THE CHLORINE INSTITUTE

Pamphlet 165

Instrumentation for Chlorine Service

Edition 2

A LEGACY OF SAFETY STEWARDSHIP
since 1924

July 2009

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1. INTRODUCTION

1.1 SCOPE

This pamphlet is intended to assist the Chlor-Alkali industry in management of instrumentation systems. It includes information on the design as well as the maintenance of the instrumentation systems.

It provides guidance on the selection of materials, the selection of primary elements and control devices, and the design and installation of instrumentation, including the sensing lines for wet and dry chlorine gas and dry liquid chlorine service. Only critical instrumentation issues related to chlorine applications are addressed. The recommendations of this pamphlet are based on the experience of chlorine producers and consumers and represent current industry practices. It is not the intent of this pamphlet to limit the use of specific materials or instruments, provided they have been engineered for the specific design conditions and the particular requirements of chlorine service.

This pamphlet does not address sample collection equipment, chlorine analysis equipment, or general instrumentation practices. However, operators of chlorine systems should consider the need for on-line (continuous) analysis of the chlorine for impurities such as nitrogen trichloride, water, or hydrogen, and follow up with research of the various analyzer manufacturers available.

It also includes information on the elements of an effective maintenance program. This includes methods to classify, inspect, test and manage the records of the control elements. Key Performance Indicators are provided to manage the maintenance program.

1.2 CHLORINE INSTITUTE STEWARDSHIP PROGRAM

The Chlorine Institute, Inc. exists to support the chlor-alkali industry and serve the public by fostering continuous improvements to safety and the protection of human health and the environment connected with the production, distribution and use of chlorine, sodium and potassium hydroxides, and sodium hypochlorite; and the distribution and use of hydrogen chloride. This support extends to giving continued attention to the security of chlorine handling operations.

Chlorine Institute members are committed to adopting CI's safety and stewardship initiatives, including pamphlets, checklists, and incident sharing, that will assist members in achieving measurable improvement. For more information on the Institute's stewardship program, visit CI's website at www.chlorineinstitute.org.

1.3 DEFINITIONS

In this pamphlet, the following meanings apply, unless otherwise noted:

ANSI	American National Standards Institute
ASTM	Formerly known as "The American Society for Testing and Materials" (100 Barr Harbor Drive, West Conshohocken, PA 19428-2959)
CPVC	chlorinated polyvinylchloride
dry liquid chlorine	Liquid chlorine with its water content dissolved in solution; see CI Pamphlet 100. For the purpose of this pamphlet, dry liquid chlorine is considered non-corrosive to carbon steel piping systems below 300°F (149°C).
dry chlorine gas	Chlorine gas that contains moisture exerting a vapor pressure of no more than 2.0mm of mercury; see CI Pamphlet 100. For the purpose of this pamphlet, dry chlorine gas is considered non-corrosive to carbon steel piping systems below 300°F (149°C).
ECTFE	Ethylene chlorotrifluoroethylene
ETFE	Ethylene tetrafluoroethylene
FEP	Fluorinated ethylene propylene
final control element	Equipment used to adjust a process variable in response to the signal(s) from the primary element(s)
Hastelloy®	A registered trademark of Haynes International, Inc.
Institute	The Chlorine Institute, Inc.
ISA	International Society of Automation, formerly Instrument Society of America
KPI	Key Performance Indicator
Monel®	A registered trademark of Inco Alloys International, Inc.
primary element	Equipment used to sense and measure a process variable
PFA	Perfluoroalkoxy
PTFE	Polytetrafluoroethylene
PVC	Polyvinylchloride
PVDF	Polyvinylidene fluoride
wet chlorine gas	Chlorine gas that contains moisture exerting a vapor pressure of more than 2.0mm of mercury; see CI Pamphlet 100. For the purpose of this pamphlet, wet chlorine gas will generally refer to low pressure gas as typically seen before the drying towers in a producer's plant.

1.4 DISCLAIMER

The information in this pamphlet is drawn from sources believed to be reliable. The Institute and its members, jointly and severally, make no guarantee, and assume no liability, in connection with any of this information. Moreover, it should not be assumed that every acceptable procedure is included, or that special circumstances may not warrant modified or additional procedures. The user should be aware that changing technology or regulations may require a change in the recommendations herein. Appropriate steps should be taken to ensure that the information is current when used. These recommendations should not be confused with federal, state, provincial, municipal or insurance requirements, or with national safety codes.

1.5 APPROVAL

The Institute's Health, Environment, Safety, and Security Issue Team approved Edition 2 of this pamphlet on July 23, 2009.

1.6 REVISIONS

Suggestions for revision should be directed to the Secretary of the Institute.

1.6.1 Significant Revisions in Current Edition

The primary revision to Edition 2 is the addition of Section 6: Mechanical Integrity and Reliability Program. This new section includes guidance and suggestions for elements that comprise a successful reliability program for critical instruments.

1.7 REPRODUCTION

The contents of this publication are not to be copied for publication, in whole or in part, without prior Institute permission.

2. GENERAL INFORMATION AND MATERIAL SELECTION

2.1 PRECAUTIONS

Chlorine is a hazardous material. Additional information about general precautions in chlorine handling can be found in CI Pamphlet 1.

The majority of instrumentation is installed in piping. More detailed information on dry chlorine piping can be found in CI Pamphlet 6.

