CHEMICAL RECOVERY BOILERS

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1.0 SCOPE

This data sheet contains recommended practices for the design, operation, and maintenance of black liquor recovery boilers used in the pulp and paper industry. The primary focus is recovery boilers used in the Kraft or sulfate recovery process. Recommendations may also be applied to black liquor recovery boilers in the "soda" or sodium carbonate recovery process. Both boilers are commonly known as black liquor recovery boilers in North America, and as soda recovery boilers outside North America.

This data sheet is not applicable to red liquor recovery boilers used in the (ammonium or magnesium) recovery process. See Data Sheet 6-13, *Waste Fuel-Fired Facilities*, for further guidance.

This is a system-based data sheet covering the feedwater control valve, main header safety shutoff valve for each auxiliary fuel, firing liquor supply from the final indirect liquor evaporator or concentrator, combustion air with each forced-draft fan, any direct-contact firing liquor evaporator, electrical power as needed to operate boiler auxiliary equipment and controls, flue gas equipment (any direct contact evaporator, induced-draft fans, and electrostatic precipitators, and the steam piping from the boiler, including the two main-steam shutoff valves.

Guidance is also provided on collection and transport of noxious or flammable pulp mill waste streams for incineration or firing in the boiler furnace.

1.1 Changes

April 2025. Interim revision. Minor editorial changes were made for additional clarity referencing water treatment program guidance in Data Sheet 6-23, *Watertube Boilers*.

2.0 LOSS PREVENTION RECOMMENDATIONS

2.1 Introduction

Recommendations in the following sections specify a desired level of performance rather than particular actions. The data sheet user may choose from several written industry practices to achieve the recommended performance, and clients of FM may work with FM engineers to develop alternative actions. Note that some specific practices permitted or recommended by written industry standards are not in accordance with FM guidelines. Currently, written industry standards include the following:

- Those produced by Sodahuskommitten (Swedish-Norwegian Recovery Boiler Committee, SHK)
- Those produced by Suomen Soodakattilayhdistys (Finnish Recovery Boiler Committee, FRBC)
- Those produced by Black Liquor Recovery Boiler Advisory Committee (United States of America, BLRBAC)
- European Standard EN 12952, Water-Tube Boilers and Auxiliary Installations

2.2 Boiler Pressure Parts

Establish and implement a chemical recovery boiler inspection, testing, and maintenance program. See Data Sheet 9-0, *Asset Integrity*, for guidance on developing an asset integrity program.

This section addresses hazards associated with damage to boiler pressure parts.

2.2.1 Boiler Pressure Parts - Design, Construction and Repair

2.2.1.1 Specify that boiler design, construction, and repair be in accordance with an FM recognized code. Refer to Data Sheet 6-23, *Watertube Boilers*, for further guidance.

All pressure retaining part repairs are to be performed in accordance with the National Board Inspection Code (NBIC), Part 3, Repairs and Alterations. The external weld metal buildup repair method (i.e., base metal restoration) can be used to repair wasted areas due to erosion and/or corrosion, restoring base metal thickness to meet applicable code requirements. Prior to performing this repair method, subject the pressure parts to volumetric nondestructive examination (NDE) including material thickness. This examination includes butt welds if they are part of the repair area. Evaluate the cause of the erosion/corrosion so that any required corrective action can be completed to prevent reoccurrence. Weld metal buildup should not be used as a repair method where cracking is identified. Completed repairs are also subjected to NDE to verify repair integrity.

When welded repairs are performed on pressure parts in areas where a leak could occur into the furnace, the integrity of the weld repair should be reevaluated at the next outage.

Qualified welding procedures should be used for all repairs. For tube repairs, the welding technique and procedure should minimize excessive weld penetration into the tube internal diameter.

2.2.1.2 Specify that all boiler pressure part welds that could admit water to the furnace be examined using a volumetric method.

2.2.1.3 Specify boiler tube materials having corrosion and erosion resistance appropriate for the boiler's operating conditions.

2.2.1.4 Specify construction of the boiler furnace to be gas-tight (fully welded).

2.2.1.5 Specify boiler design to avoid use of a furnace water screen.

2.2.1.6 Specify new or replacement boiler waterwalls to provide explosion relief in one or more corners of the furnace.

2.2.1.7 Establish and implement a documented water treatment program to effectively control potential damage mechanisms that can impact the boiler system, downstream equipment and/or processes. Maintain boiler feedwater quality (external to the boiler - raw/make up water supply/condensate) quality, boiler water quality (internal to the boiler) and steam purity is maintained within the boiler original equipment manufacturer's recommended parameters and chemistry limits and/or industry guideline limits. Establish procedures that are appropriate for the boiler operating pressure and sized for the maximum possible steam demand or startup demand, whichever is greater. See Data Sheet 6-23, *Watertube Boilers*, for additional guidance on water treatment programs.

2.2.2 Boiler Pressure Parts – Protection Devices

2.2.2.1 Provide boiler overpressure protection. Refer to Data Sheet 6-23, *Watertube Boilers*, and 12-43, *Pressure Relief Devices*, for further guidance.

2.2.2.2 Provide a boiler dry-firing or low-water protection system.

Due to the smelt-water explosion hazard, the preferred systems are the following:

A. One low-water trip through the use of the drum-level signal developed by an auctioneering system used in the feed-water control system.

B. One low-water trip through the use of a state-of-the-art instrument that utilizes internal redundancy, self-checking internal diagnostics, redundant power supplies, and which provides an audible and visible alarm in the control room when internal diagnostics detect a fault condition in the instrument.

C. Three differential pressure drum-level measurements for low-water protection using two-out-of-three tripping logic.

For any BLRB exposed to freezing temperatures (32°F, 0°C), freeze protection is needed to ensure reliable signal transmission for this system and all water-level alarms and indicators (gage glasses, etc.).

Refer to Data Sheet 6-12, *Low-Water Protection*, for additional information.

2.2.2.3 Provide an operator-actuated, smelt-water emergency isolation system designed to minimize the potential for a smelt-water explosion. Also provide an alternative means for the operator to accomplish each of the functions of this system.

Expected actions include prompt stop of all fuel to the boiler (MFT), minimize combustion in the furnace (minimize combustion air entering below liquor gun level), stop feedwater to the boiler, stop all other water sources to the boiler, stop all steam sources to boiler auxiliaries, isolate the boiler from the mill steam header, record the temperature of a representative number of floor tubes, drain the boiler to the 8 ft (3 m) level in approximately 20 minutes, and expedite reduction of pressure remaining in the boiler by opening additional boiler vents once the boiler has drained.

2.2.2.4 Provide a reliable means (a motorized stop valve or non-return valve) of maintaining boiler pressure as part of the smelt-water emergency isolation system.

EN 12952-7 requires a motorized shutoff valve. SHK B8 recommends a motorized stop valve on the boiler outlet.

2.2.2.5 Provide a reliable smelt bed imaging system (infrared camera) that covers the majority of the bed in the furnace with a monitor in the control room.

2.2.3 Boiler Pressure Parts – Operation

2.2.3.1 Maintain boiler operating parameters to minimize carry-over and plugging, with the objective of limiting furnace water wash to coincide with planned pressure part inspections and to avoid performing any “thermal shedding” procedure.

2.2.3.2 If unavoidable, carefully plan and execute thermal shedding (chill and blow – the process of fracturing fireside tube deposits by rapidly reducing furnace temperature) to avoid damaging the boiler. Maintain a steam flow of at least 40% of design at all times. Return the boiler to normal operation within three hours (most shedding will occur during the first two hours).

2.2.3.3 Perform a walk-down inspection of the boiler for unusual conditions at least once per shift, and if possible, do this inspection with sootblowers off at least once per day.

2.2.3.4 Perform inspection and cleaning of boiler ports at a frequency sufficient to avoid plugging of instrument, air, and smelt ports.

2.2.3.5 Monitor boiler feedwater, boiler water and boiler steam at intervals to ensure water and steam purity is maintained within the appropriate operating limits. See Data Sheet 6-23, *Watertube Boilers*, for additional guidance.

2.2.4 Boiler Pressure Parts – Inspection, Testing, and Maintenance

2.2.4.1 Conduct a cold-side, fireside and waterside boiler condition assessment and inspect boiler pressure parts that could admit water to the furnace at each major outage. During the condition assessment, conduct a hydrostatic test to at least the boiler operating pressure prior to returning the boiler to service.

2.2.4.2 Visually inspect boiler overpressure protection at least annually. Verify provided relief capacity is adequate for current boiler steam generating capacity. Verify safety valve set pressure and operability by testing every three years or as determined by operating experience and demonstrated by testing history. Record the tests, including any corrective action taken. Refer to Data Sheet 12-43, *Pressure Relief Devices*, for further guidance.

2.2.4.3 Functionally test and calibrate the dry-firing or low-water protection system when removing the boiler from service for a planned outage. Record the tests, including any corrective action taken. Refer to Data Sheet 6-12, *Low-Water Protection*, for further guidance on testing, maintenance, and bypass switches.

2.2.4.4 Functionally test the smelt-water emergency isolation system at each major outage. Record the tests, including any corrective action taken. Confirm burn-out of the smelt bed and check for pressure part leaks prior to isolating rapid drains from the boiler. Do not perform the functional test with rapid drains isolated from the boiler when molten smelt is present.

2.2.4.5 Individually verify satisfactory operation of each motorized rapid drain valve at least monthly. Permit only one rapid drain to be isolated any time molten smelt is present. Maintain records of these tests, including position of the manual isolation valve following the test.

2.2.4.6 Ensure manual rapid drain block valves are locked open or electronically supervised with visual indication in the control room. Have them visually inspected monthly to ensure the valves are in the open position. Maintain records of these inspections.

2.2.4.7 Individually flush each rapid drain line to ensure the piping is not obstructed at each major outage. Maintain records of each flushing.

2.2.5 Boiler Pressure Parts – Training

Train operators to standard and emergency operating procedures. See Data Sheet 10-8, *Operators*, for guidance on developing operator programs.

2.2.5.1 Train operators in recognizing and responding to indications of a pressure part leak, including actuation of the smelt-water emergency isolation system at least annually.

2.2.5.2 Train operators in recognizing and responding to indications of low boiler water level.

2.2.5.3 Train operators to monitor boiler feedwater, boiler water, and boiler steam at intervals to ensure purity is maintained within the operating limits.

2.2.5.4 Train operators in appropriate methods for manual removal of salt cake or ash accumulations from pressure parts (salt cake on superheaters or upper furnace, generation bank, economizer, and water screens, salt cake in burner or air port openings, and solidified smelt in smelt spout openings).

2.3 Liquor Firing System

This section addresses hazards associated with firing of black liquor.

2.3.1 Liquor Firing System – Design and Construction

2.3.1.1 Design, locate, and protect the piping of the firing liquor system as recommended for ignitable liquid piping in *Data Sheet 7-32, Ignitable Liquid Operations*.

2.3.1.2 Design the firing liquor piping system to minimize potential for inadvertently introducing water to the furnace.

2.3.1.3 Design piping for ignitable liquid streams (soap, residual acid, methanol, turpentine) being blended with the firing liquor to minimize potential for introducing water to the furnace.

2.3.2 Liquor Firing System – Protection Devices

2.3.2.1 Provide a firing liquor solids monitoring, permissive starting, and protective tripping system, using redundant refractometers, designed to prevent firing liquor of 58% or less solids or wash water from entering the furnace.

