



Technical Information

Magmeter Basics

A Technical Reference Guide

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Magmeter Basics

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Section 1

INTRODUCTION TO MAGNETIC FLOWMETERS

Magnetic flowmeters (magmeters) are designed to measure the flow of electrically conductive liquids in a closed pipe. They are volumetric flow measuring devices that have been commercially available since the mid 1950's. Sizes for the ABB Inc. magmeters range from 1/25 inch to 96 inches. This covers a flow range of about 0.003 to 750,000 gallons per minute. Early units were flanged devices that bolted up to adjacent pipe flanges. They were large, heavy, and expensive, but they offered several advantages over other flow meters available at that time.

The advantages include an obstructionless design, linear output, corrosion resistant wetted parts, and high accuracy. With the obstructionless design, there are no moving parts to wear and no pressure drop other than that offered by a section of pipe, the same size. The only wetted parts are the electrodes, insulating liner and ground ring, if needed. These can be selected for compatibility with the most corrosive of chemicals as well as to meet sanitary requirements for food applications such as milk and other dairy products. The output signal is linear and directly proportional to the flow velocity. Accuracy over a wide range (50 to 1) has evolved from 1% of full scale reading to 0.2% of rate as standard. The basic fundamentals of operation, selection, installation, and maintenance will be discussed in this bulletin.

OPERATING PRINCIPLE

Magnetic flowmeters operate on the principle of Faraday's law of electromagnetic induction. Without getting involved in the mathematics of this theory, we can simply state that:

$$E_s = \frac{1}{C} BVD \quad (\text{Equation 1})$$

In this equation,

- E_s = the induced electrode voltage
- B = The magnetic field density
- V = liquid velocity
- D = magmeter pipe diameter (conductor length)
- C = dimensionless constant

Equation 1 says, essentially, that a voltage is developed when a conductor is passed through a magnetic field. It further states that the voltage developed is proportional to the density of the magnetic field, the length of the conductor moving through the field. There is nothing in the equation about temperature, pressure, fluid density, or viscosity because the magmeter develops its signal independent of these parameters.

In the conventional construction of a magnetic flowmeter, coils are mounted on the outside of a nonmagnetic pipe section. The coils are typically powered by a pulsed DC signal. As current passes through the coils, a magnetic field is generated inside the pipe. Liquid passes through the pipe section perpendicular to the plane of the magnetic field. This is schematically illustrated in Figure 1-1.

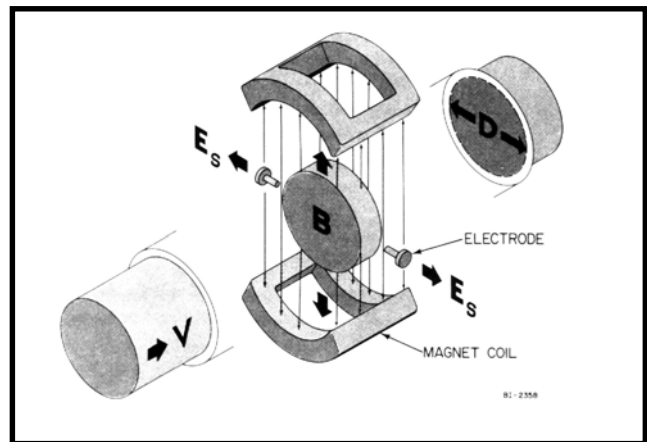


Figure 1-1. Magnetic Flowmeter Principle

As conductive liquid flows through the flow tube a voltage is generated which is proportional to the flow rate. The voltage is extracted through a pair of electrodes which are installed on opposite sides of the pipe. When the pipe section is constructed of a conductive material, such as stainless steel, it is lined with a nonconductive material to insulate the pipe from the electrodes and prevent the flow voltage from being dissipated into the pipe section.

The magnetic field density is fixed for each magmeter size. The length of the conductor is essentially the distance between the electrodes and is also fixed by meter size. This leaves velocity as the only variable in equation 1.

Consequently, it can be said that magmeters are velocity measuring devices. Note that the conductor length is not simply the straight line distance between the electrodes but the sum of an infinite number of conductors that make up the cross sectional area of pipe at the electrodes. All the velocities in this slice are summed to get an accurate flow measurement with minimal effects from flow profile. In addition, a coil design feature introduced in 1967 by ABB Inc. characterized the magnetic field to make the magmeter even less sensitive to flow profile problems. Prior to this, a magnetic field of uniform density was generated across the pipe and which extended for considerable distance up and downstream from the electrode plane. The uniform magnetic field design is still used by some manufacturers.

Liquid particles flowing through a magmeter do not all move at the same velocity and do not generate a voltage of the same magnitude in a uniform field. A signal generating coefficient must be applied which varies with the radial and axial displacement of the individual liquid particles from the electrodes. This is a geometric phenomenon that depends only upon the location of the liquid particles. Compensation for these variations can be achieved by shaping the coils so that the magnetic flux is greatest where the signal generating coefficient is lowest and vice versa. A graphic representation of the field reduces errors resulting from non-symmetrical flow patterns. Because of this, the magmeter rates very highly among the flow metering devices that are least affected by piping configurations. More about piping effects is discussed in Section 5 installation of Magnetic Flowmeters.

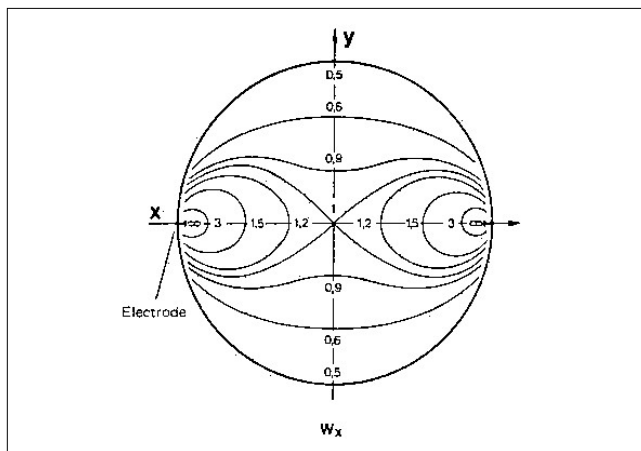


Figure 1-2 . Weighted Compensating Coefficients

THE SYSTEM

The voltage developed at the electrodes is an extremely low level signal. The actual voltage varies by model and type and from manufacturer to manufacturer.

For example, the flow signal could be on the order of 70 microvolts per foot per second. Most manufacturers have established an arbitrary maximum flow velocity for each size magmeter of about 30 feet per second. At 70 microvolts per foot per second, the maximum output would be 7.5 millivolts. By comparison, a 1.5 volt flashlight battery has 650 times the voltage that is developed in a magnetic flowmeter at its maximum output. In order to use this low level signal, a transmitter or signal converter is provided to amplify, condition, and present a more usable signal usually in the form of 4 to 20 (mA dc) which is the industry standard. A frequency output such as 0-1000 Hz or 0-10,000 Hz may be used in place of the current output. With the current output, an optional scaled frequency output is available for totalization. Remember that the output signal from the magmeter is strictly linear with the velocity of the flowing medium. Therefore, the transmitter output signal is 4 mA dc at zero flow and 20 mA dc at 100% flow with all points in between being directly proportional to flow velocity. In the case of the frequency output, zero flow is represented by 0 Hz and 100% by 1,000 Hz or a custom engineered frequency, depending upon which of these frequencies are available.

The combination of the magmeter (Primary) and the converter (Secondary) is considered a system. A typical system is illustrated in Figure 1-3. It shows a transmitter mounted remote from the magmeter. A converter is available mounted integral to the magmeter. One is not used without the other. However, converters are interchangeable with the same series magmeter without the need to go through any further calibration.

Newer systems may employ a EEPROM located in the converter, it carries all the calibration data of the primary. This EEPROM must stay with the primary in case the converter is replaced.

Finally, beyond EPROM technology, unique to ABB is its 'Fit and Flow' data storage technology, which resides within all FlowMaster systems. The need to match sensors and transmitters in the field, or re-plug EPROMs from old to new, replacement transmitters, is eliminated by employing Sensor Memory, which allows for onboard replication of data stored in the transmitter and sensor. On initial installation, the self-configuration sequence automatically replicates all calibration factors, meter size and serial numbers into the transmitter; as well as customer site-specific settings, allowing pertinent data to reside in two locations, the transmitter and sensor. This eliminates the opportunity for set-up errors and leads to increased speed of start-up. There is no longer a need to replace EPROMs upon electronic failure, or to program electronics with sensor data.

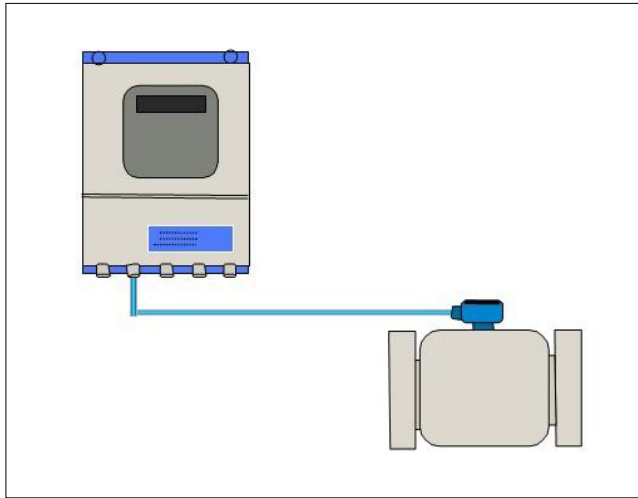


Figure 1-3. Magnetic Flowmeter System

RANGEABILITY

Rangeability here is defined as the ability of the magmeter system to provide an output that is within the specified accuracy from some upper limit to some lower limit. The upper limit can be the capacity of the magmeter or some lower range value. Although magmeters are designed to measure maximum flows of 30 feet per second and higher, most flows do not reach such high velocities. Typical maximum flows or upper range values are more on the order of 3 to 15 ft/sec. The user wants to see an output signal of 4 mA dc at zero flow and 20 mA dc at the actual maximum flow and not at the 30 ft/sec capacity of the meter. This is accomplished by setting the range in the converter.

LOW FLOW CUTOFF

Below 1 or 2 % of range setting, most magmeter systems have a cutoff built into the signal converter that drops the output to zero (4 mA dc) when the flow drops to that level. One reason for this is that at zero flow, there may be sufficient movement in the pipe, such as sloshing, or enough electrical noise in the system to produce an output signal even when there is no real flow in the system. The dropout feature can be removed completely for special applications that require flow to be measured at these low levels. It can also be elevated to higher values (as much as 10%). The microprocessor type converters can change the cut off amount by software.

EMPTY PIPE

Magnetic flowmeters are designed to measure conductive liquids and slurries only. If air or gas is mixed in the output becomes unpredictable. At this point, we will examine one of the problems that can occur at no flow. Some piping configurations by design allow the magmeter to drain empty during conditions of no flow. As liquid drains below the level of the electrodes, the converter sees a condition for which it was not designed to respond. In an empty pipe condition, it will respond but with an unpredictable, sporadic output. This can be an intolerable situation if these outputs end up as counts on a totalizer or DCS system.

The zero return feature was designed to correct this problem. It is included as a standard part of every magmeter converter. It is activated by an external dry contact such as the contact on a pump. Operation of the dry contact system requires running two wires from the transmitter to a pair of normally open contacts on the pump. When the pump stops, the contact closes, and the zero return is activated. When the zero return is activated, the converter output goes to its normal zero output. If the pump is not located near the transmitter or if the system operates on gravity feed the external contact may be located on a valve or flow switch.

In some installations, an external contact may be difficult or impractical to use.

This problem has been addressed in the microprocessor based transmitters, which have an **empty pipe detection circuit** that senses when the pipe drains empty. When this occurs, an internal zero return circuit is automatically activated, and the outputs go to zero. External wiring is not required to activate this system. It is all integral to the converter. Some initial on site calibration of this circuit may be required, but its operation is completely automatic.

Coils

In the conventional magmeter design, the magnet coils are mounted on the outside of the meter body as shown in Figure 1-4. This means that the magnetic field must pass through the body into the pipe area to develop the flow signal. Consequently, the meter body must be constructed of a magnetically non-permeable material. If the body is metal it is generally made of 304 stainless steel with strict requirements regarding the magnetic properties of the material. If the body is of a nonmetal insulator material then magnetic permeability is not a concern nor is insulation of the body from the electrode. Plastic, fiberglass, and ceramic are examples of insulator materials that have been used to construct magmeter bodies.

Electrodes

Electrodes typically are made of some type of metal. They are installed through the meter body and are in contact with the process liquid. If the meter body is also made of a metal it must be insulated from the electrode. This is done by installing a liner that goes between the body and the electrode to prevent the flow signal from being shorted to the body.

Electrodes are available in a wide assortment of materials. Included in that assortment are 316 stainless steel, Hastelloy B, Hastelloy C, titanium, tantalum, zirconium and platinum. Tantalum and platinum are the most chemically compatible and the most expensive. A rule of thumb for selecting electrodes is to pick the lowest cost material that does the job.

Materials of Construction

The survival of magnetic flowmeter in a given application depends primarily on the proper material selection of liner, and electrode and grounding ring (if needed). These are the only parts of the magmeter that are in contact with the process. Excessive wear to these parts could cause the meter to cease functioning and result in damage to other parts as well. The principle factors to consider when making liner and electrode material selections are the chemical makeup, operating temperature, % concentration, and abrasive characteristics of the process. In the majority of applications, the concern is for the affect of these three process parameters on the liner and electrodes. In some applications, however, the process itself could be affected by contact with the liner or electrode materials. This is especially true for sanitary food processes. The selected materials could be acceptable based upon chemical, temperature, and abrasive characteristics of the process but might be unacceptable because they could contaminate the process. In addition, some materials act as a catalyst to the process.

For example, platinum, which is perhaps the most inert of all electrode materials accelerates decomposition of hydrogen peroxide. A guide for the selection of liner, electrode and gasket materials is provided in this document.

Cleaning

The manner in which the process lines are cleaned must not be overlooked. Liner and electrode materials must be compatible with the cleaning materials as well as process materials. For example, tantalum is an excellent electrode material for use in a ferric chloride process. However, if sodium hydroxide (caustic) were used to clean this same line the electrode would be destroyed. How long it would take for this to happen depends upon the concentration, temperature and the length of time the cleaning process requires. Steam cleaning should be limited to about 300°F (149°C) and to high temperature liners such as Teflon. Rapid cooling of the process lines after steam cleaning could result in the creation of a partial vacuum in the line, causing ceramic liners to crack, or a Teflon liner to collapse. Installation of a vacuum break in the process line is recommended when this condition exists.

Selection

There are many publications that list the compatibility of the various liner and electrode materials with chemical processes. Two references used frequently by this author are "Corrosion Data Survey" by the National Association of Corrosion Engineers and "Handbook of Corrosion Resistant Piping" by Philip A. Schweitzer, P.E. Using these and similar references, Section 4 lists liner and electrode materials and compatibility with various processes. The recommendations are for reference only and do not constitute a guarantee regarding compatibility of material and process. Selections should be made on the basis of compatibility of specific materials with specific chemicals over the % concentration and temperature range expected in the process and cleaning cycle of the applications.

Materials should not be selected on the basis of pH only. For example, heavily chlorinated water can have a low pH (acidic) or high pH (alkaline) depending upon whether the source of chlorine is chlorine gas dissolved in water or sodium hypochlorite in water. Not all material combinations are compatible with the full range of process conditions. At low pH, chlorine gas can permeate a Teflon liner and damage the meter housing. At high pH, several electrode materials are subject to attack.

THE MAGNETIC FIELD

As was pointed out earlier, the strength of the magnetic field is fixed by size. 1 tells us that as the meter size increases, the magnetic field strength must decrease proportionately in order to generate the same voltage for a given change in flow velocity. This simplifies the job of the transmitter to recognize the flow velocity change and to output the same value for that change regardless of the size magmeter. There are two basic methods being used to excite the magnetic field. They are AC and pulsed DC excitation. These are graphically illustrated in Figure 1-13. AC excitation was used in the earliest designs and is still in use today on a limited basis. The pulsed DC excitation was introduced in 1974 and is currently the most used method for coil excitation in magmeters.

AC Excitation

In AC excitation, line voltage (typically 120 or 240 volts at 50 or 60 herz) is applied directly to the magnet coils or is supplied by the converter, as in our 50SM1000 Model. This generates a magnetic field in the meter body that varies in strength with the frequency of the applied voltage. The variation follows the pattern of a sine wave as shown in Figure 1-13. This means that the flow signal will also look like a sine wave. The amplitude of the sine wave will be proportional to flow velocity. This system produces an accurate, reliable, fast responding magmeter but it has its drawbacks in some applications. Faraday's law says that a conductor passing through a magnetic field will generate a voltage. This law also states that if a stationary conductor is located in a changing magnetic field a voltage will be developed. This is what happens in a magnetic flowmeter. The flow signal is picked up by electrodes and is passed through wires connected between the electrodes and the signal converter. These wires are located within the magnetic field that was generated to develop a flow signal. The changing magnetic field induces a voltage in the electrode loop. Consequently, the converter sees two signals. One of these is the flow signal, and the other (created by the changing magnetic field) we will call noise. As far as we are concerned, anything that is not a flow signal is noise, and a way must be found to separate the two.

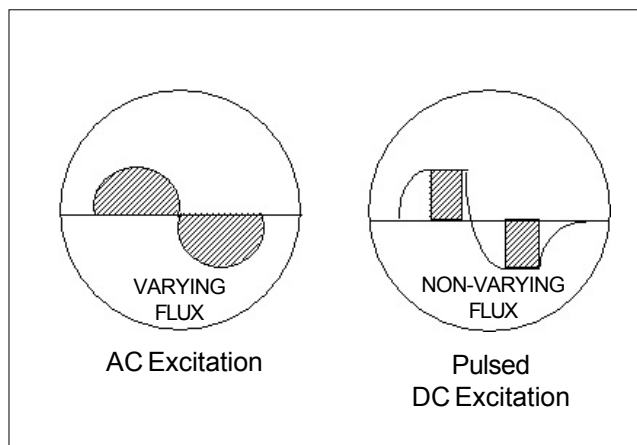


Figure 1-4. Coil Excitation

AC voltages can be in phase or out of phase with each other. If the signals are out of phase they can be separated with circuitry in the electronics. The method of eliminating noise has been referred to as quadrature rejection, and it does the job well for those signals that are out of phase with each other. However, the noise voltages that are in phase with each other or are of the exact opposite phase must be eliminated.

Zero Adjust

A full pipe, no flow condition could provide the information necessary to eliminate the in phase noise. This requires setting the magmeter up so that it is full of the process liquid; there is no liquid movement through the meter, and power is applied to the system. Under these conditions, the output of the converter should be zero (4 mA dc in our example). If the output is greater than or less than 4 mA dc there is noise present, and the transmitter is adjusted so that the output is 4 mA dc. This procedure constitutes the zero adjust, and it is required during initial start-up of any AC type magnetic flowmeter. There are several ways that the zero adjustment is made. In some systems, a current meter is required to be connected to the output of the transmitter so that the zero can be adjusted until the meter reads the proper value. A simpler system used is a "zero adjust" parameter in the software. Adjustment is simple -- just achieve a full pipe at no flow, and initiate the zero adjust with a push of a button. The converter automatically cancels the noise.

In many applications, no further adjustments are necessary. However, sometimes external inductive signals are injected into the electrode loop from inductive motors located near the magmeter. As the motor is turned on and off the influences on the electrode loop change and so does the zero. Relocating the magmeter or shielding it could be a solution. A more common and more serious problem is electrode coating. Process particles deposited on the electrodes will cause the zero to shift. This is the major cause of zero shift in AC type magmeters.

Pulsed DC Excitation

In the pulsed DC type magmeter, line voltage is still the basic source of power. But instead of being applied directly to the coils, it is first applied to a magnet driver circuit. This circuit sends low frequency pulses to the coils to generate the magnetic field. The frequency of these pulses in pulsed DC systems are approx. 7.5, 15, and 30 Hz.

The main reason for developing the pulsed DC system was to eliminate the zero shift problem. That goal was achieved. To understand how this was done, start by looking at the drawing in Figure 1-13. This drawing shows that the magnetic field goes through a period of time when the strength is varying, and then it reaches a period of time when the field strength remains constant. During the time that the field is changing noise is induced into the electrode loop. During the time that the field strength remains constant, noise is not injected into the loop. Remember that it takes a changing magnetic field to induce a voltage in a stationary conductor such as the electrode lead. The key to eliminating zero shift is to take the flow measurement during the time that the magnetic field is not changing. At this time, only the flow signal is present because the major source of the zero shift, a changing magnetic field, has been isolated from the flow signal. Zero shift is, therefore, essentially a problem that is associated with the AC type magmeter where the magnetic field is constantly changing during measurement of the flow signal.

The virtues of the methods used to create a pulsed DC magnetic field may be extolled in literature of the various manufacturers. They imply that one system may establish a more stable zero than another. The fact of the matter is that they all work. The system that operates the coils at a lower frequency than the other tends to be more stable. For example, a pulsed DC system operating at 7.5 Hz is more zero stable than a system operated at 30 Hz. The advantages of higher coil operating frequencies is discussed later.

Power Consumption

An additional feature of the pulsed DC system is low power consumption. AC type magmeters consume considerably more power than do the pulsed DC type. In the AC type, power consumption is pretty much a function of size, and sizes larger than 4 inch could require from 250 to 1000 volt amps. Today's pulsed DC systems require on the order of 15 to 30 volt amps regardless of size. Because of the reduced power consumption, the pulsed DC system can be powered by 24 volts DC.

Accuracy

Pulsed DC excitation is somewhat more accurate than AC excitation for most applications. If zero shift is a problem then the long term accuracy would be better in the pulsed DC system. Most of the new transmitter development that results from changing technology is going into the pulsed DC units. This may provide some overall improvement in the system accuracy. The standard accuracy is 1/2% of rate on frequency outputs of pulsed DC units. Optional 1/4% of rate accuracy is possible over a limited rangeability.

AC VERSUS PULSED DC

Although the pulsed DC method of magnetic field generation has become the predominant method, it has not replaced the AC method entirely. Each system has advantages over the other, but the pulsed DC system is being improved and is gradually acquiring the advantages of both systems. Basically, the pulsed DC system is superior to the AC system in terms of zero stability, and the AC system is superior in applications where process generated noise is present.

Electrode Coating

One of the most common process problems encountered by the magmeter is electrode coating. Coatings are particles that attach themselves to the pipe wall, grounding devices, the liner, and electrodes. The coating material can have a higher conductivity, a lower conductivity, or the same conductivity as the process as a whole. Very heavy coatings that significantly change the diameter of the magmeter and the pipe cause errors due to increased velocity and reduced area at the electrodes. This type coating is not the subject of this discussion because it is more of a piping problem than it is a magmeter problem. We are concerned with the thin coatings that result in span and zero shifts. Thin coatings that are of the same conductivity as the overall process conductivity have no noticeable effect on the output signal. The effects of electrode coating is discussed in detail in Section 6.

Speed of Response and Recovery

Speed of response is the time it takes for the converter output to show that a change in flow has occurred. It is normally expressed as the time it takes to show a 100% change in flow. For the AC system, this is about one second. Until 1983, the response time for the pulsed DC system was about 4 seconds. In 1983, it became about one second for some pulsed DC systems. Today, pulsed DC response time can be less than one second which approaches the speed of a turbine meter. This is important for batching operations where the batch time is extremely short. In some applications, the batch time can be as short as several seconds.

Speed of recovery is the time it takes for the magmeter to recover from an empty pipe condition and produce a normal flow signal. Unpredictable outputs that occur during empty pipe conditions were discussed earlier. When the magmeter is filled with liquid from an empty pipe condition, the unpredictable output continues until the transmitter has time to recover. This recovery time is one second for the AC system and microprocessor based pulsed DC systems.

Process Generated Noise is a phenomenon associated with the pulsed DC system that appears in some slurry processes and is the result of particles in the process impinging upon the electrodes. It is manifested as noise in the output signal. In severe cases, it can cause the output to fluctuate as much as 60% above and below the true flow signal. In hard slurries such as coal, phosphate, and sewage containing grit, the noise developed is proportional to the size of the solids in the slurry, the hardness of the solids, the amount of solids, and the flow velocity. Paper stocks are more complicated than the hard slurry, and there is less understood about them than in the less complex hard slurries. The chemical additives found in various paper stocks make it difficult to predict accurately whether or not noise will be a problem in the application. Generally speaking, paper stocks with less than 4% consistency should not produce sufficient noise to adversely affect the output signal. In addition, chemicals added to any process results in nonhomogeneous conductivities. This means that pockets of different conductivity are present in the process. If the chemical is added upstream of the magmeter and the pockets do not combine to form a relatively constant conductivity a noisy output can be expected.

Over the years, three solutions have been developed to solve the noise problem. Each has been partially to fully successful depending upon the severity of the problem. An early solution was a hard electrode tip made from a material such as tungsten carbide. This reduced the level of process generated noise significantly. It was a satisfactory solution to many slurry processes. Another solution increased the magnet coil operating frequency. It was discovered that doubling the coil frequency reduced the noise level by about half. This is the main reason that coil frequencies have gone from 3 3/4 Hz to 7.5 Hz to 15 Hz and now to 25 Hz. This coupled with the hardened electrode tip was the solution to some of the processes that were noisy with the hardened electrode alone. Finally, a noise reduction function was developed for the microprocessor based transmitter. This, coupled with the first two solutions, provides an effective solution for most process generated noise. The noise reduction feature is covered in more detail later.

CONDUCTIVITY

The first parameter to consider in deciding whether or not to use a magnetic flowmeter is conductivity. Does the process liquid have sufficient conductivity to meet the minimum requirement as a conductor? The requirement varies from manufacturer to manufacturer and from magmeter type to magmeter type. The conductivity unit of measure is microsiemens/cm or micromhos/cm which are the same in terms of actual value. Until recently the term micromho was used exclusively, but today the word siemen is used regularly in place of mho. The word mho is ohm spelled backwards. The ohm and the mho are reciprocals, hence the use of these terms to indicate resistance or conductivity. You may see either mhos or siemens used to denote conductivity.

The standard minimum conductivity level has been 5 microsiemens/cm. There are also some magmeters that require a minimum of 20 microsiemens/cm. The lowest conductivity limit for most DC coil excited meters is 5 microsiemens/cm. The electrodeless type magmeter will function in some processes with conductivity as low as 0.05 microsiemens/cm. All applications involving conductivities below 5 microsiemens/cm should be discussed with factory applications personnel.

The actual conductivity of many liquids can be found in Section 2. If the information is not available, a conductivity test can be conducted on site or at our factory. The test must be conducted at the normal process temperature because temperature has an effect on the conductivity. When the process temperature dictates that the test sample be heated or if the liquid is hazardous, testing should be conducted on site. Shipping and disposing of any sample must be done according to OSHA standards. Consequently, any testing is best carried out on site.

A magmeter that is used on a relatively low conductivity (5 microsiemen/cm) process one day can be used on a high conductivity (1000 microsiemens/cm) the next day with no change in calibration. Why is that? Conductivity is the reciprocal of resistance. Therefore, as the conductivity of the process drops, the resistance (impedance) of the process increases. This creates a condition similar to that of electrode coating which results in signal loss. We can substitute the impedance of the process for the impedance of the electrode coating and look at this as an electrical series circuit where R_c is the impedance of the transmitter and R_p is the impedance of the process. See Figure 1-5.

