Recommended Practice for Installation and Operation of Wet Steam Generators

API RECOMMENDED PRACTICE 11T
SECOND EDITION, NOVEMBER 1, 1994

American Petroleum Institute
1220 **L Street, Northwest**
Washington, D.C. 20005

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Exploration and Production Department

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FOREWORD

This recommended practice is under the jurisdiction of the American Petroleum Institute (API) Committee on Standardization of Production Equipment.

This standard shall become effectiveon the date printed on the cover but may be used voluntarily from the date of distribution.

Recommended Practice for Installation and Operation of Wet Steam Generators

1 Scope

1.1 INTRODUCTION

1.1.1 The Wet Steam Generator used in enhanced oil recovery is a forced circulation once-through design. It is also known by many other common names such as thermal recovery heater, oil field heater, etc. The once-through design enables the use of water essentially free of hardness and suspended solids, but of relatively high total dissolved solids. The equipment normally uses a fixed water flow system with some modulation capabilities for reduced output. The equipment does not contain drums or level controls, which are normally associated with stationary boilers. The Wet Steam Generator can be designed for installation in environments found in oil production areas of the world. Minimum operator attention is required.

1.1.2 For the most common sizes of Wet Steam Generators, field construction is held to a minimum. Most units are skid mounted and can be transported by rail, truck, or ship. The Wet Steam Generator is equipped with necessary controls and instrumentation to monitor operating pressures, flows, temperatures, etc., to protect personnel and equipment.

1.2 RATING

1.2.1 Wet Steam Generators are usually rated in millions of BTU's per hour of heat absorbed. They may also be rated by pounds per hour of steam, boiler horsepower, burner heat release capability, etc.

1.3 COMPONENTS

The basic parts of the Wet Steam Generator are as follows:

1.3.1 Feedwater System

Comprised of feedwater pumps and controls to provide a regulated quantity of water to a Wet Steam Generator.

1.3.2 Feedwater Preheater

Usually a double pipe heat exchanger. The heat source for this exchanger is normally taken from the convection section outlet. Its purpose is to elevate the inlet feedwater to a temperature above the flue gas dew point to prevent acid gas corrosion of carbon steel.

1.3.3 Convection Section

The last heat exchange area in the Wet Steam Generator to be exposed to the flue gases. The convection coil makes up most of the heating surface of the generator. The first tubes exposed to the flue gas in the convection section are bare and are designed to reduce the gas temperatures prior to entering the finned section, and prevent luminous radiant heat on finned tubes. The convection section is normally a counter flow exchanger.

1.3.4 Radiant Section

Comprised of a combustion chamber with a serpentine radiant coil being the most common configuration. Here, the desired steam quality is obtained.

1.3.5 Fuel System

Wet Steam Generators burn a variety of fuels, the most common being natural gas or crude oil. The fuel gas system is designed with safety shutoff valves and pressure regulators. The fuel oil system normally includes safety shutoff valves, strainers, steam/oil heat exchanger, electric oil heater, pressure regulators, bypass systems, air and steam atomizing systems. The burner is designed for the required heat input, fuel and proper flame pattern.

1.3.6 Safety Equipment

Includes pressure relief and safety valves, flame safeguard equipment, and temperature, pressure and flow monitoring systems designed for safe equipment operation.

2 Specifications

2.1 This section establishes the minimum information to be furnished by the purchaser in order that minimum design, safety and environment considerations are established.

2.2 APPLICABLE AND STANDARDS

2.2.1 API

2.2.2 ASME

2.2.3 NEC

2.2.4 NFPA

2.2.5 EPA

2.2.6 ANSI

2.2.7 ASTM

2.2.8 OSHA

2.2.9 NEMA

2.2.10 State Codes

2.2.11 Local Codes

2.3 RATING AND EFFICIENCY

2.3.1 Wet Steam Generators should be rated in millions of BTU's per hour absorbed (MM BTU/Hr.) at the required discharge pressure (PSIG) and steam quality. Purchaser should specify that suppliers also state output capacity in pounds per hour of wet steam generated based on the feed-water temperature and desired steam quality specified by the purchaser.

2.3.2 Wet Steam Generator thermal efficiencies should be based on the higher heating value (HHV)* of the fuels to be burned, the specified exhaust gas temperature, and the excess oxygen or excess air in the flue gases.

2.3.3 Wet Steam Generator thermal efficiencies may also be based on the lower heating value (LHV)** of the fuels to be burned, the specified exhaust gas temperature, and the excess oxygen or excess air in the flue gases.

2.4 SPECIAL CONSIDERATIONS

Since each generator site is different, the following information should be supplied by the purchaser in the specifications to the vendor.

2.4.1 Fuel Oil Analysis—(See Table 1)

2.4.2 Fuel Gas Analysis—(See Table 2)

2.4.3 Other Fuels Analysis

2.4.4 Feedwater Analysis--(See Table 3)

2.4.5 Other Utilities Available

a. Electrical Power ______V. ______Ph. _____ Hz.
b. Compressed Air: _____ SCFM P S I G _____ Dew Point
c. Pilot Fuel: ______Type _____SCFM _____ PSI

2.4.6 Site Conditions

a. Ambient Air Temp. °F: _____ Max. _____Min. _______Design
b. Wind Velocity, MPH: ______Max. Min. _______Design
c. Elevation, Ft. Above Mean Sea Level: ______________________________
d. Seismic Zone: _______________
e. Rainfall In./Yr.: ______________Avg.
f. Humidity %: Max. ___ Min. Design __________
g. Atmospheric Conditions
List unusual conditions such as H_2S, Sand, Dust, Salt, Air, etc.

2.4.7 Environmental Considerations

a. SO, Emission Limits,
PPM: _______Current _____Future
Lbs/Hr.: _______Current _____Future
b. NO, Emission Limit,
PPM: _______Current _____Future
Lbs/Hr.: _______Current _____Future
c. Particulate Emission Limit,
Gr/SCF: _______Current _____Future
Lbs/Hr.: _______Current _____Future
d. Waste Liquid Emission Limits

2.4.8 Transportation

List unusual transportation restrictions such as Tunnels, Narrow Or Weak Bridges, Restrictive Roads, etc.

Table 1—Fuel Oil Analysis

Higher Heating Value (HHV)	____________	BTU/Lb.
Lower Heating Value (LHV)	____________	BTU/Lb.
Density, 60°F	____________	Lb/Ft³
or Specific Gravity, 60°F	____________	
or API Gravity, 60/60°F	____________	
Viscosity @ 60°F	____________	SSU
122°F	____________	SSU
200°F	____________	SSU
Other ____ °F	____________	SSU
Conradson Carbon Residue	____________	% Wt.
Ash	____________	% Wt.
Carbon (C)	____________	% Wt.
Hydrogen (H)	____________	% Wt.
Sulfur (S)	____________	% Wt.
Nitrogen (N)	____________	% Wt.
Water (H_2O)	____________	% Wt.
Sediment	____________	% Wt.
Vanadium (Va)	____________	mg/l
Iron (Fe)	____________	mg/l
Magnesium (Mg)	____________	mg/l
Sodium (Na)	____________	mg/l
Chloride as NaCl	____________	Lb/100 Bbl.

*The higher heating value of a fuel is defined as the heat evolved, as measured by a constant pressure calorimeter, when a fuel is completely burned at stoichiometric conditions and the products of combustion are cooled to 60°F and the water vapor produced is completely condensed to liquid at that temperature. Heating values are reported in BTU/SCF for gaseous fuels, BTU/Lb. or BTU/Gal. for liquid fuels and BTU/Lb. for solid fuels.
**The lower heating value of a fuel is defined as the higher heating value minus the latent heat of vaporization of the water formed by the combustion of the hydrogen in the fuel. For a fuel with no hydrogen, the lower and higher heating values are the same.

