Biomass Gasification: A Comprehensive Demonstration of a Community-Scale Biomass Energy System

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Chapter 1: UMM Biomass Gasification System Standard Operating Procedures

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Standard Operating Procedures for Biomass Gasification Systems

The University of Minnesota, Morris has installed a biomass gasification system to heat, cool, and power the 2,000 student campus. The system is unique in that it is designed to operate with agricultural biomass feedstocks / fuels. Traditional fuels for gasification systems are well defined with known operating procedures. The engineering firm for the University, HGA, provided the initial standard operating procedures for the gasification system (Exhibit 1).

The purpose of Standard Operating Procedures (SOPs) as defined by the United States Environmental Protection Agency is to provide a set of written instructions that document a routine or repetitive activity followed by an organization. SOPs articulate technical, process, and programmatic information required for proper and safe operation of systems and the work of personnel. SOPs are generally considered to be a ‘work-in-progress’ and must be reviewed periodically to be effective. SOPs are used as a resource for staff during normal startup, operation, and shutdown as well as a quick reference for emergencies and troubleshooting.

Biomass gasification systems typically present additional challenges for operators considering the diverse feedstock types, forms, moisture levels, and other characteristics. The energy system operator not only needs to monitor and adapt to load / energy demand variables, but also must pay particular attention to the diverse and dynamic fuel requirements.

The UMM Biomass Gasification System Standard Operating Procedures are included as an exhibit to this chapter. The SOPs are a ‘work-in-progress’ and more will be added as operational knowledge and sequence / programming information is learned. UMM’s SOPs can be used as a reference in planning other community-scale biomass gasification systems - with the explicit understanding that all biomass gasification systems are unique and require individual SOPs. Important considerations for biomass gasification system SOPs include:

- Feedstock Type, Form, Moisture, and Quantity
- Control and Safety Systems Check
- Startup and Operating Parameters to Achieve Gasification
- Feedstock / Fuel Intake and Throughput within the Gasifier
- Air-Intake of Gasification Systems
- Energy Utilization / Load Requirements
- Emissions Monitoring and Mitigation
- Ash Removal from System, Storage, and Permitted Disposal
- Procedures for Shutdown including Short and Long-term Durations
- Maintenance of Downstream Equipment Including Boiler(s), Turbines, Etc
- Emergencies and Troubling Shooting
- Redundant Systems
- Access including Research, Public Tours, Training / Teaching

Additional information on SOPs can be found at [http://www.epa.gov/quality/qs-docs/g6-final.pdf](http://www.epa.gov/quality/qs-docs/g6-final.pdf)
Attached Operating Procedures

Updated by: Michael Reese and Lowell Rasmussen, University of Minnesota

1 System Configuration

Gasification, as we are using it, is a process of staged combustion that may more accurately be termed “pyrolysis”, in that we are partially combusting the stover in the gasifier, then completing the combustion of the released volatile gases with one of two over-fire air fans.

Campus loads peak between 28,000 and 30,000 lbm/hr but over 80% of the load could be handled with a gasifier generating 15,000 lbm/hr of steam. Generating 15,000 lbm/hr of high pressure steam will require approximately 3,400 lb/hr of stover at design conditions -- 0” F with 20% moisture by weight. System steam demand dips to 2,500-5,000 lbs/hr of steam in the summer. To shift more base energy use to this renewable energy system, summer steam demand will be increased by adding a steam driven chiller or steam turbine generator. Initially we envisioned a two-stage, high pressure absorber (125 psig steam) because of poor cycle efficiency associated with a condensing steam turbine generator. A preliminary study showed that a chiller would be more efficient and would directly offset more electrical demand and use than directly producing electricity.

The design was modified to generate 300 psig steam (instead of 125 psig steam) at a small efficiency penalty and generate electricity through a backpressure turbine with a single-stage steam absorber as a condensing device. The renewably produced electricity supplements wind energy currently supplied to the campus and complements the campus’s goal to be carbon neutral.

The UMM campus uses an estimated 7,000 to 9,000 tons per year of biomass (15% moisture). Under the University’s modified existing air permit, the system is limited to 9,000 tons per year. Peak days require about 36 tons of fuel. Depending on load density, this equates to three to five trucks per day. The test burns and an ultimate analysis showed the fuel contains 3.5% ash. On a peak day, the system generates about 1.5 tons of ash. Annually, 250-315 tons of ash will be generated. Dirt and non-combustibles add to the volume and mass of the ash waste stream. Ash dropping out of the gasifier is collected in a quench bin and transferred by screw to a covered belt conveyor. The quench bin was initially operated dry, but is now used for a water bath to condition and adjust the pH of the ash as required. The University will be performing studies to determine the feasibility and benefit of spreading the ash on the fields from which the stover was harvested, as well as exploring other uses for the ash. Ash disposal / removal is regulated by the Minnesota Pollution Control Agency (MPCA) and field application must have prior approval (for each feedstock).
Combusted corn stover contains HCl, about 19 lbm/hr at peak system load, or 66 tons per year. A wet scrubber was selected to remove HCl and particulate. NaOH is used in the scrubber spray to help neutralize the HCl (HCl + NaOH becomes NaCl + H₂O). The stoichiometric consumption of NaOH in HCl sequestration would be 3 to 4 gph of 50% NaOH at 100% steam output. The actual consumption is significantly less because HCl is soluble in water. A solution of 50% NaOH in water is pumped from a storage tank to the scrubber to maintain a pH in the scrubber quench water. A sand filter removes and concentrates particulate and other impurities from the scrubber. Operators manually blow down the sand filter based on filter pressure drop.

The gasifier is located on a lower operating level to simplify and shorten the fuel feed system. A drop into the gasifier feed bin avoids a fuel handling transition point to an elevator which eliminates one potential jamming area, minimizes required floor space and equipment, and reduces parasitic losses. The design basis for the fuel feed is uncut stover. A pair of spiked rollers loosens the fuel between the walking floor and an open, sloped stainless steel fuel feed bin to reduce the potential for fuel bridging. Following commissioning and considerable testing, it has been determined that uncut stover will not work within the system so several types of densified corn stover and other feedstocks were tested. Wood and corn cobs work well within the system. Additional information regarding the testing of various feedstock types and forms can be found in section I, chapter 3 and section II, chapters 5 and 8 of this report.

The biomass gasification system components and subsystems can be described in the order they are connected.