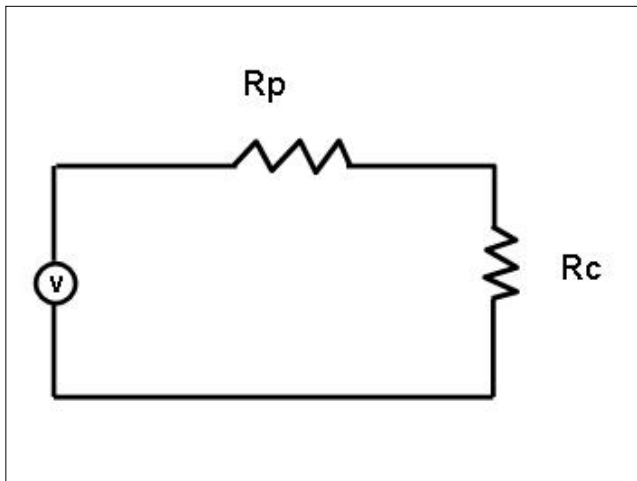


Figure 1-5. Equivalent Impedance Circuit

In an electrical series circuit, the sum of the voltage drops around the circuit is equal to the applied voltage. In this example, the applied voltage is the flow signal voltage that is generated by the process passing through the magnetic field. The voltage drops are a ratio of the impedance of the transmitter and the impedance of the process.

$$V_{\text{total}} = V(R_c) + V(R_p)$$

$$\% \text{ signal loss} = R_p / (R_c + R_p) \times 100 \quad (\text{Equation 2})$$

Consider two conductivity values - one of 1 microsiemen/cm and the other of 1000 microsiemens/cm. All we have to do is convert conductivity to impedance. First, convert microsiemens to siemens. A siemen (mho) is one million microsiemens (micromhos). Therefore, a microsiemen is one millionth of a siemen (0.000001 siemen) and 1000 microsiemens is 0.001000 (0.001) siemens. Divide the number one by each of these values and substitute that number for R_c in equation 2 and you will get the % span shift for each of these conductivities. Using 10^{10} as the transmitter input impedance, we calculate the following:

For 1000 microsiemens/cm, we get % error = $10^3 / (10^3 + 10^{10}) \times 100 = 0.00001\%$

It is clear from the calculation that signal loss is insignificant and that at higher conductivities the loss is practically nonexistent.

Low Conductivity

There are special design magmeters that allow them to measure process flow where the conductivities are well below 5 microsiemens/cm. As the conductivity level drops below five microsiemens/cm, electrical noise becomes a problem. This is manifested as an oscillating output signal.

This is manifested as an oscillating output signal. The amplitude of the noise is proportional to the flow velocity and inversely proportional to conductivity and viscosity. So, as the velocity increases, the amount of noise increases. Consequently, low conductivity magmeters should be sized so that max flow is about 3 feet per second. On the other hand, as either the conductivity or the viscosity drops, the amount of noise will increase.

Normally we are not concerned with the viscosity of process where magmeters are concerned. In fact, it still is not a factor in the development of the flow signal. But it does affect the amount of noise that is present in the process, and this could make the flow measurement extremely difficult or even impossible.

Perhaps the most difficult of the low conductivity processes is deionized water. Water conductivities vary widely. Well water can be in the neighborhood of 80 microsiemens/cm, while deionized water can be as low as 0.04 microsiemens/cm. Viscosity does not get much lower than deionized water, so we have a worst condition for noise if we make a flow measurement with a magmeter. Depending upon the amount of noise, it could be overcome by adding smoothing (damping) to the output signal. This slows down the response of the transmitter to flow changes, but it can reduce the noise in the output signal to a usable level.

THE TRANSMITTER

Up to this point, our discussion has been devoted almost exclusively to the primary sensing element of the magmeter system. It was mentioned that the low level signal developed by this primary element had to be conditioned by a transmitter and presented in usable form such as 4-20 mA dc or a scaled frequency of 0-1000 Hz, or some other value. The early transmitters did just that and very little more. The transmitter of today is a highly sophisticated device with a wide variety of features that simplify operator checks and adjustments and facilitate interface with computerized control systems.

Basic Transmitter Outputs

We have already said that the basic transmitter receives the signal from the magmeter and produces a typical 4-20 mA dc output signal that will be compatible with the input of one or more receiving devices such as an indicator, recorder, controller, or computer. These devices typically have input impedances of 250 ohms. The transmitter current output can operate into 0 to 750 ohms for Model 50XM1000. This means that the number of devices that can be driven by the transmitter is limited to the number of receivers whose total impedance does not exceed 750 Ohms. This is normally not a problem.

However, an application could require that one transmitter operate four receivers having 250 ohms input impedance each for a total of 1000 ohms. The transmitter with 0 to 750 ohms output driving current will not drive these four receivers. An additional device such as a current to current converter might be required to make the system functional. If the output is frequency rather than current it is used as input to a digital device such as a computer or totalizer. The input requirements of the receiving device must be compared with the output specifications of the transmitter to insure compatibility between the two.

Output Options

In addition to the standard analog output, many converters have an optional frequency output that can be scaled into engineering units. This output can be an active pulse such as 24 V dc to drive a counter directly as in the 50XM1000. It can also be a passive output such as an opto coupled transistor that does not supply a voltage to drive the receiving device as in the 10DX4311 or 10D1475Y. Counters and other receivers that work with passive input devices have an internal power source or use an external power supply to furnish the necessary drive voltage. Both types of frequency output can be scaled to engineering units so that the pulse represents the engineering value directly based upon the maximum range setting. For example, one pulse could represent one gallon, and the range setting could be 200 gpm, 300 gpm, or some other maximum value.

Enclosures

All remote mounted converters are enclosed in a field mount housing that carries an environmental rating of NEMA 4X and can be mounted on a wall or pipe near the magmeter or in a room some distance away. The distance for an AC system is about 50 ft, and the pulsed DC system is about 500 ft. Check the individual specifications for details. 50XM1000 transmitters can be mounted integral to the magmeter. This location of the transmitter reduces installation costs and is quite popular where flow parameters do not change over long periods of time. However, all controls and adjustments are located in the transmitter. If flow ranges or scaling requirements change frequently it might be wise to locate the transmitter in a place where these adjustments can easily be reached. This is especially important if the magmeter is located in a pit, high above ground level, or some other area that is difficult to access. In addition, process conditions can dictate that the transmitter be mounted remote from the magmeter. Excessive pipe vibration and high process temperature could dictate that the transmitter be located in a less hostile environment. Also, if the magmeter is located in a pit that could become flooded it is necessary to remote mount the transmitter in a dry location.

Readouts

There is a multitude of information available on the readouts of today's microprocessor based converters. The XE and 50XM1000 converter comes standard with a backlit 2 line - by 16 character LCD. The information available includes rate-90, rate-engineering units, tag number, totalizer forward, reverse or difference, 4-20 mA, flow direction and diagnostics for troubleshooting. The display is shown in Figure 1-6. There are two drawbacks to the liquid crystal displays. One is the temperature limits beyond which the display will fade out or freeze up. The operating range of the 50XM1000 display is 14 to +122°F (-10 to 50°C). This display will not be damaged if the temperature does not exceed -13 to 140°F (-25 to 60°C). Displays that have faded or frozen up will show updated information when temperatures return to the operating limits of the display. The second drawback is readability. Most liquid crystal displays require some light to make them readable. However the XE and 50XM1000 are supplied with back lighting. These displays are readable even in a darkened room.

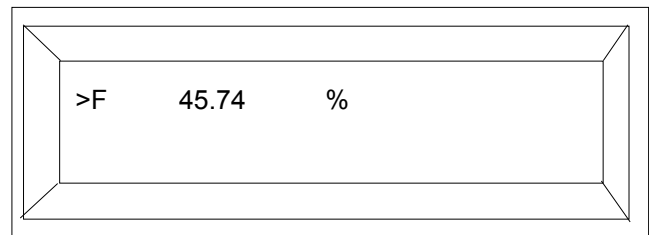


Figure 1-6. Digital Indicator/Totalizer Display

Batching

The size limitation of the transmitter precludes the integral mounting of batching type totalizers. This totalizer is designed to provide a contact closure output after a preset number of counts. The contact closure is then used to perform some function in connection with the process. It could be used to stop a pump or close a valve either fully or partially. If the application requires moving a specific quantity from one point to another (batching) the presettable totalizer provides a simple way to do the job inexpensively.

These totalizers are available as electromechanical (requires live voltage to operate) as well as light emitting diode or liquid crystal types that can operate with a contact closure or opto coupled input. They are larger than the standard totalizer, and are normally available as panel or desk mount devices.

The Microprocessor Based Transmitter

The microprocessor based transmitter became available in 1983. It really deserves a separate section from the conventional transmitter, so it will be covered here. Nearly every magmeter manufacturer now offers this type either as the standard or as an optional transmitter. Micro electronics make it possible for this type of transmitter to offer a lot of "bells and whistles," but it has the potential for some truly operational features that make it very operator friendly and very functional. Unfortunately, there is a very wide interpretation of what constitutes a microprocessor based transmitter. Do not assume that the word "microprocessor" in the transmitter specification means that it is equal to other microprocessor based transmitters. This section will be devoted to defining the features that are desirable as minimum standard requirements for a microprocessor based transmitter and are included among the many features in the XE and 50XM1000 transmitters.

Memory

Data stored in memory of the transmitter is not lost when power is removed from the system. Some transmitters use a battery back up, while others, including ABB Inc., use a type of EEPROM that does not require battery back up to retain memory for as long as ten years.

Configuration

The microprocessor should not require any programming knowledge on the part of the operator. What the operator does is properly called configuring. This simply requires that certain known values be entered into memory by use of push buttons or a numerical key pad. Calculations should not be required of the operator for such parameters as range settings or totalizer scaling factors. This should all be done by the computer in the transmitter.

The microprocessor based transmitter has what can be classified as two operating modes. One is the "on line" mode where data is monitored, stored in memory and displayed on a readout device. The other is the "configuration" mode where the various parameters such as range, damping, scaling, and engineering units can be changed. **When the configuration mode is entered, the on line functions should continue without interruption.**

There are microprocessor based transmitters that "freeze" the data at the last known value when the configuration mode is entered and some that drop the output signal to zero. The XE and 50XM1000 transmitters continually update information and transmit an output that accurately reflects changes in flow when the transmitter is in the configuration mode. Specifications should clearly state that the output signal and new data is constantly updated during configuration.

Programming

The display in the microprocessor based converter not only transmits flowrate, total and diagnostics it also is used to configure the parameters associated with a particular application. For example, selection and change of parameters is done from a menu. 50XM1000 display with push buttons is shown in Figure 1-16. The top line of the display shows instantaneous flow rate in percent of the full scale range setting. This can be changed to direct reading flow rate by entering the configuration mode and selecting it from a menu. In this unit, the configuration mode is entered by pressing the third push-button from the left marked C/CE. The other two push-buttons are used to step through the menus and to enter or change parameters. Escape from the configuration mode is made by pressing C/CE again. The unit will return to the monitoring mode automatically if no changes to the data base are made for a period of about 20 seconds. The bottom line of the display shows the totalized flow. The units always show both the instantaneous flowrate and the total flow simultaneously. Some converters show either flowrate or totalization on demand. The ">F" in the display indicates data for the forward flow. Most microprocessor based converters are inherently bidirectional. They display and store data in both the forward and reverse direction automatically.

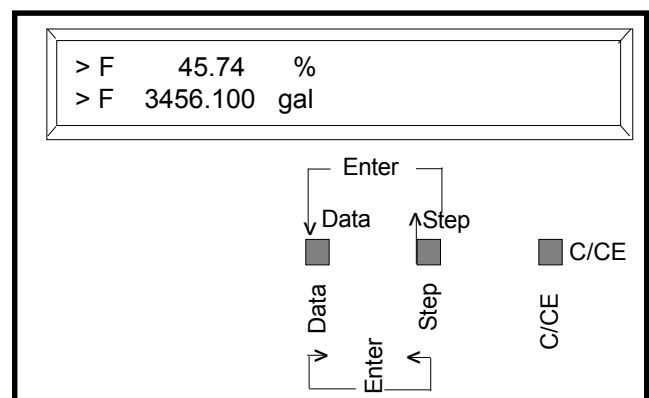


Figure 1-7. Display with Push Buttons

Figure 1-8 shows the display in the configuration mode. The top line shows the parameter to be changed. In this case, it is the range in the forward direction. A separate range can be set for each direction, and they need not be the same value. The second line of the display shows the value to be changed. In this case, the selected engineering unit is gpm. The numerical value of the range is set by entering the appropriate number using the push buttons on the left to call up the numbers one at a time. Any value within the range limits of the magmeter can be set in. This unit will display an alarm message if an attempt is made to set the range outside these limits.

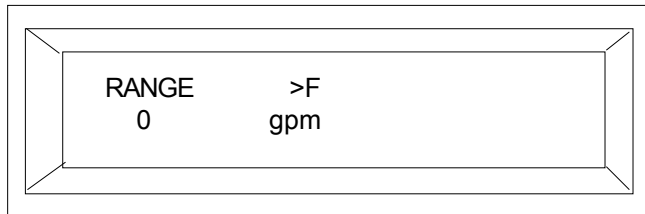


Figure 1-8. Menu for Range Change

Figure 1-9 shows one of the alarm messages that are standard in this converter. The error message appears on the top line of the display. This one states that flow has exceeded 130% of the range setting. This could happen if a valve were improperly positioned or if the range were inadvertently set below the actual flow. The error message is accompanied by an alarm contact in the transmitter when an alarm condition occurs. The contact closes automatically upon alarm and can be used to operate a light or buzzer to announce the alarm condition in a remote location.

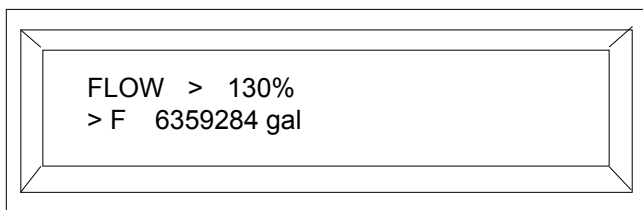


Figure 1-9. Alarm Message

Self Check

Most microprocessor based converters have a self check feature. This feature is used when it is suspected that the unit is not functioning properly and is used as a trouble shooting tool. When the self check feature is selected, the transmitter is taken off line, and data is not updated. This is logical because the data is not correct if the unit is malfunctioning. The check can include one or more menus from which various software and hardware items can be selected for test. The EPROM, the data memory, the display, alarm contacts, calibration of span and outputs, and zero return are some of the items that can be tested. It should be possible to perform the actual test by selecting the appropriate parameter from a self check menu and reading the results in the transmitter display. It should also be possible to make calibration type adjustments through software.

Communications

A full blown microprocessor based converter should be able to pass information over a data link to a computer terminal or some other remote control device located in a control room or some other convenient location. It should be possible through these devices to access all the information in the data base and to change it if necessary. Whatever functions the operator can perform at the converter should also be possible from the remote terminal. In addition, flow data as well as the parameters and performance of the flowmeter can be collected and stored at the remote computer for future evaluation. Most converters have this capability and use one of two systems to communicate. One of these is a four wire data link using an RS232C or an RS485 interface. The other system is the HART® protocol which superimposes a high frequency signal on the 4-20 mA dc output signal.

The four wire system is the faster of the two. It is capable of operating at speeds as high as 28,800 baud. The two wire system saves costs on wire installation but is limited to speeds up to about 1200 baud. This low baud rate is fine for changing or collecting data from a small number of transmitters. However, time becomes a critical factor when a large number of units require updating. The ideal data scan time is one that provides the shortest time between live data updates. This would be about one second, and at this scan rate, 100 updates are possible at 28,800 baud while only 3 updates are possible at 1200 baud.

The Hart protocol system passes data over the 4-20 mA dc output and includes a hand held communications device that can be plugged into the transmitter analog output at strategic points. This allows an operator to scan the data base, change parameters and perform diagnostic checks if necessary. This is all done without removing the cover from the converter which is important if the unit is installed in a hostile environment. The four wire system can be set up in a similar manner by using a remote keypad control unit to which the transmitters would be connected. When operated in this manner, both systems provide a method of communicating without requiring hookup to a computer or distributed control system.

Noise Reduction

Noise reduction acts a little like a damping function in that it reduces or eliminates process generated noise. However, it does not slow down the response to flow changes severely as does damping. Damping is used to smooth out pulsations in flow that are generally caused by pulsating type pumps. It slows the response to every change in flow and to any noise that may appear in the process.

Noise reduction, on the other hand, selectively eliminates large short duration signals that are not flow changes but noise that has appeared at the electrodes. Figure 1-10 illustrates how effective the noise reducing software can be. The illustration shows a noise level in excess of 40% above and below the true flow with the function turned off. With the function turned on, the flow signal shows variations of only about 2%. While the 40% oscillations are unacceptable for control purposes, the 2% fluctuations are quite manageable. It is a good idea to discuss process applications of this type with factory applications personnel to insure that the proper system is selected including electrode type, coil energizing frequency and the possibility that noise reduction may be required.

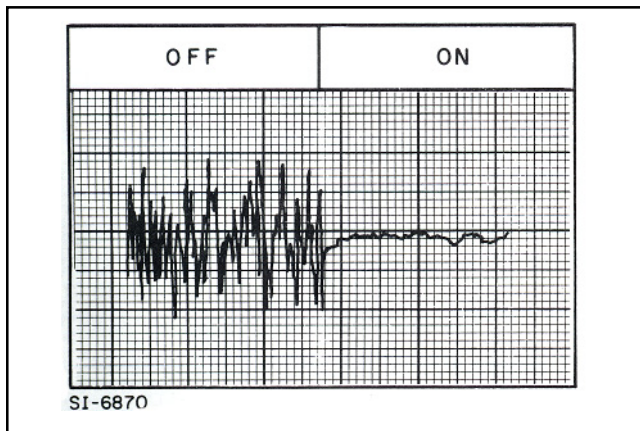


Figure 1-10. Noise Reduction

Microprocessor Based Converter in Summary

Microprocessor based converters have become commonplace. They are extremely easy to use while providing functional features that would have been expensive options in the conventional design if they could be had at all.

CALIBRATION

There are two calibrations involved in a magmeter system. One is an electronic calibration that is performed on the converter. The other is a hydraulic calibration that is performed on the magmeter. We now perform a system calibration on every magmeter we supply. Each converter is set to the customer's specifications.

Transmitter Calibration

An electronic test fixture that simulates the output of a magnetic flowmeter is used to calibrate the transmitter. Inputs from the simulator are compared to the outputs of the transmitter which must agree within tolerances specified by the quality standards department. The simulator is periodically checked against a laboratory standard which is traceable to the National Institute of Standards and Technology (NIST), formerly the National Bureau of Standards (NBS).

A field calibrator is available. Like the factory simulator, it simulates the output of the magmeter. It has already been pointed out that range setting is not a calibration procedure, and a calibrator is not required for this purpose. This was a requirement in the early days of magmeter development, but technology has brought magmeters a long way since those days. Today, the calibrator is used primarily as a trouble shooting device. If the system appears to be malfunctioning a check of the transmitter with a calibrator could isolate the problem to either the magmeter or the transmitter. If the transmitter is at fault the calibrator can be used to further isolate the problem to a section of the transmitter. Calibrator Model 55MC1018B is used for the 50SF2000; Model 55MC1020 is used for both the CD1 and 50PZ1000; and Model D55XC4000 is used for the 50SD1000, M2, XE and 50XM1000 converters.

Magmeter Calibration

A true calibration of the magmeter cannot be made with an electronic simulator. This must be done by passing a known volume of liquid through the magmeter and checking the output against the known value. This can be done in several ways. The liquid that passes through the magmeter can be diverted into a tank, and the tank can be weighed. This is a highly accurate means of calibrating a magmeter. However, it has some practical limitations. Each calibration should cover at least three flow points, and for a weigh tank calibration, this means emptying the tank after each run. This slows down the production process and increases production costs. In addition, there is a physical limitation. Magmeters larger than about 20 inches can fill a typical weigh tank in a matter of seconds. Again, building larger weigh tanks with larger scales is expensive and only adds to the costs of manufacturing. Master meters can do the job as well at a fraction of the cost.

Master meters frequently are turbine meters or magnetic flowmeters that are installed in the hydraulic flow loop with the meter to be calibrated. The master itself is calibrated by the weigh tank method and is accurate to better than 0.15%. This is the basis for calibrating the magmeter to 1/2% of rate. Using the master meters for calibration makes it possible to maintain flow through the magmeter for longer periods of time for a more accurate measurement without the need to stop the process and empty the weigh tank for another run.

Our hydraulic calibration facility maintains traceability to the National Institute of Standards and Technology through the weight tanks. The master meters are certified through the weight tanks. The weight tanks are certified by weights maintained by the facility, and the weights, themselves, are certified at a state or other government facility that is traceable to the NIST.

A copy of the data showing the results of the hydraulic calibration is shipped with every magmeter. It includes the measured flow through the magmeter, the measured flow through the master meter, and the percent difference between the two. It also includes a statement that the system is traceable to the NIST. There is one final point to be made about magmeter calibration. Magmeters are not normally calibrated for a specific user range. The magmeter's well established linearity (proportionality between output and flowrate) makes it possible to calibrate a magmeter over a standard range. For example, a magmeter calibrated over a range of 1 to 10 feet per second will produce the same calibration factor for a user range of 3 to 30 feet per second. This makes it possible to accurately calibrate for 120,000 gallons per minute which would amount to 30 feet per second in a given magmeter using a calibration flow rate of 40,000 gallons per minute at a velocity of 10 feet per second. Standardized flow ranges per meter size make it possible to computerize the control of the calibration facility and minimize set up time. Additional details regarding the hydraulic calibration of magnetic flowmeters are contained in Section 7.

INSTALLATION

The importance of proper magmeter installation cannot be overemphasized. No matter how accurate and reliable the magmeter system is, it will not perform satisfactorily if it is not installed properly. For example, magmeters can measure the flow of conductive liquids in both the forward and reverse directions. However, flow in the forward direction develops a voltage that is opposite in phase or polarity from the flow in the reverse direction. Unless the system is designed for bidirectional flow, it cannot detect this difference. Consequently, many magmeters are built with a flow direction arrow to indicate the proper direction for flow through the meter. If a unidirectional magmeter is installed so that flow goes through it opposite to the direction of the flow arrow the output from the transmitter will remain at zero flow indication.

Removing the magmeter from the line, turning it around, and reinstalling it will correct the problem. But this could be very expensive and time consuming. There is a simpler solution. The flow signal polarity can be reversed by reversing the connections of the flow signal leads. This is normally a simple procedure that can be accomplished at the transmitter terminals. The flow signal leads are marked 1 and 2, so connect the number 2 lead to the number 1 terminal and the number 1 lead to the number 2 terminal. The output signal should now be normal assuming that there are no other problems with the system.

The Model XE and 50XM1000 converter can indicate that the magmeter is installed in reverse of the flow. If the unit is set up for unidirectional flow, the flow direction indicator and letter "R" blink to show that the meter has been installed opposite to the direction of flow. This is corrected simply by selecting reverse instead of normal from the menu for flow indication. This restores the system to normal operation.

Some basic principles regarding installation of magmeters follow. More detailed information is contained in Section 5.

Orientation

The preferred orientation for a magmeter is vertical with flow upward through the meter. Also preferred is a sloping installation with flow upward through the meter. Acceptable and perhaps most common is horizontal. In every case, precautions must be taken to insure that the magmeter is filled with process liquid at all times during flow measurement. A vertical installation, with flow upward through the magmeter, assures a filled magmeter under low flow conditions and minimizes wear on the meter lining by abrasive particles that may be in the process. Electrodes should be oriented so that they are not at the top of the pipe in a horizontal or sloping installation. This prevents entrained air from coming in contact with the electrodes and causing errors in the flow signal.

Minimum Piping Straight Run Requirements

Magnetic flowmeters are most forgiving of piping configurations, but they are not immune. Some complicated configurations cannot be analyzed without actually duplicating the system and measuring the results. However, some basic rule of thumb guidelines can be recommended based upon studies done at manufacturing facilities and at independent laboratories using magnetic flowmeters with minimum face to face dimensions of 1.5 times the magmeter size. These guidelines cover elbows, reducers, valves, and pumps. Distances are measured from the center line of the magmeter to the mating flange of these devices. The downstream side of the magmeter is much less critical than the upstream side. Essentially, all that is required of the downstream side is that sufficient back pressure is provided to keep the magmeter full of liquid during flow measurement. Two diameters downstream should be acceptable for any of the devices mentioned above.

Elbows should be located a minimum of three pipe diameters upstream from the magmeter. This applies to a single elbow or a double elbow in the same or a different plane. Control valves should always be located on the downstream side of the magmeter.

Valves can create turbulence that may result in air pockets that will affect meter accuracy. If for some reason the control valve cannot be located downstream, then at least ten diameters are required between the meter and the valve. This requirement also applies to pumps.

Blocking valves should be operated fully open or fully closed. When open, the throat of the valve should be equal to or larger than the opening of the magmeter. Upstream diameters smaller than that of the magmeter could result in error signals caused by cavitation.

Reducing a line to a smaller diameter magmeter has little effect on accuracy. Reducers of 8° or less have often been

installed immediately upstream of the magmeter with little or no adverse effect. This applies to either an eccentric or a concentric reducer. However, two or three diameters

between the magmeter and the reducer are suggested if the reducer angle >8°. These piping recommendations are valid for standard accuracies. For optional high accuracies, the upstream requirements of three and ten diameters of straight run should be increased to six and twenty diameters respectively.

Grounding

Magnetic meter grounding is really a combination of standard grounding procedures and of bonding the meter body to the process liquid. The most important of these by far is the bonding which is nothing more than insuring that the meter body is in electrical contact with the process liquid. If this is not done properly the meter will function poorly, and in the case where there is no bonding, those flow signal circuits which are completed through the process liquid will not function at all.

Stray electrical currents are common in magnetic meter installations. These currents can develop as leakage from deteriorated insulation in motors and from capacitive or inductive coupling from motor windings and other conductors. Pipelines form excellent conductors for these stray currents. When a magnetic meter is installed in a pipeline, it becomes a part of the path for any stray current traveling down the pipeline or in the process itself. If these currents are allowed to pass through the magnetic meter a zero shift may occur. The amount of error that this causes depends upon the magnitude of the stray current and the conductivity of the process. Bonding provides a short circuit by which the stray currents can be routed around the magnetic meter instead of through it.

Magnetic flowmeter instruction bulletins go into detail on how to properly bond and ground a magnetic meter. Separate installation instructions, including grounding are shipped with the magnetic meter in addition to the standard instruction bulletin.

A conductive pipe requires only that the grounding straps be attached between the flanges of the magnetic meter and then to a good earth ground. If the pipeline is made of a nonconductive material or is lined with a non-conductive material then grounding rings or similar conductive devices are required to create a conductive path between the magnetic meter body and the process liquid. This allows stray currents that may be traveling along the pipeline in the process to pass from the liquid to the grounding ring to the body of the magnetic meter and back to the process on the other side of the magnetic meter. These currents follow the path of least resistance, and the metal grounding strap, and body present less resistance than the process liquid.

Remember that anything that is in contact with the process must be compatible with the chemicals in it or be consumed by it. This includes the meter liner, electrodes and grounding rings. Consequently, electrodes and grounding rings are often made of the same material. At times, however, the grounding ring may be made of a slightly less corrosion resistant material than the electrode in order to reduce costs or delivery time. This is an acceptable practice because the grounding ring has much more material than the electrode and will take a much longer time to wear away. For example, tantalum or platinum are the preferred electrode material choices for sodium sulfate, but they are also the most expensive of the materials of choice. On the other hand, most of the less costly materials for grounding rings are rated only slightly lower on corrosion for this service than are tantalum and platinum.

The typical grounding ring is basically a paddle type orifice plate with a bore equal to the nominal magnetic meter size. Their function is not to develop a pressure drop but simply to make contact with the process liquid. Consequently, the thickness of the plate can be much less than a standard orifice plate in order to reduce costs.