Table 2—Fuel Gas Analysis

	Natural Gas	
Higher Heat Value	______	BTU/SCF
Lower Heat Value	______	BTU/SCF
Molecular Weight or Density, 60°F & 14.696 PSIA	______	Ft^3/Lb.
Temperature	______	°F
Supply Pressure	______	PSIG
Components (Mole %)		
Carbon Dioxide (CO_2)	______	%
Hydrogen Sulfide (H_2S)	______	%
Nitrogen (N_2)	______	%
Oxygen (O_2)	______	%
Methane (CH_4)	______	%
Ethane (C_2H_6)	______	%
Propane (C_3H_8)	______	%
Butanes + (C_4 +)	______	%

Table 3--Water Analysis

Source:	______	
Pressure:	______ PSIG	
Temperature:	______ °F (Min)	______ °F (Max)
Components		
*Calcium, (Ca)	______ mg/l	
*Magnesium, (Mg)	______ mg/l	
*Oxygen, (O_2)	______ mg/l	
Barium, (Ba)	______ mg/l	
*Iron, (Fe)	______ mg/l	
*Sodium, (Na)	______ mg/l	
Copper, (Cu)	______ mg/l	
Potassium, (K)	______ mg/l	
Ammonium, (NH_4)	______ mg/l	
*Chloride, (CI)	______ mg/l	
Iodide, (I)	______ mg/l	
Bicarbonate, (HCO_3)	______ mg/l	
Carbonate, (CO,)	______ mg/l	
Silica, (SiO_2)	______ mg/l	
Sulfate, (SO_4)	______ mg/l	
Hydroxide. (OH)	______ mg/l	
Hydrogen Sulfide (H_2S)	______ mg/l	
Organic Acids	______ mg/l	
*Total Alkalinity	______ mg/l	
*Total Hardness, ($CaCO_3$)	______ mg/l	
*Total Dissolved Solids	______ mg/l	
*Total Suspended Solids	______ mg/l	

*pH ______ Specific Gravity @ 60°F ______

Color ______

*Oil ______ mg/l Resistivity @ 75°F ______ Ohm-meter

*Minimum Data Required

2.4.8 Transportation

List unusual transportation restrictions such as Tunnels, Narrow Or Weak Bridges, Restrictive Roads, etc.

2.5 SAFETY EQUIPMENT

The following safety instrumentation and limit switches should be supplied for fully-automatic, unattended operation and for maximum safety of personnel and equipment.

2.5.1 Safety Instrumentation & Equipment

a. ASME Code Required Safety Valve(s).
b. Electronic Flame Monitoring Device and Combustion Controller including pre-purge, proof-of-pilot, proof-of-main flame, and post-purge sequence.
c. Steam pressure controller
d. Feedwater Flow Rate Transmitter & Controller
e. Feedwater Pump Relief Valve
f. Burner Firing Rate Controller
g. Appropriate Temperature and Pressure Indicating Devices

2.5.2 Operating Safety Limits

The following safety limit devices are recommended, each limit should shut burner fuel valve(s) and require manual restart after malfunction:

*a. Flame Failure
b. High Steam Pressure
*c. High Steam Pressure
*d. High Tube Temperature
e. High Stack Temperature
f. High Burner Throat Temperature (oil fired only)
g. Burner Throat Switch (swing-out burners only)
h. High/Low Atomizing Pressure (oil fired only)
i. High Fuel Gas Pressure (gas fired only)
j. Low Fuel Oil Pressure (oil fired only)
k. Low Fuel Oil Temperature (oil fired only)
*l. Low Feedwater Flow Rate
*m. Low Combustion Air Pressure
n. Low Instrument Air Pressure
o. Low Steam Pressure
p. Power Failure

2.6 AESTHETICS

Special consideration should be given to the locale of the Wet Steam Generator installation. The following should be considered:

2.6.1 Installation Housing

2.6.2 Installation Color Scheme

*Minimum required by Federal and most state codes. Others may be required by some states or insurance codes.

2.6.3 Noise Levels

2.6.4 Visible and/or Noxious Emissions

2.6.5 Other

2.7 HOOK-UP

If special design considerations are required for connections, user should specify service, size, rating and location for the following.

2.7.1 Feedwater Inlet

2.7.2 Steam Outlet

2.7.3 Fuel Inlets

2.7.4 Electrical Connection

2.7.5 Other

3 Installation

3.1 INSPECTION FOR SHIPMENT DAMAGES

3.1.1 Wet Steam Generators should be visibly checked for shipment damage and missing components immediately after delivery.

3.1.2 The Wet Steam Generator should be checked internally for refractory breakage.

3.1.3 All shipping damages should be reported to the carrier immediately.

3.2 FOUNDATION

3.2.1 Foundations for skid mounted Wet Steam Generators should be level and sufficient to support the weight of the Wet Steam Generator. Foundation loads are normally highest under the convection section.

3.2.2 Clearance must **be** provided for installing and servicing the Wet Steam Generator. Clearance space should include area required for replacing convection or radiant tubes and removal of complete component sections.

3.3 HEAVY LIFTING SERVICES

Lifting methods should be in accordance with manufacturer's recommendations.

3.4 REMOVAL OF SHIPMENT BRACES AND PROTECTIVE COVERS

Material installed to prevent **enroute** coil movement and all protective covers installed for shipping should be removed.

3.5 WATER AND STEAM CONNECTIONS

Consult manufacturer's installation drawings for connection sizes. All external piping should be same size or larger than Wet Steam Generator connections.

3.6 FUEL CONNECTIONS

3.6.1 Natural gas for gas fired units should be clean and free of liquids at the specified pressure. Sufficient volume should be provided upstream of safety shut off valves and inlet gas supply reducing regulator to provide a cushioning effect and reduce pressure surges. A relief valve should be installed on gas inlet supply piping if supply pressure can exceed safe working pressure or Wet Steam Generator gas train components.

3.6.2 Liquid fuels should be of consistent quality and void of free water, gas and sand. Heavy oil burners can operate satisfactorily with a small quantity of emulsified water. Manufacturer's specifications should be consulted for fuel oil inlet temperature, pressure and flow requirements. A return oil line from the Wet Steam Generator to the storage tank should be installed to provide for fuel oil circulation.

3.7 WASTE DISCHARGE CONNECTIONS

Wet Steam Generators may be supplied with individual drain connections or a central drain system and should be connected to an appropriate disposal system.

3.8 BLOW DOWN DISCHARGE CONNECTION

The Wet Steam Generator may be supplied with an optional blow down valve upstream of the outlet stop valve. End of the blow down line should be firmly anchored for discharge in an appropriate area.

3.9 PILOT FUEL CONNECTIONS

3.9.1 Wet Steam Generators require a pilot burner or other igniters to ignite the main burner. Pilot burner fuel normally is natural gas or LPG. Manufacturer's specifications should be followed for fuel gas supply.

3.9.2 Check pilot gas supply system for proper regulators to reduce pilot gas supply to specified pressure.

3.9.3 Light oil pilot burners may be used for special applications.

3.10 ELECTRICAL CONNECTIONS

3.10.1 Normally one power supply connection is made to the Wet Steam Generator. Manufacturer's specifications should be consulted for full load power supply requirements.

3.10.2 Manufacturers normally complete and test all electrical wiring before shipment. Wiring between skids and electrical components removed for shipment should be in accordance with manufacturer's specifications and all applicable codes.

3.10.3 Grounding connections should be installed between all applicable equipment and electrical systems to proper ground in accordance with manufacturer's specifications and all applicable codes.

