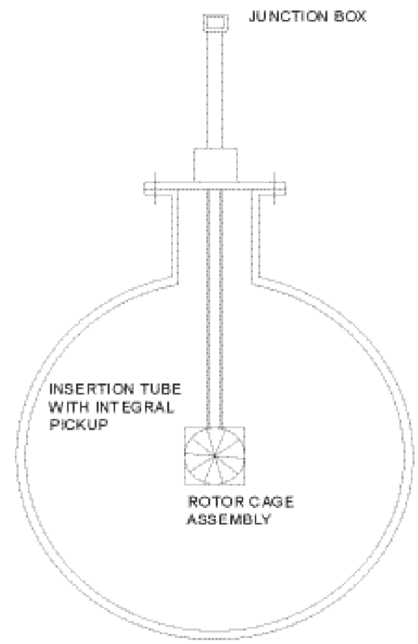


A TYPICAL MAGMETER (COURTESY SPARLING INSTRUMENTS, INC)

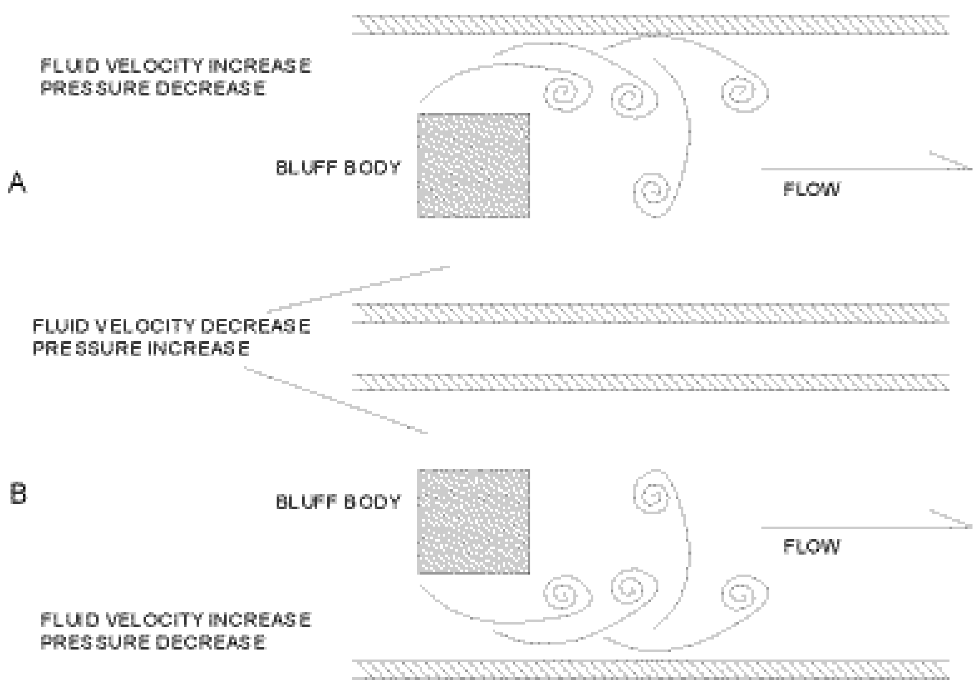
Magnetic Flowmeters: These devices rely on magnetism and Faraday's Law of Electromagnetic Induction to provide flow measurement with no obstruction and pressure loss. In it's simplest form, a magmeter is a spool piece (pipe with two flanges) wound with a coil of wire. Two or more electrodes are positioned on the insides of the pipe wall. If the coil is energized, a magnetic field will be developed in the tube. As a process fluid is passed through the tube, voltage is induced and passed to the electrodes. The level of induced voltage is directly proportional to the flow rate. Magmeters are always supplied as a "full-bore" device, meaning that the instrument measures the full diameter of the pipe.

The major disadvantage of this type of meter is the unavoidable process interruption required for meter repair or replacement. Magmeters require at least five pipe diameters upstream and three downstream. A Magmeter requires a full pipe to provide the best accuracy; if the meter electrodes are exposed or partially submerged, the meter will operate erratically, if at all. These meters are available in a wide range of sizes and liner materials and because there is no obstruction in the pipeline, cause no pressure drop in the system. A variety of process fluids and slurries can be accommodated. The meter can be configured as bi-directional models allowing flow measurement in both directions.

Turbine Meters: Turbine meters operate by placing a multi-bladed propeller into the process stream. The flow of liquid impinges upon the blades, causing it to rotate. A magnetic pickup senses this rotation; the speed at which the propeller rotates is directly proportional to flow rate. Turbine meters offer two types of installation: insertion and full-bore. Full bore meters are constructed similarly to the magmeters described above. Turbine meters can be rendered unusable by a poor installation. Turbulence at the meter resulting from installation close to bends will adversely affect meter operation; valves or other upstream disturbances will also cause erratic operation. Cavitation is another concern and will result in erratic operation and possibly damage the meter over a long period of time. The meter must be protected from damage by any debris and a screen may be required upstream for this purpose. Total pressure drop across turbine meters is typically in the range of 3-6 PSIG at full flow. Turbine meters require at least fifty diameters of straight pipe upstream in order to avoid this problem. In order to avoid this requirement, flow-straightening devices are used to reduce the requirement to a manageable ten diameters upstream and downstream. Turbine Meters may be used for clean liquids and gases and are available in bi-directional models allowing flow measurement in both directions.