Torquing

Magmeters are too often treated like another piece of pipe by the people who install them. Flange bolts are tightened well beyond what is required to provide a good seal between magmeter flanges and mating pipe flanges. As a result, some magmeters are damaged to the extent that they must be returned to the factory for rework. The installation instructions supplied with the magmeter are often not even read until after the damage has been done. Teflon lined magmeters are the most susceptible to installation damage, and even the Teflon liner protector cannot prevent damage from over tightening of flange bolts.

Hazardous Locations

Magmeters are sometimes required to be installed in hazardous locations. It is a misconception to think of these meters as explosion-proof, a term commonly used to describe requirements for this service. Hazardous locations are defined in Article 500 of the National Electric Code ANSI/NFPA 70-1987. The conditions most commonly encountered for magmeter service are: General Purpose (Non-hazardous), Class I, II and III, Division 2, and Division 1. Class I locations include flammable gases or vapors and flammable liquids. Class II locations contain combustible dusts, and Class III locations contain ignitable fibers or flyings. These conditions must be clearly defined in order to select the proper magmeter for the service.

Standard magmeters manufactured in the United States by ABB Inc. are designed for service in Class I, II, and III, Division 2 hazardous locations. In general terms, this means that flammable gasses, vapors and liquids, or combustible dust, or ignitable fibers or flyings may be present in the area but only if there is failure of containment. These materials will normally be confined within closed containers or closed systems. The failed containment need not be the magmeter. The meter designed for Class I, II, and III, Division 2 service must not have arcing or sparking contacts and must not have any surface temperatures exceeding 80% of the ignition temperature of the specified hazardous material.

The basic difference between a Division 1 location and a Division 2 location is that in Division 1 locations the hazardous material may be present even if there is no containment failure. Design requirements for this service are much more stringent than for Division 2.

It is assumed that the interior of the pipeline and the magmeter can be classified as a Division 1 location where the hazardous material is periodically or continuously present. For example, the pipeline could drain empty of liquid during no flow conditions. In the absence of the liquid, flammable vapors could collect in the pipeline and in the magmeter. Factory Mutual (an approval agency) requires that magmeters approved for Class I, Division 2, Groups A, B, C, and D, hazardous locations, must have electrodes that are intrinsically safe for the Class I, Division 1, Group A, B, C, and D hazardous location inside the pipe. However, this does not mean that the magmeter is "Intrinsically Safe."

Class I, Division 1 magmeters are often referred to as "explosionproof". An explosionproof enclosure is designed to contain an explosion of the most easily ignitable concentration of a specified mixture of gas or vapor and air. The enclosure is not gas tight, but is designed with specific gap or flame path dimensions. These flame paths will allow the explosion pressure to escape, but will quench or cool any flame front, preventing ignition of the surrounding hazardous atmosphere. Use of this protection technique could result in a very expensive design, especially for large magmeters.

An alternative to "explosionproof," is an "air purged" design. This protection technique, described in NFPA 496-1986, in the case of magmeters, will permit the use of a Class I, Division 2 magmeter, with air purging, in a Class I, Division 1 hazardous location. In principal, air purged equipment is pressurized by a supply of non hazardous air or gas preventing any surrounding hazardous atmosphere from entering the enclosure. Fischer & Porter magmeters manufactured in the United States for FM approved Class I, Division 1 service do not require air purging.

The three most common agencies used for magmeter approvals in North America are Factory Mutual (FM), Canadian Standards Association (CSA), and Underwriter Laboratories (UL) in that order. The approval agency for Bailey-Fischer & Porter U.S. manufactured magmeters is Factory Mutual. Approvals for hazardous service are contained in the appropriate specification. Summaries of current approvals are published by when new approvals are received.

Hazardous Location Certifications in Europe

Within the European Economic Community (EEC), electrical apparatus designed for use in potentially flammable atmospheres must be certified by a national test house. The EEC member countries have agreed to abide by the standards established by the European Committee for Electrotechnical Standardization (CENELEC). CENELEC members are the national electrotechnical committees of: Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Italy, Norway, Portugal, Spain, Sweden, Switzerland, and the United Kingdom.

A product that is certified to the CENELEC standards by a national test house is automatically accepted by all member countries. Unfortunately, there is no reciprocal agreement between North America and Europe. North American Manufacturers must submit their products to a European test house such as BASEEFA in the U.K., LCIE in France, CESI in Italy, or PTB in Germany for certification to CENELEC standards. European manufacturers must submit their products to North American agencies such as CSA in Canada and UL or FM in the U.S. for approval to those standards.

Work is proceeding in the standards writing committees of organizations such as ISA, UL, CSA and others in North America and the International Electrotechnical Commission (IEC) in Europe to harmonize the various standards related to hazardous locations. The eventual goal is universal acceptance of a products safety certification anywhere in the world. In the meantime, agreements have been reached between some test houses in Europe and Australia with agencies in North America to accept testing to each country's standards.

MAINTENANCE

This section is not intended to be a comprehensive trouble shooting dissertation but a common sense guide for simple failures. Instruction Bulletins contain step by step procedures for the particular magmeter design.

There is very little maintenance involved in magnetic flowmeters. The converter simulator discussed earlier can isolate problems in the converter. A few simple checks with an ohmmeter can identify component failures in the magmeter. There are only the magnet coils, electrode circuit, and an interface board in the magmeter.

To check the coils, a resistance reading should show that they are open, short, or acceptable. Resistance values for the coils are available in the appropriate Instruction Bulletin.

Electrodes are checked for continuity or no continuity, but they are difficult to check in a magmeter that is installed and full of liquid. Electrodes are insulated from the body of the magmeter and should show infinite resistance between the electrode and the meter body. However, with liquid in the line, an electrical path exists from the electrode through the liquid to the body, and a resistance value that includes the resistance of the liquid plus a 36K to 100K ohm resistor in the electrode circuit can be read. Consequently, a suspected short in the electrode circuit, such as loss of one half the flow signal, should be checked with the magmeter removed from the line and dry. On the other hand, an open electrode could be detected with the magmeter in or out of the pipeline.

Electrode coating in an AC type magmeter could be manifested by difficulty in adjusting the zero or by sluggish response to changes in flow. It could be detected in both pulsed DC and AC types by a resistance check of the electrode circuit. If the resistance between the electrodes is measured with the magmeter in the line, full of process and with clean electrodes, that resistance value can be a reference point. If, after a period of service, coating is suspected because of a span or zero shift a second resistance reading could be taken. If the second reading is significantly higher than the reference reading it would indicate that the electrodes may have an insulating type coating. Appropriate action to clean the electrodes should return the meter to normal service.

CONCLUSION

The material presented in this publication is basic and somewhat general in nature. Some subjects including Liner and Electrode Selection, Rangeability, and Conductivity, among others, require more extensive coverage. Separate publications have been devoted to these and other magmeter subjects. Refer to the Technical Information Bulletins posted in the "Login to Secure Areas" link of website www.abb.com/ instrumentation.

Section 2

FLOW MEASUREMENT OF CONDUCTIVE LIQUIDS USING MAGNETIC FLOWMETERS

INTRODUCTION

The first application requirement to consider in deciding to use a magnetic flowmeter is conductivity. Does the process liquid have sufficient conductivity to meet the minimum as a conductor? What is the minimum requirement? The requirement varies from manufacturer to manufacturer and from magmeter type to magmeter type. The conductivity unit of measure is $\mu\text{S}/\text{cm}$ ($\mu\text{S}/\text{cm}$) or μmhos (micromhos/cm) which are identical. Until recently the term micromho was used primarily, but today the term μsiemen is used regularly in place of μmho . The ohm and the mho are reciprocals, hence the use of these terms to indicate resistance and conductivity.

CONDUCTIVITY LIMITS

The standard minimum conductivity level for magnetic flowmeters has been $5 \mu\text{S}/\text{cm}$. All applications involving conductivities below $5 \mu\text{S}/\text{cm}$ should be discussed with factory applications personnel.

LOW CONDUCTIVITY

There are special designs in some magmeters that allow them to measure process flow where conductivities are well below $5 \mu\text{S}/\text{cm}$. This is done by what is called driven electrode shields. A voltage from the transmitter is applied to a wire shield that surrounds the electrode wire. The driven shields provide protection against capacitance losses and process-generated noise.

NOISE

As the conductivity level drops below $5 \mu\text{S}/\text{cm}$, electrical noise becomes a problem. This is manifested as an oscillating output signal. The amplitude of the noise is proportional to the flow velocity. So, as the velocity increases, the amount of noise increases. Consequently, low conductivity magmeters should be sized so that the maximum flow is about 3 feet per second. Normally, viscosity is not a factor where magmeters are concerned. In fact, it still is not a factor in the development of the flow signal, but it does affect the amount of noise present in the process. Very low viscosities could make the flow measurement extremely difficult with low conductive fluids.

Perhaps the most difficult of the low conductivity processes is deionized water. Water conductivities vary widely. Well water can be in the neighborhood of $80 \mu\text{S}/\text{cm}$, while deionized water can be as low as $0.04 \mu\text{S}/\text{cm}$. Viscosity is low on deionized water, so a large amount of process generated noise can be expected. Depending upon the amount of noise, it could be overcome by adding smoothing (damping) to the output signal. This slows down the response of the transmitter to flow changes, but could reduce the noise to a usable level.

With the advent of digital signal processing (DSP), which relies both on software and analog hardware for signal processing, there are now more effective methods of separating the flow signal from process noise. Accordingly, when DSP is implemented less dampening of the flow signal is required due to noise introduced into the system because of vibration, hydraulic dynamics and temperature fluctuations, therefore, allowing for faster speed of response to actual variations in process flow rate.

Finally, the magnet coil operating frequency can reduce noise. It has been determined that higher coil frequencies manage the noise better than lower coil frequencies. Consequently, a 50XM signal converter operating at 15 Hz coil frequency will perform better than a converter operating at 3.75 Hz. Accordingly, ProcessMaster and HygenicMaster, which operate at 25 Hz coil excitation, aside from employing DSP for signal stabilization, offer better performance than low frequency excitation converters, some of which still employ 3.75 Hz excitation frequency.

CONDUCTIVITY DATA

The conductivities of numerous liquids have been measured and documented. Many of these are listed in the Table 1. This table lists conductivities of aqueous solutions and pure liquids which have been compiled from data in Lange's Handbook of Chemistry, Tenth Edition. It also contains liquids that have been tested for conductivity by ABB Inc. The data has been simplified for easy reference. It is shown by levels of conductivity that indicate whether the conductivity is below the minimum requirement (less than 0.01 or 0.05), near the minimum (less than 5), slightly above the minimum (less than 100), comfortably above the minimum (greater than 100), or well above the minimum (greater than 1000).

Liquids having conductivities below the minimum required for magnetic flowmeters have been identified by a single asterisk (*). A magnetic flowmeter should not be considered to measure the flow of these liquids. Those with conductivities that are marginal are identified by a double asterisk (**). Applications that fall into this latter category should be discussed with factory applications personnel. Temperatures that are above or below the limits of magnetic flowmeter are marked with a triple asterisk (***)

ABB Inc. has facilities for testing the conductivity of liquids. Samples must not be of a hazardous nature. For an accurate measurement, the test must be conducted at process temperatures because temperature does affect conductivity. For most liquids, higher temperature mean higher conductivities. Some liquids can be below the minimum requirement at room temperature but would be acceptable at process temperatures. When the process temperature dictates that the test sample be heated, or if the liquid is hazardous, testing should be done on site. Shipping and disposing of any sample must be done in accordance with OSHA standards and must be accompanied by a Material Safety Data Sheet (MSDS).

Table 1. Conductivity of aqueous solutions and pure liquids in $\mu\text{S}/\text{cm}$.

* Conductivity is below minimum required for magnetic flowmeter.

** Consult factory applications personnel for appropriate magmeter.

*** Temperature is too high or too low for magmeter.

LIQUID	% BY WEIGHT	TEMP. °C	CONDUCTIVITY
Acetaldehyde	100	15	1.7
Acetamide	100	100	43
Acetic Acid	70	18	Greater than 100
Acetic Acid	100	18	Less than 0.05*
Acetic Anhydride	100	25	0.48**
Acetone	100	18	Less than 0.05*
Acetonitrile	100	20	7
Acetophenone	100	25	Less than 0.05*
Acetyl Bromide	100	25	2.4**
Acetyl Chloride	100	25	0.4**
Adipic Acid	100	170	0.2***
Alizarin	100	233	1.45***
Allyl Alcohol	100	25	7
Alum (Aqueous)	Any	25	Greater than 100
Ammonia	100	-79	0.13***
Ammonia	31 Max.	15	Greater than 100
Ammonium Chloride	5 - 25	18	Greater than 100
Ammonium Iodide	10 - 50	15	Greater than 1000
Ammonium Nitrate	5-50	15	Greater than 1000
Ammonium Sulfate	5-31	15	Greater than 1000
Aniline	100	25	Less than 0.05*
Animal Fat	100	70	Less than 0.01*
Animal Glue	Unknown	55	Greater than 1000
Anthracene	100	25	Less than 0.05*
Asphalt Emulsion	Unknown	30	Greater than 1000
Arsenic Tribromide	100	35	1.5**
Arsenic Trichloride	100	25	1.2**
Barium Chloride	5 - 24	18	Greater than 1000
Barium Hydroxide	1 - 3	18	Greater than 1000
Barium Nitrate	4 - 8	18	Greater than 1000
Benzaldehyde	100	25	0.15**
Benzene	100	25	0.076**
Benzoic Acid	100	125	Less than 0.01*
Benzonitrile	100	25	0.05**
Benzyl Alcohol	100	25	1.8**

LIQUID	% BY WEIGHT	TEMP. °C	CONDUCTIVITY
Benzyl Benzoate	100	25	Less than 0.01*
Benzyl Chloride	100	25	Less than 0.05*
Benzylamine	100	25	Less than 0.01*
Black Liquor	Any	100	Greater than 1000
Bromine	100	18	Less than 0.01*
Bromobenzene	100	25	Less than 0.01*
Bromoform	100	25	Less than 0.05*
Butyl Alcohol (Butanol)	100	25	Less than 0.05*
Butyric Acid	70 Max.	18	Greater than 100
Butyric Acid	100	18	0.06**
Cadmium Bromide	43 Max.	18	Greater than 100
Cadmium Chloride	50 Max.	18	Greater than 100
Cadmium Iodide	45 Max.	18	Greater than 1000
Cadmium Nitrate	48 Max.	18	Greater than 1000
Cadmium Sulfate	36 Max.	18	Greater than 100
Calcium Chloride	35 Max.	18	Greater than 1000
Calcium Nitrate	50 Max.	18	Greater than 1000
Capronitrile	100	25	3.7**
Caramel	Unknown	60	102
Carbon Disulfide	100	1	Less than 0.05*
Carbon Tetrachloride	100	18	Less than 0.05*
Carboxylic Acid	100	18	5
Chlorine	100	-70	Less than 0.05*
Chloroacetic Acid	100	60	1.4**
Chloroaniline	100	25	0.05*
Chloroform	100	25	Less than 0.05*
Chlorohydrin	100	25	0.5**
Coal Tar	100	20	Less than 0.05*
Cola Syrup	100	20	Greater than 100
Coffee Extract		84	Greater than 1000
Corn Syrup		32	16
Cranberries Crushed		38	26
Cream Cheese Mix		79	Greater than 1000
Creosol	100	25	Less than 0.05*
Cupric Chloride	35 max.	18	Greater Than 1000

Table 1. Conductivity of aqueous solutions and pure liquids in $\mu\text{S}/\text{cm}$.

* Conductivity is below minimum required for magnetic flowmeter.

** Consult factory applications personnel for appropriate magmeter.

*** Temperature is too high or too low for magmeter.

LIQUID	% BY WEIGHT	TEMP. °C	CONDUCTIVITY
Cupric Nitrate	35 Max.	18	Greater than 1000
Cupric Sulfate	17 Max.	18	Greater than 1000
Cyanogen	100	18	Less than 0.01*
Cymene	100	25	Less than 0.05*
Dichloroacetic Acid	100	25	0.07**
Dichlorohydrin	100	25	12
Diethyl Carbonate	100	25	Less than 0.05*
Diethyl Oxalate	100	25	0.76**
Diethyl Sulfate	100	25	0.26**
Diethylamine	100	-33.6	Less than 0.01*
Dimethyl Sulfate	100	0	0.16**
Enamel Paint (oil base)		25	Less than 0.01*
Epichlorohydrin	100	25	Less than 0.05*
Ethyl Acetate	100	25	Less than 0.01*
Ethyl Acetoacetate	100	25	Less than 0.05*
Ethyl Alcohol (Ethanol)	100	25	Less than 0.01*
Ethyl Benzoate	100	25	Less than 0.01*
Ethyl Bromide	100	25	Less than 0.05*
Ethyl Ether	100	25	Less than 0.05*
Ethyl Iodide	100	25	Less than 0.05*
Ethyl Isothiocyanate	100	25	0.126**
Ethyl Nitrate	100	25	0.53**
Ethyl Thiocyanate	100	25	1.2**
Ethylamine	100	0	0.4**
Ethylene Bromide	100	19	Less than 0.05*
Ethylene Chloride	100	25	Less than 0.05*
Ethylidene Chloride	100	25	Less than 0.05*
Ethylene Glycol	98.8	25	0.32**
Eugenol	100	25	Less than 0.05*
Fat (Animal)		71	Less than 0.01*
Formaldehyde	44	38	Greater than 100
Formamide	100	25	4**
Formic Acid	100	25	64
Fudge		57	46
Fuel Oil		25	Less than 0.01*

LIQUID	% BY WEIGHT	TEMP. °C	CONDUCTIVITY
Furfural	100	25	1.5**
Gallium	100	30	Greater than 1000
Germanium Tetrabromide	100	30	78
Gin	90 proof	25	10
Glycerol	100	25	0.064**
Glycol	100	25	0.3**
Guaiacol	100	25	0.28**
Heptane	100	25	Less than 0.01*
Hexane	100	18	Less than 0.01*
Hydraulic Fluid		25	Less than 0.01*
Hydriodic Acid	5	15	Greater than 1000
Hydrobromic Acid	5 - 15	15	Greater than 1000
Hydrochloric Acid	5 - 40	15	Greater than 1000
Hydrofluoric Acid	0.004 - 0.03	18	Greater than 100
Hydrofluoric Acid	0.06 - 29.8	18	Greater than 1000
Hydrofluosilicic Acid	40	25	Greater than 1000
Hydrogen Bromide	100	-80	Less than 0.01*
Hydrogen Chloride	100	-96	Less than 0.05*
Hydrogen Cyanide	100	0	3.3**
Hydrogen Iodide	100	Boiling Point	0.2**
Hydrogen Peroxide	90	60	2**
Hydrogen Peroxide	35	60	Greater than 100
Hydrogen Sulfide	100	Boiling Point	Less than 0.01*
Ink		93	Less than 0.05*
Iodine	100	110	Less than 0.05*
Isopropyl Alcohol		25	3.5**
Kerosene	100	25	Less than 0.01*
Lard		50	Less than 0.01*
Latex		25	Greater than 1000
Latex Paint		25	Greater than 100
Lead Nitrate	5 - 30	15	Greater than 1000
Lime Slurry		22	Greater than 1000
Lithium Carbonate	0.2 - 0.6	18	Greater than 1000
Lithium Chloride	2.5 - 40	18	Greater than 1000
Lithium Hydroxide	1.25 - 7.5	18	Greater than 1000

Table 1. Conductivity of aqueous solutions and pure liquids in $\mu\text{S}/\text{cm}$.

* Conductivity is below minimum required for magnetic flowmeter.

** Consult factory applications personnel for appropriate magmeter.

*** Temperature is too high or too low for magmeter.

LIQUID	% BY WEIGHT	TEMP. °C	CONDUCTIVITY
Lithium Iodide	5 - 25	18	Greater than 1000
Lithium Sulfate	5 - 10	15	Greater than 1000
Magnesium Chloride	5 - 24	18	Greater than 1000
Magnesium Nitrate	5 - 17	18	Greater than 10000
Magnesium Sulfate	5 - 25	15	Greater than 1000
Manganese Chloride	5 - 28	15	Greater than 1000
Mercuric Chloride	0.229	18	4.4**
Mercuric Chloride	1 - 5.08	18	Greater than 100
Mercury	100	0	Greater than 1000
Methyl Acetate	100	25	3.4**
Methyl Alcohol (Methanol)	100	18	0.44**
Methyl Ethyl Ketone	100	25	0.1**
Methyl Iodide	100	25	Less than 0.05*
Methyl Nitrate	100	25	4.5**
Methyl Thiocyanate	100	25	1.5**
Naphthalene	100	82	Less than 0.01*
Nitric Acid	6.2 - 62	18	Greater than 1000
Nitrobenzene	100	0	Less than 0.05*
Nitromethane	100	18	0.6**
Nitrotoluene	100	25	0.2**
Nonane	100	25	Less than 0.05*
Oil (Tall)		100	Less than 0.01*
Oil (Vegetable)		50	Less than 0.01*
Oleic Acid	100	15	Less than 0.01*
Oleum	20	25	Greater than 100
Orange Syrup		25	Greater than 100
Oxalic Acid	3.5 - 7	18	Greater than 1000
Oxygen	100	-	Less than 0.01*
Paraffin Wax		66	Less than 0.01*
Paint (Enamel)		25	Less than 0.01*
Peanut Butter (Unsweetened)		93	Less than 0.05*
Pentane	100	19.5	Less than 0.05*
Petroleum	100	-	Less than 0.01*
Phenetole	100	25	Less than 0.05*
Phenol	100	25	Less than 0.05*

LIQUID	% BY WEIGHT	TEMP. °C	CONDUCTIVITY
Phenyl Iso Thiocyanate	100	25	1.4**
Phosgene	100	25	Less than 0.05*
Phosphoric Acid	10 - 87	15	Greater than 1000
Phosphorus	100	25	0.4**
Pinene	100	23	Less than 0.01*
Piperidine	100	25	0.2**
Polyurethane		22	Less than 0.05*
Potassium Acetate	4.67 - 65.33	15	Greater than 1000
Potassium Bromide	5 - 36	15	Greater than 1000
Potassium Carbonate	5 - 50	15	Greater than 1000
Potassium Chloride	5 - 21	18	Greater than 1000
Potassium Cyanide	3.25 - 6.5	15	Greater than 1000
Potassium Fluoride	5 - 40	18	Greater than 1000
Potassium Hydroxide	4.2 - 42	15	Greater than 1000
Potassium Iodide	5 - 55	18	Greater than 1000
Potassium Nitrate	5 - 22	18	Greater than 1000
Potassium Oxalate	5 - 10	18	Greater than 1000
Potassium Sulfate	5 - 10	18	Greater than 1000
Potassium Sulfide	3.18 - 47.26	18	Greater than 10000
Proionaldehyde	100	25	0.85**
Propionic Acid	1 - 69.99	18	Greater than 85
Propionic Acid	100	25	Less than 0.07**
Propionitrile	100	25	0.1**
ISO-Propyl Alcohol	100	25	3.5**
M-Propyl Alcohol	100	25	Less than 0.05*
M-Propyl Bromide	100	25	Less than 0.05*
Pyridine	100	18	0.053**
Quinoline	100	25	Less than 0.05*
Salicylaldehyde	100	25	0.16**
Silver Nitrate	5 - 60	18	Greater than 1000
Sodium Acetate	5 - 32	18	Greater than 1000
Sodium Carbonate	5 - 15	18	Greater than 1000
Sodium Chloride	5 - 26	18	Greater than 1000
Sodium Hydroxide	1 - 50	18	Greater than 1000
Sodium Iodide	5 - 40	18	Greater than 1000

Table 1. Conductivity of aqueous solutions and pure liquids in $\mu\text{S}/\text{cm}$.

* Conductivity is below minimum required for magnetic flowmeter.

** Consult factory applications personnel for appropriate magmeter.

*** Temperature is too high or too low for magmeter.

LIQUID	% BY WEIGHT	TEMP. °C	CONDUCTIVITY
Sodium Nitrate	5 - 30	18	Greater than 1000
Sodium Sulfate	5 - 15	18	Greater than 1000
Sodium Sulfide	2.02 - 18.15	18	Greater than 1000
Soybean Oil		25	Less than 0.05*
Starch		27	Greater than 1000
Stearic Acid	100	80	Less than 0.05*
Strontium Chloride	5 - 22	18	Greater than 1000
Strontium Nitrate	5 - 35	15	Greater than 1000
Styrene		22	Less than 0.05*
Sugar Solution Dilute		30	Greater than 100
Sugar Solution Pure		10	3**
Sulfonyl Chloride	100	25	2**
Sulfur	100	130	0.12***
Sulfur Dioxide	100	35	Less than 0.01
Sulfuric Acid	5 - 99.4	18	Greater than 1000
Tall Oil	100	22	Less than 0.05*
Titanium Dioxide		25	Greater than 1000
Titanium Tetrachloride	100	25	Less than 0.05*
Toluene	100	-	Less than 0.05*
O-Toluidine	100	25	2**
P-Toluidine	100	100	Less than 0.01*
Toothpaste		25	Greater than 100
Trichloroacetic Acid	100	25	Less than 0.05*
Trimethylamine	100	-33.5	Less than 0.05*
Turpentine	100	-	Less than 0.01*
Urea		25	Greater than 1000
ISO-Valeric Acid	100	80	Less than 0.05*
Vodka	100 Proof	25	4**
Water (Distilled)	100	-	Less than 0.05*
Water (New York City)		25	72
Xylene	100	-	Less than 0.05*
Zinc Oxide		25	Greater than 1000
Zinc Sulfate	5 - 30	18	Greater than 1000

Section 3

PRESSURE LOSS FOR MAGNETIC FLOWMETERS LESS THAN LINE SIZE

INTRODUCTION

It is frequently desirable to use magnetic flowmeters smaller than line size. Some reasons for this are:

1. Higher flow velocity improves self cleaning.
2. Better potential accuracy.
3. Reduced meter weight.
4. Reduced cost.

There is, however, an increased pressure loss associated with two reducers and a small-sized meter when compared to a line-size meter. Consequently, it is necessary to be able to predict just how much pressure loss will exist for certain conditions. This is especially true when comparing the cost of a magnetic meter with that of a venturi tube or flow tube installation. Pressure loss varies as the square of the flow rate (turbulent region). If friction is determined at maximum flow rate, it will be only one fourth of that value at one half of the flow rate.

There are three components of the pressure loss which must be determined separately. Then the sum of the three is the total pressure loss for the assembly.

DEFINITIONS

To estimate pressure loss of water, first determine the five hydraulic and dimensional conditions listed and defined by Figure 3-1. there are many types of cast or fabricated reducer fittings. For convenience, a table of approximate cone angles for standard cast flanged reducers is presented on the next page. If this is not applicable, more specific dimensions must be made available to proceed. The "lay lengths" for ABB Inc. brand magnetic meters are listed in the appropriate meter specification sheet.

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Gylon® is a registered trademark of Garlock Ind.
Klinger Sil® is a registered trademark of Richard Klinger, Inc.