3.10.4 Manufacturer's drawings and specifications should be checked for possible control wiring between Wet Steam Generator control panel and associated equipment.

3.11 AIR SUPPLY CONNECTIONS

Individual Wet Steam Generators are normally supplied with air compressor and filters for instrument and atomizing air supply. Wet Steam Generators for centralized locations without air compressors should be connected to an instrument and atomizing air supply system. Manufacturers specifications should be consulted for pressure, volume, and maximum moisture requirements.

3.12 MANUFACTURER SUPPLIED DATA

Manufacturer should supply purchaser with a Heat Balance Performance Data Sheet (See Figure 1) and Mechanical Data Sheet (See Table 4).

4 Commissioning

4.1 This section establishes the minimum procedures that should be adhered to by the user for initial start up of a new, or altered Wet Steam Generator, or one which has had an extended shut down. Manufacturer's recommendations should be followed for initial start-up and break-in procedures.

4.2 LUBE OIL LEVELS

Check lubrication oil level in feedwater pump and air compressor crank cases. Fill packing or rod lubricator reservoirs if provided. Special oil may be necessary to follow manufacturer's recommendations.

4.3 PULSATION DAMPENER CHARGE

Follow manufacturer's recommendations to check proper charge in pulsation dampers. Nitrogen charging system is required to increase charge pressure.

4.4 MOTORS

Make sure all motors are clean, dry, and serviceable. Follow manufacturer's instructions to check proper rotation.

4.5 COMPRESSOR

Table 4—Example Mechanical Design Data Sheet

Wet Steam Generator Model No. ____________________ Fuel ____________________

Maximum Pressure __________ PSIG   Absorption Rate __________ BTU/Hr.

Convection Section   Radiant Section

Tube length (each) __________ Ft.   Tube length (each) __________ Ft.

Number of bare tubes __________   Number __________ Size __________ In.

Number of finned tubes __________   Number __________ Size __________ In.

Effective Surface __________ Sq. Ft.   Effective Surface __________ Sq. Ft.

Fin Configuration __________ In. High __________ In. Thick __________ Fins Per Foot

Approximate Shipping Weight of Wet Steam Generator ____________________ Lbs.

Approximate Weight of Radiant Section Assembly ____________________ Lbs

Approximate Weight of Convection Section Assembly ____________________ Lbs.

Total Electrical Load __________ KVA   Largest Electric Motor __________ __________ HP

Thermal Design Specifications

	Inlet		Outlets	
Liquid	______	Lbs. Hr.	______	Lbs. Hr.
Vapor	______	Lbs. Hr.	______	Lbs. Hr.
Temperature	______	°F	______	°F
Outlet Design Pressure			______	PSIG
Enthalphy	______	BTU/Lb.	______	BTU/Lb.

Burner Maximum Designed Heat Release __________ BTU/Hr.

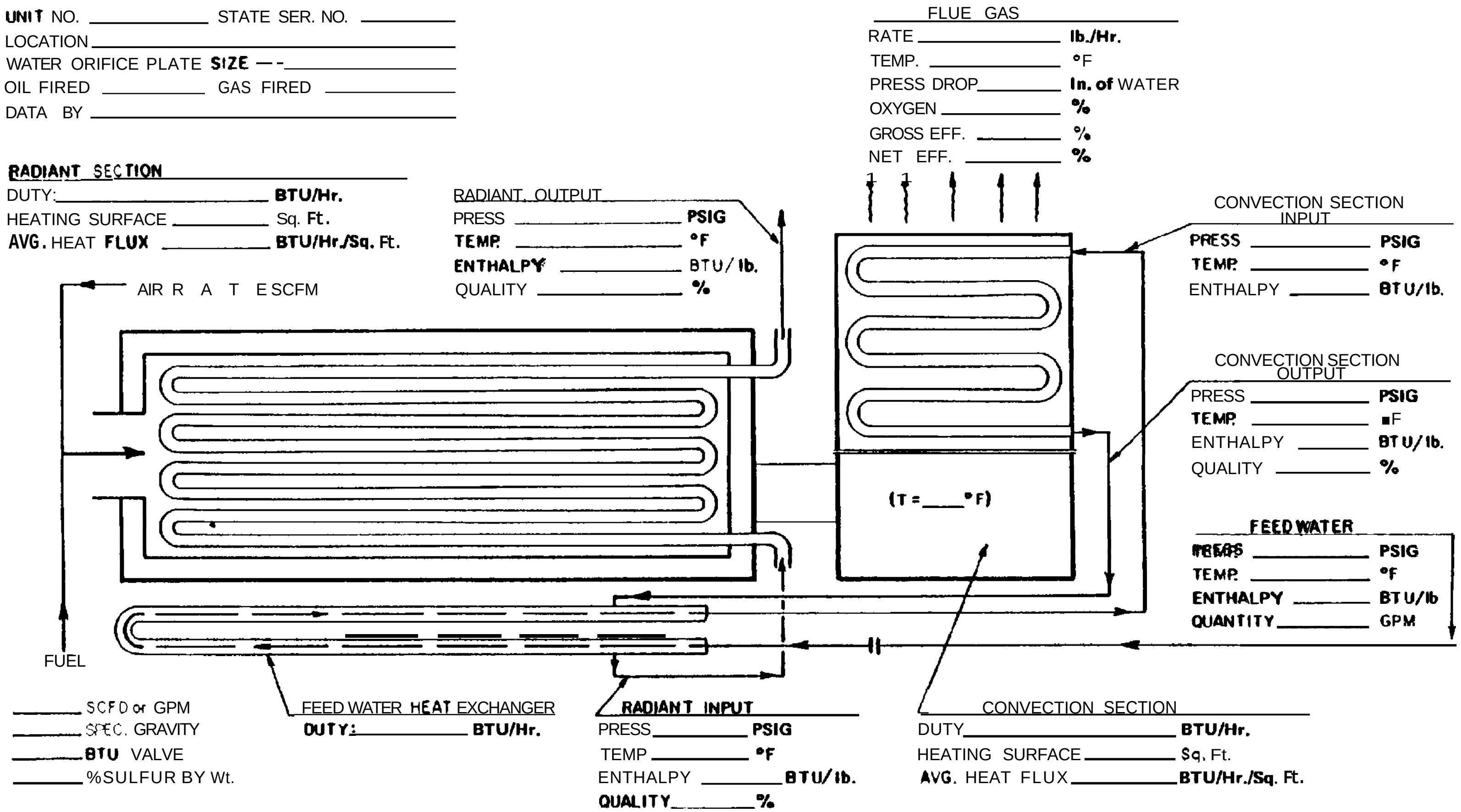


Figure 1—Example Heat Balance Performance Data Sheet

4.5.1 Allow air compressor to build up to pressure cut off point. Set cut off switch if necessary. Bleed off pressure and check compressor cut in set point. Compressor must run long enough for proper lubrication as recommended by manufacturer.

4.5.2 Blow down pneumatic air lines at all filter drains and check for proper regulator operation.

4.6 WATER-STEAM PIPING SYSTEM

4.6.1 Open feedwater inlet and close steam outlet valves. Allow piping to fill with water from supply system and check for low pressure leaks. Open all vent valves or plugs at high points in piping system and bleed air.

4.6.2 Open blowdown or steam discharge valve and start feedwater pump. Observe pump operation at low pressure.

4.6.3 Test entire system for leaks up to working pressure following manufacturer's recommended procedure.

4.7 FUEL OIL SYSTEM

4.7.1 Follow recommendations to start separate fuel oil pumping and preheating unit if supplied. Fuel oil pumping and preheating unit should deliver fuel to Wet Steam Generator at specified temperature, pressure, and volume.