2.3.2.2 Provide permissive starting interlocks and protective tripping interlocks to ensure all conditions are satisfactory to initiate and maintain admittance of firing liquor to the furnace.

2.3.3 Liquor Firing System – Operation

2.3.3.1 Develop and implement procedures to ensure operation of the liquor firing system does not result in a pyrolysis gas explosion, smelt-water, or smelt-weak liquor explosion.

2.3.3.2 Develop and implement procedures to ensure black liquor firing does not result in heat input to furnace tubes exceeding design.

2.3.4 Liquor Firing System – Inspection, Testing, and Maintenance

2.3.4.1 Functionally test and calibrate the manual and automatic liquor divert system, the sootblower water wash spool piece out and the smelt spout cooling water flow satisfied, dissolving tank level satisfied, and black liquor header wash system in ″wash” position permissives at least every major outage. Other permissive starting and protective tripping systems at least every three years. See Data Sheet 9-0, *Asset Integrity*, for guidance on developing an asset integrity program.

2.3.5 Liquor Firing System – Training

2.3.5.1 Train operators in the safe operation of the liquor fuel firing system. See Data Sheet 10-8, *Operators*, for guidance on developing operator programs.

2.4 Auxiliary Fuel Firing Systems

This section addresses hazards associated with firing of all fuels other than black liquor.

2.4.1 Auxiliary Fuel Transport Systems – Design and Construction

2.4.1.1 Design the piping for auxiliary fuel gas and low-volume high-concentration gas (LVHC, also known as concentrated noncondensible gas or CNCG) as recommended in Data Sheet 6-5, *Oil- or Gas-Fired Multiple Burner Boilers*, and 7-54, *Natural Gas and Gas Piping*, and arrange it to minimize piping damage due to a boiler explosion.

2.4.1.2 Design the piping for auxiliary fuel oil and ignitable liquid waste stream piping as recommended in Data Sheet 6-5 and in Data Sheet 7-32. Arranged the piping to minimize piping damage due to a boiler explosion.

2.4.1.3 Design ductwork for high-volume low-concentration gas (HVLC, also known as dilute noncondensible gases or DNCG) as recommended in Data Sheet 7-78, *Industrial Exhaust Systems*.

2.4.2 Auxiliary Fuel Firing Systems – Protection Devices

2.4.2.1 Provide auxiliary fuel safety and combustion controls consistent with recommendations in Data Sheet 6-5, *Oil- or Gas-Fired Multiple Burner Boilers*, except that local starting by an operator observing igniter and burner light-off are acceptable practice.

2.4.2.2 Provide gas (LVHC) and liquid waste stream fuel system safety and combustion controls consistent with recommended practice in Data Sheet 6-13, *Waste Fuel-Fired Facilities*, except that local starting by an operator observing igniter and burner light-off is acceptable practice.

2.4.2.3 Provide HVLC gas waste stream safety system and combustion controls consistent with recommended practice in Data Sheet 6-11, *Thermal and Regenerative Catalylic Oxidizers*.

2.4.3 Auxiliary Fuel Firing Systems - Operation

2.4.3.1 Develop and implement procedures to ensure operation of the fuel firing systems (fuel oil, fuel gas, and all waste streams) does not result in a fuel explosion.

2.4.3.2 Develop and implement procedures to ensure firing of fuels does not result in heat input to furnace tubes exceeding their design.

2.4.4 Auxiliary Fuel Firing Systems – Inspection, Testing, and Maintenance

2.4.4.1 Functionally test and calibrate the high and low furnace pressure fully integrated trips, the master fuel trip of the manual fuel trip, (for the auxiliary fuels and the CNCG/SOG/DNCG waste streams, if provided in the field), the local manual burner shutdown activation trip, and the boiler steam flow < 50 MCR (if not dedicated burner design) at each major outage. Other auxiliary fuel firing system permissive starting and tripping systems, including those on waste stream systems, at each three years or as recommended in Data Sheet 6-5. See Data Sheet 9-0, *Asset Integrity*, for guidance on developing an asset integrity program.

2.4.4.2 Functionally test all auxiliary fuel flame monitors (igniter and burner) and safety shutoff valves (for automatic closure), including those on waste stream systems, at least monthly.

2.4.5 Auxiliary Fuel Firing – Training

2.4.5.1 Train operators in the safe operation of the auxiliary fuel firing systems. See Data Sheet 10-8, *Operators*, for guidance on developing operator programs.

2.5 Direct Contact Evaporator (DCE) Systems

This section addresses fire hazards associated with direct contact evaporator systems.

2.5.1 DCE – Construction and Location

2.5.1.1 Design direct contact evaporator systems and electrostatic precipitator systems to minimize the accumulation of combustibles, and construct the systems with noncombustible materials.

2.5.1.2 Avoid installing any fan between a DCE and an electrostatic precipitator. Preferably, locate an ID fan following an electrostatic precipitator.

2.5.1.3 Provide ample access openings in DCE systems for manual firefighting.

2.5.2 DCE − Protection Devices

2.5.2.1 For all DCE systems, provide high-temperature alarm and high-high temperature permissive starting and protective tripping interlocks for flue gas temperature leaving the DCE and leaving the electrostatic precipitator.

2.5.3 DCE − Fire Protection

2.5.3.1 Provide automatic fire protection for all DCE, ID fans, and all ductwork between the DCE and the electrostatic precipitator. Fire protection may also be needed for the electrostatic precipitator if construction is combustible or if combustibles may accumulate in the electrostatic precipitator. Provide one nozzle per 10 ft (3.3 m) of enclosure covering 100 ft^2 (9.3 m^2) of horizontal surface.

2.5.4 DCE − Operation and Maintenance

2.5.4.1 Develop and implement procedures to ensure the operation of the DCE, ID fan, and electrostatic precipitator systems do not result in a fire. See Data Sheet 9-0, *Asset Integrity*, for guidance on developing an asset integrity program.

2.5.4.2 At least once per shift verify satisfactory operation of DCE. For cascade type, verify satisfactory liquor level and density and proper rotation of cascade wheel. For cyclone type, verify liquor level and proper operation of pumps.

2.5.4.3 Internally inspect DCE system at each outage, and remove all combustible deposits.

2.5.4.4 Functionally test and calibrate automatic fire detection and interlocks at each outage.

2.5.4.5 Inspect fire protection piping and nozzles at each outage, and remove any liquor deposits obstructing the nozzles.

2.5.4.6 Maintain the normal cascade liquid level when firing auxiliary fuel or firing liquor.

2.5.5 DCE − Training

2.5.5.1 Train operators to respond to a DCE fire by manually terminating boiler firing, minimizing air flow through the DCE, and manually actuating the fire protection system. Train operators or emergency responders in the locations of access openings to the DCE system and locations of extinguishers and small hose to be used for first-aid firefighting efforts. See Data Sheet 10-8, *Operators*, for guidance on developing operator programs.

2.5.5.2 Train operators to maintain cascade liquid level and cascade wheel rotation during a cascade fire.

2.5.5.3 Train operators to maintain cyclone circulation and dilution during a cyclone fire.

2.6 Control and Equipment Rooms

Control and equipment rooms can be a critical element in operations. These areas should be afforded maximum protection through proper spacing from the boiler, or explosion-resistant construction when necessary. Construction should minimize the combustible load present, and fire protection systems should be provided where needed. The boiler control room should be located to permit operators to perform recommended emergency actions.

2.6.1 Control and Equipment Room Construction and Location

2.6.1.1 Locate control and equipment rooms a safe distance from the boiler. The determination of a safe distance should be based on a study of the particular boiler arrangement.

2.6.1.2 For control or equipment rooms located in the boiler building:

A. Provide a cutoff commensurate with the exposure, but of at least 1-hour fire resistance with self-closing access doors, unless the area is noncombustible with no fire or explosion hazard.

B. If the control or any equipment room is exposed to damage from a boiler or support equipment explosion or fire, provide pressure-resistant construction. (See Data Sheet 1-44, *Damage-Limiting Construction*)

2.6.1.3 Construct raised floors and suspended ceilings of noncombustible materials. Cover or screen openings into the space under raised floors to keep out combustible debris. If the spaces created by raised floors or suspended ceilings are used for cables, wires, plastic tubing, or air handling, provide easily removable panels or other ready means of access. (See also Data Sheet 5-32, *Electronic Data Processing Systems*, for other protection and prevention recommendations for spaces with cables)

2.6.1.4 If the control or equipment rooms are located near a potential source of substantial release of corrosive gases, maintain the rooms under a positive air pressure of at least 0.1 in. of water (25 Pa). Supply fresh air from a contaminant-free location.

2.6.1.5 If it is determined the control area cannot be attended as recommended during emergency conditions, provide an alternate, remote control interface so all recommended emergency actions, including boiler monitoring, can be accomplished.

2.6.2 Control and Equipment Room Protection

2.6.2.1 Provide automatic sprinklers:

A. Throughout the control or equipment room, unless construction is entirely noncombustible and there are no combustibles in the room except instrument charts and logs that are in use (not stored).

B. In record storage, supply storage, and maintenance areas where the amount of combustibles would warrant such protection.

2.6.2.2 Where the control or equipment room has extensive electronic control or data processing equipment, refer to Data Sheet 5-32 for additional loss prevention advice.

2.6.2.3 Provide portable 10 to 15 lb (4-6 kg) clean agent or carbon dioxide fire extinguishers for potential fires in electrical equipment. Avoid the use of dry-chemical extinguishers. Provide 2-1 2 gal (10 L) water-type fire extinguishers for fires in ordinary combustibles in the control room or associated storage rooms.

2.7 Contingency Planning

2.7.1 Equipment Contingency Planning

When a chemical recovery boiler breakdown would result in an unplanned outage to site processes and systems considered key to the continuity of operations develop and maintain a documented viable chemical recovery boiler equipment contingency plan per Data Sheet 9-0, *Asset Integrity*. See Appendix C of that data sheet for guidance on the process of developing and maintaining a viable equipment contingency plan. Also refer to sparing, rental, and redundant equipment mitigation strategy guidance in that data sheet.

2.7.2 Sparing

Sparing can be a mitigation strategy to reduce the downtime caused by a chemical recovery boiler breakdown depending on the type, compatibility, availability, fitness for the intended service, and viability of the sparing. For general sparing guidance, see Data Sheet 9-0, *Asset Integrity*.

2.7.2.1 Routine Spares

Routine chemical recovery boiler spares are spares that are considered to be consumables. These spares are expected to be put into service under normal operating conditions over the course of the life of the chemical recovery boiler, but not reduce equipment downtime in the event of a breakdown. This can include sparing recommended by the original equipment manufacturer. See Section 3.4 for routine spare guidance.

3.0 SUPPORT FOR RECOMMENDATIONS

3.1 Boiler Operating History

Operating experience for chemical recovery boilers is very similar to larger watertube boilers in general for hazards other than smelt-water explosion. Refer to Data Sheet 6-23, *Watertube Boilers*, for pressure part experience; Data Sheet 6-12, *Low-Water Protection*, for low-water experience; Data Sheet 6-5, *Oil- or Gas-Fired Multiple Burner Boilers*, for fuel combustion experience; and Data Sheet 6-13, *Waste Fuel-Fired Facilities*, for fuel combustion experience.

3.1.1 Sodahuskommitten (Swedish-Norwegian Recovery Boiler Committee, or SHK)

The SHK (www.sodahuskommitten.se) was founded in 1965 to study and publish recommendations for actions to prevent disasters caused by water leakage into the furnace.