The selection of instrumentation for chlorine service should only be undertaken by qualified individuals with a full understanding of the properties of chlorine and the requirements of chlorine systems. Particular attention must be given to:

1. Atmospheric boundary interfaces. In dry chlorine service, there is the possibility of moisture exposure at atmospheric boundary interfaces (e.g., valve stems, threaded connections, flange connections). In these areas special materials of construction must be considered. Additional information can be found in CI Pamphlet 6.

2. The conditions and quality of the chlorine, liquid or gaseous phase, water content, pressure and temperature, all of which play a role in the selection of materials and types of control elements.
3. The properties of potential contaminants (e.g., ferric chloride), the effects of the contaminants on component materials (e.g., corrosion), and the consequences of contaminant accumulations (e.g., plugged passageways).
4. Materials selection. Many materials that are acceptable for dry chlorine are not acceptable and can be hazardous in wet chlorine service and vice versa (See Section 2.2).
5. Moisture intrusion. Dry chlorine systems should be protected against the intrusion of moisture.
6. Requirements for location with respect to geometry and elevation. Review the manufacturer's recommendations for location. Allow adequate working space for operation and routine servicing.
7. Chlorine reaction. Instrumentation and materials used in chlorine service should be thoroughly cleaned and dried. Materials should be free from oils, grease, and other materials that could react with chlorine to cause fire, corrosion, pressure increase or harmful deposits (See CI Pamphlet 6).
8. The need to isolate and purge instrumentation prior to calibration or maintenance and the need to prevent the release of chlorine into the atmosphere.
9. The effects of variation in temperature on chlorine and the implications of auto refrigeration, flashing, two-phase flow, density changes, dissolved gases, and excessive pressure drops. Additional information can be found in CI Pamphlet 100.
10. Thermal expansion of liquid chlorine. Protect equipment and piping from over-pressure where chlorine can be trapped between closed valves. Liquid chlorine has an unusually high coefficient of thermal expansion that can cause rupture as temperature increases, unless the system is protected with items such as expansion chambers or relief devices.

2.2 MATERIALS

See Tables 2-1 and 2-2 for a list of common materials and their compatibility in chlorine service and for recommended materials of construction for primary element components. Materials are listed in the tables in general terms. Users should investigate and select the appropriate grade or alloy for each specific application. See Section 4 for information on materials in final control elements.

2.2.1 Dry Chlorine Service

For an exact definition of dry and wet chlorine see CI Pamphlet 100.

Carbon steel is commonly used in dry chlorine service but should not be used where process temperatures are expected to exceed 300°F (149°C) due to increased corrosion rates and possible ignition at higher temperatures.

Many carbon steels are susceptible to brittle fracture at temperatures below -20°F (-29°C). Special low temperature steels (e.g. ASTM A333 carbon steel) or Monel® can be used for these applications. Additional information can be found in CI Pamphlet 6.

Material selection is related to component thickness. Components with a thickness of less than $^1/_8$ inch are generally made of a higher alloy material giving additional corrosion protection. Monel®, Hastelloy® C and tantalum are commonly used for instrument components that are in contact with dry chlorine.

Some stainless steels of the 300 series have useful properties at low temperatures but can fail due to chloride stress corrosion cracking in the presence of moisture.

Aluminum, titanium and tin must not be used in dry chlorine because they will react violently at room temperatures. Aluminum is often used in instrument housings, where it is not in direct contact with chlorine, but the exterior should be painted or coated to prevent corrosion.

Plastics are often used as liners, seals and ancillaries such as tubing and fittings. Fluoropolymers are the most common lining material; PTFE, FEP, ECTFE, PVDF and PFA are all used as liners. Chlorine will permeate all fluoropolymers to a degree. The rate of permeation is dependent on the compound, material density, temperature and other factors, and should be considered when selecting liner material and the underlying material behind the liner material. Plastics should be used only as specified by a designer or equipment manufacturer who is experienced in handling chlorine. Reference is made to CI Pamphlet 6. Typical limitations on the use of plastics in chlorine service are shown in Table 2-1.

Nonferrous Tubing Systems

Nonferrous metal piping or tubing is generally used for flexible instrument connections.

Because of the reaction between chlorine and tin, no tin should be used in brazing alloys for flexible connection fittings. Therefore, silver brazing alloys must contain no tin and should contain at least 44% silver.

In situations requiring protection against external corrosion, protective coatings such as cadmium or zinc plating are recommended. Tubing components should be limited to a single manufacturer since connectors are not compatible between manufacturers.

Gasket type connections are preferred where they are disconnected frequently. Flared type fittings are not recommended.

Table 2-1 identifies some commonly used nonferrous materials. Consideration should be given to the mechanical protection of tubing systems from external damage.

2.2.2 Wet Chlorine Service

Please see CI Pamphlet 100 for an exact definition of dry and wet chlorine.

Wet chlorine is corrosive to many of the materials commonly used for dry chlorine service. Plastics including PVC, CPVC, FRP, dual laminates and fluoropolymers are commonly used because of their resistance to wet chlorine gas. However, use of plastic pressure-containing components should be carefully reviewed to ensure they do not mechanically fail in pressurized gas service (i.e., rupture, loss of strength with increasing temperature, brittleness, UV attack). For higher pressures, titanium or fluoropolymer lined metallic systems can be used.

Plastics are often used as liners, seals and ancillaries such as tubing and fittings. Fluoropolymers are the most common lining material; PTFE, FEP, ECTFE, PVDF and PFA are all used as liners. Chlorine will permeate all fluoropolymers to a degree. The rate of permeation is dependent on the compound, material density, temperature and other factors, and should be considered when selecting liner material and the underlying material behind the liner material. Polypropylene and polyethylene are susceptible to cracking and are generally not used in wet chlorine systems.