4.7.2 Set electric fuel oil heater thermostat to temperature required for proper atomization of fuel. Close hot water or steam valves to hot water or steam heated fuel oil heat exchanger.

4.7.3 Open manual fuel by-pass on Wet Steam Generator to start circulation. Close manual by-pass and set fuel back-pressure regulator.

4.7.4 Set burner fuel pressure regulator if fuel can be returned to supply downstream of regulator.

4.7.5 Adjust hot water or steam fuel oil heat exchanger control for desired fuel oil temperature when Wet Steam Generator is operating at temperature sufficient for heating fuel oil to proper atomizating temperature.

Set electric fuel oil heater thermostat slightly below required fuel oil atomizating temperature after hot water or steam fuel oil heat exchangers are operational.

4.7.6 Heavy fuel pumping and heating systems are normally left on at all times. Light oil fuel systems may be turned off when Wet Steam Generator is not firing.

4.8 FUEL GAS SYSTEM

4.8.1 Close Wet Steam Generator inlet manual gas valves. Open gas supply and check for proper supply pressure as specified by manufacturer.

4.8.2 Depending on the type gas burner supplied, manufacturer may supply a burner gas pressure regulator either upstream or downstream of safety fuel gas valves. If burner pressure regulator is upstream of safety valve, open inlet gas cock and set regulator according to manufacturer recommendations. Burner gas pressure regulator installed down stream of safety valves should be set as outlined in 4.9.9.

4.8.3 Check pilot gas supply system for proper regulators and adjust each regulator to specified pressures.

4.9 INITIAL FIRING

4.9.1 Check all valves to assure proper position for water flow through Wet Steam Generator.

4.9.2 Operate feedwater pump on manual control to insure water system is filled and flowing through the Wet Steam Generator.

4.9.3 Check that swingout type burners are secure. Check that combustion chamber manways are secure.

4.9.4 Operate combustion air blower on manual control, preferably with dampers open, to insure complete purge of combustion chamber.

4.9.5 Turn on fuel supply system if required.

4.9.6 Follow manufacturer's recommendations for initial setting of limit devices for initial firing of Wet Steam Generator.

4.9.7 Initial startup should be with pilot gas and main burner manual fuel valves closed. Normally, electrical control switches are turned to automatic position and a reset type start switch is activated to start a programed light off. The Wet Steam Generator should go through programed start-up. Combustion control system should lock out indicating flame failure due to no pilot flame with pilot fuel valves closed.

4.9.8 Reset combustion control system, open pilot gas supply, place burner control in low fire hold and restart system with main burner manual fuel valve closed. Burner pilot should ignite, the combustion control system should indicate pilot flame and permit safety fuel valves to open. Flame failure indication should occur when pilot flame times out without lighting main burner due to closed main burner fuel valves. Adjust the pilot burner in accordance with Wet Steam Generator manufacturer instructions.

4.9.9 Reset combustion control system, open both pilot and main burner manual fuel valves. Restart system with burner control in low fire hold position. Observe flame and adjust burner and fuel pressure regulators in accordance with manufacturer's instructions for low fire operations.

4.10 DRYING OUT REFRACTORY

Follow manufacturer's recommendations for drying refractory on initial startup if applicable. Initial refractory drying is normally at low fuel and high excess combustion air rates to reduce flue gas condensation at low firing rates.

4.11 HIGH RATE BURNER ADJUSTMENTS

4.11.1 The burner operator device normally controls combustion air dampers. Fuel rate control normally is through adjustable linkage attached to the air dampers or, on special applications, by separate operators. Differential pressure regulators are often used to increase either fuel or atomizing air-steam pressure as firing rates increase.

4.11.2 The Wet Steam Generator should be run at rated capacity to set air dampers and fuel valves at maximum firing rate. The linkage system should be adjusted so burner fuel control valves and air dampers at full firing rate will permit maximum travel of the burner operator and positioner. Fuel rate on liquid fueled units and gas burner nozzle pressure on gas fired units should be noted at full firing rate for future reference when adjusting burner positioner.

4.11.3 After setting air-fuel for proper ratio at high fire rate, the burner should be reduced in steps to lower rates and air-fuel ratios checked. Adjustments may be required to provide proper air-fuel ratios over the desired firing rate range.

4.12 BURNER POSITIONER

4.12.1 The burner positioner characterizes burner travel and firing rate in relation to burner control signal. The burner control signal may be manually controlled or automatically modulated in relation to feedwater rate depending on control system design. A biasing regulator may be used to add or subtract a constant control signal to or from a feedwater flow rate signal to provide a modulating burner control signal.

4.12.2 Burner positioners on modulating type units should be set to provide the highest desired steam quality at highest feedwater and firing rates.

4.12.3 Outlet steam quality should be used to set and check burner firing rate in relation to feedwater rate. Water-fuel rate ratios in relation to outlet steam quality may be used to adjust burner positioners for firing rate to feedwater rate.

4.13 SAFETY SHUT DOWN DEVICES

All safety limit devices should be set and checked for both mechanical operation and electrical shut down of the Wet Steam Generator for unattended operation.

4.14 FLOW-PRESSURE BURNER CONTROLS

Set water flow rate controls, outlet steam pressure controls and trim burner controls if necessary for desired operating parameters prior to unattended operation.

4.15 EFFICIENCY CHECK

Heat balance performance data can be gathered and efficiency calculated after initial start up and periodically as desired. (See Figure 1.)

5 Operations

5.1 This section establishes the minimum procedures for the start-up, on-stream adjustment, and shutdown of existing Wet Steam Generator systems.

5.2 START-UP PROCEDURES

5.2.1 The start-up procedure may vary with the type of Wet Steam Generator, the control system, and individual preferences or requirements of the operating company. The control system initiates light off of the burner in a pre-set sequence of events, if all limit conditions are safe, and will prevent the main fuel valve from opening if an unsafe condition exists.

5.2.2 The control system should initiate the start-up sequence by modulating the burner blower control to high purge position, purging the Wet Steam Generator of combustible gases, and allowing the tubes to fill with water. After a predetermined time, the burner blower should modulate to low fire position. If all limits are completed, the pilot is ignited and the ultra violet (UV) flame scanner confirms flame, permitting firing of the main burner. ***Manual programming override or bypassing of safety limits should never be executed.***

5.2.3 Pre-Start Check List

Before the Wet Steam Generator is started, the following items should be checked and the manufacturer's start-up instructions reviewed. If the unit has been in prolonged storage, commissioning procedures should be followed as described in Section 4.

a. Check that all personnel are clear and all access openings properly closed, and Wet Steam Generator interior is free of residual fuel or debris.
b. Place all control switches in the off position. Turn on main electrical power supply switch and follow manufacturer's start-up sequence.
c. Check that the following utilities are available at the Wet Steam Generator: electricity, treated feed water, fuel gas or heated fuel oil, pilot gas, instrument air, and atomizing air or steam if firing fuel oil.
d. Check that the water and steam valves are opened for a clear path through the Wet Steam Generator.
e. Check that the blowdown valve (if provided) directs the water-steam flow to the blowdown area.
f. Check that there is an open pipeline to an injection well and that no one is working on the piping system or well.
g. Check that the fuel oil (if used) is at the proper operating temperature and pressure at the burner.

h. Run the feed water system in the manual mode until a full stream of water is flowing through the Wet Steam Generator.