1. Fuel Handling System
2. Gasifier
3. Breeching
4. Heat Recovery Steam Generator (HRSG)
5. Continuous Emissions Monitoring System (CEMS)
6. Fly-Ash Collector (Multiclone)
7. Economizer
8. HX-1 Flue Gas Heat Exchanger (first pass)
9. Wet Scrubber
10. HX-2 Condensing Heat Exchanger
11. HX-1 Flue Gas Heat Exchanger (second pass)
12. Induced Draft Fan
13. Stack
14. Ash Removal System
15. Control System
2 System Overview

1. Fuel Handling System

a. Uncut stover was the design basis for the fuel handling system. Keeping fuel processing to a minimum reduces parasitic power loads at the plant, making the system more efficient. Keeping the fuel uncut and baled also reduces fire potential. When compared to uncut fuel, cutting the fuel into small pieces visibly increased flue gas particulate levels during test burns. At the time of design, it was determined any fuel size reduction would take place off site or with trailer mounted equipment.

b. Site work included water management with a water retention area behind the walking floor fuel loading area. Design work included studies on truck traffic patterns and turn around requirements. One design constraint was to limit truck traffic to the edge of campus. Routing fuel trucks along the road between the power plant and the athletic facility was prohibited.

c. The truck unloading system has hydraulic unit connections at each of the five stations along the walking floor. Fuel unloading stations for hydraulic walking floor trailers were designed so fuel trailers could add to the system storage capacity. Bale cutters were envisioned at each off-loading station, however, it was decided to commission the plant and test different forms prior to making additional capital expenditures.

d. The 65-foot walking floor was designed with a high wall in the back and a lower, four-foot wall in front. The lower front wall was intended to provide easy access to the walking floor from the back of a truck, and access to the pile for inspection and to clear problems in the fuel bin. A walking floor was selected over a chain drag because of its flexibility in handling different fuel stocks with different particle sizes. It also lends itself to a future side stream take-off of fuel for a future second gasifier. Late design revisions raised both walls to 8 ft. and added doors at each loading station, reflecting University personnel concerns about weekend storage capacity.

e. A metering wall restricts the volume of fuel that can enter the feed enclosure, to prevent over-packing the fuel.

f. A guillotine door at the top of the feed enclosure can be closed manually or, in the event of a fire, by fusible link.

g. Two spiked rollers at the feed end of the walking floor loosen the fuel and break up any bridging before the fuel drops into the feed chute.

h. The feed chute directs the fuel into the feed hopper of the gasifier by gravity. A cover over the chute provides personnel protection and contains dust and dirt.
i. High and low level switches control fuel hopper level. On a high level the walking floor stops, on a low level the walking floor restarts. Walking floor speed and on and off points are coordinated during operation.

j. Video cameras within the hopper can be viewed from the control room to monitor fuel and system status.

2. Gasifier

a. Fuel enters the gasifier by a hydraulic ram. A single ram is used instead of the manufacturer’s standard feed screw, due to observed problems with stover wrapping around screw shafts.

b. The gasifier chamber uses an oscillating grate to move the fuel from the top entrance of the gasifier to the ash discharge at the lower end. Fuel residence time in the gasifier determines the completeness of the burn and the quality of ash. Too much time in the gasifier and “clinkers” will develop. Too little, and the fuel will not be fully consumed.

c. Combustion Air

   i. The original specified loose corn stover fuel has about 23% of the oxygen required for combustion. This rate changes with different types and forms of feedstocks. Note: This affects the achievable quality of the producer gas.

   ii. Air enters the gasifier under the fuel through manually controlled dampers along the length of the gasifier. These dampers control the distribution of under-fire air, while the under-fire air fan (FD-1) controls the volumetric flow with a variable speed drive (VSD).

   iii. Fuel Gas Recirculation (FGR) has its own fan and is on a VSD. The FGR is used to control nitrogen oxides (NOx) and can be a back-up to FD-1. FGR is taken downstream of the scrubber, so the gas is both saturated with water and has less oxygen than air. This makes the fuel pile cooler, even though FGR air is warmer than under-fire air.

   iv. Over-fire fan FD2-1 is the first over-fire fan, and the standard fan provided by the gasifier supplier. FD2-1 is on a VSD and introduces combustion and cooling air at the top of the gasifier.

   v. Over-fire fan FD2-2 is the second over-fire fan, and is installed for operation and experimentation. It is located further downstream than FD2-1 to provide a more clear separation of combustion and potentially reduce NOx. FD2-2 is on a VSD and introduces combustion and cooling air that will complete combustion further downstream from the gasifier.

d. Gasifier ash screws are used to remove ash from the gasifier. The primary ash screw receives the majority of ash from the end of the gasifier and runs perpendicular to the gasifier airflow.
Two secondary screws collect ash upstream of the primary ash screw. A collecting screw and trough transfers ash from the primary and secondary ash screws and directs it to the external ash conveyor.

e. The fuel feed ram is operated by a hydraulic power unit (HPU) and solenoid valves. The ram is controlled by the programmable logic control system (PLC) to feed fuel into the gasifier at a rate proportional to the steam flow rate. The “home” or “park” position of the ram is fully extended so it acts as an airlock for the gasifier. The HPU is on emergency power ensuring the ram can return to the home position on any shutdown. The PLC is supplied with a battery back-up to ensure it can send a signal to the ram, and the solenoid valves can open to park the ram on any shutdown.

f. During normal operation, fuel in the hopper will restrict most airflow through the fuel bin, limiting “tramp air” introduction at this point.

g. A flash-back control system is installed at the ram inlet to extinguish any fires in the fuel feed bin. A temperature sensor located in the gasifier fuel feed opening senses a high temperature and sends a signal to the solenoid valve located indoors. The ground water/ city water piping is sloped from the solenoid valve location inside the building to the gasifier inlet to allow drainage after operation.

h. A retort cooler consisting of a water bath is installed at the ram inlet. The retort cooler’s purpose is to prevent distortion of the steel at the fuel input point. This cooler is manually filled to limit freezing problems.

i. Access openings at the ash end of the gasifier allow inspection when the unit is shut down.

j. Several viewports are located to allow observation of the gasifier at different points.

k. A camera port is installed at the ash end of the gasifier. The port is sealed with a gasket and tempered glass cover provided to prevent tramp air from leaking into the gasifier at this viewing point. An infra-red camera has been installed to view the temperature profiles within the gasifier.

l. A total of seven view ports are located in the gasifier and breeching upstream of the HRSG.

