

by Robert G. Skrentner

INSTRUMENTATION

HANDBOOK FOR WATER & WASTEWATER TREATMENT PLANTS

by Robert G. Skrentner

INSTRUMENTATION

HANDBOOK FOR WATER & WASTEWATER TREATMENT PLANTS



LEWIS PUBLISHERS

Library of Congress Cataloging-in-Publication Data

Skrentner, Robert G.

Instrumentation handbook for water and wastewater treatment plants.

Bibliography: p.

Includes index.

1. Water—Purification—Equipment and supplies—Handbooks, manuals, etc. 2. Sewage—Purification—Equipment and supplies—Handbooks, manuals, etc. I. Title.

TD433.S49 1987 . . 628.1'62 87-31206

ISBN 0-87371-126-2

**COPYRIGHT © 1988 by LEWIS PUBLISHERS, INC.
ALL RIGHTS RESERVED**

Neither this book nor any part may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopying, microfilming, and recording, or by any information storage and retrieval system, without permission in writing from the publisher.

**LEWIS PUBLISHERS, INC.
121 South Main Street, Chelsea, Michigan 48118**

PRINTED IN THE UNITED STATES OF AMERICA

Preface

Instrumentation is the group of devices used directly or indirectly to measure or control a variable. The term includes primary elements (sensors), final control elements (control valves and pumps), and switches, pushbuttons, controllers, annunciators, and related devices used to manipulate the variable.

Instrumentation, required for proper operation of water and wastewater treatment plants, was observed in various states of working order during visits to treatment plants. Personnel at these sites often criticized the instrumentation for failure to meet reliability and usefulness expectations. However, the same instrumentation performed satisfactorily in other locations.

This book provides information to engineers and operators about the prerequisites for success with instrumentation. The material in this book is intended as a guide for the selection, application, and maintenance of primary elements and final control elements.

The first six chapters cover basic, proven primary elements that meet specific needs and provide tangible benefits. For each instrument, the following information is provided:

1. Application
2. Principle of Operation
3. Accuracy and Repeatability
4. Manufacturers' Options
5. Installation
6. Designer Checklist
7. Maintenance and Calibration
8. Deficiencies
9. References

Chapter 7 discusses quality assurance techniques to ensure the primary elements are accurate and reliable. Chapters 8 through 11 cover final control elements (pumps and valves) applications. The last chapter covers process control instrumentation.

The information should not be considered all-inclusive. It is a beginning for what really works in the field. Answers to what makes instrumentation reliable

and maintainable lie outside manufacturers' manuals. Too often this knowledge is not shared outside the treatment plant because the persons responsible do not consider their solutions unique or important.

Although it was not a company project, I would like to acknowledge the continued support and encouragement of EMA Services, Inc. in producing this work. I would like to thank Bob Manross, the editor of the handbook upon which this book is based. Significant contributions to the handbook were made by Dag Knudsen, Rich Lackman, Claude Williams, and Walt Schuk.

This book is dedicated to those plant personnel who use and maintain instrumentation. They are hard-working and creative individuals who have overcome many obstacles to develop fixes and procedures for improved instrumentation performance.



Robert G. Skrentner is the Quality Manager for EMA Services Inc., a St. Paul-based engineering firm specializing in the application of instrumentation and computers to process control. EMA provides services in all phases of process control from conception and planning, through design and implementation, to training and staffing assistance. As Quality Manager, Skrentner is responsible for instrument and control system design standards and specifications, as well as maintaining information on instrument and control system experiences throughout EMA.

Prior to becoming Quality Manager, Skrentner was project manager for various study, design, and implementation projects in both water and wastewater applications.

Before joining EMA, Skrentner worked for the Detroit Water and Sewerage Department. While assigned to the Engineering Division, he worked on various instrumentation and control projects for the wastewater collection system, water distribution system, and wastewater treatment plant. Upon transferring to the Operations Division, he was placed in charge of the process control computer system at Detroit's 1200 mgd wastewater treatment plant.

