BLACK LIQUOR SPRAYING

Rick Wessel
Consulting Engineer
The Babcock & Wilcox Company
20 South Van Buren Avenue
Barberton, Ohio 44203

INTRODUCTION

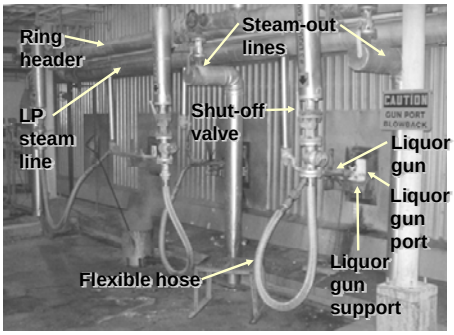
Spray droplet size and spray distribution are key variables in controlling black liquor droplet combustion, char bed combustion, smelt reduction, entrainment, and carryover. Black liquor sprayed into recovery furnaces should ideally form droplets small enough to dry and partially pyrolyze before reaching the char bed, but large enough to avoid being entrained in the furnace gas flow. Droplets about 2 to 4 mm in diameter are usually considered the proper size for good recovery boiler operation. The impact of nozzle design, fluid properties, and operation on black liquor trajectory, droplet size, and spray distribution will be presented below, and the dramatic impact of flashing on nozzle performance will be discussed.

The nozzle itself is only one component of the black liquor delivery system. The delivery system starts at the heavy black liquor storage tank. The delivery system includes black liquor pumps, mix tanks for precipitator dust and makeup chemicals, a ring header that surrounds the boiler, connecting pipes and hoses, liquor guns, and finally, liquor nozzles.

The elements which are particularly important are the ring header, the piping to the individual liquor guns, the shutoff valves, the flexible hose, the liquor gun, and the nozzle. **Slide 3** shows a photograph of the arrangement of these elements on a recovery boiler.

Slide 3

Black Liquor Guns



Slide 4 lists the key parameters that control black liquor spray. Process variables are determined by the mill processes outside of the recovery boiler. Operating parameters are usually within the control of boiler operator, but may be limited by the boiler design.

Slide 4

Key Parameters for BL Spray

Process Variables	Operating Parameters
• Liquor dry solids	• Number and arrangement of guns
• Liquor elevated boiling point	• Tilt or oscillation of gun barrels
• Physical properties (density, viscosity, etc)	• Nozzle type and size
• Liquor burning characteristics (swelling)	• Firing temperature
	• Liquor flow rate and pressure

Slide 5 lists the key variables that characterize the black liquor spray.

Slide 6 illustrates the importance of droplet size on the particle trajectory. The largest drops (> 2mm) are influenced by the initial velocity of the spray and gravity; these particles deposit on the furnace walls and char bed after partial drying and pyrolysis.

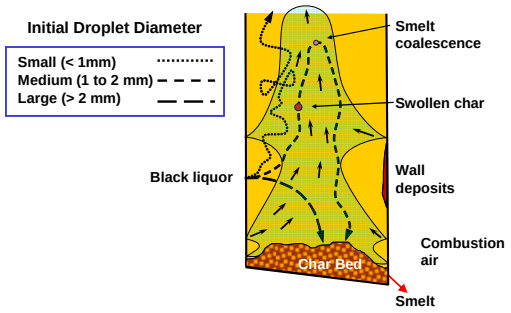
Slide 5

Spray Characteristics

- **Median droplet diameter**
- **Droplet size distribution**
- **Spray velocity**
- **Flow distribution**

Slide 6

Impact of Droplet Size on Trajectory



The smallest drops (< 1mm) have the greatest aerodynamic drag and are swept upward by the gases rising in the furnace; these particles are known as carryover and they deposit on the tubes of the convection pass and potentially plug the boiler. Intermediate size drops (1 to 2 mm) burn in suspension as the swollen particles are swept upward by gas flow, but then fall to the char bed after smelt coalesces into a dense molten smelt particle.

The objectives of black liquor spraying are summarized in **Slide 7**. The first objective is to control droplet size to achieve a mass median diameter of 2 to 4 mm. Droplet size should be large enough to minimize particle carryover and small enough to dry the liquor before it reaches the char bed. Droplet size also determines the amount of burning that occurs in suspension versus that which occurs on the char bed. A decrease in droplet size will cause an increase suspension burning and reduce the amount of char delivered to the bed, and reduce the height of the char bed.

The second objective of spraying is to distribute the liquor spray uniformly over the plan area of the furnace and char bed. The amount of liquor hitting the walls should be minimized, but can not be completely eliminated. The goal is to create a uniform symmetrical bed shape that maximizes the area for heat transfer and chemical conversion of char and smelt on the surface of the bed.

Slide 7

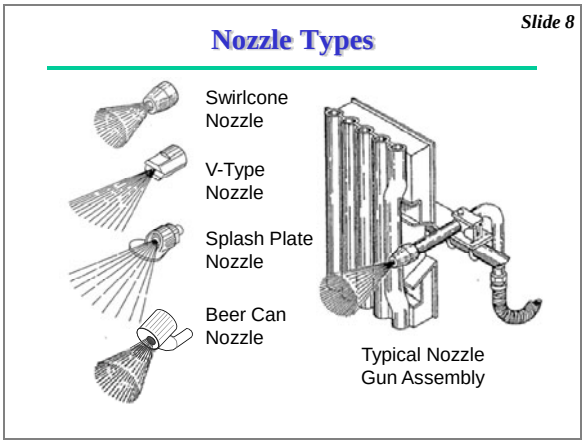
Objectives for Effective Spraying

- **Control droplet size (2 to 4 mm)**
  - **Minimize particle carryover**
  - **Deliver mostly dry liquor to bed**
  - **Control height of char bed**
- **Distribute liquor spray**
  - **Minimize liquor on furnace walls**
  - **Create a uniform symmetrical bed shape**

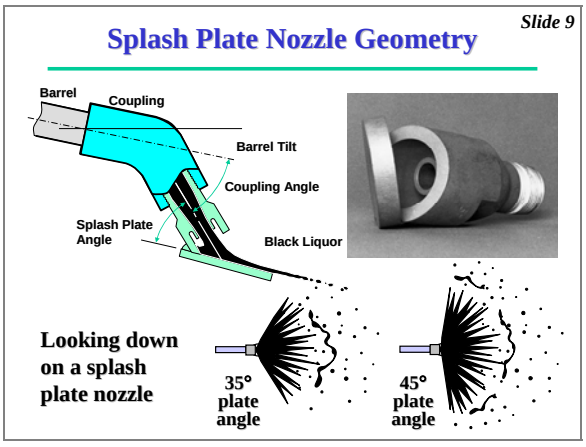
BLACK LIQUOR NOZZLES

Slide 8 shows four basic types of black liquor nozzles and a schematic of the liquor spray from each nozzle. The purpose of any nozzle is to spread out the flow of black liquor and form a sheet of liquid that breaks up into coarse drops. The spray distribution will be determined by the specific nozzle type. In general, the flat sheet from a splash plate nozzle follows the angle of the splash plate itself. For the swirlcone and beercan nozzles, the spray distribution is conical, and for a V-type nozzle the spray is flat; For all but the splash plate nozzle, the sheet follows the nozzle axis. This pattern, along with the

liquor velocity, sets the initial distribution of the liquor ligaments and drops into the furnace.