There are 30 recovery boilers in Sweden and two in Norway, with the average boiler having been in service about 30 years and having a capacity of 3,031,500 lb/day (1378 mt/day).

SHK compiles boiler incident data volunteered by member operators. Table 3.1.1 lists incidents resulting in tube leaks reported to the Committee from 2004 through 2006.

Table 3.1.1. Sodahuskommitten Incidents (2004-2006)

Water Source	Number
1. Floor tube leaks	
2. Wall tube leaks	3
3. Screen tube leaks	
4. Roof tube leaks	
5. Generating bank tube leaks	2
6. Weak liquor	
7. Water entered through liquor guns	
8. Water entered through oil guns	
9. Wash water	
10. Smelt spout leaks	
11. Economizer Tubes	7
12. Other Water Sources	
TOTAL	12

3.1.2 Suomen Soodakattilayhdistys (Finnish Recovery Boiler Committee, or FRBC)

The FRBC (http://www.soodakattilayhdistys.fi) has collected information on recovery boiler incidents, published guidelines, and recommended practices for committee members since 1964. There are 21 recovery boilers operating in Finland having an average age of 26 years and average capacity of 4,200,000 lb/day (1900 mt/day). Table 3.1.2 lists incidents reported to the Committee 1990 through 2006. These incidents may not have resulted in tube leaks.

Table 3.1.2. Suomen Soodakattilayhdistys Incidents (1990-2006)

Boiler Location	Number
1. Floor tube leaks	23
2. Wall tube leaks	67
3. Screen tube leaks	6
4. Roof tube leaks	
5. Generating bank tube leaks	44
6. Weak liquor	
7. Water entered through liquor guns	
8. Water entered through oil guns	
9. Wash water	
10. Smelt spout leaks	
11. Economizer Tubes	108
12. Other Water Sources	
TOTAL	248

3.1.3 BLRBAC Incident Data

BLRBAC (http://www.blrbac.net) compiles lists of explosions and critical exposures from data volunteered by member operators. A critical exposure is defined by BLRBAC as “a non-explosive incident involving the opportunity for smelt-water contact.” Tables 3.1.3-1 and 3.1.3-2 list the causes and numbers of incidents.

Table 3.1.3-1. BLRBAC Data on Explosions (1978-2007)

BLRBAC Explosions			
	Number		
	1978-1987	1988-1997	1998-2007
Smelt-Water Explosions			
Water Source:			
1. Floor tube leaks	4	2	
2. Wall tube leaks	6	1	
3. Screen tube leaks	2	1	
4. Roof tube leaks	1		
5. Generating bank tube leaks		1	1
6. Weak liquor	2	2	
7. Water entered through liquor guns			
8. Water entered through oil guns			
9. Wash water		1	
10. Smelt spout leaks	2	1	
11. Unknown			
Subtotal	17	9	1
Fuel Explosions			
1. Pyrolysis gas	3	1	
2. Fuel rich mixture	3		1
Subtotal	6	1	1
Dissolving Tank Explosions			
Subtotal	6	7	13

Table 3.1.3-2. BLRBAC Data on Black Liquor Recovery Boiler Critical Exposures (1978–2007)

BLRBAC Critical Exposures			
Water Source:	Number		
	1978-1987	1988-1997	1998-2007
1. Floor tube leaks	13	16	11
2. Wall tube leaks	82	148	94
3. Screen tube leaks	16	8	19
4. Roof tube leaks	2	2	2
5. Generating bank tube leaks	27	63	46
6. Weak liquor	1		
7. Water entered through liquor guns	1	2	1
8. Water entered through oil guns	2		
9. Wash water		2	1
10. Smelt spout leaks	10	10	7
11. Economizer Tubes	4	6	37
12. Other Water Sources	3	5	5
TOTAL	161	262	223

3.1.4 FM Loss Experience

For the time period 1977 through 2007, a total of 187 losses were identified as involving BLRB pressure parts. There were nine incidents involving fuel (auxiliary or pyrolysis gas), ten incidents involving combustion air fans, two identified as liquor guns not removed from furnace (smelt-water explosions resulting), four dry-fire incidents, eight spout incidents, 19 dissolving tank incidents, five “freeze” incidents, two waste streams incineration incidents, four incidents involving precipitators and associated equipment, and 53 miscellaneous incidents.

3.1.5 Illustrative BLRB Losses

Descriptions of incidents are maintained by the various BLRB organizations (Sodahuskommitten, Suomen Soodakattilayhdistys, and BLRBAC). For BLRBAC, the incident descriptions may be found in the meeting minutes posted on the BLRBAC website. For the other two organizations, the descriptions are available to members.

3.1.5.1 Improper Restart Sequence Leads to Fuel Explosion

This BLRB is rated for 1,400,000 lb/day (6.35 x 105 kg/day) recovery and 318,000 lb/hr (1.44 x 105 kg/hr) at 975 psi (67 bar). Analyzers are provided for carbon monoxide, total reduced sulfur, and oxygen.

The BLRB was firing on liquor only and adjustment was made to increase the char bed size by decreasing the liquor temperature. Liquor combustion ceased and all liquor guns were retracted. Two startup burners on one side of the furnace were started about 20 minutes into the incident. Thirty minutes later, after confirming liquor solids concentration, three liquor guns were started at five-minute intervals. These guns are opposite the startup burners that were firing.

The fireman starting the liquor guns noted no “puff” characteristic with normal gun light off. Other operators noted liquor was burning only on one side of the furnace and was not as complete as expected. About 40 minutes into the incident a recorder showed airflow decreased by 20%. A third startup burner was inserted and the igniter flame was established. As the main fuel valve was opened, about 55 minutes into the incident, a single large explosion occurred. An ESP was initiated and the building was evacuated. No smelt-water explosion occurred.

All buckstays were bowed up to 5 in. (125 mm) or broken. Furnace floor beams were deflected up to 3 in. (76 mm). The casing was bulged and refractory damaged.

Investigation revealed flammable vapors increased rapidly upon failure of liquor firing, which is expected. The flammable vapors began decreasing after the auxiliary burners were started, but again rapidly increased as the three liquor guns were restarted. The accumulating vapors were ignited when the auxiliary burner was started opposite the auxiliary burners that were in service.

The operators did not follow the established starting procedure of using starting burners in opposite corners of the furnace prior to restarting liquor firing and did not verify stable and complete liquor combustion at each liquor gun before starting successive liquor guns.

3.1.5.2 Failure to Remove Black Liquor Guns after Terminating Firing Results in Explosion

This BLRB is rated for 3,000,000 lb/day (13.6 x 10^5 kg/day) dry solids recovery and 769,400 lb/hr (3.5 x 10^5 kg/hr) steam at 890 psi (61 bar). Black liquor gun position switches were removed six months after the BLRB was commissioned. A “no divert” bypass of the automatic divert control was installed about six months before this incident in.

The BLRB was operating normally when the forced draft fans, black liquor pumps and the precipitator level tank pump tripped off. The black liquor automatically diverted and the induced draft fan continued operating. The firemen shut off the individual liquor guns and opened the steam out connections, but left the guns in place. Condensate is not manually drained from the steam out lines.

Two hours were spent locating the reason for the trip and preparing the BLRB for re-firing. Preparation included making a steam out connection between the green liquor piping and the steam ring header for the black liquor guns. It was subsequently discovered the steam pressure can drop to 30 psi (2 bar) and the green liquor pump can develop up to 60 psi (4 bar) at gun level.

At two hours and 20 minutes, the black liquor pump control was bypassed and control logic modified to start the precipitator level tank pumps. These pumps were started and the ‘‘no divert’’ was activated on the black liquor control to permit recirculation of liquor. Subsequent investigation revealed the total reduced sulfur (TRS) recorder indicated a rapid increase in TRS at this time. This would indicate black liquor was entering the furnace. At two hours and 25 minutes an explosion occurred followed by a second explosion. The feedwater valve was closed, water was observed on the boiler exterior, and the ESP was initiated at two hours and 40 minutes.

Following the recommended practice of removing the black liquor guns from the furnace prior to reopening the black liquor header valve could have prevented this incident.

3.1.5.3 Excessive Smelt Flow upon Start-up After an Unplanned Outage Results in Dissolving Tank Explosion

An electric power interruption stopped firing of this BLRB. The following day the BLRB was re-fired. Green liquor and steam shatter sprays were turned on and the dissolving tank was being filled while an operator tried to clear one spout. Tank level was above normal and a large pool of molten smelt had accumulated when one spout was opened. The flow exceeded shatter spray capacity and a solid stream of smelt entered the dissolving tank.

The subsequent smelt-water explosion damaged the dissolving tank, shatter piping and BLRB casing. Greater care in re-melting the smelt bed, maximizing the shatter sprays, and in re-opening the smelt spouts could have minimized this incident.

3.1.5.4 Why Actuation of the ESP Upon Pressure Containing Part Failure within the Furnace is Recommended

This BLRB is rated for 328,000 lb/hr (1.56×10^5 kg/hr) steam at 400 psi (26 bar) and 1,900,000 lb/day (9.1×10^5 kg/day) dry solids. Operator training is rated excellent. A complete ESP system and written procedure are provided.

The BLRB was operating normally although water chemistry analysis indicated a major change from readings of eight hours earlier. After eight more hours the chemical feed rate remained excessive. At 11 hours, a sound similar to a soot blower was noted at one liquor gun port. At 11-½ hours, it was decided a leak existed in the furnace, but there was no evidence of water entering the furnace. Control room instrumentation did not indicate any leakage.

Liquor guns were removed from service and auxiliary burners were started. With auxiliary burners in service at 13 hours, 20 minutes, a low water alarm followed by a low water trip occurred. At this time, water was observed spraying into the furnace and the ESP was initiated.

Subsequent investigation revealed the entrance to one waterwall tube was more than 80% obstructed by a foreign object. This obstruction led to short term overheating and tube rupture. Due to the obstruction, initial discharge from the rupture was steam, followed by water as boiler pressure was reduced.

3.2 Direct Contact Evaporator Loss History

3.2.1 FM Loss Study

A study of FM losses from 1977 through 2007 showed that combustible residues typically accumulate in the flue gas circuit of black liquor recovery boilers having DCE. Fire usually involves the cascade or cyclone-type DCE, the induced-draft fan, the precipitator and interconnecting ductwork.

3.2.2 BLRBAC DCE Study

In 1971, BLRBAC studied frequency and magnitude of fire in the flue gas circuit of the recovery boiler. They examined total losses of major equipment including DCE, induced-draft fans, and precipitators.

The overwhelming majority of fires occurred during the critical periods of boiler startup and shutdown. Many fires occurred when boilers were firing only auxiliary fuel. During startup or shutdown, unstable conditions can occur such as high excess air content, high amounts of residual flammable gases, high flue gas temperatures due to premature shutdown or loss of cooling liquid at the DCE, and incomplete shutdown and securing procedures.

The following were the main problems leading to fires:

A. The disc or wheel drive within the cascade evaporator failed from loss of power or high torque due to increases in liquor viscosity.

B. Liquor recirculation in a cyclone evaporator failed from strainer plugging, wall wash nozzle plugging, and plugging at the periphery of the liquor distribution umbrella.

C. Makeup liquor flow failed. This flow cools a DCE.

D. Accumulated combustible material was not removed from the ductwork and other auxiliary equipment, including the fan.

E. Correct liquid level within the cascade evaporator was not maintained, particularly during startup, shutdown and auxiliary fuel firing.