Titanium is suitable for wet chlorine service where there is a substantial amount of moisture in the chlorine such as before the drying towers in a producer’s plant. Care must be taken to ensure that titanium does not come into contact with dry chlorine under any circumstances, as it will spontaneously burn on contact. Refer to CI Pamphlet 100 for the determination of wet chlorine. Moisture content at saturated conditions in the gas phase is a function of the temperature and pressure. Table 2-3 allows the determination of the safe use of titanium at a given temperature and pressure. The location of the point on the graph will show whether or not this is a safe operating region for the titanium. The possibility of backflow of dry chlorine into a wet chlorine system should be considered when titanium is used.

Tantalum and titanium are preferred for instrument components that are in contact with wet chlorine. Hastelloy® C has also been used successfully in some applications.

Table 2-1. For Dry Chlorine Service

(See CI Pamphlet 100 for definition of dry chlorine)

COMPATIBILITY OF COMMON MATERIALS OF CONSTRUCTION IN CHLORINE SERVICE		PRIMARY ELEMENT COMPONENTS						
MATERIAL	**TYPE OF SERVICE (1)**	**BOURDON TUBES (2)**	**THERMOWELLS**	**DIAPHRAGMS OR CAPSULES**	**RUPTURE DISKS**	**TUBING**	**TUBING FITTINGS**	**COMMENTS**
Carbon Steel	Class I and IV Only	Not Used	Used	Not Used	Not Used	Not Used	Not used	
Low Temperature	Class I, II, IV and V Only	Not Used	Used	Not Used	Not Used	Not Used	Not used	
Stainless Steel	**Not Recommended**							
Hastelloy® C	Class I through VI	Not Used	Used	Used	Used	Used	Used	
Titanium	**Not Acceptable**							Titanium reacts with dry chlorine.
Monel®	Class I, II, IV and V Only	Used	Used	Used	Used	Used	Used	
Tantalum	Class I through VI	Not Used	Used	Used	Used	Not Used	Not Used	
Copper	Class I and IV Only	Not Used	Not Used	Not Used	Not Used	Used	Not Used	Frequent stressing will cause embrittlement.
Leaded Commercial Bronze	Class I and IV Only	Not Used	Not Used	Not Used	Not Used	Not Used	Used	
Silver	Class I and IV Only	Not Used	Not Used	Used	Used	Not Used	Not Used	
Aluminum	**Not Acceptable**							
Tin	**Not Acceptable**							Silver brazing alloys should not contain tin.
PVC	Pressures below 6 psig at 0°F (-18°C) to 140°F (60°C)	Not Used	Not Used	Not Used	Not Used	Not Used	Used	
CPVC	Pressures below 6 psig at 0°F (-18°C) to 160°F (71°C)	Not Used	Not Used	Not Used	Not Used	Not Used	Used	
PFA	Class I, II, III Only	Not Used	Not Used	Used	Not Used	Used	Used	
PTFE	Class I, II, III Only	Not Used	Not Used	Used	Used	Used in vacuum service	Used in vacuum service	
FEP	Class I, II, III Only	Not Used	Not Used	Used	Not Used	Not Used	Not Used	
ECTFE	Class I and II Only	Not Used	Not Used	Used	Not Used	Not Used	Not Used	
ETFE	Class I and II Only	Not Used	Not Used	Not Used	Not Used	Not Used	Not Used	
PVDF	Class I Only	Not Used	Not Used	Used	Not Used	Not Used	Not Used	
Polypropylene	**Not Recommended**							
Polyethylene	**Not Recommended**							

Footnote:
(1) For description of Service Classes, see Table 2-4.
(2) For bourdon tube use, see Section 5.

Used - Materials commonly used in the industry
Not Used - Materials technically acceptable but not commonly used in the industry
Not Recommended - Industry experience suggests materials are not suitable
Not Acceptable - Materials should not be used due to known compatibility problems with chlorine

Table 2-2. For Wet Chlorine Gas Service

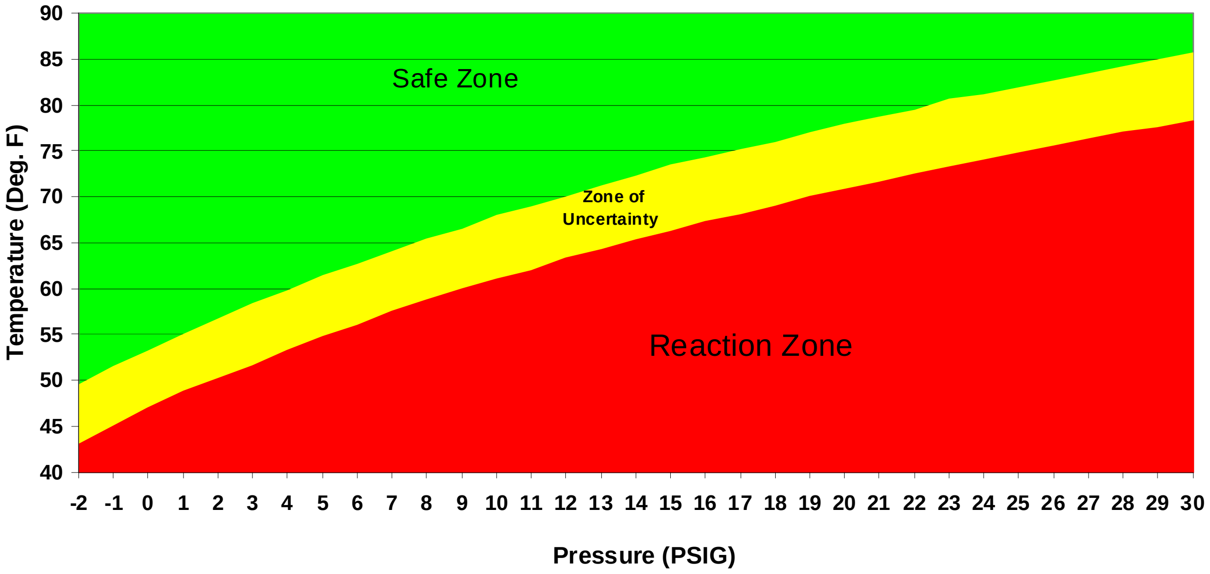
(See CI Pamphlet 100 for definition of wet chlorine)

