

SHIPBOARD WATER TREATMENT MANUAL

FOURTH EDITION



Drew Ameroid Marine Division

Marine Chemical Products

BOILER WATER TREATMENT

ADJUNCT B™ phosphate boiler water treatment
AMERZINE® corrosion inhibitor
GC™ concentrated alkaline liquid
SLCC-A™ condensate corrosion inhibitor
BFA™ 2000 marine low pressure boiler feedwater treatment
AGK® -100 boiler and feedwater treatment
LIQUID COAGULANT™ boiler sludge conditioner
AMEROID® CATALYZED SULFITE
AMERTROL®-E boiler and feedwater treatment

EVAPORATOR TREATMENT

AMEROYAL® evaporator treatment
AMEROYAL® CF concentrated evaporator treatment

COOLING WATER TREATMENT

DEWT® NC diesel engine water treatment
MAXIGARD® diesel engine water treatment
LIQUIDEWT™ cooling water treatment
DREWSPERSE® SWD seawater dispersant

FUEL TREATMENT

METONATE® fireside slag and corrosion inhibitor
F.O.T.™ fuel oil treatment
SOOT RELEASE™ soot combustion catalyst
LT SOOT RELEASE™ low temperature soot remover
AMERSTAT® 10 fuel microbiocide
AMERGIZE® deposit modifier/combustion improver
AMERGY® 1000 combustion improver
AMERGY® 222 fuel oil conditioner
PACE™ fuel evaluation program

MAINTENANCE CHEMICALS

ACC-9™ air cooler cleaner
DREW ELECTRIC™ motor and parts cleaner
O&GR™ oil and grease remover
AMERSPERSE® 280 seawater cooling treatment
CARBON REMOVER™ solvent cleaner
OSD/LT™ oil spill dispersant
AMEROID® RSR rust stain remover
SAF-ACID™ descaling compound

MAINTENANCE PRODUCTS (cont'd)

HDE-777™ heavy duty emulsifier
AMEROID® OSC one-step cleaner
AMEROID® OWS quick separating degreaser
AMEROID® DC disc cleaner
MUD CONDITIONER ballast tank water treatment
NEVAMELT™ wire rope conditioner
FERROFILM® corrosion and erosion inhibitor
CIL™ corrosion inhibitor
DREWCLEAN® 2000 quick breaking degreaser
SNC™ 2000 carbon remover
ENVIROMATE® 2000 general purpose cleaner
DEGREASER AP™ general purpose degreaser
GENERATOR CLEANER™ electric parts cleaner
DESCALE-IT™ liquid acid descaler

SANITIZERS/CLEANERS

AMEROID® MSD-PAK organic waste treatment
AMEROID® DRAINARD liquid waste treatment and drain cleaner

TANK CLEANING

EDGE® heavy duty cleaner
TC#4™ tank cleaner
LAC™ liquid alkaline cleaner
DEGREASER TK™ heavy duty degreaser

CORROSION INHIBITORS

MAGNAKOTE® rust preventative
MAGNAKOTE® PLUS rust preventative
PROTECSOL® 30E Emitter
PROTECSOL® 300E Emitter
PROTECSOL® 400E Tape
PROTECSOL® 600EZ Liquid
PROTECSOL® 700P multi-metal powdered corrosion inhibitor
PROTECSOL® 770P ferrous metal powdered corrosion inhibitor

MISCELLANEOUS

MOTORGARD™ total motor vessel protection program
ULTRAMARINE® water treatment program
ULTRATEST® reagents

FOREWORD

This manual is intended for use by persons who are concerned with the chemical testing, dosing, and control of a shipboard water treatment program. Included are explanations of why water treatment is required and a description of the methods used in modern marine practice. The purpose and application of each of the Drew water treatment chemicals is explained. This edition has been updated to include the newest treatments and tests in our line.

The power plants of modern steam and motor vessels are more efficient today than at any other time in history. Boilers and diesel engines are designed to extract the greatest possible amount of energy from the fuel and to turn that energy into work. Turbines, generators and auxiliary equipment are designed to make the most effective use of the steam or mechanical energy that is

supplied to them. Efficient operation of the marine power plant depends significantly on the quality of the water that it receives. Contaminants such as dissolved minerals, gases, oil, and even the water itself can cause serious damage to power plant equipment unless proper control steps are taken.

Testing is an important part of any water treatment program because the test results are the primary means of controlling the program and of detecting problems. All test procedures are described in this manual after discussion of the applicable treatment program. We refer the reader to the section entitled "General Information" which should be read before conducting tests. Here, recommendations are provided for proper sampling, general testing and recording techniques.

CREDITS FOR ILLUSTRATIONS

We wish to acknowledge the sources of some of the illustrations used in this manual.

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GENERAL INFORMATION

INTRODUCTION

Proper testing techniques are necessary to assure a well controlled water treatment program. This section describes the best methods for obtaining water samples and conducting chemical tests. Because test results must be recorded

using the correct units of mass, volume and concentration measurements, a section entitled "Expression of Chemical Results" has been included for your reference.

PROPER RECORD KEEPING

An important part of an analytical program is the keeping of legible and accurate logs. Complete information is essential for an accurate evaluation of the progress of the treatment program. When recording the test data, remember the following pertinent points:

- Use the proper log sheets for the system being treated.
- Record all information legibly.
- Insert carbon paper if necessary to make the required number of copies. Distribute copies to Drew Technical Department, owner's office and ship's records as indicated in the instructions on the log. Most Drew log sheets are printed in carbonless sets so that carbon paper is not needed.
- Fill in all required information to identify the ship, the ship's operating company, the voyage number, the equipment being tested, the date of the review period,

the boiler type and pressure, and in-port or full steaming conditons.

- Record test results and treatment dosages, marking proper units of measurement. If graphic log forms are being used, be sure to record the test results in the proper graphing area. The colored band will indicate the satisfactory range for each control test. Reference test results should be recorded in the appropriate boxes.

IMPORTANT: Decimal points must be placed correctly to eliminate misunderstandings and inaccurate evaluations.

- Any additional relevant information relating to the condition of the vessel, the equipment being treated, or the treatment program should be recorded in the appropriate space.

EXPRESSION OF CHEMICAL DOSAGES

CONVERSIONS (M—Metric, E—English)*

UNITS	MEASUREMENT	SYMBOL	MULTIPLY BY	TO FIND	SYMBOL
MASS (weight)					
M to M	kilogram	kg	1000	gram	gm
M to M	gram	gm	1000	milligram	mg
E to E	pound	lb	16	ounce	oz
M to E	gram	gm	0.035	ounce	oz
M to E	kilogram	kg	2.2	pound	lb
E to M	ounce	oz	28	gram	gm
E to M	pound	lb	0.45	kilogram	kg
VOLUME					
M to M	liter	ltr	1000	milliliter	ml
E to E	cup	c	8	fluid ounce	fl oz
E to E	pint	pt	2	cup	c
E to E	quart	qt	2	pint	pt
E to E	gallon	gal	4	quart	qt
M to E	milliliter	ml	0.03	fluid ounce	fl oz
M to E	liter	ltr	2.1	pint	pt
M to E	liter	ltr	1.06	quart	qt
M to E	liter	ltr	0.26	gallon	gal
E to M	fluid ounce	fl oz	30	milliliter	ml
E to M	cup	c	0.24	liter	ltr
E to M	pint	pt	0.47	liter	ltr
E to M	quart	qt	0.95	liter	ltr
E to M	gallon	gal	3.785	liter	ltr

*NOTE: The U.S. version of the English units is used in these calculations.

WATER SAMPLING PROCEDURES

The main purposes of routine water testing are:

1. To ensure that the proper residuals of treatment chemicals are maintained at all times.
2. To detect the presence of contaminants in the water that may be injurious to the boiler, diesel engine, and other equipment.

Test results are meaningful and useful only when the samples tested are representative of the water in the system at the time of testing. Recommended procedures for obtaining representative samples of boiler water, condensate, makeup water, feedwater, and cooling water circuits are discussed in the following sections.

RECOMMENDED LOCATION FOR SAMPLING CONNECTIONS

Boiler Water Sampling

Normally you can use the sampling connections provided by the boiler manufacturer. The sampling line is usually located in the steam drum, just above the generating tubes. In order to get proper results, it should be as far as possible from the internal feedwater line and the chemical feed line.

Samples drawn for routine boiler water tests should be tested **ONBOARD THE VESSEL**. Boiler water samples for laboratory analysis should be taken only in special cases. Boiler water samples **are not normally** submitted for iron and copper analyses since results are not representative of the corrosion rate in the system. This is because of the boiler water alkalinity conditions and the tendency to collect iron and copper deposits from other parts of the system than in the boiler.

Condensate and Feedwater Sampling

Sampling lines should be installed at three locations:

- Directly after the Main Condensate Extraction Pump. This line is to be used when the plant is under normal steaming conditions.
- Directly after the Auxiliary Condensate Extraction Pump. This line should be used only when the plant is under port operating conditions.
- The deaerator outlet line or from the suction or discharge of the main feedwater pump.

The latter is the best position for samples drawn for iron and copper tests; these samples will give a direct indication of the amounts of metal oxides entering the boiler with the feedwater. These connections may be used for obtaining samples for dissolved oxygen tests if they are ever required.