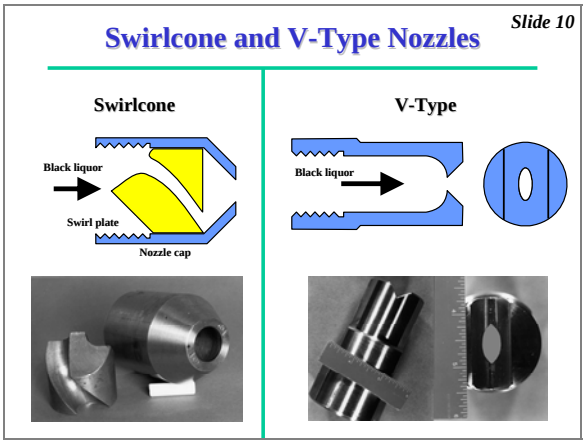


Slide 9 shows a schematic of a splash plate nozzle along with a photograph. This nozzle consists of a flat plate of rounded cross-section attached at an angle to the end of a pipe. Black liquor flows through the pipe and, when it exits from the end of the pipe, it strikes the flat face of the plate at an angle of approximately 45°. The flow is turned and flattened into a sheet of liquid. The sheet leaves the plate and breaks up into droplets.



Looking down on the splash plate nozzle, the liquid sheet spreads out to an angle of 120° to 180°. The selection of nozzle splash plate angle controls the spreading angle of the spray.

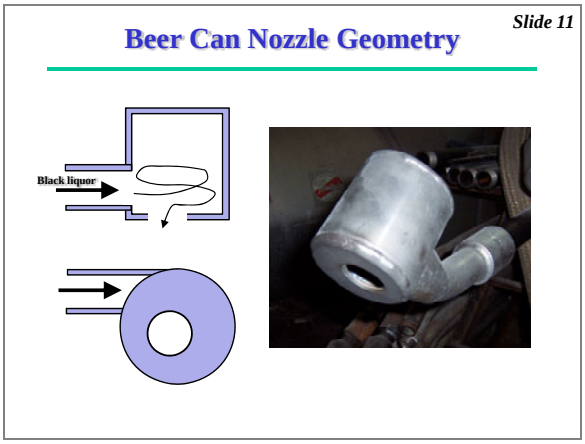
Slide 10 shows schematic diagrams and photographs of a swirlcone nozzle and a V-type nozzle.



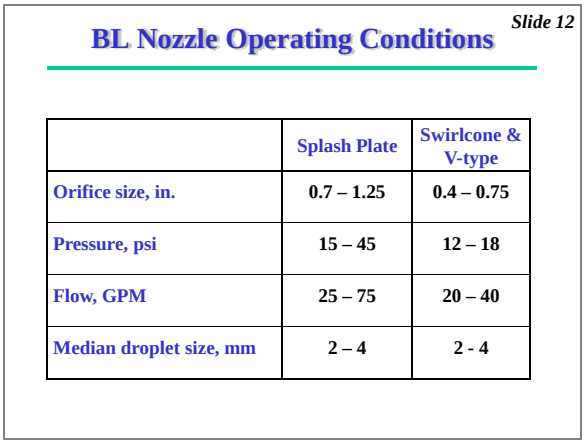
Though the appearance of the swirlcone nozzle is quite different, the droplet formation process is similar to that for the splash plate. Black liquor flows down a barrel to the nozzle. Just ahead of the nozzle is a block or swirl plate with spiral grooves which cause the flow to rotate as it flows along the walls of the nozzle cap. A short distance downstream is the circular nozzle exit. The rotating hollow flow exits from the nozzle in the form of a conical sheet of black liquor. This conical sheet of liquor breaks apart by the same mechanism as the flat sheet from the splash plate nozzle.

The V-type nozzle consists of a cylindrical tube topped with a hemisphere that has been cut across the tip with a V-shaped channel. Liquor flows at relatively low velocity to a position just ahead of the nozzle exit opening and then is accelerated and discharged in a flat sheet.

Slide 11 shows a schematic of the beer can nozzle. The nozzle consists of a cylindrical chamber with a tangential inlet. The liquor swirls around in the cylinder and is discharged through a hole at the bottom, creating conical spray pattern.



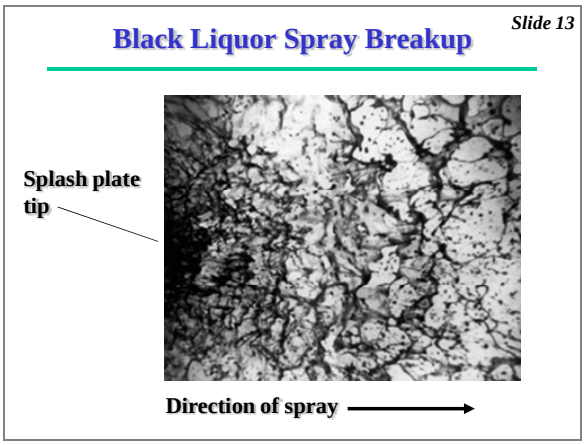
The typical size, operating conditions, and black liquor droplet size for the different nozzles is summarized in **Slide 12**.



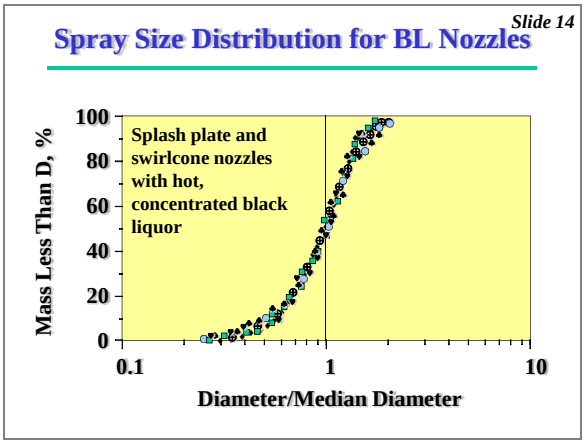
	Splash Plate	Swirlcone & V-type
Orifice size, in.	0.7 – 1.25	0.4 – 0.75
Pressure, psi	15 – 45	12 – 18
Flow, GPM	25 – 75	20 – 40
Median droplet size, mm	2 – 4	2 - 4

DROPLET SIZE DISTRIBUTION

Slide 13 shows a stop-action picture of a black liquor spray with the characteristic initial formation of ligaments followed by droplet formation.



There have been several investigations of black liquor nozzles and spray size distribution. **Slide 14** shows data from one of these studies for a wide range of operating conditions using hot, concentrated black liquor. The droplet size distribution is normalized to the median droplet diameter.



Within experimental error, the size distribution is identical for all nozzle types and black liquor properties. This means that for all current black liquor nozzles, only the median size can be changed by nozzle geometry and operating conditions. Once the conditions have been set for a particular median droplet size, the breadth of the distribution is fixed. Selection of nozzle type and size should only be based on such factors as the flow rate, median droplet size, or spray distribution rather than on the breadth of the size distribution.

Data from black liquor spray studies has been used to develop correlations for median droplet size as a function of operating conditions. **Slide 15** shows one of these correlations.