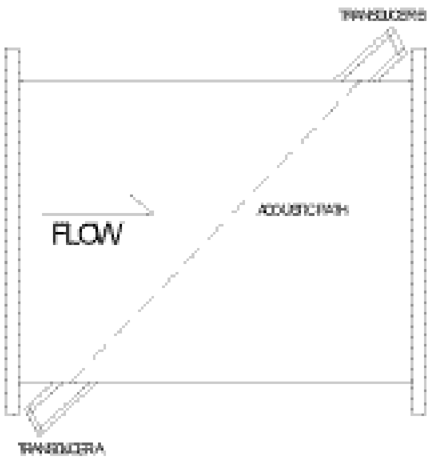


INSERTION TURBINE FLOWMETER SCHEMATIC



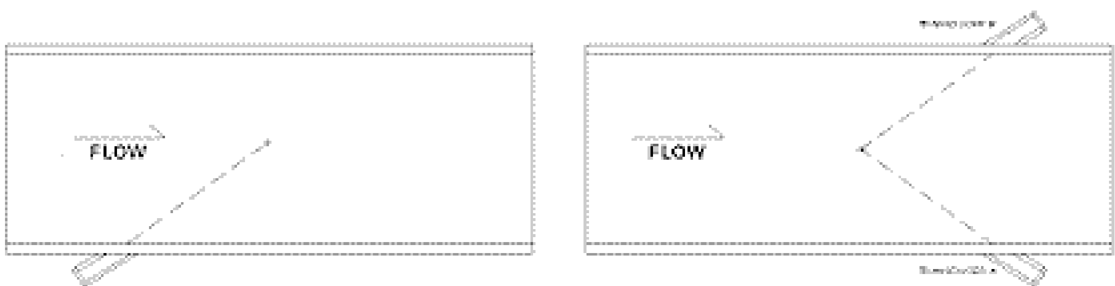
Vortex Flowmeters: These are devices that produce vortices within the meter body in order to measure flow rate. Two methods are used to develop and measure vortices. The first is Vortex Shedding. In this method, a “bluff body” is placed into the process stream. The impact of the fluid upon the bluff body causes shedding of vortices alternately from either side causing the pressure across the bluff body to alternate from high to low pressure. As a vortex forms on one side, fluid velocity increases, lowering pressure; the opposite side of the bluff body experiences a rise in pressure with a drop in fluid velocity. The frequency of vortex shedding is proportional to the fluid flow rate. Vortex shedders are used in all types of clean service for liquids and gases. Upstream pipe diameters vary with the meter, but range from 5 to 150 diameters upstream. As always, straightening vanes or tubes can be used to reduce this requirement. Downstream requirements are usually 5 diameters.

Vortex precession meters utilize spiral guide vanes to produce a controlled swirl in the process stream, causing a swirling vortex to form. As the vortex moves through the meter, it remains cohesive and presents a higher fluid velocity at a given point in the meter at a period proportional to the fluid flow rate. This change in velocity is sensed using thermistors or piezoelectric sensors. The amount of heat removed from a heated thermistor is measured. As heat is removed, the heater voltage changes and can be measured. The amount of heat removed is proportional to and dependent on the fluid flow rate. Because of the high tolerances required when machining the meter bodies, these meters are more expensive than other types of meters. Vortex flowmeters are comparable in accuracy to other types of meters, but are limited to use in clean fluids and gases.



TRANSIT TIME FLOWMETER

Ultrasonic flowmeters: These use ultrasonic energy to measure flow rate. Aside from open-channel flow measurement, which will be discussed below, two types of ultrasonic meters are in common use. The first type is known as a Transit Time Flowmeter and operates by measuring the time for an ultrasonic pulse to traverse a pipe section both with and against the process flow. The fluid flow adds and subtracts a velocity component to the transit times; these times are calculated and return a flow rate. This type of meter is available as a “clamp-on” where the transducers are clamped around an existing pipeline. Transit time meters are also available as “spool pieces” which are inserted into the line and contain integral transducers. Transit Time meters require a full pipe to operate correctly and must be installed with 10-20 straight pipe diameters upstream and 5 diameters downstream. Solids are tolerated by these devices, but bubbles in the process stream will cause erratic or unusable readings. In order to provide a more reliable signal, particularly in larger pipe diameters, multiple transducers with multiple acoustic paths are used. Bi-directional models are also available for flow measurement in either direction.