Skrentner holds a BS and an MS in Civil Engineering from Wayne State University. He has contributed to a book on process control computer systems and one on combined sewerage monitoring and remote control, and has written numerous technical papers in the area of computer utilization in process control and control system management.

Contents

PREFACE	iii
1 ANALYTICAL MEASUREMENT	1
Total Chlorine Residual	1
Dissolved Oxygen	7
pH	13
Suspended Solids	22
2 FLOW MEASUREMENT, CLOSED CONDUIT LIQUID FLOW	33
Magnetic	34
Sonic	43
Turbine	51
Venturi Tubes and Flow Tubes	56
Vortex Shedding	66
Insertion Magnetic	71
3 FLOW MEASUREMENT, CLOSED CONDUIT GAS FLOW	81
Orifice Plate	81
Venturi Tubes and Flow Tubes	91
Averaging Pitot Tubes	99
Turbine Flow Meters	106
Thermal Mass Flow Meters	110
4 FLOW MEASUREMENT, OPEN CHANNEL	119
Weirs	119
Parshall Flume	126
Palmer-Bowlus Flume	133
Kennison Nozzle	139
Velocity-Area	143
5 LEVEL MEASUREMENT	149
Bubblers	149

	Capacitance Probes	155
	Floats	161
	Sonic and Ultrasonic	166
6	PRESSURE MEASUREMENT	173
	Pressure Cells	173
	Differential Pressure	178
7	QUALITY ASSURANCE TESTING	189
	Objectives	189
	Acceptance Testing	190
	Determining Instrument Reference Values	194
	Performance Monitoring	201
8	PUMPS FOR VARIABLE FLOW SERVICE	205
	Metering	205
	Positive Displacement	208
	Centrifugal	212
9	VARIABLE SPEED DRIVES	219
	Magnetic Coupling	219
	Liquid Rheostat	221
	Variable Frequency	222
	Variable Pulley	224
	Direct Current (SCR)	226
10	CONTROL VALVES FOR MODULATING SERVICE	229
	Valve Types	229
	Valve Sizing	235
11	CONTROL VALVE ACTUATORS	247
	Electro Mechanical (Motor Gear Train)	247
	Solenoids	250
	Pistons	252
	Pneumatic Diaphragm	255
	Quarter Turn	258
12	PROCESS CONTROL INSTRUMENTATION	261
	Control Strategies	262
	Operational Considerations	271
	Process Control System Options	272
	Process Control System Implementation	277
	GLOSSARY	283
	INDEX	293

Chapter 1

Analytical Measurement

Analytical instruments perform on-line, real time analysis of process parameters that can also be analyzed in a laboratory. For water and wastewater applications, this includes chlorine residual, dissolved oxygen, pH, suspended solids, turbidity, respiration rate, total organic carbon, and various ion-specific analyses such as ammonia, nitrate, nitrite, etc.

This chapter includes amperometric chlorine residual, dissolved oxygen, pH, suspended solids, and turbidity.

TOTAL CHLORINE RESIDUAL

Applications

The most common method of disinfecting water and wastewater is chlorination. Free chlorine gas or hypochlorite acts as an agent to destroy microscopic organisms that are disease-producing or otherwise objectionable.

Chlorine residual analyzers measure the residual chlorine indirectly. Current technology is based on the assumption that maintaining a minimum chlorine residual (usually 1.0 mg/L) 30 minutes after adding chlorine will result in an effective disinfection level.

Principle of Operation

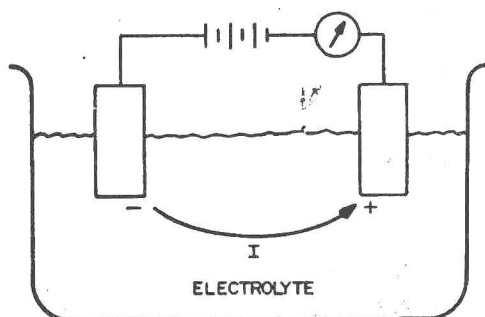
Several different measurement methods are used for chlorine residual, including colorimetric, amperometric, and polarographic. Amperometric is discussed here since it is the more common method measuring total chlorine residual.