F. Auxiliary fuel oil atomized improperly, allowing oil droplets to carry over.

G. The boiler was not in a fire-free condition which should have been checked as part of the shutdown procedures.

H. Boiler operation resulted in poor liquor combustion.

I. Unburned fuel accumulations in the electrostatic precipitator were susceptible to ignition through electrical short-circuiting or excessive arcing.

J. Air leaked through open seams, loose doors, corrosion holes, etc., into ductwork and hoppers contributed to fire intensity.

3.3 DCE Hazards

3.3.1 Process Description

The manufacture of kraft and soda pulp and paper requires cooking of wood chips with chemicals in a digester to separate lignins from fiber. After the cooking cycle, the pulp is separated from the spent chemicals, washed and sent to other process areas. The spent chemical solution is known as weak black liquor. The weak liquor is about 85% water and is stored in a large tank. Much of the water must be evaporated before the liquor can be fired in the boiler. This evaporation may be accomplished entirely in multiple-effect tubular evaporators, or accomplished in multiple effect evaporators with final concentration in a DCE (Figures 3.3.1-1 and 3.3.1-2). In a DCE the hot flue gas concentrates the liquor to 60% or more solids. The concentrated black liquor is fired in the boiler to generate steam and to recover chemicals.

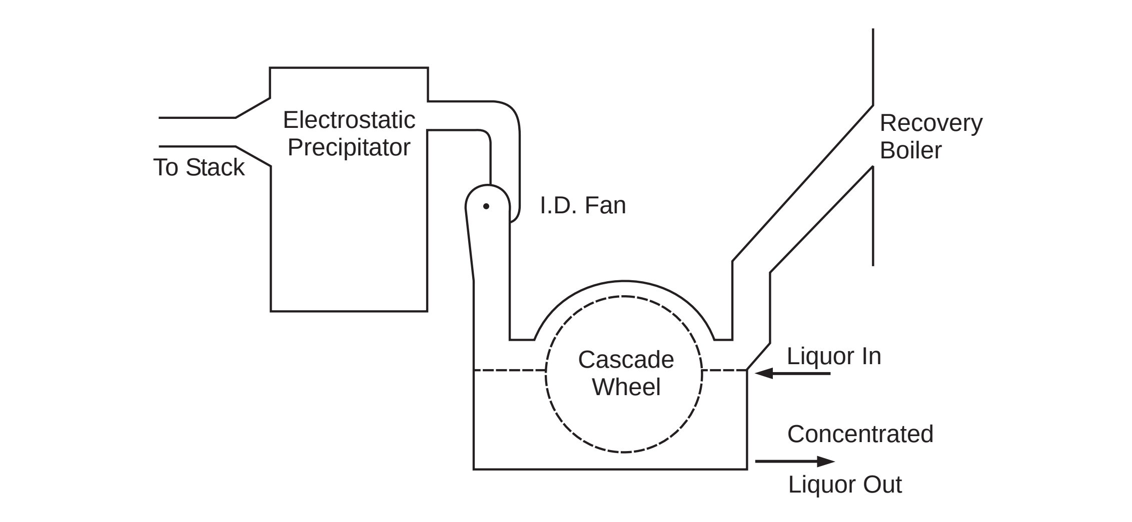

Fig. 3.3.1-1. Cascade evaporator system

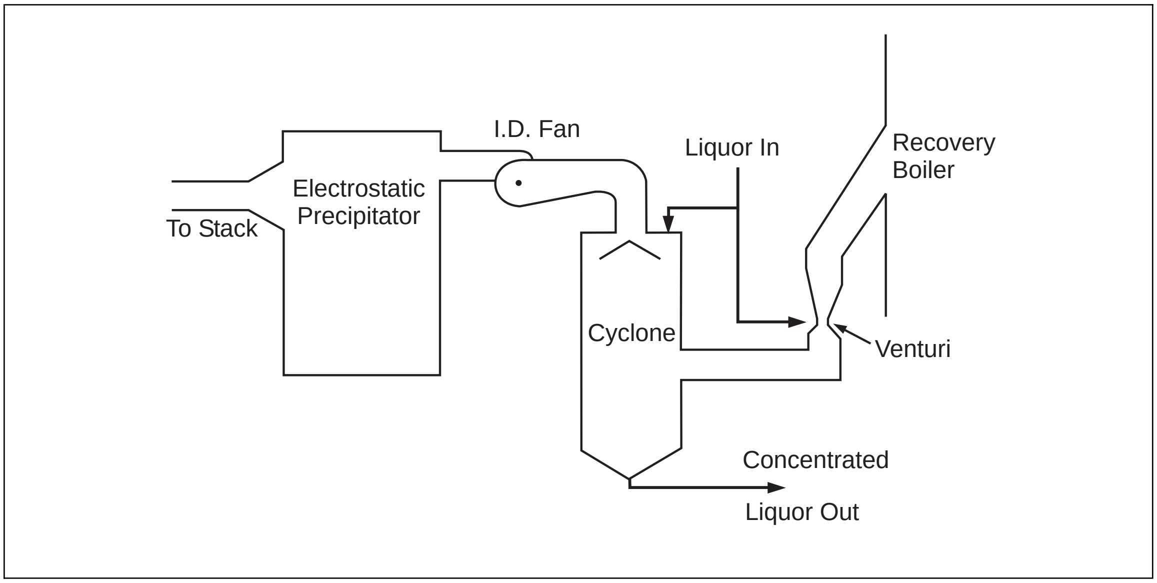

Fig. 3.3.1-2. Cyclone evaporator system

The interior of a DCE and ductwork can accumulate combustible, organic deposits commonly called char. Deposits occur because the hot flue gas directly contacts the weak liquor. The flue gas is cooled and the liquor is concentrated. Liquid droplets and solids from the liquor are deposited in the DCE and on surfaces and ledges in the ductwork. Over time, layers of char deposits build up, creating a concealed, generally inaccessible fire hazard.

Fire in the char deposits can occur due to process upsets. During normal conditions, flue gas flow through the ductwork is oxygen deficient due to high carbon dioxide component. Even though char is constantly exposed to temperatures well above its autoignition temperature, it normally will not ignite because of limited oxygen. However, during process upsets, oxygen can increase in the flue gas stream, creating optimum conditions for the preheated char to auto ignite. In addition, loss of power to the cascade evaporator wheel drive can allow liquor to dry out and auto ignite on the wheel. Increased liquor viscosity may cause high torque, which in turn trips the cascade drive, also resulting in autoignition of the char.

Fires in char deposits display surface-burning characteristics rather than deep-seated burning characteristics and can be extinguished by a quickly actuated steam suppression system.

Because the fire is in a concealed space and provision for access for manual suppression is not provided nor practical during normal operation, lack of a fixed automatic suppression system can lead to an uncontrolled fire within the DCE, ductwork and downstream equipment. Damage to the equipment and extended business interruption can result.

During complete shutdown, when ductwork is open for maintenance or inspection, char deposits have been ignited by hot work and electrical appliances. Manual response with fire water hoses or extinguishers can be effective during shutdown when steam might not be available or is undesirable.

DCE is not typically installed on a new BLRB and many DCE have been removed from existing BLRB due to air quality requirements. In the “low odor” design the DCE is replaced by another evaporator, known as a “concentrator”. To maintain boiler efficiency, the low odor boiler will have extended economizer surface and may have feedwater-to-combustion-air heat exchangers.

3.3.2 Cascade Evaporators

With the cascade evaporator (Figure 3.3.2), the flue gas enters the evaporator at 600°F to 800°F (315° to 430°C) and evaporates water from the black liquor adhering to the rotating, partly submerged, tubular wheel. The flue gases, cooled to about 300°F (150°C) at the evaporator outlet, pass through the induced-draft fan, an electrostatic precipitator, and then to a stack and atmosphere. The induced draft fan is frequently located between the cascade outlet and the precipitator where it may accumulate char. Or, it may be located after the precipitator, where it would not accumulate char.

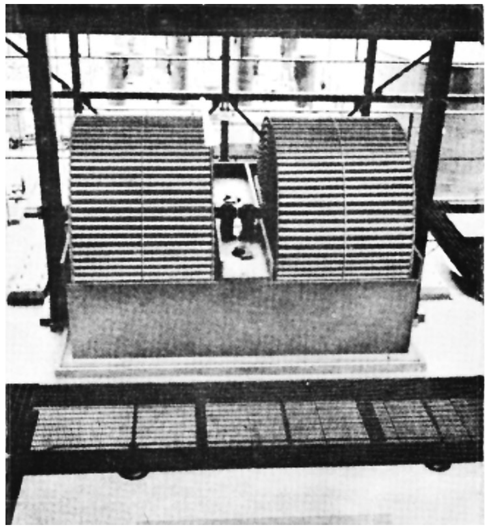

Fig. 3.3.2. Tubular cascade evaporator with outer casing removed

3.3.3 Cyclone Evaporators

With the cyclone evaporator (Figure 3.3.3-1) or venturi evaporator-scrubber with cyclone separator (Figure 3.3.3-2), the flue gas, at 600°F to 800°F (315°C to 430°C), passes through the venturi throat (if used) and to the cyclone inlet. Then the gases pass through the cyclone, counter-flow to the black liquor spray, and exit at about 300°F (150°C). Again, the induced-draft fan is frequently located between the cyclone outlet and the precipitator where it can accumulate char. Or, it may be located after the precipitator, where it would not accumulate char. (See Figure 3.3.3-3.)

3.3.4 Steam Suppression Systems

Because water presents unusual exposure to BLRB operation, primarily from the smelt-water explosion potential, a concern exists about using water-based fire protection systems. FM recommends conventional water suppression systems, primarily due to better reliability and adequacy of water supplies over steam supplies. However, steam suppression systems are acceptable when installed and maintained as recommended.

3.3.5 Fire Protection System Maintenance

Severe corrosion and abrasion conditions exist in the DCE and flue gas system. The rate of deterioration of the ducts and fire protection devices is highly variable. The composition of the flue gas and black liquor, and the method of boiler operation can affect deterioration.

Heat detectors and spray nozzles or sprinklers are exposed to the adverse conditions in the DCE and ducts. Use of a reasonably corrosion-resistant material for piping, spray nozzles, sprinklers and thermocouple or heat detector wells can reduce the rate of deterioration. Corrosion-resistant sprinklers have been used with reasonable success with and without protective corrosion-resistant caps. Installations using these materials for nozzles or sprinklers have not required replacement for at least one year. Some have been reported in satisfactory condition after more than five years.

Overall maintenance of the installation requires considerable effort. The systems require periodic testing, inspection and replacement. Actual operating experience may dictate cleaning of DCE system deposits and maintenance of fire protection equipment more frequently than the planned boiler pressure part condition assessment intervals.

