# Care and Maintenance of BOILERS in Food Processing Plants

**Sea Grant**
Extension Division
Virginia Polytechnic Institute and State University
Blacksburg, Virginia 24061

## I. Introduction

A boiler is a pressure vessel that generates steam by heating water, using electricity or some other fuel. Efficient boiler operations involve correct operation and maintenance procedures that become even more important when large quantities of steam are generated and consumed. Food processing plants utilizing steam for can sterilization, retort cooking, presurized cleaning, or other direct heating purposes, require a constant supply of live steam and thus a continuous supply of water to replenish water lost as steam. Improper water quality can tremendously reduce boiler efficiency because the impurities cause scale to be deposited on the heating surface; for example, a quarter-inch scale deposit increases fuel consumption by 25 percent (Fig. 1). Boiler efficiency is also reduced, and energy wasted, when fuel combustion is not adequately controlled.

Proper operation and maintenance procedures are also good safety practices. Most boilers operate above atmospheric pressure and could be dangerous if improperly operated or maintained. For this reason, the American Boiler Manufacturers Association and the American Society of Mechanical Engineers have established standards and codes for boiler construction. States and insurance companies have also set stringent specifications and requirements for boiler operations. A well-designed and constructed boiler does not guarantee safety, however. For example, if the boiler is neglected, scale and corrosion accumulations or faulty valves and gauges may cause hazardous conditions within the boiler; also, erroneous operating procedures can cause safety as well as mechanical problems.

This manual briefly reviews basic boiler construction, water quality, maintenance, operating principles, and selection considerations. For further details, consult the references listed in section IX.

## II. Basic Boiler Elements and Types of Boilers

A boiler consists of two basic parts: a heat source and a vessel in which boiling water generates steam for heating and cooking. Surfaces in the vessel that water and steam contact are called <u>watersides</u>, and surfaces contacting the heating source are called <u>firesides</u>.

As shown in Figure 2, a boiler receives feed-water from a well or municipal source combined with the return steam condensate.

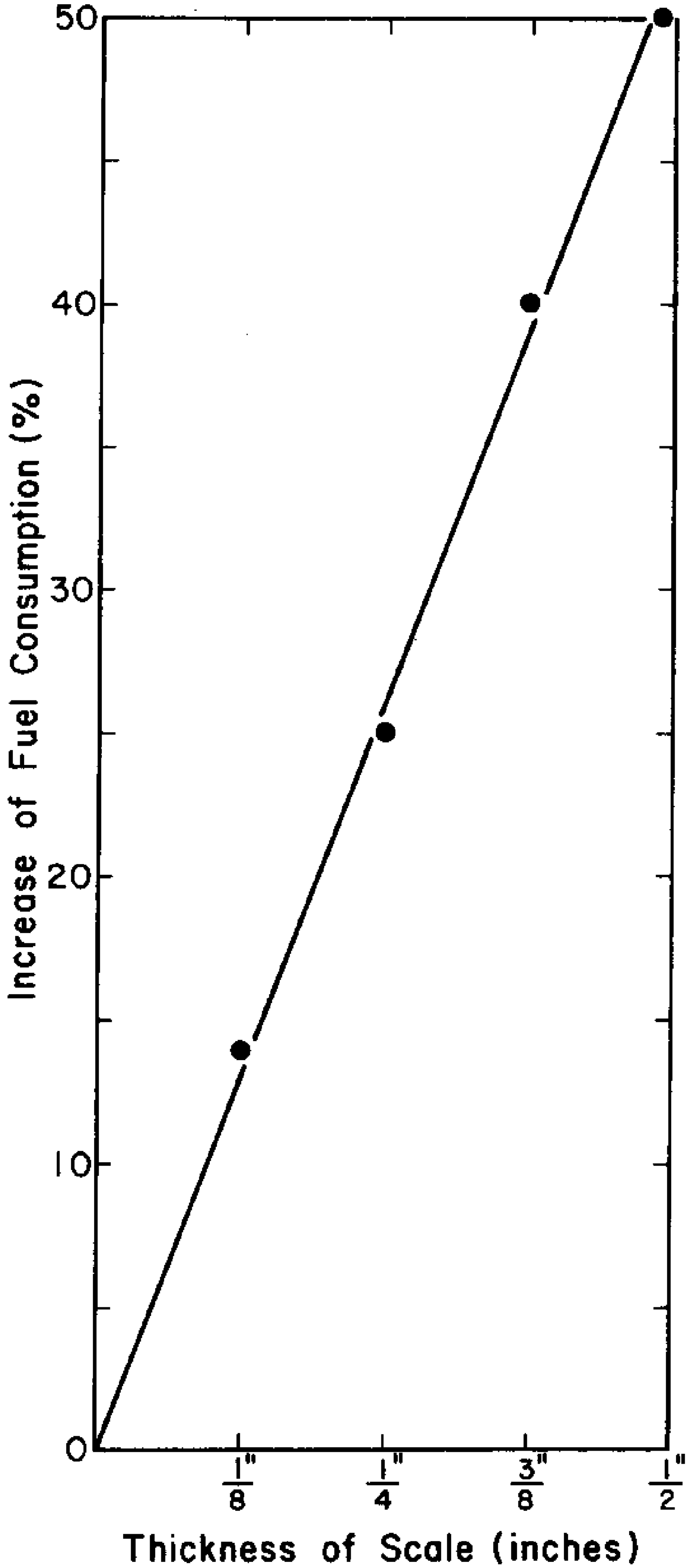
50
40
30
20
10
0
Increase of Fuel Consumption (%)
1"/8
1"/4
3"/8
1"/2
Thickness of Scale (inches)