Slide 15

Median Droplet Size

$$D_{median} = 0.290\, K_L K_N \frac{D_n^{1.23} S^{0.62}}{Q^{0.23} T^{0.14}}$$

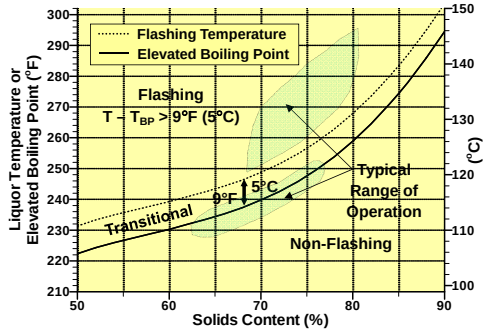
- **Splash plate, swirlcone, and V-type nozzles**
- **D_{median} = median droplet diameter**
- **K_N, K_L = nozzle and liquor constants**
- **S = liquor dry solids (weight fraction)**
- **T = liquor temperature, °C (non-flashing)**
- **D_n = nozzle diameter, m**
- **Q = volume flow rate, m^3/s**

The study involved three types of nozzles (splash plate, swirlcone, and V-type) and eight different liquors operating at non-flashing conditions in a cold test chamber. The constant K_N varies ±10% for different nozzles and the constant K_L varies ±10% for most liquors. The dependence on nozzle diameter is approximate. Therefore nozzles which are much larger than the 0.35 in (0.9 cm) diameter used in this study should not be expected to follow this relationship very accurately.

Slide 16 shows the elevated boiling point of black liquor as a function of liquor dry solids. The boiling point increases with liquor dry solids, and can vary by several degrees for different liquors with the same dry-solids. It is common practice to control the liquor temperature at or above the elevated boiling point. High liquor temperature ensures that the liquor is not too viscous and that it can be pumped through the delivery system without excessive pressure drop. High temperature (low viscosity) is also needed for effective droplet breakup. Typical liquor firing temperatures are 230-290°F (110-143°C) corresponding with dry solids of 65 to 80%.

Slide 16

Elevated Boiling Point

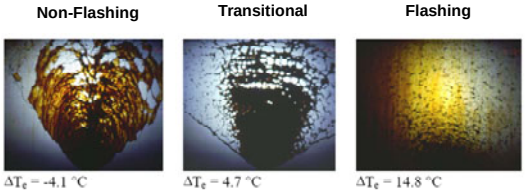


Slide 16 also shows the range of temperatures and solids which flashing occurs, and the transition region between non-flashing and flashing conditions. The transition is approximated by an offset of about 9°F (5°C), which varies for different liquors and different nozzles.

Slide 17 shows the effect of flashing on the spray from a splash plate nozzle. The break-up of the liquid sheet is affected dramatically when flashing occurs. Droplet size is much smaller under flashing conditions. In this illustration, the excess temperature $\Delta T_e = T - T_{EBP}$ is used to quantify the degree of flashing.

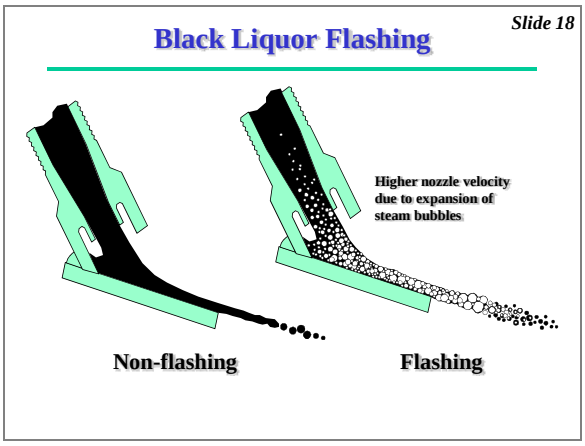
Slide 17

Three Temperature Regimes

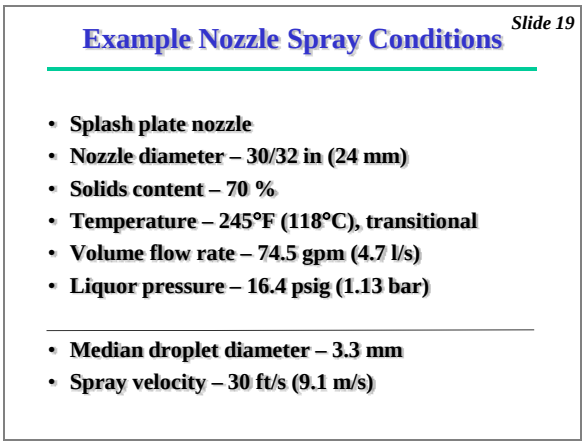


Solids = 69%, EBP = 115°C
Excess Temperature, $\Delta T_e = T - T_{EBP}$

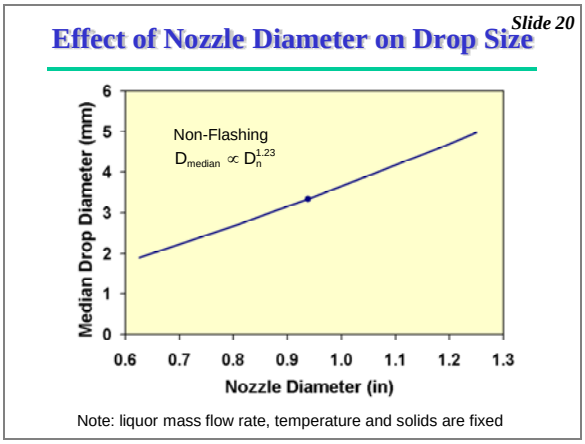
Slide 18 shows a schematic representation of the effects of flashing on black liquor spray formation. Within the delivery system, the liquor starts at a pressure higher than one atmosphere in the ring header. The pressure decreases due to frictional losses in the piping system as the liquor approaches the nozzle orifice. The liquor pressure reaches the ambient pressure (typically 1 atm) at the nozzle orifice. If the liquor is fired at or below its elevated boiling point, no water can evaporate within the enclosed piping system. As the liquor temperature is raised above the elevated boiling point, evaporation within the delivery system can occur. With modest increases of only a few degrees above the elevated boiling point, the rate and impact of the evaporation would be very modest. Any evaporation or bubble formation would only occur at the nozzle orifice. As liquor temperature is raised further, evaporation occurs at higher pressures further upstream of the nozzle. This evaporation, or flashing, has a very pronounced effect on flow and droplet formation.



Slide 19 shows an example set of spray conditions that will be used to illustrate changes in key operating parameters. At these conditions, the liquor is slightly above the elevated boiling point.

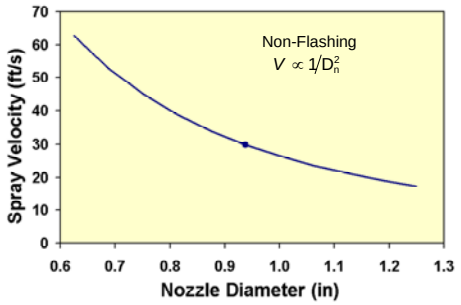


Slides 20 and 21 show the effect of nozzle diameter on median droplet size and spray velocity (assuming that liquor temperature, flow rate, and solids are fixed). The selection of nozzle size is important for establishing the right droplet size and the trajectory of the spray. However the operator cannot be expected to change the nozzle size to respond to subtle changes in bed size and carryover.