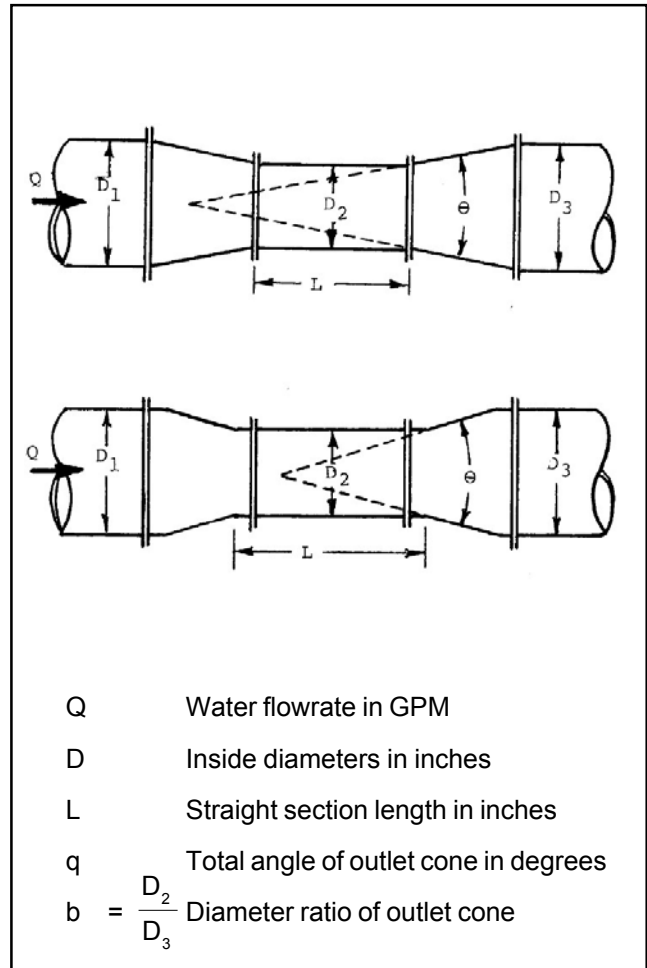


Figure 3-1

CALCULATIONS

Nomographs along with the formula on the next page are used to determine which component of the pressure loss as shown by the dotted line example. Notice that the answer from the first determination is used as one input for the third determination.

SUMMARY

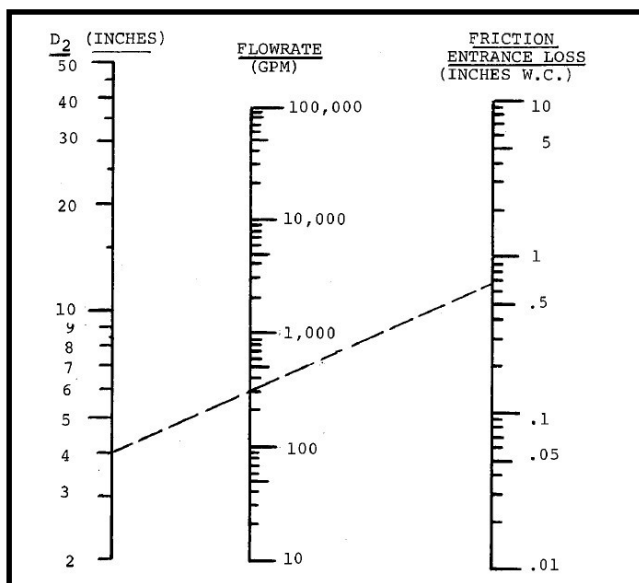
In order to keep the pressure drop across the magmeter to a minimum, the reducers' cone angle should be as small as possible. Typically, when reducing magmeters from the process line by one size (example: 4 inch line to 3 inch mag back to 4 inch line), the pressure drop, in most cases, is very small. Additional aids are available for calculating pressure drop across the magmeter. These can be found in the magmeter sizing program.

Table 2

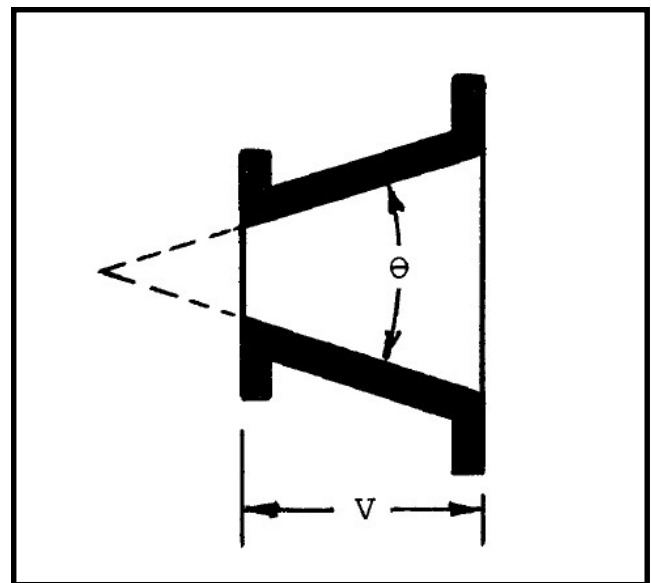
Size (")	V (")	θ
5 x 4	8	7°
6 x 4	9	15°
8 x 4	11	21°
8 X 6	11	10°
10 X 4	12	28°
10 X 6	12	19°
10 X 8	12	10°
12 X 4	14	32°
12 X 6	14	24°
12 X 8	14	16°
12 X 10	14	8°

Size (")	V (")	θ
14 x 6	16	25°
14 x 8	16	18°
14 x 10	16	11°
14 x 12	16	4°
16 x 8	18	22°
16 x 10	18	16°
16 x 12	18	10°
16 x 14	18	6°
18 x 10	19	21°
18 x 12	19	15°
18 x 14	19	11°
18 x 16	19	6°
20 x 12	20	20°
20 x 14	20	17°
20 x 16	20	11°
20 x 18	20	6°

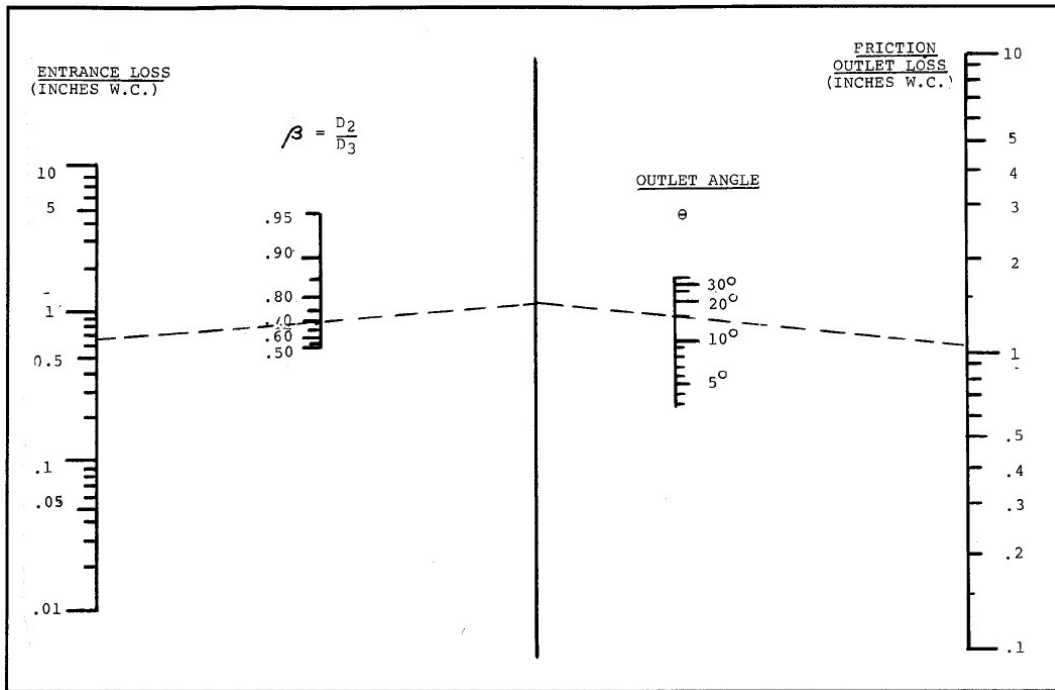
Size (")	V (")	θ
24 x 16	24	18°
24 x 18	24	11°
24 x 20	24	9°
30 x 18	30	23°
30 x 20	30	19°
30 x 24	30	12°
36 x 20	36	25°
36 x 24	36	20°
36 x 30	36	10°
42 x 24	42	15°
42 x 30	42	16°
42 x 26	42	8°
48 x 30	48	21°
48 x 36	48	14°
48 x 42	48	7°



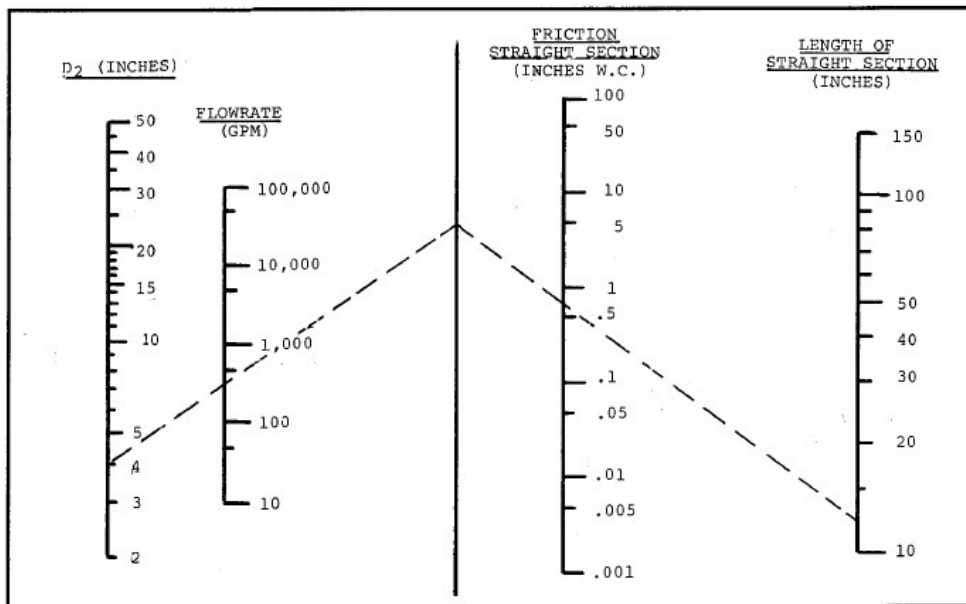
FRICTION LOSS IN INLET REDUCER



APPROXIMATE CONE ANGLES OF CAST IRON OR CAST STEEL REDUCING FITTINGS (SCHEDULE 40)



FRICITION LOSS IN
OUTLET REDUCER



FRICITION LOSS IN
STRAIGHT SECTION

$$F_{STR} = 0.00142 \frac{(GPM)^{1.8} (L)}{(D_2)^{4.8}}$$

$$F_{OUT} = 58.5 F_{IN} (\tan \frac{\theta}{2})^{1.22} (1 - \beta^2)^2$$

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Section 4

MAGNETIC FLOWMETER SELECTION GUIDE FOR WATER AND WASTEWATER TREATMENT

Introduction

This bulletin is intended to assist in the proper selection of magnetic flowmeters (magmeters) in typical water and wastewater treatment applications.

Brief descriptions of the process streams normally measured by magnetic flowmeters are presented with selection and design recommendations.

Liner and electrode coatings have been major problems for magnetic flowmeters over the years. Creative engineering has combined new technologies with extensive experience to produce magnetic flowmeters that solve the coating problems.

Coatings

There are two types of coating that are of concern. They are those that are more conductive than the overall conductivity of the process and those that are less conductive (insulating coatings). Coatings that have the same conductivity as the overall conductivity of the process are not a concern. Thickness of the coating can be less than 1/16 of an inch and still cause deterioration of the flow signal if the coating is more conductive or less conductive than the process as a whole. These are the types of coating that this bulletin addresses. Thick coatings that significantly change the inside diameter of the magmeter will also change the inside diameter of the piping. These coatings are not addressed here.

Conductive Coatings

A conductive coating is a serious problem when it coats the magmeter liner. The liner is an insulator, and the coating effectively changes it to a conductor. It reduces the flow signal by creating a low resistance path or short circuit between the electrodes. The flow signal will deteriorate and may go to zero.

Other than periodic cleaning, there is little that can be done to solve this problem. Periodic flushing of the pipeline and the magmeter may be a solution. Because coating occurs more at low flow velocities than at high velocities, sizing the magmeter for flows of five feet per second or higher will reduce the probability of coating. A dense, slick liner material such as TEFLON® or TEFZEL® or a ceramic carbide body may resist coating more than other materials.

Fortunately, conductive coatings are encountered in only a very small percentage of applications. They may appear in industrial waste where metals can plate out or in slurries where fine metal particles might attach themselves to the liner.

A conductive coating can also result from adding chemicals to the process. One such additive is ferrous chloride which is used as a coagulant in wastewater treatment. When chlorinated or aerated, ferrous chloride changes to ferric chloride which then changes to ferric hydroxide or hydrated ferric oxide. This is insoluble at PHs above about 2.2. It appears as a brown residue when dried and as a brown gelatinous mass when suspended in water. The residue will coat the liner of the magmeter. It is more conductive than the process and will cause the flow signal to read low. Other coagulating agents, such as alum, can perform the same function without adverse affects to the flow signal.

Insulating Coatings

The most common type of coating is one that is less conductive than the process as a whole. These insulating type coatings can cause significant zero shifts in AC type magmeters and some span shift in pulsed DC type magmeters.

Definitions

The following are brief descriptions of some process streams commonly found in water and waste water treatment facilities. Terminology may be different from one locale to another. Consequently, it may be necessary to identify the make-up of the process rather than referring to it by name, in order to make proper judgments in the selection of a magmeter type and the selection of compatible wetted parts.

Potable Water

This is drinking water intended for human consumption. Coating should not be a problem, but a concern for this process is that the liner material be of a quality that will not contaminate the water.

Raw Sewage

This is the domestic sewage as received at the treatment plant or as it passes interceptor or pumping stations in the sewerage network. It may be free of large solid particles if it has already passed through bar screens at the plant inlet. Raw sewage is usually low in solids content.

Settled Sewage

The clarified overflow from the primary settling process is called "settled sewage". It is quite low in suspended solids.

Primary Sludge

This is the sludge drawn off the bottom of the primary settling tanks. It is normally very thick, greasy, and hard to handle.

Mixed Liquor

In the second stage of the sewage treatment process, settled sewage is fed to aeration tanks where organic matter is decomposed by aerobic bacteria. Oxygen is supplied as air or pure oxygen. The unsettled overflow from the aeration tanks is called "mixed liquor". It contains a low percentage of fine solids.

Activated Sludge (Return & Waste)

After the aeration tanks, the mixed liquor is allowed to settle in the secondary clarifiers. The sludge from the bottom of these clarifiers is split into two paths. One part is returned to the inlet of the aeration tanks to replenish the aerobic bacteria concentration. This is called "return activated sludge." The other part is withdrawn from the main process stream for eventual disposal. It is called "waste activated sludge." These sludge flows are fairly low in solids content and are relatively easy to measure.

Thickened Sludge

In order to improve economies of sludge disposal, the sludge may be dewatered to produce a paste-like material which is very thick. For measuring devices other than magmeters, it is more difficult and sometimes impossible to measure in this form.

Thickened primary sludge will also contain high grease concentration.

Digester Sludge

Further degradation of the solids is done by anaerobic bacteria in a closed vessel called a "digester". This is the sludge drawn from the digester after digestion. It is very thick and high in solids concentration.

Digester Supernatant Liquor

This is the liquid layer in the digester which lies above the settled solids and below the scum on the surface. If primary sludge is fed to the digester, the supernatant liquor may contain high concentrations of grease. Solids concentration is low.

Industrial Wastes

The effluent of industrial plants will vary greatly depending on the type process of the plant. High acidic or alkaline conditions may be encountered. Therefore, corrosion resistance must be considered carefully. See Section 9 for material recommendations.

Liner Selection

Except for potable water, the liner material should be selected for its corrosive and abrasive compatibility with the process. Of the liner materials presently offered by ABB, elastomer & polypropylene are acceptable for potable water.

Liner & Electrode Selection Guide

Selection of liner and electrode materials for corrosive processes should be based upon the guidelines contained in the Liner and Electrode Selection Guide in Section 9 of this document.

Coating Effects *(Also see Section 6)*

The effects of coatings on electrodes and liners is presented in Section 6. This publication discusses, in detail, the development of solutions to coating problems and the selection of the appropriate magmeter and signal converter for these processes. It points out that over the years, ultrasonic electrode cleaning has been a tool for preventing build-up of coatings on electrodes. However, with the introduction of pulsed dc coil energizing, the need for electrode cleaning was virtually eliminated.

Submersion

Magnetic flowmeters are quite often installed in pits or in other locations where they can become submersed in water because of pump failure or poor drainage. Standard magmeters are not designed to withstand hostile environments of this type. They are normally designed to NEMA 4 standards which is basically wind, rain, and hosedown resistant. Submergence for even a few hours could cause the meter to fail.

Occasional Submergence

Occasional submergence options prepare the magmeter to continue operating for short periods while completely covered with water. This is usually for 48 hours or less in up to 30 feet of water. It is difficult to control the period of submergence, and the meter will most likely be submerged for periods longer than 48 hours. This could result in damage to the electronics, causing the meter to be out of service.

Continuous Submergence

For submergence protection, ABB's standard WaterMaster is inherently submersible (IP68, NEMA 6P) for long periods of time, under pressure - eliminating the need for expensive metering chambers.

As a rule, most magmeters size 14 inch and larger are vulnerable to submergence by virtue of their installed location. In addition, any magmeter installed in a pit is a potential flood victim. All such magmeters should be of the continuous submergence design. This will ensure long term service without failure from flooding regardless of how long the meter is submerged.

Chemical Feed

Chemical treatment involves the addition of various chemicals to the process, usually in very small quantities. It is important in these small flows to size the magmeter so that that flow velocities are high enough to provide accurate flow data. The velocities should be at three feet per second or better at the maximum flow. This could mean sizing the magmeter to be smaller than line size.

For example, a flow rate of one liter per minute in a size 1/2 inch magmeter reaches 0.43 feet per second when the flow is at its maximum. In a size 5/32 inch magmeter, the velocity is 4.44 f/s at maximum flow. At 25% of max flow, the velocity is 0.11 f/s for the 1/2 inch meter and 1.1 f/s in the 5/32 inch meter. The flow signal is about ten times stronger in the 5/32 inch size than in the 1/2 inch size making it a much better choice for these flows.

Hazardous Locations

ABB magmeters are Factory Mutual approved for Division 2 hazardous locations. These locations will have hazardous materials present only if there is containment failure. A Factory Mutual approved Division 1 option is available. In a Div 1 location, the hazardous material will be present even though there is no containment failure. Most locations in water and wastewater treatment facilities are Div 2, but a few may be classified as Div 1 areas.

Summary

Electrode coating has been a persistent problem for magnetic flowmeters in waste water treatment applications for years. Flooding has caused failure of magmeters that were installed without submersible options. Most of these problems can be overcome by intelligent selection of magmeter type and appropriate options. Chemical feed applications require careful sizing to insure accurate flow measurement. This publication provides guidelines for making the right choice. In addition, qualified factory personnel are available to discuss applications that are beyond the scope of those listed here. ABB recommendations for liner material and electrode type are shown in Table 1.

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Section 5

ELECTROMAGNETIC FLOWMETER PIPING CONFIGURATIONS

Introduction

Electromagnetic flowmeters are fairly forgiving regarding piping configurations, but are not immune to problems caused by incorrect piping schemes. Most manufacturers indicate that 5 diameters upstream of any disturbance is sufficient to give measurement to the specified accuracy of their electromagnetic flowmeter. Some even state that 3 diameters is enough. This is not the case, electromagnetic flowmeters are, as stated, fairly forgiving, but definitely not immune to disturbance effects, and for this reason ABB states that it is best to have 5-10 diameters between a disturbance and a flowmeter. Complicated configurations of disturbances cannot be easily analysed without either modelling them on expensive Computerised Fluid Dynamics (CFD) Software or physically duplicating the system in the calibration laboratory and measuring the results. However, some basic 'Rule of Thumb' guidelines can be recommended based on a host of studies performed at manufacturers plants and independent laboratories using various manufacturers electromagnetic flowmeters. These guidelines cover elbows (bends), reducers valves and pumps. Distances are measured from the centreline of the electromagnetic flowmeter to the mating flange of the disturbance device. The downstream side of the flowmeter is much less critical than the upstream side. Essentially all that is required of the downstream side is that sufficient back pressure is provided to keep the electromagnetic flowmeter full of liquid during flow measurement and that really bad disturbances are kept a short distance away from the meter. Generally two diameters downstream should be acceptable for any of the devices mentioned above.

Elbows

The distance that elbows should be mounted upstream of the flowmeter depends on the alignment of the electrode plane with the plane of the bend. If the plane of the electrodes is 0° to that of the bend, then a distance of 5 diameters is necessary to bring the extra error introduced to around $\frac{1}{2}\%$ FSD (See Figure 5-1). If the plane of the electrodes is 90° to that of the bend, the error is small enough to be negligible.

(See Figure 5-2).

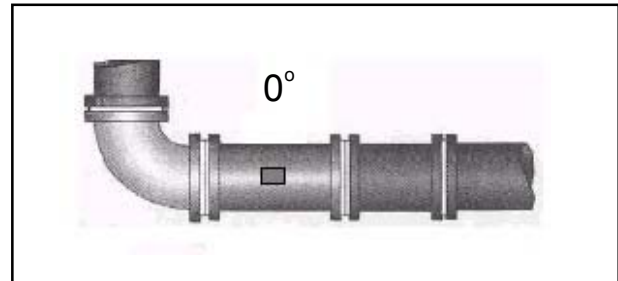


Figure 5-1

This applies to single elbows, see Figure 5-1, however, double elbows in the same or a different plane have significantly different effects. Elbows in the same plane (see Figure 5-3) have a similar or slightly less effect than that of the single bend. In a similar way the effects can be reduced by careful choice of the alignment of the planes of the bends with that of the electrodes of the flowmeter. A further variable on the effect produced is the separation of the two elbows as can be seen in Figures 5-4 & 5-5.

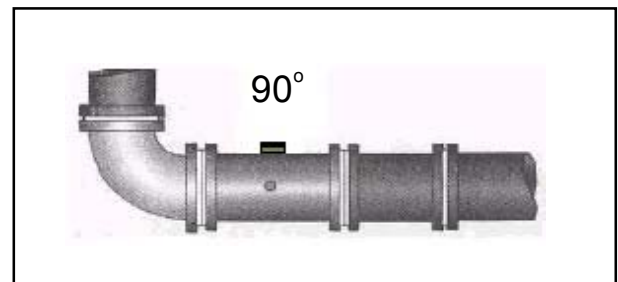


Figure 5-2

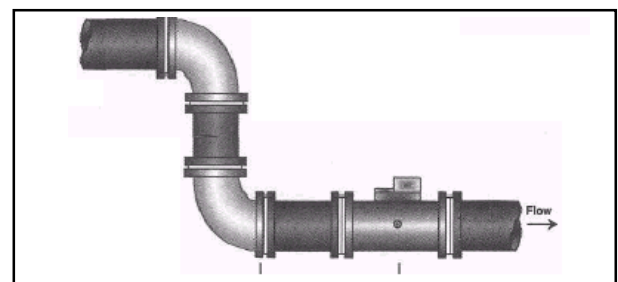


Figure 5-3

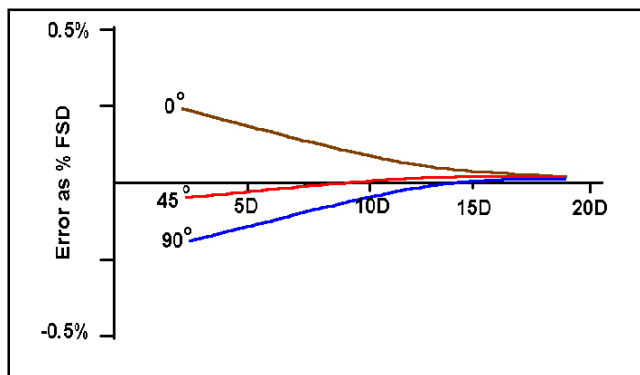


Figure 5-4

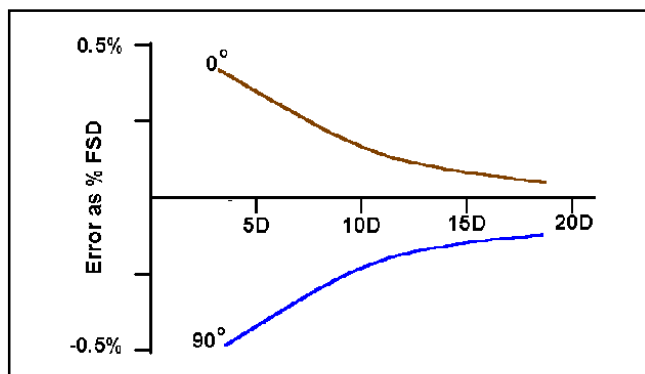


Figure 5-5

If the two elbows are in different planes, then swirl will be introduced and the effect will then vary with distance from the disturbance. Users will need to keep a very large number of diameters of pipe after such a disturbance before they can be sure of unaffected measurement (See Figure 5-6).

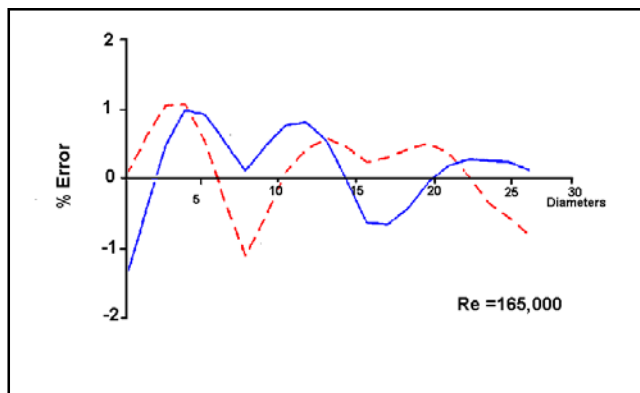


Figure 5-6

If the application is abrasive slurry, the distance should either be increased or a lining protection flange should be used to prevent excessive wear on the leading edge of the lining.

In most cases, an elbow may be mounted directly on the downstream flange of an electromagnetic flowmeter without affecting its performance. (See Figure 5-7)

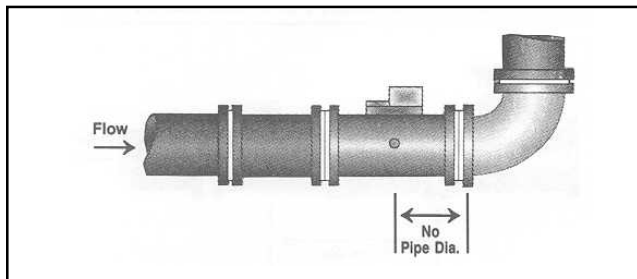


Figure 5-7.

Control Valves

Control valves should always be mounted on the downstream side of an electromagnetic flowmeter as shown in Figure 5-8. The most common type of control valve is a butterfly valve, which should always be mounted at least two diameters downstream of the flowmeter as the position of the butterfly disc can cause back flow disturbances which will affect the flowmeter if closer than two diameters. If it is not possible to mount the control valve downstream of the flowmeter then great care must be taken to position the valve. A butterfly valve will require at least ten diameters between it and the flowmeter as it will cause errors both from the disturbance effect of the valve disc and the possibility of cavitation which will then allow air to pass through the meter with consequent effects on accuracy.