Figure 1

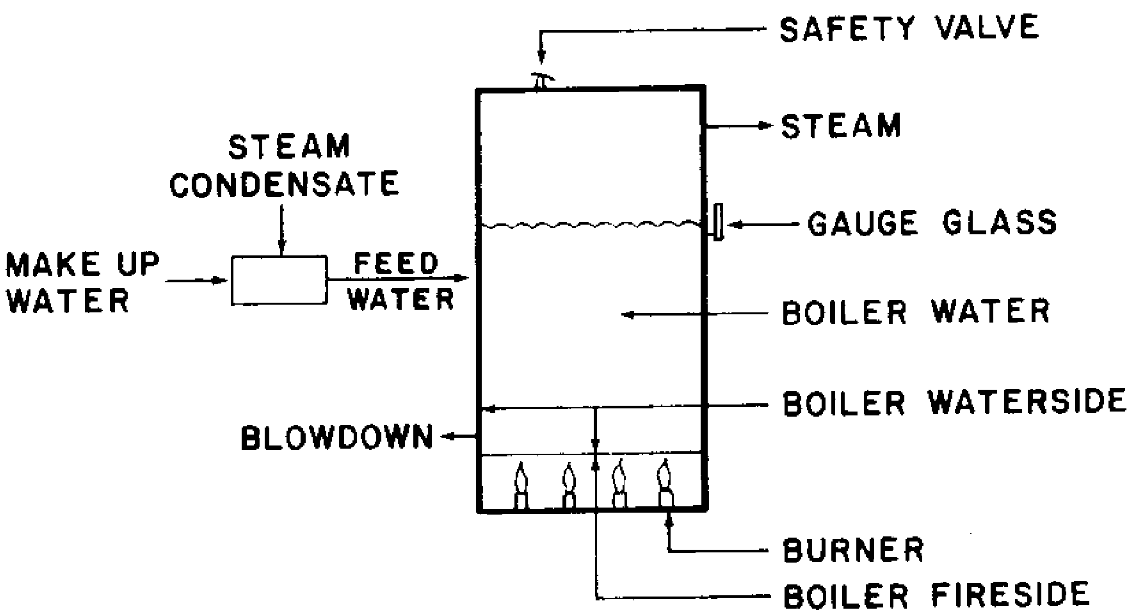


Figure 2

A boiler system can be either closed or open. In the closed system, steam is employed as an indirect heating agent; the steam pipes do not have openings outside the boiler (Fig. 3).

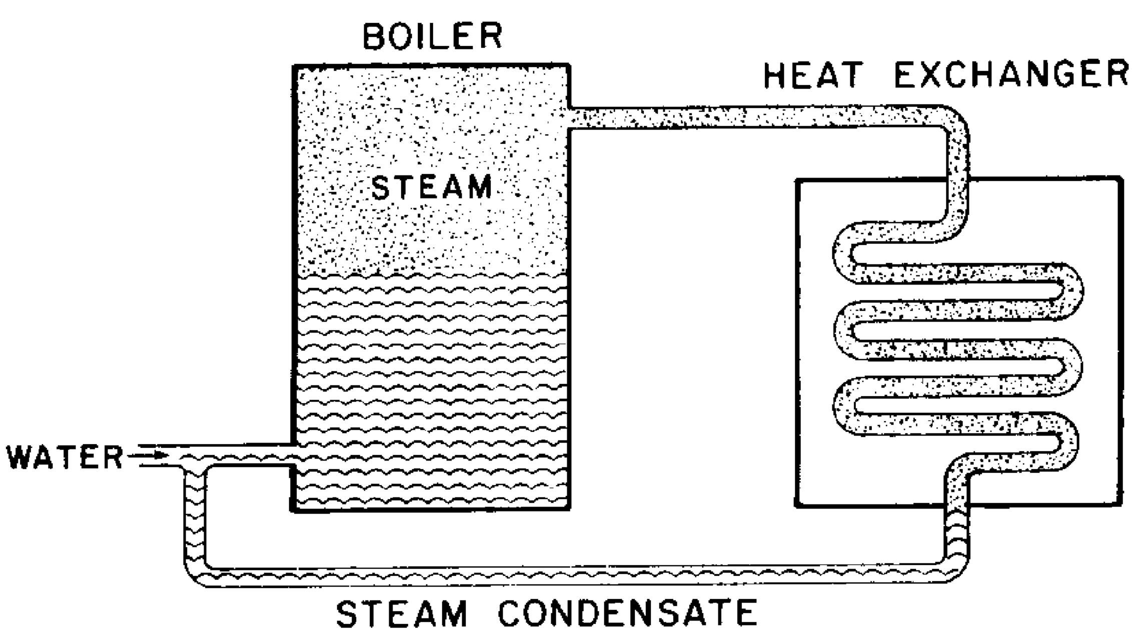


Figure 3

Thus, the steam condensate is recycled to the boiler for steam generation. Steam jacket kettles and space heaters are good examples of this arrangement. An open system employs steam as a direct heating agent. In this case, steam condensate will not return to the boiler (Fig. 4).

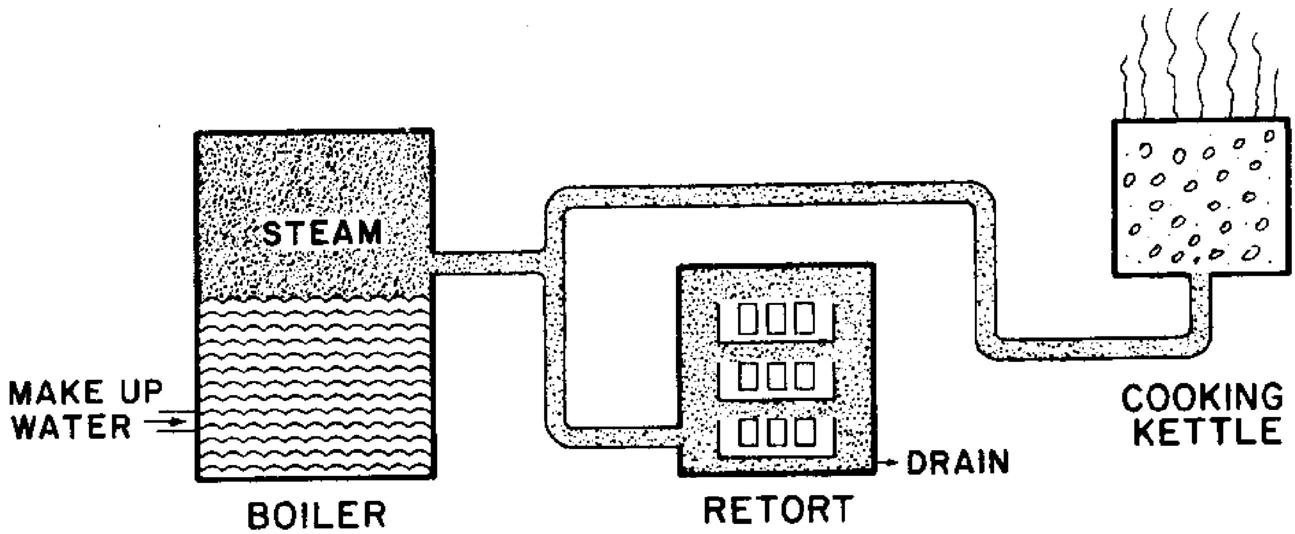


Figure 4

Consequently, a constant water flow will be necessary to "make up" water losses. Retort cooking and sterilization in food processing are examples of this system.

Efficient steam generation requires as much water as possible to be brought in close contact to the heating source. To meet this requirement, boilers are constructed with either watertubes or firetubes (Fig. 5). In both cases tubes passing through the boiler provide efficient heat transfer. A watertube boiler allows water to flow inside the tubes, whereas a firetube boiler directs the heating agent through the tubes. A watertube boiler generally consists of a water and steam reservoir drum and has large capacities with high steam pressures. A firetube boiler is often built with additional passes to maximize heat usage. Boilers may be designed for horizontal installation, or, to save space, vertical construction.