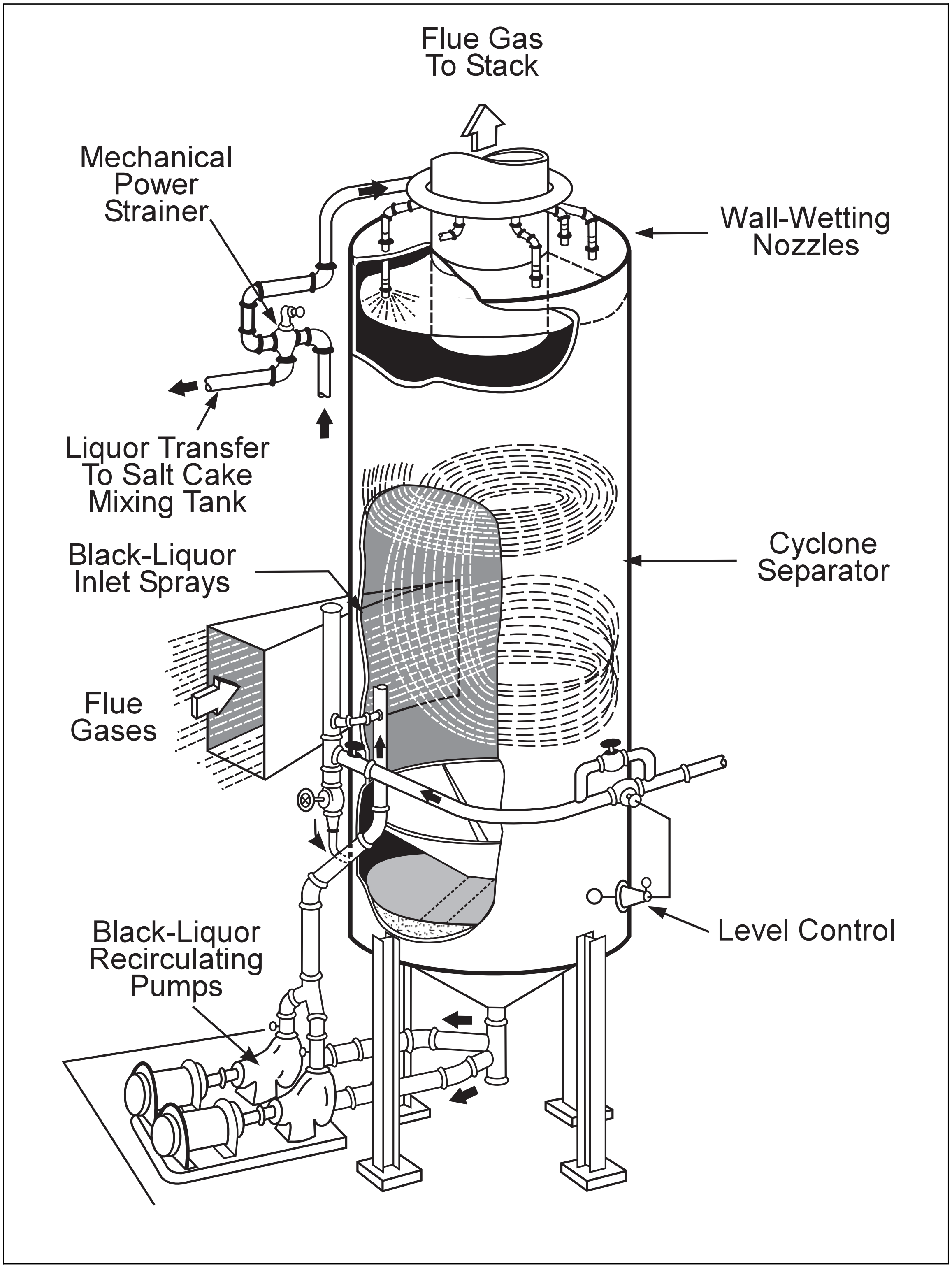

Fig. 3.3.3-1. Cyclone evaporator

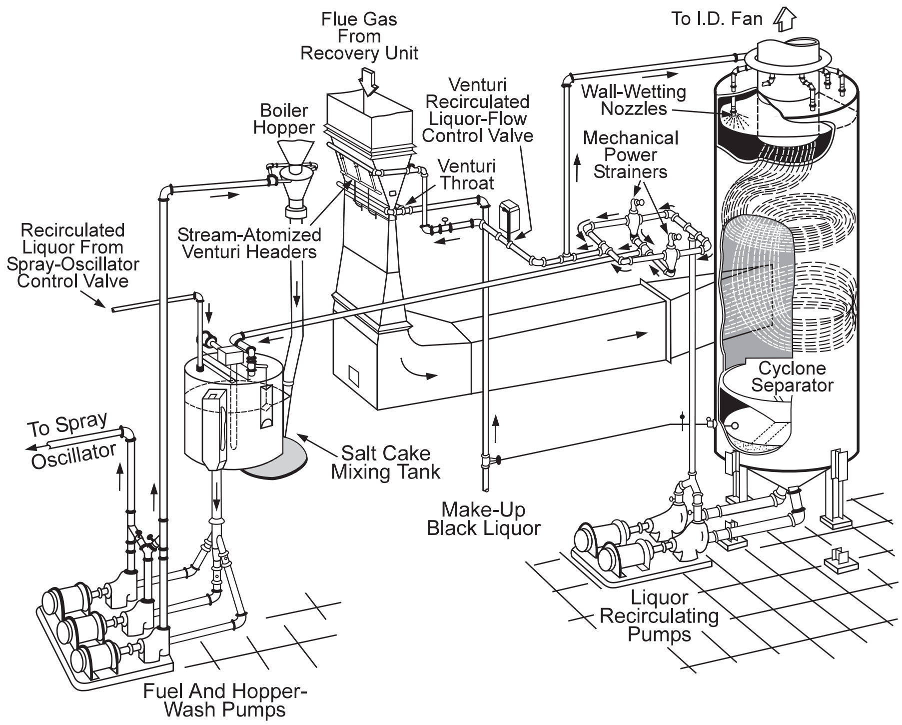

Fig. 3.3.3-2. Venturi evaporator-scrubber and cyclone separator

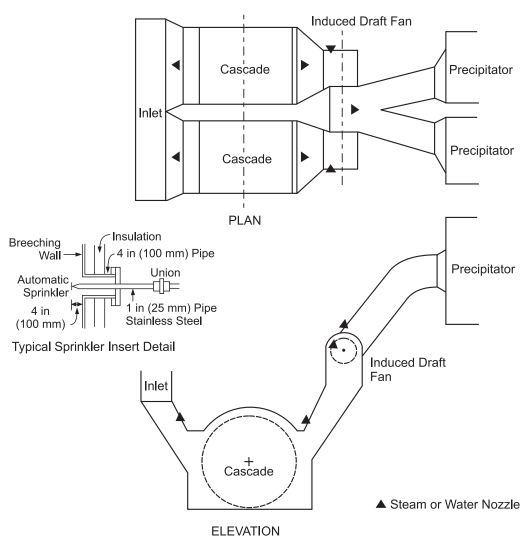

Fig. 3.3.3-3 Nozzle location for cascade evaporator and induced draft fan

3.4 Routine Spares

The following are common routine spares for chemical recovery boilers. Store and maintain the routine spares per original equipment manufacturer recommendations to maintain viability. Refer to Data Sheet 9-0 for additional guidance.

- Instrument controls
- Refractometer parts
- Tubes
- Tube bends
- Motors
- Gear set components
- Soot blower lances
- Smelt spouts
- Liquor nozzle (to include splash plates)

4.0 REFERENCES

4.1 FM

Data Sheet 1-44, *Damage-Limiting Construction*
Data Sheet 5-32, *Data Centers and Related Facilities*
Data Sheet 6-5, *Oil- or Gas-Fired Multiple Burner Boilers*
Data Sheet 6-11, *Thermal and Regenerative Catalytic Oxidizers*
Data Sheet 6-12, *Low-Water Protection for Boilers*
Data Sheet 6-13, *Waste Fuel-Fired Facilities*
Data Sheet 6-23, *Watertube Boilers*
Data Sheet 7-32, *Ignitable Liquid Operations*
Data Sheet 7-78, *Industrial Exhaust Systems*
Data Sheet 9-0, *Asset Integrity*
Data Sheet 10-8, *Operators*
Data Sheet 12-43, *Pressure Relief Devices*

4.2 Others

See Appendix C, Bibliography.

APPENDIX A GLOSSARY OF TERMS

A.1 Common Acronyms

ABTCP	Brazilian Technical Association of Pulp and Paper
AF&PA	American Forest & Paper Association
ASME	American Society Of Mechanical Engineers
BLRB	Black Liquor Recovery Boiler (generic for either Kraft or soda)
BLRBAC	Black Liquor Recovery Boiler Advisory Committee
BMS	Burner Management System
BTU	British Thermal Unit
CGSB	Canadian Government Standards Board
CNCG	Concentrated Noncondensible Gases
CO	Carbon Monoxide
CPU	Central Processing Unit
DA TANK	Deaerator Tank
DCE	Direct Contact Evaporator
DCS	Distribution Control System
DNA	Does Not Apply
DNCG	Dilute Non-condensable Gases
E&I	Electrical & Instrumentation
EPA	Environmental Protection Agency
ESP	Emergency Shutdown Procedure
FBM	Field Bus Module
FD Fan	Forced Draft Fan
FRBC	Finnish Recovery Boiler Committee, Suomen Soodakattilayhdistys
HVLC	High-Volume Low-Concentration (waste gases, see DNCG)
I/O	Input/Output
ID Fan	Induced Draft Fan
IPST	Institute of Paper Science and Technology (Georgia Institute of Technology, USA)
LVHC	Low-Volume High-Concentration (waste gases, see CNCG)
LWCO	Low-Water Cutoff (fuel trip)
MAWP	Maximum Allowable Working Pressure
MCC	Motor Control Center
MFT	Master Fuel Trip
MT	Magnetic Particle Testing
NBIC	National Board Inspection Code
NCG	Noncondensible Gases
NDE	Nondestructive Examination
NDT	Nondestructive Testing
OD	Outside Diameter
P&ID	Piping And Instrumentation Diagram
PES	Programmable Electronic System
PLC	Programmable Logic Controller
PPB	Parts Per Billion
PPM	Parts Per Million
PT	Liquid Penetrant Testing
SHK	Swedish-Norwegian Recovery Boiler Committee (Sodahuskommitten, SHK)
SOP	Standard Operating Procedure
SSOV	Safety Shut-Off Valve
TAPPI	Technical Association Of The Pulp And Paper Industry
UPS	Uninterruptible Power Supply
UT	Ultrasonic Testing
WFMT	Wet Fluorescent Magnetic Particle Testing

A.2 Terms

A.2.1 Liquid and Gas Fuels

Atomizing Medium: Steam or air typically supplied to a heavy oil burner to assist the atomization of the oil.

Atomizing Medium Interlock: Usually a differential pressure sensing device to close an oil burner safety shutoff valve (BSSV) when the differential pressure between the atomizing medium and oil is not within predetermined limits for safe firing.

Auxiliary Fuel: Fuel gases or fuel oils which are required to initiate recovery boiler firing and may be used to supplement or stabilize black liquor firing.

Auxiliary Fuel Safety Shutoff Valve: A fuel shutoff valve having proof of closure, which automatically and completely shuts off the flow of auxiliary fuel to a burner, group of burners or igniters.

Burner: A device for the introduction of fuel and air in a pattern to establish ignition and maintain stable combustion.

Hearth or Start-up Burner: A burner located below the liquor guns used to establish suitable conditions to initiate liquor firing and may be used to stabilize liquor firing.

Upper Level or Load Burner: A burner located above the liquor gun port elevation provided to supplement steam generation.

Burner Air Flow Interlock: System that senses (direct or indirect) combustion air flow to each burner and interrupts fuel flow at a predetermined minimum safe air flow.