Slide 21

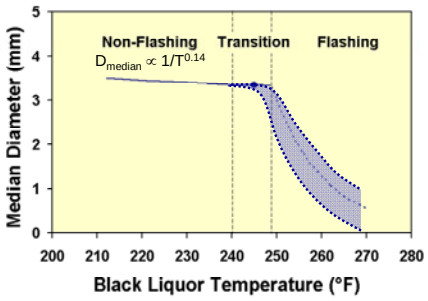
Effect of Nozzle Diameter on Velocity



Note: liquor mass flow rate, temperature and solids are fixed

Slide 22

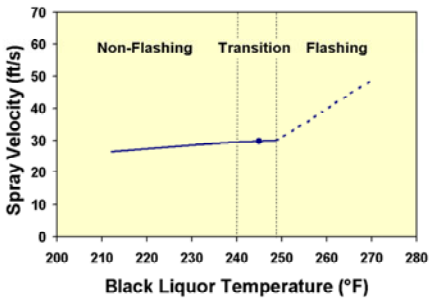
Effect of Temperature on Drop Size



Note: liquor mass flow rate, solids, and nozzle diameter are fixed

Slide 23

Effect of Temperature on Velocity



Note: liquor mass flow rate, solids, and nozzle diameter are fixed

Slides 22 and 23 shows the effect of temperature on median droplet size and spray velocity (assuming nozzle diameter, flow rate and solids are fixed). Below the elevated boiling point, temperature has a relatively minor effect on the spray. As the liquor temperature is raised several degrees above the boiling point there is a consistent, and dramatic change in spray characteristics. With temperatures significantly above the elevated boiling point, there is a substantial decrease in spray droplet size compared to non-flashing conditions. There is also a corresponding large increase in spray velocity. These changes strongly affect spray trajectory, droplet burning, and droplet entrainment. It is a common practice to use liquor firing temperature as the key operating variable to control the median droplet size and height of the char bed. This strategy works more effectively for firing high solids black liquor than for low solids.

SPRAY DISTRIBUTION

Slide 24 shows two basic strategies for spraying black liquor. ***Wall firing*** was commonly practiced in many early boiler designs and is still used on some small boilers with liquor dry-solids of 68% or less. One or two oscillating liquor guns are located in the center of the furnace wall. The guns are continuously moving up and down, and rotating side-to-side, spraying liquor in a figure eight pattern to cover a wind band of the walls above the hearth. The objective is to distribute the liquor on the walls of the boiler where it can dry out before it falls to the char bed.

The second basic strategy known as ***stationary firing*** is now more commonly practiced on large recovery boilers with

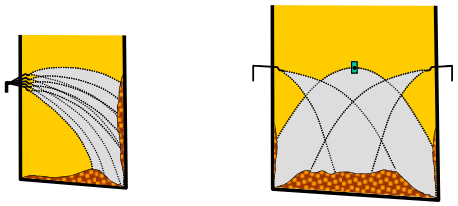
liquor dry-solids of 68% or more. Black liquor is sprayed into the furnace with 4 to 12 fixed guns, to achieve drying of liquor spray in suspension with hot gas rising from the furnace hearth. The objective is to minimize the amount of liquor sprayed on the walls, control droplet size to minimize carryover and distribute partially dried liquor and char over the bed.

Slide 24

Liquor Spray Distribution

Wall Firing
- **Small boilers**
- **1 or 2 oscillating guns**

Stationary Firing
- **Large boilers**
- **4 to 12 fixed guns**



After leaving the liquor nozzle, the spray distribution in the boiler is determined by the trajectories (or flight paths) of many droplets (of varying size) as they fall under the influence of gravity and aerodynamic drag. As shown previously in **Slide 6**, the actual droplet trajectory can be strongly influenced by the gas flow pattern in the furnace and by the dramatic changes in droplet size and density as they go through the stages of burning in the furnace. The gas flow in recovery boiler furnaces is often channeled flow with high velocity peaks and recirculation zones. The trajectories of different size droplets can be very different, with small droplets entrained and carried out of the furnace, large droplets going directly to the char bed, and intermediate droplets taking a complicated route through burning and smelt coalescence before going to the char bed.

Direct observation of droplet trajectories and burning in a recovery furnace is extremely difficult, at best. In the past decade computational models for the flow and combustion in recovery boiler furnaces have been developed. Results from these models have been favorably compared observable conditions in recovery boilers and they have become useful tools for design and optimization of recovery boilers. They are particularly good at showing the sensitivity of boiler operation to changes in air system and liquor spraying. They also can show the interaction of various parameters on boiler operation. Recently some of the complexity of these computational techniques has been relaxed to yield a model that predicts the trajectory and deposition of black liquor sprays within a recovery boiler furnace. The full description of this model is given in the paper "*Black Liquor Spray Calculator*" listed in the section **Further Reading** below.

Slide 25 describes how this calculator can be used and **Slide 26** gives some basic information about one particular recovery boiler that will be used as an example here. The results described below are only specific to this recovery boiler, but they demonstrate the utility of this approach and indicate the relative impact of several operating changes.

Slide 25

Predicting Spray Distribution and Deposits

- **Based on computer model simulation of the trajectories of large drops**
- **Examples for one particular boiler**
  - **Demonstrate sensitivity to operating parameters**
  - **Visualize the effect on spray distribution**
- **Modeling is useful for initial spray optimization**

Slide 26

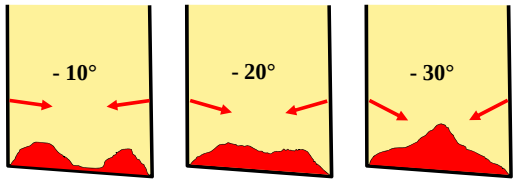
Recovery Boiler Used in Examples

Floor dimensions	**31.5 x 28.4 ft (9.6 x 8.7 m)**
Firing method	**Stationary firing**
Number of guns	**4, one at center of each wall**
Barrel tilt	**- 20° (median)**
Nozzle size	**#38 (38/32 inches or 1 3/16")**
Splash plate angle	**49° (median)**
Liquor dry solids	**65.8%**
Liquor temperature	**220°F (104.4°C) non-flashing**

Slide 27 shows the impact of barrel tilt angle on the char bed shape for the example boiler. These three char bed shapes are familiar to almost every recovery boiler operation at one time or another. Though the specific impact of barrel tilt on bed shape is almost certainly not correct for every recovery boiler, the results indicate that barrel tilt is probably the right parameter to adjust if char bed shape is the only issue being addressed. Applying the spray calculator to the specific geometry and operation of a specific boiler would be a good option if char bed shape is a chronic problem.

Slide 27

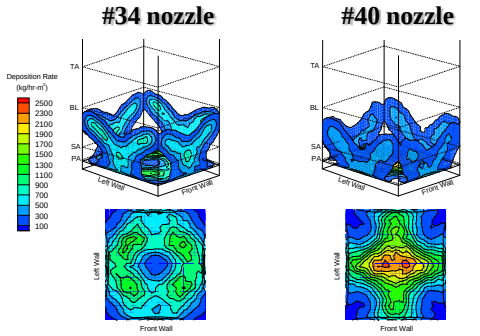
Impact of Barrel Tilt on Bed Shape



Slide 28 shows the impact of nozzle size on black liquor deposition in the example furnace. The total black liquor flow was constant in these calculations so the larger nozzle resulted in lower liquor velocity at the nozzle, larger median droplet size and higher deposition rates of liquor near the center of the char bed.

Slide 28

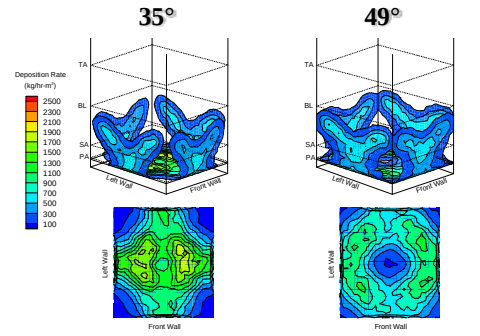
Impact of Nozzle Size



Slide 29 shows the impact of splash plate angle on black liquor deposition in the example furnace. Splash plate angle has multiple effects on the liquor spray. Here the higher angle spreads the liquor more to the periphery than the center of the char bed. Slides 27 and 28 make it clear that more than one parameter can influence the char bed deposition rate, and that optimization will depend on the interaction of several parameters.