SINGLE TRANSDUCER

DOUBLE TRANSDUCER (A -> B)

DOPPLER FLOWMETER CONFIGURATIONS

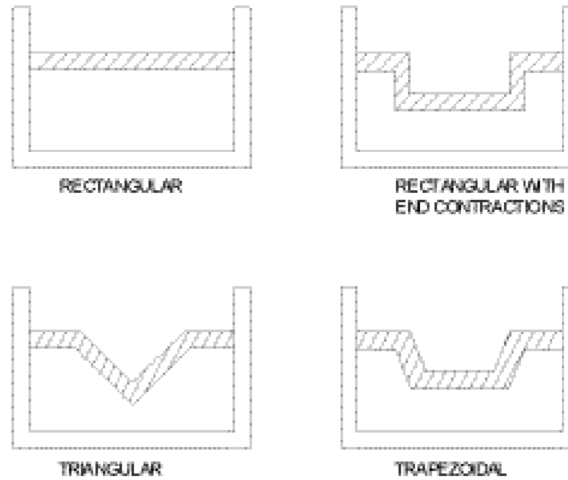
Doppler Flowmeters rely on the presence of bubbles and solids in the process stream in order to function properly. Most manufacturers will specify the lower limits of solids concentration or size required for the particular meter to operate. The device operates by bouncing an ultrasonic pulse off of a moving particle. The reflected pulse is shifted according to the Doppler principle. Another consideration for proper operation is the requirement that flow be sufficient to keep particles in suspension. Typically 10-20 straight pipe diameters are needed upstream with 5 diameters downstream. Transducers are mounted on the outside of the pipe and are available in one or two transducer models. Two transducer models “shoot” an ultrasonic pulse through the pipe against the flow.

Ultrasonic meters are relatively inexpensive and reasonably accurate. Proper installation is crucial because of the nature of the measurement technique. Improper alignment of the transducers on either type of instrument will result in almost certain headaches. This type of flowmeter allows measurement without process interruption, however, and allow portability.

Open Channel Flow Measurement

In open channel flow measurement, weirs and flumes are used to produce known and repeatable characteristics in the process stream. Weirs, flumes and other devices develop a liquid head that is used to measure flow rate. These devices are particularly useful when large flows are to be measured or where liquids are handled in open channels or in pipelines that are not ordinarily full. Flows from 100,00 GPM to the millions of gallons per day are measured using these devices.

Weirs are the simplest and most economical flow-measuring devices available. Basically, weirs are obstructions or dams placed across the channel containing openings or apertures of known geometry through which flows the liquid to be monitored. Weirs may be rectangular, trapezoidal (Cippoletti), “V” notch or a combination of these types. Head is measured as the rise in level of liquid in the pool upstream of the weir. V notch weirs are used for smaller flow rates than those handled by rectangular or trapezoidal weirs. All produce known characteristics in the process stream that can be measured to indicate flow rate. Weirs use staff gauges mounted on the side of the weir box to provide a measurement of head. Ultrasonic level instruments are commonly used to measure the rise in head. The use of a stilling well should be considered if foaming or excessive turbulence is encountered.



TYPES OF WEIRS

Flumes are slightly more complex devices. Flumes use complex geometries to form the process stream into a controlled flow that allows accurate and repeatable measurement over the range of the flume. The loss of head through a flume is about one-quarter that of a weir of equal capacity. Flumes have been around since the 1920’s. The most common flume is the Parshall Flume, named for Dr. R. L. Parshall, who developed it for use in irrigation. A Parshall Flume installed in a pre-fabricated manhole. Note the ultrasonic transducer over the stilling well on the left.

A Parshall Flume installed in a pre-fabricated manhole.
Note the ultrasonic transducer over the stilling well on the left.

The **Parshall flume** places a constriction on the stream and then drops the stream at the throat of the flume to produce a repeatable, cohesive surface to provide a flow measurement. The surface of the stream at the throat rises and falls linearly with the flow rate. A staff gauge is usually affixed to the inside surface of the flume for reference. A stilling well may also be provided, allowing the use of an additional electronic measuring device such as an ultrasonic or admittance type meter. Advantages of flumes are the ability to self-clean, low head loss and wide operating range. Several different type of flumes are in use, including:

- Palmer-Bowlus
- Leopold-Lagco
- Cutthroat Flume

Mass flowmeters, rota-meters and specialized flow instruments are not included in this discussion and will be explained in a future column. The reader is invited to pursue further reading on the subject of flow measurement. The Internet is a wealth of information on the subject. A good starting point is the bureau of reclamation's website, which features a full text version of their flow measurement manual. The Bureau's website is:

http://www.usbr.gov/wrrl/fmt/wmm/

Other useful references are ISCO, Inc.'s "Open Channel Flow Measurement Handbook". ISCO is located in Lincoln, NE. As always, I welcome any questions, comments or observations from readers.

Next month: Level Measurement Methods and Devices.

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Welcome to Ask Tom!, a monthly column by our resident water treatment guru, Tom Keenan of National Environmental Services Agency (NESA). Tom addresses the issues that bug you the most. And Tom knows!! With 35 years experience in providing environmental support services to public and private sector clients on a wide range of environmental issues.

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