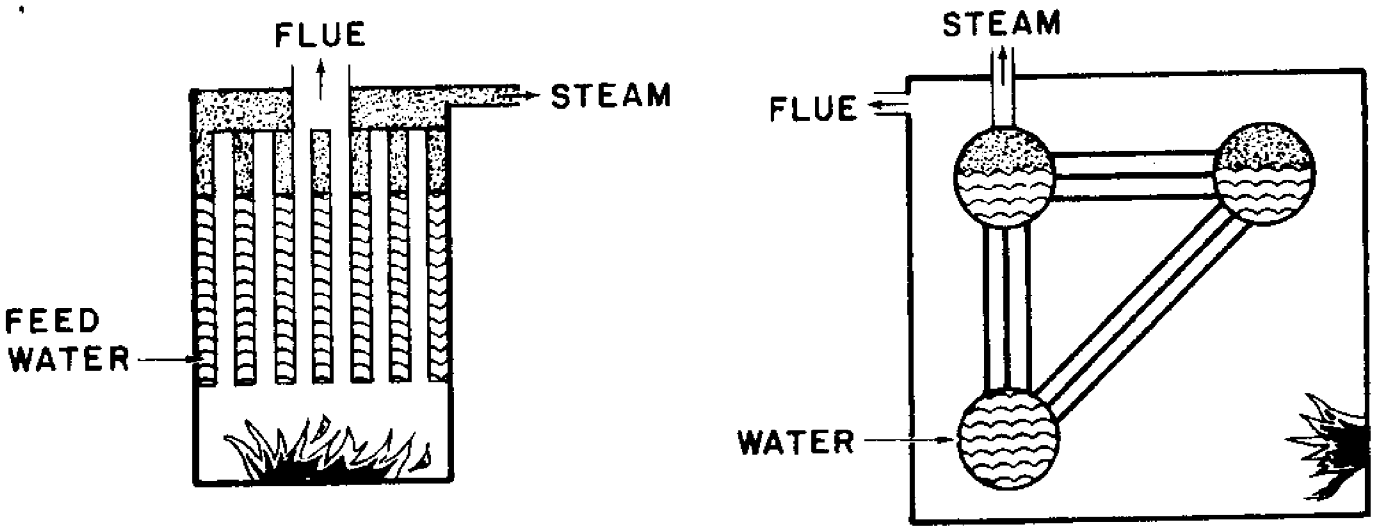


Figure 5

Some boilers use electricity rather than fuel. In this case, heat is generated between metal electrodes submerged in the boiler water. Since an electric current will continue to flow only when water is present, the water level automatically controls heating in the boiler. There are also smaller steam generators that simply use electric heat elements for their source of thermal energy.

Boilers may be rated according to their horsepower, heating surface, evaporation capacity, or equivalent direct radiation. Boiler horsepower is equivalent to the evaporation of 34.5 lb. of water per hour at 212°F (33,472 btu/hr). Evaporation capacity is expressed in lb. steam/hr at specified steam conditions. The heating surface is the total square footage on the fireside of the tubes. Equivalent direct radiation (EDR) is 242 btu/hr-ft$^2$ for steam boilers.

Boiler efficiency is determined by comparing the output heat (steam) to the input heat (fuel). In order to achieve high efficiency, a boiler should be designed to minimize heat losses. In addition, proper care and maintenance must be exercised routinely so that high efficiency may be sustained and operational safety warranted.

A boiler that is "clean" and "tight" is one that is properly operated and maintained. Feed water quality is most important in maintaining boiler cleanliness. Undesirable water quality can cause scale formation, corrosion, carryover (that is, continual discharge of slag in the steam, and caustic embrittlement (that is, the development of cracks in the boiler system). Also, proper fuel-air mixing is important. Poor fuel adjustments cause soot and ash deposits to accumulate on the firesides, reducing efficiency and increasing operation costs. Correct operation procedures can greatly reduce these problems.

A "tight" boiler is free from water, steam, or air leaks. Periodic inspection and repair of faulty valves, gauges, steam pipes, etc., through the entire boiler system is necessary to ensure tightness. A routine maintenance schedule provides opportunities in both cleaning and repairing. Maximum efficiency, long boiler life, and better safety conditions will result.

## III. Water Quality

This section deals with the basic principles, problems, and treatment of boiler water. Methods are discussed for determining water quality, water treatment, and correct operation procedures to reduce effects of impurities in water.

Boiler water is used for generating steam or transferring heat. Its quality is of vital importance to the efficiency and safety of the boiler. Good boiler water is free from impurities that may cause detrimental effects within the boiler. Several tests can be made to determine water quality, including pH, acidity, alkalinity, odor, color, turbidity, total solids, total dissolved solids, dissolved gases, hardness, chlorine content, etc. Fortunately, in many cases, depending on the specific situation, not all tests are necessary.

### A. pH, Acidity, Alkalinity

The pH represents the intensity of the acid or alkaline condition (hydrogen ion concentration) of water. It can be easily determined using a pH meter. Electrodes are inserted into the sample and the pH value is read on the meter. Since the water temperature affects the reading, a correction must be made on each measurement. Normally, pH 7.0 is the neutral point. A value lower than 7 indicates acidity (like vinegar), and a value greater than 7 indicates alkalinity (for example, soapy water). To measure the total amount of acid or alkali in a sample, employ a titration method using an alkali or acid solution of known concentration.

The proper pH of feedwater for boilers ranges from 7.5 to 9.5, and that of blowdown water from 10.2 to 11.5. Improper pH induces corrosion. As corrosion continues, metal thickness is reduced, resulting in greater boiler stresses and unsafe operating conditions. If a steel boiler is subjected to long exposure to highly alkaline waters, caustic embrittlement can result. In such cases, cracks develop below the water line and under rivets, welds, and seams.

Boiler water is considered acidic when its pH is below 8.5. The acidity is a result of dissolved carbon dioxide and/or dissolved minerals and organic acids. Normally, municipal water has a pH between 6 and 7. Thus, for boiler use, city water is normally too acidic and requires adjusting by addition of caustic soda or by installation of a de-aerator.

### B. Dissolved Gases

As mentioned above, dissolved carbon dioxide can lower the pH in water, causing corrosion. Corrosion also takes place when oxygen is present in the boiler water. Corrosive reactions accelerate at the elevated temperatures at which boilers normally operate; if uncorrected, localized pitting or cracking can eventually rupture boiler tubes. When rusty water shows in the gauge glass, it is a sure sign of corrosion in the system.