5.2.4 Start-Up

After being sure that the above and any other necessary steps have been properly completed, prepare to start the Wet Steam Generator. With control power on and all appropriate switches in on/automatic position, reset the combustion control system. With most control systems the following sequence of events should occur.

a. The feed water flow is established satisfying the low water flow limit.
b. The main blower starts satisfying the low combustion air limit.
c. The unit will cycle to the high purge position and should provide a minimum of four firebox volumes of air displacements.
d. The burner will return to the low fire position and the burner low fire interlock must be satisfied for ignition sequence to continue.
e. The ignitor is energized and the pilot fuel valve opens.
f. The UV flame scanner must prove the pilot flame.
g. With the pilot confirmed the safety fuel valve(s) can be opened. The safety fuel valve(s) may be designed for automatic or manual operation.
h. Flame scanner must prove the main flame.
i. The control system should sequence to the normal fire position and allow the burner firing rate to be controlled manually or automatically.
j. When suitable atomizing steam is available, atomization should be switchcd to steam.
k. When the desired operation conditions are met, discharge steam should be opened to injection system and then the blowdown valve(s) closed.

5.2.5 If a safety limit condition is exceeded, the fuel safety valve(s) will close and the control system will initiate post purge sequence.

5.3 ADJUSTING THE WET STEAM GENERATOR FOR UNATTENDED OPERATION

5.3.1 In order that the Wet Steam Generator operate unattended in a safe, stable, and efficient manner, it must be properly adjusted.

5.3.2 Flame Condition

The flame shall be adjusted to minimize impingement on tubes or tube hangers causing "hot spots." A clean fuel nozzle, radiant section pressure, and the air-fuel ratio contribute to a good flame pattern. For oil fired burners the proper fuel pressure and viscosity, and suitable atomizing steam-air pressure and quality are also significant factors.

5.3.3 Operating Pressure

If the Wet Steam Generator's maximum output is greater than the injection well's capacity, the output must be reduced so a maximum pressure is not exceeded. Both the water and firing rates must be reduced.

5.3.4 Water to Fuel Ratio

The steam quality is established by the water to fuel ratio. This ratio must be high enough to prevent excessive concentration of dissolved solids in the liquid phase which can cause tube wall scaling (See Appendix A.2.2). The ratio must also be low enough so that sufficient enthalpy leaves the Wet Steam Generator. The most common practice is to limit steam quality to 80%. The operating water-fuel ratio or steam quality should be checked and adjusted by the operator periodically.

5.3.5 Water Temperature to the Convection Section

The water temperature to the convection section inlet should be high enough to prevent flue gas condensate corrosion of the convection section.

5.3.6 Thermal Efficiency

Thermal efficiency is dependent on design and operation. Controlling excess oxygen at a low value and maintaining minimum stack temperature with periodic convection section cleaning maintains high thermal efficiency. Daily logs of pressure in the radiant section or increased flue gas temperature may indicate fouling in the convection section.

5.3.7 Safety Checks

The safety shutdown devices must be operational and checked periodically in accordance with the state or local regulations and manufacturer/operator recommendations. The safety limits are designed to close the fuel safety valve and cause the Wet Steam Generator to shut down if a safety limit is exceeded. They will also prevent the pilot or main burner from lighting if an unsafe condition exists. The safety limits may be set close to the operating point and are generally set at the closest point that will not cause frequent nuisance shutdowns or at the maximum limit for safe operation.

5.4 SHUTDOWN PROCEDURES

5.4.1 Normal Shutdown

If the Wet Steam Generator is to be shut down for a routine reason, the burner on/off switch may be used. However, the preferred method is to trip a safety limit that does not interfere with the post purge cycle. An unattended shutdown can be simulated by a limit switch set point or an operating parameter change. This will check the proper operation of the limit shutdown, the first outage indicator, and the post purge blower and feed water pump timers.

5.4.2 Emergency Shutdown

A prominent switch should be provided on the control panel and, if necessary, a safe distance from the Wet Steam Generator to kill the control (110 volt) power that operates the main motor starters. The high voltage main switch can then be opened without a load. ***These procedures should only be used when normal shutdown cannot be safely conducted.*** Provision to shut off the fuel supply should be provided remotely in case of fire. A fire detection system to shut off the fuel supply may also be provided.

5.4.3 Prolonged Shutdown

If the Wet Steam Generator is to be shut down for a prolonged time, the following minimum steps should be taken for equipment protection.

a. Drain the water from the tubes and close the valves to exclude air.
b. Drain and purge all systems which may contain moisture.
c. If the Wet Steam Generator is fired with heavy oil, displace the heavy oil in the fuel system with light oil.
d. Protect the pneumatic and electric instruments from the elements.
e. Remove the main electric supply fuses or breakers and take steps to prevent unauthorized operation.
f. Place a cover over the stack to protect the interior from the elements. Place a cover over the blower intake.
g. Review manufacturer's recommendation for prolonged shutdown and storage.

6 Maintenance

6.1 It is recommended that maintenance and inspection procedures be performed daily, monthly and annually. All repairs and maintenance should be documented. The manufacturer's recommendations should always be a part of maintenance and inspection, and forms should be designed for each specific application. (Figure 1 and 2 and Tables 4, 5, 6 and 8 are offered as a guide to record the events.) Consider the environment in which a generator operates. Severe environments may require special maintenance and inspection.

6.2 DAILY MAINTENANCE AND INSPECTION

6.2.1 A minimum daily routine of inspecting and recording of all instrument readings is recommended and the following is a list of the minimum readings that should be recorded: (See Table 5)

a. Feedwater pump discharge pressure
b. Feedwater flow rate
c. Steam outlet pressure
d. Steam outlet temperature
e. Water inlet temperature
f. Radiant tube skin temperature
g. Fuel nozzle pressure
h. Stack temperature
i. Radiant section pressure
j. Fuel rate
k. Excess air or O_2

6.2.2 In addition there are other parameters that require testing, calculations, or judgment and should also be monitored and recorded. The following items are recommended:

a. Water quality (See Appendix A)
b. Steam quality
c. Flame pattern
d. Visual internal and external inspection
e. Lubricating oil levels of the feedwater pump power end
f. Lubricating oil level of the air compressor
g. Filter and strainer efficiency

6.3 MONTHLY MAINTENANCE AND INSPECTION (See Table 6)

6.3.1 Feedwater pump, fluid and power ends and drive systems should be inspected. The manufacturer's recommended maintenance procedures should be followed. The crankcase oil should be inspected and replaced as specified by the manufacturer.

6.3.2 All motors should be inspected and lubricated as specified by the manufacturer.

6.3.3 Fuel, water, air strainers and filters should be cleaned and serviced, as required.

6.3.4 If the Wet Steam Generator is shut down the condition of the convection section and radiant section tubes should be noted. Fin loss deterioration or fouling should be noted and recorded.

6.3.5 If the Wet Steam Generator is shut down, the flame stabilizer/diffuser and fuel nozzle, used with heavy oil burners should be inspected and cleaned as required.

6.4 SAFETY INSPECTION (See Table 8)

6.4.1 It is recommended that all safety devices be tested at a minimum of once each sixty days. State and local codes may require more frequent testing.

6.4.2 Some regulations require a minimun of five safety shutdown devices to be responsive.

a. High steam pressure
b. High tube temperature
c. Flame failure
d. Low combustion
e. Low feedwater flow rate

6.4.3 Most manufacturers and purchasing companies require additional safeties, and local codes may require others. Any additional safeties should be tested and the results recorded.