3. Breeching

a. The insulated and refractory-lined breeching from the gasifier to the HRSG will experience consistent temperatures of 1800° F. The refractory was selected by the gasifier supplier to specifically to stand up to the HCl and particulate in the flue gas. Airspaces and interior insulation between the gasifier and breeching reduce the surface metal temperature to about 160-180° F.
4. Heat Recovery Steam Generator (HRSG)
   a. The HRSG is an a-frame, water-tube steam generator with a mud drum, a steam drum and lower headers at the base of each water wall.
   b. Main and auxiliary level transmitters with high and low level alarms and a low level cutout (LLCO) are provided in accordance with code requirements.
   c. The main feed-water valve (MFWV) is a rotary valve with a class IV shutoff at 350 psig. An independent control module on the HRSG controls the MFWV with a two-element controller utilizing level and steam flow inputs.
   d. An angle-style gate valve and main isolation gate valve are located at the steam drum discharge main. A free-blow drain between the two valves terminates at the nearest floor drain. ANSI B31.1 typically requires the first valve to be a non-return valve; however the variable pressure operation may cause the valve to chatter at low flows and pressures. Rather than risk valve damage, a gate valve is used. Further, the HRSG minimum operating pressure of 70 psig is well above the 18 psig operating pressure of boilers B-1, -2, and -3, so there is no opportunity for reverse flow. Start-up procedures do not open this valve until the HRSG is at the minimum operating pressure.
   e. A surface blow-down valve located at the discharge end of the steam drum discharges into a flash tank and ultimately into the surface blow-down heat recovery cooler.
   f. Bottom blow-down piping includes two quick opening valves and one slow opening valve.
   g. A chemical injection port in the steam drum provides a direct injection point for boiler chemicals.
   h. Drains are located at each end of the mud drum.
   i. Two steam relief valves set at 325 psig with drip pan elbows relieve through the roof.
   j. A steam flow meter is located downstream of the second boiler main steam isolation valve.
   k. Two steam pressure gauges are on the main steam header. P-500 is wired to the PLC and used to control the gasifier firing rate. P-501, connected to the direct digital control system (DDC), provides a control signal to dictate feed system pressure.
   l. An independent control panel on the HRSG takes an input from the PLC and dictates operation of the three compressed air sonic soot-blowers. Soot-blowing is initiated by the PLC, but the soot-blower control panel controls actual sequencing.
      i. A compressed air receiver located underneath the boiler helps reduce the pressure transients on the compressed air system.
m. There are three ash bins on the bottom side of the HRSG. Each bin has a rotary airlock to separate flue gas from the ash. Because the HRSG is at a negative pressure, a small amount of air leaks into the HRSG as the air lock rotates.

n. One ash screw collects the ash from the three bins, while the other is set at 90 degrees to the first and transfers the ash to the conveyor in the pit area. Ash screws are totally enclosed, and accessible for maintenance.

5. Continuous Emissions Monitoring System (CEMS)

a. Immediately downstream of the gasifier is the Teledyne CEMS instrumentation. This is installed to continuously monitor CO, CO\textsubscript{2}, NO\textsubscript{x}, SO\textsubscript{2}, opacity, mass flow, wet and dry O\textsubscript{2} and percent moisture. Controls for the CEMS instrumentation are located in a cabinet on the west wall of the main level, with some auxiliary panels near the sensors in the breeching. This instrumentation was installed to continuously monitor the condition of gases leaving the combustion process, in order to monitor pollutants leaving the gasified fuel. The CEMS is not intended nor required for the purpose of stack emissions testing. Originally, two CEMS units were to be installed, but the stack monitor was removed to reduce project cost. Two stack ports located 90 degrees apart are located about 15 feet above the induced draft fan (ID) for the purpose of emissions testing.

b. Calibration and testing of the CEMS modules is detailed in the CEMS operating manuals and will not be repeated here.

6. Fly-Ash Collector (Multiclone)

a. Located downstream of the HRSG, just after the CEMS instrumentation, the multiclone fly-ash collector utilizes multiple cylindrical passages to remove particulate from the air stream through centrifugal force. There is no instrumentation tied into the PLC on the multiclone.

b. A manometer provides a visual measure of pressure drop across the ash collector.

c. Ash removed from the combustion air stream passes through the rotary airlock at the bottom of the multiclone and is transferred to the main ash conveyor through an ash screw.

7. Economizer

a. The fly-ash collector discharges into a flue gas economizer that recovers additional energy from the flue gas stream and preheats feed-water prior to entering the HRSG.

b. Design conditions for the economizer take entering feed-water from the deaerator at 227° F and raise it to 301° F, while flue gas enters at 550° F and leaves at 325° F. At full flow, 30 gal/min of feed-water is heated with about 32,000 lbm/hr of combustion gas.

c. The economizer has isolation valves, a bypass and a safety relief valve set at 350 psig.
d. Flue gas entering temperature is measured upstream of the economizer between the ash collector and the economizer. The PLC controller monitors flue gas temperature entering and leaving the economizer.

8. HX-1 Flue Gas Heat Exchanger

a. A heat exchanger is used to cool flue gases leaving the economizer prior to entering the scrubber. This reduces the amount of quench water that must be added to the system upstream of the scrubber.

b. The cooling stream for HX-1 is flue gas leaving the scrubber and HX-2.

9. Wet Scrubber

a. A wet scrubber puts flue gas and water in the same flow stream to collect particulate and HCl from the flue gas, reducing pollution.

b. The scrubber water comes from an open loop system consisting of piping, a pump which takes suction from a storage volume of water in a feed tank, and the spray nozzles in the breeching and scrubber. Portions of the system water are evaporated into the flue gas stream, cooling the gas. A sodium hydroxide-and-water mixture neutralizes HCl in the flue gas while particulates are absorbed into the water stream and filtered out.

c. Quench water is sprayed into the breeching upstream of the scrubber. With the gasifier supplier’s design, water is intentionally over-sprayed and circulated through the scrubber. Water is separated from the airstream in the scrubber and in HX-2, carrying with it particulate and NaCl from the neutralization of HCl.

d. The scrubber performance is guaranteed by the gasifier supplier to remove 95% of the HCl and 85% of the particulate. This will be verified under normal operating conditions when both the CEMS and stack emissions test are performed at the same time.

e. A discharge fan located at the top of the scrubber offsets scrubber pressure drop. This fan follows ID fan speed and has its own VSD.

f. A float level controller in the make-up tank maintains tank water level.

g. NaOH concentration in the scrubber water system is controlled with a pH sensor.

h. NaOH is fed into the system via a double wall pipe routed from the 2,000 gallon NaOH storage tank. The inner wall of the tank is vented to the outdoors near the fill station. The outer wall of the tank is vented into the space. The double wall pipe has a telltale drain/site glass to indicate a leak in the fill piping. The double wall tank has a sensor to detect water/NaOH between the inner and outer walls.
i. The NaOH feed pump has a relief valve/bleed path that prevents the pump from being deadheaded. This pump is started manually and runs continuously during gasifier/HRSG operation per the gasifier supplier’s design.

j. A sand filter removes particulate from the scrubber water system. A differential pressure gauge tied into the PLC control system warns the operator of high pressure drop across the sand filter. Upon receiving this alarm, operators can cycle a manual blow-down valve to reduce pressure drop. Sand filter blow-down discharges into the sewer system. This effluent including some ash and NaCl was discussed with city personnel during the design process and can be discharged to drain without local processing.

10. HX-2 Latent Heat Removal Exchanger

a. Downstream of the scrubber is a heat exchanger/moisture separator intended to remove some of the water and particulate from the flue gas prior to the stack discharge.

b. Removing condensate helps remove particulates from the air. The condensate from HX-2 returns to the scrubber tank where the sand filter removes particulates from the water.

c. HX-2 also reduces the visible plume leaving the system.

d. HX-2 is city water cooled. Approximately 10 gal/min at 60°F will condense out the required moisture and particulate.

i. To reduce wasted water, HX-2 effluent serves two make-up water loads: scrubber make-up (30-40%), and boiler make-up (30-50%) via the plant softener. The remainder discharges to storm drains.

ii. A control valve modulates the flow in order to dump to drain only the amount of water required to maintain HX-2 effluent at 100°F.

iii. Ultimately, city water will be replaced by groundwater to reduce city water usage.

iv. Cooling tower make-up is a possible future use of dumped water, also.