COMPATIBILITY OF COMMON MATERIALS OF CONSTRUCTION IN CHLORINE SERVICE			PRIMARY ELEMENT COMPONENTS						
MATERIAL	**LOW TEMPERATURE RATING**	**HIGH TEMPERATURE RATING**	**BOURDON TUBES (1)**	**THERMOWELLS**	**DIAPHRAGMS OR CAPSULES**	**RUPTURE DISKS**	**TUBING**	**TUBING FITTINGS**	**COMMENTS**
Carbon Steel	**Not Acceptable**								
Stainless Steel	**Not Acceptable**								
Hastelloy® C	-100°F (-73°C)	300°F (149°C)	Not Used	Used	Used	Used	Used	Used	
Titanium	-100°F (-73°C)	300°F (149°C)	Not Used	Used	Used	Used	Used	Used	See Table 2-3 Titanium should not come into contact with dry chlorine under any circumstances, as it will spontaneously burn on contact.
Monel®	**Not Acceptable**								
Tantalum	-100°F (-73°C)	300°F (149°C)	Not Used	Used	Used	Used	Not Used	Not Used	
Copper	**Not Acceptable**								
Silver	**Not Acceptable**								
Aluminum	**Not Acceptable**								
Tin	**Not Acceptable**								Silver brazing alloys should not contain tin.
PVC	**Not Recommended**								
CPVC	**Not Recommended**								
PFA	-350°F (-212°C)	400°F (204°C)	Not Used	Not Used	Used	Not Used	Used	Used	
PTFE	-350°F (-212°C)	400°F (204°C)	Not Used	Not Used	Used	Not Used	Used	Used	Has a higher permeation rate than PFA or FEP.
FEP	-350°F (-212°C)	350°F (177°C)	Not Used	Not Used	Not Used	Not Used	Used	Used	
ECTFE	-50°F (-46°C)	300°F (149°C)	Not Used	Not Used	Used	Not Used	Not Used	Not Used	
ETFE	-50°F (-46°C)	200°F (93°C)	Not Used	Not Used	Not Used	Not Used	Not Used	Not Used	
PVDF	-50°F (-46°C)	175°F (79°C)	Not Used	Not Used	Used	Not Used	Not Used	Not Used	
Polypropylene	**Not Recommended**								
Polyethylene	**Not Recommended**								

Footnote: (1) For bourdon tube use, see Section 5.

Used - Materials commonly used in the industry
Not Used - Materials technically acceptable but not commonly used in the industry
Not Recommended - Industry experience suggests materials are not suitable
Not Acceptable - Materials should not be used due to known compatibility problems with chlorine

Table 2-3 Titanium Reactivity Zones for Water Saturated Chlorine Pressure vs. Temperature



2.3 GASKETS

Gaskets used for the installation of instrumentation are typically the same as used for the rest of the piping system. CI Pamphlet 95 contains recommendations for gaskets used in chlorine service.

2.4 LUBRICANTS AND SEAL FLUIDS

Chlorine can react violently with hydrocarbon based oils, grease, and other seal fluids. For this reason, fluorocarbon based greases and seal fluids are used in chlorine service.

2.5 DESIGNED FOR CHLORINE USE

Some instrument manufacturers have experience in providing instrumentation used in wet and dry chlorine service. It is recommended that product selection and use be reviewed with the manufacturer. Selection of these instruments should ensure that appropriate materials, lubricants and seal fluids have been used and that the instrument has been cleaned, dried and packaged for chlorine service.

Table 2-4. Service Classes

I	Gas only vacuum to 150 psig (1034 kPa) and -20°F to 300°F (-29°C to 149°C)
II	Gas only vacuum to 150 psig (1034 kPa) and -50°F to 300°F (-46°C to 149°C)
III	Gas only vacuum to 150 psig (1034 kPa) and -150°F to 300°F (-101°C to 149°C)
IV	Gas or liquid vacuum to 300 psig (2068 kPa) and -20°F to 300°F (-29°C to 149°C)
V	Gas or liquid vacuum to 300 psig (2068 kPa) and -50°F to 300°F (-46°C to 149°C)
VI	Gas or liquid vacuum to 300 psig (2068 kPa) and -150°F to 300°F (-101°C to 149°C)

3. PRIMARY ELEMENT SELECTION

3.1 PRESSURE SENSING ELEMENTS

Pressure sensing elements may be protected from the chlorine by a liquid-filled seal or isolating diaphragm, filled with a fluorocarbon that is not reactive with chlorine. Types of pressure sensing elements commonly used are:

Type	**Comments**
Manometer	Usually used on select applications involving very small pressure drops, such as on electrolytic cells. Devices are vulnerable to process upsets and may require surveillance to avoid an environmental incident.
Bourdon Tube	Inexpensive device but moving parts may be susceptible to corrosion.
Diaphragm or Capsule Type	Variety of materials available, many different installation options.
Bellows	Usually used on select applications involving very small pressure drops. Used in low pressure applications and differential pressure applications.