Makeup Water Sampling

The sampling line for this water may be located in one or two positions:

- In the line between the distilled water storage tank and the point of entrance of makeup water to the condensate system.

- Directly from the distillate condenser.

SAMPLING EQUIPMENT

Before testing, boiler water, hot condensate and feedwater samples must be cooled to 25°C (77°F) by collecting through a sample cooler for safety and to prevent flashing which concentrates the sample. Stainless steel sample coolers should be used except where seawater is used for the cooling. Where seawater is the only coolant, contact your Drew representative for proper handling procedures or a special coil.

Stainless steel piping or tubing used for sample lines should be installed with the least possible number of fittings and/or sharp bends. This is a precaution against plugging the lines with solid contaminants. The stainless steel sampling lines must meet international pressure code requirements. Tubing size should be 0.95 cm (3/8 in.) O.D.; nominal pipe size should be 0.95 cm or 1.27 cm (3/8 in. or 1/2 in.). Stainless steel is recommended to prevent contamination of sample by corrosion from the lines.

OBTAINING SAMPLES FOR SHIPBOARD TESTS

1. Allow the sample stream to run for 5-10 minutes in order to thoroughly flush out the line before taking a sample for testing.
2. A convenient and desirable procedure is to open the sample valve and allow the stream to run throughout the testing period. Appropriate samples for each individual test may be taken from the sample stream as needed. Test equipment, graduated cylinders, titration dishes, etc., should be clean and rinsed with the water to be tested and thoroughly drained.
3. If analysis of a sample must be delayed for any reason, the sample should be kept tightly capped in a clean sample bottle which has been thoroughly rinsed with water from the sample stream. After a long delay, resample. Test results for pH, alkalinity, hydrazine, sulfite or ammonia will be less accurate if testing is delayed because of the effect of air on these treatments.

OBTAINING SAMPLES FOR LABORATORY TESTING

The following special procedures are to be followed when obtaining samples for testing at shoreside laboratories:

1. A boiler water sample for laboratory analysis should be collected in a glass bottle. Minimum sample volume for boiler water analysis is 1,000 ml (one U.S. quart).
2. Condensate and feedwater samples for iron and copper analyses must be collected in special high purity plastic bottles. The minimum sample volume required for iron and copper analyses is 120 ml (4 oz.)
3. If oil contamination is suspected in a water system, a 500 ml (one U.S. pint) water sample should be obtained in a glass bottle.

4. Draw samples while boilers are operating under full or normal steaming conditions.
5. Flush the sample line for 5-10 minutes prior to obtaining a sample for testing. Flush for a longer time if the line is rarely used.
6. The sample container should be thoroughly rinsed with the water being tested and completely filled to overflowing so there will be no air space at the top of the sample

bottle. However, if there is a danger of freezing leave some freeboard in the bottle for expansion, otherwise, the bottle will burst. Tightly seal and properly label the sample bottle with the following information: vessel name, source of the sample, date of sampling, and information which describes the reason for sampling and any existing problems. This information is essential in order to determine what tests should be conducted and in the evaluation of results.

ANALYTICAL TECHNIQUES

Accurate analytical testing procedures are essential for proper control of chemical treatment programs. This section briefly describes the basic information common to all treatment programs and the procedures which should be followed for each of the analytical control tests.

PREVENT CONTAMINATION AND STORE REAGENTS PROPERLY

To ensure accurate test results, the analyst should take the necessary precautions to prevent contamination of the testing equipment before, during and after each test. It is imperative to have clean hands, a clean working surface, and, most important, clean test equipment and uncontaminated reagents within their normal shelf life.

CARE OF REAGENTS

Reagents by their nature are reactive. Care must be taken to prevent contamination and deterioration. Close all reagent bottles tightly with their original stoppers or caps. Use separate clean, dry spoons or droppers for each reagent to prevent cross-contamination of reagents. Never return excess reagent solution or powder to storage bottles.

To ensure freshness, periodically replace reagents. Store spare chemical supplies in a clean, cool cabinet, preferably outside of hot, humid areas. Air-conditioned rooms are a good environment for reagents. Powdered reagents can absorb moisture if stored in refrigerators so storage in an air-conditioned area is preferable.

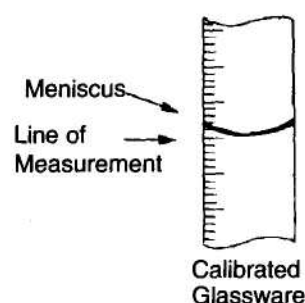
Some reagents are light sensitive so it is a good general rule to store them in the original bottles in which they are supplied in closed closets.

USE OF COLORIMETRIC EQUIPMENT

For accurate results using the color comparator slides, the path of light through the viewing tubes must be free of dirt or other obstructions. Before inserting the viewing tubes into the comparator, gently tap the tubes against the palm of your hand to dislodge any gas bubbles from the test solution. Clean the outer surface of each tube to remove water droplets and fingerprints. The outside surface of the comparator slide and color standards should also be clean.

There should be sufficient lighting behind the comparator when running the test to obtain accurate color comparison and uniform results. Daylight fluorescent light is preferred.

READING CALIBRATED GLASSWARE



When filling or reading liquid levels in calibrated glassware such as burettes and graduated cylinders, read the level where the bottom of the concave liquid surfaces reaches the line of measurement. The concave surface of a water solution is called the meniscus.

BURETTE TITRATION

Proper titration technique is important to assure accurate test results. The titrating solution should be slowly added to the sample while stirring until the desired endpoint is reached. Addition of titrant should be slowed to one drop at a time as the endpoint approaches to avoid overshooting the endpoint. The approaching endpoint is signaled by temporary color change where the titrant enters the sample. The first permanent color change throughout the sample is the endpoint.

PROPER MEASURING SPOONS

The measuring spoons have been specially selected to make the addition of reagent easy. The amount of reagent added to a sample can be critical to the result. In some procedures, the addition of reagent is similar to titrating the solution with a standard liquid. It is important to know how much was added and reacted with the specific constituent before reaching the endpoint in order to determine the amount of substance in the solution.

Each spoon holds a specific amount of reagent. Because it is important to know the amount of reagent added, the proper spoon size should be used. Diagrams of the spoons follow and the appropriate tests are noted beside each drawing.

- | | |
|--|--|
| <p>Code: <input type="checkbox"/> 0224-01-4</p> <p>Description: Brass, 0.2 Gram</p> <p>Test: DEWT* NC
Phosphate (Low/Medium Pressure)
Conductivity)</p> | |
| <p>Code: <input type="checkbox"/> 0436-01-5</p> <p>Description: Plastic, 0.1 Gram
(Marked No. 0699)</p> <p>Test: Phosphate (High Pressure)</p> | |
| <p>Code: <input type="checkbox"/> 6358-01-5</p> <p>Description: Plastic, 0.05 Gram
(Marked No. 0696)</p> <p>Test: Ammonia (High Pressure)</p> | |
| <p>Code: <input type="checkbox"/> 9637-01-0</p> <p>Description: Plastic, 2.0 Gram</p> <p>Test: Sulfite</p> | |

WATER ANALYZER GENERAL INSTRUCTIONS

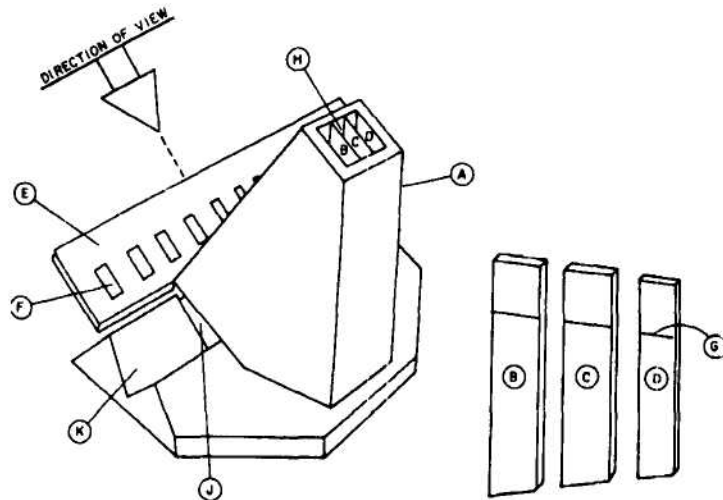
The Water Analyzer is used to determine hydrazine, silica and ammonia concentrations and pH values.

Specific instructions for these tests may be found in this section.

The Water Analyzer consists of a base structure (A), three glass tubes (B)(C)(D), and one or more comparator slides (E) fitted with transparent color standards (F). The tubes are modified "Nessler" tubes, and each has an etched mark at 150 mm or 250 mm above the bottom (G). The base has a compartmented holder (H) for the tubes, which supports them at a 45° angle above a mirror (J) set into the base. The slides move in a slot in the base (K) above the mirror and beneath the tubes.