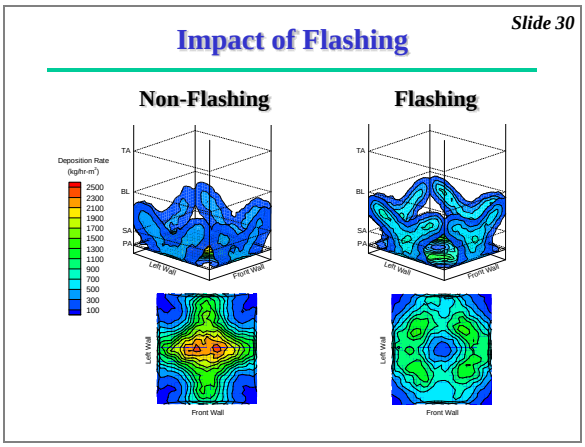
Slide 29

Impact of Splash Plate Angle



Slide 30 shows the impact of liquor flashing on the liquor deposition on the char bed. Flashing impacts both the median droplet size and liquor velocity at the nozzle. This results in very different deposition rates on

the char bed under flashing and non-flashing conditions.



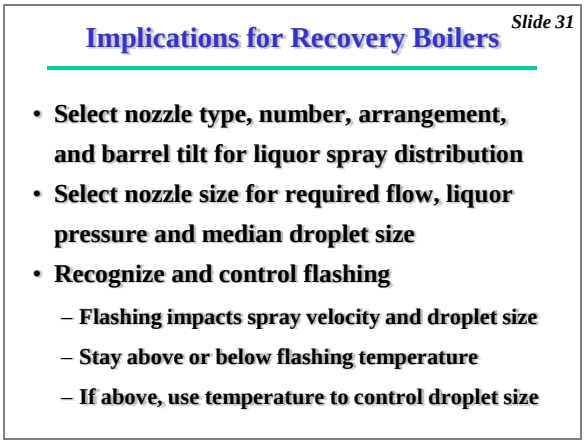
SUMMARY

Median droplet size and spray distribution have been described for several black liquor nozzle designs and a range of operating conditions. Approximate correlations of the median droplet size are available for a few nozzles under non-flashing conditions.

One of the most important aspects of black liquor nozzle performance is the impact of flashing on spray droplet size. Flashing occurs whenever the liquor firing temperature is more than a few degrees above its elevated boiling point. Flashing decreases the median droplet size of the spray and increases spray velocity.

Spray distribution after leaving the black liquor nozzle is complex function of nozzle geometry and boiler operating conditions. Computational models are useful for examining the sensitivity of liquor spray deposition to operating parameters and for initial optimization.

The implications for Kraft recovery boilers are summarized in **Slide 31**.



FURTHER READING

Kraft Recovery Boilers, Adams, T. N., Frederick, W. J., Grace, T., Hupa, M., Iisa, K., Jones, A. K., and Tran, H., T. N. Adams editor, TAPPI Press, Atlanta, GA, 1997.

"Black Liquor Spray Calculator", Viscardi, R.P., Wessel, R.A., Jorgensen, K.I., and Rivers, K.A., International. Chemical Recovery Conference, Charleston, SC, June 2004.

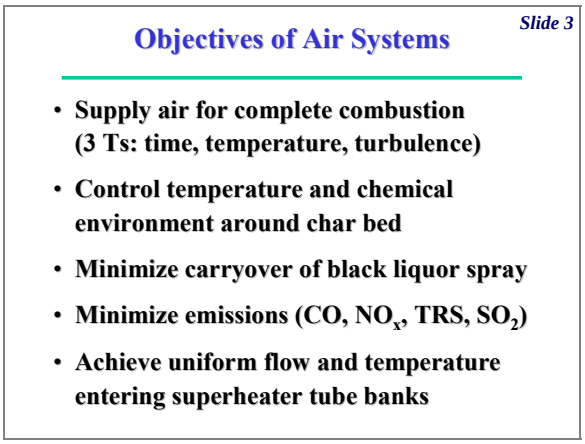
RECOVERY BOILER AIR SYSTEMS

Rick Wessel
Consulting Engineer
The Babcock & Wilcox Company
20 South Van Buren Avenue
Barberton, Ohio 44203

INTRODUCTION

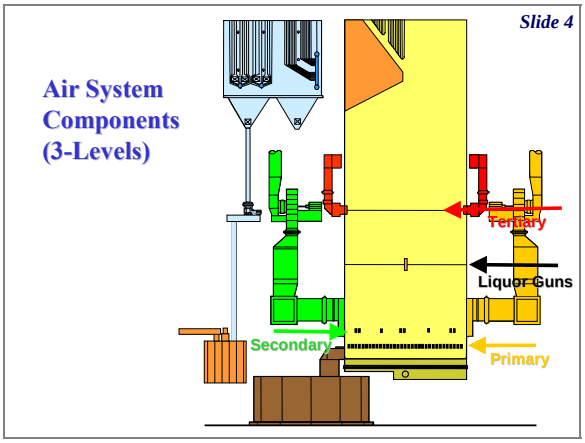
This paper presents the equipment and layout of recovery boiler air systems, and their purpose. Several arrangements of the individual air levels are shown along with the gas flow patterns found in the lower furnace of recovery boilers. A few of the problems that are typically encountered will also be addressed. **Slide 1** and **Slide 2** are the title and outline for the presentation.

Slide 3 states the objectives of the recovery boiler air system. The primary objective is to supply air to the boiler for complete combustion of black liquor. Complete combustion is achieved by a combination of the three Ts – time (residence time), temperature, and turbulence (mixing). The second objective is to control the temperature and chemical environment around the char bed for good chemical conversion of the char and smelt. Third is to minimize carryover of black liquor spray that can lead to fouling of superheater tube banks. Fourth is to minimize emissions of carbon monoxide (CO), nitrous oxides (NO_x), total reduced sulfur (TRS), and sulfur dioxide (SO_2). The last objective is to achieve uniform gas flow and temperature distribution entering the superheater for reduced fouling, even metal temperatures, and balanced heat transfer to the steam.



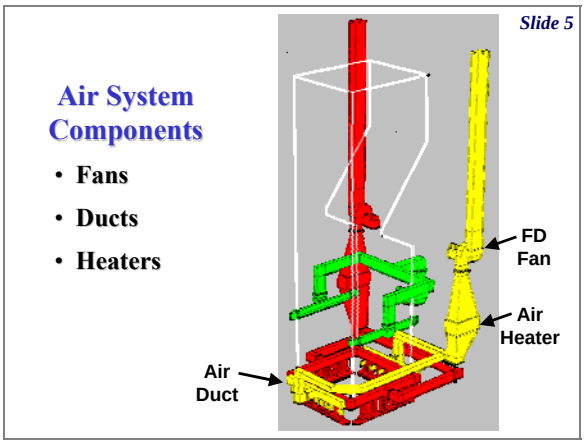
AIR SUPPLY AND DELIVERY

Slide 4 shows a side elevation of the lower furnace of a recovery boiler along with its dissolving tank.