3.2 TEMPERATURE SENSING ELEMENTS

Types of temperature sensing elements commonly used are:

Type	Comments
Resistance Temperature Device (RTD)	Common sensing element often paired with a transmitter or field indicator.
Thermometer	Bi-metallic field indications are very common.
Thermocouple	Thermocouple metals should be selected for resistance to corrosion in ambient conditions, i.e., Type J should not be used.
Infrared	Portable hand held unit

NOTE: For ease of maintenance replacement and to eliminate corrosion of the temperature sensors, isolating thermowells are commonly used with all these devices except infrared.

3.3 LEVEL SENSING ELEMENTS

Types of level-sensing elements commonly used are:

Type	Comments
Visual Level Indication	Additional information is available in CI Pamphlet 5. Plain gauge glass systems should not be installed for any chlorine application. Armored refractive type, with forged steel body is recommended.
Load Cells	Additional information is available in CI Pamphlet 5. Volumetric measurement should be compensated for the chlorine temperature. Load cell component failure should limit tank movement by design of structural tank support.
Differential Pressure	Differential pressure transmitters with remote diaphragm seals and capillaries with fluorocarbon based fill.
Radar	Maintenance may require evacuation of the system. Non-contacting device with no moving mechanical parts and unaffected by density. Stilling wells should be considered to eliminate problems with surface movement. Stilling wells should contain vent holes to equalize pressure.
Nuclear	Non-contacting and adaptable for all shapes of vessels and unaffected by density.
Capacitance	Maintenance may require evacuation of the system. Stilling wells should be considered to eliminate problems with surface movement. Stilling wells should contain vent holes to equalize pressure.
Ultrasonic	Maintenance may require evacuation of the system. Stilling wells should be considered to eliminate problems with surface movement. Stilling wells should contain vent holes to equalize pressure.

3.4 FLOW SENSING ELEMENTS

Types of flow sensing elements commonly used are:

Liquid Flow

Type	Comments
Coriolis (Mass)	High rangeability, excellent accuracy, flanged connections are a standard option, high cost. The best overall metering principle for liquid chlorine. Insure pressure drop across meter does not introduce cavitation/flashing within the meter or down stream piping. Include dissolved gases (i.e. nitrogen) in the calculations.
Differential Pressure	The differential pressure required by the measuring device usually results in downstream cavitation/flashing. Many potential leak points are introduced into the system by tubing and valves normally associated with this measurement principle.
Positive Displacement	Meters contain many moving parts and seals. Proper metallurgy of internal components is usually an issue.
Sonic	Must consider the temperature of the liquid and its effects on the transducers. Connections at the transducers must be sealed to prevent ambient moisture from condensing and interfering with electrical signals.
Thermal (Mass)	Thermal energy introduced by meter may cause evaporation and result in cavitation/flashing at the measurement RTD.
Vortex	The differential pressure required usually results in downstream cavitation/flashing.

Gas Flow

<u>NOTE</u>: For all chlorine gas applications the gas must be superheated. If the gas is not superheated the possibility of two-phase flow exists. If any liquid is present in the metering system, accuracy is affected.

Type	Comments
Coriolis (Mass)	High rangeability, excellent accuracy, flanged connections are a standard option, high cost. Insure system can handle high pressure drop required by Coriolis meters in gas applications.
Differential Pressure	Low cost, numerous materials available, easily understood system.
Positive Displacement	Meters contain many moving parts and seals. Proper metallurgy of internal components is usually an issue.
Sonic	Materials of construction should be carefully considered.
Thermal (Mass)	Thermal energy introduced by meter may be above system specifications.
Vortex	High rangeability, excellent accuracy, flanged connections are a standard option.

4. FINAL CONTROL ELEMENTS

Control valves are devices that automatically manipulate the flow rate of the process fluid. They consist of a valve sometimes combined with a positioner and actuator that change the position of the closure member as a function of an input signal. The functionality and special design of control valves and their use in chlorine service requires particular attention to valve specifics that are not covered in this pamphlet.

Materials for use in chlorine service must be chosen carefully to suit the conditions of the intended application in terms of moisture, fluid state, temperature, and pressure. For materials in contact with dry liquid and dry gaseous chlorine the recommendations and guidelines in CI Pamphlet 6 should be considered.

Several standards such as the international standard IEC 534-1 cover terminology, sizing, and noise considerations of industrial process control valves. Throttling control continuously cycles the stem/shaft of a control valve in order to obtain the desired process condition. Due to the cycling particular attention should be paid to the stem/shaft guiding and the stem/shaft sealing. A variety of special seals are available such as bellows seals, live loaded stem seals or lantern ring design. Stem and sleeve material must be resistant to wet chlorine corrosion. If a bellows seal is used, ensure the seal has adequate cycle life for the intended use.

Control valves are usually not required to provide a tight shutoff. Guidance for control valve leakage rates can be taken from standard ANSI FCI 70-2 or IEC 534-4.