To remove dissolved gases in boiler water, a de-aerator can be installed on the feedwater line. Sodium chromate, sodium sulphite, or hydrazine can also be used to control corrosion. Sodium sulphite and hydrazine react with the oxygen in water and thus eliminate oxygen.

### C. Odor, Color, Turbidity

Normal boiler water should not have odor, discoloration, or turbidity problems. Excessive amounts of suspended matter which either diffuse or interfere with the passage of light cause turbidity and give color to the water. Filtration or sedimentation can usually eliminate the suspended solids in water.

## D. Total Solids and Hardness

Total solids include dissolved and undissolved solids that are separated by filtration. Undissolved solids are usually referred to as suspended matter. Because the amount of suspended solids in most water supplies is relatively small, it is rarely a concern for boiler maintenance. On the other hand, total dissolved solids is an important test, which can be determined by either evaporating a water sample and drying the residue or by means of a conductivity meter.

Among the dissolved solids, sulfates, chlorides, and carbonates of calcium and magnesium are notorious in their tendency to form boiler scale. Their presence is indicated by the concentration of calcium carbonate in a water sample. It is called degree of hardness. Carbonate hardness can precipitate with prolonged boiling, and therefore is termed temporary hardness. Noncarbonate hardness, formerly called permanent hardness, does not precipitate from water by physical means.

Total dissolved solids range from 20 to 1,000 milligrams per liter (mg/l) in potable waters and increase with hardness. The necessity to reduce or totally eliminate these dissolved solids prior to feeding water into the boiler cannot be overemphasized. Scale formed on the heating surface, due to the presence of the dissolved solids, has the same effect as insulation: it retards the flow of heat, lowers fuel efficiency, and permits overheating of the firesides. The procedure to eliminate hardness in water is commonly known as softening. It can be done by addition of phosphates, polyphosphates, or lime, or by application of ion-exchange resins or reverse osmosis techniques. When chemicals are used to precipitate the hard-water salts, certain organic compounds may be added to keep the insoluble matter in suspension as a sludge to be flushed out periodically. When the resins and reverse osmosis units are applied, they can be regenerated by passing strong salt solutions through them, or they can be cleaned for further use.

In addition, blowdowns of the boiler water from the drain valve can remove the loose sludge settled on the bottom and also reduce the concentration of scale-forming substances. Scale formation is thus discouraged. Continuous blowdown can be achieved by installing automatic control devices. However, considerable hot water is lost through this practice. A system designed to recover the water and thermal energy lost in blowdown should be considered.

Undissolved substances, such as grease, scale particles, and dirt, in boiler water can cause foaming and carryover problems in the system. Foaming is the existence of a layer of froth and suds on the water's surface in the boiler drum. When foaming is severe, boiler water, scale particles, corrosion, oil, grease, or dirt can be discharged with steam into pipes (that is, carryover). Deposits of the carried-over substances and dissolved solids in water may settle in the steam piping and valves, causing a loss in efficiency or a blockage to steam passage. To remedy carryover and foaming problems, the total-solids concentration in boiler water must be reduced to, and maintained at, a minimum level. Mild cases of carryover can be limited by installing a mechanical separating device in the drum.

Occasionally, undesirable contaminations can be brought from the boiler into steam piping by a sudden carryover of boiler water. This priming problem may be due to a sudden change in demand for steam, or a surging or spouting in the drum. It can result in shocks and water-hammer in the steam lines. Because priming and foaming represent undesirable and often dangerous conditions, immediate investigation and correction is necessary.

## E. Other Tests

For specific purposes, tests to determine metal ions, phosphate, sulfite, sulfate, nitrate, grease, etc., can also be conducted to evaluate water quality. They are not normally considered routine procedures in testing boiler water.

The chloride content is used as an index in determining sea water intrusion and also as a tracer for pollution of wells. Chloride concentration generally increases as the mineral concentration increases. Thus, in boiler maintenance, chloride concentration can be used to determine the need for, and frequency of, blowdown.

## F. Sampling, Testing and Reporting

A complete boiler water analysis should include samples of makeup water, feedwater, and blowdown from each boiler in a plant. Clean containers should be used to collect samples. Water should be filled to container volume and containers should be closed airtight, if possible, to avoid contamination with air or dirt. Since the water can be dangerously hot, care should be taken in collecting pressurized boiler water from the blowdown drain valve. It is preferable that the sample be taken just before or at the time of blowdown. The samples should be cooled and tested immediately.

Detailed testing methods and result reporting can be found in the Annual Book of ASTM Standards (American Society of Testing and Materials), under section D for water analysis. Table 1 lists some ASTM tests and procedures.

Table 1. ASTM tests most frequently used for boiler water analysis

| Test | ASTM Method |
|---|---|
| Acidity and alkalinity | D 1884 |
| Carbon dioxide | D 513 |
| Chloride ion | D 512 |
| Dissolved oxygen | D 888 |
| Electrical conductivity | D 1125 |
| Hardness | D 1126 |
| Hydroxide | D 514 |
| Nitrate | D 992 |
| Phosphate | D 515 |
| Reporting | D 596 |
| Sampling water | D 3370 |
| Sulfate | D 516 |
| Sulfite | D 1339 |

The chemical tests which may be used for prevention or control of specific boiler problems are tabulated in Table 2.

Table 2. Chemical tests used in controlling boiler problems

| Test | Boiler Problems | | | |
|---|---|---|---|---|
| | Scale | Corrosion | Embrittlement | Carryover |
| Makeup water: | | | | |
| Acidity/alkalinity | -- | x | -- | -- |
| Hardness | x | -- | -- | -- |
| Feedwater: | | | | |
| Acidity/alkalinity | x | x | -- | -- |
| Hardness | x | -- | -- | -- |
| Boiler water: | | | | |
| Acidity/alkalinity | x | x | -- | -- |
| Hydroxide | x | x | x | x |
| Nitrate | -- | -- | x | -- |
| Phosphate | x | -- | x | -- |
| Sulfite | -- | x | -- | -- |

## IV. Fireside Maintenance

Boiler inefficiency can also result from improper operating procedures and poorly maintained firesides. Problems that can develop include either excess or deficient combustion air, fouled and inefficient heating surfaces, and faulty burners.

### A. Excess or Deficient Combustion Air

A theoretical amount of air is required to completely burn the fuel. If more than enough air is used, energy is wasted in heating up the excess air and discharging it into the flue. Figure 6 shows the relationship between the percent theoretical air required for combustion and the fuel efficiency. When excess air (beyond 100%) of required air for a complete combustion is supplied, the fuel efficiency falls below its maximum possible level.

On the other hand, if the combustion air is insufficient, the efficiency is greatly reduced. The fuel efficiency can be improved considerably simply by increasing the supply of air for combustion from 50 percent to 100 percent of the amount required for a complete combustion, as shown in Figure 6.