6.4.4 Where possible always test both the electrical and sensing portions of any safety device.

6.4.5 Any safety that does not function must be replaced or repaired.

6.4.6 The following is a listing of the safety devices that should be tested each 60 days.

a. Flame failure
b. High steam temperature
c. High steam pressure
d. High tube temperature
e. High stack temperature
f. High burner throat temperature (oil fired only)
g. Swing out burner switch
h. High/Low atomizing pressure (oil fired only)
i. High fuel gas pressure
j. Low fuel pressure
k. Low fuel oil temperature
l. Low feedwater flow rate
m. Low combustion air pressure
n. Low instrument air pressure
o. Low steam pressure

6.5 ANNUAL MAINTENANCE AND INSPECTION (See Exhibit 6.4.)

6.5.1 Permanent and progressive records should be maintained for each Wet Steam Generator. It is recommended that the following documents and information be included:

a. All ASME Manufacturers' Data Reports.
b. Drawings showing the location and thickness of monitored or critical inspection locations.
c. If material loss is found within the piping system the maximum allowable working pressure and temperature should be recomputed by a qualified person and the Wet Steam Generator derated or repaired accordingly. All calculations should be made a part of the annual record. All name plates, permits, etc., must reflect the change. In addition, a name plate rubbing should be included in the records.
d. Hydrotest the steam piping from the feedwater pump discharge to the steam outlet at the time of inspections. If applicable record the hydrotest pressure.
e. Schedule date of next inspections.
f. Date of any significant changes in service conditions.
g. Complete pressure relieving device information including safety relief valve spring data and dates of latest and next inspection.
h. The completion of a performance data sheet (Figure 1) is recommended. The data can be a useful inspection/maintenance tool.
i. The Wet Steam Generator Mechanical Design Data Sheet (Table 4) should be completed and become a part of the initial records. It should be checked and updated annually to reflect any changes.

6.5.2 A safety check should coincide with an annual maintenance procedure and in addition to the items inspected daily and monthly, the following points should be inspected for proper annual maintenance:

a. External Inspections. Any evidence of steam or water leaks should be investigated. Leakage from behind insulation, coverings or supports should be investigated and corrective action taken.
   1. All pressure and temperature instruments should be calibrated and replaced as required.
   2. Safety relief valves should be carefully examined at each inspection and there should be no accumulations of rust, scale or other foreign substance in the valve body which will interfere with the free operation of the valve. It is recommended that annually the safety valves be removed from the unit, tested and reset at an approved safety valve testing facility or by the valve manufacturer. State or local regulations may require more frequent inspection or testing.
   3. Electrical. The continuity and condition of all electrical components should be checked.

b. Internal Inspections. Where there is evidence of insulation or refractory failure the material should be repaired or replaced.
   1. The surface of all tubes should be carefully examined for any evidence of corrosion, erosion, deformation, bulging, sagging, cracks or defective welds. The radiant coil or tubes and the convection section should be spot checked for wall thickness by a non-destructive test. If repairs are made to the code sections of the Wet Steam Generator, a record of the repair must be made. A partial data sheet, ASME form P-3 for the material or piping used, is to accompany the repair form. (See Table 10)
   2. Tube hangers, yokes and hanger bolts should be inspected for thinning, cracking, stress or deformation.
   3. THE HYDROSTATIC TEST PRESSURE SHOULD BE 1½ TIMES THE MAXIMUM ALLOWABLE WORKING PRESSURE AND SAFETY PRECAUTIONS MUST BE EXERCISED.

Table 5—Wet Steam Generator Daily Log

Date or Time	Water Inlet Temp.	Feedwater Flow Rate	Feedwater Pump Disch. Pressure	Steam Outlet Press.	Steam Outlet Temp.	Stack Temp.	Radiant Tube Skin Temp.	Fuel Nozzle Press.	Radiant Section Pressure	Fuel Rate	*Excess* O_2	Etc.

Table 6—Monthly Maintenance and Inspection Example Wet Steam Generator Check List

Item No.[1]	Description of Item	Inspected		Condition			Date of Service or Inspection	Inspector	Comments
		Yes	No	OK	Faulty	Replaced			
A-6	Feedwater Pump Crankcase—Drain and refill as specified by manufacturer.								
A-10	Feedwater Pump Motor[2] Lubricate as specified by manufacturer.								
A-35	Convection Coil[3]								
A-40	Radiant Coil								
F-2	Fuel Oil Filters and Strainers[4]								
	Water Filters								
	Air Filters								
J-2	Burner Blower Motor[2]								
J-3	Miscellaneous Motors								
	Burner Stabilizer/Diffuser Plate								

Note: Super Scripts Refer to Table 7.

Table 7

1. Refer to Exhibit 6.4.

2. Keep all motors clean and ventilation openings clear of dust, dirt and other debris. Do not over grease.
WARNING: Disconnect all power sources to the unit and discharge all parts which may retain an electrical charge before attempting any maintenance or repair. Screens and covers must be maintained in place when unit is in operation.
Some small motors have sealed-for-life type bearings which require no relubrication.
Motors that do require lubrication, can be regreased by stopping the motor, removing the drain plug and pumping new grease into fillhole. Run the motor with the drain plug removed, for a short period, to discharge excess grease. Replace the drain plug.
Motors that operate at speeds greater than 1800 RPM should be lubricated on a more frequent maintenance schedule depending on duty cycle.

3. On occasion it may be necessary to remove deposits from between the fins on the tubes in the convection section. The frequency of cleaning the fin tubes will be determined by the type of fuel oil being used.
The convection section fin tubes may require cleaning when increase in back pressure of approximately 2" w.c., above new and clean condition, is indicated on the radiant section manometer.

4. The frequency of service required for the filters and strainers is determined by operating time using fuel oil and the quality of the fuel oil being used.
One indication of a dirty element is a drop in oil pressure to the burner (as indicated on pressure gauge).

Table 8—Wet Steam Generator Safety Inspection Check Sheet

Unit No. ________ State Serial No. ________ Inspection Date ________

Make of Unit & Fuel Used ________ Location ________ Inspector's Signature ________

1. Enter OK or failed in column headed "Proper Operation"
2. Enter set point of control in column headed "Set Point"
3. Describe any safety failure under "Comments" and describe repairs made
4. Draw line through any safety listed that is not on this unit

Shutdown	Proper Operation	Set Point	Comments
High Steam Pressure			
High Tube Temperature			
High Steam Temperature			
Flame Failure			
Low Combustion Air Pressure			
Low Water Flow			
Low Fuel Pressure			
High Fuel Gas Pressure			
Low Steam Pressure			
Low Instrument Air			
Burner Throat Temperature			
Swing Out Burner Switch			
High Stack Temperature			
Low Atomizing Pressure			
Low Fuel Oil Temperature			
Safety Relief Valves*			

Visual check of external wiring, conduit, piping, tubing and fittings for obvious leaks or defects. All gauges must be checked for proper calibration.
*Consult state and local codes for test procedures.