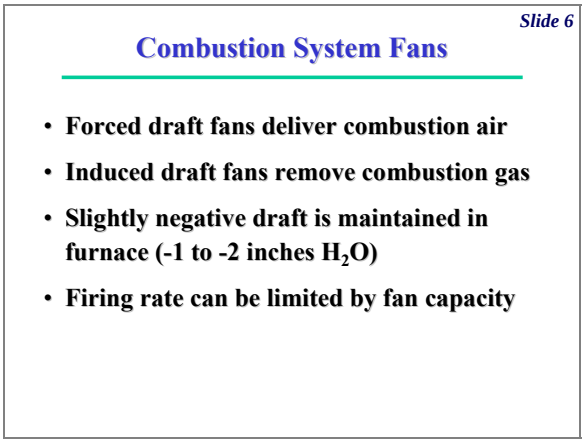


This boiler has a 3-level air system. The primary air level is very near the bottom of the furnace. The secondary air level is about 5 feet above the primary level and 10 to15 feet below the liquor gun level. The tertiary air level is 10 to 15 feet above the liquor guns. Most recovery boilers have three levels of combustion air, but some have two and a few newer boilers have four or more levels.

Slide 5 shows just the combustion air system with the fans, ducting and air heaters. There is more than one forced draft fan on most recovery boilers. In this case, two fans deliver air through large air heaters located in the ducting to the primary and secondary air level while a third fan delivers ambient air to the tertiary level.

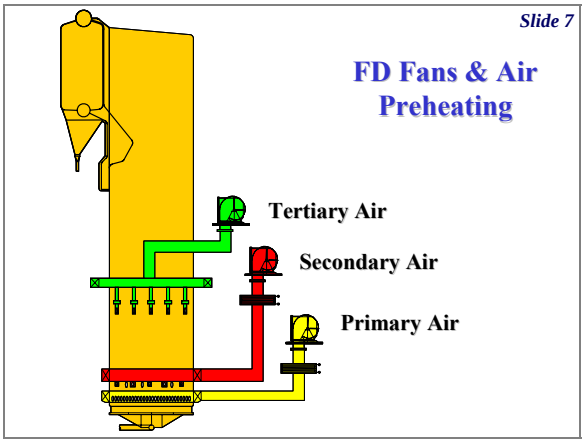


Slide 6 presents the two types of fans used with recovery boilers. Forced draft (FD) fans deliver combustion air to the furnace. Induced draft (ID) fans remove the combustion gases and maintain a slightly negative draft in the furnace.



Slide 7 shows one arrangement for the forced draft (FD) fans. Recovery boilers can be operated with just one combustion air fan, but most boilers have two or three.

Until recently, the combustion air to all levels was preheated. Now there are many applications where unheated air is used above the liquor gun level. The furnace gas at this level is nearly 2000°F (~1100°C) so air preheating is not required. Cold tertiary air also increases jet penetration due to its high density; this promotes mixing of the flue gases.



A table of typical air system design parameters is presented in **Slide 8**. A two level air system is common on older boilers and is the only design which the secondary air level is located above the liquor guns. For systems with three or more levels, the secondary air includes any air injection ports between the primary air level and the liquor guns; the tertiary air includes any air injection ports above the liquor guns.

Slide 8

Typical Air System Designs

Total Number of Levels	Air Levels	Static Pressure in. H_2O	Percent of Total Air Flow	Temp. °F
2	Primary	2 - 4	50 - 70	200 - 400
	Secondary	4 - 8	30 - 50	200 - 400
≥ 3	Primary	2 - 4	30 - 40	200 - 400
	Secondary	6 - 12	20 - 50	200 - 400
	Tertiary	6 - 20	15 - 40	Ambient

AIR SYSTEM ARRANGEMENTS AND GAS FLOW IN THE FURNACE

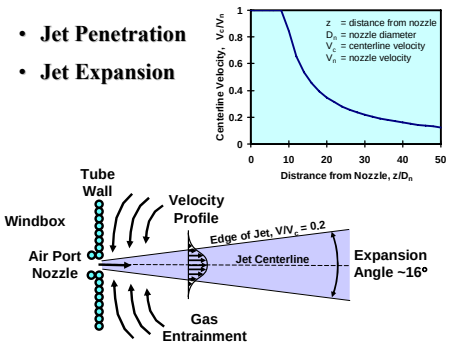
Air port nozzles at the primary, secondary, and tertiary levels are arranged to distribute the air, and produce gas flow patterns for effective mixing and combustion in the furnace. The smallest element of the air system is a single air port nozzle for injecting air into the furnace.

Slide 9 describes the characteristics of a turbulent jet which emerges from each air port nozzle on the furnace wall and penetrates a distance into the furnace. The jet typically expands with an angle of about 16 degrees as it entrains surrounding gases. The jet velocity decreases with distance from the nozzle, and the jet is deflected upward from gases flowing upward from below.

Slide 9

Characteristics of Turbulent Jets

- **Jet Penetration**
- **Jet Expansion**



Slide 10 describes the role of the primary air in a recovery furnace. **Slide 11** presents an inside view of primary air ports and discusses their arrangement.

Slide 10

The Role of Primary Air

- **Primary air controls the char bed perimeter**
  - **Controls bed burning near primary air ports**
  - **Pushes wall-shed material away from port**
  - **Pressure is important, too low is common problem**
- **Primary air keeps smelt hot and fluid**
  - **Blowing on a fire increases burning rate and temperature**
  - **Campfire and blacksmith are examples**

Slide 11

Primary Air Arrangement

- **Many, small ports on all four walls feed air to perimeter of the char bed**
- **Isolation dampers control local burning rates and bed shape**
- **Hot air improves combustion stability**



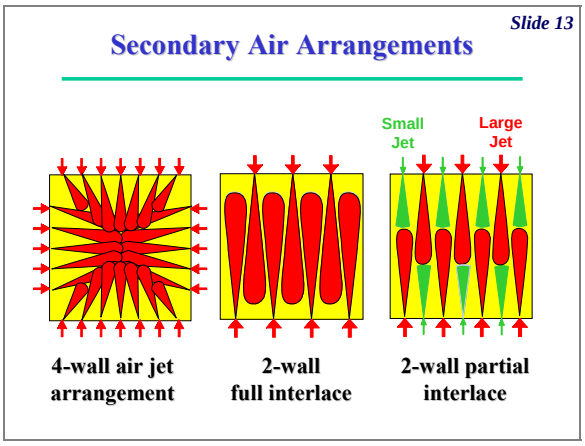
Slide 12 describes the role of the secondary air in a recovery furnace.