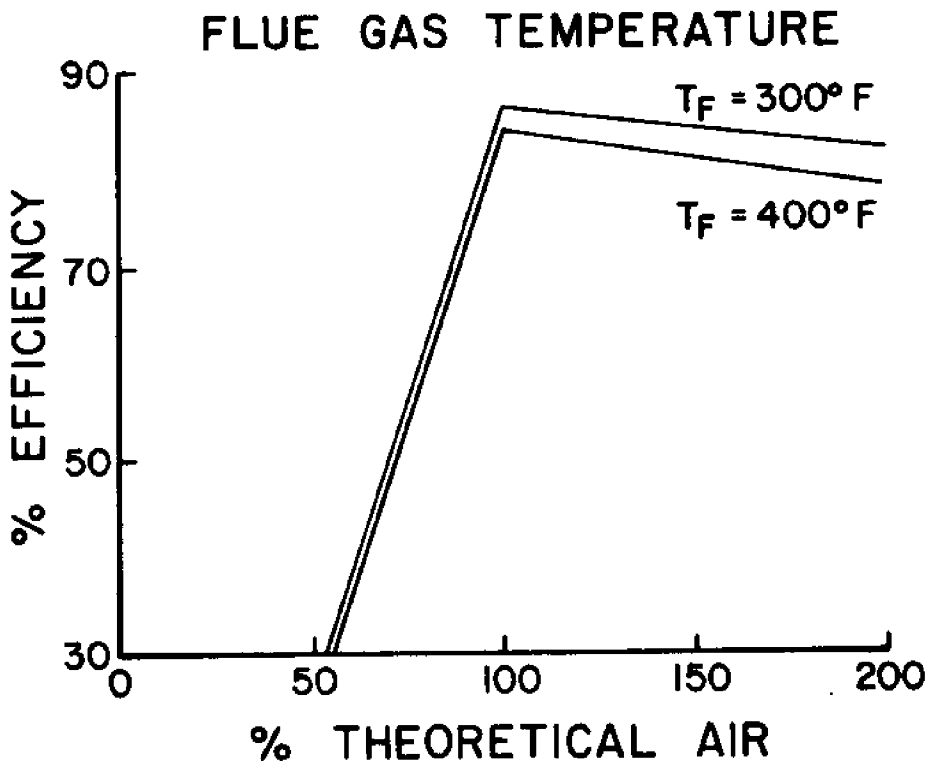


Figure 6

Because fuel does not burn completely without sufficient air, a deficient air supply not only can cause a severe loss of fuel efficiency, but also constitutes a safety hazard. The residuals of an incompletely combusted fuel may deposit on the heating surface a soot or ash, causing overheating, or may escape the flue as smoke and pollutants.

To assure complete use of fuel, a properly controlled combustion should allow 10 to 20 percent excess air. This control can be achieved by using a forced draft system to regulate the air-fuel ratio. To determine if a correct adjustment has been achieved, test the flue gas using Orsat analysis or an oxygen indicator.

## B. Fouled Heating Surface

A fouled heating surface reduces heat transfer from the combustion gases to the water. The major symptom of this problem is increased flue gas temperature. Unfortunately, a number of conditions tend to obscure this indicator. For example, deficient combustion air and fouled or eroded burners tend to decrease flue-gas temperature. This decrease could offset the increases due to a fouled heat transfer surface. In addition, priming, foaming, and carryover can cause excess water in the discharge steam line, increasing the flue-gas temperature. Thus, it is important to insure that these latter conditions do not exist before using flue-gas temperature as an indicator of heat-transfer surface fouling. If this precaution is taken, the change with time of the flue-gas temperature indicates the amount of fouling. Of course, the flue-gas temperature should be approximately equal to the design value specified by the manufacturer. Any deviation (assuming proper combustion air burner operation, etc.) indicates fouling.

A visual inspection of the boiler tube surfaces will reveal fouling if present. This fouling includes corrosion and scale formation on the waterside as well as the deposit buildup and corrosion on the fireside. Such fouling directly affects the heat transfer, which can be monitored by the installation of chordal thermocouple tubes in the tube wall. Periodic checks of tube metal temperatures can signal the build-up of harmful deposits. When necessary, internal cleaning can be performed to avoid overheating damage.

## C. Insufficient Heating Surface

Insufficient heating surface limits the amount of energy transfer that can take place between the hot gases and water. A high flue-gas temperature results. The flue-gas temperature should be compared to the minimum allowable (approximately 230°F for natural gas and 290°F for fuel oil) as specified for a particular boiler. Any flue-gas temperature in excess of this minimum value may indicate insufficient heat transfer surface. Additional heat surface can be made in the form of an air preheater or economizer. This installation can pay off its own cost in less than one year for any boiler with a design flue-gas temperature exceeding 400-425°F.

## D. Faulty Burners

A number of problems can occur with burners -- including fouling, improper design, and material degradation. The result of any of these conditions will be poor fuel-air mixing and consequently incomplete combustion.

Thus, extremely large amounts of air compared with the theoretical requirement will be needed to allow complete combustion of the fuel. The Orsat analysis will indicate significant amounts of carbon monoxide and unburned fuel if the burner is faulty and a reasonable amount of excess air is used.

Periodic cleaning to free the burners from foreign matter and carbon residues can minimize fouling. Pilot burners, ignition equipment, and other parts should be inspected to insure proper flame performance.

## V. Other Sources of Deficiencies and Energy Losses

### A. Leaks

Since a boiler is a pressure vessel, it ought to be "tight" -- that is, free of leakage. Routinely checking the steam pressure, investigating abnormal water loss, and looking for leaking tubes are some recommended maintenance practices to ensure a tight boiler.

Unless an automatic recorder is used, frequent checking of steam pressure is a sure way of knowing about any abnormal pressure drops or increases in a boiler before it is too late. For this reason, dependable pressure gauges are necessary; they should be checked routinely and old, worn out, or faulty ones should be replaced.

Due to a buildup of corrosive deposits around the bottom of the valve, a safety valve may fail to open at the set pressure. It may leak or even cause safety hazards.

Water losses can be determined by the water level observed at the gauge glass and/or the amount of makeup water used in a period of time. In general, a boiler used for a closed system (that is, all steam will return as condensate) should not lose more than three inches of water per month. Otherwise, there is probably a leak in the system.

Leaking tubes cause abnormal water loss. An unusual "hiss" or a sudden demand for feedwater without a corresponding increase in load may indicate a leak. One leaking tube could mean more faulty ones. Therefore, a thorough inspection of the boiler should take place as soon as possible.