Electrician ________ Date ________

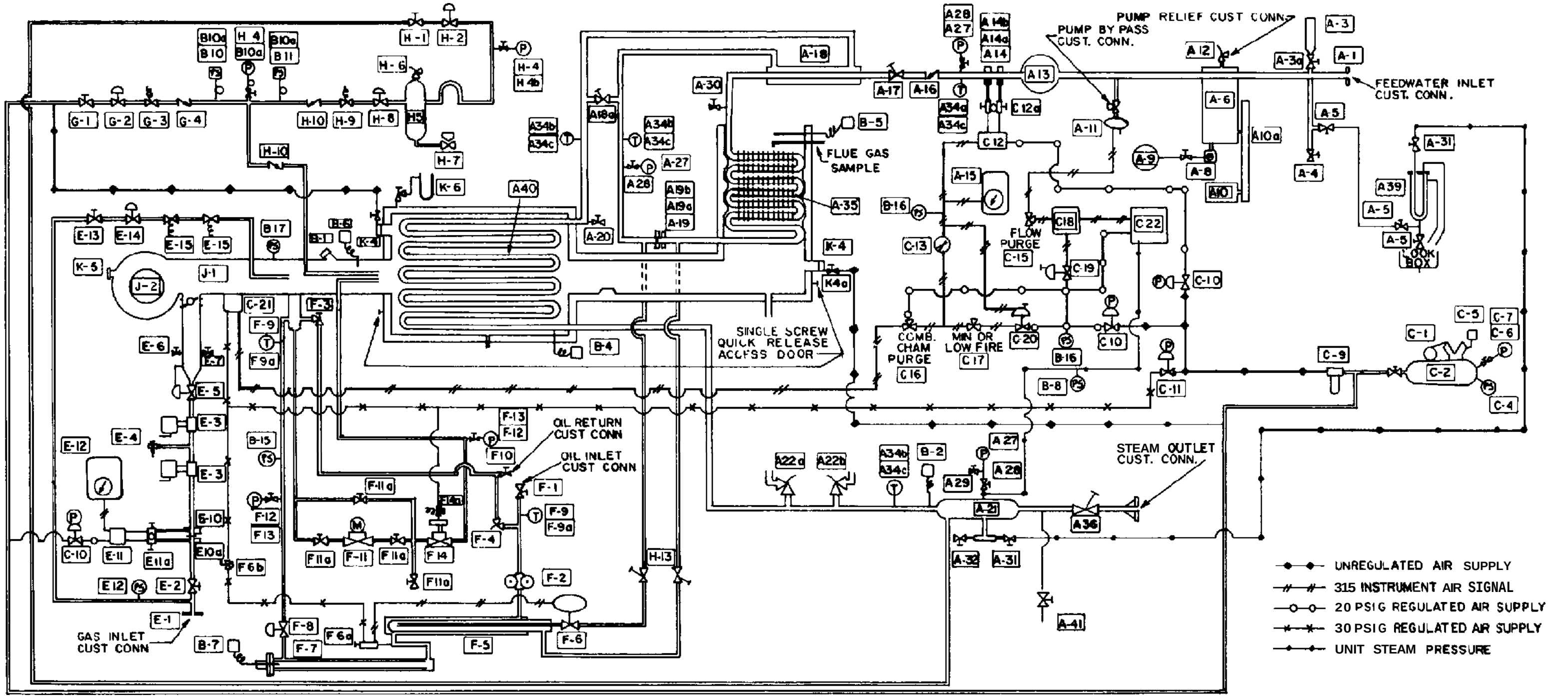
Mechanic ________ Date ________

Operator ________ Date ________

Foreman ________ Date ________

ANNUAL MAINTENANCE & INSPECTION

EXAMPLE WET STEAM GENERATOR FLOW DIAGRAM



UNIT NO. ______________________

STATE SERIAL 10. ______________________

MAKE & MODEL ______________________

LOCATION ______________________

DATE OF LAST INSPECTION ______________________

HOURS OF SERVICE
(SINCE LAST INSPECTION> ______________________

FUEL USED ______________________

INSPECTION DATE ______________________

INSPECTORS SIGNATURE/S ______________________

____

____

Figure 2

Table 9—Wet Steam Generator Annual Check List

Item No.	Description of Item	Inspected Yes	Inspected No	Condition OK	Condition Faulty	Condition Replaced	Comments
	WATER FLOW SYSTEM						
A-1	Water Inlet Flange						
A-3	Suction Dampener						
A-3a	Isolation Valve						
A-4	Water Inlet Drain Valve						
A-5	Cooling Coil Valvc						
A-6	Feedwater Pump						
A-8	Oil Level Control						
A-9	Oil Reservoir						
A-10	Pump Motor						
A-10a	Belt Guard						
A-11	Pump By-Pass						
A-12	Pump Relief Valve						
A-13	Discharge Dampener						
A-14	Feedwater Orifice						
A-15	Feedwater Flow Record						
A-16	Inlet Check Valve						
A-17	Inlet Stop Valve						
A-18	Feedwater Preheater						
A-18a	By-Pass Valves						
A-19	Diverting Orifice						
A-20	Radiant Coil Vent Valve						
A-21	Steam Discharge Separator						
A-22a	Safety Valve						
A-22b	Safety Valve						
A-27	Pressure Gauges						
A-28	Pressure Gauge Valve						
A-29	Pressure Gauge Test Valve						
A-30	Vent Valve						
A-31	Cooling Coil Valve						
A-32	Drain Valves						
A-34	Thermometer with Socket						
A-35	Convection Section						
A-36	Stop/Check Valve(s)						
A-39	Sample Cooler						
A-40	Radiant Section						
A-41	Blowdown Valve						
	ANNUNCIATOR PANEL						
B-1	Flame Monitor						
B-2	High Steam Temp.						
B-4	High Tube Temp.						
B-5	High Stack Temp.						
B-6	High Burner Temp.						
B-7	Low Oil Temp.						
B-8	High Steam Press.						
B-10	High Atom. Press.						
B-11	Low Atom. Press.						
B-12	Low Gas Press.						
B-15	Low Oil Press.						
8-16	Low Instrument Air Press.						
B-17	Low Combustion Air Press.						
	PNEUMATIC SYSTEM						
C-1	Air Compressor						
C-2	Air Receiver Tank						
C-4	High/Low Press. Switch						
C-5	Air Relief Valve						
C-6	Pressure Gauge						
C-7	Gauge Valve						
C-9	Instrument Air Filter						
C-10	Air Pressure Regulator						
C-11	Air Pressure Regulator						
C-12	Pneumatic Transmitter						
C-12a	Transmitter Valve Manifold						
C-13	Water Flow Rate Gauge						
C-14	Burner Control Signal						

Table 9--Wet Steam Generator Annual Check List (Continued)

Item No.	Description of Item	Inspected		Condition			Comments
		Yes	No	OK	Faulty	Replaced	
C-15	Flow Purge Solenoid						
C-16	High Purge Solenoid						
C-17	Low Fire Solenoid						
C-18	High Signal Selector						
C-19	Manual Loader (Water)						
C-20	Bias Regulator (Burner)						
C-21	Burner Operator w/Positioner						
C-22	Pressure Controller						
	MAIN GAS SYSTEM						
E-1	Gas Inlet						
E-2	Manual Gas Stop Valve						
E-3	Safety Shut Off Valves						
E-4	Vent Valve						
E-5	Gas Pressure Regulator						
E-10	Gas Orifice Flanges						
	PILOT GAS SYSTEM						
E-13	Manual Pilot Gas Stop Valve						
E-14	Pilot Regulator						
E-15	Pilot Solenoid Valve						
	FUEL OIL PIPING						
F-1	Oil Inlet Valve						
F-2	Oil Strainer						
F-3	Manual Bypass Valve						
F-4	Oil Pressure Relief Valve						
F-5	Steam/Oil Heater						
F-6	Temp. Control Valve						
F-6a	Temp. Controller						
F-6b	Pneumatic Valve						
F-7	Electric Oil Heater						
F-8	Oil Pressure Regulator						
F-9	Thermometer						
F-10	Oil Return Valve						
F-11	Oil Meter						
F-11a	Oil Meter Valves						
F-12	Pressure Gauge						
F-13	Gauge Valve						
F-14	Burner Oil Valve						
F-14a	Solenoid Valve						
	ATOMIZING AIR SYSTEM						
G-1	Air Stop Valve						
G-2	Air Pressure Regulator						
G-3	Air Solenoid Valve						
G-4	Air Check Valve						
	ATOMIZING STEAM SYSTEM						
H-1	Steam Stop Valve						
H-2	Primary Steam Regulator						
H-4	Pressure Gauge						
H-5	Steam Separator						
H-6	Steam Press. Relief Valve						
H-7	Steam Trap						
H-8	Secondary Steam Regulator						
H-9	Steam Solenoid Valve						
H-10	Steam Check Valves						
	BURNER						
J-1	Burner						
J-2	Blower Motor						
J-3	Flame Stabilizer/Diffusers Plate						
	MISCELLANEOUS						
K-4	Observation Ports						
K-6	Manometer						