For Dry Chlorine Service and Wet Chlorine Gas Service

Type	**Recommendation**	**Points to Consider**	**Comments**
Globe Valve	Acceptable	•Higher precision and good control •Seat erosion can result in diminished sealing characteristics •Bellows seal can be used	If bellows seal is not used consider live loaded stem seal or lantern ring design. Stem and sleeve material must be resistant to wet chlorine corrosion.
Rotary Disc (Eccentric Butterfly)	Acceptable	•Best C_v to control ratios •Seal can't be bellows	Consider live loaded stem seal or lantern ring design. Stem and sleeve material must be resistant to wet chlorine corrosion.
Ball Valve	Acceptable	•Good sealing characteristics •Need a vented ball so as not to trap liquid chlorine	Consider live loaded stem seal or lantern ring design. Stem and sleeve material must be resistant to wet chlorine corrosion. Not recommended for control. Commonly used for on-off applications.
Plug Valve	Acceptable	•Torque requirements change as it ages (swelling from water in PTFE) •Good sealing characteristics •Most are reduced port requiring a larger valve or more delta P •Need a vented plug so as not to trap liquid chlorine	Consider live loaded stem seal or lantern ring design. Stem and sleeve material must be resistant to wet chlorine corrosion. Not recommended for control. Commonly used for on-off applications.
Butterfly Valve	Not Recommended for liquid service. Acceptable for dry and wet gas service.	•Seal can't be bellows	Consider live loaded stem seal or lantern ring design. Stem and sleeve material must be resistant to wet chlorine corrosion.

5. INSTALLATION GUIDELINES

Installation Consideration

Good installation practices should be used and should take into account the following considerations:

- Instrumentation installed in chlorine service should be dry and free of any organic compounds, including carbon grease and oils.
- Instruments should be specified “clean for chlorine service”.
- Shut-off or isolating valves are recommended to permit service of instrumentation while the system is in use. Provision should be made to isolate and purge instrumentation prior to calibration or maintenance, and provision should be made to prevent the release of chlorine into the atmosphere.
- Pipe dope should contain only materials that do not react with chlorine.
- Provide proper support. Do not use pipe to support heavy instrumentation. If located in an area where seismic activity can be significant, review local code requirements to determine if special design considerations are necessary.
- Locate all instrumentation, valves, and controls in accessible areas where they can be monitored, operated, and serviced conveniently.

Guidelines for installation of temperature sensing elements are:

Measurement Type	**Installation Guidelines**	**Comments**
Thermometer/RTD/ Thermocouples	Wetted materials must be chlorine compatible. Thermowells should be used for wet and dry chlorine service.	Conduit can become a chlorine pipeline to a remote area if a thermowell fails. Conduit seals are not always chemically compatible and may not protect the remote area.

Guidelines for installation of liquid flow sensing elements are:

Measurement Type	**Installation Guidelines**	**Comments**
Coriolis (Mass)	For U or bow tie shaped primary elements the elements should be installed with the meter in the horizontal plane to prevent trapping bubbles. Vertical flow up is preferred for straight run meters.	

Guidelines for installation of pressure sensing elements are:

Measurement Type	Installation Guidelines	Comments
Manometer	System fluid must be compatible with chlorine.	
Bourdon Tube	Isolating diaphragms recommended for wet chlorine service.	Use of an isolating diaphragm should be considered to extend gauge life in dry chlorine service.
Diaphragm/Capsule Sensors - General	Consider the use of isolation valves. Wetted materials must be compatible with chlorine. Fill material must be compatible with chlorine.	Instrument response time can be adversely affected if sensor fill fluids are not rated for the surrounding temperatures.
Diaphragm/Capsule Sensors - Direct Mount Style Instrument	Sensor and transmitter are often flange mounted to an isolation valve.	The use of a remote sensing seal direct mounted to a transmitter or other device eliminates additional connection equipment (tubing, capillaries, etc.) simplifying some installations.
Diaphragm/Capsule Sensors - Tubing and Manifold Style Connections		Higher moisture content may be present in instrument connections such as tubing and manifolds. Materials should address this.

Guidelines for installation of gas flow sensing elements are:

Measurement Type	Installation Guidelines	Comments
Coriolis (Mass)	For U or bow tie shaped primary elements the elements should be installed with the meter in the horizontal plane to prevent trapping any reliquified chlorine that may appear in the system. Vertical flow up is preferred to eliminate trapping reliquified chlorine.	
Differential Pressure	Design system with a minimum of fittings and valves. Consider close coupled direct mount assemblies. Impulse tubing should drain back to primary element. Heat tracing may be required to prevent chlorine from reliquifying in the impulse tubing	
Vortex	Consider using meters with attached flanges for accurate pipe to meter alignment.	

6. MECHANICAL INTEGRITY AND RELIABILITY MANAGEMENT

6.1 PROGRAM EXECUTION

ANSI/ISA-84 is recognized as good engineering practice for instrument and control design, installation, and maintenance requirements. The following are examples of a program that would meet the requirements of ISA-84 as of the publication date of this document.

6.2 SAMPLE MECHANICAL INTEGRITY AND RELIABILITY PROGRAM

This example is not intended to be all-inclusive. Moreover, it should not be assumed that every acceptable procedure is included, or that special circumstances may not warrant modified or additional procedures. Consider reviewing the ISA-84 Standard.

6.2.1 Identify and Classify All Devices to be Included

a. Identify all applicable devices. Assign classification to each applicable device. Classification can be done in several ways. Ultimately the classification should be based on the reliability requirements needed for the device. As an example, an emergency shutdown system may be classified as needing higher reliability than a notification alarm. Ensure that appropriate representatives from operations, maintenance, technical, etc. are involved in the classification process. Two examples of classification procedures are: Layer of Protection Analysis (LOPA) or Process Hazard Analysis (PHA).

b. **NOTE:** When classifying devices the team must consider all modes of operation (e.g. normal, startup, shutdown, and emergency).

c. The Management of Change MOC procedure should require classification assignment to all new devices and require development of routine maintenance and function check testing and inspection procedures and associated frequencies for each device and/or loop.

d. Establish and maintain testing, inspection, and/or replacement frequencies (e.g. for devices such as pressure transmitters, rupture discs, etc.) based on service conditions, criticality, prior history, and any manufacturer's recommendations.