Steam leakage from faulty valves and joints on the discharge steam pipes, and worn gaskets on cooking vessels, can also cause considerable heat loss. These leaks are generally apparent and should be corrected immediately.

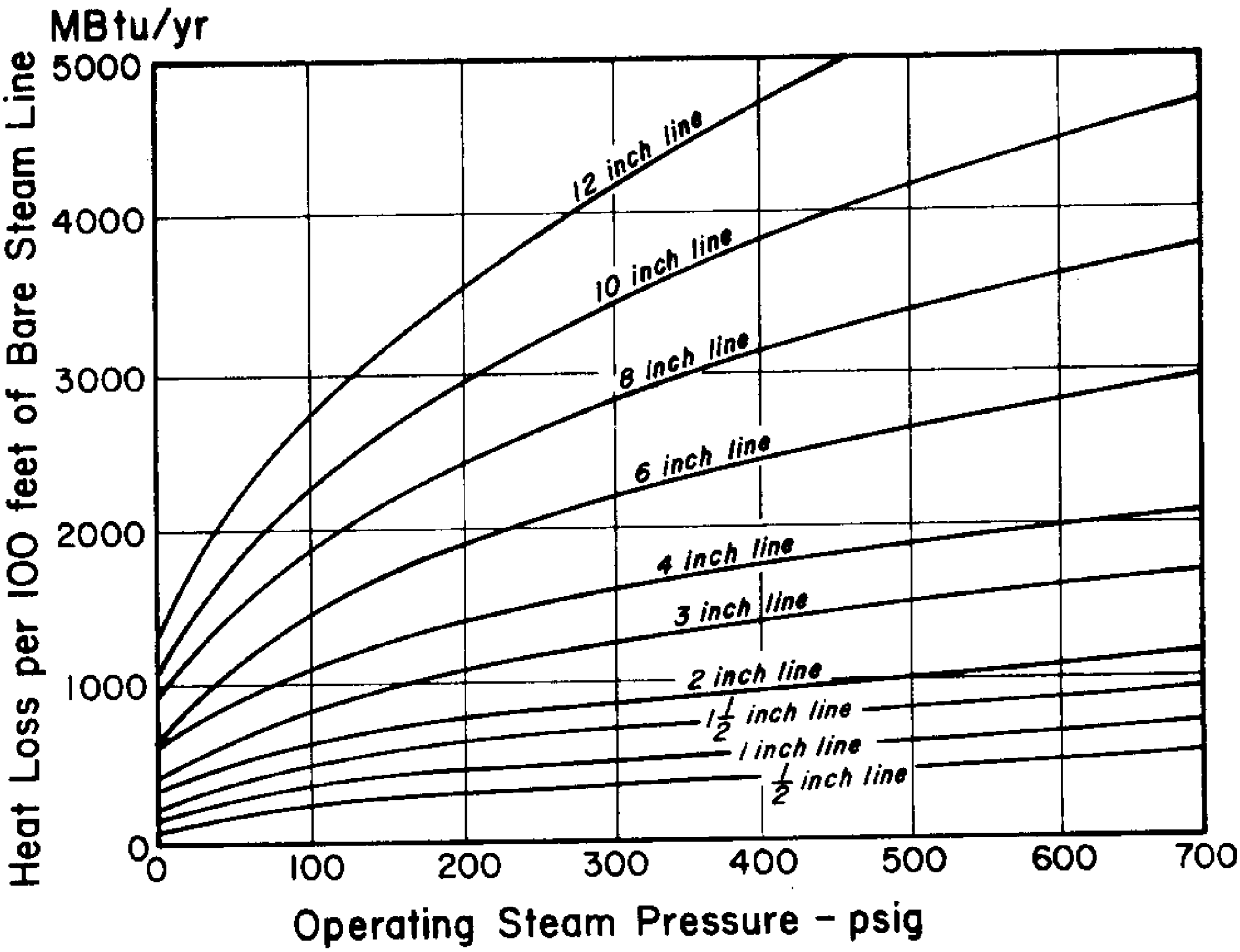


Figure 7. From Dyer, *et al.*, 1977.

B. Lack of Proper Insulation

Without proper insulation, heat can escape through the boiler shell, from the walls of steam pipes, or from cooking vessels such as retorts. An uninsulated retort may lose more than twice the energy needed to operate it!

Losses due to uninsulated steam pipe may seem insignificant, but they do, in fact, represent a relatively high energy loss. Figure 7 shows the expected yearly heat loss of variously-sized (diameter) steam pipes. And (Fig. 8) the heat loss per foot of uninsulated hot water pipe is indicated.