The amperometric measurement method uses two dissimilar metals held in a solution or electrolyte. A voltage is applied to the two metals which act as electrodes. Electrons flow from the negative electrode to the positive electrode generating a current. Figure 1.1 illustrates the amperometric cell.

The amount of current flowing between the electrodes is proportional to the amount of chlorine present in the solution.

The basic amperometric chlorine residual analyzer is illustrated in Figure 1.2. It consists of an inlet sample tank and flow regulator, reagent solutions with metering pumps, measurement cell, and electronic signal converter. The metered sample stream acts as the electrolyte as it flows through the measurement cell. Since chlorine in the sample can exist in many different chemical forms, the sample is conditioned with other chemicals in order for the cell to measure all chlorine present in the stream.

The current generated in the measurement cell is very sensitive to temperature variations. A reading can change as much as 3% per degree C temperature change. Therefore, automatic temperature compensation is necessary. A temperature sensor is located in the measurement cell to provide temperature feedback to the electronic converter. This feedback is then used to correct the indicator and output signals to compensate for the temperature effects.



"I" PROPORTIONAL TO Cl CONCENTRATION

Figure 1.1. Amperometric measurement.

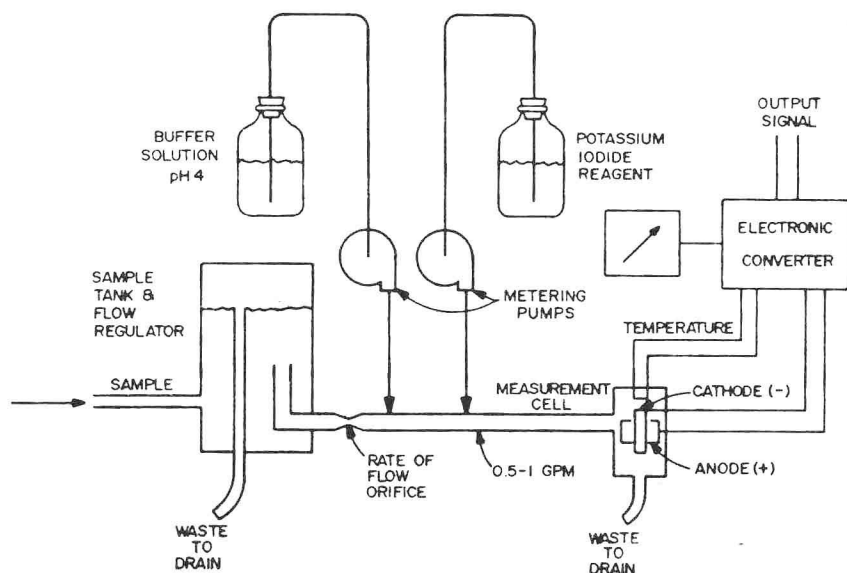


Figure 1.2. Amperometric total chlorine residual analyzer.

Accuracy and Repeatability

Accuracy $\pm 3\%$ of full scale

Several ranges are normally available from 0-1 mg/L to 0-20 mg/L. The measurement error could range from 0.03-0.6 mg/L depending on the operating range used.

Repeatability $\pm 1\%$ of full scale

Automatic temperature compensation should enable this accuracy and repeatability to hold over a sample temperature range of 0-50°C (32-122°F).

Manufacturers' Options

Options available from manufacturers of chlorine residual analyzers are as follows:

1. Local indicator in the analyzer case
2. Supply of reagents
3. Integral solids filter
4. Output signal for remote monitoring of the chlorine residual

Installation

Chlorine residual analyzers are normally housed in freestanding enclosures. The sample is piped from the chlorine contact basin to the analyzer. The sample system is a critical element for a successful analyzer application. A complete installation consists of a sample point, sample transport, and the analyzer.