6.2.2 Provide Up-To-Date Documentation for the Program

a. P&IDs, loop drawings, control schematics, instrument specifications, and basic design data shall be accurate and part of this documentation.

b. Establish and maintain a database (electronic or paper) for device process safety information (PSI) to document and track device make, model, P&ID number, set points, and other information.

6.2.3 Test, Inspect and Maintain the Devices

a. Establish and maintain formal routine maintenance testing and inspection procedures for each applicable device. Establish criteria for acceptable test results for each device.

b. Establish and maintain formal function check testing and inspection procedures for each applicable device. Establish criteria for acceptable test results for each device and/or system.

c. Incorporate formal routine maintenance and function check testing and inspection procedures and developed frequencies into an appropriate preventive maintenance (PM) program.

d. Ensure that all technicians who perform inspection, testing and repair activities have training and qualifications supported by appropriate documentation.

e. Establish and maintain formal documentation and recordkeeping systems for all inspection and testing results, including “as-found” and “as-left” data. Establish and maintain formal system to set future PM frequencies based on mean-time-between-failure (MTBF) data, “as-found" data, site experience, and other conditions that may impact device reliability.

f. Establish and maintain a system to track all inspection, testing, and repair activity to completion. Ensure that any non-routine or emergency work is documented.

g. Establish and maintain a system to correct device or system deficiencies that are outside accepted limits before further use or to ensure that necessary measures are taken to assure safe operation.

6.2.4 Inspection and Testing

Written procedures shall be established to perform the inspection and testing of all applicable devices. The following items shall be addressed in these procedures:

a. All test equipment that is used for these purposes shall be periodically calibrated in accordance with the manufacturers’ recommendation and shall be certified and traceable to the National Institute of Standards and Technology (NIST).

b. Personnel working on these devices shall be properly trained and qualified to perform testing, inspection, and repair on these systems. Training shall also be provided and documented for personnel involved in executing the program to ensure that they understand the procedures, safe practices, and the proper use and application of special equipment or unique tools that may be required.

c. Procedures shall be written to prove the integrity of all devices within each loop, from the initial sensing element to the final control element. Furthermore, the procedures shall verify that all applicable devices function together and properly as a system.

d. Function Test procedures shall include (where applicable and feasible), but not be limited to, verifying the following:

   1. Operation of all input devices including primary sensors and input modules;
   2. Logic associated with each input device;
   3. Logic associated with combined inputs;
   4. Trip initiating values (set points) of all inputs;
   5. Alarm functions;
   6. Operating sequence of the logic program;
   7. Function of all final control elements and output modules;
   8. Function of the manual trip to bring the system to its safe state;
   9. Function of the user diagnostics;
   10. Complete system functionality; and
   11. QA/QC verification that the device or loop is operational after testing activities have been completed and prior to unit startup.

e. The criteria for acceptable test results shall be defined in order to provide consistent evaluation and implementation of the program. Examples are provided below.

   1. Failure – The device does not function properly, or is greater than X% from desired set point.
   2. Acceptable – The entire loop functions properly, and the set points are within Y% of desired set point. No adjustment is necessary.
   3. Discrepancy – Any deviation from set point that exceeds Y%, but is less than X% of desired set point. Equipment or instruments in this category should be adjusted and the discrepancies documented. However, these items need not be classified as a failure.

6.2.5 Recordkeeping

a. Each inspection and test shall be documented, whether performed by in-house or contractor personnel. The documentation shall include:

   1. The date of the inspection or test;
   2. The name of the person who performed the inspection or test;

3. The serial number, tag number, or other identifier of the equipment on which the inspection or test was performed;

4. A description of the inspection or test performed;

5. The results of the inspection or test (including condition and set-point of the device "as found" and "as left", and

6. Description of any adjustments, alterations, or repairs performed to re-establish the integrity of the device.

NOTE: Each facility should consider including in their testing program the documentation of the serial number or other identifier of the major test equipment used to perform the test.

b. In addition, each facility shall keep the following records for checks and inspection to ensure that new or replaced equipment is installed properly and in accordance with design specifications and appropriate manufacturers' instructions.

1. Initial calibration or test documentation as described above.

2. Data sheet information for each device, where applicable.

    a. Manufacturer, tag and model number;

    b. Size and connections;

    c. Material of construction;

    d. Device set-point range and calibration;

    e. Special features or any accessories;

    f. Fail-safe mode or specific action.

3. Documentation that qualified personnel are used for any fabrication or installation procedures.

4. Verification of applicable inspection and testing performed.

    a. Equipment installed and connected as shown on the documentation and in accordance with job construction specifications;

    b. Devices visually checked after installation to verify nameplate data and proper orientation;

    c. Equipment tested and calibrated per applicable manufacturers' recommendations;

d. Equipment meets vendor's published specifications;

e. Wire and cable tested electrically for continuity and insulation (grounds);

f. Installation inspected for proper craftsmanship, good connections, and the use of appropriate connectors, sealants, wire gauge, fuses, etc.;

g. Software loaded and functioning as intended, and

h. Devices function together and properly as a system as well as individually.