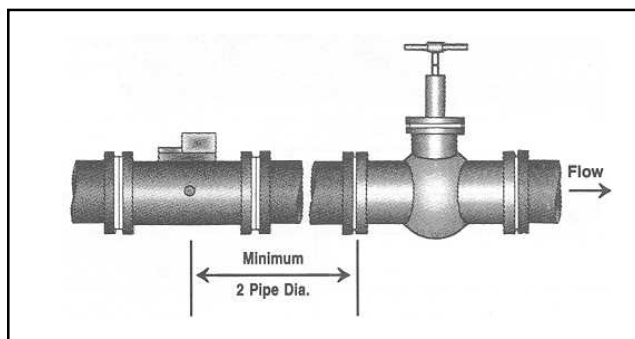


Figure 5-8

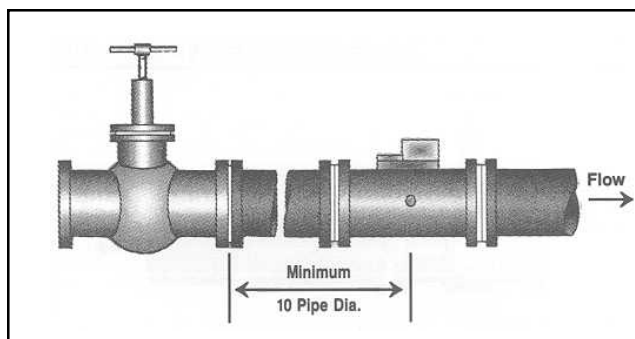


Figure 5-9

Figure 5-10 shows the effects of a butterfly control valve placed at 10 diameters upstream of an electromagnetic flowmeter, the disturbance effects can clearly be seen.

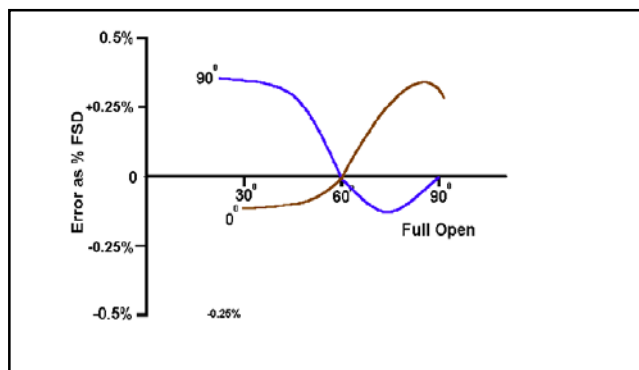


Figure 5-10

Pumps

The minimum requirement of 10 diameters also applies to pumps when placed on the upstream side of an electromagnetic flowmeter (See Figure 5-11). In addition pump glands can leak and allow air to be drawn in which may cause an error if there is insufficient pressure to keep the air bubbles in solution.

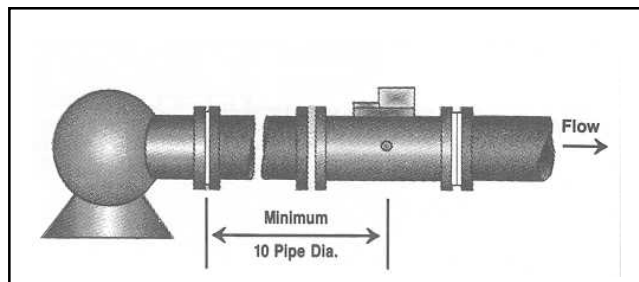


Figure 5-11

Isolation or Blocking Gate Valves

When isolation or blocking valves are used they are either fully open or fully closed. It is usual that the throat of the valve is the same size as the bore of the flowmeter. Provided that both these conditions are complied with then the valve may be mounted directly on the upstream or downstream flange of the flowmeter with a minimum effect on accuracy. (see Figure 5-12)

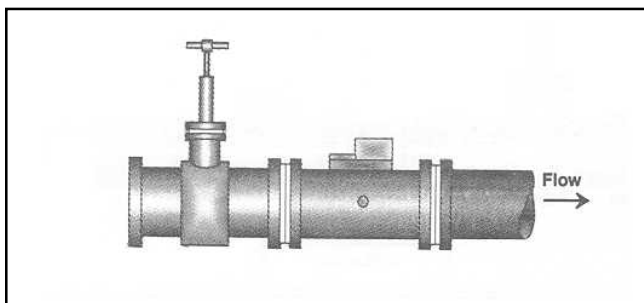


Figure 5-12

Reducers or Cones

Reducing or coning down to fit a smaller electromagnetic flowmeter than the line size has two effects. It affects the accuracy, depending on the distance from the flowmeter, (See Figure 5-14), in addition it will cause a pressure loss. The pressure loss can be minimized by keeping the included angle of the cone to around 16° . (see Figure 5-13a)

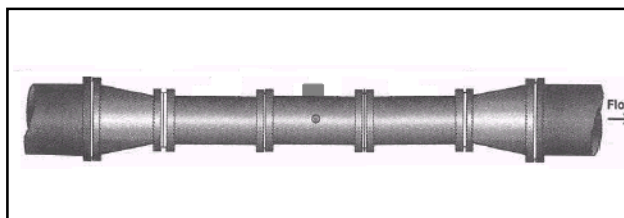


Figure 5-13

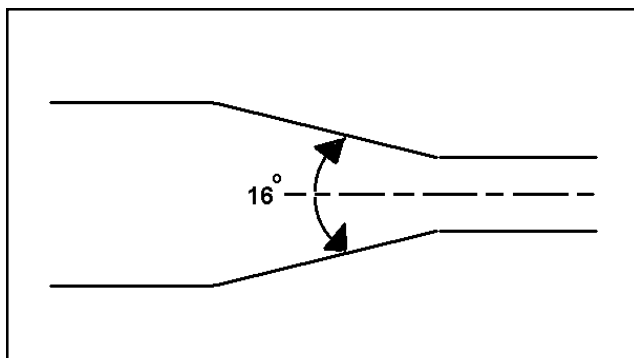


Figure 5-13a

The accuracy effects shown in Figure 5-14 are for concentric reducers only, if eccentric ones are used, then the effects upon accuracy will be greater.

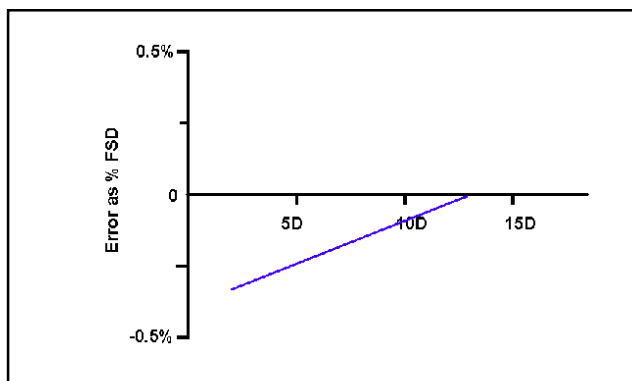


Figure 5-14

Tees

Tees are more complicated as the effects will vary depending on which input of the Tee, the flow comes from.

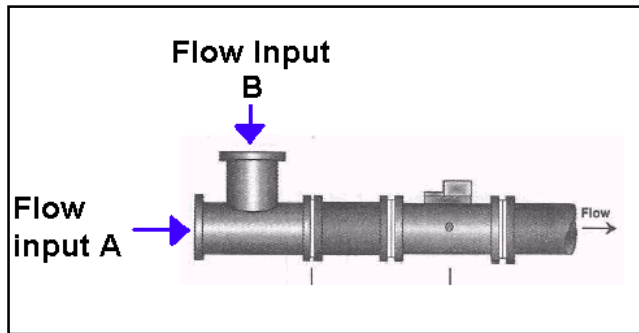


Figure 5-15

Referring to Figure 5-15, if the flow is coming from input A then the effect on the flowmeter is small, if from B then the effect will be large unless there is more than 5 diameters between the Tee and the flowmeter. If the flow comes from A and B, then the effect will be different and will depend on the ratio of flow from A and B. A conservative approach is to have ten diameters between the flowmeter and the output of the Tee.

Summary

These are simplified guidelines and if adhered to should significantly reduce the guesswork as to whether the flow profile has stabilised enough for the electromagnetic flowmeter to read the flow properly. Flow straighteners may be used to reduce pump and valve distances, but care should be taken when using such devices. If there is a combination of disturbances then the effects will be additive to a degree and advice should be sought from ABB technical support.

Configuration	Up	Down	Comments
	Stream	Stream	
Elbow	3	None	
Tee	3	None	
Reducers	None	None	<15°
Control Valves	10	2	
Gate Valves	None	None	Fully open
Check Valves	10	None	
Butterfly Valves	10	2	
Pump	10	None	
Magmeter accuracies of 1% can be achieved with these configurations			

Figure 5-16
Condensed chart, piping configuration, up/downstream are measured in pipe diameters

Introduction

Magnetic flowmeters have been commercially available since about 1954. They perform extremely well in a wide variety of processes including slurries that contain high concentrations of suspended solids. However, one performance limiting problem has always plagued magmeters. That problem is electrode coating that results in span and zero shifts. The purpose of this paper is to provide some insight to the coating problem and the solutions that have been developed over the years.

Type of Coatings

Coatings are particles that separate from the process and attach themselves to the pipe wall, grounding devices, the magmeter liner, and the electrodes. The coating material can have more conductivity, less conductivity, or the same conductivity as the process as a whole. If it has the same conductivity, the magmeter output signal should not be affected.

Conductive Coatings

The two remaining types of coating (more conductive or less conductive than the process) may cause both zero and span shifts in the output signal. A coating that is more conductive than the process is more serious and more difficult to deal with than a coating that is less conductive than the process. If coatings were limited to the electrode, the conductive-type coating would not be a problem. It would act as an extension of the electrode, and the effects would be minimal. However, coatings can cover the walls of the magmeter as well as the electrodes. Insulating-type coatings are not a problem because the wall (liner) is also an insulator. Conversely, a conductive coating on the liner constitutes a low resistance path or short circuit between the electrodes and ground. The result is a reduced flow signal.

There is not much that can be done to remove conductive coatings from the magmeter liner. Periodic flushing of the pipeline and the magmeter may be an acceptable solution. Because coating occurs more at low flow velocities than at high velocities, sizing the magmeter for flows of five feet per second or higher will reduce the probability of coating. A dense, slick liner material such as TEFLON® or ceramic may resist coating more than a rougher material such as rubber. If at least one of the above measures cannot be implemented, a magnetic flowmeter may not be the proper choice for a flow measuring device.

Fortunately, conductive coatings are encountered in only a small percentage of applications. They may appear in industrial waste where metals could plate out or in slurries where fine metal particles might attach themselves to the liner. A conductive coating can be the result of additives to the process. One of these additives is ferrous chloride which is used as a coagulant in wastewater treatment. It is completely soluble at normal PH (7). When chlorinated or aerated, ferrous chloride or hydrated ferric oxide. This is insoluble at PHs above about 2.2. It appears as a brown residue when dried and as a brown gelatinous mass when suspended in water. The residue will coat the pipeline and the liner of the magmeter. It is more conductive than the process as a whole, and will cause the flow signal to read low and possibly drop to zero over a period of time. Coagulating agents such as alum can perform this function without adverse affects to the flow signal.

Insulating Coating

The most common type of coating is one that is less conductive than the process as a whole. These coatings are ignored with DC type magmeters, but may contribute significantly to shifts in the magmeter zero and span with AC type meters. These are the types of coatings which this paper addresses.

Zero Shift

It is important to understand that zero shift is a problem that is unique to AC type magmeters. The magnetic field in this type magmeter is generated by applying standard line voltage (typically 120/240 Vac 50/60 Hz) to the magnet coils. This creates a constantly changing magnetic field. The flux from the changing field induces a voltage in the loop that is formed by the electrode leads, the electrodes, and the process liquid. This voltage appears as part of the flow signal, but it does not contain flow information. Therefore, it must be eliminated.

A condition must be created that will show that the unwanted voltage is present and by how much. This condition exists at no flow where it is known that the output signal should be zero (4mA dc). It requires that the magmeter be full of the process liquid and be blocked off so that there is no movement of the liquid in the meter. If the output signal is above or below 4 mA dc, it must be adjusted until it reads 4 mA dc. The adjustment is required initially at start-up and must be checked periodically thereafter.

Various conditions can cause the zero to shift after it has been set. The major cause is coated electrodes. Very light coatings on the electrodes can change the geometry of the electrode loop, resulting in a significant change in the induced voltage (zero shift). The zero shift problems of AC type magmeters have been most prevalent in wastewater treatment facilities. Processes such as raw sewage, settled sewage, primary sludge, mixed liquor, return and waste-activated sludge, thickened sludge, digester sludge, and digester supernatant can leave an insulating-type deposit on the electrodes which can change the characteristics of the electrode circuit. Coupled with the varying flux of the AC generated magnetic field, the coating results in a zero shift. Shifts as large as $\pm 20\%$ of the full scale flow value may occur.

Span Shifts

Insulating type coatings add resistance to the electrode circuit. This added resistance causes some of the flow signal voltage to be dropped across the electrodes. Ideally, all the flow signal voltage should be dropped across the signal converter. If this were possible, then a process flowing at 100% of its span setting would produce a 100% output signal at the signal converter. In actual service, this does not happen. Some of the process generated signal is lost before it reaches the signal converter. Some of it is dropped across the coating impedance, and the remainder is dropped across the input impedance of the signal converter. It is the ratio of the coating impedance to converter impedance that determines how much of the flow signal is lost. These are much heavier coatings than those that cause zero shifts in the AC type magmeter. However, they do not, as a rule, build up to the point where the diameter of the magmeter is changed enough to affect the velocity of the flow through the meter. Coatings that significantly change the diameter of the magmeter and the adjacent piping are a separate problem and are not included in the span and zero shift problems discussed here.

Loss of Signal

Initially the electrode signal will increase as the coating builds up, until such time as the added impedance between the fluid and electrode becomes about 2% of the signal converter input.

Then, as the coating impedance increases, the signal will decrease until it is entirely lost. As the coating impedance increases, the electrode becomes more susceptible to electrostatic pickup from nearby line frequency devices, and this produces additional zero shifts.

The signal converters have input impedances that are typically on the order of 10^{12} ohms. The coating impedance varies widely, but is considerably less than that of the converter. Coatings can reach resistances of 10^7 (10,000,000) ohms and serious low readings could result for converter input impedances of 10^6 to 10^8 (1,000,000 to 100,000,000) ohms. Using these values, errors of 90% for a converter impedance of 10^8 can be expected. The converter with 10^{11} ohms impedance yields a signal error of only 0.01%. The impedance for the XE, 50XM1000 and MFE signal converters is even higher at 10^{12} ohms.

The percent error for coating processes can be determined by applying the ratio of the impedances to the process generated voltage. In an electrical series circuit, the voltage drops around the circuit must equal the applied voltage. An equivalent electrode series circuit is shown in Figure 6-1.

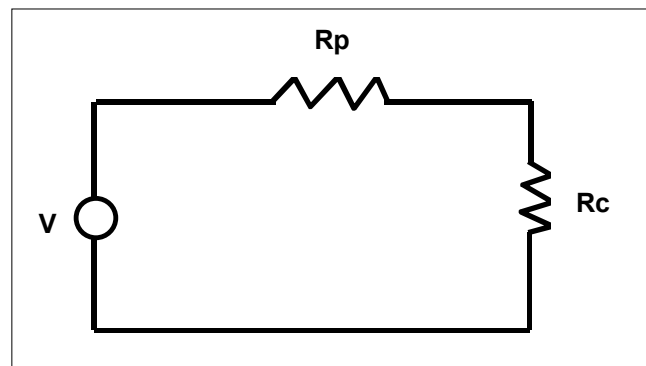


Figure 6-1. Equivalent Circuit

$$V \text{ (applied)} = V(R_p) + V(R_c)$$

V = flow voltage generated by the process

R_p = impedance of the coating

R_c = input impedance of the converter

Using the input impedance value for the 50XM1000 converter of 10^9 ohms and an extreme value for coating of 10^7 , the calculated error is less than 1%.

$$\% \text{ error} = 10^7 / (10^{12} + 10^7) \times 100 = 0.00099\%$$

For these coating conditions, there will be less span error for signal converters with higher input impedances such as the XE, 50XM1000 and MFE converter. Significant span errors are possible for converters with input impedances of 10^8 ohms or less. Therefore, it is important to remember that span shifts caused by electrode coating can be minimized by using magmeter systems with high input impedance (10^{12} ohms or higher) signal converters.

Solutions

The insulating type coating and the resultant zero shift problem was recognized soon after magmeters were introduced, and methods to prevent or reduce electrode coating began to appear.

Brush Cleanout

In 1958, Brush Electrode Cleaning was introduced. In this special electrode design, a small brush was inserted into a hollowed out electrode, and cleaning of the electrode tip was done manually.

Burn Off

Shortly thereafter, the burn-off method was developed. In this method, line voltage (120 Vac) is applied across each electrode while the magmeter is full of process liquid or water. Current flows through the electrode circuit, and as it does, the coating is burned off. This approach can be satisfactory at times, and it is still used occasionally. It has some drawbacks, however, such as the loss of flow signal during the burn-off period. Some stubborn coatings can require ten to fifteen minutes to burn off, and the meter does not measure the flow during this time. A second drawback is the possible discoloration or pitting of certain electrode materials.

Sludgemeter

In 1963, the sludge-type magmeter was introduced. It featured a heated tube design utilizing an aluminum tube to generate heat from eddy currents induced into the tube by the changing magnetic field. The theory behind this design was that by heating the tube, the process liquid would in turn be heated. The intent was to keep grease in the sludge from forming a hard coat on the electrodes and liner. This method was marginally effective.

Removeable Electrodes

Electrodes that could be removed from the magmeter body, cleaned and replaced were attractive options in the early years and even have some appeal today. Where electrodes are installed from outside the magmeter body, such as in polyurethane or rubber lined magmeters, they can be removed without removing the magmeter from the pipeline. However, the process must be drained to below the level of the electrodes so that it doesn't run out on the ground. There are specially designed removable electrodes that can be removed without draining the process line. Whether it is even practical to remove electrodes for cleaning is debatable at best. This could damage electrode wiring or disturb adjustments that would affect the meter accuracy. In the case of electrodes that are removable under line pressure, there is concern that this system is susceptible to electrode leak, especially if the electrodes have been removed several times.

Removing electrodes for cleaning may have had some merit in the early days of magmeter development. Today, there are much better ways to handle electrode coating. These methods are discussed in the paragraphs that follow.

Ultrasonic Cleaning

In 1967, the Company introduced yet another electrode cleaning method. This time it was ultrasonic cleaning. In this method, crystals are attached to the back of the electrode, and an ultrasonic generator, Model 55UC2000, applies a high voltage, high frequency signal to the crystal. The crystal then vibrates, causing the electrode to vibrate with it. If the coating on the electrode is relatively hard, the vibrations will cause it to break up and be washed downstream with the process. This method is not effective against soft, sticky processes such as latex. It is somewhat effective against hard coatings such as calcium carbonate.

Self Cleaning Electrodes

Another early development (1967) was the bullet nose or self cleaning electrodes. Prior to this design, electrode tips were flat and were installed so that the tips would flush with the inner surface of the liner. The bullet nose protrudes into the flow stream by about 1/4 inch, and this protrusion creates a turbulence around the electrode. The turbulence scrubs the electrode and tends to keep it clean. This has been an extremely effective method for cleaning where flow velocities periodically reach 5 feet per second.

A New Era

Although there were generally effective methods to handle coating processes, research continued for an even more effective way to prevent zero shift. A more effective way was developed and introduced in 1974 as Mag-X. This design takes a different approach to solving the electrode coating problem. The magnetic field is not energized by line voltage, but by low frequency pulsed DC voltage. Consequently, the magnetic field does not vary constantly as it does in the AC type magmeter. There is a period of time when the pulse is applied to the coil and the flux field is relatively constant. It is at this time that the flow signal is measured. By eliminating the varying flux field from the flow measurement, the principal cause of zero shift has been removed. Years of field experience have proven that the pulsed DC type magmeters do not have zero shift problems.

The New Approach

There are now new guidelines governing zero and span shift, and a new approach to solving the problem. It is known from theory and experience that the pulsed DC type magmeter has an inherently stable zero. It is also known that high impedance signal converters (10^{12} ohms) enhance span stability by providing a very high signal voltage divider ratio between the converter and the electrode circuit.

The combination of pulsed DC magmeters and high impedance signal converters solves a majority of the problems of coating applications, including those in the wastewater industry. There is very little need for ultrasonic cleaning or heating tubes to do the job. This is one of the reasons that the Company initially developed Models 10D1465 and 10D1475 without these options. Ultrasonic cleaning was added to the Series 10D1465 primarily to satisfy customers who insist on having this feature.

Summary

Time has come to take full advantage of modern day technology in selecting an appropriate magmeter for applications involving coating type liquids. All of the pulsed DC type magmeters are well equipped with high input impedance signal converters for this service. It is wise, however, to ensure that they are sized so that the velocity through them reaches 5 feet per second on a regular basis.

Section 7

HYDRAULIC CALIBRATION

Every magnetic flowmeter manufactured by ABB Inc., Warminster, PA is hydraulically calibrated prior to shipment to the user. This calibration requirement has been a company policy since we built our first magnetic flowmeter. It has also been company policy to maintain traceability to the National Institute of Standards and Technology (NIST) for calibration flow facilities. This traceability, historically, was through measurements of volumetric standards which were used to calibrate turbine meters and magnetic flowmeters as transfer standards.

In 1979, an improvement was made to the flow facility which added weight standards to provide direct traceability to NIST in addition to transfer standard traceability. This facility is used to calibrate magmeters from sizes 1/25-inch (1 mm) up to and including size 30-inch (750 mm) over flow ranges as low as 0 to 0.14 gallons per minute (0 to 50 cubic centimeters per minute) and as high as 7000 gallons per minute.

STANDARD ACCURACY REQUIREMENTS

Magmeters that are calibrated to a standard accuracy of 0.5%, $\pm 0.25\%$ or 0.15% of rate, depending upon the published accuracy, are calibrated against master flowmeters which are regularly certified in place against laboratory primary weight and volume standards. Calibrations typically are performed using two masters which are compared in an overlapping flow region.

For standard accuracies, magmeters are calibrated over a broad range of the meter's capacity by evaluating a minimum of three points at various velocities.

CALIBRATION RANGES

There is one important point that must be understood about magnetic flowmeter calibration. That is that magmeters are not normally calibrated for a specific customer range. The magmeters' well established linearity (proportionality between output frequency and flow rate) makes it possible to calibrate a meter over a standard range. For example, a meter calibrated over a range of 1 to 10 feet (0.3 to 3.0 meters) per second will produce the same calibration factor as that for a customer's range of 3 to 30 feet (0.9 to 9.5 meters) per second. This makes it possible to accurately calibrate a meter that will measure a flow of 120,000 gallons per minute at a velocity of 20 feet per second using a calibration maximum flow rate of 32,000 gallons per minute at a velocity of 8 feet per second.

We can provide special calibration requests such as, specific calibration points or customer witness. This increases manufacturing costs which must be passed on to the customer.

TEST REPORTS

Data compiled from the calibrating is used to prepare a Calibration Test Report. The report contains the actual flow as measured by the calibration standard, the flow as indicated by the magmeter under test and the percent difference. There are two formats for this report. One is a computer printout as shown in Figure 7-1 and is available to customers at no charge. The second format, shown in Figure 7-2, is a computer plotted reproduction of the calibration points as well as the actual flow data. This format is available at a nominal charge for all magmeters.



Certificate of Calibration

Serial No.:3K620000017998	Date :22 JUN 2009
Sales Order No.:53467	Line Item:10
Meter Size : .250 inch	Model No.:10D1475YN04PD29AC11C
Excitation :7.5 Hz	Line frequency :60 Hz
Max Flow: 264.000 LPH	Sp. Gr. : 1.000
Cz : -.02300	Cs : -37.53000
Meter Capacity	1199.9 LPH

Run #	Actual LPH	Indicated LPH	Diff % Rate
01	562.898	564.000	+.196
02	292.349	293.032	+.233
03	77.740	77.847	+.137

All Flowmeters are calibrated in accordance with ANSI/Z540 and are traceable to the NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY. The ABB Automation Inc., Instrumentation Division, Warminster facility is certified to ISO 9001.

This Calibration report may not be reproduced, except in full, without written permission.
Secondary used in calibration 50XE Program Version :PRB179 B13

Hydraulic test performed by :G. Slugg

CALIBRATION OK

Test Equipment :
E1028 3852A COUNTER
E1054 3852A COUNTER
E3407 MULTIMETER
T0091 THERMISTOR
T0092 THERMISTOR

SWS.BAS, Rev 21 RM 301007 14:21:55 4 49

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Figure 7-1. Calibration Test Report



Certificate of Calibration

Customer Name: Customer PO no.: Tag information: ABB Serial no.: 3K620000000000 ABB Sales Order No.: 00000001 Meter type: MAG Model Number: FEP311-080A1D1A1B0A1A0A1B1C1 Meter Size (inch): 3 Process Connection: ASME Class 150 Flange Material: Carbon Steel Lining/Electrodes: PTFE/HAST. C-4 Excitation: 7.5 Hz Customer Range: 0-600 GPM	Certificate Number: 3K620000000000 Accreditation Number: 3K620000000000 Date of Calibration: 5 FEB 2009 Location: Calibration: Warminster U.S.A Location: Test Rig: 4L Fluids: water Sensor Qmax: 793 GPM Calibration Range: 500 GPM Calibration Type: Standard accuracy Sensor Factor Sz: -3.0539mm/s Sensor Factor Ss: 175.84% Accuracy Specification: +/- .4 % Rate +.02%FS Reference: Masters
--	--

Run #	Actual GPM	Indicated GPM	% Cal. Range	Error \$ Rate
01	482.226	482.186	96.437	-.008
02	219.811	220.158	44.032	+.158
03	64.929	64.898	12.980	-.047

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Certified by :G. Slugg

TEST EQUIPMENT
 QC # Description
 E3222 VOLTMETER
 E3073 4L FREQ. COUNTER
 T0137 THERMISTOR
 R0045 4L-3 Inch Master
 R0046 4L-2 Inch Master

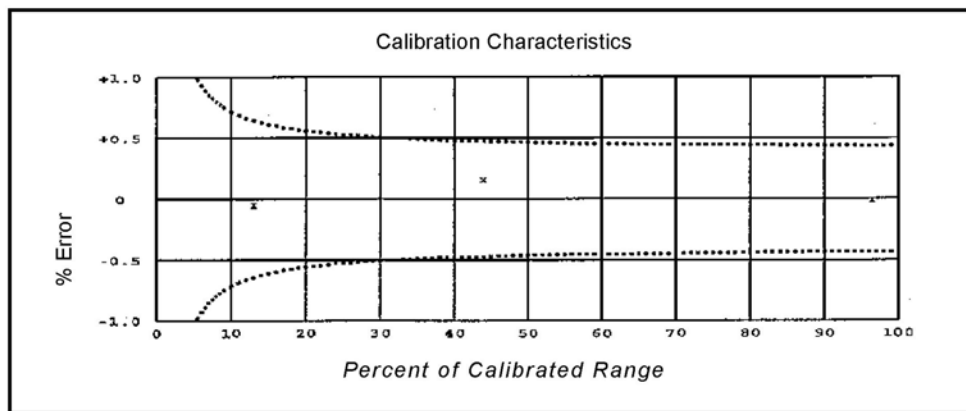


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Figure 7-2. Computer Plot with Calibration Data

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Q&A - AC vs DC FROM FLOW CONTROL NETWORK

Q: How do electromagnetic flowmeters work?

A: The basic principle of operation for magnetic flowmeters is the same for all types, regardless of manufacturer. Faraday's Law states that the induced voltage across a conductor moving at a right angle through a magnetic field is directly proportional to the velocity of the conductor. Accordingly, a conductive fluid that passes through a magnetic field at a right angle to the magnetic field generates a voltage directly proportional to the fluid velocity. Given a velocity measurement and a known free cross-sectional area (ID of the meter body), a volumetric flow can easily be derived.

A pair of electrodes on either side of the flowmeter detects the voltage proportional to fluid velocity. The voltage goes to a transmitter that processes the raw flow signal and converts it to a scaleable useable signal for process control or simple totalization.