11. HX-1 Flue Gas Heat Exchanger

a. This is the second time flue gas passes through HX-1 as described above. HX-1 reheats the effluent flue gas stream prior to discharge, pulling it away from saturation, and thus reducing the visible plume.

12. Induced Draft Fan

a. The ID fan is a single width, single inlet, belt-driven fan discharging directly into the stack. This fan, located on the mezzanine level, is driven by a VSD and is controlled to maintain -0.5 inches
water glass in the gasifier chamber. This fan takes up the majority of the pressure drop from the duct breeching system, and is assisted by the scrubber fan and stack effect.

b. A fan drain is piped to sanitary to remove any water that makes it through the stack drain system.

13. Stack

a. The 24-inch, stainless steel, double wall stack discharges effluent flue gas straight out of the system, discharging 60 ft. above grade. The high velocity discharge is at this elevation for local pollution abatement, to prevent flue gas from dropping down to the ground level.

b. Sample ports 90° apart are installed at a level approximately 10 ft. above the roof. A catwalk facilitates access to these ports. Convenience electrical outlets installed at the stack are for emissions testing equipment.

c. A stack inline drain discharges into the building sanitary system to prevent rainwater from accumulating in the stack.


a. The PLC controls the ash removal system, which collects ash from the gasifier, HRSG and fly-ash collector. A drag chain conveyor lifts the ash approximately 25 feet and drops it into an ash hopper and trailer outside the building. The entire system is enclosed to limit ash dust problems.

b. The weight of the ash is determined by subtracting the weight of the empty hopper and trailer from the total weight. The ash is then disposed or land applied according to the provisions allowed within the MPCA permit.

c. The PLC control system sets the VSD speed serving the drag-chain ash conveyor motors to a speed proportional to the system power output.

15. Control Systems

a. The PLC controller manages all gasifier functions, fan operations, and HRSG operation.

   i. Sequences are described by the gasifier supplier.

   ii. Some of the following sequences may be combined under a single command.

b. Emergency shutdown buttons located at three entrances to the gasifier pit allow manual emergency shutdown of the gasifier.

c. HVAC and boiler feed system functions are controlled by the DDC building automation system.

d. A data historian is used to record all gasifier parameters available through the PLC.
16. Fire Protection System  
   a. Inside lower level, operating floor and mezzanine are served by a wet sprinkler system. High temperature heads are located in the area of the gasifier breeching, HRSG and discharge duct breeching.
   b. The gasifier level floor area is served by a dry-pipe deluge system with a double interlock valve requiring signals from both a heat detector and smoke detectors. A dry pipe system was selected because of freezing conditions in the pit area during the winter. A deluge system was chosen because sprinkler heads located near the ceiling may not detect a fire at the floor level. Heat detection is used because of the potential for dust or dirt from the outdoors setting off a smoke detector. Heat detection was added at two levels, the 13 ft. level to detect lower fires and the roof level to detect a roof fire.
   c. The fuel feed / walking floor area is served by a second dry-pipe deluge system with double interlock valve requiring signals from both a heat detector and smoke detectors. Justification is similar to that above, except the detectors are only a few feet above the fuel pile. A deluge system is selected because of the potential for a fast developing fire in the fuel storage area.
   d. The walking floor will back fuel away from the building on the combined signal from smoke and heat detection in either the walking floor or the pit area.
   e. The gasifier will shut down on the combined signal from smoke and heat detection in either the walking floor or the pit area.

17. Operating Sequences  
   a. Sequences and operating parameters vary with the type and form of feedstocks. Through testing, operation and research staff will continue to develop protocols for each type, form, and individual characteristics (moisture, etc.) of a diverse group of feedstocks.

3 Startup (Cold Start)

1. Normal system start-up and operation prerequisites  
   a. Fire Protection Systems  
      i. No fire alarms actuated.
      ii. Smoke detectors on line with no smoke detectors tripped.
   1. It may be permissible to start with a smoke detector in the fuel bin area or gasifier operating area tripped, provided the unit is checked, cleaned and
functioning properly, the cause is known to be dust or dirt, and all heat detectors are working properly. Understand in this case, even a spurious heat detector trip would cause the deluge system to operate, soaking the operating area.

iii. Heat detectors on line with no heat detectors tripped.
iv. Deluge valves working properly and closed.
v. Fire protection water post indicating valve (PIV) open, with water pressure available to the facility.
vi. Stairway and egress doors closed but not locked, to allow escape from operation area.

b. Compressed Air
   i. Compressed air available with at least 90 psig pressure.
   ii. Instrument air available with at least 80 psig pressure downstream of the air dryer.

c. Electric Power
   i. Normal power available.
   ii. Emergency generator has fuel and is in standby, available to come on line on loss of power.
   iii. Control power available.
   iv. Battery back-up uninterruptable power supply (UPS) available to PLC controller.

d. Controls
   i. PLC in operation on UPS.
   ii. DDC system in normal operation or feed system in manual operation.
   iii. All alarms cleared.
   iv. All equipment controls are in automatic, except where manual control is required or desired.
   v. All motors starters and VSDs in auto position, except where manual control is required or desired. The following table shall be used for a check list of equipment in automatic control and those being manually controlled for the start-up.
### Table: Equipment and Motor Specifications

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<th>Motor Tag</th>
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e. Steam System

i. It is preferable to start-up the gasifier with a gas-fired steam boiler available and on line. This will allow heat up of boiler water and limit condensation and potential corrosive gas condensation in the HRSG.

ii. At least one gas boiler should be in operation or hot standby.

iii. A minimum steam load of 3000 lb/hr available or will be available at start-up.

1. If steam system heat-up is to begin with HRSG start-up, immediate load is not required. However, the benefits of starting the system into a hot steam system are noted above.

iv. The pressure reducing station is in operation, or the backpressure turbine is ready for operation.

v. All relief valves available for operation.

vi. Valve positions are shown for beginning of start-up of HRSG, operation with the HRSG, and operation independent of the HRSG.

vii. Place all steam, feed and condensate valves in position according to start-up valve line-up table (see following pages).