Slide 12

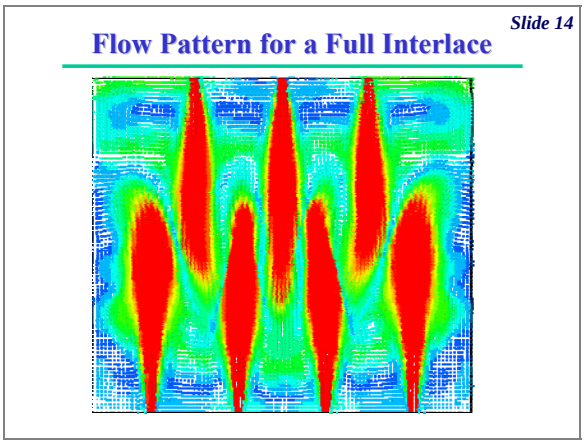
The Role of Secondary Air

- **Secondary air controls char bed height**
  - **Jet penetration to center of furnace needed**
  - **Large ports and high pressure air required**
- **Secondary air burns char and volatiles**
  - **Intensive mixing of air and combustion gases**
  - **Heat release needed to dry liquor spray**
- **Optimized to match liquor firing conditions**

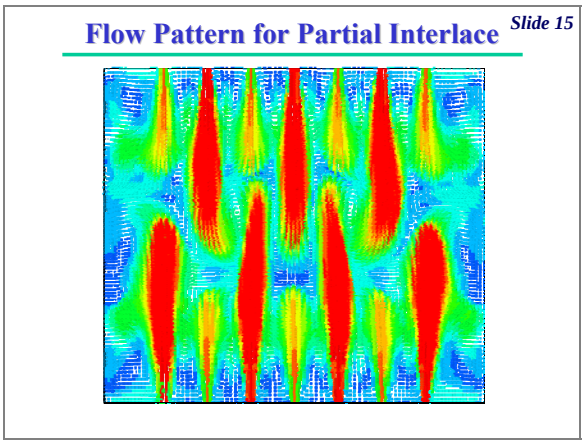
Slide 13 shows three common arrangements for the secondary air nozzles. The 4-wall arrangement is most common on older boilers, but 2-wall arrangements are used on most retrofits and new boilers. The interlaced arrangement in the center of Slide 13 is a 4x3 nozzle pattern. The arrangement of air nozzles allows sufficient room for jet expansion without interference from neighboring jets.



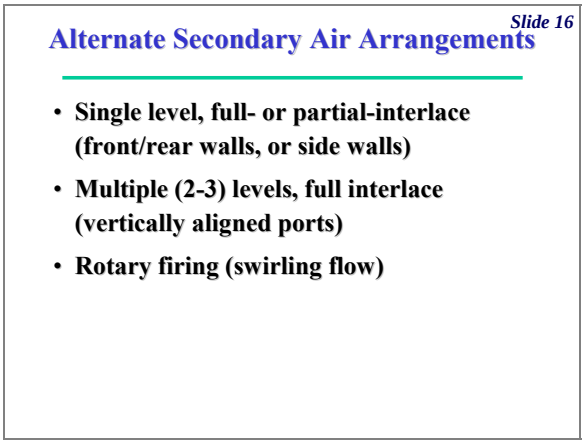
The flow pattern which is shown in **Slide 14,** is the result of a Computational Fluid Dynamics (CFD) calculation. The small arrows indicate the gas velocities at the secondary air level, and the color indicates the gas speed. The velocity vectors confirm that the jets interlace effectively for a 4x3 pattern in a furnace that is nearly square.



Slide 15 shows a similar result for a 2-wall partial interlace arrangement which uses a pattern of large jets opposed by small jets in a similar interlace configuration. There is slightly less penetration of the large jets with this arrangement because some of the flow is diverted to the small jets, but the two flow patterns are otherwise similar.



Slide 16 lists several secondary air port arrangements that are commonly used in recovery boilers. These arrangements will be discussed further after describing the tertiary air level.



Slide 17 describes the role of the tertiary air in a recovery furnace. Reducing conditions in the lower furnace improve smelt reduction and reduce NO_x emissions. Oxidizing conditions in the upper furnace reduce CO and TRS emissions and minimize corrosion of furnace wall tubes.

Slide 17

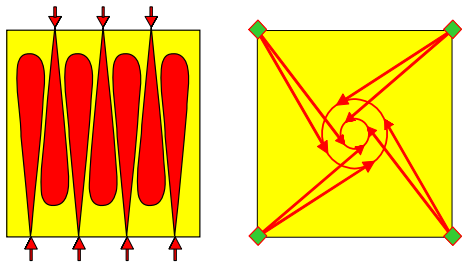
The Role of Tertiary Air

- **Tertiary air completes mixing and burning of combustible gases (CO, H_2S, etc.)**
  - **Jet penetration to center of furnace needed**
  - **Large ports with high pressure air required**
- **Tertiary air is essential for staged combustion**
  - **Reducing conditions in lower furnace**
  - **Oxidizing conditions in upper furnace**

Slide 18 shows two air nozzle arrangements at the tertiary air level. The interlace pattern here is a 4x3 configuration. This pattern, or a 5x4 pattern, is typically used at the tertiary level. The concentric tertiary air on the right is a modification of a tangential pattern used by one vendor; this produces rotating gas flow in the upper furnace and is known to cause unbalanced flow and temperature distribution entering the superheater. The interlaced arrangement produces more balanced conditions in the upper furnace.

Slide 18

Tertiary Air Arrangements



Interlaced Tertiary Air **Concentric Tertiary Air**

Slide 19 lists several tertiary air port arrangements that are commonly used in recovery boilers.

Slide 19

Alternate Tertiary Air Arrangements

- **Single level, full interlace (front/rear walls)**
- **Multiple (2-4) levels, full interlace (vertically aligned ports)**
- **Two separate levels, 10 to 20 feet apart (upper most level - quaternary air)**
- **Concentric tertiary air, or tangential tertiary air (swirling flow)**

Newer boiler designs and retrofits have demonstrated certain advantages for more than 3 levels of air, particularly for units firing high solids liquor. As previously mentioned, multiple air levels can be used to supply secondary air, tertiary air, or both. Some commercial trade names for these systems are Vertical Air, Stacked Air, and QuantumAir.

Slide 20 lists the advantages and disadvantages of multi-level air systems. These designs should be implemented with caution due to the potential for combustion instability on the char bed and corrosion in the upper furnace.

Slide 20

Multi-level Air Systems

- **Advantages of multi-level secondary and tertiary air systems**
  - **Reduced fouling by carryover**
  - **Better mixing and emissions control**
- **Potential disadvantages**
  - **Difficult to control char bed combustion at low-medium solids**
  - **Accelerated corrosion by reducing gases reaching above composite tube line**

Slide 21 describes how an air system arrangement is selected for a particular boiler design and operation. Any one combination of the previously described arrangements may not work on all boilers.

Slide 21

Selecting An Arrangement

- **The best arrangement depends on furnace design, liquor properties, spray conditions, and firing rate**
- **Arrangement is optimized by CFD and combustion modeling**
- **Performance is demonstrated by field testing and operating experience**

Engineers must consider the boiler design, liquor properties, spray conditions and firing rate to determine the best arrangement. CFD and combustion modeling of the recovery furnace is the most common approach to optimize the air system arrangement. Field testing and operating experience is the ultimately the most reliable means to demonstrate air system performance.

AIR SYSTEM PROBLEMS

Two of the problems encountered with recovery boiler air systems are their inflexibility once installed, and their need for frequent port cleaning. This is described in **Slide 22**.

Slide 22

Air System Operating Problems

- **Air delivery systems are inflexible**
  - **ΔP proportional to square of flow**
  - **Limits recovery boiler turndown**
  - **Port velocity control dampers increase flexibility**
- **Air ports need frequent cleaning**
  - **Automatic port rodders improve performance**

Slide 23 describes the two common types of dampers. A louver damper can be used in the air delivery duct to adjust the air flow and pressure to the windbox that houses an individual air port or a group of air ports. The illustration in Slide 23 shows another type of damper that is located immediately upstream of the air port nozzle. The velocity damper controls the nozzle area, and allows higher velocity and pressure over a wider range of total air flow rates. The velocity damper increases the flexibility of the air delivery system.