Burner Management System (BMS): A control system designed to ensure safe operation of fuel burners. The system requires the operator to follow a predetermined sequence to initiate firing, provides system status information to the operator and permits operator intervention. The burner management system includes the fuel interlock system, fuel trip system, master fuel trip system, flame monitoring and tripping systems, ignition subsystem, and main burner subsystem.

Combustion Control System: System to regulate the furnace fuel and air inputs for both auxiliary fuel (including NCG streams and other liquid waste streams) and black liquor and maintain air/fuel ratio within the limits required for safe combustion throughout the operating range of the recovery furnace.

ESP Interlock: Interlock that interrupts all fuel firing (closes auxiliary fuel safety shutoff valves and diverts black liquor) and prevents firing of auxiliary fuel until interlock is manually reset by the operator.

Direct Contact Evaporator Outlet Temperature Interlock: System that monitors direct contact evaporator outlet temperature and terminates combustion air flow on trip and may actuate a fire extinguishing system.

Firm power: Two independently supplied AC sources not susceptible to the same interruption. Uninterruptible power supply or emergency generator power, sufficient duration of the power is available to permit a safe and controlled shutdown upon loss of the primary power supply.

Furnace High Pressure Interlock: System to sense excessive high pressure in the furnace that may damage the boiler. All fuel firing is terminated.

Furnace Low Pressure Interlock: System to sense excessive low pressure in the furnace that may damage the boiler. All fuel firing is terminated.

Hearth Zone: Portion of the furnace from the liquor gun port elevation down to the furnace floor.

High/Low Gas Pressure Interlock: A system that interrupts fuel gas flow if fuel gas pressure is outside of the predetermined safe limits.

High/Low Oil Pressure Interlock: A system that interrupts fuel oil flow if pressure is outside of the predetermined safe limits.

Igniter: A device providing sufficient energy to immediately ignite a burner. An igniter may be gas or oil fired or may be an electric device to directly ignite a burner.

Continuous Gas or Light Oil Fueled Igniter: A spark ignited, supervised pilot supplying sufficient energy to ignite and maintain ignition of an associated fuel burner under all light off and firing conditions. Location and capacity of the igniter ensures minimum ignition temperature for any ignitable combination of burner fuel and air inputs.

Interrupted Gas or Light Oil Fueled Igniter: A spark ignited, supervised pilot used to ignite an associated fuel burner under prescribed light-off conditions. Interrupted igniters may be shutdown at the end of the main burner trial for ignition period or may be left in service to support combustion of the main burner fuel under controlled firing conditions. When left in service beyond the main burner trial for ignition, interrupted igniters are either sized as continuous igniters or are provided with flame supervision independent of that provided for the fuel burner. When not sized as a continuous igniter, loss of main burner flame after the trial for ignition period, causes the shutdown of both the burner and igniter fuels.

Interrupted Direct Electric Igniter - A retractable igniter providing a high energy electrical spark discharge or high energy electric arc capable of directly igniting the auxiliary fuel burner. (Interrupted service only.) Supervision of main burner flame is required.

Supervise: Monitor conditions and automatically initiate corrective action upon detection of condition beyond prescribed limits (unsafe condition).

Minimum Furnace Purge Airflow: Purge air flow of sufficient volume and duration to ensure removal of flammable gases from the furnace prior to initiating any fuel firing.

Trial for Ignition: Time interval during which the burner flame safeguard system permits the BSSV to be open without proof of burner flame.

Vent Valve: Automatic valve on fuel gas vent line located between two fuel safety shutoff valves. Vent valve is interlocked to open when safety shutoff valves close. This reduces chance of gas leakage into the recovery furnace when the safety shutoff valves are closed.

A.2.2 Firing Liquor

Automatic Recirculation Shutoff Valve: High solids firing liquor is sometimes automatically recirculated to a pressurized firing liquor storage tank. The recirculation line is equipped with an automatic shutoff valve interlocked to close if any firing liquor trip condition occurs and prevents back flow of liquor to the firing header from the pressurized tank.

Black Liquor: Aqueous liquid by-product resulting from the alkaline pulp manufacturing process and containing inorganic and organic substances.

Low Solids Black Liquor: Black liquor containing 58% or less total solids.

Firing Liquor: Black liquor concentrated to greater than 58% total solids. Also known as heavy black liquor.

High Solids Black Liquor: Typically, firing liquor containing greater than 75% total solids.

Firing Liquor Divert: Automatic actions necessary to prevent firing liquor or low-solids liquor from entering the furnace. Action may be accomplished in differing fashions, but always provides two means of preventing flow into the furnace.

Firing Liquor Divert Valve: An automatic valve to prevent liquor from entering the firing liquor header.

Liquor Sprayer or Gun: Device used to inject and disperse firing liquor in the furnace.

Firing Liquor Isolated From Furnace Interlock: System of interlocks proving at least two means of preventing liquor from entering the furnace are engaged. One means is typically trip of liquor supply to liquor header. Second means may be proof of liquor sprayer SSV closed or could be proof of liquor sprayer removed from furnace.

Firing Liquor Header(s): The piping manifold through which firing liquor is fed to the liquor sprayers.

Firing Liquor Header Valve: An SSV that allows or shuts off the flow of firing liquor to the header(s).

Firing Liquor Header Wash Switch: A multiple position switch that allows the liquor header SSV to open when it is proven that either all of the liquor sprayer SSV are closed (and a procedure followed that requires dismantle of all sprayer and placement of a solid cover over the sprayer port) or proves all sprayers are out of the furnace and a solid cover has been placed over each sprayer port.

Firing Liquor Divert System or Valve: An automatic system that prevents flow to the liquor sprayers.

Firing Liquor Diversion: The automated process of preventing flow to the liquor sprayers.

Firing Liquor Heaters:
Direct Steam Heater: Firing liquor is heated by steam injected into the firing liquor flow.
Indirect Steam Heater: Firing liquor is heated in a shell-and-tube heat exchanger.

Firing Liquor Pump: Any pump that delivers firing liquor to the liquor header.

Furnace-Pressure (high or low) Interlock: A furnace pressure sensing system providing protection from predetermined high or low furnace gas pressures.

Hot Restart: Re-establishing liquor firing after a flame out, partial black out or furnace trip (no auxiliary fuel burner in service) with a hot smelt bed.

Liquor Purge Credit: A system that proves that the firing liquor header(s) contains only firing liquor.

Lower Furnace Wash System: A system of interlocks and a multiple position switch that bypasses the firing liquor refractometers to permit washing of the lower furnace once the operator has verified furnace conditions are appropriate for entry of wash water.

Managed System: A system using jumper tags and logs to track temporary system changes.

Moisture Balance: An analytical instrument used to determine the total solids content of black liquor.

Monitor: To sense and alarm a condition requiring attention, without initiating corrective action.

Non-Operating Water Source: Any water or weak black liquor that is not part of the process cycle (i.e., wash water, cascade fire protection water, etc.).

Operating Water Source: Any water or weak black liquor that is part of the process cycle (i.e., direct contact evaporator dilution water, gland seal water, steam for heaters, and steam out connections, etc.).

Precipitator Outlet Temperature: Temperature of the flue gases leaving an electrostatic precipitator of a recovery boiler system.

Prove: To establish, by measurement or test, the existence of a specified condition such as flame, level, flow, pressure, temperature, or position.

Recirculation Valve: A valve on the black liquor header that when open allows the black liquor to flow through the header(s) and recirculate back to the final evaporator or storage. The recirculation valve can also be a valve that allows black liquor to constantly recirculate from the black liquor firing header back to a pressurized black liquor storage on high solids fired recovery boilers. These recirculation valves shall be interlocked in the safe firing of black liquor firing and tripping logic.

Recovery Superintendent: Person having direct operational responsibility for the recovery boiler.

Refractometer: An optical instrument that measures the dissolved solids in black liquor; it will not measure suspended solids.

Supervise: To sense and alarm a condition requiring attention, and automatically initiate corrective action.

Total Solids: All non-water constituents of the black liquor which is the sum of dissolved and suspended material in the liquor.

A.2.3 Waste Streams Incineration

Chip steamer: a vessel used for the purpose of preheating or pretreating wood chips prior to the digester, using flash steam from the digester or live steam.

Control device or **combustion device:** an individual unit of equipment, including but not limited to, a thermal oxidizer, lime kiln, recovery furnace, process heater, or boiler, used for the thermal oxidation of organic hazardous air pollutant vapors or ignitable liquids extracted in the process, such as, turpentine or methanol. These Guidelines will only take into consideration the recovery furnace as the control device.

Concentrated noncondensible gas (CNCG): gas containing a concentration of sulfur compounds and/or turpentine, methanol and other hydrocarbons that is above the upper explosion limit (UEL), frequently referred to as Low Volume, High Concentration gases (LVHC). The CNCG definition is exclusive of volume.

CNCG collection system: the gas collection and transport system used to convey gases from the CNCG sources to the recovery boiler, or other combustion device.

CNCG system: the collection of equipment including the digester, turpentine recovery, evaporator, and steam stripper systems.

Dilute noncondensible gas (DNCG): gas containing a concentration of sulfur compounds that is below the lower explosion limit (LEL), frequently referred to as High Volume, Low Concentration Gases (HVLC). The DNCG definition is exclusive of volume.

DNCG collection system: the gas collection and transport system used to convey gases from the DNCG system to the recovery boiler, or other combustion device.

DNCG system: the collection of equipment including the pulp washing, knotter, screen, decker, and oxygen delignification systems, black liquor storage tanks, and boiler house chemical ash mix tank.

EPA: Environmental Protection Agency.

ESP: emergency shutdown procedure (ESP) M the steps taken to shutdown a recovery boiler in a very rapid, crash method. This procedure is used to reduce the possibility of an unsafe condition, such when water is entering the furnace from a leaking water wall tube, causing a smelt-water explosion. Operating devices, such as valves and dampers are automatically taken to a safe position and liquor burning is discontinued. (See the Safe Guidelines for Black Liquor Burning.)

Firm power: Two independently supplied AC sources not susceptible to the same interruption. Uninterruptible power supply or emergency generator power, sufficient duration of the power is available to permit a safe and controlled shutdown upon loss of the primary power supply.

Flammability limits: a fuel is flammable within two limits referred to as the UEL and LEL. Between these percentages of a fuel-air mixture, the gas once ignited propagates a self-sustaining flame.

Hazardous air pollutants (HAP): Phase I of the EPA Cluster Rule sets standards for these emissions at all pulping and bleaching facilities in the USA.

High Volume, Low Concentration (HVLC): generally those gases that represent high volume streams with a concentration of sulfur compounds that is below the lower explosion limit (LEL). The term does not reflect all of the low concentration streams in a mill, as some are low volume.

Lower Explosion Limit (LEL): a fuel-air mixture below this limit does not have enough fuel to support a flame. The LEL is fuel dependent. (See flammability limits.)

Low volume, high concentration (LVHC): generally those gases that represent low volume streams with a concentration of sulfur compounds that is above the upper explosion limit (UEL). The term does not reflect all of the high concentration streams in a mill, as some are high volume. (See concentrated noncondensible gas.)

Maximum flame propagation (MFP): the fastest velocity at which a flame will travel through a flammable vapor.

Methanol (CH_30H): an alcohol by-product created during the pulping and bleaching process by the derogation of the methoxy groups on lignin. Methanol is flammable and provides positive net Btu value. Methanol is water soluble and may be found in solution or as a vapor.