1. Existing plant valve positions are not listed, as this depends on boilers in operation at time of start-up.

2. Abbreviations used in valve line-up table are as follows:

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<th>Abbreviation</th>
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* - As required for plant operations
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f. Boiler Feed System
   i. Valve line-up in accordance with valve schedule above.
   ii. Condensate system is operational.
   iii. Deaerator at normal operating level.
   iv. Make-up water is available to the deaerator.
   v. Emergency feed pump and at least one normal power feed pump available.
   vi. Boiler feed pressure reducing station on line and functional.
   vii. Initial boiler feed pressure at 40 psig to feed gas plant only.
   viii. Surface blow-down/ feed-water preheater heat exchanger is on line.
      1. Alternatively, surface blow-down heat exchanger is bypassed at the boilers and diverted to bottom blow-down cooler.

g. As a minimum, the following system sensors calibrated and in operation:
   i. HRSG steam pressure sensor
   ii. HRSG steam flow meter
   iii. Oxygen sensor

h. CEMS system in operation
   i. As a minimum, the opacity sensor fans are in operation to protect the equipment.
   ii. CEMS cabinet operational.
   iii. Air conditioner operational.
      1. Cabinet in normal operating temperature range.
   iv. Umbilical sample line
      1. Heat tracing operating.
      2. Umbilical line up to temperature.
   v. Instrument air is available to CEMS.
   vi. Power available to CEMS.
   vii. Sample cooler operational.
   viii. Remote calibration gas panel available.
   ix. Verify calibration gases are available.
Chapter 1: Standard Operating Procedures

1. NOx
2. O₂
3. CO
4. CO₂
5. SO₂

i. Fuel Feed System
   i. Verify fuel available for operation period anticipated and initial charge of fuel is on walking floor.
   ii. Additional fuel trailers on site or scheduled to arrive in time to support continuous gasifier operation.
   iii. Two hydraulic power units for walking floor are in operation.
   iv. Fuel in hopper to the high operating limit switch.
   v. Guillotine door open.
   vi. Metering wall set at desired height for fuel being used.
   vii. All access and safety doors closed and latched. All limit switches confirming access doors are closed.
   viii. Power is available to both spiked rollers, and both rollers in operation, except where fuel does not require spiked roller operation.

j. Gasifier
   i. ID fan operational.
   ii. FD-1 operational.
   iii. FD2-1 operational (Note only one FD-2 is required for operation; both are desirable).
   iv. FD2-2 operational (Note only one FD-2 is required for operation; both are desirable).
   v. Ram HPU available.
   vi. Control panel energized.
   vii. Flashback water available with solenoid and temperature switch energized.
   viii. Retort cooler water bin filled to normal operating level (NOL).
ix. Ash gate operational with IA to operator.

x. Normal fuel level in feed bin.

xi. Camera port sealed off.

xii. Inspection ports closed and bolts torqued to specifications.

xiii. PLC powered.

xiv. Power to control panel.

k. HRSG

i. Initial start-up, boil-out and checks completed.

ii. HRSG closed out and all man-holes torqued to manufacturer’s specifications.

iii. Water at normal operating level

   1. Main LLA clear
   2. Aux LLA clear
   3. HLA clear

iv. Manual feed water valve (MFWV) on line and in automatic control.

v. Soot blowers available for operation.

vi. Ash hopper access ports closed, bolted and torqued to specifications.

vii. Pressure transmitter has power and is not isolated from boiler steam drum.

viii. Boiler chemical and chemical make-up pump available.

ix. Steam stop valves closed.

x. Steam drum vent open.

xi. Feed-water chemistry:

   1. Dissolved oxygen at deaerator < 7 ppb.
   2. pH > 7.
   3. Hardness 17 ppm as CaCO₄.
   4. Total suspended solids (TSS) = 0.
   5. Oil and organic matter = 0.
xii. Boiler water chemistry in normal operating specifications.
   1. Alkalinity 100-250 ppm as NaCO₄.
   2. NaPO₄ = 30-60 ppm excess disodium phosphate.
   3. Cl- < 500 ppm.
   4. pH 11-11.5
   5. Oil and organic matter = 0.
   6. Total solids (TS) < 3500 ppm.
   7. Silica < 50 ppm and < 1% TS.

xiii. Bottom blow-down cooler available or cooling water to cool blow-down available.
   1. It is possible, but not desirable, to operate without bottom blow-down for a limited time if it is known the blow-down cooler will become available within <8 hrs.

xiv. Surface blow-down cooler/ feed-water pre-heater available or cooling water to cool blow-down available.

xv. Ash screw covers are locked in place.
   1. Number and confirm by segment.

xvi. Power to ash screws (2).

xvii. Power to rotary air locks (3).

I. Ash Collector / Multiclone
   i. Power to ash screw.
   ii. Power to rotary air lock.
m. Economizer
   i. Economizer valves lined up to place economizer in operation.
   ii. Economizer bypass closed.
   iii. Economizer relief valve is operational and closed.

n. Scrubber
   i. Scrubber quench water at normal operating level.
   ii. Scrubber make-up water available.
   iii. Scrubber fan available in automatic to track ID fan speed.
   iv. Sufficient quantity of NaOH available in storage tank.
   v. Scrubber pumps operational.
      1. NaOH Pump
      2. Quench Water pump
      3. Sand Filter circulation pump
   vi. Scrubber controls available through PLC.
   vii. Sand filter blown down and on line.

o. HX-2
   i. Cooling water valves opened.
   ii. Dump valve controls in automatic on PLC.
   iii. Water temperature transmitters on line and available.
      1. Alternatively, the flow may be manually controlled on a temporary basis. (This may mean more water than necessary is used, or insufficient condensation in HX-2.)
   iv. Valve line-up for HX-2 completed, allowing make-up to scrubber and boiler, as well as dumping water to drains.

p. Ash Collection System
   i. Ash hopper with available capacity staged and ready for operation.
   ii. Ash screws
      1. Tensioners installed and rotational checks completed.
2. Power is available to gasifier primary ash screw.

3. Power is available to (3) gasifier secondary ash screws.

iii. Power to chain drag ash conveyors.

1. Lower conveyor

2. Upper conveyor

iv. Covers installed on all ash conveyors, except as required for observation.

1. Verify by segment that conveyor covers are in place.

2. Outdoor ash chute cover is in place.

3. Ash hopper cover is in place.

q. HVAC & Plumbing

i. Ventilation unit is available for summer operation.

ii. Unit heaters available with LP steam header warmed up and on line.

iii. Pressure control dampers are available.

iv. Groundwater sump pumps operational with float switches working properly.

v. Sanitary lift station pumps operational with float switches working properly.

vi. Roof drains not plugged.

2. Boiler warm-up

a. Throttle open steam plant cross-connect valve V-257 to warm up low pressure steam piping with low pressure steam from gas plant.

b. When steam pressure in low pressure steam piping is steady at 18 psig, fully open V-257.

c. Throttle open pressure-reducing station bypass valve V-244A, admitting low pressure steam into the heating plant steam header to heat the system to 250° F.

d. Open mud drum heating coil isolation valve to warm up boiler. It may take up to two days to complete this HRSG warm-up.

e. As steam begins to pass through steam drum vents, close vents.
f. When HRSG steam side is at 15 psig,
   
i. Commence gasifier flame initiation and warm-up.
   
   Notes:
   
   1. *Heat up the HRSG prior to running on a solid fuel.*
   
   2. *The mud drum heating coil will be used on any cold start of the system.*
   
   ii. Close the mud drum heating coil steam isolation valve.
   
   iii. Shut the condensate valve at the low pressure return (LPR) header.
   
   iv. Open and leave open the strainer blow-down valve (upstream of the trap).
   