USE OF THE WATER ANALYZER

1. Set the appropriate comparator slide for the desired test in the slot in the base. The row of numbers on the slide (corresponding to pH values, ppm hydrazine, etc.) should be visible when the slide is viewed from above the mirror.
2. Fill the two outer tubes (B & D) to the etched mark with reference blanks according to the instructions for the particular test. Place these tubes in the two outer compartments in the base.
3. Add reagent chemicals to another portion of the sample, according to the instructions for the particular test.
4. Fill the middle tube (C) to the etched mark with the treated sample and place it in the middle compartment in the base.
5. Set the base on a flat surface so that the mirror faces the operator and a light shines into the open ends of the tubes.
6. Move the slide back and forth, while observing the colored ovals that will appear in the mirror. Continue until the color of the middle oval matches that of one of the side ovals. Note that the comparison can be made only when one of the arrows on the slide is opposite the middle tube.
7. When a color comparison is obtained, read the test result (in pH, ppm hydrazine, etc.) from the numbers on the slide.



DIRECTIONS FOR USING THE TITRETOR™

1. Fill the sample cup to the 25ml mark with your sample.
2. Push the valve assembly (in ampoule tray) onto the Titret ampoule tip until it fits snugly (Figure 1).

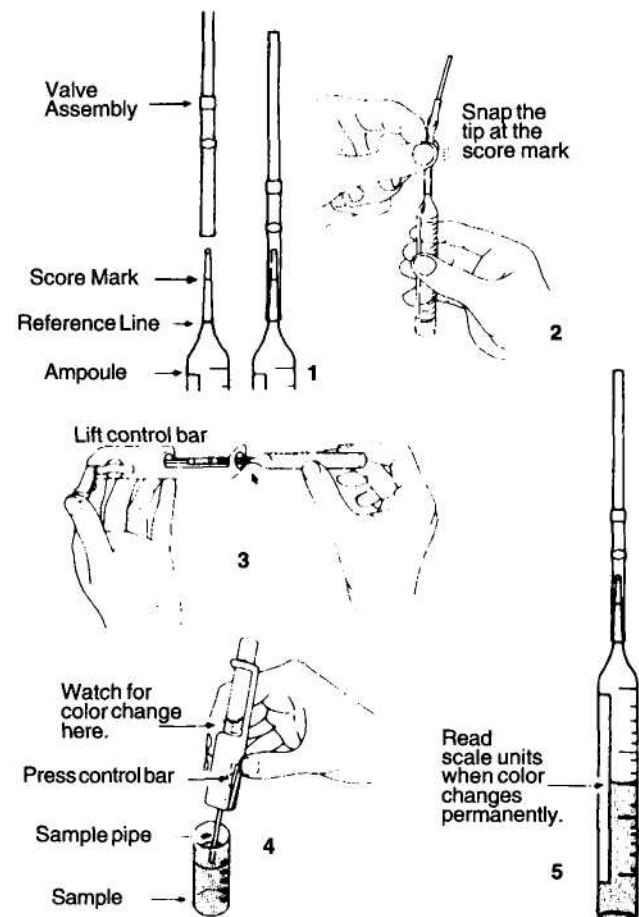
NOTE: The valve assembly should reach the reference line on the neck of the ampoule.

3. Gently snap the tip of the ampoule at the score mark (Figure 2).
4. Lift the control bar and insert the Titret assembly into the body of the Titrettor (Figure 3).
5. With the tip of the sample pipe immersed in the sample, press the control bar firmly, but briefly, to pull in a small amount of sample (Figure 4).

CAUTION: If the control bar is pressed when the sample pipe is not immersed in the liquid, then the vacuum in the Titret will be destroyed.

6. Press the control bar again briefly to allow another small amount of sample to be drawn into the ampoule.
7. After each addition, rock the entire assembly to mix the contents of the ampoule. Watch for the color change (end point).
8. Repeat steps 6 and 7 until the end point is reached.
9. Remove the ampoule from the Titrettor. Hold the Titret ampoule in a vertical position and carefully read the test result on the scale opposite the liquid level (Figure 5).

SEE NOTES ON THE SPECIFIC TESTS BEFORE PROCEEDING.



FILTER PAPER

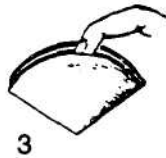
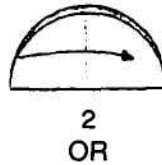
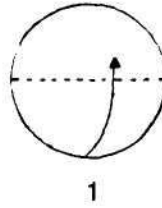
Filtration is required in some test procedures. This is especially true if suspended solids appear in the sample. Failure to filter a sample when required or the repeated use of the same filter paper will result in an incorrect value. There is one exception to this rule. If a sample remains cloudy after the first filtering, the sample should be refiltered through the **same** filter paper since the filter becomes more retentive on the second filtration.

Some filter papers are specially prepared to minimize contaminants. (Drew specifies a Whatman #5 filter paper).

There are two techniques for folding filter paper; either is acceptable. Clean hands are important for both.

Quarter Fold

The simplest method is to fold the paper in half and then in half again.



Pull three quarters of the paper to one side and crease to hold the cone shape. Insert the tip of the cone into the funnel.



Fluted Paper

The other technique is to fold the paper in half and then in half again.

Fold it into a fan shape making many small folds. Crease and then open the paper to a full circle. Insert the tip of the cone into the funnel. This method increases available surface area.

Pour the sample into the center of the cone. Do not fill the funnel above the upper surface edge of the filter paper. Sample which flows between the paper and funnel will add unwanted materials to the filtered sample.

EXPRESSION OF CHEMICAL RESULTS

REPORTING OF QUANTITY

When reporting the results of an analysis, it is necessary to express the quantity of each constituent that is determined. In the analysis of most materials, the quantity of each constituent is given in terms of percent--the amount of each constituent per 100 parts of the material. For example, an analysis of a metallic sample may show 60 percent copper which would mean that every 100 parts of the sample contain 60 parts of copper.

Reporting by percent would be awkward in water analysis since the amounts of the materials determined are extremely small. For example, the silica content of natural waters, if expressed in percent, would be in the range from 0.0001% to 0.01%. To avoid the use of very small numbers, the terms "parts per million" (ppm), "parts per billion" (ppb), and "equivalents per million" (epm) are used in water analysis. The terms ppm and ppb are utilized by Drew in its publications and reports.

Parts Per Million (ppm)

One part per million (ppm) is an expression of the relationship of one part of a substance to one million parts of another. As examples, if a water contains one ppm of silica, there would be one part of silica in 1,000,000 parts of the sample.

$$\frac{1 \text{ gram silica}}{1,000,000 \text{ grams (1 metric tonne)}} = 1 \text{ ppm silica}$$

In a million grams (1 metric tonne) of this water, there would be one gram of silica; or in a million pounds of water, there would be one pound of silica. Expressing results in terms of parts per million is a simple method to use, and for most determinations, the results are given in whole numbers.

Parts Per Billion (ppb)

One part per billion (ppb) is used to express the relationship of one part of a known substance to one billion parts of another. For example, a sample of water may contain one part of silica to one billion (1,000,000,000) parts of water. As indicated above for "ppm", "ppb" may be applied to quantities expressed in any unit of measure.

Equivalents Per Million (epm)

An additional method for expressing results of water analysis is by means of equivalents per million (epm). Results in equivalents per million are obtained by dividing the concentration in parts per million by the chemical combining weight or equivalent weight for each ion or substance.

Equivalent weights can be obtained from suitable tables. For example, to convert 25 ppm of chloride to epm:

$$\frac{25 \text{ ppm chloride}}{\text{equivalent weight of chloride}} = \frac{25}{35.5} = 0.71 \text{ epm}$$

REPORTING OF pH Acidity, Neutrality, Alkalinity

An aqueous solution can be either acidic, neutral or alkaline. The accepted manner of expressing this condition is pH. pH is the reciprocal of the logarithm of the hydrogen ion (H⁺) concentration in solution, $-\log[H^+]$ on a scale of 0 to 14. The midpoint pH at 7.0 is considered "neutral".

Values below 7.0 are increasingly acidic, and those above 7.0 are increasingly alkaline. In common practice, pH can be determined by electrical instruments, color indicators, or specially treated test paper.

Alkalinity is defined as the state of being alkaline or "basic". The alkalinity is determined by the concentrations of hydroxide, carbonate, and certain other chemicals, such as phosphate and silicate.

Phenolphthalein ("P") Alkalinity is a measure of the alkalinity above a pH of 8.2-8.3. All of the hydroxide, one-half of the carbonate, and one-third of the phosphate, plus all other alkali-producing materials present in a water sample such as silicate are included in the Phenolphthalein Alkalinity.

Total ("T") Alkalinity is a measure of the alkalinity above a pH of 4.2-4.3. All of the hydroxide, all of the carbonate, and two-thirds of the phosphates, plus all other alkali materials are included in the Total Alkalinity.

REPORTING OF DISSOLVED SOLIDS CONCENTRATION AS CONDUCTIVITY

In boiler water, the dissolved solids consist of contaminants, treatment chemicals, and naturally occurring chemical constituents. Dissolved salts ionize and conduct an electric current. The amount of current that a water sample carries from one electrode to another at a specific temperature is termed its conductivity. The concentration of ionized dissolved solids in any water is proportional to its electrical conductance. For example, distilled water has a very low conductivity; in contrast, seawater has a very high conductivity. Therefore, the amount of dissolved solids can be estimated by the water's conductivity. A conductivity meter, which records conductance in micromhos (μmhos), is used to measure this characteristic of the water.

$$\text{Conductivity as micromhos} = \frac{1}{1 \text{ million ohms}} = 1.0 \times 10^6 \text{ ohms} = 1\mu\text{mho}$$

(Neutralization is required before testing the conductivity of boiler water samples because strong bases (or strong acids) conduct more than a proportional amount of electricity based on their actual solids concentration, giving a false high reading.