Sample Point Location

Analyze the effluent after there is sufficient contact time between the chlorine and effluent stream for disinfection to occur. A commonly accepted disinfection period is 30 minutes. Therefore, deliver a sample to the analyzer 30 minutes after adding chlorine. To do this, you must be concerned about the time in the contact tank plus the time to deliver a sample to the analyzer. This is the total contact time as shown in Figure 1.3.

Physically locate the sample point so it does not contribute unnecessary deadtime in chlorine residual analysis. In addition, take care to ensure the sample point is clean, thoroughly mixed, and representative of the monitored stream.

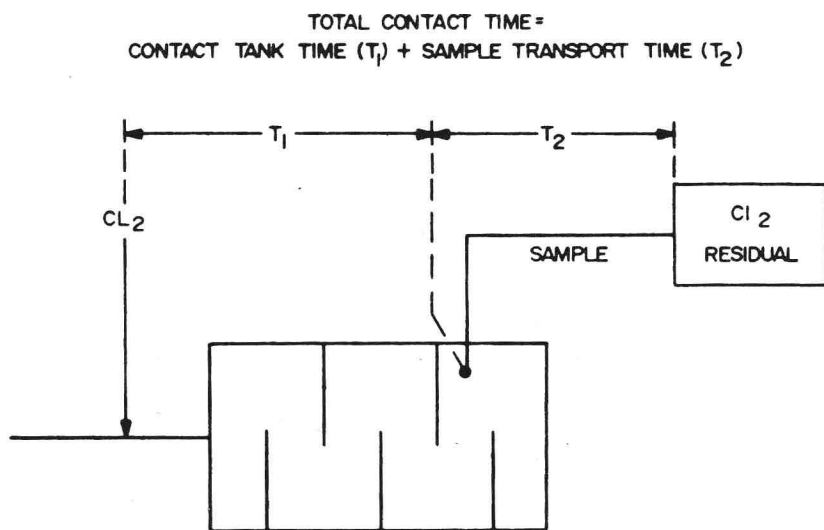


Figure 1.3. Sample point location.

Sample Transport

A sample line and pump are required to deliver the sample to the analyzer. Features of this sample transport assembly are shown in Figure 1.4.

- Select a pump capable of delivering 20–40 L/min (5–10 gpm).
- Size the pipe for a sample velocity of 1.5–3.0 m/s (5–10 ft/s).
- Determine the length of sample line so it will provide the desired transport time.
- Install a valve next to the analyzer so samples can be taken for calibration checks on the analyzer.
- Provide a source of clean water and required valves so the sample line can be backflushed to prevent plugging.
- If solids are present, install a filter.

Chlorine Analyzer

Install the analyzer so it is easy to service and maintain.

- Provide ample space, minimum of 1 m (3 ft), around all sides of the analyzer.

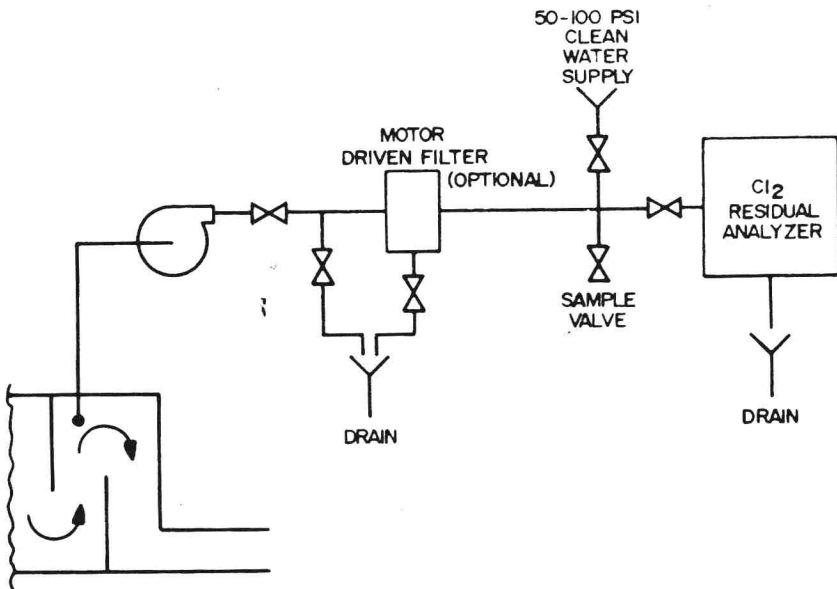


Figure 1.4. Sample transport.