Slide 23

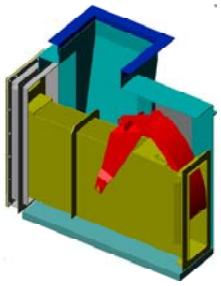
Air Port Dampers

Louver damper

- **Adjusts flow rate**
- **pressure and velocity decrease with flow rate**

Velocity damper

- **Adjusts air port nozzle area and flow rate**
- **Maintains higher pressure and velocity**



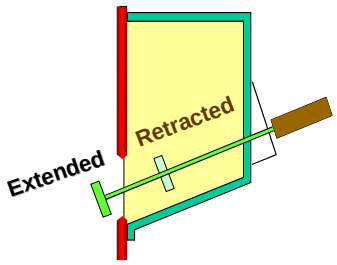
Velocity Damper

Slide 24 shows an automatic port cleaning system. The black liquor char and inorganic salts cause deposits on the walls of the lower furnace. The air ports can become constricted or clogged with deposits and

must be cleaned periodically. The traditional method is hand rodding of the ports. The diagram in Slide 24 illustrates one of several designs for cleaning the ports automatically.

Slide 24

Automatic Port Cleaning



There are several other potential design problems with recovery boiler air systems. These are described in **Slide 25**.

Slide 25

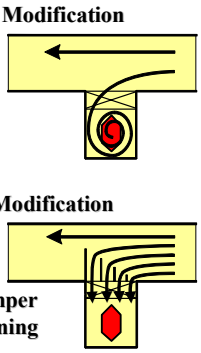
Air System Design Problems

- **Insufficient fan capacity for increased loads**
- **Duct size, length, and bends can limit flow**
- **Duct flow is not always uniform**
- **Duct arrangement can affect nozzle flow**
- **Boiler supports interfere with duct/nozzle placement**

Slide 26 shows one example of the type of problem that can be encountered in air duct and air nozzle design. In this case, the nozzle in the top of the slide is not being fed uniformly. This causes improper air flow through the nozzle and therefore poor furnace operation. The lower nozzle arrangement shows an inexpensive modification used to solve this problem.

Slide 26

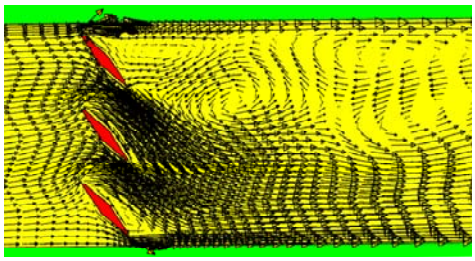
Windbox Flow Problems



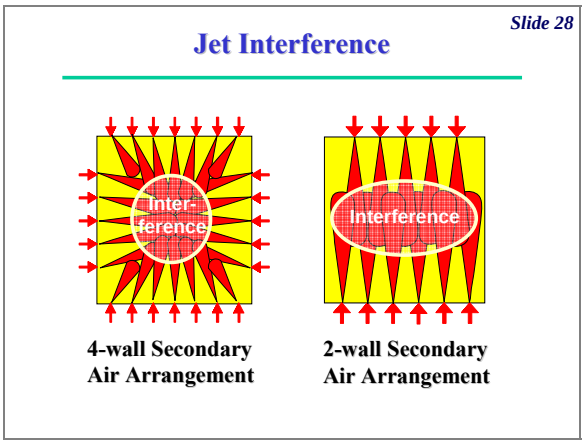
Flow problems can also be generated by other equipment in the delivery ducts. The velocity vectors in **Slide 27** show the very non-uniform flow pattern that is generated by one type of damper arrangement. If this damper were near an elbow or nozzle, air delivery could be very non-uniform and intermittent.

Slide 27

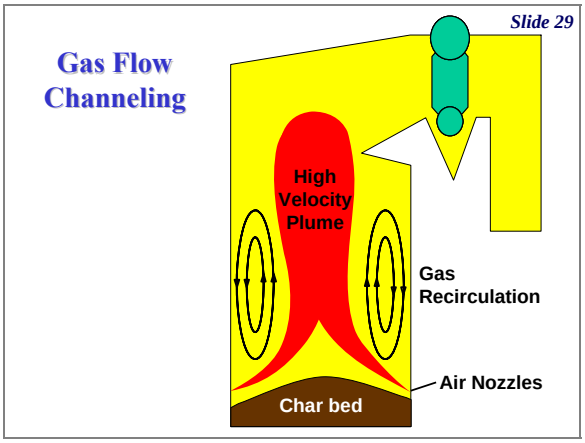
Damper Flow Problems



Slide 28 shows 4-wall and 2-wall secondary air arrangements with significant jet interference. The air jets cannot traverse the furnace without crashing into opposing jets, and being deflected away from a path of free penetration. For the two-wall secondary air arrangement, the air nozzles are too tightly spaced for the jets to expand and form an effective interlace.



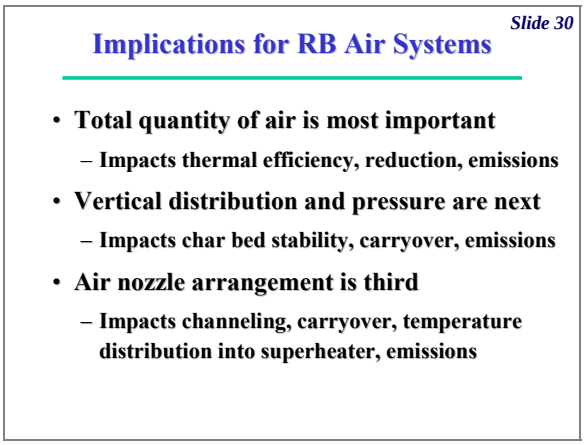
Gas flow channeling is shown in **Slide 29**, which is the result of significant jet interference at the secondary or tertiary levels. A plume of high upward velocity is formed which travels up the furnace, with gas recirculation along the walls. This channel is usually not steady, and can move around between the center and any of the corners depending on slight differences in flow and pressure on each wall of the furnace.

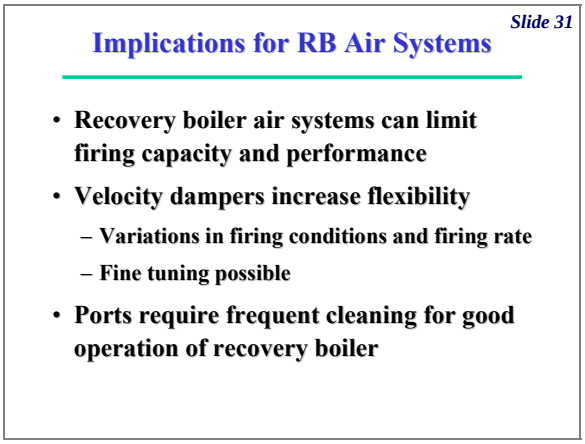


Gas flow channeling can result in severe carryover fouling in the upper furnace and insufficient gas mixing to destroy TRS gases that are released in the lower furnace reducing zone.

SUMMARY

Slides 30 and 31 summarize the main points from this introduction to recovery boiler air system design and operation.





FURTHER READING

Adams, T. N., General Characteristics of Kraft Black Liquor Recovery Boilers, Chapter 1 of Kraft Recovery Boilers, Adams, T. N., Ed., TAPPI Press, Atlanta, GA, pp. 1-38 (1997).

Jones, A. K., Recovery Boiler Air Supply and Gas Flows, Chapter 7 of Kraft Recovery Boilers, Adams, T. N., Ed., TAPPI Press, Atlanta, GA, pp. 181-214 (1997).