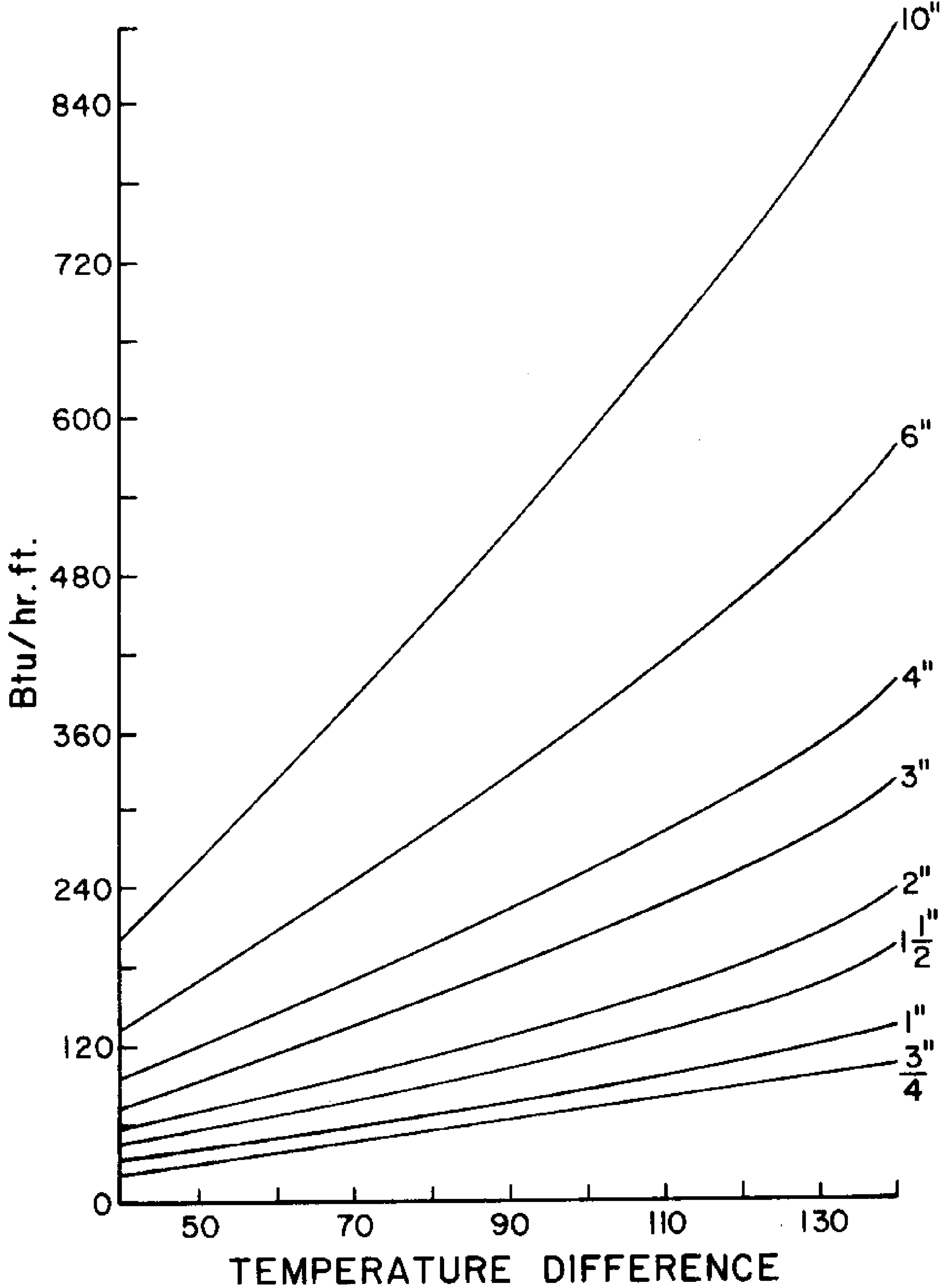


Figure 8. From Dyer, *et al.*, 1977.

A comparison of Figures 7 and 8 with Figure 9 makes evident the energy saved by applying insulation.

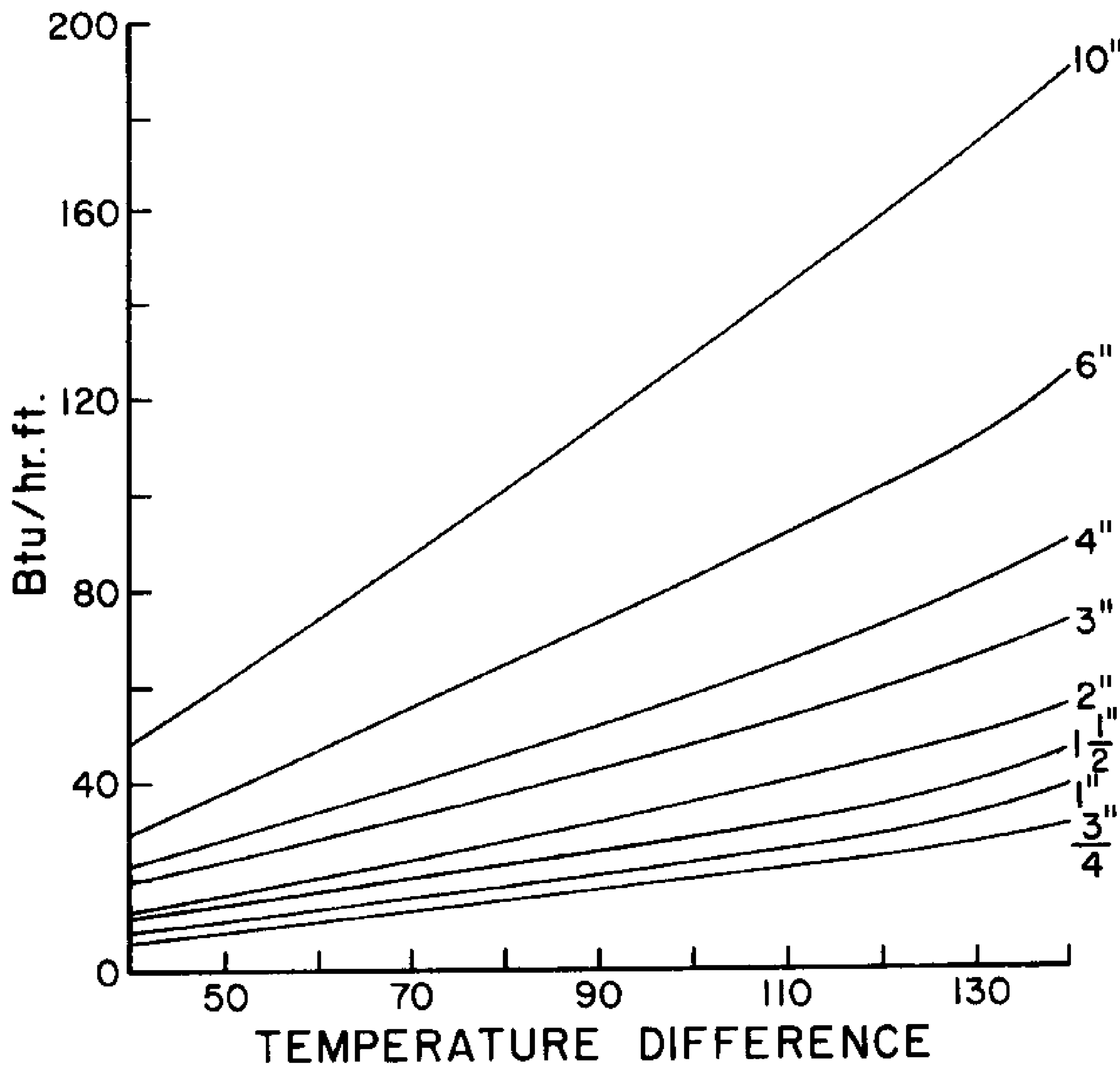


Figure 9. From Dyer, *et al.* 1977.

C. Improper Operational Practices

Operational procedures and specifications recommended by the manufacturer should be closely followed. Otherwise, difficulties or hazards may result. For example, <u>priming</u> may occur if the water level in the boiler is too high; great energy losses can arise if blowdown is too frequent or the flue-gas temperature is maintained too high; stress or waste may result if a boiler is utilized over or under its capacity; and problems can get bigger, and more difficult to solve, if routine checkups are ignored.

Also, certain economical measures may be considered in order to conserve energy and reduce operating costs. For instance, cleaning the heating surfaces periodically, installing a forced-draft system,utilizing a preheater for feedwater and combustion air, adding heat recovery systems, and using accurate gauges or monitors may all prove to be effective.

## VI. Maintenance

Following are the routine maintenance schedules for heating boilers and hot water boilers recommended by the American Society of Mechanical Engineers (ASME).