- Locate the analyzer next to a floor drain.
- Provide a table nearby with the necessary equipment and chemicals to perform calibration checks.
- Provide a separate circuit on a lighting panel to power the analyzer.

Designer Checklist

If you can answer yes to the following questions when designing or reviewing chlorine residual analyzer applications, the application should be correct.

- Is remote monitoring required? If so, has an output signal compatible with the receiving instrument been specified?
- Is a local indicator provided?
- Is the sample point located so that during normal plant flows the sum of the contact tank time and sample transport time equals 30 minutes?
- Is the sample pipe length tuned to provide the required delivery time?
- Will the sample point location be thoroughly mixed and representative of the process stream?
- Are the sample pump and pipe sized to provide the recommended flow rates and velocities?
- Has a sample valve been provided adjacent to the analyzer?
- Can the sample line be backflushed?
- Is there adequate space around the analyzer for servicing the instrument?

Maintenance and Calibration

Task	Frequency
1. Check reagent supply	Daily
2. Check analyzer calibration	Daily
3. Check sample flow through analyzer	Daily
4. Check reagent flow to sample line	Daily
5. Calibrate analyzer	When need is indicated by calibration check
6. Replace tubing on reagent pumps	Monthly
7. Backflush sample line	Weekly
8. Clean analyzer drain lines	Weekly
9. Clean cell electrodes	Monthly

Deficiencies

The following problems have been encountered in existing chlorine residual analyzer installations:

- The sample point does not provide a representative mixed sample. This may be due to poor mixing, sample point location, or contact tank design.
- Contact time from the point of chlorine addition to the analyzer is too long.
- Sample lines plug and cannot be backflushed.
- No provision for taking a sample at the analyzer for calibration checks.
- Cramped space around the analyzer making maintenance difficult.
- No reagents in the analyzers.
- Using reagents with the wrong concentration.

DISSOLVED OXYGEN

Applications

Generally, dissolved oxygen (DO) meters in wastewater plants provide an approximate measurement of the oxygen available to support biological activity. In receiving waters, the DO meters monitor one parameter of water quality. DO meters are generally not used in water plants. (See Table 1.1 for DO meter application guidelines).

Principles of Operation

Dissolved oxygen meters consist of an electrochemical cell, the probe, and a signal conditioner or transmitter.

The two principal types of electrochemical cell used in DO probes are the galvanic cell and the polarographic cell. Galvanic and polarographic cells have very similar operating principles. Both cells consist of an electrolyte and two electrodes as shown in Figure 1.5.

Table 1.1. Dissolved Oxygen Meter Application Guidelines

Recommended	Not Recommended
Aeration tank	Chlorine contact tank
Oxygenation basins	H ₂ S bearing streams
Mixed liquor streams	
Secondary effluent	
Plant effluent	
Sample systems	

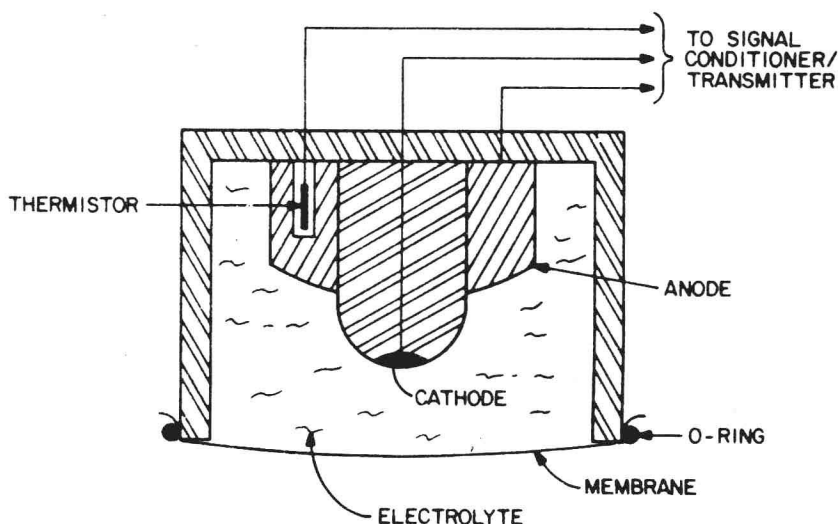
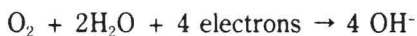