Noncondensible gas (NCG): refers to the gases containing sulfur and/or organic compounds, i.e., CNCG, DCNG, and SOG. Some mills refer to NCG as TRS gases.

Other waste streams: refers to any other waste stream that may be identified in the future for collection and treatment similar to the NCG.

Oven-dried pulp (ODP): a pulp sample at zero percent (0.0%) moisture content by weight.

Recovery boiler building (or area): this referring to the recovery boiler building, battery limit or whatever boundary is used within a mill to identify the areas around a recovery boiler that are affected by an ESP. Personnel are not to enter these areas until after an ESP is completed and entry is permitted.

Red oil: mixture of turpenes and TRS compounds.

Soap: a by-product formed during the pulping process by the reaction of alkali and fatty wood acids.

SSV: Safety shutoff valve.

Stripper off-gas (SOG): methanol, reduced sulfur gases and other volatiles removed by a steam stripping and distillation process from digester and condenser condensates (this definition deviates from the Cluster Rule definition).

Ton per day (tpd): tons (2000 lb) per day. When used, the term is qualified by the addition of phrases such as “of unbleached air dried or bone dry pulp”, indication whether the pulp is “bleached or unbleached”, “oven dry black liquor solids”, etc.

Total reduced sulfur (TRS): the total sulfur compounds existing in gaseous sulfate emissions, condensate, and waste waters that are the result of the reduction of sulfur by the pulping process. TRS typically includes hydrogen sulfide (H_2S), methyl mercaptan (CH_3SH), dimethyl sulfide (CH_3SCH_3), and dimethyl disulfide (CH_3SSCH_3).

Upper Explosion Limit (UEL): fuel-air mixtures above this limit are too rich (insufficient oxygen) to support a flame. The UEL is fuel dependent. (See flammability limits.)

A.2.4 Direct Contact Evaporator

Black Liquor - Aqueous liquid by-product resulting from the alkaline pulp manufacturing process and containing inorganic and organic substances.

Low Solids Black Liquor - Black liquor containing 58% or less total solids.

Heavy Black Liquor - Black liquor containing greater than 58% total solids.

Strong Black Liquor - Black liquor leaving multiple effect evaporators.

Weak Black Liquor - Black liquor before multiple effect evaporators.

Cascade Evaporator - A cylindrical bundle of tubes or plates attached to a hub and rotated by a horizontal axle. The horizontal elements and axle shaft form a wheel much like a paddle wheel, except that the elements provide lower resistance to the black liquor and flue gases. As the wheel rotates, the elements dip into and pass through the black liquor pool in the bottom. The rotation acts like a pump to lift the black liquor out of the pool. The hot flue gases heat the surface film, evaporating the moisture and concentrating the black liquor. The cascade evaporator is a direct contact evaporator because the hot flue gases directly contact the liquor being evaporated.

Cyclone Evaporator - An evaporator in the shape of a cylinder in which the flue gases enter tangentially near the bottom and exit at the center of the top. The black liquor is sprayed into the flue gases at the tangential entrance and around the top of the cylinder. The concentrated black liquor flows down the sides of the cyclone cylinder into a funnel and out the bottom. The evaporated moisture is carried out the top with the flue gases. A cyclone evaporator is a direct contact evaporator.

DCS: Distributed Control System - a control system whereby intelligent controllers and associated input/output hardware control different parts of the process, and are interconnected to each other by communication links.

Direct Contact Evaporator (DCE) - A heat exchanger in which hot flue gases are in direct contact with the black liquor. As the flue gases heat the liquor, water is evaporated. This is used to concentrate the black liquor up to a minimum of 58 percent total solids for firing.

Direct Contact Evaporator Outlet Temperature Interlock - A system that monitors direct contact evaporator outlet temperature, alarms at 100°F (55°C) above operating temperature and interrupts all fuel firing at 200°F (110°DC) above operating temperature. It also terminates combustion airflow on trip and may actuate a fire extinguishing system.

Emergency Shutdown Procedure (ESP) System - The ESP system permits immediate termination of all fuel firing and rapid draining and depressurization of the boiler if water is suspected to be entering the recovery furnace.

Evaporator Outlet Temperature - Temperature of the flue gases leaving either the cyclone or cascade-type black liquor evaporator of a recovery boiler system.

Interlock - A device that senses a limit or off- limit condition or an improper sequence of events. It causes shutdown of the offending or related piece of equipment, or it prevents proceeding in an improper sequence, to prevent a hazardous condition. Direct signals rather than transmitted signals shall be used wherever possible to actuate interlocks.

Monitor - To sense and alarm a condition requiring attention, without initiating corrective action.

Precipitator -A means (usually electrostatic) of collecting dust in the flue gases just before they go up the stack. The flue gases pass through a high- voltage electric field and dust particles take on an electrostatic charge. The charged dust particles are then attracted to oppositely charged plates or wire in the chamber. The dust particles attach themselves to the plate or the wire and accumulate into clumps that are too heavy to be carried in the flue gas stream. These clumps fall into a hopper and are carried away.

Precipitator Outlet Temperature - Temperature of the flue gases leaving an electrostatic precipitator of a recovery boiler system.

Supervise - To sense and alarm a condition requiring attention. This may also automatically initiate corrective action.

Total Solids - All non-water constituents of the black liquor, which is the sum of dissolved and suspended material in the liquor.

A.2.5 Miscellaneous Terms

Analog: Continuous variable signals or values.

Attemperator: A device to reduce the steam temperature by mixing it with lower temperature steam or water, or by passing it through tubes immersed in water of a boiler drum, generally by means of automatic control. The same as desuperheating.

Auto-manual Control: A control station (or selector station) which permits the operator to select either automatic or manual operation of equipment, can be at a location remote from the actual physical hardware, e.g., the operator may make an adjustment in the control room to change the position of a damper in an air duct hundreds of feet away. The operator may place the control station in the automatic mode and permit a controller to position the damper as required to maintain proper control.

Basic Process Control System (BPCS): (ISA-S84.01 P. 3.1.5) A system that responds to input signals from the equipment under control and/or from an operator and generates output signals that cause the equipment under control to operate in the desired manner. Also referred to as a Process Control System.

CRT: A display device resembling a television used to view items in the control system.

Clad Tube: Tube having corrosion protection in the form of a co-extruded corrosion resistant material (composite tube), or corrosion resistant weld metal, or a corrosion resistant diffusion coating (chromized tube)

DCS: Distributed Control System M a control system whereby intelligent controllers and associated input/output hardware control different parts of the process and are interconnected to each other by communication links.

Desuperheat: To reduce the temperature of a gas, i.e., steam to a lower temperature or to its saturation temperature. The saturation temperature is the boiling temperature of a liquid at its operating pressure.

Digital: Two-state signals or values, i.e., On-Off, High-Low, One-Zero.

Economizer: A tubular heat exchanger following the boiler bank. The boiler feedwater flows through the tubes increasing the water temperature just before it enters the boiler drum. The flue gases give up more of their heat as they pass through the economizer. This reduces the fuel required to produce steam; therefore, it is called an economizer.

Evaporator, Cascade: A cylindrical bundle of tubes or plates attached to hubs and rotated by a horizontal axle. The horizontal elements and axle shaft form a wheel much like a paddle wheel, except that the elements provide lower resistance to the black liquor and flue gases. As the wheel rotates, the elements dip into and pass through the black liquor pool in the bottom. The rotation acts like a pump to lift the black liquor out of the pool. The hot flue gases heat the surface film, evaporating the moisture and concentrating the black liquor. The cascade evaporator is a direct contact evaporator because the hot flue gases directly contact the liquor being evaporated.

Evaporator, Cyclone: An evaporator in the shape of a cylinder in which the flue gases enter tangentially near the bottom and exit at the center of the top. The black liquor is sprayed into the flue gases at the tangential entrance and around the top of the cylinder. The concentrated black liquor flows down the sides of the cyclone cylinder into a funnel and out the bottom. The evaporated moisture is carried out the top with the flue gases. A cyclone evaporator is a direct contact evaporator.

Evaporator, Direct Contact: A heat exchanger (Cascade or Cyclone Evaporators) in which hot flue gases are in direct contact with the black liquor. As the flue gases heat the liquor, water is evaporated. This is used to concentrate the black liquor up to a minimum of 58 percent total solids for firing.

Functional Test: A method of proving all elements of a system operate as designed.

Micro Processor: An intelligent piece of hardware, usually capable of executing only pre-defined programs. It usually cannot store or retrieve data from bulk storage devices.

Modification: A change or alteration that results in a deviation from the original design specifications or criteria.

Monitor: A means of showing (or reminding) the operator of conditions as they occur. A monitor displays a condition or measurement.

Noxious Stack Gas Analyzers: A group of gas analyzers which measure the presence and concentration of objectionable gases which are contained in the flue gases of a recovery boiler. Examples are: TRS (totally reduced sulfur), SO2 (sulfur dioxide), NOX (Nitrogen Oxides), etc.

Opacity (Smoke, Particulate): The measurement of light transmittance through a duct or stack. By proper calibration methods an opacity meter can measure particulate matter solids suspended in a gas stream, i.e., flue gases. An opacity meter can also measure smoke density, turbidity in liquids, etc. It is basically a means of measuring the loss of light between a light source and a light receiver.

Percent Total Solids in Black Liquor: The percentage of solids by weight in black liquor fluid in the recovery system. For example, if the black liquor is 70% solids, then 30% is water.

Powered Relief Valve: An electrically or pneumatically operated quick opening valve which relieves excess steam pressure. It is generally set at a lower pressure than mechanically (spring) operated relief valves.

Precipitator: A means (usually electrostatic) for collecting dust in the flue gases just before they go up the stack. The flue gases pass through a high voltage electric field and dust particles take on an electrostatic charge. The charged dust particles are then attracted to oppositely charged plates or wire in the chamber. The dust particles attached themselves to the wire where they precipitate into large groups or clumps which are too heavy to be carried by the flue gas stream. These clumps fall into a hopper where they are removed.

Primary Black Liquor Heater: Usually a direct contact heater which injects steam directly into the low temperature black liquor. This heater is normally located on the suction side of the black liquor nozzle pump. Indirect heaters may be used to avoid dilution of the black liquor.

PC: This abbreviation may represent programmable controller, or personal computer, depending on the context of its use. Throughout these recommendations, PC is used to represent programmable controller.

Programmable Logic Controller (PLC): A digital first level control device utilized for sequencing operations which are configured using ladder logic and may have limited analog or continuous control capability.

Record: A measurement that is continuously collected over a given time sample, using a chart recorder or trend log in a DCS system. **NOTE:** The time sample rate selected represents the most accurate record.

Safety Instrumented System (SIS): (ISA-S84.01 P.3.1.53) System composed of sensors, logic solvers, and final control elements for the purpose of taking the process to a safe state when predetermined conditions are violated. Other terms commonly used include Emergency Shutdown Procedure/System (ESP), Safety Shutdown System (SSD), Safety Interlock System and Flame Safety Supervisory System (FSSS).

SAMA Logic: Represents the total control loop philosophy with symbols and a diagramming format. (SAMA-Scientific Apparatus Manufacturers Association).

Secondary Black Liquor Heater: Usually a direct contact heater which injects steam directly into the warm black liquor. This heater is between the discharge of the black liquor nozzle pump and the black liquor spray nozzles in the furnace. Indirect heaters may be used to avoid dilution of the black liquor.

Smelt Bed Camera: A video camera to observe smelt bed and combustion conditions.