   1. *The coil will dry out with boiler operation. This will not hurt the coil.*

3. System flame initiation / HRSG warm-up

   a. Start ID fan on low speed stop.
   
   b. Gasifier operation can be initiated by manually igniting biomass fuel, accessing through inspection port at the ash end of the gasifier.
   
   c. Start under-fire air fan at low speed.
   
   d. As flame develops, slowly feed fuel into gasifier, controlling gasifier temperature with FD-1 until fuel bed temperature is 700° F.

      i. Bring gasifier and breeching slowly up to temperature in accordance with the time constraints shown in the following graph.

      ii. This graph shows a 45° F/hr limit on refractory heat-up rate.

      iii. Take the actions outlined below at key temperatures and events during the warm-up.
1. As steam begins to pass through HRSG steam drum vents, close vents.

2. All subsequent references to gasifier temperatures are taken downstream of FD2-2, at TT230-3. Either or both FD2-1 and FD2-2 can be used for the start-up. With only FD2-1 operating, TT230-3 should closely track TT230-2.

3. At 250° F HRSG entering temperature:
   
   a. Close mud drum heating valve.

   b. Close V-244A, pressure reducing station bypass valve.

   i. This is to avoid over-pressurizing the low pressure steam system. HP steam header may temporarily lose pressure.
ii. As HRSG pressure rises above steam header pressure, steam header can be pressurized by the HRSG, but only after main steam valves are opened. Since EBT requires 70 psig minimum HRSG operating pressure, steam non-return valve is not opened until HRSG pressure reaches 70 psig.

c. Slowly open the angle-style gate valve to heat piping between boiler isolation valves.
   i. Note this valve is not a non-return valve as is customary in this location. HP boiler inspector approved the use of a gate valve to address EBT’s concern of non-return valve chatter at lower operating pressures, when the valve is selected for 280 psig.

   ii. Minimum HRSG operating pressure is 70 psig and all other boilers on the system are 18 psig, there is no opportunity to feed steam back into the HRSG even in standby, if these procedures are followed.

d. Close the free-blow drain valve when clear steam issues from discharge point.

e. Override boiler feed pressure to 90 psig to allow for boiler feed as system continues to heat up.

   i. Feed pressure is controlled by a steam pressure transmitter located downstream of the HRSG main steam stop.

f. Turn on scrubber fan.

g. Initiate scrubber quench water flow.

   i. Turn on NaOH Pump.

   ii. Place Quench water pump in “AUTO”, or “ON” from PLC control panel.
iii. Start sand filter circulation pump.

h. Place HX-2 dump valve in auto, to control HX-2 leaving water temperature to 100° F.

4. At about 310° F HRSG entering flue gas temperature, HRSG pressure will begin to approach 70 psig.

5. At 70 psig steam pressure, hold gasifier system temperature until steam system is stabilized:

   a. Throttle open remaining HRSG main steam isolation valve and allow steam piping to continue heating up.

      i. **Boiler pressure will drop, and recover over some time period.**

   b. Fully open HRSG main steam valve when steam system heat-up is complete.

   c. Open pressure reducing station discharge valve, allowing the HRSG to serve the steam load. This should force the operating boiler into standby as soon as the HRSG can handle the load.

      i. **With pressure stabilized, the boiler is on line with potentially no load.** Although the system is still heating up, to an operational temperature of about 415° F (for operation at 280 psig), if there was no flow on the system, HRSG entering flue gas temperature and leaving flue gas temperature would be roughly the same. Refractory warm up cannot continue without a load on the system, or the economizer and downstream components will overheat.

      ii. **The gasification system cannot achieve full output until a few hours after the refractory is up to temperature.**

   d. Continue gasifier heat-up, monitoring economizer leaving temperature and not allowing it to exceed 370° F. Start FD2-1 or FD2-2 to limit flue
gas temperature downstream of economizer to 370° F. *(Design temperature is 363° F.)*

6. At 500° F HRSG entering flue gas temperature, start FD2-1 on low speed set-point if not already started. Increase FD2-1 speed if necessary to hold system to heat up schedule and maintain.

7. At approximately 700° F in the fuel pile, back-off under-fire air to its minimum set-point. If temperature rises downstream of FD2-1 (or FD2-2), gasification is occurring and combustion is being completed at FD2-1 (or FD2-2). Control FD2-1 (or FD2-2) to limit the worst case of HRSG entering temperature schedule and economizer leaving temperature to 363° F.

8. Switch to automatic gasifier control at 1500° F and a reliable steam load is being served. Eight more hours of heat-up are still required.

9. At about 1350° F at TT230-1, spontaneous combustion is possible in all un-combusted gas. Controlling the TT230-2 or TT230-3 at or below 1800° F provides enough excess air to maintain complete combustion of the gases.

e. When easifier and HRSG are up to operating temperature and system is in automatic control, set steam pressure set-point at the desired pressure as follows:

   i. With no absorption chiller and no backpressure turbine generator, set steam pressure to 70 psig.

   ii. With backpressure turbine available, set steam pressure to 280 psig.

f. Switch boiler feed pumps (BFP) to automatic control.

   i. Boiler feed pumps will operate in accordance with operating steam pressure.

   1. Gasifier not in operation:

      a. Steam pressure=18 psig,
      b. BFP at 40% speed,
      c. 40 psig feed header pressure,
      d. Maximum flow through 1 BFP = 53 gpm.
2. Gasifier in operation:
   a. Steam pressure = 70 psig,
   b. BFP at 55\% speed,
   c. 90 psig hp feed header pressure,
   d. Maximum speed through 1 BFP = 60 gpm.

3. Gasifier in operation:
   a. Steam pressure = 280 psig,
   b. BFP at 100\% speed,
   c. 310 psig hp feed header pressure,
   d. Maximum speed through 1 BFP = 75 gpm.

g. Start CEMS gas sampling.
   i. Follow CEMS manufacture start-up instructions.

h. Sample chemistry when system warm-up is complete and adjust if necessary.

i. Observe and maintain the operating temperature profiles as shown in the schematic diagrams.

j. Monitor ash condition and adjust gasifier grating speed to maintain complete combustion without developing clinkers.

4. Shutdown

1. System Shutdown

   a. **Short term shutdown**: A short term shutdown assumes the gasifier will be left hot, in the “low fire maintenance” or “smolder” mode.

   b. This shutdown is used when the system will brought back on line within 12-18 hours. In this mode, a small amount of fuel is added and ash is periodically removed, to allow gasifier mass to keep the chamber hot. The main steam stop (MSS) is left open until the ID fan is stopped. This allows steam to escape and prevent build-up of energy in the HRSG. It may also be necessary to track flue gas temperatures downstream of the economizer. When the MSS is closed in this option, and possibly before, FD2-1 or FD2-2 must be used to maintain flue gas temperature at or below saturated steam temperature entering the HRSG which is also the temperature of
water leaving the economizer. As the gasifier cools down, immediate restart becomes less possible without a planned warm-up time. Fuel does not need to be completely consumed, however, care must be exercised to prevent storing a large amount of damp and loose fuel on the walking floor, as it could spontaneously combust. It is assumed that the short term shutdown is a planned event.