Q: What might introduce electronic noise into a system and does noise affect AC and DC magnetic flowmeters in the same way?

A: Besides the flow velocity signal, internal electronic noise sourced to capacitive and inductive couplings for example can be present in metering systems, which can be addressed by sound cabling practices; appropriate measures such as shielding, insulation, and capacitance neutralization are recommended. In addition to internal noise components, process-induced noise sourced to electrically charged fluids, large particles, and electrochemical potentials at the electrode interface can be introduced into the system. Such externally induced noise does not affect AC and DC excited systems in the same way with respect to zero shift and continuous flow signal.

Conventional AC systems remain more susceptible to zero shift than DC systems. This phenomenon is best understood by appreciating that Faraday's Law cuts two ways. As previously noted, the voltage proportional to velocity is created by a conductor (i.e., conductive process fluid) passing through a magnetic field. It is equally true that nonmoving conductors - such as electrode wires - near to a changing magnetic field also produce voltage.

In AC-excited magnetic flowmeters the continuous alternating current in the presence of a stationary conductors or couplings between the magnetic coils and electrode wires can create a varying non-flow induced voltage, which is electronic noise. In AC systems, if the noise and flow signals are out of phase with each other they can be distinguished with circuitry or software, enabling the pure flow signal to be processed and understood. Field affects that are peculiar to the installation and not present during factory calibration must, of course, be dealt with in the field. Accordingly, nonmoving insulating coatings that accumulate on the electrodes during normal process conditions (i.e. after zeroing the system in the field) can cause an apparent shift in zero in AC systems.

DC magnetic flowmeters excite magnetic coils with a pulsating direct-current, making it possible to subtract-out noise signals that would otherwise be generated by the continuously changing magnetic field in traditional AC excitation systems. Within "square wave" excitation technology there is an inherent settling time for noise that would otherwise be induced in continuous alternating current systems.

In DC systems, depending upon the frequency of excitation, remaining noise that affects zero can be easily detected in isolation from the flow signal when the magnetic coil has no current flowing through it, enabling the noise component to be subtracted from the aggregate of the noise and flow signal that is present when the magnet is turned on. Accordingly, a DC system has the potential of continuously compensating for zero-shift without the need of having to manually re-zero the system.

Q: What are the key pros and cons of traditional AC and pulsed-DC excitation methods for magmeters?

A: As discussed above, due to the changing magnetic field in AC systems, traditional AC systems are inherently prone to zero-shift, whereas DC signals are not. In addition, power requirements are less for DC systems. The coils in DC systems are energized intermittently, being a pulsed system; and the power consumption in AC magnetic flowmeters is a function of meter size, which is not the case with DC-excited systems.

Originally DC magnetic flowmeters were driven at low frequencies, on the order of 3.75 Hz, which afforded excellent zero stability, but were also susceptible to $1/f$ noise, which is electronic noise that is inversely proportional to excitation frequency. By increasing the excitation frequency of DC meters, certain kinds of process noise can be addressed but at the cost of zero stability since at higher operating frequencies the square wave begins to take on the characteristics of AC meters and, therefore, the inherent weaknesses of traditional AC-driven magnetic flowmeters, as discussed above. Moreover, the zero-stability advantage of DC meters is diminished through attempts to filter out $1/f$ noise. Distortion of the square waveform occurs, which in turn affects how cleanly and instantaneously the signal changes from its high to low state, directly limiting the meter's ability to distinguish and subtract out noise from the noise plus flow signal.

AC systems, because they are continuous (not pulsed) systems, have faster response times than DC systems, making them more suitable when dynamic response is critical. However, the main advantage of AC systems is with respect to process-generated noise. AC systems have higher signal-to-noise ratios and operate in more ideal noise spectrums, due to higher signal strength and excitation frequency respectively. Accordingly, AC systems are more robust in noisy applications (e.g. slurries and pulps). In addition, inherent to a DC-excited (square wave) system is a large bandwidth, which reacts to all noise components at the excitation frequency and at each odd harmonic of the excitation frequency, making the system less suitable in noisy applications. Whereas conventional AC (sinusoidal) excited systems have a narrower bandwidth and, therefore, are affected by noise voltages primarily in the range of the excitation frequency.

Q: Why does ABB believe its new FSM4000 magmeter offers the best of AC and DC excitation in a single device?

A: The FSM4000 magmeter from ABB uses a continuous nonpulsed AC excitation, which allows for faster dynamic response yielding tighter accuracies (most notably during pulsating flow conditions) and higher signal-to-noise ratios. The FMS adjustable noise damping facility enables response times of down to 50 milliseconds.

The FSM4000 also operates at an optimal 70 Hz, a frequency that is significantly higher than line frequency and in a low part of the noise spectrum. Operating at this frequency eliminates virtually all need for output signal dampening used in noisy applications.

FSM4000 employs digital signal processing (DSP), which is more flexible and effective than hardware in separating flow signal from unwanted noise. Digital filters with sharp drop-offs enable the system to eliminate hydraulic and line noise from the overall signal. DSP allows for faster A/D conversions from the sensor signal and allows for greater numbers of sampling points when compared to non-DSP technologies.

The FSM4000, through use of a search coil, directly measures the strength of the magnetic field. As opposed to utilizing a constant-coil drive current, the measured value of the magnetic field is fed back into the coil drive circuit in order to control the coil drive so that a constant magnetic field is maintained. Accordingly, losses to the magnetic field that would otherwise affect meter performance are dramatically reduced. The improved signal quality produced by DSP technology eliminates the need to routinely reset zero. The processing power of the DSP Converter increases zero stability and low-flow performance, enabling the meter to function with extreme accuracy over higher turndowns and a wide range of process conditions. Tangible advantages include improved measurements in applications involving vibration, hydraulic noise, and temperature fluctuation.

Section 9

LINER AND ELECTRODE SELECTION GUIDE

Introduction

A magnetic flowmeter always comprises a nonferromagnetic pipe (magnetically nonconductive) with a lining material, coils with a magnetic core and two measuring electrodes. The measuring pipe is generally stainless steel (304SS, 1.4301) with flanges to ANSI, AWWA, DIN, SA, SAA, BS or JIS standards. The lining material separates the pipe from the liquid being measured. The electrode receives the signals and is insulated from the pipe as only the electrodes are in contact with the liquid being measured.

The durability of a magnetic flowmeter in a given application depends primarily on the proper selection of liner and electrode/grounding ring materials. These are the only wetted parts of the magmeter. However, excessive wear or corrosion to these components can cause the meter to fail, resulting in damage to other components as well. The purpose of this publication is to provide compatibility data that will serve as a guide in the proper selection of these materials. Because flange gaskets are also wetted by the process, they should also be considered when evaluating compatibility.

The principle factors to consider when making liner, electrode/grounding ring or gasket material selections are the chemical composition, operating temperature, and abrasive characteristics of the process. In some applications, the process could be affected by contact with the liner or electrode materials. This is true for some sanitary food processes.

The selected materials could be acceptable based upon chemical, temperature, and abrasive characteristics of the process but could be unacceptable because they do not meet the sanitary requirements.

Cleaning

Liner and electrode materials must be compatible with the cleaning materials as well as the process materials. For example, tantalum is an excellent electrode material for use in a ferric chloride process. However, if sodium hydroxide (caustic soda) were used to clean the process line, the tantalum electrode would be destroyed. How long this would take depends upon the temperature and concentration of the caustic soda and the frequency and duration of the cleaning process.

Steam cleaning should be limited to 300°F (149°C) for meters lined with Teflon®, and meters with ceramic bodies. Polyurethane or rubber lined meters should not be exposed to steam cleaning.

Rapid cooling of the process line after steam cleaning could result in the creation of a partial or full vacuum in the line. This could cause a Teflon or PFA liner to collapse. A vacuum breaker is recommended when this condition could exist. In the case of a ceramic meter body, a sudden change in temperature between the meter body and the process in excess of 122°F (50°C) could cause the meter body to crack. If steam cleaning lasts longer than five minutes, the signal converter should be mounted remote from the magmeter. This is done to prevent the temperature of the electronics from exceeding the operating limit.

Liner and Gasket Materials

ABB Inc., manufactures magnetic flowmeters with liners of hard rubber, soft rubber, PTFE, PFA, ETFE, ceramic carbide, polypropylene & elastomer. Magmeters approved for sanitary service carry a 3-A authorization. The specification for each magmeter series contains data regarding this authorization.

Flange gaskets are made of Teflon®, neoprene, Gylon 3500®, and Klinger Sil 4101®. Teflon® is used with Teflon lined magmeters. Klinger Sil® and Teflon® are used with tefzel lined meters.

Raised Face and Flat Face Flanges

Pipe flange mating surfaces can be flat face or raised face. The raised face design has a slightly raised (about 1/16 inch) portion inside the bolt circle, which is used as the sealing surface. The flat face flange is flat across its entire flange surface.

There should be no difficulty creating a seal between a flat face flange and a raised face flange because there is sufficient raised face area for proper sealing. However, when a liner material is added to the raised face area, the gap between the magmeter flange and the mating pipe flange becomes obvious. It will be more obvious when both magmeter and mating flanges are raised face than when one of them is flat faced.

This is not a problem, unless the pipe fitter attempts to close the gap by over tightening the flange bolts. This could damage the liner, and if the mating flange and pipe are of a nonmetal material such as plastic, it could crack.

Flange nuts should be tightened in an alternate pattern (e.g., 1-3, 2-4) to produce equal pressure distribution around the flange face. Bolt torque should be limited to the values and procedures detailed in the Installation and Operations Manual. For Teflon-lined meters, the bolt-torque must be sufficient to force the flared liner flat against the flange's raised face.

Liner Materials

Teflon (PTFE & PFA)

Because of its high temperature rating and its inertness to a wide variety of acids and bases, PTFE is the most commonly used flow-tube lining material. The PTFE liner is a sleeve that is inserted into the magmeter spool assembly and then flared over the face of the spool flange. This results in a raised face flange configuration

The PFA liner is injection-molded and mechanically retained. This construction allows for operation in full vacuum applications. Teflon is an excellent liner material for chemical and heat resistance. It does not hold up as well as polyurethane or rubber in abrasive processes although it does quite well if the suspended solids are fine particles and the flow velocity is limited between 3 to 10 FPS.

The upper temperature limit of a Teflon lined magmeter varies from 250°F (120°C) to 356°F (180°C) depending upon the model. Refer to the appropriate magmeter specification for temperature limits.



Figure 9-1. PTFE Lined Magmeter

Polyurethane

For some applications, a Teflon lining does not have adequate abrasion resistance. Where extreme resistance to wear or erosion by solid particles in the process stream is required, polyurethane lining is often the best choice. ABB Inc. brand magmeters use polyurethane that is a urethane elastomer called Adiprene. It is spun into the magmeter spool and is allowed to flow out over the raised face portion of the meter flanges. This produces a raised face configuration.

Polyurethane is resilient and abrasion resistant, but it cannot be used at very high temperatures or with strong acids or bases. Its temperature limit is 190°F (88°C). Consequently, the chemical and temperature characteristics of both the process and the cleaning materials must be relatively mild if polyurethane is to be the selected liner material.

Rubber / Neoprene / Elastomer

Rubber and neoprene lined flow tubes have excellent abrasion resistance, and like polyurethane, have received wide acceptance as liner materials for abrasive processes. It is more corrosion resistant than polyurethane, but less resistance than Teflon and is moderately resistant to chemical attack. They can be used at higher temperature than polyurethane-line tubes and are considered a good general-purpose flow tube.

The rubber or neoprene is vulcanized in the magmeter spool assembly. The liners that provide a raised face flange configuration. ABB Inc. standard rubber liner material is neoprene with temperature limit of 190°F (88°C).



Figure 9-2. Rubber Lined Magmeter

Polypropylene

Polypropylene liners are inserted and backfilled with resin to maintain integrity and to insure against moisture penetration. Polypropylene has many of the same characteristics of Teflon and Tefzel but used primarily in water and municipal wastewater applications. The WaterMaster with polypropylene liner has a process temperature limit of 158°F (70°C).

Tefzel

Tefzel is injection molded into the magmeter body and is brought out over the raised face portion of the flange face. This produces a raised face flange configuration. The corrosion resistance of Tefzel is very much like that of Teflon, however, its abrasion resistance is somewhat higher. The upper temperature limit of a Teflon is 250°F (120°C).



Figure 9-3. Tefzel Body Magmeter

Ceramic Carbide

Ceramic Carbide, as offered in ProcessMaster, is especially well suited for highly abrasive, fine-grained liquids, offering increased life of 2 to 3X than that of thick PTFE. With an operating temperature of 176 degrees F, edge protection and full vacuum integrity, ceramic carbide offers a more robust solution for applications that were previously served by Ceramic liners, which are inherently susceptible to damage due to physical vibration and / or thermal shock.

Material Selection Guide

The purpose of this guide is to provide a general resource for the selection of materials for magnetic flowmeter. One of the advantages of the electromagnetic flowmeter is that it is suitable for a wide variety of applications including severely corrosive chemicals and highly abrasive slurries. The key to this versatility is that there is a large choice of materials available for the electrodes and the flowtube liner.

The guide is a collection of information from a number of sources including "Corrosion Data Survey" by National Association of Corrosion Engineers and "Handbook of Corrosion Resistant Piping" by Philip A. Schweitzer, P. E. This data is for reference only and does not constitute any guarantee by ABB Inc. regarding compatibility of material and processes.

How To Use This Guide

Chemical names are listed in alphabetical order. Each chemical may have one or more temperature and concentration combination.

In instances where the temperature limit is not given or the compatibility information is left blank, this indicates there is no information available.

Flowtube Liner

Each liner material has two considerations - compatibility to the chemical and temperature limit. The following codes define the compatibility with each chemical listed:

Note: Temperature limit values are generally conservative and were chosen to best represent data available. Note that if an A1 code is specified the actual temperature limit of the material may be in excess of 248 °F (120°C).

Electrode Material

Each electrode material has two considerations- corrosion rate per year and temperature limit. The following codes define the compatibility with each chemical listed:

Note: Temperature limit values are generally conservative and were chosen to best represent data available. Note that if an A1 code is specified the actual temperature limit of the material may be in excess of 248 °F (120°C).

DISCLAIMER

The data presented in this guide is based on field experience and published data. However, because of the wide variety of processes and applications it is impossible to guarantee material compatibility in a given process without performing corrosion tests under actual operating conditions. Therefore, the final decision of material selection resides with the user. Additionally, some of the process fluids listed in this guide do not meet the minimum conductivity requirements (5 micro-siemens/cm) for a magmeter. However, they are listed to aid the user in instances where there may be trace amounts contained in the process fluid.

ABB Inc. neither represents nor warrants the accuracy or sufficiency of the information set forth in this guide for specific end-user applications. Ultimate responsibility for material selection remains with the end-user. Nothing in this guide constitutes a change to the terms and conditions under which the ABB product was sold.

REFERENCES

The data found in the Material Selection Guide is based on field experience and data from the following sources:

National Association of Corrosion Engineers (1985) Corrosion Data Survey.

Miller, Richard W. (1989) Flow Measurement Engineering Handbook.

Schweitzer, Philip A. P.E. (1991) Corrosion Resistance Tables.

Pruett, Kenneth M. (1983) Compass Corrosion Guide II, 2nd Edition

Magmeter Material Selection Guide Legend

Compatibility	Code
Resistant	A
Not resistant	N
No Information	-

Temperature Limit	Code
248°F (120°C)	1
212°F (100°C)	2
176°F (80°C)	3
140°F (60°C)	4
68°F (20°C)	5

Corrosion Rate per Year	Code
Less than 0.002 in.	A
Less than 0.020 in.	B
Less than 0.050 in.	C
Greater than 0.050 in.	N
No Information	-

Temperature Limit	Code
248°F (120°C) 1	
212°F (100°C) 2	
176°F (80°C) 3	
140°F (60°C) 4	
68°F (20°C) 5	

Magmeter Material Selection Guide

Process Liquid	Maximum Concentration	Flowtube Liner									Electrode Material					
		Polypropylene	PTFE Teflon	ETFE Tefzel	PFA	Polyurethane	Hard Rubber	Soft Rubber	Neoprene	Elastomer /Linatex Rubber	316SS/90 4L	Hastelloy C-276/C4	Hastelloy B3	Tantalum	Platinum-10% Iridium	Titanium
Acetaldehyde	100%	A	A1	A2		N			A2	N	B4	A4	A4	B5	A5	A1
Acetamide	100%	A	A1	A1	A	N			A3	N	B1		A5			
Acetic Acid	50%	A	A1	A1		N			A4	N	B3	A3	A1	A1	A	A1
Acetic Acid	75%	A	A1	A2		N			A4	N	N	A1	A1	A1	A	A1
Acetic Acid, Glacial	100%	A	A1	A2		N			N	N	A1	A1	A	A1	A	A
Acetic Anhydride	100%	A	A1	A1		N			A5	N	B1	A1	A1	A5	A2	A1
Acetone	50%	A	A1	A4	A	N			N	N	B1	A3	A1	A3	A	A3
Acetone	100%	A	A1	A4	A	N	N	N	N	N	A1	A4	A2	A1		A3
Acetophenone	100%		A1	A1	A				N	N	B1	B3	A1	B5		B3
Acetonitrile	100%		A1	A4	A						B4			B5		
Acetyl Chloride (dry)	100%	N	A1	A4		N			N	N	B1			B5	A2	
Acetylene	100%	A	A1	A1	A		A	A	A3	A5	A1	B3		B5		B5
Acetylene Tetrabromide	100%			A		N										
Acetylene Tetrachloride	100%			A							C5		B2	A3	A2	A3
Acid Mine Water	100%		A1	A2							A4	A5		A5		A5
Acrylonitrile	100%	A	A1	A4	A				A4	A5	B3	B3		B3	A2	B3
Adipic Acid	100%	A	A1	A1	A				A4	A5	B3	A3		B3		A1
Alcohol & Glycerin	100%		A			N			N		A	A		A	A	A
Alcohol, 2-Aminoethanol	100%		A1	A3							A1	AB3		A3	AB3	
Alcohol, Allyl	100%		A1	A3	A				A5	A5	A1	B1		B1	A2	B3
Alcohol, Amyl	100%	A	A1	A1							A4	A3				AB3
Alcohol, Butyl	100%	A	A1	A1							A4	A3		A5		A3
Allyl Chloride	100%		A1	A3	A				N	N	B3		A5	A3	A2	A3
Alum	10%	A	A		A				N		B	B		A	A	A
Alum	100%	A	A1	A1	A				A3	A4	B3	B4		B5	A	A3
Alumina	100%		A			N			N		N	A		A	A	A
Aluminium Flouride	100%	A	A	A							N	N		N	A	
Aluminium Hydroxide	100%	A	A	A							B	N		A	A	
Aluminum Ammonium Sulfate	100%		A5	A1												
Aluminium Sulfate	100%	A	A	A5		N			A		B	B		A	A	B
Aluminum Chloride	20%	A	A	A	A	N			A		N	A	A2	A	A5	B
Aluminum Chloride Aqueous	100%	A	A1	A1	A	A5			A3	A4	N	A3		B1	A5	N
Aluminum Chlorohydrate	100%		A								N	B		A	A	

Process Liquid	Maximum Concentration	Flowtube Liner									Electrode Material					
		Polypropylene	PTFE Teflon	ETFE Tefzel	PFA	Polyurethane	Hard Rubber	Soft Rubber	Neoprene	Elastomer /Linatex Rubber	316SS/904L	Hastelloy C-276/C4	Hastelloy B3	Tantalum	Platinum-10% Iridium	Titanium
Aluminum Fluoride	Saturated	A	A1	A1		N			A3	A4	B5		A4	N	A5	A5
Aluminum Hydroxide	100%	A	A1	A1					A3		A1	B5	A2	A5		B4
Aluminum Oxychloride	100%		A1	A1												
Aluminum Nitrate	Saturated	A	A1	A1					A3	A4	B3	B		B5	A	A3
Aluminum Potassium Sulfate	100%	A	A1	A1		N			A3	A4	N		A2	B3	A3	A3
Aluminum Sulfate	Saturated	A	A1		A	N	A	N	A3	A4	B3	B3		A1	A2	A3
Amidosulfonic Acid	100%		A								N	N		A	A	
Amino Acids	100%			A												
Ammonia (Anhydrous)	100%	A	A1	A1	A	A5			A3	N	A1	B1	B3	A1		A1
Ammonium Bicarbonate	50%		A			N			N		B	N	A2	A	A	A
Ammonium Bicarbonate	100%		A1								B4	B5	A2	B3	A2	A3
Ammonium Bifluoride	50%	A	A			N			N	N	N	B	A	N	A	N
Ammonium Bifluoride	100%	A	A1	A1		N			N	N		B1	A		A5	
Ammonium Bisulfate	100%		A						A					A	A	A
Ammonium Bromide	5%		A1	A1							B1	A5	A5	B3	A2	
Ammonium Carbamate	50%		A			N			N		N	B				A
Ammonium Carbonate	50%	A	A	A		N			N		B	B	B2	A	A2	
Ammonium Carbonate	Saturated	A	A1	A1					A3	A4	B1	B1	A2	A3	A5	A3
Ammonium Chloride	50%	A	A1	A1					A3	A4	N	A3	A2	A3	A2	A3
Ammonium Chloride	Saturated	A	A1	A1	A	A			A3	A4	N	B1	B	A1	A2	A3
Ammonium Dichromate	100%			A												
Ammonium Fluoride	10%		A1	A1	A				A5	A4	B5	A3		N	A	B5
Ammonium Fluoride	25%		A1	A1	A				A3	A5	N	A3		N	A	A5
Ammonium Fluoride	100%		A	A	A						N	B		N	A	
Ammonium Hydroxide	25%	A	A1	A1		A5			A3	N	A5	B1	A4	A1	A2	A5
Ammonium Nitrate	5%	A	A			A			N		A1	B		A	A1	A

Process Liquid	Maximum Concentration	Flowtube Liner									Electrode Material						
		Polypropylene	PTFE Teflon	ETFE Tefzel	PFA	Polyurethane	Hard Rubber	Soft Rubber	Neoprene	Elastomer /Linatex Rubber	316SS/904L	Hastelloy C-276/C4	Hastelloy B3	Tantalum	Platinum-10% Iridium	Titanium	
Ammonium Nitrate	100%	A	A1	A2		N			A3	A4	A1			A3	A1		
Ammonium Perchlorate	100%			A										A1	A1		
Ammonium Persulfate	100%	A	A1	A1		N			A3	A5	N	N		A5	A2	B5	
Ammonium Phosphate	100%	A	A1	A1	A	N			A3	A4	N	N		A	A	A	
Ammonium Sulfate	40%	A	A1	A1	A	N			A3	A4	B1	B3	B2	A1	A1	A3	
Ammonium Sulfide	100%		A1	A1	A				A4		B1			B5			
Ammonium Thiocyanate	100%		A1	A1					A3		B5	B3		B5			
Amyl Acetate	100%	A	A1	A1	A	N			N	N	A1	A1	A1	B1	A2	A3	
Amyl Alcohol	100%	A	A1	A1	A	N			A4	A4	B1	B3	A3	B1	A2	B4	
Amyl Chloride	100%	N	A1	A1	A				N	N	B4	A5	A2	B1	A2		
Aniline	100%	A	A1	A2	A	N	N	N	N	N	A1	B1	A3	B3	A1	A3	
Aniline Hydrochloride	100%	N	A1	A2	A				N	N	N	N		B3	A2	A3	
Anthraquinone	100%		A1	A1							B3	B3		A3	A2	A3	
Anthraquinone-Sulfonic Acid	100%		A1	A1								B5		B3			
Antimony Pentoxide	100%		A								N	N		A	A		
Antimony Trichloride	100%	A	A1	A3					A4		N	B3		B3	A2	B5	
Aqua Regia	100%	A	A1	A3	A5	N			N	N	N	N	N	A1	N	A5	
Arsenic Acid	100%	A	A1	A1					A3	A4	B1	B3	B2		A2		
Arsenous Acid	100%		A								N	N		A	A		
Asphalt Emulsions	100%	A	A1						N		A5						
Barium Acetate	100%		A								N	N		A	A		
Barium Carbonate	Saturated	A	A1	A1	A				A4	A3	B5	B1	A5	B5	A	A5	
Barium Chloride	Saturated	A	A1	A1					A3	A5	B3	A3	A5		A2		
Barium Hydroxide	50%	A	A			A			A		A	B	B2	A	A2		
Barium Hydroxide	Saturated	A	A1	A1	A		A	A	A3	A4	B1	B1	B2	B1	A2	A3	
Barium Sulfate	100%	A	A1	A1		A			A4	A3	B3	N	A3	B3	A	A3	
Barium Sulfide	100%	A	A1	A1	A		A		A4	A4	B3	N		B5	A4	B5	
Battery Acid	100%			A1													
Bauxite Slurry	100%		B			A	A		B		N	A		A	A	A	
Beer	100%	A	A1	A1	A	N			A5	A5	A1	A5	A5	A5	A	B5	
Benzaldehyde	100%	N	A1	A3	A	N			N		B1	B3	A3	B3	A2	B5	
Benzene	100%	N	A1	A3	A	N			N		B1	B3	B2	A2	A2	A2	
Benzene Sulfonic Acid	100%	N	A1	A3						N	B3	B3	B2		A2	B3	
Benzoic Acid	100%	A	A1	A1	A	N			A3	A4	B1		A3	A3	A2	A1	

Process Liquid	Maximum Concentration	Flowtube Liner									Electrode Material					
		Polypropylene	PTFE Teflon	ETFE Tefzel	PFA	Polyurethane	Hard Rubber	Soft Rubber	Neoprene	Elastomer /Linatex Rubber	316SS/904L	Hastelloy C-276/C4	Hastelloy B3	Tantalum	Platinum-10% Iridium	Titanium
Benzonitrile	100%		A1	A3							B3			A1	A2	A1
Benzoyl Chloride	100%		A1	A4						N	A5			A1	A2	
Benzyl Alcohol	100%		A1	A1	A				N	N	A1	B3	A4	B3	A2	B3
Benzyl Chloride	100%	A	A1	A1					N	N	B3			B2	A1	
Bismuth Carbonate	100%		A1	A1										B5		
Black Liquor	100%		A1	A1		N			A3	A5	B5	C1		N	A	B
Bleach, Active Chlorine, 12.5	100%		A1	A3		N			A5	A5	N	A4	A4			
Borax	100%	A	A1	A1		A			A3	A4	A1	A5	A4	N	A	B3
Boric Acid	100%	A	A1	A1					A3	A4	B1	A1	A2	A1	A	A3
Boron Fluoride	100%		A			N			N		N	N		N	A	N
Brine Acid	100%		A1	A1					A4	A3	N	A4	B5	A	A	A
Bromic Acid	100%		A1	A1					A5					B5	A2	
Bromine Liquid	100%		A1	A1		N			N		N		A4	A1		
Bromobenzene	100%		A1	A3		N			N	N				A1	A2	A3
Bromoform	100%			A							B3			A3		B3
m-Bromotoluene	100%			A							A3			A5		A3
Butadiene (Butylene)	100%		A1	A2	A	N			A5	N	B1	B3		B5		
Butane	100%	A	A1	A1	A	A5	N	A	N	N	B1	B2	A5	A5	A2	A5
Butanediol	100%			A	A						B3			A1	A2	A1
Butyl Acetate	100%	A	A1	A2	A5	N				N	B1	B1	A1	B5	A2	A3
Butyl Acrylate	100%			A		N			N							
Butyl Alcohol	100%		A1	A1					A3	A4	A1	B3	A3	B5		B3
Butyl Alcohol Secondary	100%		A1	A1							B5	B5		B5		B3
Butyl Alcohol Tertiary	100%		A1	A1							B5	B5		B5		B3
n - Butylamine	100%		A1	A5		N			N		B1	B3	B3			B3
sec - Butylamine	100%			A												
tert - Butylamine	100%			A												
di-n-Butyl Amine	100%			A												
tri-n-Butyl Amine	100%			A												
Butyl Amine	100%	A				N			N		A3	AB3	AB3			AB3
Butyl Bromide	100%		A1	A1												
Butyl Chloride	100%		A1	A1					N		B5	B5		B3	A2	B5
Butyl Ether	100%	N	A1	A3		N			N		A5					
Butyl Phenol	100%		A1	A2					N		A1	B3		B2	A2	
Butyl Phthalate	100%	A	A1	A4							B3	B3	AB3	B3		B3
Butylene (Butadiene)	100%		A1	A1		N			A4	N	B1			B5		
Butyraldehyde	100%		A			N			N		A2	A2				A3
Butyric Acid	100%	A	A1	A1	A	N	A	N	N	N	B1	A1	A2	B1	A2	A3