A. For steam boilers:

1. Daily (boiler in service). Observe operating pressures, water level, and general conditions and correct.
2. Weekly (boiler in service).
    a. Test low-water cutoff and/or water feeder. Blow down boiler if considerable makeup is used.
    b. Test water column or gauge glass.
    c. Observe condition of flame; correct if flame is smoky or if burner starts with a puff (for oil, observe daily).
    d. Check fuel supply (oil only).
    e. Observe operation of condensate or vacuum pump.
3. Monthly (boiler in service).
    a. Safety valve, try lever test.
    b. Test flame detection devices.
    c. Test limit controls.
    d. Test operating controls.
    e. Sludge blowdown where required.
    f. Check boiler room floor drains for proper functioning.
    g. Inspect fuel supply systems in boiler room area.
    h. Check condition of heating surfaces (for preheated oil installation, inspect more frequently: twice a month).

4. Annually
   a. Internal and external inspection after thorough cleaning.
   b. Routine burner maintenance.
   c. Routine maintenance of condensate or vacuum return equipment.
   d. Routine maintenance of all combustion control equipment.
   e. Combustion and draft tests.
   f. Safety valve pop test.
   g. Slow drain test of low-water cutoff.
   h. Inspect gas piping for proper support and tightness.
   i. Inspect boiler room ventilation louvers and intake.

B. For hot water boilers:

1. Daily (boiler in service). Observe operating pressures and temperature, and general conditions. Determine cause of any unusual noises or conditions and make necessary corrections.
2. Weekly (boiler in service).
   a. Observe condition of flame; correct if flame is smoky or if burner starts with a puff (for oil, observe daily).
   b. Check fuel supply (oil only).
   c. Observe operation of circulating pumps(s).
3. Monthly (boiler in service).
   a. Safety relief valve, try lever tests.
   b. Test flame detection devices.
   c. Test limit controls.
   d. Test operating controls.
   e. Check boiler room floor drain for proper functioning.
   f. Inspect fuel supply system in boiler room area.
   g. Check condition of heating surfaces (for preheated oil installation, inspect more frequently: twice a month).
   h. Perform combustion and draft tests (preheated oil only).
   i. Test low water fuel cutoff and/or water feeder if piping arrangement permits without draining considerable water from the boiler.

4. Annually
   a. Internal and external inspection after thorough cleaning.
   b. Routine burner maintenance.
   c. Routine maintenance of circulating pump and expansion tank equipment.
   d. Routine maintenance of entire combustion control equipment.
   e. Combustion and draft tests.
   f. Safety relief valve(s) - pop test.
   g. Slow drain test of low water cutoff.
   h. Inspect gas piping for proper support and tightness.
   i. Inspect boiler room ventilation louvers and intake.

Maitenance and cleaning procedure for specific purposes or situations can also be found in the ASME Handbook, as well as your manufacturer's manual.

C. Chemical Treatments:

To clean the grease, scale, and corrosion deposit from the internal surfaces of the steam generator system, alkaline detergent solution may be applied to remove the oily matter, followed by acidic or basic solvent to dislodge other foreign materials. However, this type of cleaning is highly technical and should be supervised by qualified personnel.

The United States Food and Drug Administration and the Department of Agriculture have approved a list of chemicals which can be applied for boiler water treatment. Only the approved chemicals may be used in an open system where steam may be in direct contact with food materials (Table 3).

## VII. Basic Considerations in Boiler Selection

In selecting an adequate boiler for plant operation, the following criteria should be considered.

A. Capacity, temperature and pressure
B. Future expansion
C. Fuel availability and economy
D. Initial cost of unit
E. Space requirement
F. Insurance policy

Table 3. FDA approved additives for boiler water treatment*

| | |
|---|---|
| Acrylamide-sodium acrylate resin | Sodium metasilicate |
| Ammonium alginate | Sodium metabisulfite |
| Cobalt sulfate | Sodium nitrate |
| Lignosulfonic acid | Sodium phosphate |
| Monobutyl ethers of polyethylene-polypropylene glycol | Sodium polyacrylate |
| Polyethelene glycol | Sodium polymethacrylate |
| Polyoxypropylene glycol | Sodium silicate |
| Potassium carbonate | Sodium sulfate |
| Potassium tripolyphosphate | Sodium sulfite |
| Sodium acetate | Sodium tripolyphosphate |
| Sodium alginate | Tannin |
| Sodium aluminate | Tetrasodium EDTA |
| Sodium carbonate | Tetrasodium pyrophosphate |
| Sodium carboxymethylcellulose | Cyclohexylamine |
| Sodium glucoheptonate | Diethylaminoethanol |
| Sodium hexametaphosphate | Hydrazine |
| Sodium humate | Morpholine |
| Sodium hydroxide | Octadecylamine |
| Sodium lignosulfonate | Trisodium nitrilotriacetate |

**For usage limitations, labelling requirements and other details, refer to the Code of Federal Regulations, Title 21 173.310*

## VIII. Conclusion

A properly maintained boiler can provide maximum efficiency with no abnormal safety hazards. Boiler care means the difference between saving and wasting. Do not let your boiler problems get ahead of you. A routine checkup allows an early warning so that you can correct boiler troubles early, eliminating excessive maintenance expenditures.

This manual provides basic information and draws processors' attention to the importance of bioler maintenance. It must, however, be emphasized that boiler services should always be supervised by trained experts or professionals because of the complications, the regulatory implications, and the potential dangers involved in many of the maintenance procedures.

## IX. References

ASME Boiler and Pressure Vessel Code - An American National Standard, 1974 (revised annually). Section 6 - Recommended Rules of Care and Operation of Heating Boilers; Section 7 - Recommended Rules for Care of Power Boilers. American Society of Mechanical Engineers. New York, NY 10017.

Annual Book of ASTM Standards, 1974 (revised annually). American Society for Testing and Materials. Philadelphia, PA 19103.

Dyer, David, and Glennon Maples. 1978. Industrial - Commercial - Institutional Boilers: Measuring and Improving Efficiency. Paper presented February 1-2, 1978, North Carolina State University, Division of Continuing Education.

Dyer, D. F., G. Maples, J. C. Maxwell, Jr., D. Pride, and W. G. Dickie, Jr. 1977. Measuring and Improving the Efficiency of Boilers. Paper prepared for Federal Energy Administration, Washington, D. C. November, 1976. Contract No. FEA-CO-04-B0100-00. Revised.

## ACKNOWLEDGEMENTS

The authors thank Cloyde W. Wiley and John Hope of the Bureau of Shellfish Sanitation, Virginia State Department of Health; and George J. Flick and Harry Pence of Virginia Polytechnic Institute and State University, for their valuable comments and suggestions. We also thank Mary C. Holliman, who edited the manuscript; Sharon Chiang, who drafted the figures; and Linda Thompson, who designed the cover.