The sample should be a cooled sample, its temperature taken and the temperature compensation dial on the meter, if there is one, should be properly set before taking the conductivity reading.

DILUTION OF WATER SAMPLES

There are two conditions under which dilution of a sample may be necessary:

- When a sample is highly colored, even after filtration, which would make it impossible to determine a colorimetric end point.
- When the initial test result is exceedingly high or beyond the normal range of the test procedure.

These dilution and multiplication factors can be used for any sample.* The accuracy of the result, however, is dependent upon the care taken in making the dilution.

Dilution of a sample should always be done with distilled water. If a sample is diluted, the test result must be multiplied by the appropriate factor. Examples follow:

EXAMPLE: Phosphate Test

1. Draw a 25 ml sample of water.
2. Dilute sample with 25 ml of distilled water.
(Total volume=50 ml)
3. Conduct phosphate test. (Result=45 ppm phosphate)
4. Multiply test result by a factor of 2. (45 ppm x 2 = 90 ppm phosphate)
5. Final test result=90 ppm phosphate

* Avoid dilution of a sample when testing for an oxygen scavenger. When testing for oxygen scavenger, the water used to dilute the sample should be deoxygenated.

WATER SAMPLE	+	DISTILLED WATER DILUTION	=	TOTAL VOLUME	MULTIPLE TEST RESULT BY FACTOR OF:
25 ml		25 ml		50 ml	2
50 ml		50 ml		100 ml	2
10 ml		40 ml		50 ml	5
20 ml		80 ml		100 ml	5
10 ml		90 ml		100 ml	10

BOILER WATER SYSTEMS AND TREATMENT

INTRODUCTION

A boiler converts the chemical energy in fuel to heat energy in steam for the purpose of doing work. There are many types of boiler plants, but all of them function on the same basic principles of thermodynamics. A complete discussion of either plant design or thermodynamics is beyond the scope of this presentation. However, some basic concepts will be presented here to introduce the systems which we will discuss in the sections below.

In the world fleets today, we see some ships which operate boilers for propulsion (some at pressures over 63 kg/cm², 900 psig) and motor vessels equipped with auxiliary oil-fired and waste heat boilers which operate at lower pressure levels (7-24 kg/cm², 100-350 psig).

All boilers operate on the common premise that heat is transferred to water to create steam which is then used to do work onboard. Diesel engines depend on scale-free heat transfer surfaces for cooling. They share common problems of scale formation and corrosion, although some forms of corrosion will be more evident in high pressure boilers and others are more often seen in engines.

The water used onboard, for whatever purpose, comes primarily from the sea. In order for seawater to be safely used for steam production, the salts and other contaminants must be removed from the water. An evaporator or distiller is generally installed for the purpose of purifying the water until it contains only trace levels of minerals. Seawater also

contains dissolved gases which have been absorbed from the air or formed by decaying organic matter. They can be mechanically removed by deaeration, thermally reduced by increased feedwater temperature and/or chemically scavenged.

An effective water treatment program minimizes scale and corrosion in the boiler system. Since distillation and mechanical/thermal deaeration cannot remove all of the contaminants, routine chemical treatment programs are necessary for the efficient maintenance of all steam generating and cooling system equipment.

The primary goals of a controlled water treatment program in any power generating plant are:

- To maintain clean, scale-free waterside heat transfer surfaces in steam generating and cooling water systems.
- To prevent metal loss due to corrosion.
- To ensure efficient production of steam in boiler systems without priming, foaming, or carryover contamination.
- To prevent formation of deposits in steam/condensate systems.
- To minimize heat loss from the system due to excessive blowdown from boilers.
- To keep all power generating and auxiliary equipment, and associated water and steam systems at their most efficient levels and thereby minimize costs.

PRODUCTION OF HIGH QUALITY DISTILLATE

The water used on ships, for whatever purpose, comes primarily from the sea. In order for seawater to be used for steam production, the salts and other contaminants must be separated from the water to minimize scale formation and corrosion in boiler water and steam circuits. Mechanical and chemical technology is used in combination to do both. This section will discuss the production of high quality water, corrosion and scale mechanisms, mechanical and chemical corrections for these conditions before moving on to the test procedures used to control the chemical treatments and monitor the contamination.

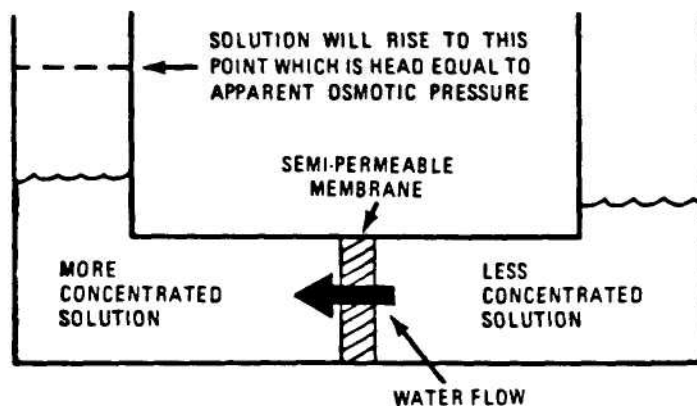
Distillation, ion exchange, and reverse osmosis (RO) are processes which may be used for the desalination of seawater. In the marine industry, distillation is the most widely used method because of its relative simplicity and cost effectiveness. Brief descriptions of the other methods follow.

Ion exchange: Cation ion exchange units will effectively remove hardness constituents (calcium and magnesium) from water but not the anions, i.e. chloride and sulfate ions or other contaminants. The extremely high concentrations

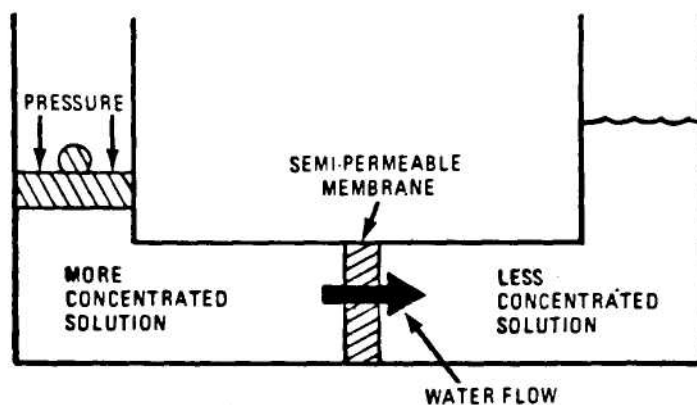
of the salts in seawater pose a challenge to these units. The most common ion exchange units must be regenerated with sodium chloride brines which can contribute chloride ions to the contamination. Ion exchange resin beds must be designed in such a way to prevent channels which will allow water to flow through untreated.

Reverse osmosis is an effective means of desalination. However, a single pass unit will not produce water of sufficient quality for use in marine systems and further demineralization is necessary. A number of units in series could theoretically produce an effluent of acceptable quality and quantity for boiler feedwater.

The normal process of **osmosis** involves two solutions of different dissolved solids concentration that are in a single container, separated by a semipermeable membrane. The common solvent in both solutions is water. The water flows from the more dilute solution through the membrane to the more concentrated solution. In time, the equalizing effect creates equal dissolved solids concentration in both compartments.



OSMOSIS



REVERSE OSMOSIS

The **reverse osmosis** process is created when pressure is exerted upon the more concentrated solution so that the water flows in the reverse direction through the semipermeable membrane from the concentrated side to the dilute side, leaving the majority of the dissolved solids behind.

When reverse osmosis is used to produce fresh water from seawater, a reverse osmotic pressure is created to force the water from the brine (seawater side) into the fresh water compartment. Theoretically, the only energy required is that which is needed to overcome the osmotic pressure and pump the feed water. In practice, much higher pressures (between 56-70 kg/cm², 800-1000 psig) are required to produce useful volumes of water per unit area of membrane.

Generally, the reverse osmosis process is not as widely used onboard ship as distillation.

DISTILLATION (EVAPORATION PROCESS)

A marine evaporator is normally used to provide high quality distillate from seawater for the vessel's water systems. There are many types of evaporators, but they are all designed for the same purpose. Hot cooling water or auxiliary steam is often used as a heat source increasing cost effectiveness.

In some type of evaporators, seawater is heated or flows over a series of coils or tubes through which auxiliary steam is passed. Heat is transferred to the seawater until steam forms. In other types, the heated seawater enters a chamber under vacuum, vaporizing a major portion of the water. The resulting vapor is scrubbed by a mist eliminator as it leaves the evaporator unit to remove entrained moisture which contains a small amount of dissolved solids.

The vapor is then cooled in a condenser to produce pure distillate. It is pumped to storage tanks for use as boiler water makeup, engine cooling water, potable water and other domestic purposes.

The majority of dissolved solids are left behind, accumulated and concentrated in the brine section of the unit for overboard discharge. The purified water now contains only traces of minerals which can be easily handled with boiler water treatment chemicals.