A short term shutdown can be used for longer periods, however, the system will cool down to the point where immediate recovery is not possible and a modified start-up procedure is required to heat-up the gasifier before full capacity can be achieved.

c. **Manual initiation of short-term shutdown**
   i. Consume most of the fuel supply from walking floor, leaving amount estimated for the shutdown period.

   ii. If steam use will continue during shutdown period, a gas fired boiler must be operating in hot-standby, prepared to take the load.

   iii. Stop fuel feed; leave the ram in the “home” position (fully extended).

   iv. Load will naturally transfer to gas boiler as low pressure (LP) steam pressure drops downstream of the reducing station leaving pressure.

   v. Shutdown FD-1.

   vi. Stop FGR fan if operating.

   vii. Then stop FD2-1 and FD2-2.

   viii. Stop the scrubber fan.

   ix. Stop the NaOH pump.

   x. Stop the quench water circulation pump.

   xi. Stop the sand filter circulation pump.

   xii. Perform a boiler soot-blowing sequence.
xiii. Stop HRSG ash handling screws and rotary air locks after soot blowing sequence is completed.

xiv. Stop HRSG ash handling screws and rotary air locks.

xv. Stop fly-ash collector ash handling screws and rotary air lock.

xvi. Fuel on the grate will slowly burn down in this low fire maintenance (“smolder”) mode. Feed fuel periodically to maintain a slow burn rate, to keep gasifier warm.

xvii. Leave ID fan running at preset “low fire maintenance speed” to pull gases through the system and cool chamber for approximately 1 hour.

1. Low fire maintenance mode ID fan speed: 15%. (Minimum speed stop.)

xviii. Stop the ID fan.

xix. Close the main steam stop valve.

_The main steam stop (MSS) is left open until the ID fan is stopped. This allows steam to escape and prevent build-up of energy in the HRSG. It may also be necessary to track flue gas temperatures downstream of the economizer._

_When the MSS is closed in this option, and possibly before, FD2-1 or FD2-2 must be used to maintain flue gas temperature at or below saturated steam temperature entering the HRSG which is also the temperature of water leaving the economizer._

_It may be preferable to operate in this condition with the MSS open, and FD2-1 and FD2-2 shut down._

xx. Align steam and condensate valves in accordance with valve line-up “HRSG offline” column.
d. **Automatic Initiation of Short Term Shutdown**

*Note: the gasifier supplier has not provided any sequences or operating procedures to date. This is the anticipated sequence, should such a sequence exist. This must be confirmed and completed by the gasifier supplier.*

1. Select “low fire maintenance mode” on PLC control panel. Close the main steam stop on the HRSG upon initiation of this low fire sequence.

2. Under-fire air fan will stop.

3. FGR fan will stop.

4. ID fan will remain in operation at low speed for a period of 60 minutes.

5. Fuel feed will continue on an intermittent basis to keep gasifier warm.

6. FD2-1 or FD2-2 will operate if necessary to keep temperature entering HRSG down to 370°F, the maximum economizer leaving temperature.

7. Perform a boiler soot-blowing sequence.

8. Stop HRSG ash handling screws and rotary air locks after soot blowing sequence is completed.

9. Ash screws will operate periodically to prevent ash build-up in gasifier.

10. Gasifier grating will operate slowly to prevent ash build-up in gasifier.

11. Scrubber fan will stop.

12. Scrubber quench water will stop.

13. Scrubber filter pump will stop.

14. Fly-ash collector rotary air lock will stop.
15. Fly-ash collector ash screw will stop.

16. HRSG rotary air locks will stop.

17. HRSG ash screws will stop.

The main steam stop (MSS) is left open until the ID fan is stopped. This allows steam to escape and prevent build-up of energy in the HRSG. It may also be necessary to track flue gas temperatures downstream of the economizer.

When the MSS is closed in this option, and possibly before, FD2-1 or FD2-2 must be used to maintain flue gas temperature at or below saturated steam temperature entering the HRSG which is also the temperature of water leaving the economizer.

It may be preferable to operate in this condition with the MSS open, and FD2-1 and FD2-2 shut down.

18. Align steam and condensate valves in accordance with valve line-up “HRSG offline” column. Auxiliary valves can remain in HRSG operating condition.

5. Restart

1. Restarting after a short term shutdown
   a. If shutdown period was greater than 18 hrs or chamber temperature (TT230-1) is less than 1000°F, the system must be reheated at a rate not to exceed 90°F per hour.
      i. Re-feed walking floor fuel bin for anticipated operating period.
         Note: Some of the following steps may be initiated by the gasifier supplier control panel.
      ii. Start ID fan and purge system for 2 minutes.
      iii. Start the scrubber fan. Scrubber system is started before gasification is reinitiated when starting a warm plant.
      iv. Start the NaOH pump.
      v. Stop the quench water circulation pump.
      vi. Stop the sand filter circulation pump.
vii. Start over-fire air fan FD2-1 and/or FD2-2. *Starting over-fire fans before under-fire fan on a warm start-up ensures complete combustion of any gasified fuel.*

viii. Open the main steam stop valve.

ix. Start under-fire air fan FD-1.

x. If warm-up is required, control FD-1 to limit warm-up rate to 45° F/hr. *Refractory warm up is limiting factor. Bed temperature shown for comparison.*

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2. **Long term Shutdown**

   a. **Long term shutdown:** A long term shutdown is used to shut down the gasifier for longer periods and cool the system down for maintenance. This shutdown is used when the system will not be brought back on line within a day or two. Fuel should be completely consumed or removed from the storage area during a long term shutdown, to reduce the possibility of fuel fires. This procedure assumes that the long term shutdown is a planned event.

   i. If steam use will continue during shutdown period, a gas fired boiler must be operating in hot-standby, prepared to take the load.

   ii. Reduce high pressure steam (HPS) loads by shutting down HPS equipment.
iii. With walking floor empty, shut guillotine door.
iv. Stop addition of more fuel to walking floor.
v. Consume or remove fuel supply from walking floor.
vi. Consume or remove fuel from feed chute.
vii. Consume or remove fuel from feed ram.
viii. Stop fuel feed; leave the ram in the “home” position (fully extended).
ix. Let fuel burn out on gasifier grate.
x. Load will naturally transfer to gas boiler as LP steam pressure drops downstream of the reducing station leaving pressure.
xi. Shutdown FD-1.
xii. Stop FGR fan if operating.
ixiii. Stop the scrubber fan.
ixiv. Stop the NaOH pump.
ixv. Stop the quench water circulation pump.
ixvi. Stop the sand filter circulation pump.
ixvii. Perform a boiler soot-blowing sequence.
ixviii. Stop HRSG ash handling screws and rotary air locks after soot blowing sequence is completed.
ixix. Stop Multiclone ash collector ash handling screws and rotary air lock.