NOTE: Each facility shall consider including in their inspection program the documentation to verify that any flushing or testing of the equipment or associated process piping is completed in such a fashion that will protect the integrity of the device.

6.3 EXAMPLES OF KEY PERFORMANCE INDICATORS (KPIS)

The following indicators could be useful in assisting a plant in the management of its Mechanical Integrity Program.

1. ***Number (or percent) of overdue inspections.*** A high number (or rate) of overdue inspections may indicate resource constraints or that equipment is not being made available for scheduled maintenance.

2. ***Number (or percent) of inspections that uncover a failure.*** Clearly, one objective of the mechanical integrity element is to discover and correct hidden failures before they lead to catastrophic accidents. However, an increase in this metric may indicate that risk associated with equipment failure is gradually increasing.

3. ***Number of devices included in the mechanical integrity program.*** Although this number has very little meaning in isolation, it could be used as a basis to compare mechanical integrity programs, particularly if the company operates similar processes at multiple facilities.

4. ***Total number of deferred repairs, such as known deficiencies that will be addressed at the next turnaround.*** Note that this metric will often increase linearly over time until the next maintenance shutdown, when it drops off sharply. However, the rate of increase could be a leading indicator of risk.

Other Performance Indicators

Companies may find it helpful to track additional performance indicators, such as those listed below.

1. ***Number of inspection work orders (per month or quarter) that apply to devices that are no longer present at the facility.*** A higher than expected number may indicate a weak link between the mechanical integrity and management of change (MOC) elements. If the inspection plan and preventive maintenance work orders in the CMMS are not updated when equipment is removed from service, it is quite likely that they are not updated when new equipment is installed.

2. ***Number of inspectors/maintenance employees holding each type of required certification.*** A decline in this metric may be a leading indicator of skill gaps or a higher than acceptable backlog for inspection tasks.

3. ***Number of emergency/unplanned repair work orders per month.*** One of the primary objectives of the mechanical integrity element is to reduce unplanned/breakdown maintenance work. Although many unplanned failures may not involve equipment included in the scope of the mechanical integrity program, an increase in this metric may be a leading indicator of an overall slip in the effectiveness of the maintenance program at the facility.

4. ***Work order backlog for the inspection group, in other words, planned activities that are not yet past due.*** Similar to the number of past-due inspection tasks, a backlog may indicate resource constraints. However, this metric may be a better leading indicator than the number of past-due inspection tasks.

5. ***Total time charged to inspection tasks each month/quarter.*** A decline in the amount of time that is charged to these activities may indicate a change in focus for the maintenance department. Note that changes could be cyclical by design or could be an intended result (e.g., an effort to rationalize redundant or unnecessary calibration activities should result in a decline in time spent on inspection tasks).

6. ***Average time to address/correct deficiencies.*** This can be another leading indicator of risk and may help indicate if a step change has occurred in the ability to quickly repair equipment. However, at a continuous plant, this metric may be heavily influenced by a few deficiencies that are scheduled to be repaired at the next turnaround. Facilities may need to exclude “turnaround jobs” from this metric to provide a meaningful trend line.

7. ***Equipment reliability (or availability).*** Similar to the previous metric, a decrease in reliability (or availability) may indicate that risk associated with equipment failure is gradually increasing.

7. REFERENCES

7.1 INSTITUTE PUBLICATIONS

(Please check the Institute's website: www.chlorineinstitute.org for the latest edition of the following publications.)

7.1.1 *Chlorine Basics*, ed. 7; Pamphlet 1; The Chlorine Institute: Arlington, VA. **2008**

7.1.2 *Bulk Storage of Liquid Chlorine*, ed. 7; Pamphlet 5; The Chlorine Institute: Arlington, VA. **2005**

7.1.3 *Piping Systems for Dry Chlorine*, ed. 15; Pamphlet 6; The Chlorine Institute: Arlington, VA. **2005**

7.1.4 *Gaskets for Chlorine Service*, ed. 4; Pamphlet 95; The Chlorine Institute: Arlington, VA. **2008**

7.1.5 *Dry Chlorine: Definitions and Analytical Issues*, ed. 3; Pamphlet 100; The Chlorine Institute: Arlington, VA. **2002**

APPENDIX A

PAMPHLET 165 CHECKLIST

This checklist is designed to emphasize major topics for someone who has already read and understood the pamphlet. Taking recommendations from this list without understanding related topics can lead to inappropriate conclusions.

Place a check mark (✓) in the appropriate box below:

Yes	No	N/A		
☐	☐	☐	1. Does the user understand that the pamphlet provides information that pertains to materials, primary elements, and control devices for instrumentation for chlorine service?	{1.1}
☐	☐	☐	2. Is the user aware that Table 2-1 should be used for information on dry chlorine service (gas or liquid) and Table 2-2 should be used for information on wet chlorine service (gas only)?	{2.2}
☐	☐	☐	3. Does the user understand the restrictions for the use of titanium as a material of construction and how to use Table 2-3?	{2.2.2}
☐	☐	☐	4. Has the user reviewed the information in Section 3, Primary Element Selection, prior to selecting a primary sensing element?	{3}
☐	☐	☐	5. Has the user reviewed CI Pamphlet 6, Section 4 for additional information on chlorine valves?	{4}
☐	☐	☐	6. Does the user understand the definitions of dry chlorine and wet chlorine?	{2.2.1, 2.2.2}
☐	☐	☐	7. Does the user understand the requirements of a Mechanical Integrity and Reliability Program?	{6}

REMINDER:

Users of this checklist should document exceptions to the recommendations contained in this pamphlet.

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