Evaporator Scaling

During the evaporation process, the solubility of most of the dissolved minerals, which remain in the evaporator brine, is exceeded and precipitation occurs, forming scale deposits on heat transfer surfaces. The three most common scales formed in an evaporator are calcium sulfate, calcium carbonate, and magnesium hydroxide. These are efficient heat transfer barriers. Reduced heat transfer results in reduced water production. Eventually, distillers must be shut down and cleaned to remove the insulating scale.

Evaporator Foaming and Carryover

The higher concentration of dissolved solids in the brine increases the surface tension of the water, acting like an elastic skin at the water level. The increased surface tension hinders the release of vapor bubbles and gases and promotes foaming.

When the bubbles burst, droplets containing concentrated salts are thrown into the vapor space and are carried over into the distillate. This results in reduced water quality.

Foaming also may be caused by "organic" substances in the water, which are formed by the decay of organic materials or contamination with petroleum products.

Mechanical Control

Foaming and carryover from evaporators can be minimized by proper management of the water level and salinity (brine) control.

- Improper water level control is often due to the malfunction of the automatic controls and alarms. Automatic equipment and alarms should be maintained in good operating condition.
- Salinity control is an important factor in the prevention of scale deposits as well as carryover. Salinity management refers to the continuous removal of concentrated brine from the evaporator in order to control the amount of dissolved solids buildup. Normally the brine concentration should be maintained at 1.5 (1.5/32nds) concentrations, although some vapor compression units operate at 2.0 (2.0/32nds) concentrations or more.

Chemical Treatment

The problems of scale formation and foaming can be minimized by the addition of chemical treatments containing polymeric scale inhibitors and antifoams. The polymer molecules attach themselves to the scale-forming minerals to disrupt the densely packed crystalline structure. This prevents hard scale from building up on the heat transfer surfaces. Instead, nonadherent, suspended crystals are formed which can be removed easily by overboard brine discharge.

Polymer treatments can remove existing scale from heat transfer surfaces by the same action. If treatment is used, water production can be maintained, and acid cleaning to remove scale can be minimized.

Modern formulations include an antifoam ingredient which reduces the surface tension of the water and allows vapor to escape without the formation of foam. This helps to maintain water quality.

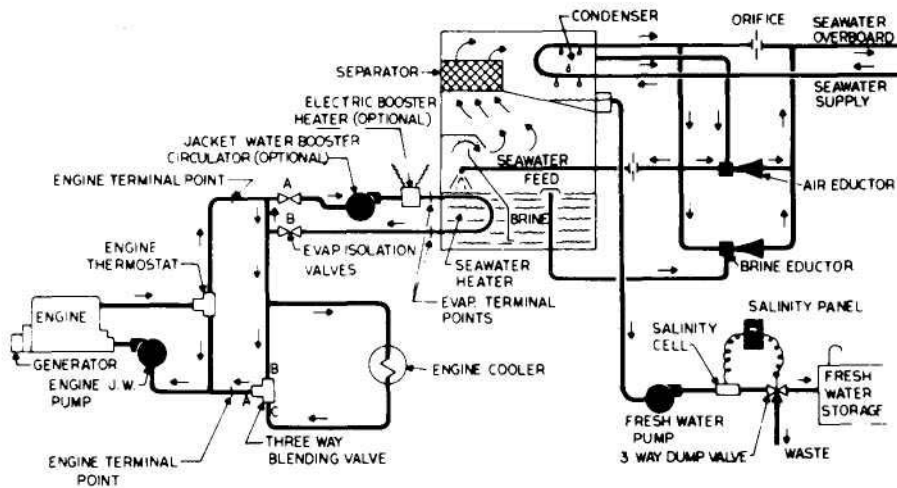
Drew Evaporator Treatments

AMEROYAL[®] evaporator treatment is a liquid combination of an active polymer with a highly effective antifoam agent. It is effective in seawater and brackish water. The antiform agent in AMEROYAL treatment reduces surface tension and, thereby, prevents foaming and carryover. AMEROYAL treatment is the most widely used evaporator treatment in the marine industry.

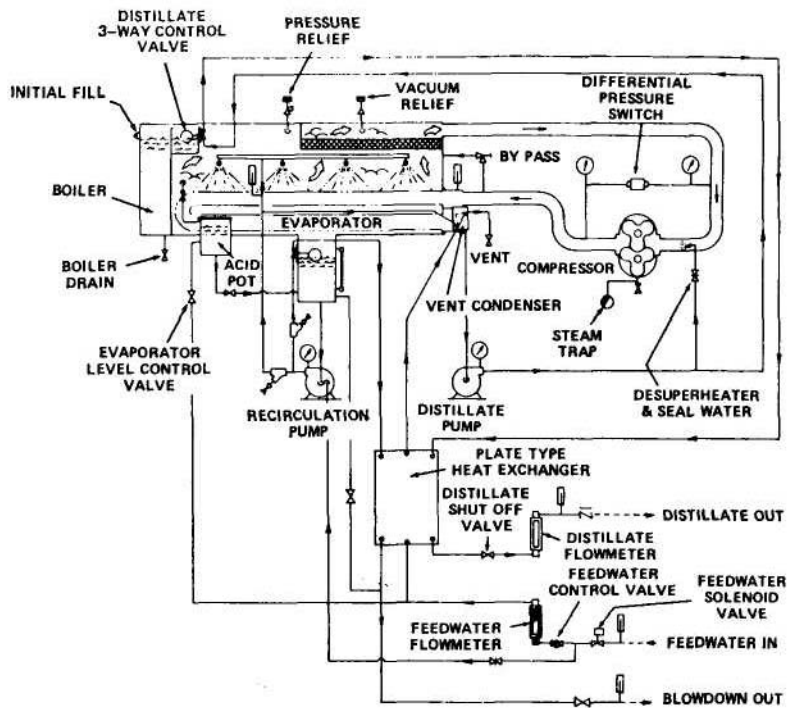
AMEROYAL CF concentrated evaporator treatment is a concentrated liquid formulation of active polymers and antifoam agents developed specifically to prevent scale deposition and carryover in high temperature, high production multi-stage evaporators. AMEROYAL CF treatment has been proven capable of significantly reducing the amount of acid cleaning required to maintain design distillate production.