Process Liquid	Maximum Concentration	Flowtube Liner									Electrode Material					
		Polypropylene	PTFE Teflon	ETFE Tefzel	PFA	Polyurethane	Hard Rubber	Soft Rubber	Neoprene	Elastomer /Linatex Rubber	316SS/90 4L	Hastelloy C-276/C4	Hastelloy B3	Tantalum	Platinum-10% Iridium	Titanium
n-Butyl Mercaptan	100%		A1	A1							B3	B1				
Cadmium Chloride	100%		A								N	N		A2	A2	
Calcium Bisulfate	100%		A1	A1							B3	N		A1	A	
Calcium Bisulfite	100%	A	A1			C			B	A5	B1	B5	A5	A5	A5	A3
Calcium Carbonate	100%	A	A1	A1		A			A5	A3	B3	B3	AB4	A2	A2	A2
Calcium Chlorate	30%		A			N			A		B4	B3		B3	A2	B4
Calcium Chlorate	100%		A1	A1					A3	A4	B3	B3		B3	A2	B4
Calcium Chloride	50%	A	A	A		A			A		N	A	A1	A1	A2	A
Calcium Chloride	Saturated	A	A1	A1	A5	A5	A5	A5	A3	A4	B3	A1	A2		A2	A3
Calcium Hydroxide	25%	A	A1	A1		A5			A2	A3	B3	A4	A4	A1	A5	A2
Calcium Hydroxide	Saturated	A	A1	A1	A4				A2	A3	B3		A4	A1	A2	A2
Calcium Hypochlorite	Saturated	A	A1	A1	A4				A5	A5	B5		N	B1	A2	A3
Calcium Nitrate	10%	A	A			A			A		B	B	AB3	A	A2	A
Calcium Nitrate	100%	A	A1	A1	A5	A5	A5	A5	A3	A4	B1	B3	AB3	B5	A2	B3
Calcium Oxide	100%	A	A1	A1					A5		B5	B5				
Calcium Sulfate	10%	A	A	A	A	N			N		A		B	A	A2	A
Calcium Sulfate	100%	A	A1	A1	A5	N	A5	A5	A4	A3	B3	B1	B4	B3	A	A3
Calcium Sulfide	10%			A		A			A		B3					
Cane Sugar Juice	100%		A			N			A		A	A		A	A	A
Caprylic Acid	100%		A1	A3							B1	B1		B1		B3
Carbon Dioxide (Dry)	100%	A	A1	A1	A2	A5	A2	A2	A3	A4	B1	A1	A1	B1	A1	A5
Carbon Dioxide (Wet)	100%	A	A1	A1		A5			A3	A4	B3	B3	A1	A1	A1	A5
Carbon Disulfide (Bisulfide)	100%	N	A1	A4	A5				N	N	B1	B3	AB3	A5		A3
Carbon Slurry	100%		N			A			N		A	A		A	A	A
Carbon Tetrachloride	100%	N	A1	A1	A3	N			N	N	A1	A5	A5	A1		A3
Carbonic Acid	100%	A	A1	A1	A4		A4	A4	A5	A3	B1	A5	A4	B1	A1	A3
Castor Oil	100%		A1	A1	A5		A5	A5	A4	A4	B4	A5				
Caustic Soda	50%		A	A		N			N		B			N	A	B

Process Liquid	Maximum Concentration	Flowtube Liner									Electrode Material					
		Polypropylene	PTFE Teflon	ETFE Tefzel	PFA	Polyurethane	Hard Rubber	Soft Rubber	Neoprene	Elastomer /Linatex Rubber	316SS/904L	Hastelloy C-276/C4	Hastelloy B3	Tantalum	Platinum-10% Iridium	Titanium
Cellosolve	100%		A1	A1					N	N	B1	B3	A3	B3		B3
Cheese	100%		A			N			N		A	A		A	A	A
Chloral Hydrate	100%		A1	A3												
Chlorinated Brine	100%		A	A		N			N		N	A				A
Chlorinated Phenol	100%			A												
Chlorine (Liquid)	100%		A1	A	A5		A5	A5	N	N	N	A5		B1	N	
Chlorine Dioxide	15%		A1	A1					N	N	N	A4		A1		A3
Chlorine Dioxide	100%		A	A					N		N	N		A	N	A
Chlorine Water	Saturated	N	A1	A5					N	A4	N	A3	AB3	B1	A	A3
Chlorinated Water		A	A	A							N	A	A		A	A
Chloroacetic Acid	100%	A	A1			N			N	N	N	A4	AB2	A1	A2	A3
Chloroacetic Acid (50% H2O)	50%	A	A1	A2					N	N	N	B3	AB2	A3	A2	A3
Chlorobenzene (Phenylchloride)	100%	A	A1	A3					N	N	B1	A1		B1		B3
Chlorobenzyl Chloride	100%			A												
Chloroform	100%	A	A1	A2	A5	N			N	N	A5	B3	B2	A3	A2	A3
Chlorohydrate Aluminum	100%		A								N	N		A	A	
Chlorohydrin	100%			A							B1			A1	A1	
Chlorohydroxide (wet)	100%															
Chlorophenol, 5% Aqueous	100%		A1								B1	A5			A2	
Chlorosulfonic Acid	100%	N	A1	A5					N	N	N	A2		B3	A1	A3
Chlorosulfuric Acid	100%		A								N	B		A	A	
Chromic Acid	30%	N	A1	A4					A5	N	B1	B3		B1	A2	A3
Chromic Acid	50%	N	A1	A4					A5	N	B4	B3		A1	A2	A3
Chromic Acid	100%	N	A	A		N			N		N	N		A	A2	B
Chromic Chloride	100%			A												
Chromium Fluoride	100%		A													
Chromium Sulfate	50%		A			N			N		B	B	B4	A	A2	
Chromium Sulfate	100%		A								N	B	A3	A	A	

Process Liquid	Maximum Concentration	Flowtube Liner									Electrode Material					
		Polypropylene	PTFE Teflon	ETFE Tefzel	PFA	Polyurethane	Hard Rubber	Soft Rubber	Neoprene	Elastomer /Linatex Rubber	316SS/90 4L	Hastelloy C-276/C4	Hastelloy B3	Tantalum	Platinum-10% Iridium	Titanium
Chromyl Chloride	100%		A1	A3							B3	B3		B3	A2	B5
Clorox Bleach Solution (5.5% Chlorine)	100%	N	A1	A3					N	N	B5					
Citric Acid	50%	A	A1	A3	A5	N	A5		A	A4	B1	A3	A2	A1	A2	A3
Clay Slurry	100%		A			A			A		A	A		A	A	A
Coal & Water Slurry	100%		N			A			A		N	A		A	A	A
Coffee Extract	100%		A			A			A		A	A	A1	A	A	A
Cola Syrup	100%		A		A	A			A		A	A		A	A	A
Copper Chloride	5%	A	A			A			A		N	B	A5	A	N	A
Copper Chloride	100%	A	A1	A1					A3	A4	N	B3	N	A1	N	A3
Copper Cyanide	100%	A	A1	A1		A5			A4	A4	B3	A4	AB2	B1	A	A5
Copper Fluoride	100%		A1	A1					A4		N	N		N	A	
Copper Nitrate	50%	A	A	A		A					B	N	N	A	A	A
Copper Nitrate	100%	A	A1	A1					A3	A3	A1	B5	N	B1	A	A5
Copper Oxychloride	100%		A								N	N		N	A	
Copper Sulfate	40%	A	A			A			A		B	A	N	A	A2	A
Copper Sulfate	70%	A	A			A			A		B	A	N	A	A	B
Copper Sulfate	100%	A	A1	A1					A3	A4	B1	A3	AB3	A1		A3
Copper Sulfide	100%		A								B	B		A	A	
Corn Oil	100%		A1						A3	N	B1					
Cottonseed Oil	100%		A1						A4	N	B4					
Cresol	100%	N	A1	A1		N			N	N	B5	B3	AB3			B3
Cresylic Acid	100%	A	A1	A1		N			N	N	B1	A1	A1	B2		B5
Cresyldiphenyl Phosphate	100%		A3													
Croton Aldehyde	100%		A1	A3					A5			B3		B3		
Crude Oil	100%		A1	A1		A5			N	N	A3	A5	A	A5		A5
Cupric Chloride	50%		A1						A4		N	B3		A5	N	B3
Cupric Chloride	100%		A	A							N	N	B5	A	A	B
Cyclohexane	100%	N	A1	A1	A5				N	N	B1	B3	AB3	B5	A2	A1
Cyclohexanol	100%		A1	A1					N		B5	B5		B5	A2	B5
Cyclohexanone	100%	N	A1	A1	A5				N	N	B3	B3		B5		B5
DDT	100%			A							A1			A2	A2	A2
Dairy Products	100%		A			N			N		A	A		A	A	A
Decalin	100%			A	A3	N			N							
Decane	100%		A	A		B			N							
Detergents	100%	A	A1	A1		A5			A3		B1	A5	AB3	A4		A4
Dextrin	100%		A1	A1					A3			B5				
Diacetone Alcohol	100%	A	A1	A3					N		B1	BA3	A4	A2	A2	A2

Process Liquid	Maximum Concentration	Flowtube Liner									Electrode Material					
		Polypropylene	PTFE Teflon	ETFE Tefzel	PFA	Polyurethane	Hard Rubber	Soft Rubber	Neoprene	Elastomer /Linatex Rubber	316SS/90 4L	Hastelloy C-276/C4	Hastelloy B3	Tantalum	Platinum-10% Iridium	Titanium
1,2-Dibromopropane	100%			A												
Dibutyl Phthalate	100%		A1	A4					N	N	B1	B3	AB3	B3	A1	B3
Dichloroacetic Acid	100%		A1	A4					N					A1		A1
Dichlorobenzene	100%	A	A1	A4	A5				N	N	B5	A1	A1		A2	
Dichloroethylene	100%		A1	A4					N		B3	B3		B3	A2	B3
Dichloropropionic Acid	100%			A												
Diesel Fuel	100%	A	A1	A1	A3				A5	N	A5	B3	AB3			B3
Diethylamine	100%	A	A1	A2					A5	A5	B1				A2	
Diethyl Benzene	100%		A	A												
Diethyl Cellosolve	100%		A1	A1					A5		B3					
Diethyl Ether	100%	A	A1	A3	A3				N	N	B2	B5	A3	B5		B5
Diethylene Triamine	100%		A1	A3							A3			B5		A5
Diglycolic Acid	100%		A1	A3					A3		B1	B3		B3	A2	B3
Diisobutyl Ketone	100%			A		N			N		A3			A3		A3
Diisobutylene	100%			A		N			N		A5					
Dimethylamine	100%		A1	A5	A3				N					B5	A2	
Dimethyl Aniline	100%	N	A1	A1					N	N					A2	
Dimethyl Formamide	100%	A	A1	A1	A5				A4	N	B1					
Dimethyl Phthalate	100%		A1	A3					N	N	A5					
Dimethyl Sulfate	100%			A												
Dimethyl Sulfoxide	100%		A1	A3												
Diocetyl Phthalate	100%		A1	A4	A5				N	N	B5				A2	
Diphenyl Ether	100%	N	A3	A	A5						A5	A5				
Disulfide	100%															
p-Dioxane	100%		A2	A								A5				
Divinyl Benzene	100%			A												
Dowtherm (Diphenyl)	100%	N	A1	A4		N			A3	N	B3	B3	A3	B3		B3
Dyes	100%		A			N			N		A	A		A	A	A
Epichlorohydrin	100%		A1	A4					N	N	B1	A5		B5	A2	
Ethylamine	100%			A							B3					
Ethers	100%	N	A1	A3					N	N	A3	B3	A3	B3		B5
Ethyl Alcohol	100%		A1	A1		N			A		B1	A2	B2	A3		A3
Ethyl Acetate	100%	A	A1	A4	A5	N			N	N	B1	B1	A1	B3	A1	A3

Process Liquid	Maximum Concentration	Flowtube Liner									Electrode Material					
		Polypropylene	PTFE Teflon	ETFE Tefzel	PFA	Polyurethane	Hard Rubber	Soft Rubber	Neoprene	Elastomer /Linatex Rubber	316SS/90 4L	Hastelloy C-276/C4	Hastelloy B3	Tantalum	Platinum-10% Iridium	Titanium
Ethyl Acrylate	100%		A1	A3					N	N	B3	A3	A1	B5	A2	
Ethyl Chloroacetate	100%			A												
Ethyl Chloride	100%	N	A1	A1					N	N	A1	B3	B5	A3	A1	A3
Ethyl Cyanoacetate	100%			A												
Ethyl Acetoacetate	100%		A	A		N			N							
Ethylene Bromide	100%	N	A1	A1					N	N	A3	A3		B5		B3
Ethylene Chloride	100%	A	A1	A1					N	N	B2		A1	B3		A3
Ethylene Chlorohydrin	100%	N	A1	A4					N	N	B3	B3		B3		B3
Ethylene Diamine	100%		A1	A5					N	A5	B1	N		B5	A2	A5
Ethylene Dichloride	100%	N	A1						N	N	B1	B2	A1	A3	A2	B3
Ethylene Glycol	100%	A	A1	A1	A1	A5			A4	A4	B1	A1	A2	A5	A2	A3
Ethylene Oxide	100%	N	A1	A2	A5				N	N	B1	A5		A5	A2	A5
Esters	100%			A												
Fatty Acids	100%	A	A1	A1					A4	N	A1	A1	A	A1	A1	A3
Ferric Chloride 50% H2O	50%	A	A1	A1	A5		A5	A5	A4	A4	N	B3	N	A3	A	A3
Ferric Hydroxide	100%		A1	A1					A5		A5	A5	AB4	A3	A5	B3
Ferric Nitrate	10%	A	A1	A1		A			A3	A4	B1	A5	AB2	B3	A2	A5
Ferric Nitrate	100%	A		A1		A					A5	B4	AB2	A5	A2	A3
Ferric Sulfate	10%	A	A		A5			A5			A3	A4	A5	A2	A2	A2
Ferric Sulfate	100%	A	A1	A1					A3	A4	N	B3	N	A3	A	A
Ferrous Chloride	10%	A	A			N			N		N	N	B3	A	A2	A
Ferrous Chloride	Saturated	A	A1	A1					A5	A4	N	B1	A3	A3	A2	A3
Ferrous Hydroxide	100%			A												
Ferrous Nitrate	100%		A1	A1					A3	A4	B5	B		A	A	A
Ferrous Sulfate	10%	A	A		A5	N			N		N	N	B	A	A	A
Ferrous Sulfate	50%	A	A1			N			N		N	N	B2	A	A	A
Ferrous Sulfate	100%	A	A1	A1					A3	A4	B3	B2	A2	B1	A	A5
Fluoroboric Acid	100%	A	A1	A1					A4	A4	N	A3	AB3	N		N
Fluosilicic Acid	40%	A	A			N			N		N	N	B5	N	A	N
Fluosilicic Acid	100%	A	A1	A1					A4	A5	B3	B5	AB3	N		N
Formaldehyde	35%	A	A1	A2		N			A4		A3	B3		A1	A2	A3

Process Liquid	Maximum Concentration	Flowtube Liner									Electrode Material					
		Polypropylene	PTFE Teflon	ETFE Tefzel	PFA	Polyurethane	Hard Rubber	Soft Rubber	Neoprene	Elastomer /Linatex Rubber	316SS/904L	Hastelloy C-276/C4	Hastelloy B3	Tantalum	Platinum-10% Iridium	Titanium
Formic Acid	50%	A	A1	A1		N			A4	N	B1	A2	B2	A1	A2	B5
Formic Acid	80%	A	A1	A1		N			A4	N1	B1	A3	A3	A1	A2	B5
Formic Acid	100%	A	A1	A1		N			A5	N	B3	A2	A3	A1	A2	B5
Freon F-11	100%	A	A1	A3		A5			A3	N	B1					
Freon F-12	100%	A	A1	A2		A5			A3	N	B1	A5	A5	B5		B5
Freon F-22	100%	A	A1	A2		N			A5	N	B1	B1	A5	B5		B5
Fruit Juices, Pulp	100%	A	A1		A	N			A3		B1	A3	A5	A5	A	A5
Fuel Oil	100%	A	A1	A1					A4	N	B4	B3	A3	B3		A5
Fumaric Acid	100%			A		N			B							
Furan	100%	N		A	A5	N			N		A4					
Furfural	100%	N	A1	A3		N			A3	N	B1	B5	B1	A1		A3
Gallic Acid	100%	A	A1	A3		N			A5	A4	B1	B3	B2	B5		
Gas Oil	35%		A		A						N	B		N	A	
Gas Oil	100%		A		A						N	N		N	A	
Gas - Manufactured	100%		A1	A1							B5					
Gasoline - Leaded	100%	A	A1	A1		A5			A5	N	B5	A5	A3	A5		A5
Gasoline - Unleaded	100%	A	A1	A3		A5			A5	N	B5	A1	A3	A5		B5
Gasoline - Sour	100%		A1	A1		A5			A5	N	B5	B1		B5		
Glacial Acetic Acid	100%		A	A2		N			N		N	A		A	A	
Glucose (Corn Syrup)	100%	A	A1		A3	N			A5	A5	B1	A		A	A	A
Glycerin (Glycerol)	100%	A	A1	A1		A5			A3	A4	A3	A1	A2	B5	A	A3
Glycol	100%		A1	A1					A4	A5	B5					
Glycolic Acid	100%	A	A1	A1					A3		B1	B3		B3		A3
Green Liquor	100%		A1		A	N			A4	A4	B	B		A	A	A
Heptane	100%	A	A1	A1					A3	N	B1	A3	AB3	B3	A2	B3
Hexane	100%	A	A1	A1	A3	A5			A5	N	A1	A1	AB3	B5	A2	A4
Formaldehyde	100%		A								N	B		A	A	
Hydrazine	100%	A	A	A	A5	N	A5	A5	B		A4			A5		A5
Hydrazine Dihydroanionide	100%			A												
Hydriodic Acid	100%			A												
Hydrobromic Acid	50%	A	A1	A1		N			N	A5	N	B5	AB1	A1	A2	A3
Hydrochloric Acid	5%	A	A								N	N	B4	A	A2	
Hydrochloric Acid	20%	A	A1	A1		A5			A5	A4	N	A5	B1	A1	A2	N
Hydrochloric Acid	40%	A	A1	A1					A5	A3	N	A5	A4	A1	A2	N
Hydrocyanic Acid	10%	A	A1	A1		N			N	A5	B3	B	A3	A	A2	B
Hydrofluoric Acid	20%	A	A1	A1	A5	N			A3	A5	N	B3	AB3	N	A2	N

Process Liquid	Maximum Concentration	Flowtube Liner									Electrode Material					
		Polypropylene	PTFE Teflon	ETFE Tefzel	PFA	Polyurethane	Hard Rubber	Soft Rubber	Neoprene	Elastomer /Linatex Rubber	316SS/90 4L	Hastelloy C-276/C4	Hastelloy B3	Tantalum	Platinum-10% Iridium	Titanium
Hydrofluoric Acid	35%	A	A1	A1		N			A3	A5	N	B3	AB3	N	A2	N
Hydrofluoric Acid	70%	A	A1	A1	A5	N			A3	N	N	B3	AB5	N	A2	N
Hydrofluorosilicic Acid	35%	A	A1	A1					A4	A5	B5	B5	N	N	A	N
Hydrofluorosilicic Acid	100%	A	A1	A							AB2	B1	AB3			
Hydrogen Cyanide	100%		A1	A1					N	A5	A5	A5		B5	A	
Hydrogen Fluoride	100%		A1						N	N	A5	B1	A	N	B	A5
Hydrogen Peroxide	30%	A	A1	A1	A5	N			N	N	B1	A5	N	B1	A2	A3
Hydrogen Peroxide	50%	A	A1	A4		N			N	N	B1	B5	N	B1	A2	A3
Hydrogen Peroxide	90%	A	A1	A4	A5	N			N	N	A5	A3	N	B1	A2	B3
Hydrogen Sulfide	100%	A	A1	A1	A1				A3	N	B1	A5	A3	A1		A5
Hydrogen Phosphide	100%		A1	A4												
Hydroquinone	100%	A	A1	A1					A3	A5	B1	B3		B3	A1	B3
Hydroxy Acetic Acid	35%		A1								B	B		A	A	
Hydroxy Acetic Acid	70%		A1								B	B		A	A	
Hypochlorous Acid	20%		A								N	B		N	A	B
Hypochlorous Acid	100%		A1	A1		N			N	A4	N	B5		B1	A2	B5
Iodine	100%	A	A1	A2					N	N	N	A1	A1	B1	A1	A5
Iodoform	100%		A1	A2	A5						A1	N		B3	A2	B2
Iron Chloride	100%		A								N	B		N	A	
Iron Nitrate	100%		A								N	B		A	A	
Iron Sulfate	100%		A								N	B		A	A	A
Isobutyl Alcohol	100%		A1	A		N			A		A4	A4	A4	A5		A4
Isopropylamine	100%			A							A3					
Jet Fuels - JP4	100%	A	A1	A2	A5	N			N	N	B1	A5	A5			A5
Jet Fuels - JP5	100%	A	A1	A2		N			N	N	B1	A5	A5			A5
Kerosene	100%	A	A1	A1	A3	N			A3	N	B1	B2	A3	B5		A5
Ketones	100%	A	A1	A1	A5				N		B1	A5	A3			A5
Kraft Liquor	100%		A1						A5		A5	A5				
Lactic Acid	100%	A	A1	A1	A5		A5		A5	A5	B	B2	AB3	A1	A2	A1
Lard Oil	100%		A1	A1					N	N	B5	A5	A5	A5		
Latex	100%	A	A			N					A	A		A	A	A
Lauric Acid	100%		A1	A1	A5						B5	B5			A2	

Process Liquid	Maximum Concentration	Flowtube Liner									Electrode Material					
		Polypropylene	PTFE Teflon	ETFE Tefzel	PFA	Polyurethane	Hard Rubber	Soft Rubber	Neoprene	Elastomer /Linatex Rubber	316SS/90 4L	Hastelloy C-276/C4	Hastelloy B3	Tantalum	Platinum-10% Iridium	Titanium
Lauryl Chloride	100%		A1	A1												
Lauryl Sulfate	100%			A												
Lead Acetate	100%	A	A1	A1					A3	A5	B3	B3	A5	B3	A2	A3
Lead Nitrate	100%	A	A1	A5					A3	A3	B5	B3	B2	A	A2	
Lime Slurry	100%		A			A			A		A	A		A	A	A
Linoleic Acid	100%	A	A1	A1					N	N	B1	B1		B1		B3
Linseed Oil	100%		A1	A1	A1				A3	N	B5	B5	A5	B3		A5
Lithium Bromide	100%		A1	A1					A3		B1					
Lithium Chloride	30%	A	A1	A5							N	A3		A3	A	A3
Lithium Chloride	100%	A	A1	A5							N	A		A	A	A
Lithium Hydroxide	10%		A1	A1							B3	B3		B3		
Lubricating Oil	100%		A1	A1	A5				A3	N	B4					A5
M-Cresol (crude)	100%		A1	A1							A3	AB3				AB3
Magnesium Bisulfate	100%	A	A5	A5							B	B				
Magnesium Carbonate	10%	A	A								B	B		A		
Magnesium Carbonate	100%	A	A1	A1					A3	A3	B3			B3	A	A5
Magnesium Chloride	42%	A	A1	A1		A5			A2	A4	B2	A1		A1	A	A1
Magnesium Chloride	100%	A	A1	A1	A1	A5			A3	A4		A1				
Magnesium Hydroxide	100%	A	A1	A1					A3	A3	A2	A2	A2	A5	A	A5
Magnesium Nitrate	100%	A	A1	A1					A3	A4	B1	A5		B3	A	A5
Magnesium Sulfate	25%	A	A1	A1		N			A		B	N	A2	A	A	B
Magnesium Sulfate	40%	A	A	A1		N			A		A	B3	A2	A4	A	A
Magnesium Sulfate	100%	A	A1	A1	A1	A5			A3	A4	B1	A	A2	A4	A	B3
Maleic Acid	100%	A	A1	A1	A1	A5			N	A5	B1	B3	B2	B3		A3
Maleic Anhydride	100%	N		A	A	N			N				A1			
Malic Acid	100%	A	A1	A1		N			A5	A5	A1	B3	A4	B3		A3
Mercuric Chloride	60%	A	A	A1		N			A		N	N	N	A	A	A
Mercuric Chloride	100%		A1	A1		N			N	A4	B1		N	A1	A2	B3
Mercuric Cyanide	100%	A	A1	A1		N			N	A4		B5	N	B1		A5
Mercuric Nitrate	100%	A	A1	A1					A5	A5	N			B1	A2	
Mercury	100%	A	A1	A1	A3	A5	A5	A5	A3	A4	A1	A1	A4	B1	N	A1

Process Liquid	Maximum Concentration	Flowtube Liner									Electrode Material					
		Polypropylene	PTFE Teflon	ETFE Tefzel	PFA	Polyurethane	Hard Rubber	Soft Rubber	Neoprene	Elastomer /Linatex Rubber	316SS/90 4L	Hastelloy C-276/C4	Hastelloy B3	Tantalum	Platinum-10% Iridium	Titanium
Methacrylic Acid	100%			A									A4			
Methane	100%	A	A1	A1	A4		A4	A4	A3	N	A1	A3	A2	B1		A3
Methane Sulfonic Acid	50%		A1	A2												
Methyl Alcohol	100%	A	A1	A1		A5			A3	A4	B1	A1	A2	B1		B3
Methyl Benzoate	100%			A		N			N							
Methyl Bromide	100%	A	A1	A1					N	N	B1		AB1	B3		
Methyl Cellosolve	100%	A	A1	A1					A3		B1			B5		
Methyl Chloride	100%	N	A1	A1	A5				N	N	A1	B5	AB3	B3		A3
Methyl Chloroform	100%		A1	A4					N							
Methyl Chloromethyl Ether	100%			A												
Methyl Cyanoacetate	100%			A												
Methyl Ethyl Ketone	100%	A	A1	A2	A5	N			N	N	B1	B3	AB3	B3		B3
Methyl Methacrylate	100%	N	A1	A4					N	N	B5			B5		
Methyl Salicylate	100%		A1	A3						N				B5		
Methyl Sulfuric Acid	100%		A1	A3							B5			A1		
Methyl Isobutyl Ketone	100%	A	A1	A1					N	N	B1	B3		B3		B3
Methyl Trichlorosilane	100%		A	A							A	A				A
Methylene Bromide	100%		A	A							A					
Methylene Chloride	100%	A	A1	A3		N			N	N	B1	A3	A2	N		A3
Methylene Iodide	100%			A												
Milk	100%	A	A1		A	A5	A	A	A3	A5	A1	A5	A3	A1	A	A5
Mineral Oil	100%		A1	A1		A5			A3	N	B1		A3	A1		A5
Molasses	100%	A	A1		A	N	A5	A5	A3	A4	A1	A5	A5	A5	A	A
Monochlorobenzene	100%		A1	A2		N			N	N	B5	B5	A1	B4		B4
Monoethanolamine	100%	A	A1	A4		N			A5	A5	A3	B3	A3	A3	A2	B3
Morpholine	100%	A	A1	A4					N		B1	A5	B4		B2	
Motor Oil	100%	A	A1		A3						B1					
Mud Drilling	100%		N			A			N		A	A		A	A	A
Naphtha	100%	A	A1	A1		A5			N	N	B3	B3	AB1	B5	A2	B5
Naphthalene	100%	A	A1	A1	A4				N	N	A1	B3	B5	B3	A1	A3