Note: Cooldown rate should be limited to warm-up rate of 45° F/hr to protect refractory.
xx. Continue to operate FD2-1 or FD2-2 to maintain economizer leaving temperature TT521-2 at or below 370° F.
xxi. When TT230-3 is less than 360° F, FD2-1 and FD2-2 can be shut down.
xxii. As flue gas temperature entering the HRSG (TT230-3) reaches 310° F:
   1. Shut both main steam stop valves.
   2. Open the free blow drain.
   3. Align all valves in accordance with the “HRSG (B4) offline” column.
xxiii. Leave ID fan running at low speed (15%) to pull gases through the system and cool chamber for approximately 24 hours.
3. Alarm and Emergency Control

1. Alarm and Emergency Control Sequences

   a. The following alarm conditions require operator action, but do not require a complete plant shut-down. Operator actions are summarized.

      i. Loss of scrubber fan

      ii. Loss of FD1

         1. Go to low fire mode.
         2. Switch to FGR.
         3. Shut-down if cannot maintain operating conditions, or FD1 not recoverable for extended period of time.

      iii. Loss of FD2-1

         1. Switch to FD2-2.
         2. Switch control sequence to operate on FD2-2 and TT230-3.

      iv. Loss of FD2-2

         1. Switch to FD2-1.
         2. Switch control sequence to operate on FD2-1 and TT230-2.

      v. Boiler feed pump (BFP-1 or BFP-2) failure.

         1. Back-up feed pump comes on line automatically.
         2. Loss of BFP on emergency power (BFP-3) requires a shutdown.

      vi. Low HRSG water level.

         1. Shutdown if plant-wide water problem exists (deaerator also low, make-up water not available).
         2. Shutdown can be avoided if action can be taken to restore level and LWCO can be avoided.
         3. Identify and correct feed problem.

            a. MFWV malfunction-

               i. manually control MFWV through PLC.
               ii. bypass MFWV and take manual level control.
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b. Level detector malfunction-
   i. manually control MFWV through PLC.
   ii. bypass MFWV and take manual level control.
   iii. Repair level controller.
c. Check feed and condensate valve line-up.

vii. High HRSG water level.
   1. Immediately blowdown boiler into proper level.
   2. If backpressure turbine is installed, an additional high HRSG level cutout will force an emergency shutdown.

viii. Low fuel in feed hopper.
   1. Unclog fuel delivery system.
   2. Loss of fuel.

ix. High fuel in feed hopper.
   1. If fuel feed system appears to be responding, allow it to reestablish proper level control.
   2. Monitor fuel feed system so fuel does not become compressed in feed hopper.

x. Low hydraulic fluid pressure walking floor.
   1. Identify and repair leak or other hydraulic pressure problem.
   2. If system can continue to deliver sufficient fuel, schedule a short term shut down and repair hydraulic system problem.
   3. If fuel feed system cannot keep up, perform a short-term shutdown.

xi. Low hydraulic fluid pressure gasifier step grating.
   1. Shutdown if grating system cannot keep up with steam load.

xii. Ash system overload.
   1. Shutdown if ash system cannot be recovered in 45 minutes.
   2. Perform a soot-blow cycle after ash system is restored.

xiii. Ash conveyor failure.
   1. Alarm is received at PLC.
2. 45 minutes to correct problem and reset timer.

3. Correct or shut-down in 45 minutes.

xiv. Ash screw failure.

1. Alarm is received at PLC.

2. 45 minutes to correct problem and reset timer.

3. Correct or shut-down in 45 minutes.

xv. High level in boiler.

xvi. Smoke detected in gasifier area.

xvii. High temperature in gasifier bed (> 900°F).

1. Alarm - shutdown not required; reduce fuel or under-fire air.

xviii. Low temperature in gasifier bed (< 700°F).

xix. High temperature entering HRSG (> 1850°F).

xx. High temperature in gasifier chamber (> 1400°F).

1. Add more air.

xxi. High temperature downstream of economizer.

xxii. Low pH (< 6) in scrubber water.

xxiii. High pH (> 8) in scrubber water.

xxiv. High conductivity in scrubber water.

xxv. Low level in scrubber water.

2. The following emergency conditions require system shutdown.

xxvi. Loss of fuel in feed ram.

xxvii. Low Hydraulic fluid pressure ram –fuel shutdown.

xxviii. Loss of quench water pressure –

1. controlled shutdown

xxix. Fire in fuel handling area

xxx. Fire in gasifier area

xxxi. Fire in Boiler room
xxxii. Loss of ID fan
   1. Indication: Loss of negative pressure at gasifier outlet.
   2. System Response:

xxxiii. Loss of power
   1. Indication: All systems lose power. Emergency generator starts.
   2. System Response:
      a. Gasifier fans shut down
      b. Emergency feed pump starts
      c. MFWV fails in position
      d. Blowdown solenoid valve closes
      e. Pressure reducing station operates
      f. NaOH feed pumps stop
      g. Scrubber feed pump stops
      h. PLC powered by UPS for 5 minutes
      i. Natural draft draws small amount of air through system, gasifier in smolder mode.
   3. Control system response:
      a. Hydraulic feed ram “parks”
      b. System holds operating position for adjustable time period up to 10 minutes. Restart within this time will start with a purge, then ramp operation to previous operating condition.
   4. Operator response
      a. Verify MFWV is closed, close valve or stop BFP to avoid overfilling HRSG.
   5. Recovery
      a. On restoration of power,
      b. ID fans initiates purge mode
      c. If restoration occurs within 10 minutes (adjustable) system returns to previous operating point.
      d. If power loss period is longer than time delay, manually restart system.

xxxiv. Backfire fire at ram stoker

xxxv. High boiler pressure

xxxvi. LWCO on boiler

xxxvii. Low temperatures leaving HRSG
6. **Other Pre-requisites**

Other Prerequisites – Cold Operational Tests

1. Material handling equipment tests
2. Fuel feed rate test (stroke capacity check)
3. Fuel hopper storage volume test (cold). Feed full then observe that no bridging occurs.
4. Throughput timing estimate (how long / number of strokes) to pull fuel through and empty full hopper.
5. Emergency cutout switch tests (open fuel hopper doors, spiked rollers stop.)
6. Fuel particle size tests.
   a. Fuel handling system performance.
   b. Gasification system performance.
7. Low fire maintenance mode ("smolder mode") test.
8. Low NOx features test:
   a. FGR use
   b. Relationship between FD2-1, FD2-2 use and NOx production.

Combined Procedures for Boiler Boil-out, Refractory Cure and Initial Start-up

7. **Research**

SOPs including safety protocols developed with the principle investigator and pre-approved by UMM staff.

8. **Public Tours**

SOPs including safety protocols developed with the tour leader and pre-approved by UMM staff.

9. **Teaching & Training**

SOPs including safety protocols developed with the lead instructor and pre-approved by UMM staff.