EXAMPLES OF EVAPORATOR UNITS

LOW-PRESSURE SUBMERGED HEATING ELEMENT DISTILLER

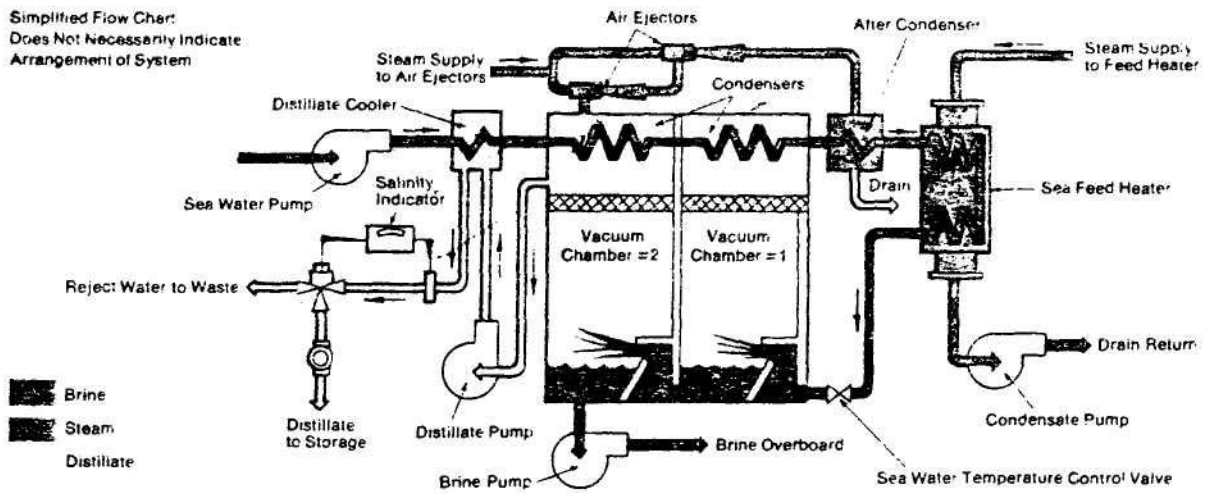


VAPOR-COMPRESSION DISTILLER

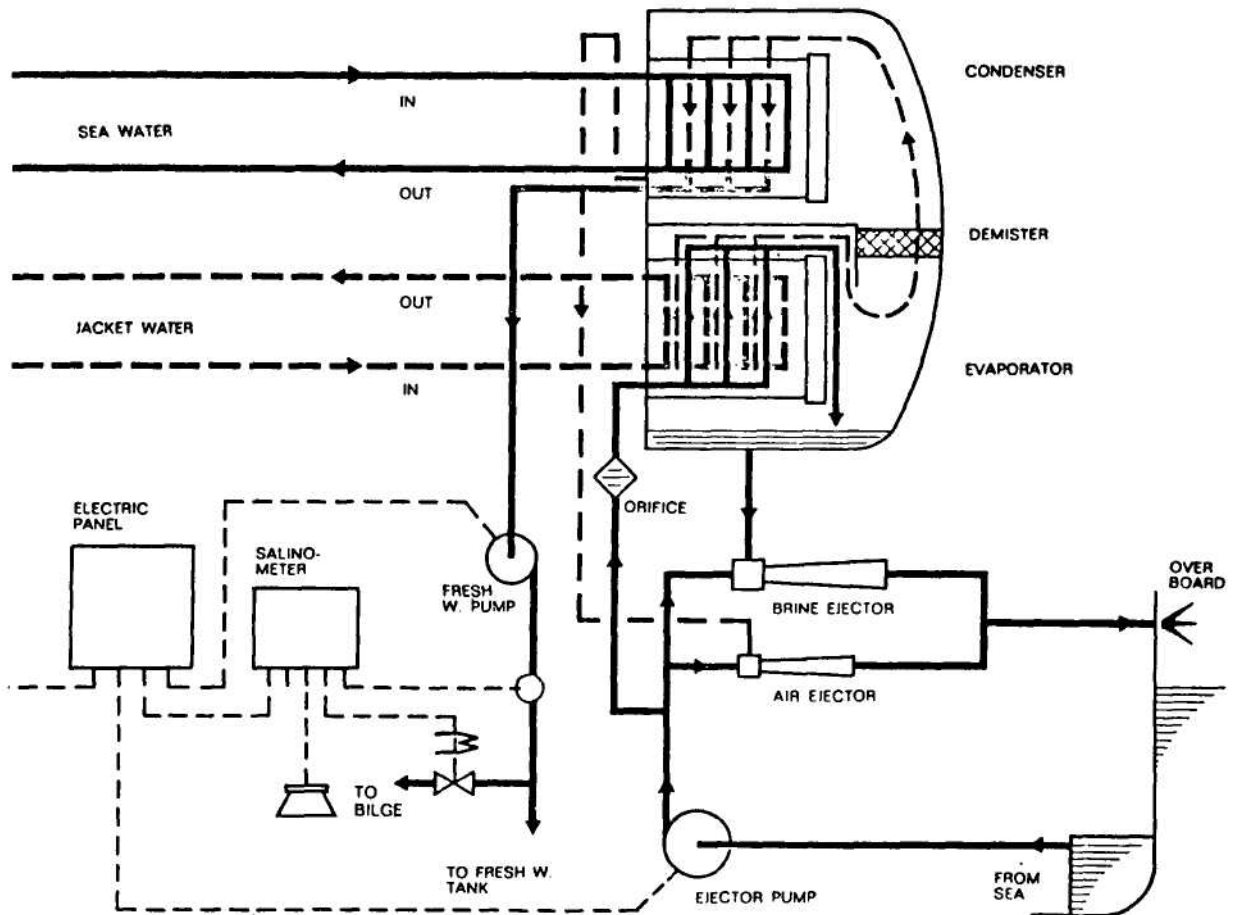


TWO STAGE VACUUM-FLASH DISTILLER

Simplified Flow Chart
Does Not Necessarily Indicate
Arrangement of System



LOW PRESSURE THIN-FILM DISTILLER



BOILER WATER CIRCULATION

A boiler is designed to convert the chemical energy contained in fuel to heat energy in the steam. This steam is then available to do work in a variety of systems onboard. The figure below illustrates the circulation pattern of a water tube boiler system. (While only one design is shown, all marine boilers function in a similar pattern.)

In a water tube boiler, the furnace is surrounded by tube banks which are connected through headers to the upper and lower drums. The fuel is burned in the furnace and the heat is passed by radiation to the surrounding generating tubes. The heat energy is passed by conduction to the recirculating boiler water in the tubes. In this way, the tube metal is cooled and steam is generated.

As the water is heated, its density decreases and it tends to rise. Colder heavier water tends to sink. As the hot water/steam rises in the generating tubes and the colder water sinks in the downcomer tubes, a natural circulation results in the boiler circuit.

As the steam/water mixture reaches the upper drum (steam drum), it separates. The steam passes to the upper half of the drum, then leaves the top of the drum to the superheater or directly to where it is needed as saturated steam. The recirculating water remains in the lower half of this drum, mixes with incoming feedwater and again passes through the complete water circuit.

In boilers fitted with superheaters, the steam which is released into the top of the steam drum passes out of the boiler through the steam line to the superheater where more heat

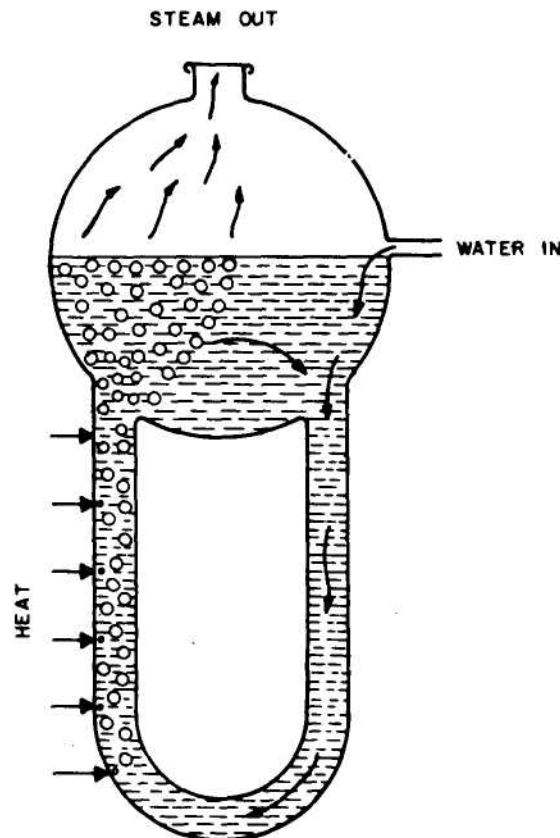
is added, increasing the energy in the steam. The superheated steam is then passed through a high pressure turbine and possibly a low pressure turbine where a major portion of steam's thermal energy is converted to mechanical energy.

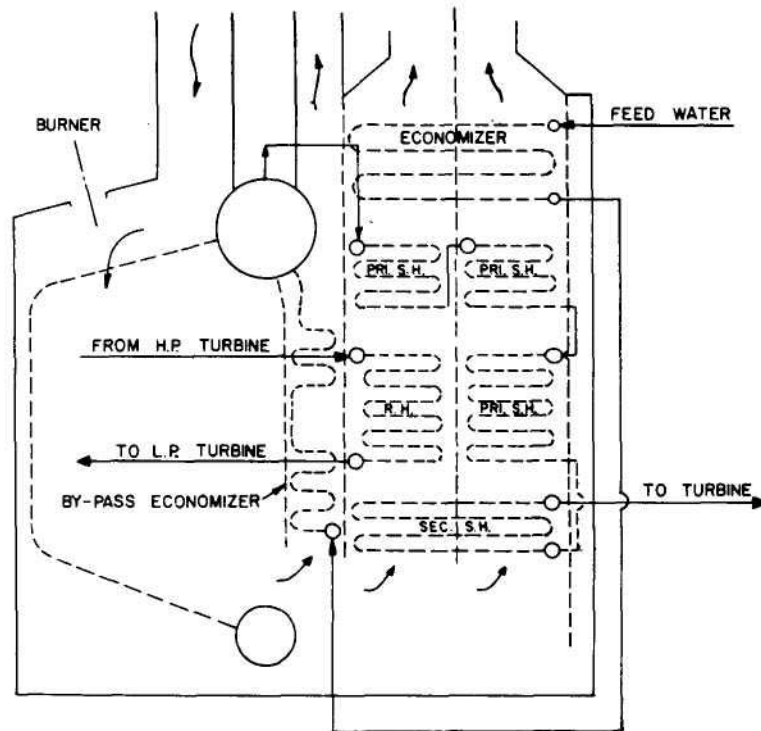
Before the steam is condensed and returned to the feed system, part of it may be bled off from the turbine system for feedwater heating and similar processes so that its thermal energy can be fully utilized.

After passing through any auxiliary systems, the steam enters the condenser where it is condensed to form water which is pumped back to the feed line, completing the boiler/feed system circuit.