Process Liquid	Maximum Concentration	Flowtube Liner									Electrode Material					
		Polypropylene	PTFE Teflon	ETFE Tefzel	PFA	Polyurethane	Hard Rubber	Soft Rubber	Neoprene	Elastomer /Linatex Rubber	316SS/90 4L	Hastelloy C-276/C4	Hastelloy B3	Tantalum	Platinum-10% Iridium	Titanium
Nickel Chloride	10%	A	A	A1		C			B		N	A	A2	B	A	B
Nickel Chloride	20%	A	A	A1		C					N	N	A2	A	A	N
Nickel Chloride	100%	A	A1	A1	A5	C			A3	A4	B5	N	A3	B3	A2	A3
Nickel Nitrate	10%	A	A	A1							AB5	B	B5	B	A	
Nickel Nitrate	100%	A	A1	A1	A5				A3	A4	A1	B1	B5	B3	A2	A5
Nickel Sulfate	10%	A	A			C			A		B	B	A5	A3		B3
Nickel Sulfate	100%	A	A1	A1	A5	C			A3	A4	B3	B3	A4	N	A2	N
Nicotine	100%		A1	A3					N		B3			B5		
Nicotonic Acid	100%		A1	A1					A3		B1					
Nitric Acid (Anhydrous)	100%		A1	N		N			N	N	A5	B5	N	A1	A2	B3
Nitric Acid	10%	A	A1	A4	A3	N			N	N	A3	A3	A3	A1	A	A1
Nitric Acid	20%	A	A1	A4	A4	N			N	N	A5	A4	A3	A1	A2	A1
Nitric Acid	40%	A	A1	A4	A4	N			N	N	A5	A5	A4	A1	A	A1
Nitric Acid	50%	A	A1	A4	A1	N			N	N	A5	A5	A4	A1		A1
Nitric Acid	70%		A1	A5	A4	N			N	N	A5	A5	A4	A1	A	A1
Nitric Acid-Sulfuric Acid	50%/50%		A1	A3							A4			B5		
Nitrobenzene	100%	A	A1	A1	A3	N			N	N	B1	N	B2	B3	A2	A3
Nitrogen	100%		A1	A1	A3	A			A3	A3	A1	A1	A1	A1		
Nitrogen Dioxide	100%		A1	A3	A5									A1		
Nitromethane	100%	A	A1	A3					N	A5	B5			B5		
Nitrous Acid	Concentrated	A	A1	A3	A5				N	N	B5	N		B1	A2	
Octane	100%		A1	A1	A5				A2		B5					
Octene	100%			A												
Oleic Acid	100%	A	A1	A1	A3	A5			N	N	A1	B3	A3	B3	A1	A5
Oleum	20%	N	A1	A4		N			N	N	B5			N	A	A
Oxalic Acid	Saturated	A	A1	A2		N			N	A4	N	B3	B2	A3	A	B5
p-Dioxane	100%		A1	A2		N			N			A5				
Palmitic Acid	Concentrated	A	A1	A1	A3				N		B1	B5				
Paper Stock	100%		A1	A1							A	A		A	A	A
Perchloric Acid	10%	A	A1	A2		N			A5	A4	N			A1		N
Perchloric Acid	70%	A	A1	A4		N			N		N	B2		A1	A	N
Perchloric Acid	100%	A	A	AB5	A2	N			B		N	N		A	A	
Perchloroethylene	100%	N	A1	A1		N			N	N	A5	B3	AB1	B3		A3
Petrolatum	100%	N	A1	A1					A3		B1			A5		
Petroleum Oils, Refined	100%		A1	A1					A5	N	B5			A1		
Petroleum Ether	100%		A1	A3							A5	A5		A5		A5
Phenol	10%	A	A1	A2		N			N	A5	B3	B1	A4	B1	A	B5
Pheno (Carbolic Acid)	100%	A	A1	A3	A1	N			N	N	A1	A1	A1	B1	A1	A5

Process Liquid	Maximum Concentration	Flowtube Liner									Electrode Material					
		Polypropylene	PTFE Teflon	ETFE Tefzel	PFA	Polyurethane	Hard Rubber	Soft Rubber	Neoprene	Elastomer /Linatex Rubber	316SS/904L	Hastelloy C-276/C4	Hastelloy B3	Tantalum	Platinum-10% Iridium	Titanium
Phenolsulfonic Acid	100%			A							B1		A2			A5
Phenylhydrazine	100%		A1	A3		N			A5	A5					A2	
Phenylhydrazine Hydrochloride	100%		A1	A3											A2	
o-Phenylphenol	100%			A												
Phosgene Liquid	100%		A1	A3	A3						B2			B1	A1	
Phosphate Slurry	100%		A								N	A		A	A	A
Phosphoric Acid	30%	A	A1	A1		A5			A3	A4	B3	A4	A1	A1		C5
Phosphoric Acid	85%	A	A1	A1		N			N	A5	B1	A3	A1	A1	A	C5
Phosphoric Anhydride	100%		A1						A5		B3			A5	A2	
Phosphorus	100%	A	A1								A5	A4	A4	B1		
Phosphorus Pentoxide	100%		A1	A2							B5	N	N	B5	A2	
Phosphorus Oxychloride	100%		A1	A3							N	B3		B1	A2	A5
Phosphorus Pentachloride	100%			A							AB5			A1	N	
Phosphorus Trichloride	100%		A1	A1	A5	N			N		A5	B5	N	A1	N	A5
Photographic Solutions	100%	A	A1			N			A3	A4	A1		A4	A5		B5
Phthalic Acid	100%	A	A1	A3					A3		A1	B1	B1	B1	A1	A5
Phthalic Anhydride	100%	N	A1	A3	A5					A4	A1	A1	A1	B1		
Picric Acid	100%	A	A1	A5					A3	N	B1	B1	A5	B3		A5
Polyvinyl Acetate	100%		A1	A1					A3		A3			B5		
Potassium Aluminum Chloride	100%			A												
Potassium Aluminum Sulfate	50%		A1	A												
Potassium Aluminum Sulfate	100%		A1			N			A4		B5	A5		A3	A	A3
Potassium Bicarbonate	30%	A	A1	A1		N			N		A3	B3		B5		A3
Potassium Bicarbonate	100%	A	A	A							B	B		A	A	
Potassium Borate	100%		A1	A1					A4							

Process Liquid	Maximum Concentration	Flowtube Liner									Electrode Material					
		Polypropylene	PTFE Teflon	ETFE Tefzel	PFA	Polyurethane	Hard Rubber	Soft Rubber	Neoprene	Elastomer /Linatex Rubber	316SS/90 4L	Hastelloy C-276/C4	Hastelloy B3	Tantalum	Platinum-10% Iridium	Titanium
Potassium Bromate	100%		A1	A1					A4							
Potassium Bromide	30%	A	A1	A1	A1				A4	A4	B1	B5	A5	A5		A3
Potassium Carbonate	50%		A1	A1					A3	A4	A3	B3	A2	B1	A2	A3
Potassium Chlorate, Aqueous	30%	A	A1	A1					A5		A1	B3	AB1	B5	A2	A3
Potassium Chloride	30%	A	A1	A1		N			A4	A4	A1		B2	A1	A	A3
Potassium Chloride	60%	A	A	A1	A5	A	A5	A5	A		B	N		A	A	B
Potassium Chloride	100%	A	A	A	A1	N			A		N	A	A1	A	A	A
Potassium Chromate	30%	A	A1	A1	A5				A5		B1	B3	A2	B5		A3
Potassium Cyanide	30%	A	A1	A1					A3	A4	B3	B3	B2	A5	A2	N
Potassium Dichromate	30%	A	A1	A1		N			N	N	A1	B3		A1	A	A3
Potassium Dichromate	60%	A	A			N			A		A	B		A	A2	A
Potassium Ferricyanide	30%	A	A1	A3	A1				A2		N	N	B2	A5	N	A5
Potassium Ferrocyanide	30%	A	A1	A1	A1				A3		N	N	B2	B3	N	A5
Potassium Fluoride	100%		A1	A1						N	B3			B5		N
Potassium Hydroxide (Caustic Potash)	10%	A	A			N			N		B	N	B1	N	A1	A
Potassium Hydroxide (Caustic Potash)	50%	A	A1	A3					A3	A5	B1	B1	A2	N	A1	A3
Potassium Hypochlorite	40%		A			N			N		N	B		B		A
Potassium Hypochlorite	100%		A1	A1							B5	B3	N	B3		
Potassium Nitrate	80%	A	A1	A1		N			A3	A4	B1	B3		B1	A	A3
Potassium Nitrite	100%		A1								N	N		A	A	B3
Potassium Perborate	100%		A1	A1												
Potassium Perchlorate	100%		A1	A3							B1					
Potassium Permanganate	10%	A	A1	A1					A5	N	B1	A5	AB3	B3	A2	B5

Process Liquid	Maximum Concentration	Flowtube Liner									Electrode Material					
		Polypropylene	PTFE Teflon	ETFE Tefzel	PFA	Polyurethane	Hard Rubber	Soft Rubber	Neoprene	Elastomer /Linatex Rubber	316SS/90 4L	Hastelloy C-276/C4	Hastelloy B3	Tantalum	Platinum-10% Iridium	Titanium
Potassium Permanganate	100%	A	N	A							N	N	AB3	A	A2	A
Potassium Persulfate	10%		A								A	N		A	A	A
Potassium Persulfate	100%		A1	A4					A4		B1	N		A	A	
Potassium Sulfate	10%	A	A1	A1		A5			A3	A4	A1	A3	A2	A5	A1	A5
Potassium Sulfate	20%	A	A		A4	N		A5	A		A	A	A2	A	A1	A
Potassium Sulfate	100%	A	A	A	A5	N	A5	A5	A		A	A	AB2	A	A	A
Potassium Sulfide	10%	A	A	A1							B			B		A
Potassium Sulfide	100%	A	A1	A1					A5		B3	B5		A5		A5
Propane	100%	A	A1	A1	A5				A5	N	B1	B5		B5		B5
Propionic Acid	100%		A1	A3					N		B3	A1	A5		A1	
Propyl Alcohol	100%		A1	A3					A3	A4	A1	A5	A4	B5		A5
Propylene Chlorohydrin	100%		A3	A3												
Propylene Dibromide	100%			A												
Propylene Dichloride	100%		A1	A3					N		A5					A3
Propylene Glycol	100%	A	A1	A5					A5		B3	B5	B5	A5	A5	
Propylene Oxide	100%		A1	A4					N	N		B5				
Pyridine	100%	A	A1	A4	A3				N	N	B1	A4	A2	B1	A2	B2
Pyrogallol	100%		A1	A4	A5						B2	B2				
Salicylaldehyde	100%		A1	A3												
Salicylic Acid	100%	A	A1	A1		N			A5	A5	B1	A1	B5	B3	A2	A5
Salt Brine	100%	A	A1	A	A5						A2	A	A2	A1		
Sea Water	100%	A	A	A	A	N	A3	A3	A		N	A	A3	A	A	A
Sewage, Raw	100%	A	A	A1		N			N		A	A	A3	A	A	A
Silicon Tetrachloride	100%			A							A5		A4			
Silver Chloride	100%		A1	A1							N		N	A5		A5
Silver Cyanide	100%		A1	A1					A3		A5	A5	A5	A5		A5
Silver Nitrate	50%	A	A	A		A			A		A5	A5	A5	A1		A5
Silver Nitrate	100%	A	A1	A1		A5			A3	A4	N		AB3	A	A	A
Sludge, Activated	100%	A	A	A		N			A		A	A		A	A	A
Sludge, Primary	100%	A	A	A		N			A		A	A		A	A	A
Sludge, Thickened	100%	A	A	A		A			A		A	A		A	A	A
Sludge, Waste	100%	A	A	A		A			A		A	A		A	A	A
Soap Solutions	100%	A	A1		A5	A5	A5	A5	A3	A4	B5	A5	A1	A5	A	A5

Process Liquid	Maximum Concentration	Flowtube Liner									Electrode Material					
		Polypropylene	PTFE Teflon	ETFE Tefzel	PFA	Polyurethane	Hard Rubber	Soft Rubber	Neoprene	Elastomer /Linatex Rubber	316SS/90 4L	Hastelloy C-276/C4	Hastelloy B3	Tantalum	Platinum-10% Iridium	Titanium
Sodium Acetate	100%	A	A1	A1		N			A3		B1		A2	A5	A1	A2
Sodium Benzene-Sulfonate	100%			A												
Sodium Benzoate	100%		A1	A1	A4							B5	A5	A5		A5
Sodium Bicarbonate	20%	A	A1	A1		N			A3	A4	A1		AB	A4	A	A3
Sodium Bicarbonate	100%	A	A	A		N			A		B	B	A4	A	A	A
Sodium Bisulfate	40%	A	A	A		N			A		N	N	B4	A	A2	
Sodium Bisulfate	100%	A	A1	A1		N			A3	A4	N	N	B4	A	A	A
Sodium Bisulfide	100%		A								N	B		A	A	
Sodium Bisulfite	40%	A	A	A1		N			A		B2	B2	B2		A2	B2
Sodium Bisulfite	100%	A	A1	A1		N			A3	A4	B1	B3	B2	B5	A5	
Sodium Borate (Borax)	100%	A	A1	A3					A3	A4	B3	B3	A4	A5	A	A5
Sodium Boric Acid	100%		A								N	N		A	A	
Sodium Bromide	100%		A1	A3					A5				B2	B1	A	B5
Sodium Carbonate	10%	A	A	A1		N			A		A	A	A2	A2	A2	A
Sodium Carbonate	20%	A	A	A1		N			A		A	A	A2	A2	A2	A
Sodium Carbonate	100%	A	A1	A1	A3	N	A5	A5	A3	A3	B1	B3	A2		A2	A3
Sodium Chloride	Saturated	A	A1	A1		A5			A3	A5	N	A	A2	A1	A2	A3
Sodium Chlorate	40%	A	A	A1		N			A		B	B		A		A
Sodium Chlorate	100%	A	A1	A1	A3	N			A5	A4	N		AB3	N	A	A3
Sodium Chloride	30%	A	A	A1	A5	A	A5	A5	A		B1	B2	A2	A	A	A
Sodium Chlorite	10%		A		A5						N	B		A	B	
Sodium Chlorite	100%		A1							A3	N	N		A1	B	
Sodium Chromate	80%		A1	A1					A5		A3	A3	A2	A	A	A
Sodium Cyanide	100%	A	A1	A1					A3	A3	A1	B5	AB3	B2	N	A5
Sodium Dichromate	100%		A1	A3					N		B5	A5		A5		

Process Liquid	Maximum Concentration	Flowtube Liner									Electrode Material					
		Polypropylene	PTFE Teflon	ETFE Tefzel	PFA	Polyurethane	Hard Rubber	Soft Rubber	Neoprene	Elastomer /Linatex Rubber	316SS/90 4L	Hastelloy C-276/C4	Hastelloy B3	Tantalum	Platinum-10% Iridium	Titanium
Sodium Ferricyanide	100%		A1	A1					N		B1	A3	A3	A5		
Sodium Ferrocyanide	100%	A	A1	A1							B5	B		A5		
Sodium Fluoride	100%	A	A1	A1					A4	A4	N	B3		N		A5
Sodium Glutamate	100%			A												
Sodium Hydrosulfite	100%		A1								B	A5		A5	A	
Sodium Hydroxide	5%	A	A1	A		N			N		A		AB2	N	A	A
Sodium Hydroxide	10%	A	A1	A3	A5	A5			A3	A4	A1	B2	AB2	N		A3
Sodium Hydroxide	25%	A	A	A		N			N		N	A	A1	N	A	A
Sodium Hydroxide	30%	A	A1	A2		A5			A3	A4	A4	B3	A1	N	A	A3
Sodium Hydroxide	40%	A	A	A							B	A	A1	N	A	A
Sodium Hydroxide	50%	A	A1	A2	A3	A5	A3	A3	A3	A4	A4	A3	A1	N	A	A5
Sodium Hypochlorite	Concentrated	A	A1	A1		N			N	A5			AB4	B1		
Sodium Hypochlorite	15%	A	A	A1		N			N		N	B		B	A2	B
Sodium Hypochlorite	20%	A	A1	A1		N			N	A5	N	N		B1	A2	B3
Sodium Hypochlorite	25%	A	A1	A1		N			N		N	B		B	A2	B
Sodium Hyposulfite	5%		A1	A1							N	A5	A5	A5		
Sodium Iodide	100%		A1	A1					A4					B5		
Sodium Lignosulfonate	100%			A												
Sodium Metasilicate	100%	A	A3	A1							A2	A2	A2			A3
Sodium Methane	100%		A													
Sodium Nitrate	40%	A	A	A1		N			B		A		AB3	A	A2	A
Sodium Nitrate	50%	A	A	A1		N			B		N	B	AB3	A	A2	A
Sodium Nitrate	100%	A	A1	A1	A3	N			A3	A4		N	AB3	B1	A2	A5
Sodium Nitrite	40%		A								B2	B2	N	A	A	A
Sodium Nitrite	100%		A1	A1	A3		A5	A5	A4		N	N	N	B3	A	A3
Sodium Perborate	10%	A	A1	A3					A3	A4	B1	B3	B2			
Sodium Perchlorate	100%			A							A5		B2	A3	A2	A3
Sodium Peroxide	10%	A	A1	A1					A3	A4	B1	B3			A2	
Sodium Persulfate	100%			A												

Process Liquid	Maximum Concentration	Flowtube Liner									Electrode Material					
		Polypropylene	PTFE Teflon	ETFE Tefzel	PFA	Polyurethane	Hard Rubber	Soft Rubber	Neoprene	Elastomer /Linatex Rubber	316SS/90 4L	Hastelloy C-276/C4	Hastelloy B3	Tantalum	Platinum-10% Iridium	Titanium
Sodium Phosphate (Mono-Basic)	100%		A	A	A3	N			A		B	A	A5	A5	A2	A2
Sodium Phosphate (Tri-Basic)	100%		A1	A1		A			A4	A4	B3	B3	B2	B2	A2	B3
Sodium Silicate	100%	A	A1	A1	A5		A5	A5	A3	A3	B1	B3	B2	B1	A2	A3
Sodium Silicofluoride	100%			A												
Sodium Sulfate	20%	A	A	A1	A3		A3	A3	A			B	B2	A1	A2	A2
Sodium Sulfate	30%	A	A	A1		N			A		B	B	B2	A1	A2	B
Sodium Sulfate	100%	A	A1	A1	A3	A5			A3	A4	A1	B3	A3			
Sodium Sulfide	10%	A	A1	A1		N			A3	A4	B2	B2	B2	B2	A2	B2
Sodium Sulfide	50%	A	A1	A1		N			A	3A4	B3	B3	B2		A2	
Sodium Sulfide	100%	A	A	A	A5	N	A5		N		N	N	AB3		A	
Sodium Sulfite	10%	A	A1	A1	A1	N			A3	A4	A3	N	A5		A2	
Sodium Sulfite	30%	A	A	A1		N					B	N	C2	A	A2	A
Sodium Sulfite	100%	A	A	A	A5	N	A5	A5	N		B	N	B3	A	A	A
Sodium Tetraboric Acid	100%		A								B	B		A	A	
Sodium Thiosulfate (Hypo)	100%	A	A1	A1		A5			A3	A4	B1	B5			A2	
Sorbic Acid	100%			A												
Sour Crude Oil	100%		A1	A1		A5						A4				
Stannic Chloride	100%	A	A1	A1					A3	A4	N		B2	B1	A	
Stannous Chloride	100%		A1	A1					A4	A4		B3	B2	B3	A2	A5
Stannous Fluoride	100%	A		A												
Stearic Acid	100%	A	A1	A1	A3	A5			A3	N	A1	A1	A3	B	1A1	A1
Stoddard's Solvent	100%	A	A1	A1					N	N	B5	A5	A3			
Styrene Monomer	100%		A3	A2	A2	N			N	A						
Succinic Acid	100%		A1	A1							B3	B3	B3	B1		A1
Sulfamic Acid	100%		A1	A3					A4	A4				B1		A3
Sugar Juice	100%		A			N			N		A	A	A5	A	A	A
Sulfinol	100%		A3								A4					
Sulfolane	100%		A5	A3							A5					
Sulfur Dioxide (Wet)	100%	A	A1	A2			A5		N	N	B4	A4	N	B1	A1	N
Sulfur Trioxide	100%	N	A1	A5	A5				N	A4	B1	B1	C5	N		N
Sulfuric Acid	10%	A	A1	A1	A3	N	A3	A3	A3	A4	N	A3	A2	B1	A1	N
Sulfuric Acid	30%	A	A1	A1	A3	N			A3	A4	N	A5	A5	B1	A1	N
Sulfuric Acid	50%	A	A1	A1	A3	N	A5	A5	A3	A5	N	A5	A5	B1	A1	N
Sulfuric Acid	60%	A	A1	A1	A5	N	A5	A5	A3	N	N	A1	A5	B1	A1	N
Sulfuric Acid	70%	A	A1	A1	A3	N			A3	N	N	B3	N	B1	A1	N
Sulfuric Acid	80%	A	A1	A1		N			N	N	B5	A5	B3	B1	A1	N

Process Liquid	Maximum Concentration	Flowtube Liner									Electrode Material					
		Polypropylene	PTFE Teflon	ETFE Tefzel	PFA	Polyurethane	Hard Rubber	Soft Rubber	Neoprene	Elastomer /Linatex Rubber	316SS/90 4L	Hastelloy C-276/C4	Hastelloy B3	Tantalum	Platinum-10% Iridium	Titanium
Sulfuric Acid	90%	A	A1	A1		N			N	N	B5	A4	A1	B1	A1	
Sulfuric Acid	95%	A	A1	A1		N			N	N	B3	A4	A1	B1	A1	
Sulfuric Acid	98%	A	A1	A1		N			N	N	B3	A5	A1	B1	A1	N
Sulfuric Acid	100%	A	A1	A1		N			N	N	B3	A5	A1	B1		N
Sulfuric Acid (Fuming)	100%	N	A1	A5					N		A5	B5		N	A1	N
Sulfurous Acid	100%	A	A1	A2	A5	N			N	N	A5	B1	B2	A1	A2	A4
Tall Oil	100%		A1	A1					N	N	B1	A1	A1	B1		
Tannic Acid	100%	A	A1	A1					A3	A5	B3	N	AB3	B3	A2	
Tartaric Acid	100%	A	A1	A1	A3	A	A5	A5	A3	A4	A1	B3	AB3		A2	
Tetraethyl Lead	100%		A1	A1		N			B		B1					
Tetrahydrofuran	100%		A1	A3		C			N	N	B1	A5	A3			B3
Tetramethyl Ammonium Hydroxide	50%		A1	A3												
Thionyl Chloride	100%		A1	A3					N	N	N			B1		
Tin Chloride	100%		A1		A2				A3	A4	B4	B1		A5		
Tin Tetrachloride	100%		A1	A							N	B2	B2	A1		A1
Titanium Dioxide	100%		A	A		A			A		A	A		A	A	A
Titanium Tetrachloride	100%		A1	A2					N	N	B5	B5	N	A5		A1
Toluene	100%	A	A1	A1	A1	N	N	N	N	N	A1	A3	A2	A1	A2	A3
Tomato Juice	100%	A	A1	A3					A3		B1	B5	A2	A5		
Tributyl Phosphate	100%		A1	A4					N	N	B5	B5				
Trichloroacetic Acid	100%	A	A1	A3	A3	A5			N	N	N	B3	B2	B1		N
Trichlorethylene	100%	A	A1	A1		N			N	N	B1	A3	A2	B3		A3
Trichloromethane	100%			A												
Triethanolamine	100%		A1	A4		N			A4	A5	B5	B3	A3	B3	A1	
Triethylamine	100%	N	A1	A2	A5						B5			A3		
Triethyl Phosphate	100%		A3	A3	A5						A5	A5	A1			
Triphenyl Phosphite	100%		A3	A3							A5					
Trisodium Phosphate	100%	A	A1	A1		A5			A3	A4				B5	A	
Turpentine	100%	N	A1	A1	A5	N	A5		N	N	A3	B5	A3	B5	A1	B5
Urea	50%	A	A1	A1	A4	N			A4	A4	B3		BC3			A3
Varsol	100%			A												
Vinegar	100%	A	A1	A3	A1	N	A5	A5	A3	A4	B3	B5	AB3	A5		A5
Vinyl Acetate	100%	A	A1	A1	A5				A5		A4	A1				
Vinyl Chloride (Monomer)	100%		A3	A	A5	N			N		B1		A3		A1	

Process Liquid	Maximum Concentration	Flowtube Liner									Electrode Material					
		Polypropylene	PTFE Teflon	ETFE Tefzel	PFA	Polyurethane	Hard Rubber	Soft Rubber	Neoprene	Elastomer /Linatex Rubber	316SS/904L	Hastelloy C-276/C4	Hastelloy B3	Tantalum	Platinum-10% Iridium	Titanium
Water (Pure)	100%	A		A												
Water, Clean or Dirty	100%	A	A			A			A		A	A	A	A	A	A
Water, Deionized	100%	A	A3	A2	A5		A5	A5			A3	A1	AB3			A1
Water, Fresh	100%	A	A		A	A	A5	A5	A		A	A	A4	A	A	A
Water, Salt	100%	A	A1	A1	A5	N	A5	A5	A3	A4	B1	A1	A3	A5		A5
Water, Sea	100%	A	A1	A1		A5			A3		B1	A1		A5		A3
Water Sewage	100%	A	A1	A1					A4		B5			A5		A5
Wax	100%		A	A							A5	A3				
White Liquor	100%	A	A1		A1	N			A4	N	B5	B5		N	A	A
Xylene	100%	A	A1	A1	A4	N			N	N	B3	A1	A3	A3	A1	A3
Zinc Acetate	100%			A		N			B							
Zinc Chloride	20%	A	A	A		N			A		B3	B1	B2	A2	A2	A3
Zinc Chloride	50%	A	A	A1		N			A		N	N	B2	A2	A2	A3
Zinc Chloride	100%	A	A1	A1	A1	N			A4	A4	N	B1	AB1	A3	A	
Zinc Hydrosulfite	10%		A	A							A5					
Zinc Sulfate	Saturated	A	A1	A1	A2	N			A4	A4	A2	A2	A2	A5	A2	A5
Zinc Sulfide	100%			A												
Zinc Sulfate	50%	A	A	A1		N			A4	A4	B3	B3	B2	A5		A5

** Ceramic Carbide Liner Option: Especially suitable for highly abrasive, fine-grained liquids, such as sand, lime milk, pulp, etc.*

Legend:	Liners:	Electrodes (Corrosion Rate per Year)	Temperatures:
	A= Resistant N= Not Resistant Blank= No Information	A= Less than 0.002 inches B= Less than 0.020 inches C= Less than 0.050 inches N= Greater than 0.050 inches Blank= No Information	1= 248F (120C) 2= 212F (100C) 3= 176F (80C) 4= 140F (60C) 5= 68F (20C)

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