Table 10—Record of Welded Repairs

This is to certify that the fusion-welded repair made by and under the direction of the undersigned on ____________________
and consisting of (Date of Repair)

____

(Description of Repair)

____

____

____

____

Unit No.	Name of Original Manufacturer	State No.	Natl. Bd. or Serial No.	Year Built

Location ____________________________________

____

(Owner or Company)

Welding was done by ________________________________

(Name of Qualified Welder)

(Note: Draw a sketch to show the repairs on hack)

Name of Repair Firm __________________________

Signed By __________________ Date __________

Address ________________________________

________________________ Date __________

(Authorized Inspector's Signature)

____

(Name of Inspection Agency Employed By)

APPENDIX A—WET STEAM GENERATOR FEEDWATER QUALITY

A.1

Feedwater quality is a critical factor to the good operation of the Wet Steam Generator. Poor quality feedwater can result in tube failures. Problems in Wet Steam Generator Systems as a result of poor feedwater quality can normally be categorized in the following areas:

A.1.1 SCALING

The production of adherent solid deposits which can enhance corrosion and cause localized over heating and poor heat transfer.

A.1.2 SOLIDS

The production of suspended solids which are undesirable as solids carryover.

A.1.3 CORROSION

The chemical attack causing oxidation of metal surfaces in contact with the feedwater.

A.2

The following factors should be considered in the treatment of feedwater:

A.2.1 TOTAL HARDNESS

To avoid operating problems, it is necessary to soften the Wet Steam Generator feedwater to less than one part per million (pprn) total hardness. Calcium, magnesium and iron ions are the most common causes of Wet Steam Generator scale.

Iron concentrations should be held below 0.1 pprn to prevent scaling. If high silica levels are present in the feedwater lower concentrations may be required to prevent premature scaling.

A.2.2 TOTAL DISSOLVED SOLIDS (TDS)

Levels of TDS in Wet Steam Generator operation become a cause for concern only when liquid phase concentrations approach solubility limits. Therefore, a unit producing 80% quality steam should be able to tolerate feedwater dissolved solids in concentrations approaching 20% of their solubility limits. For example, sodium chloride levels of 60,000 pprn are possible. At extremely high TDS levels, control of corrosion producing oxidants and scale forming materials such as total hardness becomes critical.

The practical limitation on TDS generally comes as a result of water softener operating limitations. Most softening is done with cation resin exchange systems because of their reliability and simplicity of operation. Most softeners utilize salt regenerated sulfonate (strong acid) resins whose hardness leakage characteristics limit their operation to approximately 7000 ppm TDS. Recently developed weak acid resins are able to function at TDS levels up to approximately 30,000 ppm; however, both the capital and operating costs of these resins are several times that of the strong acid resins.

A.2.3 SUSPENDED SOLIDS

Suspended solids contribute to softener fouling and sludge formation. Filtration of the feedwater to reduce suspended solids levels below 5 pprn and preferably below 1 pprn is recommended.

A.2.4 OIL

Oil contributes to scaling adherence, film boiling and coking. Ion exchange resins are quite prone to oil fouling and tend to remove most feedwater oil at the expense of resin life. To minimize softener fouling a suspended oil content below 1 pprn is recommended.

A.2.5 OXYGEN

Oxygen is a corrosion accelerator. Oxygen exclusion, deaeration, and chemical scavenging can be used to maintain oxygen levels as low as possible. Recommended maximum oxygen residuals should be less than 0.01 pprn and preferable 0.0 ppm. In practice, a residual level of scavenging chemical is usually maintained.

A.2.6 ALKALINITY

Alkalinity is primarily the result of carbonates in the feedwater and may be influenced by addition of hydroxides and sulfites. Although excess hydroxide alkalinity can contribute to caustic embrittlement, moderate alkalinity levels help reduce corrosion and maintain silica solubility. Bicarbonate alkalinity levels of over 2000 pprn should be avoided due to excess hydroxide production.

A.2.7 SILICA

Control of silica problems in Wet Steam Generator systems consists primarily of maintaining solubility. Silica solubility is strongly affected by alkalinity. Alkalinity should be maintained at least three times the silica content. Satisfactory operations with silica contents of 150 pprn are possible in the absence of scaling ions.

A.2.8 PH

The pH level of feedwater is related both to its potential for acid corrosion and alkalinity. Acceptable operation has been obtained at pH values from 7 to 12. Lower values indicate possible acidic corrosion while values of 13 or above indicate excess hydroxide alkalinity with both caustic corrosion and caustic embrittlement possible.

APPENDIX B—WET STEAM GENERATOR EMISSIONS CONTROL

B.1 Flue Gas Emissions

Concerns regarding fired equipment emissions to the environment has resulted in changes to Wet Steam Generator systems. Equipment and design modifications are used to control these emissions. Concerns center on particulates, the oxide of sulfur and oxides of nitrogen.

B.2 Control of Particulates

Some methods of control are:

B.2.1 Wet electrostatic precipitators

B.2.2 Dry electrostatic precipitators

B.2.3 Venturi sections in conjunction with wet scrubbers

B.2.4 Bag house filters

B.3 Control of Oxides of Sulfur

Some methods of control are:

B.3.1 Use of low sulfur fuels

B.3.2 Treatment of high sulfur fuels to reduce the sulfur content

B.3.3 Wet scrubbing of flue gas to remove oxides of sulfur formed in the combustion process. Some types of wet scrubbing systems are:

a. Single-alkali process
   1. Caustic scrubbing
   2. Soda ash scrubbing
b. Double-alkali process

B.4 Control of Oxide of Nitrogen

Some methods of control include both physical and chemical techniques. These are:

B.4.1 Excess air control

B.4.2 Low oxides of nitrogen burners (low NOx burners)

B.4.3 Flue gas recirculation

B.4.4 Ammonia injection

B.4.5 Catalytic conversion

APPENDIX C—WET STEAM GENERATOR FUEL OIL

C.1

Most fuel oils being used in Wet Steam Generators must be conditioned to provide viscosities not exceeding 100 to 150 SSU at the burner. If oil must be heated, electric or steam-water heaters are commonly used. Manufacturer's recommendation should be consulted to determine the proper operating viscosity.

APPENDIX D—FACTORS FOR CONVERSION TO INTERNATIONAL SYSTEM OF UNITS (SI)

Customary Unit	API Preferred Metric Unit[1]	Conversion Factor (Multiply Quantity Expressed in Customary Units by Factor to Get Metric Equivalent)	
BTU/Hr.	kJ/h	1.055 056	E+00
BTU/SCF	kJ/m³	3.725 895	E+01
BTU/Lb	kJ/kg	2.326 000	E+00
BTU/Gal	kJ/m³	7.742 119	E-02
Lbs/Hr	kg/h	4.535 924	E-01
Lbs/Ft³	kg/m³	1.601 846	E+01
Lbs/1000 Bbl	g/m³	2.853 010	E+00
Gr/CF	mg/m³	2.288 352	E+03
Ft³/Lb	m³/kg	6.242 796	E-02
In/Yr	mm/a	2.54	E+01
MPH	km/h	1.609 344	E+00
CFM	dm³/s	4.719 474	E-01
PSI	kPa	6.894	E+00
"F	°C	(°F-32)/1.8	

[1]Based on API Publication 2564, Manual of Petroleum Measurement Standards Chapter 15-Guidelines for Use of the International System of Units (SI) in the Petroleum and Allied Industries, December 1980.

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