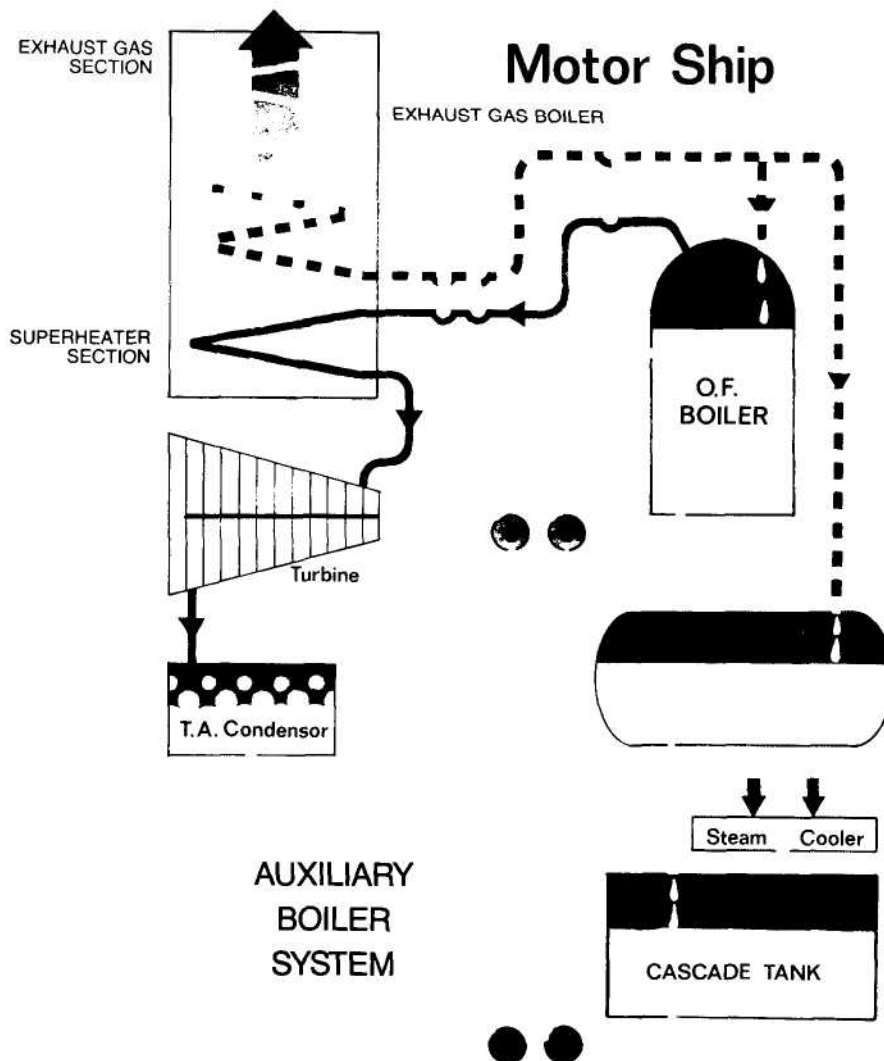
In systems operating at lower pressure levels without superheaters, the steam simply leaves the boiler from the steam drum and passes throughout the steam system before being condensed and returned as condensate to the feed equipment.

On motor vessels there are usually two steam generating systems: a waste heat economizer drawing its heat energy from the diesel engine exhaust gases and an auxiliary oil fired boiler. The waste heat economizer functions when the engine is in operation, and the auxiliary boiler functions when the ship is in port and the main engine secured. Although their design is different from the boilers used for propulsion, these boiler systems function under the same principles of heat transfer and are subject to many of the same problems due to scale and corrosion.





BOILER WITH SUPERHEATER FITTED



CORROSION OF METALS

Ferrous and nonferrous alloys are commonly used metals of construction in marine power plants although other metals are also being used. All of these metals will corrode slowly in contact with water, unless the water is properly treated. High temperatures and pressures increase the rate of corrosion. The purpose of any complete water treatment program is to protect all of the preboiler, boiler and afterboiler auxiliary equipment and systems against corrosion, both during operation and during out-of-service periods.

CHARACTERISTICS AND TYPES OF CORROSION

Corrosion is defined as the deterioration of a metal or alloy or its properties due to reaction with its environment. Characteristics of the damage caused by corrosion include the following:

- **Pitting**—A selective, localized metal attack characterized by the formation of rounded deep cavities in a metal surface. Pitting is considered to be one of the most serious forms of corrosion and often associated with oxygen attack.
- **General corrosion**—Thinning or metal loss in which the thickness of the metal is evenly reduced over a large surface area.
- **Caustic Cracking**—A localized form of corrosion or physical destruction in which a fracturing of the metal following grain boundaries occurs due to stress.
- **Embrittlement**—An effect of corrosion that changes the physical properties of a metal, its crystalline and inter-crystalline structure, causing the metal to lose its strength and ductility, thereby becoming brittle and weak.
- **Exfoliation corrosion**—A type of attack which peels or splinters the metal into thin, parallel layers.
- **Dealloying**—The selective dissolution of one metal from an alloy.

CAUSES OF CORROSION REACTION AND PREVENTATIVE MEASURES

Corrosion is a result of chemical and electrolytic action of water or air on a metal. The corrosion rate is influenced by the impurities in the metal and the water. Properly treated high purity water and metals reduce the rate of corrosion. All of these metals will corrode in water unless the water is properly treated.

The most common causes of corrosion in boiler systems are dissolved gases, improper pH levels, and mechanical conditions. Brief discussions of the specific corrosion reactions follow.

GASEOUS CORROSION

Three gases are of primary concern in a water treatment program: oxygen, carbon dioxide, and ammonia.

Oxygen gas is one of the most undesirable contaminants which enters the preboiler/boiler/afterboiler water system. Oxygen dissolves in water and causes corrosion at an ex-

cessive rate. The severity of the oxygen attack depends on the concentration of the dissolved oxygen, pH value, and temperature of the water.

Oxygen reacts with the ferrous metal surfaces to form red iron oxide (Fe_2O_3). Because this red iron oxide (ferric oxide) or rust, is porous and does not protect the metal surface, the corrosion process continues. Ultimately, the entire metal structure will be converted to ferric oxide unless corrective measures are taken.

The corrosion is often localized which results in pitting. Unless stopped by chemical or thorough mechanical cleaning, the corrosion reaction will proceed beneath a cap of porous oxide until it pierces the metal.

Carbon Dioxide: Most of the carbon dioxide in marine power plant water systems is formed in the evaporators. Heat causes carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-), which are dissolved in the seawater, to break down to carbon dioxide gas (CO_2).

Carbon dioxide gas leaves the evaporator with the vapor and dissolves in the distillate. The carbon dioxide reacts with water to form carbonic acid which reduces the pH of the water and accelerates general corrosion in the feedwater and ultimately in the boiler steam-condensate system.

The carbonic acid (H_2CO_3), a weak acid, attacks the steel in the feed and condensate lines to form ferrous bicarbonate ($\text{Fe}(\text{HCO}_3)_2$). Ferrous bicarbonate is a highly soluble compound that has no protective or passivating effect. Carbonic acid produces a general type of corrosion, which is typified by grooving along the bottom of a pipe, overall metal thinning and, particularly, loss of metal at stressed areas such as pipe bends and threaded sections.

Ammonia: The copper based metals are subject to attack by ammonia in the presence of oxygen. It is only the combined action of these gases which is corrosive. By eliminating the oxygen, the corrosive potential of ammonia is minimized.

Ammonia is formed by the decomposition of organic material or the breakdown of excessive hydrazine.

Mechanical Removal of Gases:

Air naturally dissolved in the makeup water, in-leakage and the breakdown of other compounds introduces oxygen, carbon dioxide, and ammonia. Air can enter through any opening such as makeup, drain or cascade tanks and especially systems under vacuum such as turbine seals and condensers.

To deal with this problem, marine steam systems are equipped with air ejectors, hot wells and sometimes, deaerating heaters. The efficient operation of this equipment is essential for the removal of a high percentage of the noncondensable gases which enter the system.

The following is a list of the main points to check in plant operation to reduce the entry of corrosive oxygen (O_2) and carbon dioxide (CO_2) gases:

- Check all points of possible air in-leakage in the conden-

sing and vacuum sections of the plant, (i.e., defective flanges, gaskets, valve packing, cracked valve bonnets, open return line drain valves, insufficient steam pressure on gland seals, malfunctioning steam traps, etc.)

- Check the temperature of the water in tanks operating at atmospheric pressure. Since O₂ and CO₂ gases readily dissolve in cool water, the water in all atmospheric water tanks should be heated to the highest temperature possible without creating a vapor lock at the pump suction.

NOTE: In motor vessel systems without deaeration equipment, the feed-cascade-hot well tanks must be kept at as high a temperature as possible in accordance with boiler manufacturers' recommendations to liberate the maximum amount of dissolved oxygen. Tanks which are covered must have vent lines fitted to carry away vented gases. Many ship systems have feed pumps functioning continuously with feedwater excess recirculated back to the feed tank. As the returning water may be simply dumped into the tank, any volatile chemicals which may have been dosed to the feedwater before the recirculation off-take can be lost from the system. To minimize this condition, the treatment chemicals are often dosed "downstream" of the off-take point by means of a dosing pump.

- Avoid piping drains with high oxygen concentrations to drain tanks or to any point where they may be used as boiler makeup.
- Check for inefficient operation of the deaerating heater. One thermometer should be installed in the steam space and another in the water space of the deaerator. When the unit is operating efficiently, the temperatures in the water space and in the steam space should be within one

to two degrees Centigrade of each other. If not, check thermometers for accuracy and replace if necessary. If the temperature difference is confirmed, the unit should be opened and inspected at the first opportunity to determine the cause of the problem. (See "Pressure/Temperature Table for Deaerator Checks," which follows.)