Figure 1.5. Membrane type DO probe.

The polarographic cell requires a polarizing voltage in the range of 0.5 to 1.0 Vdc. In one proprietary probe design, the electrodes are immersed directly in the process stream where process fluid acts as the electrolyte. However, in most commercially available probes, the electrolyte is contained by a gas permeable membrane, and oxygen is brought into contact with the electrodes by the action of diffusion. In either case, fluid flow past the probe greater than 30 cm/s (1 ft/s), is generally required to maintain a representative sample. Whether the probe is of the membrane or nonmembrane type, oxygen is reduced at the cathode, where the half cell reduction reaction is:



and at the anode, the anode metal is oxidized. The result of this oxidation/reduction process is a flow of electrons from the cathode to the anode proportional to the oxygen dissolved in the process stream.

The rate of this oxidation/reduction process is strongly affected by temperature. Therefore, accurate temperature measurement and compensation is essential to accurate DO measurement. Temperature is usually monitored by a thermistor located in the probe, and compensation is made in the signal conditioner/transmitter electronics.

Suspended and dissolved substances in the process stream can also affect electron flow. When solids accumulate on the membrane, they reduce the rate of oxygen transfer to the electrodes. In one design, a mechanical grindstone

continuously polishes the surface of nonmembrane probe to keep the electrodes clean. To maintain gas permeability, fouled membrane probes must be manually cleaned.

Certain dissolved gases interfere with DO measurement by either nonmembrane or membrane probes. Common gases to be avoided are chlorine, hydrogen sulfide, carbon dioxide, and sulfur dioxide. Chlorine will be read by the probe as oxygen; carbon dioxide can neutralize some electrolytes; and hydrogen sulfide and sulfur dioxide can poison some metals used for an anode.

Accuracy and Repeatability

Accuracy	± 1 to $\pm 3\%$ of full scale at the calibration temperature
----------	---

Additional error of $\pm 1\%$ can be expected for each 5.0°C (9.0°F) of change from the calibration temperature. Even with temperature compensation, an additional error of 3 to 4% can be expected over an operating range of 0 to 50°C (32° to 122°F).

A combined DO measurement accuracy of ± 2 to $\pm 4\%$ of full scale can be achieved in most meters under the conditions generally encountered at wastewater treatment plants. For a meter with a range of 0 to 10 mg/L DO, the measurement uncertainty is 0.4–0.8 mg/L. The uncertainty would double (0.8–1.6 mg/L) for a meter with a range of 0–20 mg/L.

The calibration of most probes will change after initial installation, or reinstallation after probe repair. Stabilization time, depending on the manufacturer, ranges from a couple of hours to several days. Output readings must be stabilized before the accuracies above apply.

Manufacturers' Options

1. A remote calibration unit can be installed near the probe to permit calibration where the transmitter is not within 50 ft or is not located within sight of the probe.
2. Ranges can be switch selectable. Some of the more common range selections are as follows:
 - a. 0–3 mg/L, 0–15 mg/L
 - b. 0–5 mg/L, 0–10 mg/L, 0–20 mg/L
3. Transmitter output signals
 - a. 4–20 mAdc
 - b. 10–50 mAdc
 - c. 0–5 Vdc
4. Input power
 - a. 115 Vac, 60 Hz