Smelt Spout: A trough which drains the molten smelt from the furnace into the dissolving tank. It is cooled to retard spout wastage by molten smelt. Water is commonly used as the cooling medium.

Soot Blower: A device using steam or compressed air for blowing dust, soot and ash from the fire side of the boiler tubes. Most soot blowing systems operate automatically and usually have a sequence control to blow in a specific pattern or arrangement.

APPENDIX B REVISION HISTORY

The purpose of this appendix is to capture the changes that were made to this document each time it was published. Please note that section numbers refer specifically to those in the version published on the date shown (i.e., the section numbers are not always the same from version to version).

April 2025. Interim revision. Minor editorial changes were made for additional clarity referencing water treatment program guidance in Data Sheet 6-23, *Watertube Boilers*.

October 2024. Interim revision. Minor editorial changes were made for additional clarity.

January 2024. Interim revision. Editorial revision to add clarification, update industry terminology and resolve conflicts with BLRB Audit Checklist.

July 2023. Interim revision. Minor editorial changes were made.

April 2021. Interim revision. Significant changes include the following:

A. Updated equipment contingency planning and sparing information.

B. Made minor editorial changes.

July 2013. Minor editorial changes were made.

October 2012. Descriptions of preferred low-water protection schemes are provided in recommendation 2.2.2.2.

April 2012. Minor editorial changes were made for this revision.

January 2012. Minor editorial changes were done for this revision.

July 2010. Clarified recommendation 2.2.2.3.

September 2010. Minor editorial changes were made for this revision.

April 2010. Data sheet has been completely rewritten to provide FM Global guidance only.

January 2009. Complete rewrite of data sheet.

January 2007. Only editorial changes were made in this revision.

May 2004. The Data Sheet 6-21/12-21 has been completely rewritten.

This data sheet also now includes protection recommendations for direct contact evaporators that had been in Data Sheet 6-23/17-23 Fire Protection for Direct-Contact Evaporators Used With Black Liquor Recovery Boilers.

May 2001. Only editorial changes were made in this revision.

January 2000. In this revision, the document was reorganized to provide a consistent format.

APPENDIX C BIBLIOGRAPHY

Adams, T. N. and W. J. Frederick. *Kraft Recovery Boiler Physical and Chemical Processes.* The American Paper Institute. 1988.

Adams, Terry N. *Kraft Recovery Boilers.* TAPPI Press. 1997.

American Forest & Paper Association (AF&PA) Recovery Boiler Committee. *Guidelines and Checklist for Specification and Construction of Black Liquor Recovery Boilers.* www.afandpa.org

American Forest & Paper Association (AF&PA) Recovery Boiler Committee, Operations and Maintenance Subcommittee. *Recovery Boiler Safety Audit Guidelines.* www.afandpa.org

American Forest & Paper Association (AF&PA) Recovery Boiler Committee. Operations and Maintenance Subcommittee. *The Recovery Boiler Reference Manual for Owners and Operators of Kraft Recovery Boilers, Volumes I, II, and III.* www.afandpa.org

American Society for Nondestructive Testing. *Nondestructive Testing.* Recommended Practice SNT-TC-1A. www.asnt.org.

American Society of Mechanical Engineers (ASME). Boiler and Pressure Vessel Code. Section I: Power Boilers; Section VII: Recommended Rules for Care of *Power Boilers*. www.asme.org.

Barna, J. L. and E. F. Radke. "Comparative study of membrane temperatures and stresses in composite tube recovery boilers." Presented at TAPPI Engineering September 1988.

Barna, J. L. and R. J. Mattie, et. al. "Corrosion Experience in Black Liquor Recovery Boilers." Presented at the TAPPI Kraft Recovery Operations Seminar, January 1989.

Black Liquor Recovery Boiler Advisory Committee (BLRBAC). *Materials and Welding Guidelines for Black Liquor Recovery Boilers (DRAFT).* www.blrbac.net.

Black Liquor Recovery Boiler Advisory Committee (BLRBAC). *Recommended Good Practice: Emergency Shutdown Procedure (ESP) and Procedure for Testing ESP System for Black Liquor Recovery Boilers, and Recommended Good Practice: Guidelines for Post-ESP Procedures for Black Liquor Recovery Boilers.* www.blrbac.net

Black Liquor Recovery Boiler Advisory Committee (BLRBAC). *Recommended Good Practice: Fire Protection In Direct Contact Evaporators and Associated Equipment.* www.blrbac.net

Black Liquor Recovery Boiler Advisory Committee (BLRBAC). *Recommended Good Practice: Installation Checklist and Classification Guide for Instruments and Control Systems Used in Operation of Black Liquor Recovery Boilers.* www.blrbac.net

Black Liquor Recovery Boiler Advisory Committee (BLRBAC). *Recommended Good Practice: Safe Firing of Auxiliary Fuel in Black Liquor Recovery Boilers.* www.blrbac.net

Black Liquor Recovery Boiler Advisory Committee (BLRBAC). *Recommended Good Practice: Safe Firing of Black Liquor in Black Liquor Recovery Boilers.* www.blrbac.net

Black Liquor Recovery Boiler Advisory Committee (BLRBAC). *Recommended Good Practice: Thermal Oxidation of Waste Streams in Black Liquor Recovery Boilers Recovery Boilers.* www.blrbac.net

Black Liquor Recovery Boiler Advisory Committee (BLRBAC). *Recommended Rules for Personnel Safety for Black Liquor Recovery Boilers.* www.blrbac.net

European Committee for Standardization (CEN). *Water-Tube Boilers and Auxiliary Installations.* Standard EN 12952.

Fapet OY. *Papermaking Science and Technology. Book* 6B: Chemical Pulping. TAPPI Press. 1999.

Feedwater Quality Task Group for the Industrial Boiler Subcommittee of the ASME Research Committee on Water in Thermal Power Systems. *Consensus of Operating Practices for the Control of Feedwater and Boiler Water Quality in Modern Industrial Boilers.* 1979.

Hough, G. *Chemical Recovery in the Alkaline Pulping Processes.* Third Edition. TAPPI Press. 1992.

Joint Textbook Committee of the Paper Industry. *Pulp and Paper Manufacture. Third Edition. Volume 5, Alkaline Pulping. 1989.* www.tappi.org

Joint Textbook Committee of the Paper Industry. *Pulp and Paper Manufacture.* Third Edition. Volume 4, Sulfite Science and Technology. 1985. www.tappi.org

Keiser, J. R., et. al. *"Why Do Kraft Recovery Boiler Composite Floor Tubes Crack?" TAPPI Journal,* Vol.-84:No.8. TAPPI Press. 2001.

Keiser, J. R., et. al. *"Recent Observations of Recovery Boiler Primary Air Port Cracking and Characterizations of Environmental Conditions."* Presented at the 2002 TAPPI Fall Technical Conference. TAPPI Press. 2002.

Mimms, A. *Kraft Pulping, A Compilation of Notes.* TAPPI Press. 1989.

National Board of Boiler and Pressure Vessel Inspectors. *National Board Inspection Code.* ANSI / NB-23. www.nationalboard.org

Power Specialists Associates. *AF&PA CBT-Based Recovery Boiler Training Program.* www.psa-engineering.com

Singer, Joseph G. *Combustion Fossil Power.* 4th Edition. Combustion Engineering, Inc. 1991.

Sodahuskommitten (Swedish-Norwegian Recovery Boiler Committee). Bulletins A, B, C, D, E, and F. www.sodahuskommitten.se

Smook, G. A. *Handbook for Pulp and Paper Technologists. Joint Textbook Committee of the Paper Industry.* 1986.

Suomen Soodakattilayhdistys (Finnish Recovery Boiler Committee). *Recommended Procedure for Incineration of Noncondensible Gases.* www.soodakattilayhdistys.fi

Stultz, S. C. and J. B. Kitto.-*Steam: Its Generation and Use. 41rst Edition.* The Babcock and Wilcox Company, 2005.

TAPPI. *Chloride and potassium measurement and control in the pulping and chemical recovery cycle.* Technical Information Paper TIP 0416-15 2005. www.tappi.org

TAPPI. *Collection and burning of concentrated noncondensible gases: regulations, design, and operation.* Technical Information Paper TIP 0416-09 2008. www.tappi.org

TAPPI. *Design engineer decisions tree: paper mill boiler feedwater.* Technical Information Paper TIP 0416-04 2005. www.tappi.org

TAPPI. *Estimating the first melting temperature of fireside deposits in recovery boilers.* Technical Information Paper TIP 0416-12 2004. www.tappi.org

TAPPI. *Evaluating reverse osmosis for treating makeup to the boiler feedwater in a pulp and paper mill.* Technical Information Paper TIP 0416-07 2006. www.tappi.org

TAPPI. *Guidelines for evaluating quality of boiler tube butt welds with ultrasonic testing.* Technical Information Paper TIP 0402-31 2006. www.tappi.org

TAPPI. *Guidelines for obtaining high quality radiographic testing of butt welds in boiler tubes.* Technical Information Paper TIP 0402-33 2006. www.tappi.org

TAPPI. *Guidelines for replacement of generating bank tubes with expanded joints in two-drum boilers.* Technical Information Paper TIP 0416-08 2002. www.tappi.org

TAPPI. *Guidelines for specification and inspection of electric resistance welded (ERW) and seamless boiler tube for critical and non-critical service.* Technical Information Paper TIP 0402-13 2005.www.tappi.org

TAPPI. *Inspection for cracking of composite tubes in black liquor recovery boilers.* Technical Information Paper TIP 0402-30 2001. www.tappi.org

TAPPI. *Installation and repair of pin studs in black liquor recovery boilers.* Technical Information Paper TIP 0402-15 2002. www.tappi.org

TAPPI. *Keys to successful chemical cleaning of boilers.* Technical Information Paper TIP 0416-06 2004. www.tappi.org

TAPPI. *Recovery boiler energy efficiency improvements.* Technical Information Paper TIP 0416-16 2008. www.tappi.org

TAPPI. *Recovery boiler performance calculation M short form.* Technical Information Paper TIP 0416-01 2007. www.tappi.org

TAPPI. *Response to contamination of high purity boiler feedwater.* Technical Information Paper TIP 0416-05 2005. www.tappi.org

TAPPI. *Solids Content of Black Liquor.* Test Method T 650 om-05. www.tappi.org

TAPPI. *Stripping of kraft pulping process condensates: regulations, design and operation.* Technical Information Paper TIP 0416-10 2008. www.tappi.org

TAPPI. *Ultrasonic testing (UT) for tube thickness in black liquor recovery boilers. Part I: Guidelines for accurate tube thickness testing. Part II: Default layouts for tube thickness surveys in various boiler zones.* Technical Information Paper TIP 0402-18 2001. www.tappi.org

TAPPI. *Ultrasonic technician performance test for boiler tube inspection.* Technical Information Paper TIP 0402-21 2008. www.tappi.org

TAPPI. *Water quality and monitoring requirements for paper mill boilers operating on high purity feedwater.* Technical Information Paper TIP 0416-03 2005. www.tappi.org

TAPPI. *Water quality guidelines and monitoring requirements for paper mill boilers operating with softened makeup water.* Technical Information Paper TIP 0416-14 2005. www.tappi.org

Tran, H., et. al. “Removal of Recovery Boiler Fireside Deposits By Thermal Shedding.” Presented at the 1992 International Chemical Recovery Conference. TAPPI Press. 1992.