- Provide adequate venting of gases from the deaerating heater directly to the atmosphere. The vent line must be open, and if an orifice is installed, it must be large enough to adequately remove the noncondensable gases. If the vent line is run to the gland seal exhauster, the fan on this unit must be in operation continually while the vessel is in port and when at sea. If the fan should fail, the auxiliary vent to the atmosphere on the deaerating heater must be opened until the fan is again in operation.
- Check for clogged, worn, or broken spray nozzles or springs in the deaerator. Poor atomization will result in poor deaeration regardless of the temperature.
- When taking on extra feed water:
 - a. Take on feed as slowly as possible. If feed is taken on too quickly, the deaerating heater may be overloaded, making it impossible to efficiently minimize the O₂ and CO₂ concentrations.
 - b. A higher water temperature in the makeup feed tank will reduce the absorption of O₂ and CO₂.
- Use chemical treatment for maximum protection against the remaining O₂ and CO₂. While mechanical deaeration of the feed water is a major step in eliminating dissolved oxygen and other corrosive gases such as ammonia and carbon dioxide, it needs the assistance of chemical treatment.



Pressure/Temperature Table for Deaerator Checks

Malfunction of the deaerating heater will allow gases to remain in the feedwater which will result in fluctuations in the oxygen scavenger residual in the boiler water and cause condensate pH control difficulties. An indication of proper deaerator operation is provided by the operating temperatures and pressures. The steam and water space temperatures

should be nearly equal. If the temperature difference is greater than 1°C or 2°F, the thermometers should be checked for accuracy and, if necessary, repaired or replaced. At the same time, the system should be checked for malfunctioning atomizing nozzles, steam inlet valves, vents, etc.

DEAERATOR SHELL PRESSURES AND CORRESPONDING SATURATION TEMPERATURES

Deaerator Shell Pressures		Correct Saturation Temperatures	
kg/cm ²	psig	°C	°F
0.0	0	100	212
0.11	2	103	218
0.28	4	107	224
0.43	6	110	230
0.58	8	113	235
0.69	10	115	239
0.86	12	118	244
0.99	14	120	248
1.12	16	122	252
1.26	18	124	255
1.41	20	126	259
1.56	22	128	262
1.72	24	130	265
1.83	26	131	268
1.97	28	133	271
2.10	30	134	274
2.25	32	136	277
2.34	34	137	279
2.54	36	139	282
2.68	38	140	284
2.82	40	141	287
2.96	42	143	289
3.10	44	144	291
3.24	46	145	294
3.38	48	146	296
3.52	50	148	298
3.80	54	150	302
3.94	56	151	304
4.08	58	152	305
4.22	60	153	307

CHEMICAL TREATMENT

Removal of Oxygen

Any dissolved oxygen remaining after deaeration can be completely scavenged by the addition of a chemical oxygen scavenger, such as hydrazine or sodium sulfite, to the boiler feed water

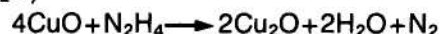
The reaction products of the hydrazine treatment are water and nitrogen gas which is inert and will not attack the metal in the system. These reaction products will not add solids to the boiler water as do the reaction products of other oxygen scavengers such as sodium sulfite.



Hydrazine has added benefits. After a boiler system has been operating for a short time with proper chemical control and adequate hydrazine concentrations, a protective film of black magnetic iron oxide (Fe_3O_4 , magnetite) forms. At the same time, any non-protective red iron oxide, (Fe_2O_3 , hematite), is slowly converted to magnetite. This magnetite film passivates the metal surfaces.

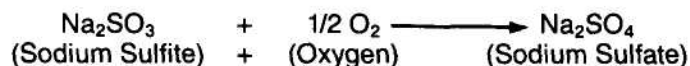
If the hydrazine residual is allowed to be depleted, oxygen will not be removed from the system. At this point the magnetite film will be converted to hematite, and corrosion of the base metal will begin.

Since hydrazine is volatile, some of it will carry over with the steam. In this way, the metals of the condensate system also can be protected. In a series of reactions similar to those described above for ferrous metals, nonferrous metals are rendered less susceptible to corrosion. For example, cupric oxide (CuO) is converted to a protective form, cuprous oxide (Cu_2O)



An alternative oxygen scavenger is sodium sulfite (Na_2SO_3). This compound readily combines with oxygen in solution to form a more stable compound, sodium sulfate (Na_2SO_4). This process efficiently removes oxygen from solution, but it does add dissolved solids to the water. As a result, it is not generally recommended for high pressure boilers where minimum dissolved solids levels are critical.

Sulfite is not volatile and it is not a metal passivator. It remains in the boiler water and does not offer protection for the condensate system.



Control of Condensate pH

As discussed above, CO_2 gas reacts with the condensate to form carbonic acid. Without chemical treatment, this acid reduces the pH of the condensate. The pH can be controlled within a specified non-corrosive range by the continuous dosage of a neutralizing amine, such as morpholine or cyclohexylamine.

ACIDIC CORROSION — ACID ATTACK

Acid attack of boiler tubes and drums is usually in the form of general thinning of all metal surfaces.

Acidic conditions, exclusive of those created by the presence of CO_2 , occur when the boiler feed water becomes contaminated by evaporator carryover or seawater in-leakage at the condenser. When magnesium chloride (MgCl_2), a seawater salt, is introduced to a boiler water system, it dissociates into ions of magnesium (Mg^{+2}) and chloride (Cl^-). The chloride ions (Cl^-) react with the hydrogen ions (H^+) in the water to form hydrochloric acid (HCl), which lowers the pH of the water and attacks the metal surfaces.

The magnesium ions (Mg^{+2}) react with the phosphate (PO_4^{-3}) and hydroxyl ions (OH^-), if these treatments are present, to form sludge. Magnesium ions may react only with the phosphate ions to form magnesium phosphate, a soft, adherent deposit which tends to bind all other deposits to the tube surfaces.

Any deposits on metal surfaces can be heat transfer barriers and can lead to overheating and increasingly destructive conditions. Water trapped beneath these deposits on high heat transfer surfaces will concentrate the acid or caustic. When this occurs, the corrosion rates become extremely high and serious localized damage occurs in a very short time.

HYDROGEN ATTACK

This type of corrosion results in embrittlement or cracking of the tube metal, damaging of the internal structure of the metal.

Hydrogen ions are generated by the concentration of acids under a hard dense deposit. The hydrogen ions (H^+) are the smallest of all elements and can penetrate the grain boundaries of the tube metal. They react with carbon atoms present in the steel to form methane.

Methane (CH_4) is a large gas molecule which exerts pressure within the metal. The high pressure combined with the weakening caused by degraphiting forces the grains of steel to separate. Eventually, cracks in the metal develop.

Hydrogen attack can occur very rapidly. Tube metal fails and ruptures when the section can no longer withstand the internal pressure.

CAUSTIC CORROSION

Caustic attack is characterized by irregular patterns of gouging of the metal. It is often referred to as "caustic gouging."

Caustic corrosion results from the presence of an excess of free sodium hydroxide (NaOH) in the boiler water, indicated by a very high pH.

Much like an acid, caustic corrosion may occur beneath layers of deposits which have formed on heat transfer surfaces allowing the sodium hydroxide to concentrate and thereby causing severe localized corrosion.

Caustic corrosion also will occur in the horizontal or inclined tubes when the interior surfaces become steam blanketed because of excessive boiling (hot spots) or separation of steam and water. Boiler water containing sodium hydroxide can splash onto the steam blanketed surface and,

as the water flashes off, the sodium hydroxide remains and concentrates on the metal.

CAUSTIC CRACKING CORROSION

Corrosion caused by caustic cracking is a type of inter-crystalline cracking. When highly caustic (alkaline) water comes in contact with steel under stress, intercrystalline cracking can result. (Metals can be stress relieved, that is, reheated at low temperatures to relieve internal stresses.) This type of corrosion occurs along the crystal boundaries of a metal or an alloy.

CORROSION FATIGUE

Corrosion fatigue manifests itself as a series of fine cracks in the tube wall. These cracks are aggravated by other corrosive conditions within the boiler which will ultimately result in tube failure.

This form of corrosion usually attacks the tube walls of high pressure boilers. It occurs generally in the high temperature areas of the tubes where irregular water circulation has been experienced and alternating stresses have been set up in the tube material.

MECHANICAL CORRECTION

The evaporator should be operated properly to avoid carryover, which will introduce contaminants as described above. Condenser piping must be maintained to prevent leaking condenser tubes which will introduce seawater.

The boiler should be operated within the design specifications in order not to overload the steam production capacity which leads to steam blanketing.

Proper burner alignment and correct atomization of the fuel oil are essential to avoid flame impingement or hot spots.

CHEMICAL TREATMENT

Acidic corrosion can be prevented by the maintenance of a proper boiler water alkalinity. Adequate dosages of an alkaline material such as sodium hydroxide (Drew GC™ concentrated alkaline liquid) will maintain the recommended alkalinity range and eliminate the possibility of acid attack. Please note: The alkalinity level may be measured directly in "ppm" or indirectly using the corresponding pH ranges. Maintain the recommended range of alkalinity or pH according to the treatment program.

Caustic corrosion readily takes place in ultra-high pressure boilers (49 kg/cm², 700 psig and over) in the presence of free caustic. The Drew ULTRAMARINE® coordinated phosphate-pH boiler water treatment program used in high pressure boilers eliminates free hydroxide (OH⁻) in the boiler water. (This program will be described in detail later in this book). Maintain the balance of treatment chemicals to minimize free caustic.

The application of the ULTRAMARINE coordinated phosphate-pH boiler water treatment also will assist in inhibiting hydrogen embrittlement, primarily by the buffering action of the phosphate and the pH control in the boiler water.